

Multi-Kinetic Apatite Fission Track Thermochronology Applied to Resolving Thermal Histories of Sedimentary Basins and Crystalline Bedrock

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Abstract

Understanding mountain building processes requires insight into the mechanisms and timing of exhumation. The integration of innovative radiometric dating techniques with field-based structural observations has significantly improved our ability to constrain the rates and timescales at which different exhumation processes operate.

This thesis investigates exhumation histories in two tectonically contrasting orogens: the Peel Plateau, adjacent to the Mackenzie Mountains which are actively undergoing crustal shortening in the Canadian Cordillera, and the Tauern Window in the Eastern Alps, where regional strain evolved from N-S compression to E-W extension during the Cenozoic. Apatite-fission track (AFT) dates are traditionally interpreted as cooling ages. For AFT dates resolved from samples that have undergone protracted cooling or comprise of apatite grains with variable annealing kinetics the ages resolved can instead represent a partial annealing date or reflect mixed age-populations and may not have been geologically significant. Herein, apatite grain-specific chemistry was used to calculate the kinetic proxy r_{mr0} , and was incorporated into thermal history models to test whether this innovative approach could reveal new information regarding the study area's upper crustal exhumation histories. Additional work in the Tauern Window documented an earlier stage of exhumation, from middle to upper crustal levels, which focussed on detailed structural analysis and deformation dates resolved via white mica $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology.

Overall, results from the Peel Plateau suggest that although erosion remains the dominant unroofing mechanism, spatially, the localized cooling can be explained by the reactivation of underlying structures. In the Tauern Window, results suggest exhumation began much earlier than previously proposed and was facilitated by tectonic unroofing along a newly discovered detachment system. Upper crustal exhumation in the core of the Tauern Window is mostly driven by erosion, whereas results from deeper structural units record an earlier onset of cooling which may be associated to tectonic unroofing. This work demonstrates that r_{mr0} captures the variability

of apatite's annealing kinetics within AFT samples, and incorporating this kinetic proxy into thermal models produces more refined results.

Collectively, this research exemplifies the complex interplay between different exhumation processes and underscores the value of integrating advanced radiometric techniques with detailed structural analysis.

Résumé

Il est nécessaire de comprendre les mécanismes qui accommodent l'exhumation et les échelles de temps sur lesquels ces processus opèrent afin de bien comprendre le cycle d'orogénèse. Notre connaissance des processus qui exhument les roches s'améliore grâce aux techniques innovatrices en datation radiométrique. L'interprétation des âges de déformation ou de refroidissement peuvent être effectuée dans le contexte des observations structurales et ensemble, nous permet de déterminer quand l'exhumation a eu lieu, et à quelle vitesse ces processus opèrent.

Cette thèse cherche à comprendre les histoires d'exhumation dans deux chaînes de montagne en contraintes tectoniques opposées: le plateau de Peel, adjacent aux montagnes Mackenzie dans la Cordillère canadienne qui est couramment en contrainte convergente, et la fenêtre des Tauern dans les Alpes orientales, qui a subi une transition de régime compressive (N-S) à un régime extensif (E-O). Les histoires d'exhumation de la croûte supérieure ont été reconstituées à l'aide de modèles thermiques basés sur la méthode des traces de fission dans l'apatite (TFA) qui intègrent le paramètre cinétique r_{mr0} , dérivé par la composition chimique de l'apatite. La fenêtre des Tauern préserve la déformation liée à la phase antérieure de l'exhumation, passant de profondeur de la croûte moyenne à la croûte supérieure. Ceci mène à des travaux supplémentaires basés surtout sur des analyses structurales détaillées ainsi que géochronologie $^{40}\text{Ar}/^{39}\text{Ar}$ sur le mica blanc pour résoudre le temps de déformation.

Les résultats du plateau de Peel suggèrent que l'érosion a facilité l'exhumation, ce qui est en accord avec les modèles actuels. Géographiquement, le refroidissement précoce localisé peut

s'expliquer par la réactivation des structures sous-jacentes. Dans la fenêtre des Tauern, on documente une nouvelle faille normale à faible pendage qu'on interprète comme étant le décollement d'un système de détachement avec d'autres failles normales dans la région. Nos résultats démontrent que ce système de détachement a déclenché l'exhumation dans la fenêtre des Tauern, et ceci a eu lieu plus tôt que prévu. L'exhumation de la croûte supérieure au cœur de la fenêtre des Tauern est principalement due à l'érosion. Cependant, pour les formations géologiques plus profondes, les modèles thermiques prédisent un refroidissement précoce qui pourrait être relié à l'exhumation du système de détachement documenté. Le paramètre r_{mr0} représente la variabilité cinétique des apatites dans les échantillons TFA, et l'intégration de r_{mr0} dans les modèles thermiques produit des résultats plus précis.

Dans l'ensemble, cette recherche démontre que l'interaction entre différents processus d'exhumation sont complexes et souligne l'importance d'intégrer des nouvelles techniques radiométriques avec les analyses structurales.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Exhumation describes the ascent of rocks from deeper crustal levels towards the Earth's surface and is governed by the interplay between the forces acting on the rock itself and the (displaced) overlying material. Virtually all rocks exposed on the Earth's surface have undergone a component of exhumation since their formation. Exhumation is often facilitated by uplift, which describes the upward displacement of the Earth's surface relative to the geoid, and, erosion, which lowers the Earth's surface by removing overburden through weathering and transport (England and Molnar, 1990). Within the theory of plate tectonics, plate collisions explain the spatial distribution of orogenic belts, and subduction zone processes account for the development of high-pressure mineral assemblages. However, plate tectonic theory does not explicitly address the mechanisms responsible for returning these deeply buried rocks to shallower crustal levels.

Significant exhumation may occur during all parts of the orogenic cycle, as evinced by the exposure of high-pressure metamorphic assemblages (e.g., Feehan and Brandon, 1999; Foster et al., 2009; Glodney et al., 2005; Green et al., 2017; Pinet and Souriau, 1988; Ring et al., 1999). Although substantial research has been devoted to reconstructing the exhumation histories of mountain belts around the world, and these efforts have improved our understanding of the processes involved, this research has also underscored the inherent complexity and variability of exhumation pathways (Froitzheim et al., 2003; Long and Kohn, 2020; Ring et al., 1999). This is due to, in part, multiple exhumation mechanisms operating simultaneously, making it difficult to isolate the relative contributions of individual processes (Long and Kohn, 2020). In addition, different processes operate within the ductile and brittle regimes, therefore, the dominant exhumation mechanism evolves as rocks ascend across different thermal and rheological boundaries (Ring et al., 1999). Moreover, regional strain can influence the mode and rate of

exhumation such that regional tectonism and discrete phases of deformation can directly influence the timescale that different processes operate (Froitzheim et al., 2003; Ring et al., 1999). Exhumation histories consequently differ between orogens and across geologic time, and remain a subject of active research and ongoing debate within the geoscience community (e.g., England and Molnar, 1990; Platt, 1993).

Characteristic structural evidence of exhumation from mid- to upper-crustal levels includes the overprinting of (warmer) ductile deformation by (cooler) brittle structures, representing a continuum of deformation across the rheological boundary of the brittle-ductile transition zone (BDT; Grasemann et al., 2012; Lister and Davis, 1989; Malavieille, 1993). However, within intensely deformed or polymetamorphic rocks, earlier features are often obscured or completely overprinted, hindering our ability to establish the sequence of deformation events and potentially lead to misinterpreted exhumation histories. Five mechanisms are known to significantly contribute to exhumation, which are discussed below (**Figure 1.1**; Froitzheim et al., 2003; Ring et al., 1999).

1.2 Exhumation mechanisms

Structural analysis can reveal important information regarding exhumation histories, as tectonic structures can be correlated to specific processes. Five mechanisms can significantly exhume rocks, which may operate at different crustal depths. Exhumation of upper-crustal rocks can be driven by 1) erosion and 2) tectonic unroofing (**Figure 1.1**). Erosion is the most intuitive mechanism, involving the physical and chemical breakdown of rocks, and removal of surficial material that exposes the underlying rock. High topography in mountain belts is largely driven by isostasy, reflecting the density contrast between crust and the underlying denser mantle over which

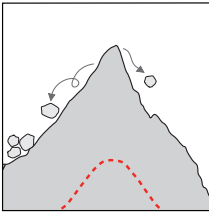
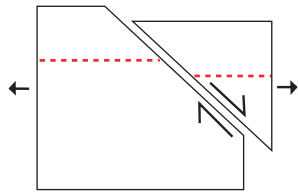
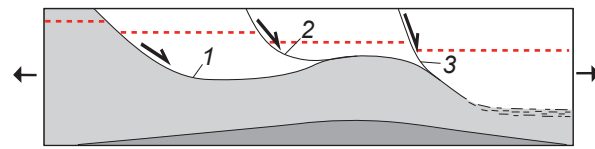
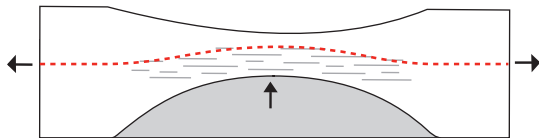
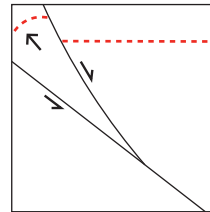
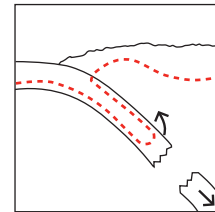
A) erosion**B) tectonic unroofing****i) High-angle normal faults****ii) LANF's and detachment systems****C) ductile thinning****D) extrusion****E) extraction**

Figure 1.1. Simplified diagrams illustrating various exhumation processes. The red dashed lines represent an arbitrary isotherm to visualize the section of rock that is being exhumed. Erosion [A] and tectonic unroofing via high-angle normal faulting [Bi] can exhume the upper crust. A) Erosion is facilitated by the high topography and progressively exposes deeper crustal rocks. Bi) High-angle normal faults can produce modest exhumation of upper crustal rocks. Bii) [1] A low angle normal fault (LANF) propagates in the ductile regime. The footwall and the fault plane are deformed during exhumation related to isostatic re-equilibration from the removal of the hanging wall. Strain is accommodated along a new fault plane [2] developed at shallower crustal depths. This process repeats itself and a new fault [3] develops. Younger faults are mechanically linked to the original LANF at depth and collectively, these structures form a detachment system. C) Ductile thinning results from vertical shortening during lateral ductile flow which exhumes the underlying rocks. Grey dashed lines denotes horizontal fabric that is characteristic of ductile thinning. Extrusion [D] and extraction [E] are exhumation mechanisms related to subduction processes and the black arrows denote the relative displacement of rock masses. Modified after Froitzheim et al., 2003 and Lister & Davis, 1989.

it resides. During erosion, the physical removal of rocks causes the crust to buoyantly rebound, thus maintaining or increasing topography and facilitating further erosion. The interplay between erosion and isostasy is capable of destructing mountains and thinning the crust. Theoretical models suggest that following the cessation of active convergence, c. 100 Myr is required to achieve isostatic equilibrium and reduce the crustal thickness to ~30 km (Blackburn et al., 2018; Pazzaglia and Brandon, 1996, Pinet and Souriau, 1988). However, these theoretical estimates are likely overestimated, as they do not account for the densification of crustal roots through granulite-facies metamorphism and long-term cooling, processes that diminish both the rate and magnitude of uplift (Blackburn et al., 2018; Fischer, 2002). Except in extreme localized tectonic environments, such as orogenic syntaxes, erosion alone generally does not account for the entire exhumation history of originally deep-seated rocks, and other mechanisms facilitated the earlier stages of exhumation (Ring et al., 1999; Zeitler et al., 2001). Deformation can facilitate erosion and dictate erosion rates. For instance, in an eroded antiform, maximal uplift occurs in the hinge zone undergoes, and the increases topography results in higher erosion rates. Consequently, hinge zones typically expose deeper structural levels compared to the limbs and this geometry reflects the combined effects of deformation and differential erosion (**Figure 1.1**). Similarly, within fold and thrust belts, a combination of uplift and erosion can exhume the hanging wall of normal faults (Lock and Willet, 2008). Erosion dictates topography and shapes landscapes, and generally accounts for the final stage of rock's exhumation history (Burbank, 2002).

Tectonic unroofing occurs under tensile strain and describes the exhumation of the footwall of normal faults. High-angle normal faults conform to Andersonian fault theory and are categorized by the steep (~60°) inclination of the fault plane, however this geometry can only modestly contribute to exhumation (**Figure 1.1**; Anderson 1951; Koyi and Skelton, 2001). Despite

contradicting classical fault mechanics, numerous studies have documented low-angle normal faults (LANF), which typically dip $\sim 30^\circ$ and propagate in the ductile regime, and are mechanically linked to high-angle normal faults at higher crustal levels (**Figure 1.1**; Axen, 2004; Campani et al., 2010; Collettini, 2014; Lister and Davis, 1989; Mancktelow, 1985; Mehl et al., 2005). As opposed to high-angle normal faults, the geometry of LANF's is better suited to accommodate extension and the removal of overburden (hanging wall) can exhume rocks from mid-crustal levels (Axen, 2007; Lister and Davis, 1989; Malavieille, 1993). By removing overburden in the hanging wall, the footwall is susceptible to isostatic uplift which deforms the original fault plane to an arched geometry. Eventually, the deformed fault plane is no longer suited to accommodate strain, and a new fault can develop at different crustal levels which is mechanically linked to the original fault surface (**Figure 1.1**; Collettini, 2011; Lister and Davis, 1989). This process can repeat itself, as newer fault surfaces are themselves deformed and exhumed, resulting in the propagation of additional faults. Collectively, these fault networks are referred to as *detachment systems* (**Figure 1.1**). The footwall of LANF's or detachment systems are characterized by ductile deformation that is overprinted by brittle-ductile structures, reflecting a progression towards shallower crustal levels during exhumation and cooling. In addition, within the footwall, the deformation gradient increases towards the fault surfaces, and ultramylonites capped with cataclasites are typically observed in the immediate footwall (Grasemann et al., 2012; Lister and Davis, 1989; Malavieille, 1993). In addition, rapid exhumation of the footwall can initiate decompression melting, producing syntectonic granitoids, which exemplifies classic metamorphic core complexes (Lister and Davis, 1989; Lister et al., 1984). Interestingly, in the actively converging eastern Himalaya, Kellett and Grujic (2012) document LANF's that are parallel to major thrusts and interpret these structures to have formed coevally.

At deeper crustal depths, within the ductile regime, a significant component of pure shear strain can induce exhumation via 3) ductile thinning (**Figure 1.1**; Ring and Brandon, 1999). Within a vertical crustal section, the redistribution of material via lateral ductile flow reduces its crustal thickness (i.e., vertical shortening) and the underlying material is exhumed via isostatic re-equilibration (Larson et al., 2010; Platt et al., 1998; Ring and Brandon, 1999). The degree of exhumation facilitated by ductile thinning is proportional to the magnitude of vertical shortening (**Figure 1.1**). Evidence of ductile thinning is ambiguous but can be supported by structural evidence and strain analysis that indicate a significant component of pure shear is related to ductile deformation. Distributed ductile thinning is characteristic within the footwall of detachment systems, thus exhumation via tectonic unroofing along LANF's and ductile thinning can operate coevally (**Figure 1.1**; Feehan & Brandon, 1999; Lister et al., 1984).

Finally, exhumation via 4) extrusion and 5) extraction operate within subduction channels. Extrusion describes the ascent of a section of the subducting plate following underplating (**Figure 1.1**). This material is in contact with the subducting plate and the stationary upper plate. As subduction processes continue, compressional forces configure this material into a wedge-shaped geometry. The relative displacement between the wedge and the subducting plate forms a thrust fault. Eventually, the wedge can exhume along the subduction channel, thus the roof of the wedge and the overriding plate act as a normal fault (Allemand and Lardeaux, 1997; Jessup et al., 2006; **Figure 1.1**). Exhumation via extrusion is rapid and can preserve high pressure mineral assemblages (Allemand and Lardeaux, 1997). Extraction, however, involves the detachment and removal of a section of a down-going slab (**Figure 1.1**; Froitzheim et al., 2003, 2006). Consequently, the underlying material is exhumed through isostasy to compensate for the removed

material. Exhumation via extraction is also rapid and is often associated to the exhumation of ultrahigh-pressure metamorphic rocks (Warren, 2013; Sandmann et al., 2015).

These summaries highlight the primary mechanisms responsible for the exhumation of crustal rocks. Insights from field studies, numerical modeling, and theoretical research demonstrate that exhumation pathways are strongly influenced by rheology, thermal conditions and geodynamic parameters. As a result, multiple exhumation mechanisms may operate simultaneously, and the dominant processes can evolve spatially and temporally in response to changing geodynamic regimes and crustal depth. To accurately reconstruct complex exhumation histories, it is essential to document exhumation-related structures and evaluate overprinting structural relationships to establish the sequence of deformation and interpret this information within the regional tectonic framework.

1.3 Low temperature geochronology

Scientific advances in the last century have introduced new tools for addressing geologic problems. Notably, the discovery of radioactive decay and the invention of mass spectrometers capable of quantitatively measuring isotopes led to the emergence of geochronology. This revolutionized our ability to solve complex geological problems by assigning absolute ages to rock-forming minerals, whereas targeting distinct mineral phases can reveal the timing of specific metamorphic events. Technological advances are continuously refining dating techniques by improving the precision of radiometric dates, and innovative instrumentation, such as Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS), have further refined dating techniques by enabling precise targeting of mineral phases and zonation with the added ability to avoid inclusions. Microstructural analysis combined with radiometric dating can

constrain the time of discrete phases of deformation by targeting fabric-forming minerals within specific structures (e.g., Barnes et al., 2023; Cossette et al., 2015; Larson et al., 2019; Rolland 2008, 2013).

Geochronometers rely on the ratio of parent-daughter isotope to determine the age of a rock and require minerals to behave as closed systems. For some systems, the daughter product is only retained within the crystal lattice below a critical temperature. Consequently, radiometric dates from these systems record the time of cooling below a critical temperature rather than the timing of crystallization, and these systems serve as thermochronometers (e.g., Armstrong, 2005; Ravenhurst and Donelick, 1992; Reiners et al., 2002). These critical temperatures rely on minerals diffusion properties which are influence by grain size, and the sample's rate of cooling (Dodson, 1973). Commonly used thermochronometers include (U-Th)/He in zircon (ZHe) and apatite (AHe), which relies on the ratio of radiogenic ^4He produced from the decay of ^{238}U , ^{235}U , ^{232}Th , and ^{147}Sm . During monotonic rapid cooling ^4He is retained in the crystal lattice at temperatures of $\sim 70^\circ\text{C}$ in apatite and $\sim 185^\circ\text{C}$ in zircon, which denotes the nominal closure temperatures for these systems (Farley, 2000; Reiners et al., 2002; Wolfe and Stockli, 2010). Experiments have revealed that within a temperature range of $130\text{--}200^\circ\text{C}$ for zircon and $30\text{--}120^\circ\text{C}$ for apatite, ^4He is partially retained, delineating the partial retention zone for these systems (PRZ; **Figure 1.2**; Djimbi et al., 2015; Flowers et al., 2009; Wolfe and Stockli, 2010). Consequently, for samples that have undergone complex thermal histories and have resided within the PRZ, AHe and ZHe dates do not necessarily record the time of cooling. Another commonly employed thermochronometer is fission track dating in zircon and apatite (ZFT and AFT, respectively). For this method, the parent isotope is ^{238}U and the "daughter products" are the linear defects preserved in the crystal lattice produced from spontaneous fission of ^{238}U , referred to as fission tracks. Fission tracks are only preserved

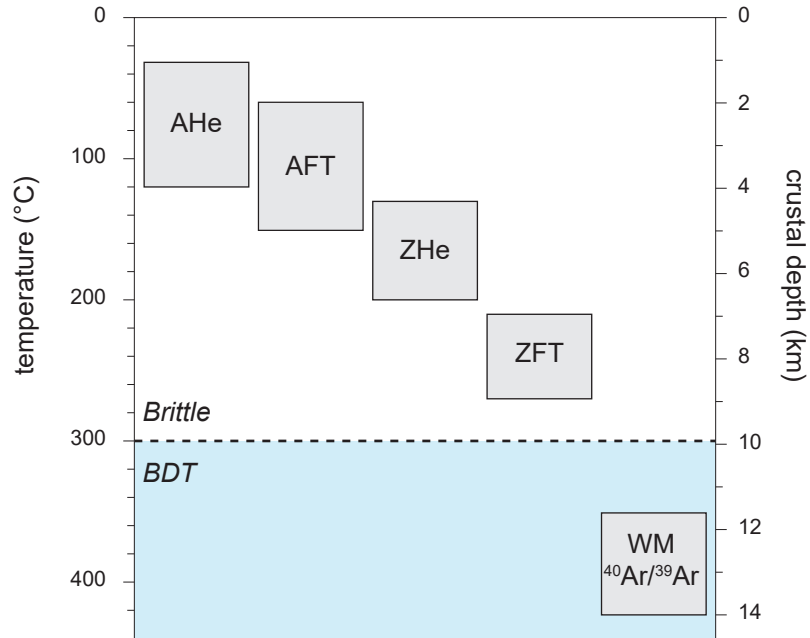


Figure 1.2. Temperature sensitivity of different thermochronometers and their corresponding crustal depth, assuming a static geothermal gradient of 30°C/km. Dashed line represents the brittle-ductile transition (BDT) for granite (Tullis, 2002). The brittle deformation regime is in white, and the brittle-ductile regime is in blue. AHe: 30-120°C (Djimbi et al., 2015, Flowers et al., 2009); AFT: 60-150°C (Armstrong, 2005; Donelick et al., 2005); ZHe: 130-200°C (Wolfe and Stockli, 2010); ZFT: 210-270°C (Brandon et al. 1998; Bernet, 2009); White mica (WM) $^{40}\text{Ar}/^{39}\text{Ar}$: 350-425°C (Harrison et al., 2009; McDougall and Harrison, 2000).

below a critical temperature threshold and at higher temperatures, the crystal lattice begins to repair itself and existing fission tracks progressively shorten and are eventually erased, a process referred to as thermal annealing (Gleadow et al., 1986; Ketcham et al., 1999). Similar to the (U-Th)/He, laboratory experiments have revealed that the rate of thermal annealing of fission tracks progressively decrease across a range of temperatures, referred to as the partial annealing zone (PAZ) which is generally considered to be ~60-150°C for apatite and 210-270°C for zircon (**Figure 1.2**; Armstrong, 2005; Bernet, 2009; Brandon et al. 1998; Donelick et al., 2005; Green et al., 1986). For samples that have undergone rapid cooling across their respective PRZ, or PAZ, (U-Th)/He and fission track dates can be interpreted to represent the time of cooling. However, for samples with complex thermal histories (e.g., slow cooling across the PRZ/PAZ or undergone multiple heating/cooling events), they have the potential to inherit a signature from their residency in the PRZ/PAZ. Partial annealing broadens the distribution of track lengths and can eventually reduce the overall density of fission tracks, consequently, producing younger dates that may not be geologic significance (**Figure 1.3**). To overcome this obstacle, thermal history modeling has proven to be a useful tool to extract meaningful information (e.g., Green and Duddy, 2012).

The AFT system is also complicated by the annealing kinetics of individual apatite specimens. Laboratory experiments have revealed that the PAZ for individual apatite grains varies depending on its grain-specific chemistry (Green et al., 1986). Consequently, assuming all apatite within AFT samples underwent thermal annealing within the same temperature range and at the same rate can lead to misguided geologic interpretations (e.g., McDannell et al., 2019; Ketcham et al., 1999). This apparent drawback, however, can be exploited by categorizing apatite grains based on grain chemistry, as they share similar annealing kinetics, thus will respond similarly to heating/cooling (Carlson et al., 1999; Ketcham et al., 1999). Kinetic populations within AFT

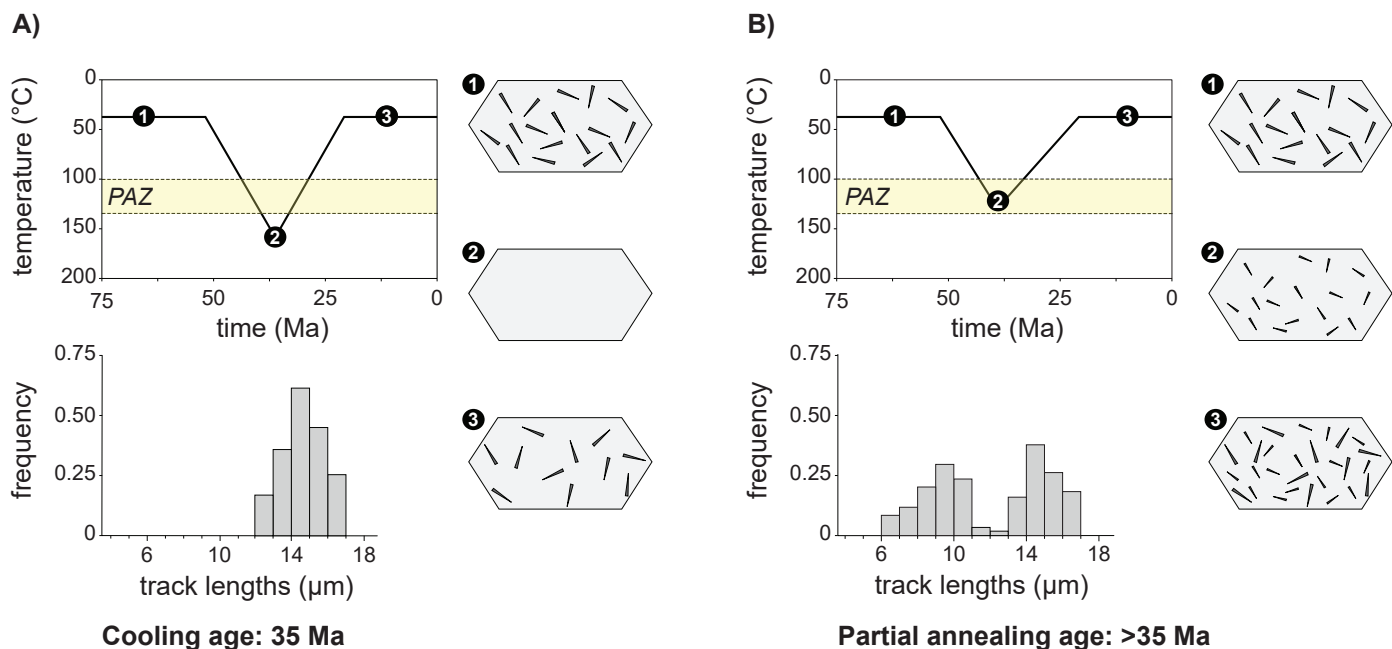


Figure 1.3. Simplified schematic of the observed track length distributions for the same apatite crystal that has undergone slightly different thermal histories. Prior to burial [1] both apatite grains have the same track length distributions. A) During burial [2] the AFT sample is heated to temperatures that exceed the partial annealing zone (PAZ), and all existing fission tracks are completely erased. Following exhumation [3] new fission tracks begin to accumulate, resulting in a unimodal distribution of track lengths. The AFT date for this sample represents the time of cooling. B) Burial temperatures [2] are within the temperature range that define the PAZ. Existing fission tracks begin to undergo thermal annealing. Track lengths progressively shorten, reducing the overall density of fission tracks. Following exhumation [3] new fission tracks begin to accumulate. As a result, the apatite grain preserves bi-modal peaks of track lengths, where the shorter tracks are a signature of the apatite's thermal history that pre-dates burial. The AFT date from this apatite grain will be older as it combines information from its earlier thermal history with the burial event [2] and is not geologically meaningful.

samples can serve as independent thermochronometers and refine thermal history models and is further elaborated below.

White mica $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology is sensitive to higher temperatures ($\sim 350\text{--}425^\circ\text{C}$) and their cooling ages can be used decipher exhumation from mid-crustal levels (**Figure 1.2**; Harrison et al., 2009; McDougall and Harrison, 2000). Due to the rheologic contrasts between mica and co-existing rock-forming minerals, micas are susceptible to mechanical and chemical break down during deformation. During this process, new syn-kinematic mica can develop, or existing mica can recrystallize within new rock fabrics, and these micas will record the time of deformation related to the observed fabric. Petrography is required to document the morphology of mica with respect to the rock fabric to determine whether $^{40}\text{Ar}/^{39}\text{Ar}$ dates record cooling ages or deformation dates. Combined with structural and petrographic analysis, white mica $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology can serve as useful tool to date deformation events (e.g., Cossette et al., 2015; Barnes et al., 2023; Dunlap et al., 1991; Rolland et al., 2008; Müller et al., 1999).

The applications of thermochronometers have proven useful to gain insight on the timing of exhumation and has aided to prospect mineral deposits and identify hydrocarbon reservoirs, as mineralization as well as the production and accumulation of oil and gas require specific thermal conditions (Armstrong, 2005; Green et al., 1989; Issler et al., 2005). Our growing understanding of radiometric dating has enabled geologists to tackle complex geological questions, as different techniques reveal information about discrete phases of a rock's history (e.g., Rubatto et al., 1999). For instance, a single sample can be analyzed to determine the age of the rock, the timing of metamorphism, pinpoint the timing of discrete deformation events and reconstruct the sample's low temperature thermal history.

1.4 Apatite fission track thermochronology

AFT dates are calculated using the ratio between the ^{238}U and the density of fission tracks (number of tracks per unit area; Ketcham et al., 1999). A unique feature of AFT in the context of low temperature thermochronology is the distinguishability of its daughter products, whereas radiogenic nuclides (^4He) measured in the (U-Th)/He system cannot be differentiated (Ravenhurst and Donelick, 1992). Track lengths encode valuable information related to the sample's thermal history and can provide insight on whether the sample has been partially annealed. For example, a wide distribution of track lengths can be indicative of protracted cooling across the PAZ: as fission tracks form at constant rate, older tracks are shorter as they are further annealed. Bimodal track-length distributions are also characteristic of partially annealed samples: shorter tracks typically represent remnants of an earlier thermal event, whereas longer tracks reflect new damage accumulated after the sample cooled below the PAZ (**Figure 1.3**). Thermal annealing is also an anisotropic process governed by apatite's hexagonal symmetry (6/m), and tracks that are increasingly misaligned with respect to the crystallographic c-axis anneal more rapidly (Barbarand et al., 2003; Carlson et al., 1999; Green et al., 1986). Although partial annealing reduces the density and average lengths of tracks within apatite grains, the orientation-dependent annealing rates also broadens the distribution of track lengths (**Figure 1.3**). Therefore, apparent AFT ages from samples that have undergone partial annealing cannot be directly interpreted as cooling ages, as it combines information of the samples' early thermal (**Figure 1.3**).

Thermal history modeling reconstructs time-temperature (t-T) pathways that best explain the fission track length distribution and its apparent AFT age. Modeling is required to extract meaningful information from partially annealed AFT samples and can help discern whether the samples experienced prolonged residency within the PAZ, and/or have undergone multiple

heating/cooling events (Green et al., 1986; Ketcham et al., 1999). Time-temperature constraints can be incorporated into the models, which can be useful to test the plausibility of competing geological hypothesis, whereas including constraints of known geologic events (e.g., surface exposure ages, burial depths, existing geo- and thermochronological dates) can refine model results. In conjunction with local paleo-geothermal gradients, the time and rate of cooling derived from thermal history models provide essential information for reconstructing exhumation histories.

1.4.1 Annealing kinetics of fission tracks

Even in locations with well resolved thermal histories, AFT samples often have significant intra-sample age dispersion. Due to comparative investigations and laboratory experiments, it is known that annealing kinetics are variable for different apatite specimens. Fluorapatite, hydroxyapatite and chlorapatite denote apatite's compositional end-member (F-OH-Cl), governed by anion substitutions within the mineral's stoichiometric formula: $\text{Ca}_{10}(\text{PO}_4)_6(\text{F,Cl,OH})_2$ (Elliott, 1994; Ketcham, 2015). Ca-F forms strong compact bonds, resulting in a symmetric crystal lattice. During thermal annealing, fluorapatite's well-ordered lattice creates efficient diffusion pathways which enable the rapid repair of fission tracks at a given temperature (Barbarand et al., 2003; Ravenhurst and Donelick, 1992). In comparison, Ca-Cl form weak, asymmetric bonds, and the crystal lattice is more distorted and less compact with increasing Cl-content. The "less ordered" crystal structure creates less efficient diffusion pathways and inhibits mobility of atoms around fission tracks (Barbarand et al., 2003). Consequently, to achieve the same degree of thermal annealing chlorapatite require higher temperatures relative to fluorapatite. D_{par} of a specimen represents the average diameter of confined fission track oriented parallel to the crystallographic c-axis. End-member fluorapatite have lower D_{par} values ($\sim 1.75 \mu\text{m}$), which generally increase in

apatite with decreasing F-content and increasing Cl-content (Green et al., 1986). Traditionally, D_{par} , Cl- and F-content have been used as proxies to predict apatite's annealing kinetics. None of these proxies can accurately predict the kinetic behavior for all apatite specimens, and laboratory experiments have also revealed that retentivity decreases for end-member chlorapatite, and OH-content can disrupt the expected correlation between F- and Cl-content and track retentivity (Barbarand et al., 2003; Carlson et al., 1999). In fact, the most retentive apatite found in nature (the B2 Bamble from Norway) has a near ternary (F-OH-Cl) composition (Carlson et al., 1999; Ketcham et al., 1999).

Laboratory-based annealing experiments have also revealed that numerous cation substitutions (e.g., Fe, Mg, Mn and REE's) can also influence the annealing kinetics of apatite (Barbarand et al., 2003; Carlson et al., 1999; Ketcham et al., 1999). These finding prompted a series of experiments that evaluated the kinetic behavior of various apatite specimens to quantify the influences that different elemental substitutions have on annealing kinetics. From these experiments, all elemental substitutions that influence retentivity were parametrized to create a multi-compositional $r_{\text{mr}0}$ equation (Carlson et al., 1999; Ketcham et al., 2007):

$$r_{\text{mr}0} = [0.027 + 0.431|Cl - I| + 0.107|OH - I| - 1.01Mn - 2.67Fe - 0.144others]^{0.25}$$

$R_{\text{mr}0}$ values are a measurement of apatite retentivity relative to the most retentive apatite found in nature (B2 Bamble; $r_{\text{mr}0} = 0$), thus more retentive apatite have lower $r_{\text{mr}0}$ values. $R_{\text{mr}0}$ values can be determined for any apatite specimen by inserting its stoichiometric chemical values into the equation, and previous work has demonstrated that it is a better suited kinetic proxy than F- and Cl-content or D_{par} . By incorporating $r_{\text{mr}0}$ values into thermal history models, plausible t-T

pathways are solved with respect to the specific annealing properties of the apatite, thus improving the resolution of model results (Carlson et al., 1999; Ketcham et al., 2007; Issler et al., 2005; McDannell et al., 2019; Powell et al., 2017, 2019).

Furthermore, AFT samples that have undergone partial annealing and include heterogeneous apatite chemistries can potentially be sub-divided into populations that share similar annealing kinetics (Issler et al., 2005). To categorize kinetic populations within AFT samples, more retentive kinetic populations (higher r_{mr0}) are expected to record older single-grain AFT dates and include the shortest track lengths, whereas less retentive kinetic populations are expected to record younger single-grain AFT dates. As the PAZ is defined by annealing kinetics, the temperature range that define the PAZ will vary among kinetic populations. AFT samples with multi-kinetic populations can serve as independent thermochronometers and produce more robust thermal history models which can potentially reveal important information regarding the timing and rate of exhumation.

1.5 Research objectives

The objective of this thesis is to decipher the timing and mechanisms of exhumation in orogenic belts by interpreting geo- and thermochronological data within the context of regional tectonism. My research focus was on two localities with contrasting tectonic settings: 1) a convergent orogen: The Peel Plateau, a foreland basin in the Canadian Cordillera that has undergone episodic burial and unroofing, and 2) an extensional orogen: the Tauern Window in the Eastern Alps of Austria exposing previously subducted rocks with a complicated exhumation history. Thermal histories were resolved from AFT data that accounts for grain-specific annealing kinetics in both field areas and I interpret these results within the context of their respective tectonism to understand how and when these rocks were exhumed into the upper crust. Results

from the Peel Plateau and Tauern Window are presented in Chapters 2 and 4, respectively. While conducting field work in the Tauern Window, previously undocumented structures were identified and interpreted to reflect exhumation from mid- to upper-crustal levels. These observations motivated a separate investigation into the early stages of exhumation in the Tauern Window, which forms the basis of Chapter 3. This work combines detailed structural analysis and deformation dates resolved via white mica $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology. Together, Chapters 3 and 4 decipher the early- and late- stages of exhumation in the Tauern Window.

1.6 Tectonic settings

1.6.1 The Peel Plateau, northern Canadian Cordillera

In the Northwest Territories, the Mackenzie Mountains fold and thrust belt are the eastern extent of the Canadian Cordillera and were formed during convergence and accretion in the Late Cretaceous to early Tertiary. The Mackenzie Mountains remain seismically active today and are estimated to have accommodated 45-80 km of crustal shortening (Cecile et al., 1982; Gordey, 1981; Vann et al., 1986). They expose Neoproterozoic and Paleozoic strata that are deformed into broad, gently plunging folds that regionally have an arcuate shape, where the orientation fold axes transition from NW-SE in the south and adapt E-W orientation in the north (Gordey et al., 2011). In the surrounding lowlands the Paleozoic strata and Neoproterozoic strata are overlaid by Phanerozoic foreland basin sequences interjected by several localized and regional unconformities (Hadlari et al., 2014).

The Peel Plateau forms the lowlands directly to the north of the "bend" in the Mackenzie Mountains. These two physiographic regions are separated by the Mackenzie Mountains deformation front that is denoted by an abrupt change in topography. In the Phanerozoic strata of

the Peel Plateau, documented facies trends and localized unconformities that coincide to structural highs (arches) and depressions (troughs) in the underlying Paleozoic/Neoproterozoic rocks (Hadlari et al., 2014; Lemieux et al., 2009; Morrow, 1999). In addition, geophysical data, surface mapping, and well data indicates major faults related to the deformation front form a foreland-vergent duplex structure that is buried below the southern limit of the Peel Plateau (Aitken et al., 1982; Lemieux et al., 2009). The Phanerozoic strata within the lowlands surrounding the Mackenzie Mountains have significant hydrocarbon potential and resolving the thermal history of these rocks are important to assess thermal maturation (Cecile et al., 1982; Lemieux et al., 2009). Localized and regional unconformities in the Peel Plateau suggest that the Phanerozoic strata have undergone a complex thermal history that may have been influenced by episodic reactivation of underlying structures. Clastic sedimentary rocks within the Phanerozoic strata susceptible to contain apatite with various chemistries and provide a unique opportunity to test the multi-kinetic AFT method and resolve complex thermal histories on rocks that have likely had a long residence at upper crustal levels. Convergence in Canadian Cordillera generated lithospheric flexure in the Peel Plateau, resulting in episodic opening and closure of foreland basins. AFT thermal history models are suitable to resolve the timing and rate of burial and exhumation of foreland basins which can provide insight on Cordilleran tectonism.

1.6.2 The Tauern Window, Eastern European Alps

Our understanding of geologic processes and the orogenic cycle has largely been based on field investigations conducted in the European Alps over the past century (e.g., Dal Piaz, 2001; Diener, 1901; Kurz et al., 1999; Murchison, 1849; Ratschbacher, 1986). The geology of the Alps consists of a stacked nappes that are derived from the Adriatic and Eurasian plates, and oceanic

crust that represent Mesozoic basins that once separated African and Eurasia (Tricart, 1984; Trümpy, 1960). The Tauern Window is located in the southwest of Austria and spans to the northern extent of Italy. It is a tectonic window comprised of two domes which are double-plunging, E-W oriented folds, and their cores expose the deepest structural units of the orogen. The oceanic nappes in the Tauern Window record evidence of subduction related metamorphism which terminated in the Oligocene and these deep-seated rocks have since been exhumed and currently form the highest peaks in Austria (e.g., Glodny 2005, 2008). During the Miocene, part of the Adriatic plate collided with the orogen which denotes the latest collisional phase in Alpine orogenesis.

The E-W oriented folds of the Tauern Window are attributed to N-S compression related to crustal indentation, and the latest stage of exhumation is attributed to erosion facilitated by the high-topography generated by the folds (Scharf et al., 2013). Erosion alone cannot account for the entire exhumation history of the Tauern Window, and other mechanisms must have contributed to the ascent of these originally deep-seated rocks (e.g., Bertrand et al., 2017). The window is bound by a complex fault network, however, the importance of these structures are debated and there is no consensus that they significantly contributed to exhumation (Decker and Peresson, 1996; Fügenschuh et al., 1997; Schmid et al., 2013). The Tauern Window is currently undergoing E-W extension, and the eastern and western margins of the window are overprinted by extensional fabrics (Scharf et al., 2013). The importance and onset of exhumation related to E-W extension has yet to be resolved.

The complexity of the Tauern Window presents a unique opportunity to resolve exhumation histories in an extensional orogen and investigate the processes operating across crustal depth. The early-stage of exhumation from deep crustal levels was resolved via structural analysis and the onset E-W extension was determined by dating deformation fabrics. In addition, previous studies

investigating the upper-crustal exhumation of the Tauern Window via AFT interpret the radiometric dates as cooling ages. AFT thermal history models that account for grain specific annealing kinetics were produced to test whether this method could reveal new information related to the exhumation history of the Tauern Window.

1.7 Thesis format

This doctoral thesis aims to improve our understanding of exhumation processes in orogenic settings by using innovative radiometric dating techniques combined with new and existing structural data. The thesis is divided into five chapters which includes three scientific articles. At the time this thesis was submitted, two of the articles have been published in peer-reviewed scientific journals and the third article under review.

In **Chapter 1**, I introduce the research objectives of this thesis and methods that were incorporated in this work. The chapter provides an overview of exhumation processes and different thermochronometers as well as a summary of the AFT systematics. Furthermore, summaries of the two field areas review their respective tectonic settings and highlight the motivation for selecting these locations for my research.

Chapter 2 focuses on the upper-crustal exhumation history of the Peel Plateau in the Canadian Cordillera. For this work, I used AFT samples from clastic sedimentary rocks and measured grain-specific chemistry to identify multi-kinetic populations within the apatites. I produced thermal history models for three samples that incorporate multi-kinetic populations and thermal constraints that represent known geologic events. I interpreted these thermal history models in conjunction with their spatial distribution and tectonic setting to gain insight on their

exhumation paths. I also created thermal history models that ignore multi-kinetic populations and compare these results with the multi-kinetic models.

This project was conceptualized by myself, David Schneider (Univ Ottawa) and Jeremy Powell (GSC). The AFT samples used for thermal history modeling were collected by Karen Fallas (GSC) during field work that was part of the Shield to Selwyn activity of the Geo-Mapping for Energy and Minerals (GEM-2) program of the Geological Survey of Canada. EPMA analysis of apatite was conducted by Scott Boroughs at Washington State University and AFT analysis was conducted at GeoSep services by Paul O'Sullivan. Jeremy Powell helped me get acquainted with thermal history modeling and the multi-kinetic approach and taught me how to use the modeling software AFTINV. Karen Fallas' and Jeremy Powell's knowledge of the regional geology were helpful to interpret the geologic significance of the model results. David Schneider, Jeremy Powell and Karen Fallas helped edit earlier versions and address the revisions of this manuscript. Chapter 2 was published in the journal of *Marine and Petroleum Geology* in June 2023.

In **Chapter 3**, I focus on the early exhumation history of the Tauern Window. This work is largely based on interpretations of field-based structural data. For this work, I categorize major structures and infer strain axes for different stages of deformation. Overprinting structural relationships were used to decipher the relative chronology of deformation, and together, these interpretations reconstruct the evolving strain field during progressive deformation. During field work, I observed deformation patterns that are consistent with exhumation under E-W extensional strain. Towards shallower crustal levels, the intensity of deformation is greater. These structural observations are consistent with deformation of the footwall of detachments, which prompted further investigations and lead to the discovery of a crustal-scale detachment system. The oldest structural evidence of E-W extension is a pervasive stretching lineation that is preserved across

the study area. Recrystallized white mica that defines the rock fabric was targeted for $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology to provide time constraints for the onset E-W extensional strain. Raman spectroscopy of carbonaceous material (RSCM) was used to determine peak metamorphic temperatures and re-define nappe boundaries.

I helped conceptualize the project with the guidance of David Schneider (Univ Ottawa), Benjamin Huet (Geosphere Austria) and Bernhard Grasemann (Univ Vienna). Most of the field work and sample collection ($^{40}\text{Ar}/^{39}\text{Ar}$ and RSCM) was conducted by Benjamin Huet and myself, and was assisted by David Schneider, Bernhard Grasemann, Wolfgang Frank (Univ Vienna), Sophia Swaton (Univ Vienna) and Emma Roberts as part of her BSc Honours thesis at the University of Ottawa. Bernhard Grassman helped interpret ambiguous kinematic indicators and with strain calculations. The acquisition of the $^{40}\text{Ar}/^{39}\text{Ar}$ data was performed by Alfredo Camacho (Univ Manitoba). RSCM was conducted by Gerd Rantitsch (Univ Leoben). David Schneider, Benjamin Huet and Bernhard Grasemann helped edit earlier versions and address the revisions of this manuscript. Chapter 3 was published in the journal of *Tectonics* in May 2025.

In **Chapter 4**, I investigate the upper crustal exhumation history in the Tauern Window via AFT thermochronology to test if new information could be retrieved by constructing thermal history models that account for grain specific annealing kinetics. Similar to the second chapter, I used apatite grain chemistry to categorize AFT samples based on annealing kinetics. However, no multi-kinetic populations could be discerned from these samples. Nonetheless, thermal history models that account for annealing kinetics were produced for three samples distributed across the Tauern Window. The onset of cooling predicted by the models are out-of-sequence with respect to their spatial distribution and potentially record a cooling signature that pre-dates folding/erosion in the Tauern Window.

I conceptualized this project with the help of David Schneider (Univ Ottawa) and Benjamin Huet (Geosphere Austria). Benjamin Huet and David Schneider assisted with field work and sample collection. EPMA analysis was conducted at the University of Ottawa with the assistance of Glenn Poirier. AFT analysis was conducted at GeoSep services by Paul O’Sullivan. Bernhard Grasemann (Univ Vienna), Benjamin Huet and David Schneider helped interpret the geologic significance of the thermal history model results and with the editing of earlier versions of this manuscript. This work is in review for a special issue of *Swiss Journal of Geosciences (16th Emile Argand Conference - Alpine Workshop)*.

My results and interpretations from these three research projects are summarized in **Chapter 5**. In this chapter, I also highlight the limitations of the various techniques used and provide suggestions to overcome certain obstacles that were encountered. In the final component of this chapter, I pose follow-up questions based on my findings as guidance for future research.

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CHAPTER 2

THERMAL HISTORY OF THE PEEL PLATEAU, NORTHERN CANADIAN CORDILLERA, RESOLVED THROUGH MULTIKINETIC APATITE FISSION-TRACK DATING

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2.1 Abstract

The Peel Plateau of the northern Canadian Cordillera has undergone multiple burial and unroofing events throughout the Phanerozoic, including subsidence and uplift associated with emergence of the Mackenzie Mountains. Episodic unroofing events are evinced by unconformities that represent a period where an unknown amount of material was deposited and eroded. Thermochronological studies have been conducted in neighboring physiographic regions, however no work has been conducted in the Peel Plateau and there is interest to determine whether it shares a similar thermal evolution as the surrounding regions. Apatite fission-track thermochronology (AFT) is a useful method for reconstructing basinal thermal histories as the system is sensitive to upper crustal temperatures, although the kinetics of the thermochronometer are complicated by numerous elemental substitutions within apatite that are known to control the specific temperature window within which fission-tracks anneal. This study uses three strategically positioned AFT samples from Phanerozoic sedimentary rocks to investigate the thermal history of the region from the Devonian to the present. Pooled AFT ages from all samples fail the X^2 test, implying there is a high level of intra-sample age dispersion and potentially indicating the samples contain multiple age populations. To assess whether the data are consistent with multiple kinetic AFT populations, we use grain-specific apatite compositions to derive r_{mr0} , a kinetic parameter that accounts for elemental substitutions known to control annealing kinetics of fission-tracks. By plotting AFT ages and track lengths against r_{mr0} we identify more-retentive and less-retentive apatite populations within each sample, which serve as independent thermochronometers when incorporated into inverse thermal history modelling. Results from a thermal history model of the Upper Devonian Imperial Formation indicate that the uppermost Paleozoic strata in the Peel Plateau reached maximum burial temperatures ($\sim 165^{\circ}\text{C}$ - 185°C) in the Triassic and were reheated to lower

temperatures ($\sim 90^{\circ}\text{C}$ - 100°C) under a Cretaceous-Paleocene foreland basin. The temperature regime of the latter burial event is supported by thermal history models of two Cretaceous samples that record peak burial temperatures ($\sim 80^{\circ}\text{C}$ - 90°C) in the Paleocene to Eocene. This study highlights the capabilities of thermal history modelling from multikinetic AFT data and serves as a reminder that addressing variable annealing kinetics of apatite grains can improve the resolution of thermal models and the associated geologic interpretations.

2.2 Introduction

There is particular interest to resolve the thermal evolution of foreland basins, despite methodological and interpretive challenges to doing so, as they provide insight on regional tectonism. Lithospheric flexure induced from tectonic loading along orogenic margins correlate to subsidence, thus dating maximum burial can effectively track the growth and propagation of the mountain range (Beaumont, 1981; Jordan, 1981; Karner and Watts, 1983; McMechan and Thompson, 1993; Plint et al., 2012). However, the stratigraphic record is often incomplete, so rates of burial and exhumation, and the amount of material that has been eroded across unconformities, cannot be resolved solely from the stratigraphic record. Resolving maximum burial temperatures and temperature history profiles of sedimentary basins has particular importance for the energy industry, as hydrocarbon maturation is sensitive to a narrow temperature window (Cooper et al., 1998; Barker and Pawlewicz, 2005; Schobert, 2013). Traditional methods employed to assess peak burial temperatures, including vitrinite reflectance (%Ro), rely on the thermal modification of organic material during burial (Mukhopadhyay, 1994; Barker and Pawlewicz, 2005). These methods solely constrain peak burial temperature and are unable to separately resolve the timing of peak burial, nor constrain temperatures of multiple burial events. In addition, organic material

is susceptible to recycling and poorly calibrated vitrinite reflectance models could yield inaccurate estimates of hydrocarbon maturation (Nzoussi-Mbassani et al., 2005; Nielsen et al., 2017).

Apatite fission-track (AFT) thermochronology can resolve thermal histories for temperatures of 50-150°C, however, apatite grain chemistry controls the specific temperature window that fission-tracks anneal (Barbarand et al., 2003; Armstrong, 2005). For example, fluorapatite is the most common specimen found in nature, and will completely anneal when heated to 60-120°C over geologic time, whereas higher temperatures are required to anneal Cl-rich apatite (Carlson et al., 1999; Armstrong, 2005; Donelick et al., 2005). This poses a challenge for AFT samples collected from clastic sedimentary rocks as multiple detrital source regions may result in a range of apatite composition that respond differently to heating and cooling.

Within an AFT sample, a kinetic population is defined by a group of apatite grains that share similar annealing properties, and AFT samples may have multiple kinetic populations (Issler et al., 2022). This apparent drawback of mixed kinetic populations within AFT samples can be exploited, as AFT grains can be separated into groups based on their respective annealing kinetics and serve as independent thermochronometers capable of producing more refined thermal history models (e.g., Ketcham et al., 2000; Issler et al., 2005; Green and Duddy, 2012; Powell et al., 2017; Schneider and Issler, 2019; McDannell et al., 2021; Issler et al., 2022). Laboratory-based annealing experiments correlate annealing kinetics to a range of apatite specimens with variable compositions deriving the r_{mr0} parameter. Measured apatite grain chemistry can be used to calculate r_{mr0} values and serve as a proxy to predict grain-specific annealing kinetics (Carlson et al., 1999; Ketcham et al., 1999).

Sedimentary strata within the Peel Plateau of the northern Canadian Cordillera has undergone a complex thermal history related to multiple burial and unroofing events (Feinstein et

al., 1996; MacLean, 2011; Hadlari et al., 2014). During the emergence of the Mackenzie Mountains fold and thrust belt, a regionally extensive Cretaceous foreland basin developed north and east of the mountain front, burying Paleozoic strata (Fallas et al., 2021; Hadlari et al., 2014). The thermal history of the region is relatively poorly constrained, especially with regards to the timing of maximum burial for Paleozoic source rocks. Thus, the region serves as an excellent natural laboratory to test the efficacy of resolving thermal history models via multikinet AFT data. In this study, three samples from the Peel Plateau that yielded dispersed AFT ages were investigated. Samples were collected from Upper Devonian, Albian (Lower Cretaceous) and Cenomanian (Upper Cretaceous) sedimentary strata (**Figure 2.1**), which were deposited in three separate deposystems, to evaluate the capacity of thermal history modeling to resolve multiple burial and unroofing events. Herein, thermal histories are resolved using AFTINV v. 6.12, an inverse numerical modelling approach that integrates Monte Carlo (MC; 0.05 significance level) and controlled random search (CRS; 0.5 significance level) methods (Issler, 1996; Price, 1977; Willett, 1997; McDannell and Issler, 2021; McDannell et al., 2021; Issler et al., 2022). To assess the significance of variable annealing kinetics, we compare AFT data modelled as a single kinetic population with multikinet populations. Ultimately, this work demonstrates that complicated thermal histories can be resolved with few samples by resolving multikinet populations within AFT samples where present.

2.3 Apatite fission-track thermochronology

Traditional geo- and thermochronometers utilize the ratio of daughter to parent isotopes and the diffusivity of the daughter isotope from the crystal lattice through thermally activated volume diffusion to calculate a date. In contrast, in fission-track thermochronology the ‘daughter’

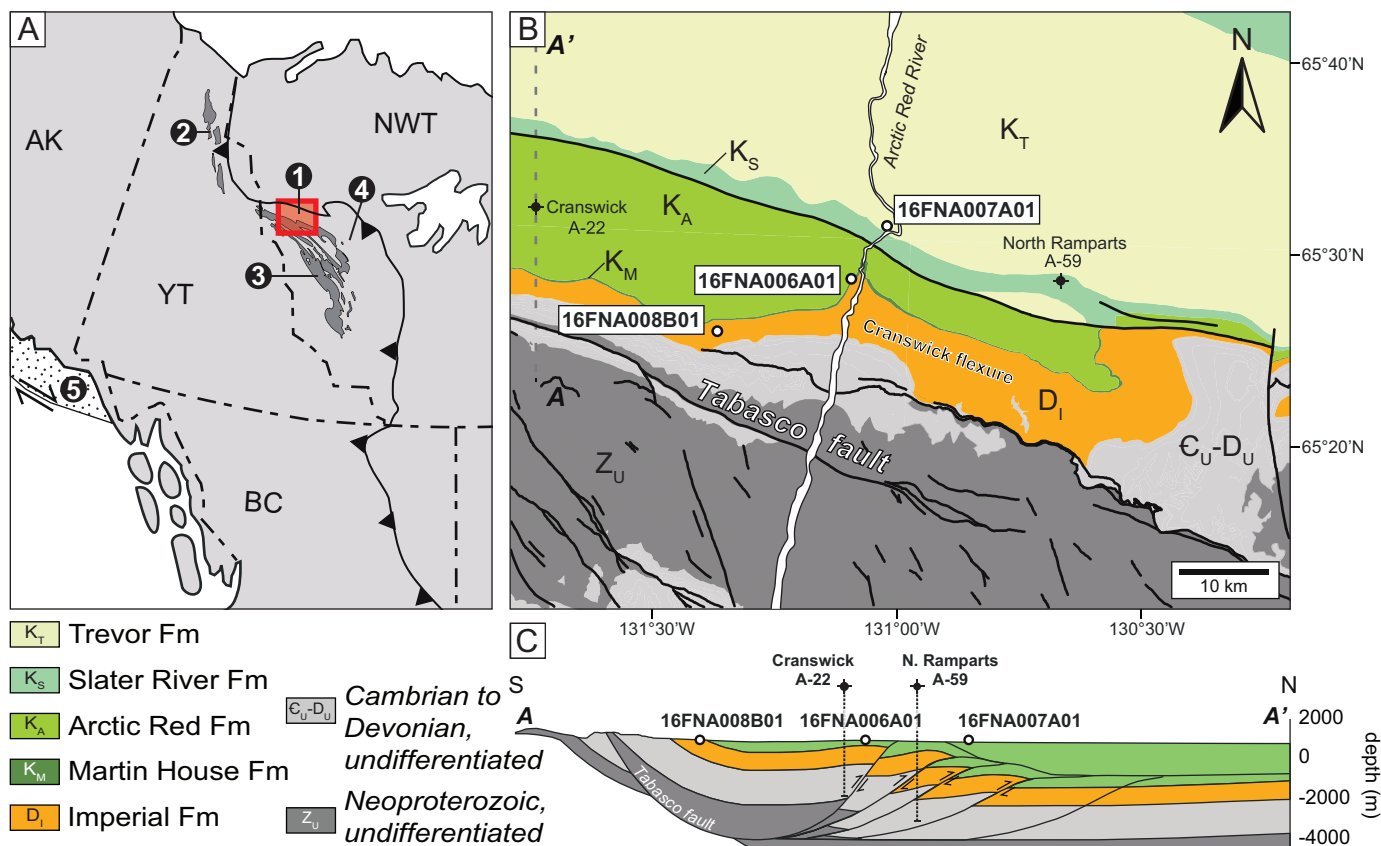


Figure 1.1. Simplified diagrams illustrating various exhumation processes. Erosion [A] and tectonic unroofing via high-angle normal faulting [Bi] can exhume the upper crust and the red dashed line represents the $\sim 100^{\circ}\text{C}$ isotherm. A) Erosion of an antiform exposes deeper crustal rocks within the hinge zone. Bi) High-angle normal faults can produce modest exhumation of upper crustal rocks. Bii) [1] A low angle normal fault (LANF) propagates in the ductile regime. The footwall and the fault plane are deformed during exhumation related to isostatic re-equilibration from the removal of the hanging wall. Strain is accommodated along a new fault plane [2] developed at shallower crustal depths. This process repeats itself and a new fault [3] develops. Younger faults are mechanically linked to the original LANF at depth and collectively, these structures form a detachment system. C) Ductile thinning results from vertical shortening during lateral ductile flow which exhumes the underlying rocks. Grey dashed lines denote horizontal fabric that is characteristic of ductile thinning. Extrusion [D] and extraction [E] are exhumation mechanisms related to subduction processes and the black arrows denote the relative displacement of rock masses. Modified after Froitzheim et al., 2003 and Lister & Davis, 1989.

product consists of the damage zone created in the crystal lattice during spontaneous fission of ^{238}U and the ‘diffusivity’ is its kinetic behavior, which dictates the preservation of fission-tracks within the crystal lattice (e.g., Donelick et al., 2005). When the sample is heated to temperatures that exceed a critical threshold ($\sim 60^\circ\text{C}$ for fluorapatite) that persists over geologic time, the crystal lattice begins to repair itself through diffusion mechanisms, which progressively shorten track lengths, and reduce track densities, a process referred to as thermal annealing (Gleadow et al., 1986; Green et al., 1989; Fitzgerald and Gleadow, 1990). The temperature window where fission-tracks undergo thermal annealing is defined as the partial annealing zone (PAZ). If apatite-bearing samples experience temperatures exceeding the upper threshold of the PAZ over geologic time, the fission-tracks completely anneal, ultimately resetting the fission-track age (Gleadow et al., 1986). Notably, thermal histories can be resolved for samples heated above the PAZ, provided the duration of heating is insufficient to completely anneal all pre-existing fission-tracks.

Fission-tracks are continuously formed by spontaneous fission; therefore, for samples that have resided in the PAZ, each track has undergone a different duration of thermal annealing. Since each track was formed at a different time, the observed track length distribution provides information that is pertinent to the sample’s thermal history. The ability to distinguish the daughter product is a unique feature of fission-track thermochronology, as radiogenic nuclides from typical thermochronometers, such as alpha particles within the (U-Th)/He system, cannot be differentiated (Ravenhurst and Donelick, 1992).

AFT dates reflect a cooling age if the sample underwent a simple thermal history where all pre-existing fission-tracks have been completely annealed during heating, followed by rapid cooling through the PAZ (Green et al., 1986; Armstrong, 2005). Sedimentary basins often have complex thermal histories involving multiple heating and cooling events and protracted residence

withing the PAZ. In these cases, fission-tracks are likely partially annealed and measured AFT ages may have no geologic significance. Thermal history modeling is required to extract meaningful information from such AFT data, however the significance of model results relies on adequate representation of the grain specific annealing kinetics (Ravenhurst and Donelick, 1992).

2.3.1 Annealing kinetics

Laboratory experiments suggest that thermal annealing of fission-tracks in apatite is an anisotropic process controlled by apatite's hexagonal symmetry, as fission-tracks that are aligned with apatite's crystallographic c-axis are most resistant to thermal annealing (Green et al., 1986; Carlson et al., 1999; Barbarand et al., 2003). These experiments also reveal that grain-specific chemistry exerts a strong control on annealing kinetics, governing the rate and specific temperature window within which fission-tracks undergo thermal annealing. Apatite's compositional end-members are fluorapatite, hydroxyapatite and chlorapatite, and are denoted by anion substitutions within the stoichiometric formula: $\text{Ca}_{10}(\text{PO}_4)_6(\text{F,Cl,OH})_2$ (Elliott, 1994; Ketcham, 2015). Annealing experiments indicate that fission-track retentivity increases with Cl content, except at very high Cl content, where track retentivity decreases (Gleadow et al., 1986; Carlson et al., 1999; Ketcham et al., 1999). Contrarily, fission-track retentivity decreases with increasing F content, and typical fluorapatite can completely anneal at 120°C (e.g., Gleadow et al., 1986; Green et al., 1989; Fitzgerald and Gleadow, 1990). The influence of OH substitution on thermal annealing is more complex, as the apatite specimens that are most resistant to thermal annealing (e.g., B2 Bamble) and least resistant to thermal annealing (e.g., Holly Spring) both incorporate significant OH in their stoichiometric formula (0.98 apfu and 1.8 apfu, respectively). Annealing experiments also

reveal that cation substitutions affect annealing kinetics, most notably Fe, Mn, Sr, Si and REE's (Carlson et al., 1999; Green et al., 1986; Ketcham et al., 1999; Barbarand et al., 2003).

AFT samples with variable annealing kinetics respond differently to heating/cooling events, resulting in dispersed AFT ages. To quantify age dispersion, the X^2 test is routinely used to decipher whether AFT samples comprise a single statistically significant age population. Populations that fail ($X^2 < 5\%$) might indicate multikinetically annealing behaviour. Alternatively, dispersed ages can reflect the varied pre-depositional histories if the apatite has not been completely annealed since the time of deposition. It is important to note that the X^2 does not determine the quality of the data: further interpretations are required to justify the groupings of multikinetically annealing populations, and the X^2 test is strongly influenced by the number of grains within the population (Green, 1981).

2.3.2 Kinetic parameters

The kinetic parameter chosen to reflect grain-specific annealing kinetics must be representative of apatite's true kinetic behavior to accurately discern multikinetically annealing populations. Commonly used kinetic proxies are D_{par} and Cl-content. D_{par} is an optical measurement of the maximum diameter of fission-track etch pit, which reflects the grain's solubility (Burtner et al., 1994). Cl-concentration and D_{par} adequately predict annealing kinetics for apatite with less retentive kinetics, however both parameters poorly represent the full range of annealing kinetics as apatite with high D_{par} ($>1.75 \mu\text{m}$) and Cl content ($>0.2 \text{ apfu}$) are not always the most resistant to thermal annealing. Numerous elemental substitutions influence annealing kinetics and neither Cl-concentration nor D_{par} can predict the full range of annealing kinetics for samples bearing a

wide range of apatite compositions (Green et al., 1986; Carlson et al., 1999; Donelick et al., 2005; Issler et al., 2022).

A multi-compositional r_{mr0} equation was developed through a series of laboratory-based annealing experiments that compare the kinetic behavior of various apatite specimens relative to the most retentive apatite specimen yet to be found in nature (Carlson et al., 1999):

$$r_{mr0} = [0.027 + 0.431|Cl - I| + 0.107|OH - I| - 1.01Mn - 2.67Fe - 0.144others]^{0.25}$$

Essentially, grain-specific chemistry is parameterized by inserting its stoichiometric chemical values into the multi-compositional equation. The derived r_{mr0} value is a measurement of the grain's annealing kinetics relative to the B2 Bamble ($r_{mr0} = 0$), thus apatite grains with less retentive annealing kinetics have higher r_{mr0} values. Recent work has demonstrated that r_{mr0} is more suitable proxy to predict annealing kinetics than D_{par} and Cl-content (Issler et al., 2005, 2022; Powell et al., 2017, 2019; McDannell et al., 2019).

2.4 Geological setting

2.4.1 Physiographic regions and regional geology

The Peel Plateau is a physiographic region that spans northeast Yukon and western Northwest Territories in northern Canada, between 65°N and 68°N (**Figure 2.1A**; Pyle and Jones, 2009; Fallas et al., 2021). Preserved stratigraphy in the Peel Plateau comprises a thick Phanerozoic sequence that unconformably overlies Proterozoic strata. South of the Peel Plateau, the Late Cretaceous-Paleogene Mackenzie Mountains fold and thrust belt occupies the eastern margin of the Cordillera. The Mackenzie Mountains are underlain by more resistant Proterozoic and

Paleozoic strata, at higher elevation and greater relief than the Peel Plateau. The boundary is marked by a sharp change in topography. (**Figure 2.1A**). The Mackenzie Mountains remain seismically active today and are estimated to have accommodated 45-80 km of crustal shortening, based on interpretations of structural cross-sections (Gordey, 1981; Cecile et al., 1982; Vann et al., 1986). The Mackenzie Mountains trend northwest-southeast for ~950 km along strike with elevations surpassing 1800 m (**Figure 2.1A**). In the study area, the north flank of the Mackenzie Mountains is marked by the Cranswick flexure (Aitken et al., 1982). Geophysical and well data combined with surface mapping suggest there is a buried foreland-vergent duplex structure north of the Cranswick flexure, in the southern portion of the Peel Plateau (**Figure 2.1C**; Lemieux et al., 2009). The roof of the thrust system is interpreted to be bedding parallel and lie within the Upper Cretaceous strata, whereas the sole of the thrust is interpreted to lie near the base of lower Paleozoic strata (Aitken et al., 1982; Lemieux et al., 2009). The Richardson Mountains are the northern continuation of the Cordillera (**Figure 2.1A**). Their location coincides with a Paleozoic trough that accumulated deep water sediments until the Devonian. Late Cretaceous deformation initiated uplift and was intermittent until the middle Tertiary. Inversion of the trough produced north to northwest trending anticlines with maximum elevation of ~1350 m (Norris, 1996; Morrow, 1999).

2.4.2 Phanerozoic tectono-stratigraphy

Phanerozoic strata in the Peel area comprises stacked deposystems separated by regional unconformities, reflecting the evolving tectonic regime during sedimentation (Cook and MacLean, 2004; Thorkelson et al., 2005; Fallas and MacNaughton, 2019; Fallas et al., 2021). These sedimentary successions were deposited along ancestral Laurentia's Paleozoic northwestern margin and within a Mesozoic-Cenozoic Cordilleran foreland basin. Provenance studies (e.g.,

detrital muscovite and zircon ages) combined with evidence of changing subsidence patterns and basin inversions indicate that sedimentation was synchronous to tectonic activity and helps constrain the source areas of sediments (e.g., Hadlari et al., 2014).

The Late Devonian Imperial Formation is a siliciclastic shelf succession distributed across the Northwest Territories and Yukon (Martin, 1959; Gordey et al., 1991). Biostratigraphic indicators suggest the unit is Frasnian-Famennian in age (Hadlari et al., 2009a,b). In addition, detrital muscovite $^{40}\text{Ar}/^{39}\text{Ar}$ ages have a significant age population at 400-500 Ma (Powell and Schneider, 2013). The Imperial Formation is interpreted to have been deposited in a foreland setting, where siliciclastic input was coeval with uplift of a clastic source related to the Ellesmerian orogeny, when ancestral Laurentia collided with an exotic landmass to the north and east (Martin, 1959; Braman and Hills, 1992; Lane, 2007). A regional unconformity separates the Imperial Formation from overlying Cretaceous strata (**Figure 2.2**).

The Northern Canadian Cordillera has evolved through discrete episodes of orogenesis related to the accretion of terranes along North America's western margin. Most of the crustal shortening occurred during two main phases of collision related to 1) Jurassic accretion of Intermontane terrane, and 2) Early to mid-Cretaceous accretion of Insular terranes (Monger et al., 1982). Tectonic loading resulted in lithospheric flexure inland and basin-forming episodes along the eastern Cordilleran margin during the Jurassic and Cretaceous. The second major phase of Cordilleran tectonism marked the emergence of the Mackenzie Mountains and lithospheric flexure formed a foreland basin and its associated sediments blanket the northern Interior Plains which comprise the northern extent of the Western Interior Basin. Lateral variations of stratigraphic thickness and facies trends track the locus of basin subsidence, and effectively trace the

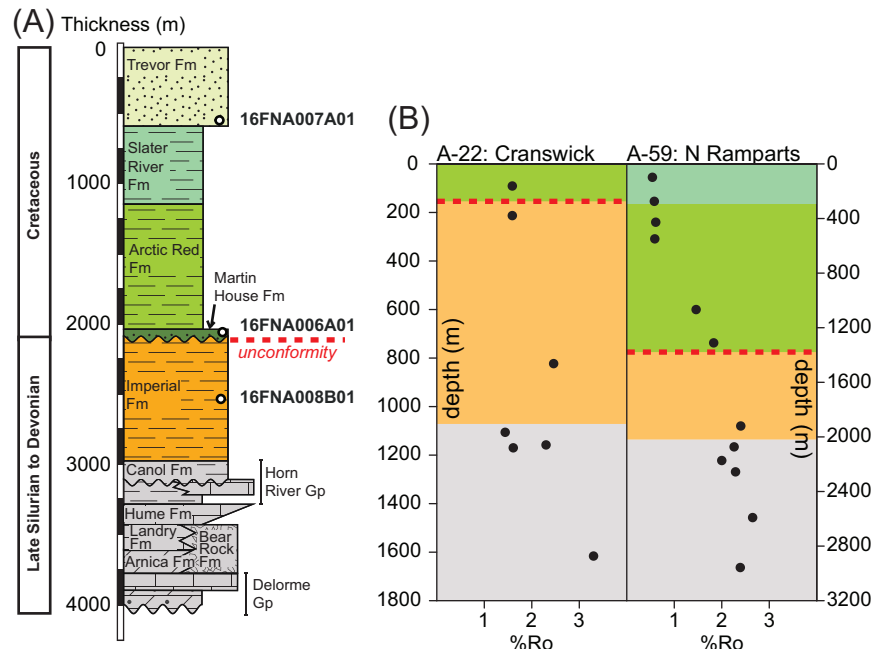


Figure 2.2. A) Stratigraphic column illustrating regional sedimentary sequence in southern Peel Plateau, NWT, Canada, and sampled intervals. Colours correspond to map units in Figure 2.1B (modified from MacNaughton et al., 2018). Vitritine reflectance data (%Ro) from exploration wells projected at depth. Well locations shown in Figure 2.1B. Surface sample from the Arctic Red Formation is 1.1 %Ro, and surface sample from the Imperial Formation is 1.7 %Ro. Values from exploration well samples are a compilation of measurements reported in Pyle and Jones (2009).

propagation of the Mackenzie Mountains fold and thrust belt to the northeast through time (Hadlari et al., 2014; Powell et al., 2016).

The Albian Martin House Formation is the oldest stratigraphic unit preserved from the Cretaceous foreland basin in the Peel Plateau. Near the Arctic Red River, the Martin House Formation is ~20 m thick and consists of shoreface sandstones at its base, followed by a transgressive sequence of interbedded sandstone siltstone and shale related to a sea level rise. The Martin House Formation is overlain by the up-to-1000 m thick shale-dominated succession of the Aptian-Albian Arctic Red Formation, recording subsequent shallowing-upwards sequence. In the Peel Plateau, Thompson et al. (2011) remarked the upper section of the Arctic Red Formation is barren of foraminifera and note the development of paleosol, evincing anoxic conditions during transgression, followed by subaerial exposure indicated by a disconformity (Hadlari et al., 2014). The sub-Cenomanian disconformity within the Peel Plateau correlates to an angular unconformity in the Peel and Mackenzie plains, and the changing nature of the unconformity is attributed to the region's paleogeographic location relative to Paleozoic arch systems that were reactivated during Cenomanian tectonism (Norris, 1985; Thomson et al., 2011).

In the Cenomanian, the Alexander Terrane collided with North America while undergoing a counter-clockwise rotation, resulting in dextral transpression within the continental interior and renewed subsidence, depositing mudstone-dominated sediment of the Slater River Formation (Irving and Wynne, 1991; McClelland et al., 1992). The Slater River Formation records a shallowing upwards succession from offshore marine at its base to marginal marine, and grades into the shoreface sandstones of the Trevor Formation (Thomson et al., 2011).

The overlying Cenomanian to Turonian Trevor Formation comprises a succession of 10-100 m thick parasequences that typically grade from mudstone to sandstone. The Trevor Formation locally exceeds a thickness of 700 m, and is the youngest stratigraphic unit preserved within the Peel Plateau. Folded Palaeocene strata in the Brackett Basin, located within the southern Mackenzie Plain, suggest that syn-tectonic deposition persisted at least until this time, however it is unclear whether sediments younger than the Trevor Formation were deposited and eroded from the Peel Plateau (Gordey et al., 2011).

It is debated whether active convergence was transferred inland of western North America since the Mesozoic to Cenozoic (Hyndman et al., 2005; Enkelmann et al., 2019). The Yakutat block is a small composite terrane comprised of oceanic and continental crust that, since the Miocene, has been obliquely colliding with North America (**Figure 2.1**), and strain from this collision is likely transferred to the interior of the Cordillera across a lower crustal detachment that underlies the upper crust of the Cordillera (e.g., Lahr and Plafker, 1980; Bruns, 1983; Plafker and Berg, 1994). Modern seismicity within the Richardson and Mackenzie mountains could be related to the ongoing indentation of the Yakutat block (Mazzotti and Hyndman, 2002).

2.5 Previous work

2.5.1 Thermal maturity indices

Thermal maturity indices are used to estimate burial temperature and hydrocarbon maturation in prospective sedimentary basins. It must be cautioned that values from the Cretaceous foreland basin strata may be contaminated with mature Paleozoic vitrinite recycled during uplift of the Mackenzie Mountains. In addition, maturation of organic material is a time-dependent process, and long residency at peak-burial conditions is required for measured indices to reflect

the samples peak burial temperature. Thermal maturation indices must be thoroughly examined to assure that they are representative or otherwise yield unrealistic estimates of thermal maturity (Issler et al., 2005; Nzoussi-Mbassani et al., 2005).

There are two exploration wells with published vitrinite reflectance data in the vicinity of the study area (Pierce and Jones, 2009). The Cranswick well (A-22) is located ~25 km west of the sample locations from this study, and the North Ramparts well (A-59) is located ~20 km to the east. The %Ro values were measured from well cuttings collected from Paleozoic and Cretaceous strata in each well (**Figure 2.2B**). Thermal maturity indices from Cretaceous strata could provide insight regarding peak burial temperatures from the two Cretaceous samples presented herein.

Within both exploration wells, thermal maturation varies from marginally mature to overmature. Within the Cranswick well (A-22), the shallowest cutting collected at a depth of 91 m from the Cretaceous Arctic Red Formation records a thermal maturity of 1.59 %Ro. The same value is measured at 213 m depth within the Imperial Formation, and values increase to 2.46 %Ro at 823 m. Strata in the underlying Canol Formation record thermal maturity indices between 1.44 %Ro and 2.30 %Ro (depth 1106-1170 m). Within the North Ramparts exploration well (A-59), the four shallowest measurements from the Slater River Formation and the Arctic Red Formation (98-549 m) have considerably lower thermal maturity indices, ranging between 0.54 and 0.61 %Ro, however values increase to 1.83 %Ro at the base of the Arctic Red Formation (depth 1311 m). A single measurement from the Imperial Formation yields a thermal maturity of 2.40 %Ro at a depth of 1920 m. Thermal maturity indices are lower within the underlying Canol Formation (depth 2073 m) and the Bluefish Formation (depth 2173 m) at 2.26 %Ro and 2.00 %Ro, respectively.

In addition, two surface samples were collected for vitrinite reflectance from the same outcrop where AFT samples of this study were collected. Sample 16FNA008A01 was collected

from the Imperial Formation (proximal to AFT sample 16FNA008B01) and yields a value of 1.7 %Ro. The second surface sample for %Ro (16FNA006B01) was collected from the Arctic Red Formation, approximately 1 m above the contact with the Martin House Formation and yields a value of 1.1 %Ro (**Figure 2.1B**). The AFT sample from the Martin House Formation sample (16FNA006A01) was collected at the same outcrop, approximately 8 m below the contact. Decreasing thermal maturation indices with increasing stratigraphic depth could reflect recycling of vitrinite material from deeper (older) units into shallower (younger) units. Similarly, high thermal maturity indices measured at the base of the Cretaceous strata likely reflect reworked vitrinite material sourced from underlying Paleozoic strata. Lower thermal maturity values from the Slater River Formation and the upper Arctic Red Formation in the North Ramparts A- 59 well (0.54-0.61 %Ro), are likely the best indication of the true thermal maturity (Pyle and Jones, 2009).

2.5.2 Low temperature thermochronology

Due to the remote location of our study area and relatively recent advances in thermochronological methods, few studies have investigated the region's low temperature thermal history. To our knowledge, no previous work has been done within Peel Plateau, although similar investigations have been pursued south of the Peel Plateau, in the Mackenzie Mountains, to the southeast in the Mackenzie Plain, and to the west in the Richardson Mountains and (e.g., Issler et al., 2005; Powell et al., 2016; Powell et al., 2017; McKay et al., 2021). Recent work from Powell et al. (2016) and Enkelmann et al. (2019) resolve the thermal history of the Mackenzie Mountains and Mackenzie Plain from zircon and apatite (U-Th)/He data. Results from Powell et al. (2019) predict peak burial (<200°C) within the Mackenzie Mountains to have occurred between the Carboniferous and Late Triassic, with the onset of cooling constrained to the beginning of the

Triassic. The Mackenzie Plain region was reburied during growth of the Mackenzie Mountains, and thermal histories vary among samples, mirroring the propagation of the thrust belt commencing at 100 Ma. In comparison, thermal history models from Enkelmann et al. (2019) are resolved for the past 120 Ma and predict the onset of cooling in the Mackenzie Mountains to have initiated in the Late Cretaceous (100-75 Ma) or during the Palaeocene-Eocene (65-40 Ma) whereas cooling in the Mackenzie Plain is predicted to have initiated during the Oligocene-early Miocene (33-20 Ma). These combined results support a model of Paleocene-Eocene cooling within the Mackenzie Mountains contemporaneous with the peak burial within the Mackenzie Plain. Notably, samples collected along the deformation front, most proximal to the Peel Plateau, predict the onset of most recent exhumation to have occurred during the Palaeocene-early Eocene (60-55 Ma; Powell et al., 2016).

Within the Brackett Basin of the Mackenzie Plain, Issler et al. (2005) conducted AFT thermochronology from a well sample and utilized Cl-content to identify two kinetic populations. Model results predict peak burial temperatures of $124 \pm 10^{\circ}\text{C}$ during the Early Triassic to Middle Jurassic (250-170 Ma), reheating to $<70^{\circ}\text{C}$ during the Albian (112-100 Ma), and a final heating event to $97 \pm 9^{\circ}\text{C}$ during the Palaeocene-early Eocene (65-50 Ma). In another study from the Mackenzie Plain, Powell et al. (2019) utilized both zircon and apatite (U-Th)/He data as well as multikinetic AFT data that incorporates the $r_{\text{mr}0}$ parameter for thermal history modelling. Results predicted peak burial temperatures of 92°C - 160°C during the Carboniferous to Early Cretaceous (338-138 Ma), and reburial to 61°C - 137°C between the Late Cretaceous and Neogene (95-18 Ma). Earlier work by Powell et al. (2017) also produced thermal history models using multikinetic AFT and apatite (U-Th)/He data within the Mackenzie Plain that predicts burial temperatures of ~ 65 - 90°C in the Late-Cretaceous to Palaeocene followed by protracted cooling throughout the

Cenozoic. In Powell et al. (2017), apatite was extracted from a bentonite layer within the Slater River Formation that is dated to 97.6 ± 1.0 Ma via zircon U-Pb geochronology and coincides with widespread c. 100-90 Ma magmatism within the northern Canadian Cordillera, suggesting regional magmatism was contemporaneous with renewed subsidence within the foreland (Hadlari et al., 2014; Powell et al., 2017). Most recently, work by McKay et al. (2021) within the northern Richardson Mountains to the northwest produced thermal history models from apatite and zircon (U-Th)/He data. Model results predicted peak burial temperatures of 70°C-110°C during the Palaeocene, with three separate solutions for the onset of cooling: Palaeocene-early Eocene (>65-50 Ma), late Eocene-Oligocene (40-30 Ma), and Oligocene-early Miocene (30-15 Ma).

The foreland basins adjacent to the Mackenzie Mountains possess an elevated geothermal gradient (30-40°C), and heat flow models predict upper crustal conditions have persisted since the Cretaceous-Paleocene (Feinstein et al., 1991, 1996; Majorowicz and Morrow, 1998). Maximum burial depths are converted from peak temperatures resolved from thermal history modeling using the current geothermal gradient. The Paleozoic deposystem is predicted to have reached peak burial depths of 2.2-6.3 km, however the timing of peak burial is loosely defined. Reburial of Devonian strata within the Cretaceous foreland basin is interpreted to have reached depths between 1.6 and 3.8 km during the Late Cretaceous and Neogene (Issler et al., 2005; Powell et al., 2017, 2019; Enkelmann et al., 2019; McKay et al., 2021). The specific timing of reburial is better defined within independent studies and depends on sample locations within the foreland basin. The broad timeframe defining reburial coincides with the onset of exhumation within the Mackenzie Mountains and is widely interpreted to reflect a pattern of lithospheric flexure related to Cordilleran tectonics (Plint et al., 2012; Powell et al., 2016; Enkelmann et al., 2019). Finally,

discrete phases of rapid exhumation during the Oligocene-early Miocene (33-15 Ma) were identified by Enkelmann et al. (2019), McKay et al. (2021), and Powell et al. (2019).

2.6 Samples and methods

The study area was chosen due to its location between the Mackenzie Plain and the Richardson Mountains. Previous work from these locations reports slightly different thermal histories, and as no previous work has been conducted in the Peel Plateau, the incentive was to decipher whether the Peel Plateau shares a similar thermal evolution (**Figure 2.1**). Secondly, there was interest to gain insight for time intervals that are missing from the rock record (Carboniferous to Jurassic, and post- Paleocene). Sampling for AFT thermochronology targeted different stratigraphic units that were known or suspected to bear apatite, from locations that follow a broad profile oriented perpendicular to the Mackenzie Mountains (**Figure 2.1**). The three samples presented herein consist of 1) chert-bearing lithic arenite from the Cenomanian Trevor Formation (16FNA007A01), collected ~14 km from the Mackenzie Mountains front and overlying a proposed buried foreland-vergent duplex structure; 2) a lithic wacke from the Albian Martin House Formation (16FNA006A01), collected ~10 km from the mountain front and 3) a lithic wacke collected from the Late Devonian Imperial Formation (16FNA008B01), collected adjacent to the mountain front (**Figure 2.1B**; **Table 2.1**).

2.6.1 AFT LA-ICPMS method

AFT analyses were conducted via the laser ablation-inductively coupled plasma-mass spectrometry (LA-ICPMS modified- ζ method; Chew and Donelick, 2012; Cogné et al., 2020) by GeoSep Services, Inc (Moscow, USA). Apatite grains were separated from rock material using standard mineral separation techniques and, apatite separates were mounted in epoxy, polished

Table 2.1

Summary of multikinetic AFT data from the Peel Plateau, NWT.

	Age grains (n)	ΣNs	ΣPiΩi	ΣσPi2Ω2	Q (%)	Dpar (μm)	One sigma (μm)	Pooled AFT date (Ma)	One sigma (Ma)	Central Age (Ma)	1σ (Ma)
16FNA007A01, chert arenite, Trevor Fm, 65.50878567, −131.05855233, 398.9 masl											
All					<1			169.6	8.4	156.0	20.8
Population 1	30	291	3.4E-05	2.2E-13	33	1.9	0.3	106.1	6.7		
Population 2 (omitted)	10	331	1.1E-05	7.8E-13	<1	1.9	0.3	357.2	35.0	381.5	44.3
16FNA006A01, lithic wacke, Martin House Fm, 65.46295917, −131.125593, 432 masl											
All					<1			59.5	5.2	66.7	8.7
Population 1 (less retentive)	23	79	2.7E-05	2.8E-12	59	1.7	0.3	36.4	4.7		
Population 2 (more retentive)	16	118	1.4E-05	8.3E-13	71	2.0	0.3	103.3	11.8		
16FNA008B01, lithic wacke, Imperial Fm, 65.41090817, −131.41356184, 722.3 masl											
All					<1			61.0	5.1	68.2	8.0
Population 1 (less retentive)	32	145	3.9E-05	3.9E-12	57	1.7	0.3	46.3	4.6		
Population 2 (more retentive)	8	75	5.8E-06	2.8E-14	89	1.8	0.2	157.7	19.0		
	Track lengths (n)		Mean track length (μm)		One sigma (μm)		Dpar (μm)		1σ (μm)		r _{mr0}
16FNA007A01, chert arenite, Trevor Fm, 65.50878567, −131.05855233, 398.9 masl											
Population 1	84		13.0		1.7		2.1		0.4		–
Population 2 (omitted)	4		12.8		1.6		2.0		0.5		–
16FNA006A01, lithic wacke, Martin House Fm, 65.46295917, −131.125593, 432 masl											
Population 1 (less retentive)	21		13.6		1.7		1.8		0.3		>0.81
Population 2 (more retentive)	30		13.2		1.5		2.2		0.5		<0.81
16FNA008B01, lithic wacke, Imperial Fm, 65.41090817, −131.41356184, 722.3 masl											
Population 1 (less retentive)	31		13.4		1.8		1.7		0.2		>0.79
Population 2 (more retentive)	7		12.8		2.0		2.1		0.4		<0.79

ΣNs is the total number of spontaneous fission tracks for each kinetic population. $\Sigma Pi\Omega_i$ is the sum of the product of $^{238}U/^{43}Ca$ ratio (Pi) and the corresponding track count area (Ω_i). $\Sigma \sigma Pi2\Omega2$ is the error for $\Sigma Pi\Omega_i$ used to calculate the error on the pooled AFT age. Q represents the chi-squared probability for each population. A population passes the chi-squared test if $Q > 5\%$. Dpar is the diameter of the etch figure parallel to the c-axis, and was averaged from AFT age grains.

using 3.0 and 0.3 μm grit, and etched in 5.5 N HNO_3 for 20 s at 21°C to reveal all natural fission-tracks intersecting the polished grain surface. A single grain mount was used to acquire AFT age, length, and D_{par} data for each sample according to the procedures described in Donelick et al. (2005), and locations of each age-grain on the mount were recorded. Spontaneous tracks (N_s) were first counted for each AFT analysis in unpolarized light at 2000x magnification using a Zeiss Axioplan microscope. When possible, N_s values were determined from 40 grains for each AFT analysis. Following this, the apatite mounts were irradiated using fission fragments from a ^{252}Cf source in a vacuum chamber to enhance the number of confined fission-tracks (CFT) available for measurement (e.g., Donelick and Miller, 1991). The irradiated apatite grain mounts were then re-etched under the same conditions to reveal a new set of horizontal CFT within the exposed apatite grains. These confined tracks were viewed and measured in both unpolarized and polarized light at 2000x magnification using a Zeiss Axioplan microscope. Only natural, horizontal, fully confined fission-tracks in apatite with clearly visible ends were considered candidates for length measurement. The length and crystallographic orientation of each fission-track was determined using a digitizing tablet interfaced with a personal computer.

Once analytical measurements were completed for AFT analyses (N_s counts and CFT measurements), an Agilent 7700x ICPMS equipped with a New Wave Nd-YAG 213 nm laser ablation system housed at Washington State University (Pullman, USA) was used to measure isotopic data necessary for all apatite FT and U-Pb grain age calculations. Data were collected for the following isotopic masses: ^{43}Ca , ^{147}Sm , ^{204}Pb , ^{206}Pb , ^{207}Pb , ^{232}Th , and ^{238}U (45 scans over 45 s). Each analysis consisted of a 6 s integration on peaks with the laser shutter closed (for background measurements) followed by the shutter opening and the laser ablating apatite for the remainder of the analysis. A 20 s delay occurred between analyses. The beam diameter was 20 μm

and the frequency was set at 5 Hz at 8 J/cm, yielding ablation pits ~16-18 μm deep. The ^{238}U concentrations were determined for the track count areas on each age-grain by measuring the ablation pits depth-weighted $^{238}\text{U}/^{43}\text{Ca}$ ratio from a fixed laser point (^{232}Th and ^{147}Sm were also measured). The volume of ablated material was estimated using ^{43}Ca , presuming Ca content respects apatite's stoichiometry. The AFT dates were calculated using the LA-ICPMS ζ -calibration approach (Chew and Donelick, 2012; Cognée et al., 2020; Donelick et al., 2005; Vermeesch, 2017) based on the Durango apatite reference monitor (31.44 ± 0.18 Ma, McDowell et al., 2005) and U-Pb dates calculated following Chew and Donelick (2012) referenced to FC Duluth Complex apatite (1099.0 ± 0.6 Ma, Paces and Miller, 1993).

2.6.2 Apatite chemistry via EPMA

Chemistry of AFT age-grains and length-grains were measured via electron probe microanalysis (EPMA), specifically to constrain halogen substitutions within individual apatite grains. The objective was to measure grain chemistry on all AFT-age and a minimum of 30 length grains, although the analysis yielded fewer successful measurements as many grains were too small relative to the probe beam, and the number of age-grains that remained intact following laser ablation were limited. To avoid chemical zonation and obtain the most representative chemical data, spot analysis for EPMA were placed adjacent to LA-ICPMS ablation pits. Quantifying grain-specific chemistry is crucial in this study, as it is necessary to calculate $r_{\text{mr}0}$ values which are used to differentiate kinetic populations.

Apatite grains were analysed in wt% oxide for thirteen elements (F, Na, Mg, P, S, Cl, Ca, Mn, Fe, Sr, Y, La, Ce) by EPMA at Washington State University (Pullman, USA) using a JEOL JXA8500F Field Emission Electron Microprobe operated at 15 kV (20 nA current) with a beam

size of 5 μm . A total of 23 analyses yielded low total wt% (<95 wt%). As Ca and P together normally comprise 97% of apatite's total weight percent (CaO: 55%, P₂O₅: 42%), Ca and P values were adjusted for these analyses to compensate for low total wt% to assure the values converted to atoms per unit formula (apfu) are realistic (Ketcham, 2015).

Apatite chemistry is converted from wt% to apfu to reflect the mineral's stoichiometry formula (Ketcham, 2015). OH values are calculated from F-Cl content following apatite's stoichiometry, where halogens (F + Cl + OH) occupy 2 apfu. The r_{mr0} values are calculated using stoichiometric chemical composition using the multi-variant equation of Carlson et al. (1999). R_{mr0} values for apatite grains without probe data were derived from D_{par} measurements following the relationships of Ketcham et al. (1999).

2.6.3 Inverse thermal history modeling

Inverse thermal history modelling was performed using AFTINV (v. 6.12) for the three AFT samples presented in this study (Issler, 1996). Geologically acceptable time-temperature and heating/cooling rate constraints were input to AFTINV and define the search space for the model to find plausible time-temperature pathways. Time-temperature pathways are resolved at 2.5 Myr intervals by randomizing cooling and heating within the limits of the input parameters and recognizing solutions where there is an acceptable statistical fit between modelled and measured i) AFT ages, ii) track lengths and iii) %Ro values. In this study, models are set up to use a non-directed random Monte Carlo (MC) approach to find 300 plausible solutions at the 0.05 significance level. The search space is then redefined to an envelope constraining the 300 MC solutions, and AFTINV searches for an additional 300 solutions via a controlled random search function (CRS) at the 0.50 significance level (McDannell and Issler, 2021). Models are set up to

include sufficient pre-depositional history to establish initial track-length distribution at the time of deposition. To avoid over-constraining our thermal history solutions, cooling and heating rates ($^{\circ}\text{C}/\text{Myr}$) are loosely defined. Our input parameter includes minimum heating and cooling rates of $0.01^{\circ}\text{C}/\text{Myr}$, and maximum heating and cooling rates vary between 10 and $15^{\circ}\text{C}/\text{Myr}$. In addition, thermal maturity (%Ro) constraints are included for Paleozoic and Cretaceous burial. Paleozoic burial is modelled with 1.55 ± 0.15 %Ro, whereas Cretaceous burial is modelled with 0.66 ± 0.66 %Ro. The thermal maturity constraint for Cretaceous reburial purposely incorporates a large uncertainty to reflect the variability in measured organic thermal maturity parameters from age-equivalent rocks. By comparison, previous work has better constrained the magnitude of Paleozoic burial therefore a smaller uncertainty is included within the input constraint for thermal history modelling (Issler et al., 2005). Finally, since samples were collected from the surface, time-temperature pathways are forced to converge to surface temperatures ($T < 20^{\circ}\text{C}$ at $t = 0$).

The motivation to separate single grain AFT data into distinct kinetic populations is to model these populations simultaneously as independent thermochronometers, where each kinetic population is suited to resolve different components of the sample's thermal history. Kinetic populations are defined in AFTINV by entering the range of $r_{\text{mr}0}$ values that define their respective population and are modelled based on a representative value that is defined by the user (**Table 2.1**). Retention ages denote the earliest time that thermal history models can be resolved for a group of apatite grains (Issler et al., 2022; Ketcham et al., 2000). They are calculated in AFTINV from the modelled age of the oldest preserved fission-track ($>2 \mu\text{m}$) as they represent the earliest time appreciable fission-tracks are preserved. Samples that have resided in the PAZ for a longer period have retention ages that are significantly older than pooled ages and the gap decreases for samples that have undergone rapid cooling from high temperatures across the PAZ.

2.7 Results

2.7.1 AFT data

A total of 120 apatite grains were dated via AFT analysis. In addition, 177 track lengths were measured from 83 different apatite grains. Grain chemistry was measured on 116 of the apatite grains that were used to calculate AFT ages and measure track lengths (**Table S2.1**). Each sample comprises 40 AFT age-grains and 20-34 AFT length-grains corresponding to 38-88 confined track lengths (**Tables S2.2 and S2.3**). One anomalously old and imprecise AFT age-grain from the Martin House Formation sample was omitted from the study due to low ^{238}U values (below the detection limit of the LA-ICPMS; 1137.5 ± 1142.3 Ma), yielding a total of 39 AFT age-grains for this sample. Excluding AFT age-grains measuring 0 Ma, AFT ages range between 7.6 ± 4.8 Ma and 702.2 ± 136.6 Ma and track lengths range between 8.9 μm and 17.3 μm . All three samples fail the X^2 test ($Q < 5\%$), indicating none comprise a single statistically significant age population (**Table 2.1, Table S2.2, Table S2.3**).

AFT ages for the Cenomanian Trevor Formation sample (16FNA007A01) record a Late Jurassic central age (156.0 ± 20.8 Ma; **Figure 2.2, Table 2.1**). Single grain AFT ages range between 35.2 ± 24.9 Ma and 702.2 ± 136.8 Ma (**Table S2.2**). A total of 88 confined track lengths were measured on 29 apatite grains with track lengths ranging between 9.5 μm and 16.8 μm (mean: 13.0 ± 1.7 μm). Average D_{par} measurements from age-grains are 1.9 ± 0.3 μm (1.3 μm -2.8 μm), whereas length-grains have slightly larger D_{par} values of 2.1 ± 0.4 μm (1.4 μm -3.9 μm ; **Table S2.3**).

For the Albian Martin House Formation sample (16FNA006A01), AFT data record a Late Cretaceous central age (66.7 ± 8.7 Ma; **Figure 2.2, Table 2.1**). Single grain AFT ages range between 7.6 ± 4.8 Ma and 526.7 ± 527.7 Ma (**Table S2.2**). A total of 51 confined track lengths were measured on 34 apatite grains with track lengths ranging between 9.3 μm and 17.0 μm (mean:

$13.3 \pm 1.56 \mu\text{m}$). Average D_{par} measurements from age-grains are $1.8 \pm 0.3 \mu\text{m}$ ($1.2 \mu\text{m}$ - $2.8 \mu\text{m}$), whereas length-grains have slightly larger D_{par} values of $2.0 \pm 0.4 \mu\text{m}$ ($1.7 \mu\text{m}$ - $3.3 \mu\text{m}$; **Table S2.3**).

AFT ages for the Late Devonian Imperial Formation sample (16FNA008B01) preserve a Late Cretaceous central age ($68.2 \pm 8.0 \text{ Ma}$; **Figure 2.2**, **Table 2.1**). Single grain AFT ages range between $9.7 \pm 9.8 \text{ Ma}$ and $202.2 \pm 90.8 \text{ Ma}$ (**Table S2.2**). A total of 38 confined track lengths were measured on 21 apatite grains with track lengths ranging between $8.9 \mu\text{m}$ and $17.4 \mu\text{m}$ (mean: $13.3 \pm 1.8 \mu\text{m}$). Average D_{par} measurements from age-grains are $1.8 \pm 0.3 \mu\text{m}$ ($1.3 \mu\text{m}$ - $2.8 \mu\text{m}$), whereas average D_{par} measurements from length-grains are $1.8 \pm 0.3 \mu\text{m}$ ($1.4 \mu\text{m}$ - $2.6 \mu\text{m}$; **Table S2.3**).

2.7.2 MultikinetiC AFT populations

Single grain AFT ages generally incorporate large uncertainties that can mask intra-sample age dispersion and impede our ability to differentiate distinct age populations within the data. A radial plot is a graphical tool used to visualize intra-sample age dispersion and can serve as a preliminary tool to discern populations within AFT samples. For each sample, AFT ages are projected on radial plots with respect to their associated uncertainty ($\pm 1\sigma$), where the horizontal distance from the origin is proportionate to the precision of AFT age, thus more precise ages plot closer to the radial arc (**Figure 2.3**). Finite mixture models are an unbiased statistical approach used to identify discrete populations within samples. In the software *IsoplotR* (Galbraith, 2005; Vermeesch, 2018), an automated finite mixture model uses Bayes Information Criterion to determine the optimal number of age populations within each sample. Age populations are referred to as “peak ages” that are read from the intersection of the radial arc and a line that projects from the plot origin through the center of a given AFT age-grain population.

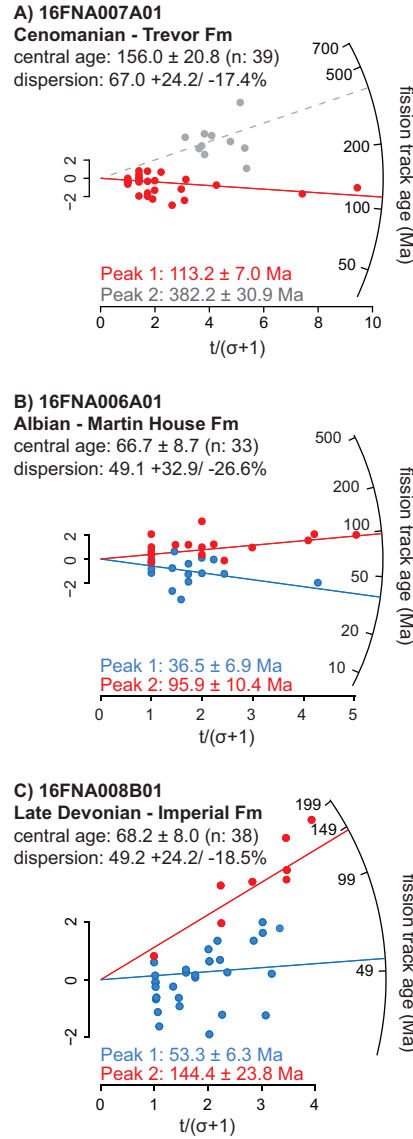


Figure 2.3. AFT radial plots for the three Peel Plateau samples showing ages and their associated error (1σ); more precise ages plot closer to the radial arc. The central age ($\pm 1\sigma$) is calculated from all of the data whereas lines representing peak ages ($\pm 1\sigma$) are calculated through a finite mixture model. Assigned colours represent multikinetetic populations resolved in Figure 2.4. Radial plots created using IsoplotR (Vermeesch, 2018).

The Cenomanian Trevor Formation sample has a Late Jurassic central age and comprises two discrete age populations (**Figure 2.3A**), with peak ages in the Early Cretaceous (113.2 ± 7.0 Ma) and Late Devonian (382.2 ± 30.9 Ma). The Albian Martin House Formation resolved a Late Cretaceous central age, and only one age population is resolved with the automated finite mixture model. For this sample, the finite mixture model was modified to search for two age populations, as two kinetic populations were later discerned using r_{mr0} values. Eocene (36.5 ± 6.9 Ma) and Late Cretaceous (95.9 ± 10.4 Ma) peak ages were resolved for this sample (**Figure 2.3B**). The Late Devonian Imperial Formation sample also has a Late Cretaceous central age and comprises two discrete age populations with Eocene (53.3 ± 6.3 Ma) and Early Cretaceous (144.4 ± 23.8 Ma) peak ages (**Figure 2.3C**).

To help define multikinetetic populations, AFT ages and confined track lengths are also plotted in kinetic space using their r_{mr0} values (**Figure 2.4**). Pooled ages are reported for kinetic populations that pass the X^2 test ($Q > 5\%$), and central ages are reported for kinetic populations with overly dispersed ages ($Q < 5\%$). Apatite grains that are more resistant to thermal annealing are expected to have lower r_{mr0} values and older AFT ages. Apatite with EPMA data were prioritized to define multikinetetic populations. For apatite grains without grain chemistry, r_{mr0} values were derived from D_{par} and then assigned to a kinetic population based on their age or track length. Despite r_{mr0} being more accurate than traditional kinetic parameters, the observed relationship between AFT ages and r_{mr0} is imperfect, and defining appropriate boundaries to separate apatite grains into different kinetic populations is somewhat equivocal. A defined r_{mr0} value is used as a “boundary” to separate apatite grains into two multikinetetic populations for the Albian Martin House Formation and the Late Devonian Imperial Formation samples. Although,

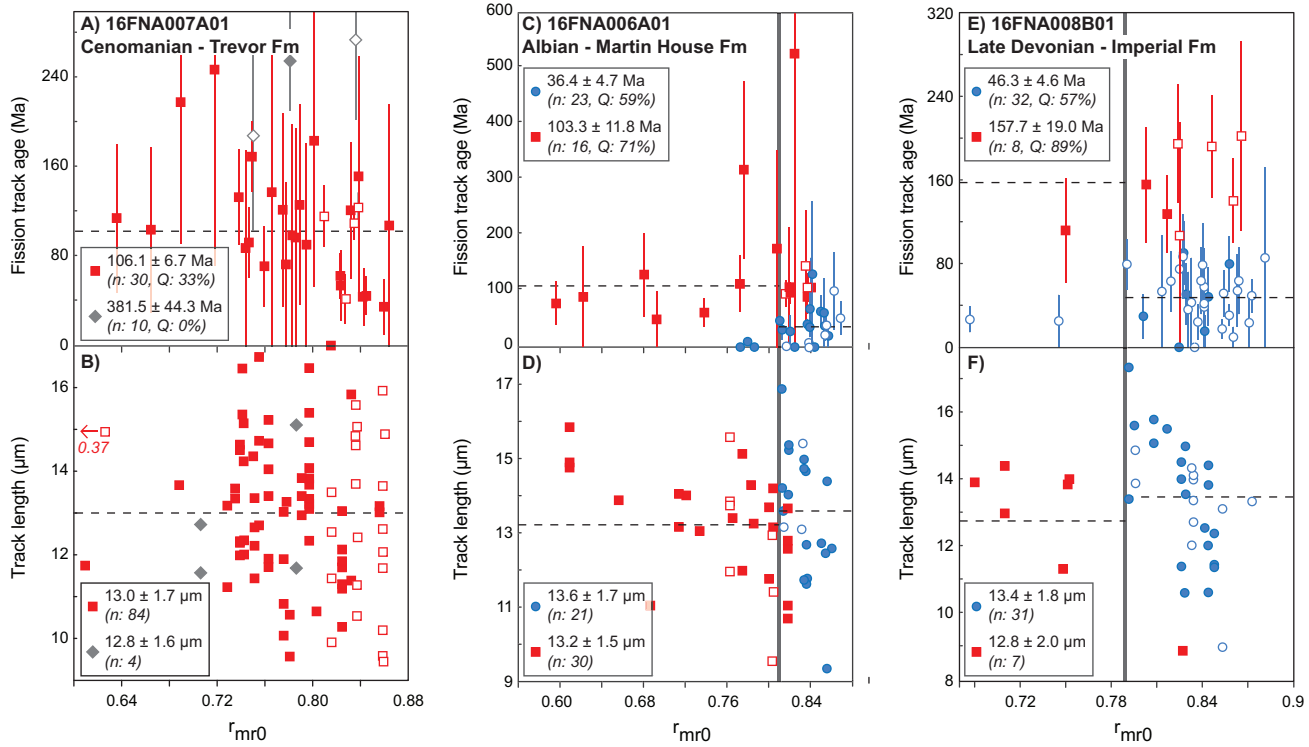


Figure 2.4: Apatite fission-track dates (A, C and E) and track lengths (B, D and F) plotted as function of the kinetic parameter r_{mr0} . Error bars on fission-track dates are 1σ . Filled symbols represent grains with r_{mr0} values derived from grain chemistry measured via EPMA. AFT age-grains that comprise statistically significant age populations pass the X^2 test ($Q > 5\%$). Empty symbols represent grains without chemical data and r_{mr0} values are derived from D_{par} . Sample 16FNA007A01 includes two detrital age populations with overlapping r_{mr0} values. The younger age population passes the X^2 test ($Q > 5\%$). A central age is reported for the older age population (grey diamonds) as it fails the X^2 test ($Q < 5\%$), note that in (A) seven age-grains project above the y-axis (> 300 Ma). Samples 16FNA006A01 and 16FNA008B01 both comprise of two kinetic populations and are defined by where the data plot in kinetic space. The vertical grey lines denote their respective kinetic boundaries. The groupings of multikinetik populations are described in the text and presented in Table 2.1. Red squares represent populations with more retentive annealing kinetics and blue circles represent populations with less retentive annealing kinetics. These multikinetik populations pass the X^2 test ($Q > 5\%$) and dashed horizontal lines represent the pooled age (C and E) and mean track length (D and F) for their respective population.

for both samples, some AFT age grains are reassigned to a different kinetic population relative to where they plot in kinetic space (**Figure 2.4C and E**). It is important to note that the multi-compositional r_{mr0} equation is calibrated to the apatite chemistry used in annealing experiments (Carlson et al., 1999). Despite these experiments incorporating apatite with end-member composition, most of the dataset is limited to apatite with r_{mr0} values of 0.73-0.84. Consequently, apatite compositions corresponding to r_{mr0} values beyond this range are less accurate (Ketcham et al., 1999). AFT age grains that are abnormally old or young relative to their expected r_{mr0} could be misrepresented and justifies the re-assignment of their kinetic population relative to their AFT age.

The workflow of this study measures ^{238}U via LA-ICPMS to calculate AFT ages, followed by EPMA to derive r_{mr0} values. LA-ICPMS is a destructive technique, capable of ablating fragments and sometimes entire apatite grains. As a result, a suitable surface area for EPMA can be limited. EPMA analysis of inclusion or apatite with chemical zonation can result in r_{mr0} values that do not reflect the grains AFT age. An additional rationale to reassign apatite grains kinetic population are r_{mr0} values that potentially reflect the composition of inclusions or a crystal domain that is compositionally different from the age-measurement. In this scenario, it is reasonable to re-assign these apatite grains to the kinetic population suggested by their AFT age.

Track lengths that have been re-assigned to a different kinetic population relative to where they plot in kinetic space are “linked” to an AFT age grain as some apatite grains are used to calculate an AFT age and measure track lengths. It is important that the AFT age and its associated track lengths are grouped in the same kinetic population, as they reflect data from the same apatite grain. Re-assigned track lengths were modified to match the kinetic population from the grains corresponding AFT age. Grouping apatite grains into kinetic populations that can produce

plausible thermal history models is an iterative process, and numerous models were attempted for various groupings. The kinetic populations presented herein reflect the groupings interpreted to produce the most accurate thermal history models. Notably, minor adjustments in the r_{mr0} boundary does not significantly impact the thermal history models.

For the Trevor Formation sample, EPMA analyses were conducted on 28 AFT age-grains and 22 length-grains, from which 66 confined track lengths were measured (**Table S2.1**). Two detrital age populations were resolved with overlapping r_{mr0} values that range from 0.37 to 0.86. The first population comprises 30 age-grains that pass the X^2 test and has a pooled age of 106.1 ± 6.7 Ma. The remaining 10 AFT age grains comprise the second population and have dispersed ages that range from 188.8 ± 84.9 Ma to 702.2 ± 136.8 Ma. This population fails the X^2 and has a central age of 381.5 ± 44.3 Ma (**Figure 2.4A**). Only four tracks were assigned to the dispersed AFT population, as they were measured from apatite grains that correspond to two age-grains that belong to the dispersed population. Average track lengths for this minor population are 12.8 ± 1.6 μm (**Figure 2.4B**, **Table 2.1**).

For the Martin House Formation sample, EPMA analysis was conducted on 29 AFT age-grains, and 28 length-grains from which 41 confined track lengths were measured (**Table S2.1**). The r_{mr0} values range from 0.60 to 0.86. This sample contains two kinetic populations, which both pass the X^2 test. A more retentive population ($r_{mr0} < 0.81$) consists of 16 age-grains with a pooled age of 103.3 ± 11.8 Ma, and a less retentive population ($r_{mr0} > 0.81$) comprised of 23 age-grains with a pooled age of 36.4 ± 4.7 Ma (**Figure 2.4C**). Three age-grains that plot in more retentive kinetic space record young fission-track ages (<10 Ma) have been reassigned with the less retentive kinetic population. Similarly, eight age-grains that plot in less retentive kinetic space record older fission-track ages (>90 Ma) and have been reassigned with the more retentive kinetic

population. For length-grains, the less retentive population consists of 21 tracks with an average length of $13.6 \pm 1.7 \mu\text{m}$, whereas the more retentive population consists of 30 tracks with an average length of $13.2 \pm 1.5 \mu\text{m}$ (**Figure 2.4D**; **Table 2.1**). Five track lengths in less retentive kinetic space are grouped with the more retentive kinetic population as these track lengths are grouped with age-grains assigned to the more retentive kinetic population.

For the Imperial Formation sample, EPMA analysis was conducted on 10 AFT age-grains, and 16 length-grains from which 27 confined track lengths were measured (**Table S2.1**). The $r_{\text{mr}0}$ values range from 0.69 to 0.88. This sample comprises two kinetic populations. A more retentive population ($r_{\text{mr}0} < 0.79$) consisting of eight age-grains with a pooled age of $157.7 \pm 19.0 \text{ Ma}$, and a less retentive population consisting of 32 age-grains ($r_{\text{mr}0} > 0.79$) with a pooled age of $46.3 \pm 4.6 \text{ Ma}$ (**Figure 2.4E**). Both kinetic populations pass the X^2 test. Age-grains for this population are poorly resolved in kinetic space, as a result, seven old age-grains ($>105 \text{ Ma}$) are grouped with the more retentive population despite possessing higher $r_{\text{mr}0}$ values. In addition, two grains with lower $r_{\text{mr}0}$ values are grouped with the less retentive kinetic population because of their young AFT ages ($<15 \text{ Ma}$). For length-grains, the less retentive population consists of 31 tracks with average lengths of $13.4 \pm 1.8 \mu\text{m}$, whereas the more retentive population consists of 7 tracks with $r_{\text{mr}0}$ values calculated from measured chemistry yield an average length of $12.8 \pm 2.0 \mu\text{m}$ (**Figure 2.4F**; **Table 2.1**). Only length-grains with $r_{\text{mr}0}$ values derived from measured chemistry are grouped with the more retentive population. Track lengths are grouped with respect to the kinetic boundary ($r_{\text{mr}0}$: 0.79) with the exception of one track length that is grouped with the more retentive population despite having a higher $r_{\text{mr}0}$ value, as this track length is linked to an age-grain that is grouped with the more retentive kinetic population.

2.7.3 U-Pb geochronology

As the LA-ICPMS method was employed to measure ^{238}U concentrations for FT analysis, U-Pb data were simultaneously acquired, with results displayed on Tera-Wasserberg diagrams (**Figure 2.5; Table S4**). Several of the apatite grains often yielded relatively low U and radiogenic Pb, resulting in poorly resolved or indeterminable U-Pb ages with ten and twenty-eight apatite grains per sample that have U and Pb concentrations below the detection limit. Since the apatite presented in this study were collected from sedimentary rocks, U-Pb ages reflect the samples' pre-depositional history, and samples with discrete age populations likely reflect groups of apatite grains originating from a common source. Apatite grains derived from a common source could have similar chemistries, and by consequence have similar annealing kinetics. To assess if U-Pb age populations coincide with multikinetetic AFT populations, U-Pb data are plotted on Tera-Wasserberg diagrams with their ellipse colours reflecting the kinetic population with which they have been grouped (**Figure 2.5**). Discrete age populations could not be discerned from the Cenomanian Trevor Formation sample nor the Late Devonian Imperial Formation sample. Instead, a representative envelope that omits outliers is defines the range of ages for these samples.

For the Cenomanian Trevor Formation sample, U-Pb ages range from c. 600 Ma to c. 165 Ma (**Figure 2.5A**). Most analyses plot closer to the upper limit, whereas the younger limit is anchored by four precise U-Pb analysis. For the Late Devonian Imperial Formation sample, U-Pb ages range from c. 680 Ma to c. 375 Ma (**Figure 2.5C**). This age range omits one anomalously old date and anchors the youngest age constraint to the time of deposition. Apatite grains grouped with both kinetic populations span the array of U-Pb ages, therefore no clear relationship exists between AFT kinetic population and U-Pb ages.

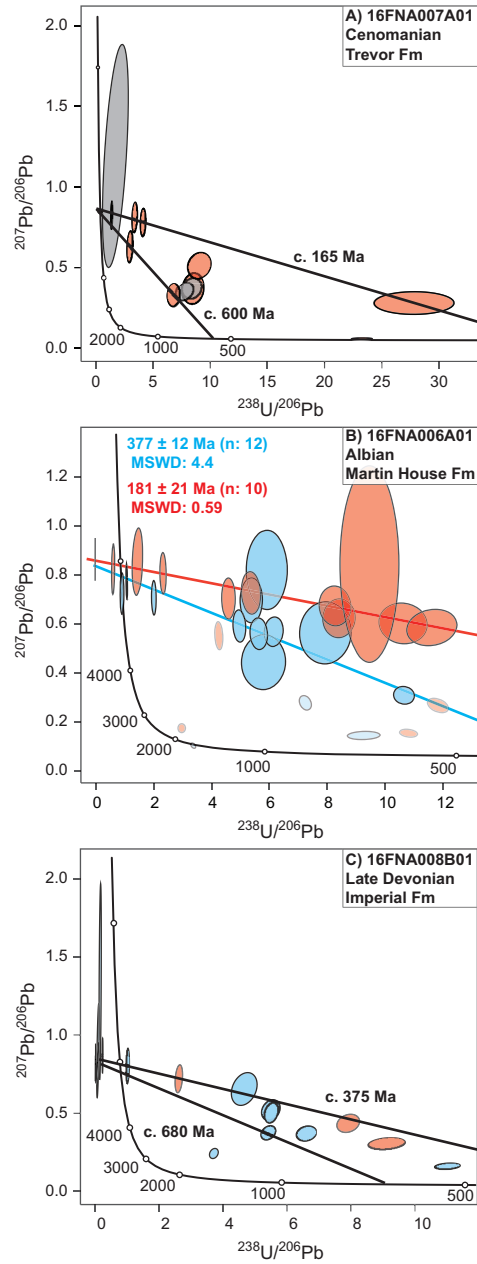


Figure 2.5: Tera-Wasserburg U-Pb diagrams showing apatite U-Pb ages (2σ error) for the samples analysed for AFT thermochronology. Ellipse colours correspond to multikinetetic populations defined in Figure 2.4. Discordia ages are calculated for each kinetic population in (B), and faded ellipses are grains that have been omitted from the age calculation. A similar relationship between multikinetetic AFT populations and U-Pb ages is absent in (A) and (C) and instead discordia lines for these samples define envelopes encompassing realistic U-Pb ages. Tera-Wasserburg diagrams created using IsoplotR (Vermeesch, 2018).

For the Albian Martin House Formation sample, we interpret two discrete U-Pb age populations, which broadly coincide with multikinetic FT age populations for that sample (**Figure 2.5B**). Intercept ages are calculated from each age population, where the less retentive AFT population records a Late Devonian U-Pb age (377 ± 12 Ma; n: 12; MSWD: 4.4) and the more retentive AFT population yields an Early Jurassic U-Pb age (181 ± 21 Ma; n: 10; MSWD: 0.59).

2.7.4 AFT thermal history model solutions

Inverse thermal history modelling for the Cenomanian Trevor Formation sample (**Figure 2.6**) excludes the older detrital population that fails the X^2 and is poorly defined in kinetic space (central age: 382 ± 44 Ma; **Figures 2.4A; Figure 2.6A**). Model parameters include random cooling from 150 Ma until deposition at 95 Ma. The model then searches for a single burial and unroofing event between 95 and 0 Ma with maximum burial temperatures constrained to 120°C. Monte Carlo solutions predict maximum burial temperatures of $89 \pm 5^\circ\text{C}$ during the Eocene (52 ± 14 Ma). CRS solutions predict similar burial temperatures of $84 \pm 2^\circ\text{C}$, however the timing of peak burial is predicted to have occurred in the Paleocene (58 ± 7 Ma; **Figure 2.6B and C**). The MC solutions poorly constrain the onset of exhumation whereas CRS solutions predict exhumation to have initiated around 45 Ma (**Figure 2.6A**). Retention ages calculated through CRS function are 140 ± 2 Ma and calculated %Ro values are 0.500 ± 0.007 (**Figure 2.6D and F**).

The Albian Martin House Formation sample (**Figure 2.7**) allows random cooling from 150 Ma prior to deposition at 110 Ma. An angular unconformity separates Albian and Cenomanian southeast of the Peel Plateau within the Mackenzie Plain. The angular relationship between Albian and Cenomanian strata is not apparent in the Peel Plateau; however, a period of non-deposition or minor erosion is evinced through a disconformity (Thomson et al., 2011). As a result, input

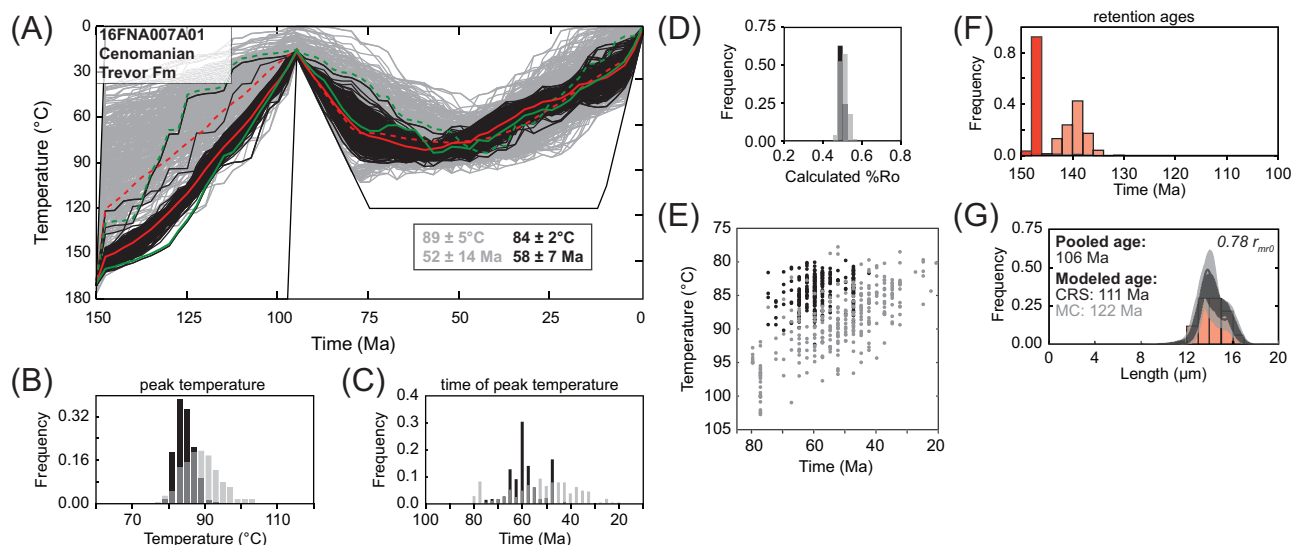


Figure 2.6. Inverse thermal history model results for 16FNA007A01 derived from the apatite population(s) defined in Figure 2.4. Models created using AFTINV (v. 6.12; Issler, 1996). A) Plausible temperature-time paths. Light grey represents 300 statistically acceptable Monte Carlo solutions (MC) with 0.05 level of significance, and black lines represent 300 statistically acceptable solutions using a controlled random search (CRS) function with 0.5 level of significance. Thin black line encompassing most of the diagram contours the models search space and is defined by input parameters based on known geologic constraints. Red lines represent the exponential mean, and green lines represents the minimum objective function (MC: dashed line; CRS: solid line). Text within figures lists average peak burial temperatures, and the timing of peak burial (MC: grey; CRS: black). B) Histogram showing maximum burial temperatures. C) Histogram showing timing of maximum burial. D) Histogram showing calculated %Ro values from model results. E) Scatter plot projecting maximum temperature as function of time from all model results. F) Histogram illustrating retention ages from model results. Faded bars represent MC solutions and solid bars represent CRS solutions. G) Diagram comparing measured track length distribution and calculated track length distribution. The histogram reflects measured track lengths and faded lines represent the probability density function of calculated track lengths from all solutions found in (A).

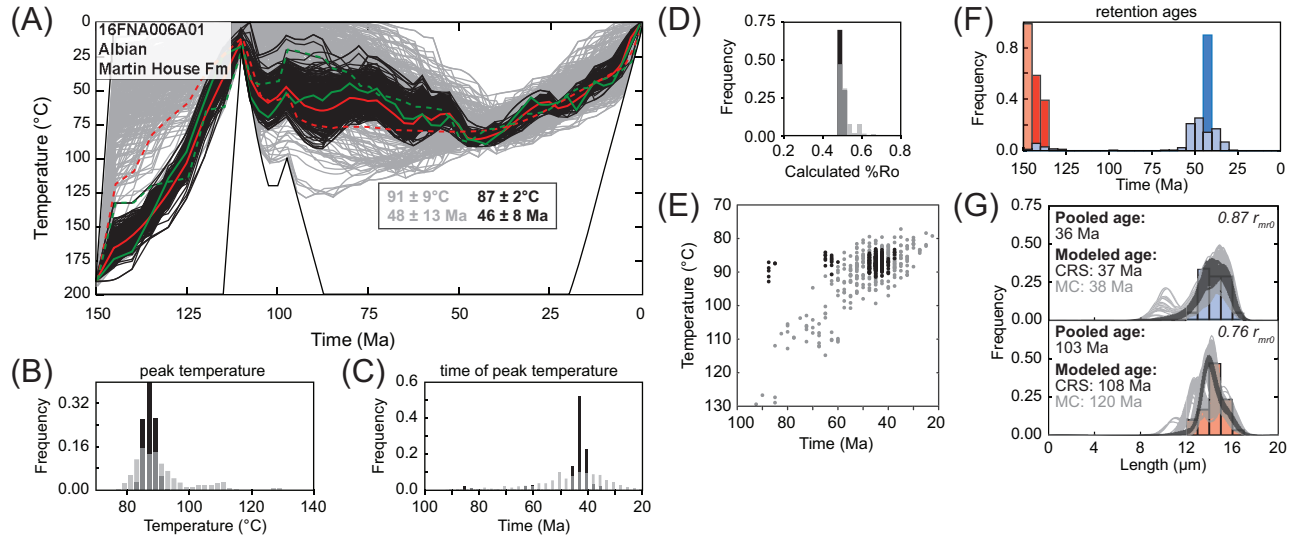


Figure 2.7. Inverse thermal history model results from 16FNA006A01 derived from multikinetic apatite fission-track populations defined in Figure 2.4. Refer to Figure 2.6 for additional details. Histogram colour fill in (F) and (G) correspond to results from corresponding multikinetic populations, and representative r_{mro} values used to generate the thermal history model are listed in top right corner of (G).

parameters include two burial and unroofing events to allow the model to decipher whether significant erosion took place between the Albian and Cenomanian. The first event is constrained from 110 to 97.5 Ma with a maximum burial temperature of 120°C and cooling to <100°C at 97.5 Ma. The second burial and unroofing event is constrained within the 97.5-0 Ma window, with maximum burial temperatures of 200°C. Model results from the MC search are poorly constrained between the time of deposition and peak burial and few time-temperature pathways predict late Early Cretaceous unroofing. Notably, model results from the CRS function do not predict significant erosion across the suspected Albian-Cenomanian unconformity (**Figure 2.7A**). Overall, similar thermal histories are obtained from the MC and CRS solutions, predicting maximum burial temperatures of $91 \pm 9^\circ\text{C}$ (MC), and $87 \pm 2^\circ\text{C}$ (CRS) during the Eocene (MC: 48 ± 13 Ma; CRS: 46 ± 8 Ma). The CRS model results predict exhumation to have occurred during two episodes of cooling: a slower phase from c. 35-30 Ma, followed by potential minor reheating, and a final phase of exhumation commencing at 20 Ma (**Figure 2.7B and C**). The CRS solutions predict retention ages of 44 ± 2 Ma for the less retentive kinetic population, and 141 ± 3 Ma for the more retentive kinetic population with calculated %Ro values of 0.500 ± 0.003 (**Figure 2.7D and F**).

Powell and Schneider (2013) reported c. 500 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ ages from detrital muscovite of the Imperial Formation. This is accounted for in the thermal history model for the Imperial Formation sample by starting the model time at 500 Ma at 200°C, allocating c. 125 Myr of cooling prior to deposition (at 375 Ma) to assure sufficient time for fission-tracks to establish their initial track length distribution (**Figure 2.8**). The regional unconformity separating Upper Devonian and Cretaceous strata requires unroofing and cooling before the Albian. The model searches for a single burial and unroofing event between 375 and 115 Ma, with burial temperatures limited to 200°C. Although the sample was not exhumed to the surface during pre-Albian unroofing (115 Ma),

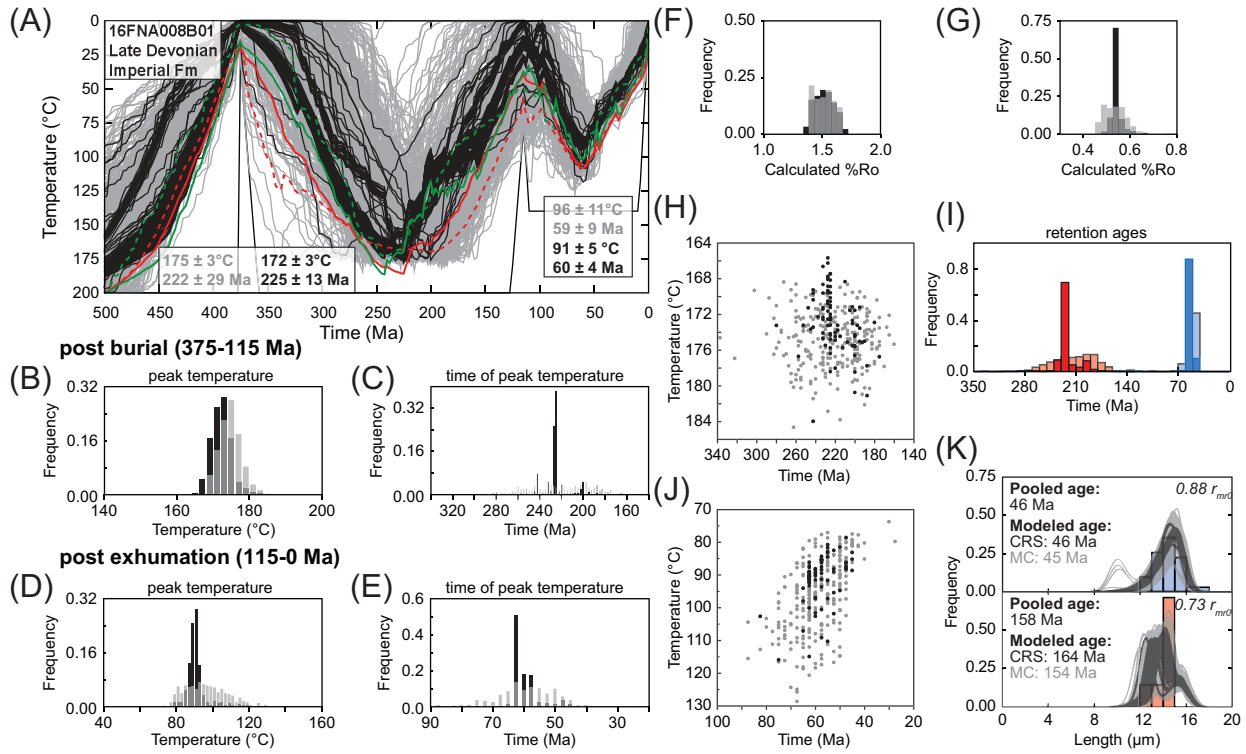


Figure 2.8. Inverse thermal history model results from 16FNA008B01 derived from multikinetic apatite fission-track populations defined in Figure 2.4. Model results include 300 MC solutions (grey) with 0.05 level of significance, and 196 CRS solutions (black) with 0.5 level of significance. Model results include burial and unroofing from two deposystems: model results for post-depositional burial are represented in (B), (D), (E), (F) and (H), and model results post-dating exhumation are shown in (C), (E), (G), and (J) Refer to Figures 2.6 and 2.7 for additional details.

stratigraphic relationships suggest it was within 500 m of the surface (**Figure 2.2**), therefore maximum temperature across this unconformity is constrained to 80°C. Following 115 Ma cooling, the model searches for two burial and unroofing events. Late Early Cretaceous unroofing was included in the input parameters for consistency as it was included for the Albian sample, however maximum temperatures are constrained to <140°C across the Albian-Cenomanian unconformity to allow the model to decipher whether unroofing occurred in this section of the basin. Thermal history solutions from MC and CRS searches predict similar maximum burial temperatures of $175 \pm 3^\circ\text{C}$ (MC) and $172 \pm 3^\circ\text{C}$ (CRS) during the Triassic at 222 ± 29 Ma (MC) and 225 ± 13 Ma (CRS; **Figure 2.8A**). Time-temperature pathways from the MC search find solutions that fill the entire search space during pre-Albian unroofing (80-0°C). In comparison, CRS solutions limit cooling during Cretaceous unroofing to 70°C or less, although most time-temperature pathways predict cooling to <50°C. Cretaceous reburial is predicted to have achieved temperatures of $96 \pm 11^\circ\text{C}$ (MC) to $91 \pm 5^\circ\text{C}$ (CRS) during the Paleocene at 59 ± 9 Ma (MC) or 60 ± 4 Ma (CRS), and unroofing at the time of the Albian-Cenomanian unconformity is not evident in the model results. Modelled retention ages from the CRS search are 54 ± 3 Ma for the less retentive kinetic population, and 222 ± 13 Ma for the more retentive kinetic population (**Figure 2.8I**). Finally, calculated thermal maturity indices for Paleozoic burial are 1.540 ± 0.086 %Ro, whereas Cretaceous reburial calculates a thermal maturity index of 0.520 ± 0.022 %Ro; **Figure 2.8F** and **G**).

2.8 Discussion

2.8.1 Correlating U-Pb data with multikinetetic AFT populations

Recent advances have dramatically increased the capabilities of AFT thermochronology by improving the resolution of thermal history models while decreasing the time- and labor-intensive laboratory procedures. One example is the increasing prevalence of studies that use LA-ICPMS analysis, as opposed to the external detector method, to measure ^{238}U concentrations. The LA-ICPMS method provides an accurate measurement of ^{238}U that is much less time consuming and presents the opportunity to simultaneously date apatite via U-Pb geochronology (Chew and Donelick, 2012). Regional thermal maturity indices and thermal modelling imply that neither Paleozoic nor Cretaceous basins achieved burial temperatures exceeding $\sim 175^\circ\text{C}$. The nominal closure temperature for the U-Pb system in apatite is significantly higher ($375\text{--}600^\circ\text{C}$; Cochrane et al., 2014; Kirkland et al., 2018), thus apatite U-Pb ages likely reflect the timing of primary crystallization or mid-crustal cooling within the sediment source region. It is reasonable to assume that apatite derived from a common magmatic, metamorphic or hydrothermal source may have a distinct chemical signature. Since multikinetetic AFT populations are discerned from a kinetic parameter ($t_{\text{mr}0}$) that is calculated from grain-specific chemistry, U-Pb age populations can potentially help define multikinetetic populations within AFT samples, and vice versa.

To test the correlation between U-Pb age populations and multikinetetic AFT populations, U-Pb data are plotted with respect to the kinetic population they have been assigned (**Figures 2.4; Figure 2.5**). The Cenomanian Trevor Formation and Devonian Imperial Formation samples contain an array of U-Pb ages and an envelope defining the range of U-Pb ages are projected on their respective Tera-Wasserburg diagrams (**Figure 2.5**). The Albian Martin House Formation contains two discrete apatite U-Pb age populations that loosely coincide with the sample's

multikinetetic populations: apatite grains assigned to the less retentive kinetic population (n: 12) have older (Late Devonian) U-Pb ages, and apatite grains from the more retentive kinetic population (n: 10) have Early Jurassic U-Pb ages (**Figure 2.5B**). The correlation is imperfect, as several apatite grains grouped with one kinetic population plot near the discordia line that loosely correlates to the other kinetic population. These grains have overlapping AFT ages with similar kinetics, plotting near the defined kinetic boundary (r_{mr0} : 0.81), and could have been grouped with either kinetic population without altering the thermal history models (**Figure 2.4C**). Notably, apatite grains that comprise the Early Jurassic U-Pb age population correspond to the more retentive AFT population and have a nearly syn-depositional pooled age (103 ± 12 Ma).

Despite the limited analyses, these results highlight the promising applications of incorporating U-Pb data with AFT data to identify multikinetetic populations, and should be considered in future AFT work, especially given the feasibility to acquire U-Pb data when using the LA-ICPMS approach to AFT dating (Jepson et al., 2021). In addition, incorporating larger U-Pb datasets would permit the interpretation of the apatite's source terrane.

2.8.2 Significance of multikinetetic AFT populations

To highlight the importance of accounting for multikinetetic populations within AFT data, we compare CRS thermal history model results from the Albian Martin House Formation modelled as i) a single AFT population that includes all apatite grains from the sample, and ii) multikinetetic AFT populations. In this example, the same constraint parameters are used to compare AFT data modelled as multikinetetic populations and a single AFT population (**Figure 2.9**).

As the AFT data reflects a wide range of annealing kinetics, we chose to use the average of all r_{mr0} values (0.80) to represent the AFT data in the mono-kinetic model. In comparison, the

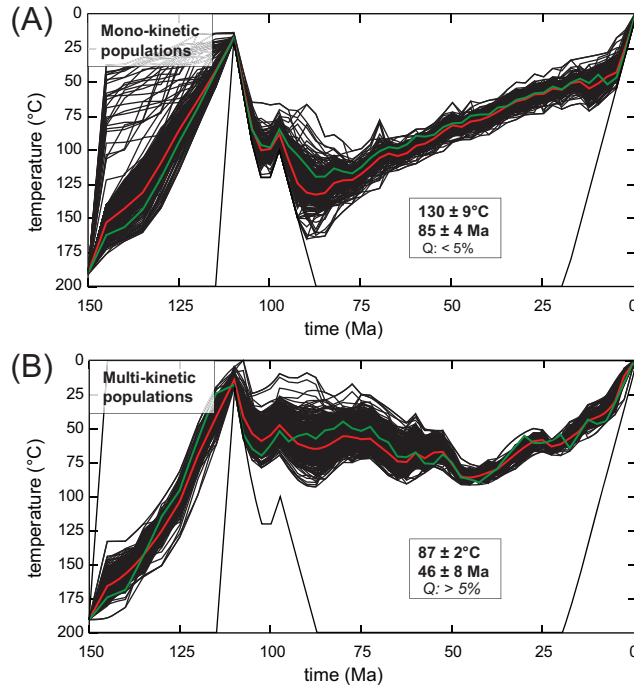


Figure 2.9. Thermal history models from sample 16FNA006A01 comparing results from AFT data modelled as a single kinetic population (A), and as multikinet populations (B). Black lines represent 300 statistically acceptable solutions using a controlled random search (CRS) function with 0.5 level of significance. Red lines represent the exponential mean, and green lines represents the minimum objective function Q represents the X^2 probability. AFT populations that pass the X^2 test have $Q > 5\%$.

multikinetik data are represented by r_{mr0} values of 0.76 and 0.87 for the more retentive and less retentive kinetic populations, respectively. The two models from the same AFT data yield significantly different thermal histories. Results from the mono-kinetic model predict rapid burial directly after deposition, reaching burial temperatures of $100 \pm 6^\circ\text{C}$ during the Early Cretaceous (102 ± 1 Ma), followed by minor cooling across the sub- Cenomanian unroofing event (**Figure 2.9A**). Peak burial temperatures are predicted to have reached $130 \pm 9^\circ\text{C}$ during the Late Cretaceous (85 ± 4 Ma). In comparison, model results from the multikinetik data predict near continuous burial through the Cretaceous, with peak burial occurring later (Eocene) and under lower temperatures ($87 \pm 2^\circ\text{C}$). The potential pre-Cenomanian cooling event is interpreted as one of many subtle cooling pulses as the rocks had not exceeded $57 \pm 10^\circ\text{C}$ at this time (**Figure 2.9B**). Ultimately, the mono-kinetic model interprets peak burial temperatures $\sim 40^\circ\text{C}$ hotter than the multikinetik model. The equivalent modelled thermal maturity indices calculated from the mono-kinetic data are 0.680 ± 0.051 %Ro, compared to 0.500 ± 0.003 %Ro for the multikinetik model. As these calculated organic thermal maturity values span the lower threshold of the oil and gas window, the hydrocarbon potential of a Cretaceous source rock would be overestimated if the interpretation was based on the mono-kinetic model.

Known geologic events, such as timing of deposition and unconformities, are imbedded within the thermal history models as “constraints” that form an envelope defining geologically plausible search space. A notable concern for the mono-kinetic model is that most of the time-temperature pathways encroach on the constraint parameters particularly until 90 Ma. The mono-kinetic model results likely do not reflect the true thermal history of the sample, as these data would preferentially find unrealistic and over-constrained solutions. In comparison, time-temperature pathways in the multikinetik model find solutions that are not restricted by the

constraints. From a geologic context, the pre-Cenomanian erosional event recorded in the mono-kinetic model is an artifact of the constraint parameters and not reflective of the thermal history of the sample.

Defining kinetic populations is not a perfect science. Often, different apatite grains with the same r_{mr0} values have a range of ages, and AFT ages are used to assign apatite to a specific kinetic population. Similarly, for apatite grains with anomalously old or young AFT ages relative to their r_{mr0} values, AFT ages are also used to assign grains to their kinetic population. These grains often were not measured via EPMA, therefore their r_{mr0} values are calculated from D_{par} and are less reliable. Multiple iterations of thermal history models for each sample were produced with various groupings of kinetic populations. Different groupings do not largely affect thermal history models, and the results presented herein are interpreted as the most robust solutions for each sample. Despite the inevitable imperfect grouping of kinetic populations, openly ignoring multikinetic AFT populations produces drastically different thermal history model results. The thermal history model from the mono-kinetic population of the Martin House Formation sample highlights how inappropriate characterization of AFT data that neglects multikinetic populations can lead to misguided geological interpretations.

2.8.3 Interpretations of thermal history models

The three AFT samples presented in this study are separated by sub- Cretaceous and Albian-Cenomanian unconformities (Fallas et al., 2021; Hadlari et al., 2014, **Figure 2.2B**). Thermal maturity indices have the potential to resolve maximum burial temperatures attained since deposition, however there is a risk that the organic material has been recycled. In this case the data may reflect information from its original source region and has little implication regarding the

thermal history of the host rock, whereas thermal history models have the capacity to increase our confidence of plausible time-temperature pathways across multiple burial and unroofing events. Here, we compare published thermal maturity indices proximal to sample locations with calculated values derived from thermal history models. In addition, we compare thermal history models with respect to sample locations and the underlying structural framework to gain insight regarding the structural and thermal evolution of the Peel Plateau.

2.8.4 Paleozoic-Mesozoic burial

The thermal history of the late Paleozoic to middle Mesozoic Laurentian margin deposystem is poorly understood due to the presence of the regional sub-Cretaceous unconformity and the absence of Triassic to Jurassic strata across the northern Mackenzie Mountains. The Late Devonian Imperial Formation sample (16FNA008B01) is an important example that illustrates the use of multikinetic AFT thermochronology and its ability to resolve multiple burial and unroofing events. Modelled retention ages from the CRS model are 54 ± 3 Ma for the less retentive population and 222 ± 13 Ma for the more retentive population, signifying both kinetic populations were completely annealed during initial burial (**Figure 2.8I**). Paleozoic-Mesozoic burial is solely resolved by the more retentive kinetic population as the c. 222 Ma retention ages overlap with the timing of peak burial. The CRS models predict maximum burial temperatures of $172 \pm 3^\circ\text{C}$ during the Late Triassic. Thermal maturity indices within the Imperial Formation proximal to the AFT sample location are 1.6-2.5 %Ro with a value of 1.7 %Ro at the sample site, whereas the model results predict values of 1.540 ± 0.086 %Ro (**Figure 2.2B**; **Figure 2.8F**).

The Peel and Mackenzie areas have a slightly elevated geothermal gradient, varying between 30 and 40°C/km, which is attributed to elevated heat flow generated from the underlying

basement (Majorowicz and Morrow, 1998; Majorowicz et al., 2005). If we assume a steady-state geothermal gradient since deposition, the models predict the Late Devonian Imperial Formation to have been buried 4.2-5.7 km during the Late Triassic and to have been exhumed to near surface conditions prior to Cretaceous reburial.

Similar burial temperatures are interpreted from thermal history model results from the Root Basin (163°C-190°C), however lower burial temperatures are predicted in the Mackenzie Plain (92°C-160°C) and Brackett Basin ($124 \pm 10^\circ\text{C}$; Issler et al., 2005; Powell et al., 2019). Peak burial occurred during the Late Triassic, as interpreted from models herein, and is in general agreement with interpretations from previous work. However, our results provide a more precise temporal constraint: at the Mackenzie Mountains deformation front, Powell et al. (2016) predict peak burial to have occurred during the Mesozoic, whereas within the Mackenzie Plain, Powell et al. (2019) estimate the timing of peak burial from Carboniferous to Late Cretaceous, and within the Brackett Basin peak burial is predicted to have occurred between the Early Triassic to Middle Jurassic (Powell et al., 2016). Models presented here find CRS solutions within the search space defined by MC solutions, whereas previous work solely resolve MC solutions (e.g., Issler et al., 2005; Powell et al., 2019). The tighter time constraint defining peak burial is attributed to integrating the CRS approach, which ultimately produces more refined plausible thermal history models.

2.8.5 Cretaceous foreland basin

Thermal history models for all three AFT samples resolve the time-temperature history associated with local burial in the Cretaceous foreland basin. Published thermal maturity indices proximal to the sample locations (~20 km) vary from 0.54 to 1.83 %Ro (Pyle and Jones, 2009).

Despite the loose input parameters to constrain the samples' thermal maturity (0.66 ± 0.66 %Ro), Cretaceous to present-day models predict similar thermal maturity for the three samples that range from 0.50 to 0.52 %Ro, which are slightly lower than all %Ro values measured proximal to the samples locations. Thus, higher thermal maturity indices measured from Cretaceous strata in wells and surface samples most likely reflect recycling of older and more mature vitrinite into the foreland.

Since none of the AFT samples were completely reset during Cretaceous burial, all thermal history models fully resolve the temperature conditions associated with this heating event. Given the proximity of the AFT samples during Cretaceous to Paleogene deposition, the magnitude of burial should correlate to the samples stratigraphic positions, as new sedimentation contributed to the progressive burial of the underlying rock formations. As expected, thermal history models predict peak burial temperatures to decrease for samples collected from younger stratigraphy: $91 \pm 5^\circ\text{C}$ from the Late Devonian sample, $87 \pm 2^\circ\text{C}$ for the Albian sample and $84 \pm 2^\circ\text{C}$ for the Cenomanian sample (**Figure 2.6B**; **Figure 2.7B**; **Figure 2.8D**). Notably, the variations in peak temperature estimates are minimal. By inferring the stratigraphic thickness that separates the rock formations where AFT samples were collected, larger gaps in peak burial temperatures are expected between the samples. Assuming a geothermal gradient of $30\text{--}40^\circ\text{C}/\text{km}$, these results predict 2-3 km of material deposited within the Cretaceous foreland basin has been eroded.

Despite resolving relatively similar burial temperatures, the timing of peak burial varies by c. 14 Myr between the three AFT samples (**Figure 2.6C**; **Figure 2.7C**; **Figure 2.8E**). Subsidence of the Cretaceous foreland basin reflects lithospheric flexure related to the emergence of the Mackenzie fold and thrust belt. The timing of peak burial reflects maximum subsidence of the basin and can be inferred to broadly track the progressive advancement of the deformation front

(Hadlari et al., 2014). The timing of peak burial is expected to become younger further away from the deformation front. Despite the short distance between our samples, the peak burial times modelled in the Cretaceous samples are ‘out of sequence’ with respect to their position relative to the deformation front to conform to this simplified tectonic scenario. Field observations coupled with geophysical data suggest the sample locations are overlying a buried foreland-vergent duplex structure (Lemieux et al., 2009). The Late Devonian Imperial Formation sample is proximal to the Mackenzie Mountains deformation front (south of the duplex) and records burial during the Palaeocene (60 ± 4 Ma) with subsequent rapid cooling until the Oligocene, when the rate of cooling decreases until reaching surface conditions (Figs. 1C and 8). As expected, the Albian Martin House Formation sample, collected ~ 12 km perpendicular to the strike of the deformation front on the southern flank of the duplex structure, predicts later peak burial during the Eocene (46 ± 8 Ma). Final cooling is predicted to have occurred as two pulses: at 45 Ma and 20 Ma, which is interpreted to reflect progressive growth of the duplex structure (**Figure 2.7**). Peak burial for the Cenomanian Trevor Formation sample is predicted to have occurred during the Paleocene (58 ± 7 Ma) defining an “out of sequence” peak burial, as the earliest timing of peak burial is recorded in the sample located most distal to the deformation front (~ 16 km perpendicular to strike; Figs. 1B and 6). This sample is located above the roof thrust of the duplex structure, and earlier peak burial and exhumation may be related to nappe stacking. Combined, the model results predict that while the region proximal to the deformation front (based on the Devonian sample) was undergoing exhumation in the late Paleocene, the foreland basin more distal to the front was undergoing peak burial.

Distinct retention ages for each kinetic population within the AFT data underscored the sensitivity of kinetic populations to various temperature windows and serve as independent

thermochronometers recording different aspects of a sample's thermal history. Retention ages for apatite modelled in the Cenomanian Trevor Formation sample, and the more retentive kinetic populations from the Albian Martin House Formation (140 ± 2 and 141 ± 3 , respectively; **Figure 2.6F**; **Figure 2.7F**) highlight the necessity to include a sufficiently long pre-depositional history that allows fission-tracks enough time to establish their initial track length, whereas retention ages that post-date deposition (e.g., 222 ± 13 Ma from the Late Devonian Imperial Formation sample; **Figure 2.8I**) retain information regarding the burial history of the Late Paleozoic-mid- Mesozoic deposystem, and cooling across the sub-Cretaceous unconformity. Young retention ages from the less retentive AFT kinetic populations indicate that the AFT systematics for those apatite were fully reset during burial within the Late Cretaceous foreland basin and these populations constrain the final cooling history to surface conditions.

A similar magnitude of burial (2-3 km) within the Cretaceous foreland basin is predicted from the three samples which agrees with results from previous work conducted within the Richardson Mountains, Brackett Basin and Root Basin (Issler et al., 2005; Powell et al., 2019; McKay et al., 2021). The tectonic setting of the northern Richardson Mountains differs from the Peel area, as the northern extent of the Cordillera is also affected by tectonism related to the opening of the Beaufort Sea (Lane and Dietrich, 1995). Within the Mackenzie Plain, models from Powell et al. (2017, 2019) resolve a similar magnitude of burial, whereas Enkelmann et al. (2019) predict significantly higher burial temperatures ($\sim 140^{\circ}\text{C}$). Subsidence related to the progressive advancement of the Mackenzie Mountains fold and thrust belt controlled the evolution the foreland basin, resulting in the timing of peak burial to range from Paleocene to Eocene within the Peel Plateau. The timing of peak burial reported within the region from previous authors are in general agreement with this study, with a few exceptions. For example, solutions from the Mackenzie Plain

by Powell et al. (2019) predict peak burial to have occurred between the Late Cretaceous and Neogene, whereas thermal history model results from select samples within the Mackenzie Plain and Richardson Mountains predict the onset of cooling to have occurred during the Oligocene-Early Miocene (Enkelmann et al., 2019), which is not observed elsewhere. Thermal history models from Enkelmann et al. (2019) predict final exhumation to surface conditions to have initiated from a discrete cooling pulse during Neogene (c. 5 Ma). Accelerated exhumation since the Neogene is observed elsewhere in the northern Cordillera and has previously been linked to manifestation of strain from far field stresses resulting from the Yakutat block colliding with North America (O'Sullivan and Currie, 1996; Hyndman et al., 2005). The collision of the Yakutat block is ongoing and is likely the source of modern seismicity as well as continued crustal shortening within the Mackenzie and Richardson mountains (Leonard et al., 2008).

2.9 Summary

Thermal history models presented for the Peel Plateau, northern Canadian Cordillera, resolve peak burial temperatures of Devonian strata that equate to burial depths of 4.2-5.7 km during the Triassic and exhumation to near surface conditions prior to reburial at 2-3 km depth within a Cretaceous foreland basin. The timing of peak burial in the foreland basin varied over 14 Myr through the Paleogene as a result of deposition of sediment derived from the adjacent Mackenzie and southern Richardson mountains. Modelled %Ro values for the Cretaceous deposystem are consistently lower than measured values from exploration wells and surface exposures, implying that measured values probably reflect recycling of vitrinite material from older strata. Results from this study are in general agreement with previous work reporting thermal history model results but provide better resolution due to the integration of the CRS search. Single

grain AFT ages and the r_{mr0} parameter serve as an appropriate proxy to predict grain-specific annealing kinetics, as it accounts for elemental substitutions that influence fission-track retentivity. The multikinetik populations defined in the AFT datasets serve as independent thermochronometers resulting in more refined thermal history models. Despite the uncertainty related to grouping kinetic populations, the multikinetik populations presented are interpreted to best reflect the variable annealing kinetics of apatite within for each AFT sample, and the thermal history models provide sufficient resolution to improve our understanding of complex burial cycles within the Peel Plateau. Ignoring variable kinetic behavior within AFT samples can potentially lead to erroneous geologic interpretations, as demonstrated by comparing thermal history model results from the same AFT sample modelled as a mono-kinetic population and multikinetik populations. It is important to acknowledge that thermal history models are themselves interpretations that need to be developed within the context of the regional geology. Through the integration of the LA-ICPMS method for AFT analysis, apatite U-Pb data can be acquired simultaneously, and potentially serve as a complementary tool to help discern multikinetik populations. Finally, as the closure temperatures of the AFT system overlap with the oil and gas window, applying the same method in prospective basins elsewhere could have significant implications for the energy exploration sector.

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CHAPTER 3

EAST TAUERN DETACHMENT SYSTEM: COUPLED OLIGOCENE DUCTILE THINNING AND MIOCENE EXTENSION OF THE EASTERN EUROPEAN ALPS

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3.1 Abstract

Differentiating between syn- and post-orogenic structures is critical for determining the contribution from any one mechanism toward net exhumation. In the Tauern Window of the Eastern Alps, new mapping in its northeastern region reveals significant deformation associated with W–E extension and a component of N–S shortening. Kinematic indicators reveal a clear top-to-E shear sense, and deformation is further highlighted by progressively deformed quartz-calcite-dolomite veins, whose rotation was used to quantify flow parameters, revealing an equal contribution of simple and pure shear. The ductile deformation is overprinted by E-dipping shear bands and faults, which transition into brittle-ductile faults compatible with incremental strain axes indicating vertical shortening during top-to-E extension. Raman spectroscopy data show a temperature gradient with higher structural levels exhibiting paleotemperatures $<450^{\circ}\text{C}$, increasing to $>500^{\circ}\text{C}$ at lower crustal levels. White mica $^{40}\text{Ar}/^{39}\text{Ar}$ ages (25–34 Ma) in both shear veins and recrystallized fabrics confirm Oligocene deformation. At higher crustal levels, the deformation gradient progressively increases toward the newly discovered top-to-E Schuhflicker Detachment, defined by a knife-sharp fault surface of ultramylonites and cataclasites. The Schuhflicker Detachment developed at mid-crustal levels during the Oligocene, and during progressive exhumation, W–E extension was transferred to the structurally higher Katschberg Fault and Katschberg Shear Zone System during the Miocene. Collectively, these structures form the East Tauern Detachment System, which accommodated tens of kilometers of exhumation in the Tauern Window, facilitating the incipient stages of its exhumation during the Oligocene and subsequent erosion- dominated unroofing in the Miocene.

3.2 Introduction

The eastern European Alps are one of the most extensively studied mountain belts, serving as a natural laboratory to understand orogenic processes (e.g., Dal Piaz, 2001; Diener, 1901; Kurz et al., 1999; Murchison, 1849; Ratschbacher, 1986). Along with many other Phanerozoic orogens across the globe (e.g., Himalaya, Caledonides), the Alps expose high-pressure metamorphic rocks within their core. The theory of rigid shell plate tectonics can explain the occurrence of high-pressure mineral assemblages through deep burial during subduction or in collisional zones. It does not, however, readily account for the mechanisms of lithospheric deformation facilitating the ascent of rocks to upper crustal levels. Different exhumation mechanisms have been invoked in syn- and post-orogenic settings. Multiple processes likely contribute to the overall exhumation of high-pressure rocks (Jolivet & Goffe, 2000; Ring & Brandon, 1999). Determining how and when once deep-seated rocks return to the surface is crucial for understanding the orogenic cycle (Brown, 2023; England & Molnar, 1990; Gerya et al., 2002; Platt, 1993).

Five main processes that exhume rock have been recognized: within subduction channels, high-pressure rocks can undergo significant exhumation via (a) extrusion or (b) extraction, both processes driven by buoyancy contrasts and subduction dynamics (Davies & Blanckenburg, 1995; Froitzheim et al., 2003; Groß et al., 2021; Keppler et al., 2016; Ricchi et al., 2020). Under regional extension with a significant component of pure shear, (c) ductile thinning can facilitate the exhumation of lower crustal rocks (Ducharme et al., 2022; Ring & Brandon, 1999). The process relies on progressive lateral flow of the middle to lower crust, resulting in vertical shortening (Platt et al., 1998; Ring & Brandon, 1999). Tectonic unroofing along (d) crustal-scale low-angle normal faults, also referred to as detachment systems, can rapidly exhume rocks to middle and upper

crustal levels (Armstrong, 1972; Axen, 2007; Buck, 1988; Jolivet et al., 2010; Moores et al., 1968; Wernicke, 1981). Detachment systems are often associated with metamorphic core complexes (Lister et al., 1984), and generally have a shallow dipping fault plane ($<30^\circ$) that initiates in the ductile regime, which is mechanically linked to high-angle normal faults at higher crustal levels (Collettini, 2011; Lister & Davis, 1989). However, high-angle normal faults are proven to only modestly contribute to exhumation (Koyi & Skelton, 2001), although large-offset normal faults that begin as high-angle faults can progressively rotate to lower dip angles and accommodate significant exhumation (e.g., Blackford et al., 2022). Lastly, the exhumation of upper crustal rocks is often facilitated by (e) erosional denudation, which consists of the physical and chemical break down and removal of overburden (England & Richardson, 1977). Erosion helps define the topography within orogenic belts, however, erosion alone generally cannot account for the entire exhumation history of originally deep-seated rocks within orogenic belts, except in extreme, localized situations (e.g., orogenic syntaxes; Zeitler et al., 2001).

Understanding and quantifying exhumation is complex, as more than one process can be active simultaneously, and the dominant exhumation mechanism likely evolved as the rocks progressively exhumed to higher, cooler structural levels. For example, detachment systems can exhibit distributed ductile thinning in their footwall, therefore ductile thinning and low-angle normal faults can operate coevally, whereas erosion often accounts for the final phase of exhumation in this scenario (Ducharme et al., 2022; Feehan & Brandon, 1999; Lister et al., 1984; Long & Kohn, 2020).

In the eastern European Alps, the timing and mechanisms of exhumation vary across the orogen (e.g., Glodny et al., 2008; Schmid et al., 2013). A longstanding debate centers on the exhumation of the Tauern Window (**Figure 3.1**; Favaro et al., 2017; Fox et al., 2016; Fügenschuh

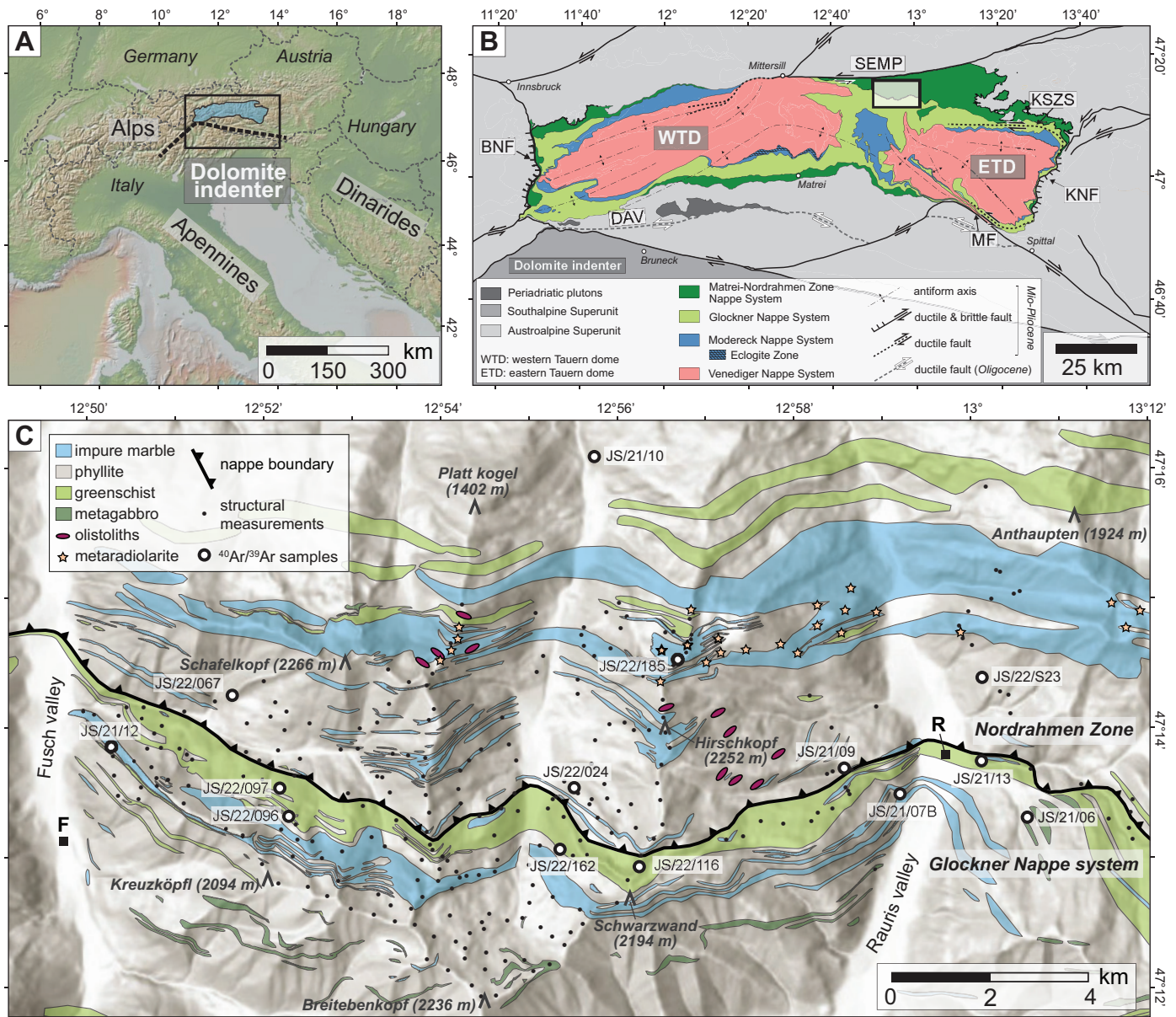


Figure 3.1. (A) Topographic map of southern Europe showing major mountain chains within the Alpine belt. The location of the Tauern Window (Eastern Alps) is highlighted in blue, and the dashed line is the front of the Dolomite Indenter. (B) Simplified geological map of the Tauern Window. Shaded box denotes the study area. Fault abbreviations are as follows: BNF Brenner normal fault; DAV Deferegggen-Antholz-Vals fault; KNF Katschberg normal fault; KSZS Katschberg Shear Zone System; MF Molltal fault; SEMP Salzach-Ennstal-Mariazell-Puchberg fault. Modified after Schmid et al. (2013). (C) Geologic map of the study area showing white mica $^{40}\text{Ar}/^{39}\text{Ar}$ sample locations and all outcrops where structural measurements were taken. Tectonic thrust denotes the nappe boundary between the Matri-Nordrahmen Zone Nappe System and the Glockner Nappe System. The new position of the nappe boundary is justified by field observations (discussed in text). Modified after Griesmeier et al. (2019).

et al., 1997; Glodny et al., 2005; Kurz et al., 1998; Ricchi et al., 2020; Rosenberg et al., 2018; Rosenberg & Schneider, 2008; Scharf, Handy, Favaro, et al., 2013; Wolff et al., 2021). This tectonic window exposes metamorphic units that have been buried to >80 km depths before being exhumed to surface conditions (Schmid et al., 2013 and references therein). Decades of research have integrated numerous analytical techniques to document the timing and processes related to the opening of the window. The most widely accepted model interprets the Tauern Window to have formed during the Miocene, where efficient erosion was facilitated by upright folding related to collision (Bertrand et al., 2017; Favaro et al., 2017; Fügenschuh et al., 1997; Rosenberg et al., 2004; Schmid et al., 2013). Recent estimates predict that erosion accounted for no more than 8 km of exhumation of the window (Bertrand et al., 2017; Schmid et al., 2013). Consequently, complementary processes must have been operating during, or before, the Miocene to account for the total magnitude of exhumation inferred (Bertrand et al., 2017; Glodny et al., 2005; Schmid et al., 2013). Bedrock geochronology from the eastern window (e.g., Glodny et al., 2005, 2008; Liu et al., 2001; Ratschbacher et al., 2004) and sedimentological data from the Northern Alpine Foreland Basin (Hülscher et al., 2021) together provide provocative evidence that deformation and unroofing may have commenced during the Oligocene.

Overprinting structural relationships from deep (ductile) to shallow (brittle) crustal levels track discrete phases of deformation that are useful to untangle complex exhumation histories. The Tauern Window preserves a penetrative horizontal foliation which can be indicative of lateral ductile flow. Whether ductile thinning contributed to exhumation has yet to be assessed, and merits further attention (Feehan & Brandon, 1999; Ratschbacher et al., 1989; Ring & Brandon, 1999; Wallis et al., 1993). Additionally, low-angle normal faults have been documented along the western and eastern margin of the window, yet no crustal-scale detachment systems have been identified

(Behrmann, 1988; Fügenschuh et al., 1997; Genser & Neubauer, 1989; Rosenberg & Garcia, 2011; Scharf, Handy, Favaro, et al., 2013; Selverstone, 1988). Herein, we present a detailed structural investigation of the northeastern Tauern Window targeting ductile and brittle-ductile structures related to progressive exhumation. Mapping, strain analysis and white mica $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology were conducted to assess whether alternative mechanisms, such as ductile thinning or a paired detachment system, contributed to the early stages of exhumation and to help resolve the time of discrete phases of deformation.

3.3 Tectonic setting

3.3.1 Tauern Window

The European Alps are a part of the Alpine-Zagros-Himalayan orogenic belt and mark the collision of the Adriatic micro-plate with Eurasia during the Cenozoic (**Figure 3.1A**). The geology of the Alpine orogeny can be simplified into four main tectonic superunits that represent specific paleogeographic realms prior to collision (e.g., Froitzheim et al., 2008; Schmid et al., 2004). The structurally lowest packages belong to the (a) Sub-Penninic Superunit and Helvetic Superunit that consist of continental basement and sedimentary basin material derived from the Eurasian Plate. The structurally overlying (b) Penninic Superunit represents the oceanic domain (Alpine Tethys) that once separated the Eurasian and Adriatic plates, and comes from oceanic lithosphere and continental microdomains contained within the ocean basin. The structurally highest packages are (c) the Austroalpine Superunit and (d) the Southalpine Superunit, both originating from the Adriatic plate. The Austroalpine Superunit formed during Jurassic-Cretaceous intracontinental collision within Adria. Continued collision and shortening resulted in S-directed subduction of the Penninic and part of the Sub-Penninic superunits beneath Adria, resulting in high-pressure

metamorphism. Within the collision zone, the Penninic and Sub-Penninic superunits were imbricated during a phase of nappe stacking, which when exhumed formed the current structure of the Alps (e.g., Frisch, 1979; Tricart, 1984; Trümpy, 1960).

Within the eastern Alps, the Tauern Window consists of two metamorphic domes that form double-plunging folds, referred to as the Eastern and Western Tauern Domes (**Figure 3.1B**), which expose deep-seated rocks from the Penninic and Sub-Penninic superunits (Schmid et al., 2013). The tectonic window is framed by the Austroalpine Superunit, defining the window's hanging wall (**Figure 3.1A and B**; Schmid et al., 2013). The southwestern margin of the window coincides with the leading edge of the Dolomite Indenter (Frisch et al., 2000), which is part of the Southalpine Superunit. Indentation represents the latest phase of collisional processes during the Miocene, and rocks from the indenter were affected by S-directed thrusting during Alpine orogenesis (**Figure 3.1B**; e.g., Favaro et al., 2017; Rosenberg et al., 2004; Sieberer et al., 2023).

A complex fault network with various displacement vectors is developed within the Austroalpine Superunit that are kinematically linked to indentation and the exhumation of the Tauern Window (e.g., Bögel, 1975; Scharf, Handy, Favaro, et al., 2013). The window is laterally bound in the west and east by N–S striking normal faults: the W-dipping Brenner and the E-dipping Katschberg normal faults, respectively (**Figure 3.1B**; Behrmann, 1988; Fügenschuh et al., 1997; Genser & Neubauer, 1989; Selverstone, 1988). At deeper structural levels, the Katschberg Shear Zone forms a mylonitic shear zone that contours the northeastern margin of the eastern dome (**Figure 3.1B**; Scharf, Handy, Favaro, et al., 2013). The northeastern limit of the Tauern Window is partly defined by the sinistral Salzach-Ennstal-Mariazell-Puchberg fault (SEMP; **Figure 3.1B**; Decker & Peresson, 1996; Frost et al., 2011; Linzer et al., 1995, 2002; Ratschbacher, Frisch, et al., 1991; Rosenberg & Schneider, 2008; Wang & Neubauer, 1998). The Mölltal Fault denotes part of

the window's southern boundary and projects northwestward as a shear zone that transects the eastern dome (**Figure 3.1B**; Frisch et al., 2000; Kurz & Neubauer, 1996).

The Penninic and Sub-Penninic superunits within the window are sub-divided into separate nappe systems based on paleogeographic reconstructions and lithotypes. The Sub-Penninic Superunit includes the lower Venediger Nappe System and the upper Modereck Nappe System (**Figure 3.1B**). The former consists of the Eurasian continental basement and its sedimentary cover, and is imbricated into a duplex structure that is exposed in the cores of the eastern and western domes (Schmid et al., 2013). The latter represents Eurasia's distal continental margin and includes the scarcely preserved Eclogite Zone: a metamorphosed volcano-sedimentary sequence with mafic intrusions that is interpreted to be a continent-ocean transition zone (**Figure 3.1B**; Frisch, 1980; Glodny et al., 2005; Schmid et al., 2013). The structurally overlying Penninic Superunit comprises the Glockner Nappe System and the overlying Matrei-Nordrahmen Zone Nappe System. The Glockner Nappe System is part of an isolated oceanic domain that opened in the Early Cretaceous (i.e., Valais Ocean), whereas the Matrei-Nordrahmen Zone Nappe System represents a branch of the Alpine Tethys that opened in the middle Jurassic (i.e., Piemont-Liguria Ocean; Schmid et al., 2013). Both Penninic units comprise similar metamorphosed ophiolite-bearing lithologies, and carbonate and silicate clastic rocks. The Matrei-Nordrahmen Zone Nappe System can be differentiated by the occurrence of olistholiths derived from the Adriatic plate and exhibits lithostratigraphic similarities to rocks of the Lower Austroalpine Unit (Frisch et al., 1987). Additionally, within the Alpine orogen, metaradiolarite exclusively occurs in oceanic domains that pre-date the Cretaceous, and consequently, metaradiolarite is only observed in the Matrei-Nordrahmen Nappe System (Schmid et al., 2013).

Pressure (P) and temperature (T) conditions related to subduction have been traditionally resolved via thermobarometry (e.g., Schmid et al., 2013). Peak temperatures have also been determined via Raman spectroscopy of carbonaceous material (RSCM) that represents the highest temperature related to graphitization, but the method does not provide information on the timing of peak temperature (e.g., Buseck & Bo-Jun 1985; Landis, 1971; Teichmüller, 1987). The Eclogite Zone is affected by eclogite facies metamorphism and is the unit that has reached the greatest depths within the subduction channel (19–25 kbar at 500–635°C; Holland, 1979; Hoschek, 2001, 2006). Parts of the Modereck and Glockner nappe systems in the central Tauern Window are eclogitized and yield peak P-T estimates of 20 kbar at 500°C and ~17–23 kbar at 570°C, respectively (Dachs & Proyer, 2001; Groß et al., 2021; Schmidt, 2015). The Matrei-Nordrahen Zone Nappe System exhibits lower P-T conditions of ~9–10 kbar at 360–370°C, indicating the nappe was subducted to shallower depths (Koller & Pestal, 2003). Similarly for the Venediger Nappe System, peak pressure estimates related to subduction are 10–11 kbar. Temperature estimates are not conclusive due to the thermal overprint associated to Barrovian metamorphism during nappe stacking. The rocks from the Venediger Nappe System reached amphibolite facies (7 kbar at 550°C), whereas the high-pressure nappes imbricated above the Venediger Duplex retrogressed to greenschist facies conditions during nappe stacking (Berger et al., 2011; Christensen et al., 1994; Droop, 1985, 2013; Franz et al., 1986; Kurz et al., 1998; Selverstone et al., 1984; Smye et al., 2011; Spear & Franz, 1986). Notably, RSCM temperatures resolved from high-pressure nappes are similar to estimates resolved via thermobarometry, and values generally decrease toward higher structural levels (Scharf, Handy, Ziemann, & Schmid, 2013). The centers of both domes represent the deepest exposures of the Venediger Nappe System, and coincide with the highest RSCM temperatures (610°C) in the window (Scharf, Handy, Ziemann, & Schmid,

2013). At higher structural levels of the Venediger Nappe System, toward the domes' margins, temperatures decrease to $\sim 440^{\circ}\text{C}$ (Scharf, Handy, Ziemann, & Schmid, 2013). Within our study area, northwest of the eastern dome, published RSCM temperatures systematically decrease from $\sim 500^{\circ}\text{C}$ at the base of the Glockner Nappe System, to $\sim 350^{\circ}\text{C}$ at the uppermost Matrei-Nordrahmen Zone Nappe System (Scharf, Handy, Ziemann, & Schmid, 2013).

3.3.2 Previous geochronology

There is a consensus that nappe stacking occurred until the late Oligocene, based on garnet Rb-Sr dates of c. 30 Ma (Christensen et al., 1994; Inger & Cliff, 1994), however, the timing of subduction cessation, and whether subduction terminated simultaneously along the entire Alpine arc, is debated (e.g., Glodny et al., 2008; Schmid et al., 2013; Thöni, 2006). The timing of subduction termination has been inferred from age constraints that either post-date the youngest radiometric date related to high-pressure metamorphism, or pre-date the oldest radiometric date related to retrogression. More specifically, competing narratives debate whether subduction terminated in the Eocene or early Oligocene (e.g., Glodny et al., 2005, 2008; Kurz et al., 2008). An Eocene termination is inferred from $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology: Ratschbacher et al. (2004) dated hornblende and mica, inferring peak high-pressure metamorphism was achieved at c. 45 Ma for the Eclogite Zone, and at c. 35 Ma for the overlying Penninic nappes. Similarly, based on retrogressed phengites, Kurz et al. (2008) determined that high-pressure conditions occurred at 42–45 Ma in the Eclogite Zone and 39 Ma in the Modereck Nappe System. Alternatively, numerous studies using various radiometric dating techniques report Oligocene dates that are interpreted to record high-pressure metamorphism. Within the Eclogite Zone, Smye et al. (2011) reported allanite-clinozoisite U-Th-Pb dates of 34.2 ± 3.6 Ma, and Nagel et al. (2013) resolved a

similar date of 32.8 ± 0.5 Ma via Lu-Hf geochronology on unaltered garnet from an eclogite. In addition, pseudomorphs after lawsonite in the Eclogite Zone and Glockner Nappe record 29.8 ± 0.5 Ma dates that are interpreted as syn-tectonic crystallization at near- peak metamorphic conditions (Gleissner et al., 2007). In the western Tauern dome, Satir (1975) reported Oligocene dates on phengites within Penninic units near the center of the window (c. 30 Ma via Rb-Sr) and near the window's southwestern margin (31 ± 2 Ma via K-Ar) that are interpreted to record peak metamorphism. In contrast, Glodny et al. (2005) resolved similar Rb-Sr dates related to eclogitization (31.5 ± 0.7 Ma) and greenschist facies vein assemblages (31.5 ± 0.5 Ma) from the same sample, and proposed the duration between high-pressure metamorphism and nappe stacking is much shorter than previously understood (<2 Myr).

Numerous studies have also reported Oligocene radiometric dates within the Tauern Window, however, the significance of the dates (e.g., primary crystallization, metamorphism, dynamic recrystallization) is often unclear due to a lack of microstructural evidence (e.g., Glodny et al., 2008). Oligocene dates are reported south of the SEMP (28–35 Ma via mica $^{40}\text{Ar}/^{39}\text{Ar}$; Urbanek, 2001; Urbanek et al., 2002) and in the prolongation of the Mölltal Fault (22–32 Ma via whole rock Rb-Sr; Inger & Cliff, 1994). Glodny et al. (2008) reported similar dates (30– 31 Ma) determined via multi-mineral Rb-Sr analyses on mylonitic shear zones that locally define nappe contacts in the central window (**Figure 3.1B**). Proximal to the Mölltal Fault, Cliff et al. (1998) documented fabric formation at 27.7 ± 0.3 Ma via Th-Pb dates on allanite developed within crenulation cleavage. South of the central window, Zimmermann et al. (1994) reported phengite $^{40}\text{Ar}/^{39}\text{Ar}$ dates of 32–36 Ma and 27 Ma. The latter date is interpreted to reflect nappe stacking, and older dates (32–36 Ma) on the Glockner and Modereck Nappe Systems likely record crystallization coeval with blueschist facies retrogression in the Eclogite Zone (Zimmermann et

al., 1994). Dispersed white mica K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ dates between 20 and 35 Ma have been interpreted to record greenschist facies retrogression (Lambert, 1970) and cooling (Liu et al., 2001; Raith et al., 1978).

Significant exhumation of the Tauern Window is generally accepted to have occurred during the Miocene (e.g., Bertrand et al., 2017; Rosenberg et al., 2004; Schmid et al., 2013), synchronous with the collision of the Dolomite Indenter that started at c. 21–23 Ma (Favaro et al., 2017; Handy et al., 2010). Collision resulted in crustal shortening, producing km-scale folds (doming) that define the internal structure of the window (Fügenschuh et al., 1997). Zircon and apatite fission track (ZFT, AFT) dating records Miocene cooling and exhumation, and the predicted isotherms derived from low-temperature thermochronometers define the contours of the axial planes of the eastern and western domes, which is consistent with exhumation via folding and erosion (Bertrand et al., 2017; Handy et al., 2010). Based on various thermochronometric data sets, Bertrand et al. (2017) estimated that erosion facilitated ~7.5 km of exhumation during the Miocene. There is a marked difference in ZFT cooling ages across the Brenner and Katschberg Faults: Miocene dates are recorded within the footwall of the Tauern Window and Cretaceous dates are preserved in the hanging wall. In the immediate footwall, Miocene ZFT ages decrease toward the Katschberg and Brenner normal faults, indicating these fault systems accommodated W–E orogen-parallel extension during this time (Favaro et al., 2015; Frisch et al., 2000; Fügenschuh et al., 1997; Ratschbacher et al., 1989, 1991a, 1991b; Rosenberg et al., 2004; Scharf, Handy, Favaro, et al., 2013). Displacement estimates along the Katschberg Fault range from 17 to 29 km (Genser & Neubauer, 1989; Scharf, Handy, Favaro, et al., 2013). For the Brenner Fault, Fügenschuh et al. (1997) predicts >70 km of displacement, however, most studies have reported more conservative

displacement estimates of 15–26 km (Selverstone et al., 1995) or 4–14 km (Rosenberg & Garcia, 2011).

3.4 Field observations and microstructural analysis

Our study area is northwest of the eastern Tauern dome, extending from the Fusch valley in the west and beyond the Rauris valley in the east (**Figure 3.1C**). The field investigation focused on documenting ductile to brittle-ductile deformation as these structures formed at mid- to upper crustal levels during exhumation and cooling. Intense deformation is characterized by ductile structures (mylonitization, pervasive folding, multiple shear sense indicators) that are overprinted by brittle-ductile faults. Lithological variations were noted and, overall, intense deformation is observed across different structural levels but is localized along lithological contacts, indicating strain partitioning is controlled by strength contrasts. Additional field photos (**Figure S3.1**) and a summary table of all localities (**Table S3.1**) is available in **Appendix B**.

3.4.1 Lithologies

The predominant lithologies include phyllites, impure marbles alternating with phyllite or mica schist (known as “Kalkglimmerschiefer”), greenschists and metagabbros. Continuous packages of impure marble (north) and greenschist (central) trisect the entire study with apparent thicknesses that range from 100 m to 2 km. Other units are discontinuous along strike and form apparently isolated lenses in map view (**Figure 3.1C**; **Figure 3.2A**). The mineralogical assemblage of the phyllites is highly variable, incorporating various proportions of quartz, calcite, mica, and graphite. Phyllites are often intercalated with mm- to m-scale sequences of impure marble and mm- to cm- scale quartzite layers (**Figure S3.1**). Within the continuous impure marble unit at the

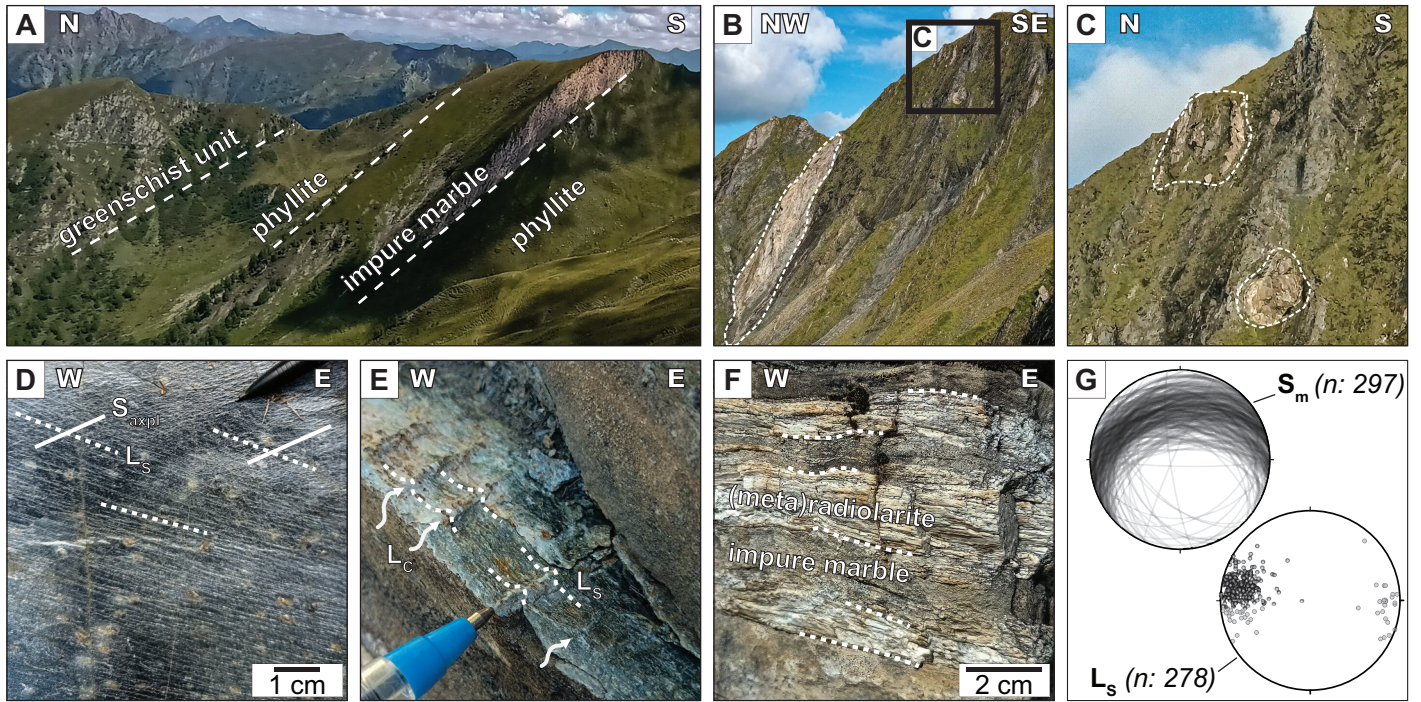


Figure 3.2. (A) Landscape view illustrating weathering contrasts of different lithologies in the field area. The greenschist unit is a continuous sequence that transects the study area. (Photo taken from N 5230489, E 340509). (B) Cliff exposure of discontinuous light colored marble olistolith (dashed white line) within phyllitic matrix. (Photo taken from N 5233999, E 340437). (C) Inset from [B] shows meter-scale blocks of marble located within phyllitic matrix. (D) Axial plane cleavage (S_{axpl}) overprinting stretching lineation (L_s). Axial plane cleavage is shallowly dipping toward the NE (N 5232173, E 343189). (E) N–S striking crenulation (L_c) spaced at ~1 cm intervals forming a new axial plane cleavage (white arrows). Crenulation overprints an intense W–E oriented stretching lineation (L_s) defined by elongated recrystallized quartz (N 5233983, E 338566). (F) Centimeter-thick packages of white/orange, thinly layered quartz mylonite that is interpreted as metaradiolarite interbedded with impure marble (N 5233851, E 344231). (G) Stereoplot of structural measurements of the foliation (S_m) and stretching lineation (L_s) from the study area. The foliation generally dips to the north to northwest and preserves an W–E oriented stretching lineation.

northern limit of the area, vertical cliff faces expose olistoliths that are m- to dam-scale blocks of pure marble in a phyllitic matrix (**Figure 3.2B and C**). Similar olistoliths were found further east and define a broad domain.

Greenschists denote metabasic aphanitic rocks that are unambiguously recognized by their characteristic light green color indicating chlorite and epidote related to greenschist facies metamorphism. Albite, actinolite- tremolite, quartz and white mica are present in all greenschists, although quartz, epidote, and white mica contents are highly variable, and locally the greenschists are carbonate-bearing (**Figure S3.1**). A W–E mineral lineation defined by actinolite and tremolite is often observed on the foliation plane, and is parallel to the stretching lineation. Metagabbros are the coarse grained counterpart of greenschists, often preserving ~0.5 cm prismatic albite that is likely replacing plagioclase, or acicular voids that are molds of eroded amphiboles (**Figure S3.1**). The greenschist unit that transects the center of the area is banded with mm- to cm-scale layers of epidote and chlorite, and locally hosts pods of metagabbro and prismatic magnetite crystals. These features disappear up-section, where the greenschist is finer grained and more foliated, displaying a deformation gradient.

Centimeter- to meter-scale packages of white, pure, ultrafine grained silicious material are observed above the continuous greenschist unit and interpreted as metaradiolarite (**Figure S3.1**). The same material is observed within the underlying phyllite unit, forming packages up to 10 m thick and locally altering from white to light green or orange (**Figure 3.2F**). The material is often intensely deformed with the stretching lineation forming an L-tectonite fabric (**Figure S3.1**). The occurrence of newly described olistoliths and metaradiolarite within phyllite and impure marble implies that the Matrei- Nordrahn Zone Nappe System extends to lower structural levels

than previously expected and justifies relocating the nappe boundary to coincide with greenschist units upper contact (discussed below; **Figure 3.1C**; Griesmeier et al., 2019; Schmid et al., 2013).

3.4.2 Ductile structures

The rocks record a variable degree of non-coaxial ductile deformation with a roughly W–E trending stretching lineation that plunges gently toward $\sim 290^\circ$. Although strongly folded (see below), the main foliation dips $\sim 45^\circ$ toward N to NW (**Figure 3.2G**). Numerous shear sense indicators like winged inclusions (Grasemann & Dabrowski, 2015), shear bands, asymmetric shear band boudinage and flanking structures record predominantly a dextral, or a top-to-E shear sense when unfolded (**Figure 3.3**; **Figure S3.1**).

Four generations of folds can be resolved, and the relative timing of different folding events is determined from interference patterns between fold generations. Here we define the individual fold structures where the notations DI-DIV represent the relative progressive stages of folding. The earliest event, DI, corresponds to isoclinal folds that formed within the (mylonitic) main foliation. DI folds possess axes parallel to the stretching lineation direction and are best preserved in banded greenschists and as folded quartz-calcite veins (**Figure 3.4A**). DII folds, which fold the main foliation, are upright to S-vergent tight folds with axes that are shallowly (30°) plunging to the W (260° – 310°) and have an axial plane dipping $>50^\circ$ to the N (330° – 030° ; **Figure 3.4B** and **E**). These folds have amplitudes from cm- to km-scale. Since these folds have axes that are roughly parallel to the stretching lineation, the shear sense is reversed (sinistral) on the inverted fold limbs (**Figure S3.1**). DIII folds are recumbent folds with axes plunging shallowly to the W and an axial plane dipping shallowly to the N ($<30^\circ$; **Figure 3.4C-E**). The relative timing of DII and DIII folds is resolved from type III hook and crescent interference patterns, where DIII folds

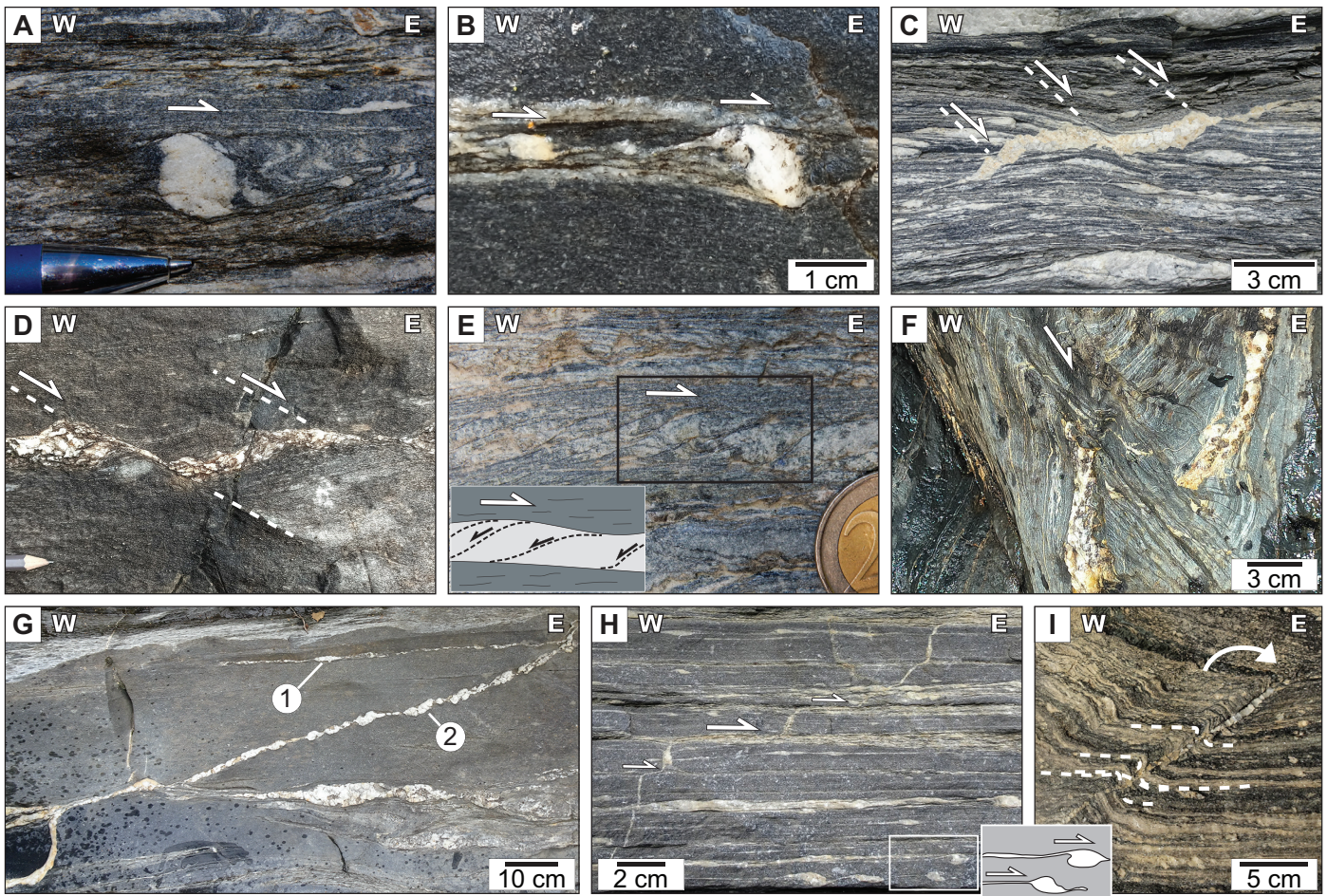


Figure 3.3. Field photos of kinematic indicators that record ductile top-to-east shearing. (A) Quartz winged inclusion in marble mylonite. Kinematics resolved from embayment in the top-left and bottom-right of the clast and asymmetric folds preserved in its strain shadow to the right (N 5232400, E 349447). (B) Pinch-and-swell calcite layer forming a train of winged inclusions (N 5232098, E 347579). (C) Boudinaged quartz-calcite vein oriented oblique to foliation and cross-cut by east-dipping shear bands (N 5232400, E 349447). (D) Boudinaged quartz-calcite layer cut by E-dipping shear bands define the necks of the boudins (N 5234285, E 348580). (E) Tiling of microlithons preserved between top-to-E marble shear zones. Note the antithetic displacement between the microlithons highlighted in the line drawing (N 5232098, E 347579). (F) Intensely folded marble mylonite offset by E-dipping brittle-ductile shear zones (N 5234849, E 342457). (G) Boudinaged quartz veins within impure marble illustrate the correlation between vein orientation and the intensity of stretching within the veins. Vein [1] is almost parallel to the foliation and records larger stretching than vein [2], which exhibits pinch-and-swell and rotated to an orientation that is $\sim 25^\circ$ from the main foliation. Folding of the vein indicates a component of shortening (bottom left of the photo; N 5232098, E 347579). (H) Marble mylonite with calcite vein perpendicular to the main foliation that is systematically offset eastward (arrows) along phyllitic layers. Veins within the foliation are stretched and locally form trains of winged inclusions (shown in line drawing; N 5232400, E 349447). (I) Quartz-calcite vein records an n-type flanking structure during E-vergent drag folding (white dashed line; N 5231547, E 345083).

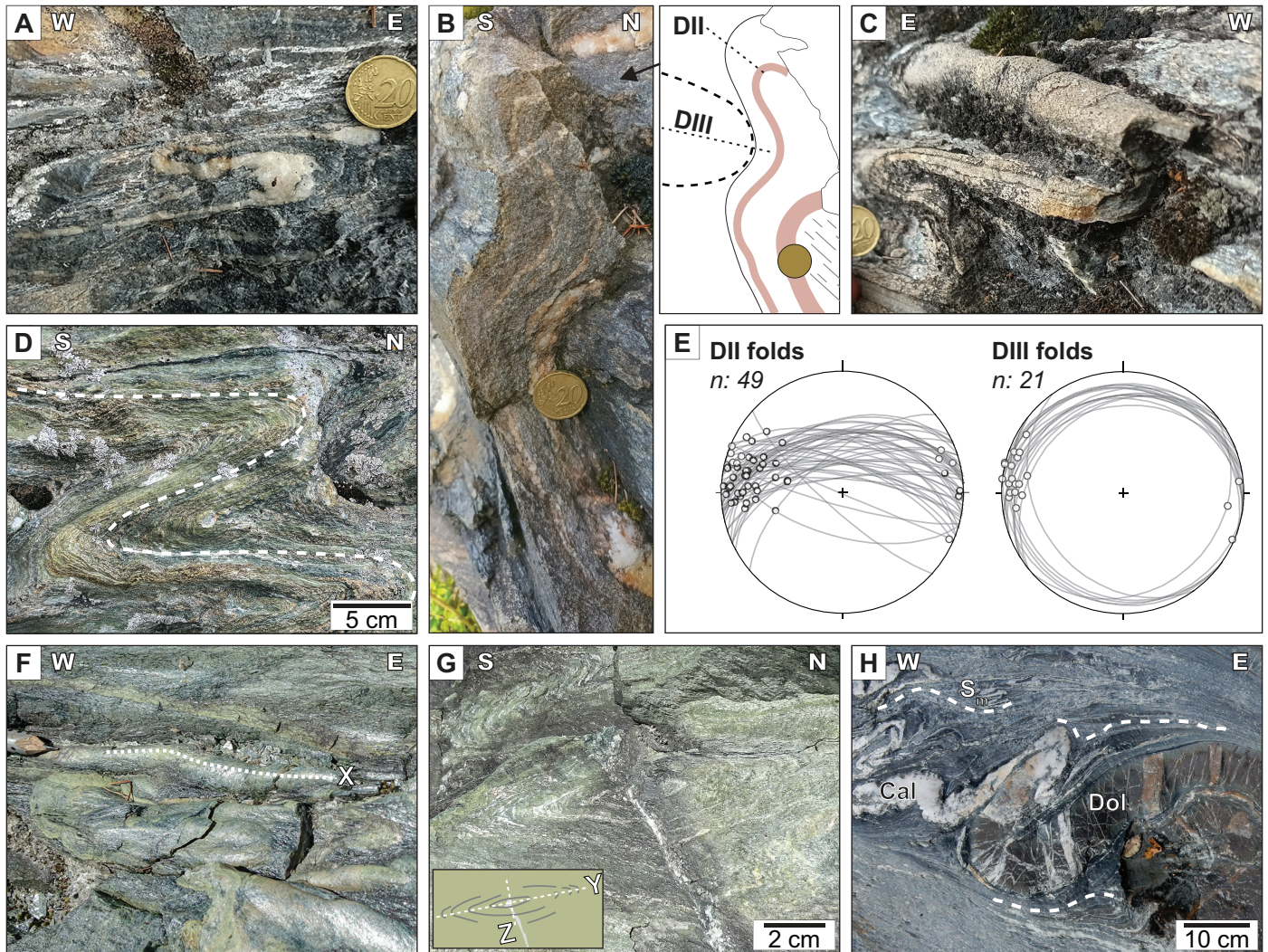


Figure 3.4. (A) Representative example of DI fold. Quartz vein forming isoclinal fold with axial planes that are parallel to the marble's mylonitic foliation (N 5233808, E 338082). (B) Representative photo of DII folds forming a type-III hook and crescent interference pattern with DIII folds. DIII folds share the same W–E oriented fold axes but have subhorizontal axial planes. The line drawing shows the profile of the DIII fold (thick dashed line); DII and DIII axial planes are projected as thin black lines (N 5233808, E 338082). (C) Representative photo of DIII fold within cm-thick marble layer (N 5233808, E 338082). (D) DIII fold train within greenschist. Compositional banding within the foliation defined by epidote and chlorite (N 5231178, E 343821). (E) Compilation stereoplots of the axial planes and fold axes for DII (left) and DIII (right) folds. (F) Multiple sheath folds within greenschist. Fold axes are curvilinear and have a broad W–E orientation (X-axis), denoted by the dashed white line (N 5231547, E 345083). (G) Cross-section view of sheath fold (Y–Z plane). The closed fold limbs of the sheath fold form an eye-shaped geometry. (H) Folded and boudinaged dolomite layer with calcite-filled fractures within mylonitic marble (N 5232098, E 347579).

distort the axial planes of DII folds (**Figure 3.4B and E**). The latest folding event (DIV) occurred during regional doming of the Tauern Window; the overall N-dipping foliation reflects the study area's position on the northern limb of the eastern dome. At one locality within the continuous greenschist unit, multiple sheath folds are observed (**Figure 3.4F**). Their curvilinear fold axes are oriented broadly W–E and a pervasive stretching lineation is preserved around their quasi-cylindrical limbs. Along fractured surfaces that cut perpendicular to the folds, the cross-section view of the folds reveals a classic ovoid geometry (**Figure 3.4G**). In regions that have experienced intense folding, differentiating between fold generations can be ambiguous.

The steeply dipping main foliation, is refolded by DII and DIII folds. It is subsequently overprinted by shallowly E-dipping shear bands and SCC' fabrics, which mainly localize in phyllitic lithologies recording top-to-E shearing. Furthermore, most ductile structures are intersected by subvertical quartz $\pm$ carbonate $\pm$ dolomite veins. Notably, undeformed veins are consistently oriented at $\sim 110^\circ$ from the foliation plane, and no veins oriented $>110^\circ$ were observed across the study area. Older quartz $\pm$ carbonate $\pm$ dolomite veins evince deformation through rotation into the shear direction during non-coaxial flow (**Figure 3.3G**). Three categories can be discriminated: (a) Veins oriented $>90^\circ$ from the foliation plane (positive angle are measured anti-clockwise) evince shortening, forming ptigmatic folds. (b) Some veins at high angles, but $<90^\circ$ from the foliation plane, preserve components of shortening and stretching (unfolding). (c) Veins at shallow angles, $<45^\circ$ (approximately subparallel to the foliation), evince stretching via intense pinch-and-swell boudinage (**Figure 3.3G**). The intensity of stretching in veins generally increases with rotation into the shear direction and is used to calculate the finite deformation tensor, as described below.

3.4.3 Quantifying strain from kinematic indicators

Kinematic indicators can be used to quantitatively assess deformation in shear zones by identifying the contribution of simple shear and pure shear to ductile flow (e.g., Derikvand & Almasi, 2022; Grasemann et al., 1999; Passchier & Urai, 1988; Simpson & De Paor, 1993; Xypolias, 2010). The mean kinematic vorticity number (W_K) describes the degree of non-coaxiality and is calculated from the cosine of the angle (δ) between the eigenvectors (a_1, a_2) of the deformation tensor (Means et al., 1980; Truesdell, 1954). For pure shear, $W_K = 0$, and for simple shear, $W_K = 1$, although it is a non-linear relationship, as simple and pure shear contribute equally at $W_K = 0.71$ (Law et al., 2004). In our study area, kinematic indicators in the unfolded main foliation unambiguously record top-to-E sense of shear, which indicates a component of simple shear is associated with ductile flow. North-south striking deformed quartz $\pm$ calcite $\pm$ dolomite veins are used to quantify deformation and to determine the mean kinematic vorticity number.

Several assumptions regarding flow parameters can be made from field observations and structural measurements of the veins as depicted in **Figure 3.5**. (a) The veins cross cut the mylonitic foliation, suggesting that the mylonitic foliation had already been established prior to vein generation and acted as the main fabric attractor during subsequent vein rotation (i.e., the orientation of a_1). (b) We assume all veins originally opened at $\sim 110^\circ$ measured anti-clockwise from the foliation as no veins exceeding this orientation were observed and undeformed veins are consistently orientated at $\sim 110^\circ$. (c) The initial opening of veins resulted from brittle failure in the direction of least compressive stress (i.e., the instantaneous stretching axis ISA_2) and subsequent fluid infiltration (Olson & Pollard, 1991). Assuming the veins opened as mode I fracture, σ_1 ($\sim 20^\circ$) also defines the maximum instantaneous stretching axis (ISA_1). (d) After emplacement, the veins

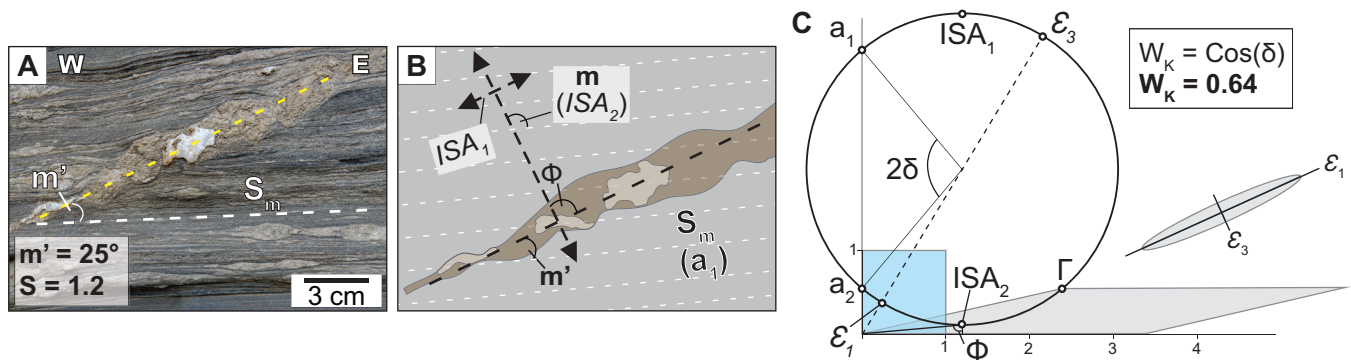


Figure 3.5. Representative example of strain analysis on veins that serve as quantitative kinematic indicators. (A) Pinch-and-swell calcite-dolomite vein which rotated into the top-to-E shear direction. The orientation of the vein (m') is measured from the foliation (S_m) and the stretching ratio (S) is estimated from the aspect ratio of pinch-and-swell fabric. (B) Schematic diagram from [A] showing flow parameters used in the Mohr Circle construction. The foliation plane acted as the fabric attractor during ductile flow and represents the eigenvector a_1 of the deformation tensor. The original opening angle of veins (m) relative to the foliation is $\sim 110^\circ$ (see text for explanation) and denotes ISA_2 . ISA_1 is perpendicular to ISA_2 and signifies the direction of vein opening. The vein has undergone an eastward rotation of 85° ($\Phi = m - m'$). (C) Deformation in strain space and physical space. In strain space, a Mohr circle of the Second Kind is constructed from the flow parameters defined in [B] and is used to position a_2 and calculate the kinematic vorticity number for the entire phase of ductile flow under steady-state conditions. In physical space, the deformed unit square and the strain ellipse are created for the vein presented in (A). The veins rotation (Φ) is used to define the origin of the coordinate system and to define the unit square (blue box), and polar coordinates from the Mohr circle are used to complete the deformed unit square (gray box). ϵ_1 is defined by a line connecting the origin (0,0) to the furthest point on the Mohr circle. From the same line, ϵ_3 is defined by the first intersection with the Mohr circle.

were progressively deformed during rotation into the shear direction. Therefore, older veins have larger rotation angles. Veins instantaneously shortened until they rotated through the orientation of maximum shear strain and further rotation resulted in instantaneous stretching. (e) Lastly, consistent opening angle of veins (ISA_1) relative to the fabric attractor (a_1) implies that flow parameters remained fixed during this phase of deformation and it is therefore assumed that ductile flow occurred under steady-state conditions (Bobyarchick, 1986; Grasemann et al., 1999). The orientation of a_2 is resolved in strain space on a Mohr circle of the Second Kind, and the angle between the flow apophyses (a_1, a_2) is used to calculate the vorticity number (**Figure 3.5**; De Paor & Means, 1984). A benefit of the Mohr circle of the Second Kind is that deformation tensors can be projected in physical space to visualize the geometry of the deformed unit square including the principal finite strain axis (ϵ_1, ϵ_3). An example is given in **Figure 3.5C** for a vein oriented at 25° from the foliation and a stretching ratio (S) of 1.2, yielding a finite strain ratio (R) of 9.5. If we accept the assumptions listed above, a significant component of pure shear is associated with steady-state ductile flow, equating to a kinematic vorticity number of 0.64. A methodological description of the construction of the Mohr circle is available in **Appendix B**, along with additional examples calculating finite strain ratios for veins that have undergone different magnitudes of rotation (**Figure S3.2**).

3.4.4 Brittle-ductile structures

Brittle-ductile faults are characterized as discrete fault planes with localized ductile deformation distributed in the surrounding host rock (**Figure 3.6**). In more intensely deformed areas, brittle-ductile faults are densely distributed (cm- to m-scale), and often cross-cut entire outcrops (>10 m; **Figure 3.6C**). Generally, the faults form conjugate normal NE- and NW-dipping

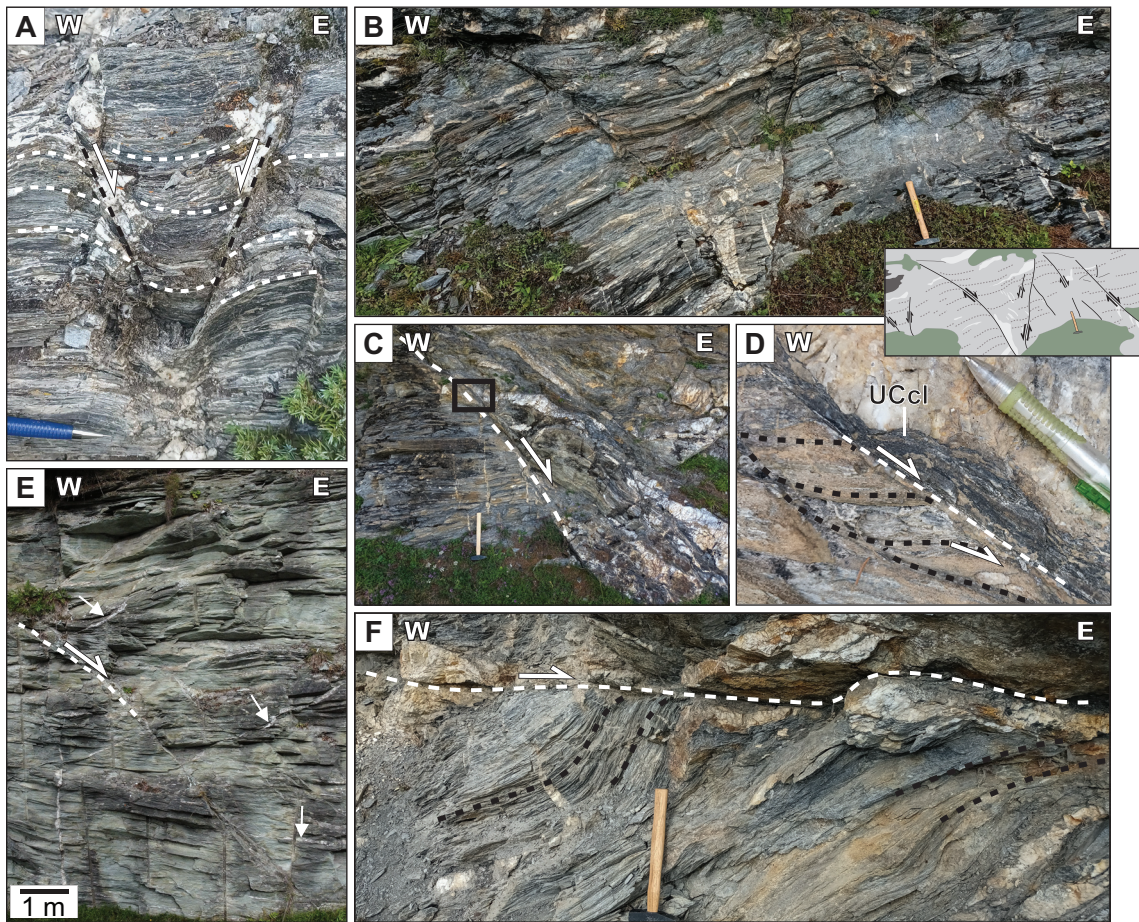


Figure 3.6. (A) Conjugate NE- and SW-dipping brittle-ductile normal faults within quartz-rich phyllite. Foliation drag (white dashed lines) show kinematics (N 5234526; E 344302). (B) Conjugate NE- and SW-dipping brittle-ductile normal faults within mylonitic marble. Foliation drag and tension gash structures indicate fault kinematics and are highlighted on the line diagram (inset; N 5233808, E 338082). (C) E-dipping brittle-ductile normal fault transecting marble mylonite. The dip of the foliation of the hanging wall evinces shearing parallel to the brittle fault whereas the foliation in the footwall appears horizontal. Black box denotes the inset [D]. (D) Knife sharp fault surface (dashed white line) where the black fault rocks are ultracataclasite (UCcl). Fault bound lenses deform ductily into sigmoidal shapes (black dashed line; N 5233808, E 338082). (E) NE-dipping normal fault transecting greenschist outcrop. White arrows show veins at various orientations that are stretched and boudinaged. Arrows are oriented perpendicular to vein orientations (N 5232527, E 348755). (F) Low-angle brittle-ductile normal fault with foliation drag (black dashed lines) illustrating fault kinematics (N 5234415, E 348528).

sets or systematically distributed NE-dipping sets (**Figure 3.6A and B**). At one intensely deformed outcrop, a NE-dipping normal fault plane preserves black fine grained material in the hanging wall with a planar curvilinear fabric parallel to the fault plane that is interpreted as an ultracataclasite (**Figure 3.6D and E**). In addition, E-dipping low-angle normal faults are preserved exclusively at locations preserving intense brittle-ductile deformation (**Figure 3.6F**). The direction of displacement is resolved via stair-stepping of slicken- fibers or slickensides on the fault plane, and is supported by the geometry of the foliation drag into the surrounding host-rock or tension gash structures that intersect fault surfaces (**Figure S3.1**).

Brittle-ductile faults consistently overprint cm- to dam-scale DII and DIII folds, and no folded fault planes are observed. In addition, there appears to be a correlation between the orientation of foliation and fault planes, as at large outcrops where the foliation varies, the orientation of fault planes changes with the foliation; the orientation of fault planes are generally consistent where the foliation is uniform. These structural relationships are used to decipher the relative chronology between brittle-ductile deformation and different folding events, where brittle-ductile deformation post-date DII and DIII folding, but pre-date doming of the Tauern Window (DIV folding) as conjugate faults are tilted in the north limb of the window-scale W–E fold. Most brittle-ductile faults evince a normal sense of displacement, although reverse faults are sometimes observed where the foliation is steeply dipping. The orientation of fault planes, their corresponding slip vector, and their surrounding foliation were documented across the study area (**Table 3.1**). For each locality, structural measurements of fault planes and their corresponding shear vector are plotted on equal area stereoplots. To remove the effect of doming (DIV) that post- dates brittle-ductile faulting, a representative foliation measurement for each corresponding locality is used to rotate the data on the stereoplots back to a pre-folding orientation and strain axes were then inferred

Table 3.1: Summary of table of principle strain axes resolved from brittle-ductile faults, Tauern Window, Austria

station	faults (n)	rep. foliation (°)	strain axis									UTM coordinates		
			θ †	ε ₁			ε ₂			ε ₃			Zone 33N	
				az.(°)	pl.(°)	R(%)	az.(°)	pl.(°)	R(%)	az.(°)	pl.(°)	R(%)	Easting	Northing
JS-22-004	6	341/49	62	279	80	88	8	0	95	99	11	89	341896	5232073
JS-22-007	6	002/36	54	208	69	95	13	22	95	105	5	91	5234518	343102
JS-22-022	11	352/44	40	310	86	94	20	1	96	112	3	91	5232191	342632
JS-22-036	4	012/59	32	241	81	95	16	6	94	108	7	99	5233262	336654
JS-22-038	5	019/73	38	27	86	89	3	5	82	98	1	89	5233060	337334
JS-22-043	3	001/46	30	193	67	89	34	22	77	299	14	89	5232608	337158
JS-22-067	25	344/31	42	106	87	88	186	1	93	279	3	91	5233808	338082
JS-22-079	2	332/36	84	-	-	-	-	-	-	-	-	-	5231589	340224
JS-22-082	4	008/60	64	266	65	94	42	21	87	139	12	89	5232982	338282
JS-22-099	13	015/60	30	332	72	9	206	8	94	116	14	89	5234849	342457
JS-22-122	5	342/41	46	197	76	9	30	15	96	301	4	87	5232302	340823
JS-22-150	11	040/70	40	43	59	83	221	27	88	311	2	84	5231184	341782
JS-22-152	2	016/45	64	-	-	-	-	-	-	-	-	-	5231793	344181
JS-22-164	15	002/56	34	2	59	85	206	28	94	111	11	87	5234526	344302
JS-22-165	6	009/34	24	5	61	94	183	27	95	274	1	94	5234268	344244
JS-22-184	4	357/50	34	107	83	88	198	0	85	289	5	97	5234529	344417
JS-22-227	4	003/50	40	323	67	91	188	16	92	94	16	98	5232895	336680
JS-22-233	3	15/49	42	212	81	98	21	9	97	112	3	99	5233626	335985
JS-22-237	5	332/54	36	326	80	97	198	6	98	108	8	98	5234415	348528
S13	35	003/54	44	20	78	88	194	13	9	285	1	92	5233132	336324
S15	29	323/50	36	357	81	9	187	7	89	99	1	9	5232438	346549
S16	62	012/36	40	93	83	92	209	3	91	300	6	91	5232527	348755
S17	14	348/37	84	284	52	93	16	2	94	106	39	92	5232440	349447
S31	13	007/45	84	313	65	91	200	8	91	107	23	9	5231771	350889
S33	24	338/26	46	335	84	98	213	2	97	123	6	97	5231395	350915
S53	8	344/35	28	346	82	97	179	7	95	89	2	95	5233500	336812
S55	22	338/41	32	260	86	92	6	1	92	97	3	96	5232148	346861
S56	10	352/33	42	236	76	94	18	10	87	111	11	87	5232201	346837
S59	16	332/45	32	183	86	87	17	5	83	107	1	92	5232494	346899
S62*	31	-	36	145	77	95	5	10	88	274	9	9	5231547	345083
zone A	17	010/16	32	153	75	93	20	10	94	288	10	97	5231547	345083
zone B	14	338/31	36	138	80	98	347	8	97	257	5	97	5231547	345083
BH-21-0059	27	003/29	44	269	89	91	17	1	88	288	0	92	5232615	348633
BH-21-0063	14	002/42	42	359	81	95	196	9	97	106	3	97	5232591	348691
BH-21-0093	13	359/51	40	56	84	92	187	4	9	277	4	92	5231074	347192

† θ represents the opening angle between different fault sets and is calculated automatically in *Tectonics FP*

az. = azimuth; pl. = plunge

* outcrop S62 is separated into zones A and B to reflect a change in foliation

Average strain axes could not be calculated from outcrops with less than three fault measurements

for each fault measurement and representative axes are determined for each locality (**Table 3.1**). A subset of the data is presented in **Figure 3.7** and a complete methodological description and all structural measurements (**Figure S3.3** and **Table S3.2**) are available in Appendix B. Regardless of the intensity of deformation, the orientation of incremental strain resolved from brittle-ductile faults have a consistent orientation across the study area (**Figure 3.7**). Results reveal that brittle-ductile faulting is compatible with a subvertical principal incremental shortening (ϵ_1), and a subhorizontal NW–SE- to W–E-oriented principal incremental extension (ϵ_3) before doming. Notably, the orientation of ϵ_3 is generally aligned with stretching lineation measured from the corresponding localities.

3.4.5 Microtectonics

Petrographic analysis was conducted to identify microstructures, assess intra-crystalline deformation mechanisms in the host rocks and veins, and document the structure of white mica in samples dated via $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology. The foliation is generally defined by elongated white mica, often occurring as bundles, as well as compositional variations of different microlithons and a shape-preferred orientation of quartz (**Figures 3.8A and 8B**). Greenschists often contain actinolite and tremolite that are aligned along an W–E trending stretching lineation (**Figure S3.4**). Elongated white mica that defines the main foliation evinces recrystallization during fabric formation. Some quartz-rich samples also preserve tabular white mica crystals that are misaligned relative to the foliation. Notably, tabular mica crystals are always observed in quartz-rich samples and tend to be adjacent to large quartz grains (**Figure 3.8E**; **Figure S3.4**). In addition, shear bands evincing the E-directed ductile flow are filled with coarse grained white mica $\pm$ quartz (**Figure 3.8H**).

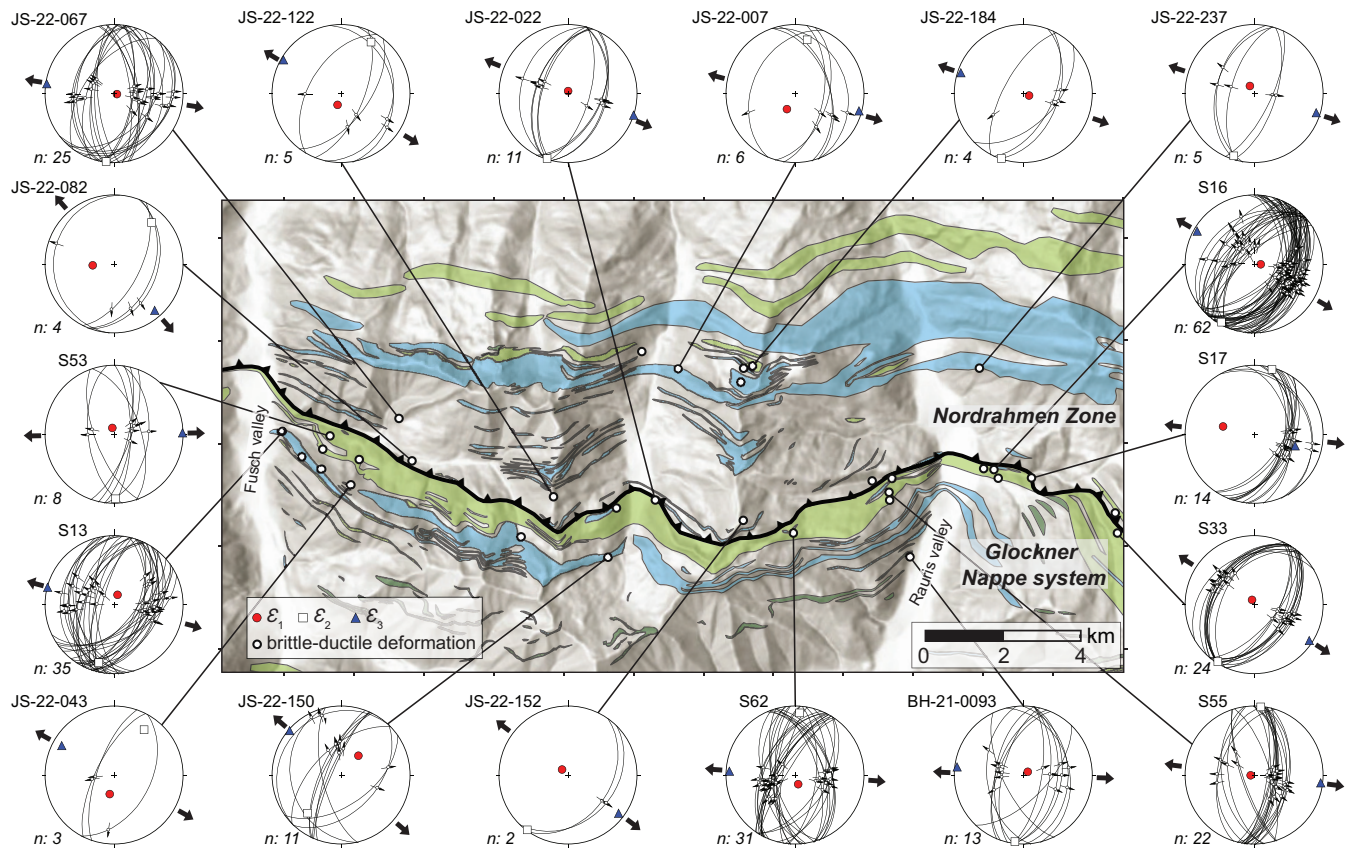


Figure 3.7. Stereoplots showing brittle-ductile fault measurements, with slip vectors and inferred strain axes from 18 representative outcrops. Identical map as Figure 3.1C. Fault measurements were back-rotated relative to the foliation to remove the effect of Miocene doming of the Tauern Window (DIV folding). The inferred strain axes indicate the principal strain axis (ϵ_1) was subvertical during brittle-ductile deformation and the direction of extension (ϵ_3) was broadly E–W and sub-horizontal, denoted by arrows around stereoplots. Structural measurements and stereoplots from all 33 localities (white dots) are available in Figure S3.3.

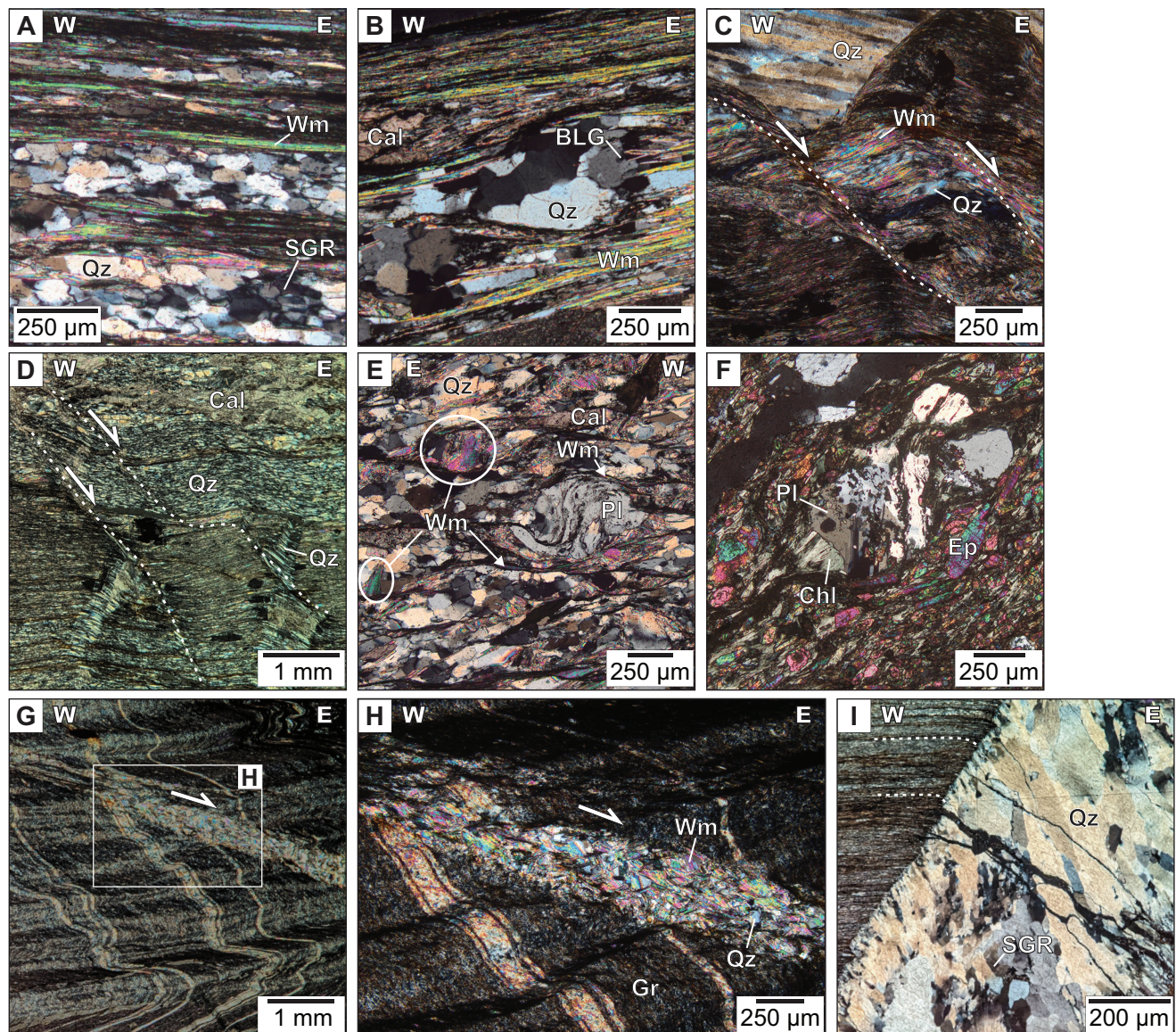


Figure 3.8. Photomicrographs of microstructures and mineral relationships. (A) Phyllitic- and quartz-rich layers. Foliation is defined by elongated recrystallized white mica and a shape-preferred orientation of quartz. Quartz is dynamically recrystallized via subgrain rotation and new grain boundaries are aligned with the foliation (N 5232098, E 347579). (B) Impure marble with foliation defined by recrystallized white mica. Quartz layers are more competent and form pinch-and-swell structures. Quartz is dynamically recrystallized via bulging grain boundaries (N 5232400, E 349447). (C) Phyllite crosscut by shear bands recording top-to-E kinematics. Recrystallized white mica develops along shear bands. Contact of phyllite is folded into a layer of quartzite with ribbon quartz that is aligned with the foliation (N 5234313, E 343514). (D) Shear bands in phyllite recording top-to-E kinematics. Shear bands are offset across quartz rich layers. Quartz ribbons developed along inflection points of the undulating foliation (N 5234313, E 343514). (E) Quartz-rich phyllite with two white mica populations: 1) tabular crystals that are discordant relative to the foliation (circled in white), and 2) elongated crystals that define the main foliation (white arrows; N 5231461, E 342695). (F) Plagioclase clast in greenschist evincing deformation by subgrain rotation and tapered twinning (N 5231178, E 343821). (G) Shear band showing top-to-E kinematics within crenulated graphitic phyllite with remnants of sedimentary lamination defined by micaceous layers. (H) Inset from [G] showing coarser-grained white mica and quartz develop within the shear band (N 5232092, E 343746). (I) Interface between quartz vein and phyllitic host rock. Vein fabric evinces syntaxial growth with fine grained material at the vein margin and large tabular crystal form the core of the vein. Quartz evinces deformation through sweeping extinction, grain boundary migration, and subgrain rotation. The asymmetry of the fabric of the quartz shows an eastward rotation and is supported by minor foliation drag along the vein-host rock interface (white dashed line; N 5234526, E 344302). Mineral abbreviations follow Whitney and Evans (2010).

Structures documented during field investigation exhibiting top-to-E sense of shear can also be observed microscopically (**Figure 3.8**). The intensity of deformation can be observed by grain size reduction and dynamic recrystallization of quartz. Quartz often preserves undulous extinction and recrystallization is primarily via bulging and sub-grain rotation (SGR; **Figure 3.8A** and **B**). With increasing deformation, grain size decreases and SGR is more pervasive with elongate sub-grains oriented parallel to the foliation (**Figure 3.8A**). Grain size reduction during mylonitization was accommodated via SGR. Deformation is also accommodated in quartz by forming ribbons oriented parallel to the foliation structures and dissolution-precipitation are commonly observed (**Figure 3.8C**; **Figure S3.4**). Within greenschists, plagioclase evinces deformation via SGR and tapered twinning (**Figure 3.8F**).

As discussed above, deformation within quartz $\pm$ calcite veins depends on the vein's orientation. Veins oriented perpendicular to the foliation exhibit syntaxial growth with smaller grain size along vein margins and fibrous quartz crystals oriented perpendicular to the host rock filling most of the vein, consistent with mode I fracturing. Veins that are oblique to the foliation are progressively more deformed. For example, syntaxial growth pattern is still apparent in veins that were moderately rotated, however the fibrous quartz crystals have a curved monoclinic symmetry, and foliation drag is observed along the vein-host rock interface (**Figure 3.8I**; **Figure S3.4**). The direction of foliation drag and the curvature of the vein filling indicate an eastward rotation. Veins oriented at low angles to the foliation are most intensely deformed. Growth patterns related to vein filling cannot be observed, as quartz grains are completely recrystallized, often via grain boundary migration (**Figure S3.4**). Dynamic recrystallization of quartz supports moderate deformation temperatures (250°C–400°C), which are equivalent to mid-crustal levels (Passchier & Trouw, 2005).

3.5 White mica $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology

Nineteen samples were dated via multiple single-grain total-fusion white mica $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology (**Table 3.2**). A description of sample preparation, detailed methodology, a full data table (**Table S3.3**) and weighted mean diagrams (**Figure S3.5**) are available in **Appendix B**. Single crystal dates are reported with 1σ errors and range between 25.1 ± 0.3 Ma and 261.2 ± 0.1 Ma (n: 160). Weighted mean dates were calculated from 16 samples and are reported with 2σ errors, and the remaining three samples have dispersed single crystal dates, therefore a range of dates are reported instead (**Table 3.2**). Fourteen samples were collected between Fusch and Rauris valleys and include nine samples from the Glockner Nappe System and five samples from the Matrei-Nordrahmen Zone Nappe System (**Figure 3.1B**; **Table 3.2**). As explained below, our structural observations prompted further investigations at higher structural levels, to the east of Rauris. In the course of this work, five additional samples collected from the Nordrahmen Zone were also dated via white mica $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology (**Table 3.2**). To evaluate whether rheology influences the recrystallization of white mica, sample selection included a variety of mica-bearing lithologies (**Table 3.2**).

Within the Fusch-Rauris area, two of the samples targeted white mica from mm- to cm-wide mica $\pm$ quartz-filled shear veins oriented oblique to the foliation. Both samples yielded Oligocene single crystal dates ranging between 28.5 ± 0.1 Ma to 33.0 ± 0.1 Ma. One anomalously old and imprecise single crystal date (c. 65.6 Ma; JS-22-S23) with low K content (Ca/K: 17) likely represents intergrowth with chlorite and was omitted. The weighted mean ages for these vein samples are 29.4 ± 0.4 Ma (MSWD: 1.9) and 32.4 ± 0.4 (MSWD: 2.0; **Table 3.2**).

Twelve samples targeted white mica that appeared to define the foliation. Microscopy revealed that nine of the samples exclusively contain elongated white mica crystals that are

Table 3.2: Summary of new white mica $^{40}\text{Ar}/^{39}\text{Ar}$ from the Tauern Window, Austria

location	nappe	sample	lithology	grains ¹ (n)	$^{40}\text{Ar}/^{39}\text{Ar}$ ages (Ma)	2σ (Ma)	MSWD	UTM coordinates	
								Zone 33N	
								Northing	Easting
study area	NRZ	JS/21/10	quartz-rich phyllite	7	216.9 - 261.2	-	-	5237057	343368
		JS/22/185	marble mylonite	7/8	30.1	0.4	5	5234114	344472
		JS/22/067	marble mylonite	7/8	28.0	0.4	3	5233808	338082
		*JS/22/S23	graphite phyllite	7/8	29.4	0.4	2	5233721	348800
		*JS/22/024	graphite phyllite	7/8	32.3	0.4	2	5232334	342923
		JS/21/09	phyllite	8/9	26.2	0.4	2	5232492	346792
	GNS	JS/21/13	greenschist	9	30.6	0.3	1	5232527	348755
		JS/22/116	greenschist	5/8	27.2	0.6	1	5231178	343821
		JS/22/097	greenschist	7/8	29.5	0.4	<1	5232464	338715
		JS/22/096	phyllite ($\pm$ chlorite schist)	7/8	30.4	0.4	3	5232058	338836
		JS/22/162	quartz-rich phyllite ($\pm$ marble)	3/8	33.6	0.6	73	5231461	342695
		JS/21/12	graphite phyllite	6/9	31.3	0.4	2	5233132	336324
		JS/21/07B	marble mylonite	9	28.5	0.3	3	5232098	347579
		JS/21/06	quartz-rich phyllite ($\pm$ marble)	8/9	216.2 - 257.0	-	-	5231702	349384
Schuhflicker	NRZ	SS 21/1	marble mylonite	8	30.4	0.4	4.3	5236903	356383
		SS 21/5	greenschist	9	31.2	0.3	1	5236435	357452
		SS 21/8	phyllite	8/9	27.7	0.4	<1	5236132	356655
		SS 21/10	graphite phyllite	7/9	35.8	0.4	6	5235370	358712
		SS 21/11	graphite phyllite	2/9	31.7	0.7	<1	5235701	355994

* denotes white mica sampled from shear veins

1: ratio describes the number of grains used to calculate the weighted mean or define the age range, and the total number of grains analyzed. Samples with a single number include all analysis.

concordant with the main foliation, evincing recrystallization during fabric formation (**Figure 3.8**). These samples represent the lithologies of the study area (greenschists, impure marble, phyllites), and yield unequivocal Oligocene single crystal $^{40}\text{Ar}/^{39}\text{Ar}$ dates (c. 25.1 Ma to c. 33.8 Ma; n: 76) with weighted mean ages ranging between 26.2 ± 0.4 Ma (MSWD: 2) and 30.6 ± 0.3 Ma (MSWD: 1.2; **Table 3.2**).

The remaining three samples contain tabular white mica crystals that are misaligned relative to the foliation. Notably, all three samples are from quartz-rich phyllites. Two of the samples have dispersed single crystal dates ranging from the Permian to Late Triassic (JS/21/06: c. 216–257 Ma; JS/21/10: c. 216–261 Ma; **Table 3.2**), omitting one anomalous Early Cretaceous age (c. 113 Ma; **Table S3.3**). The third sample (JS/ 22/162) yields dispersed single crystal dates that range from the Oligocene to the Late Triassic (c. 31 Ma to 225 Ma). Two distinct morphologies of white mica are observed in this sample: (a) tabular grains that are in proximity to large quartz crystals, and (b) elongated crystals developing within the foliation of phyllitic microlithons (**Figure 3.8E**). Three of the single crystal dates record Oligocene ages and have an imprecise weighted mean age of 33.6 ± 0.6 Ma (MSWD: 73). Single crystal Oligocene dates are similar to ages resolved from samples that exclusively preserve recrystallized mica confined to the foliation and likely reflect fabric formation, whereas older single crystal dates likely represent dates from the population of tabular mica crystals. Notably, these three samples are all quartz-rich phyllites, whereas all phyllites yielding Oligocene $^{40}\text{Ar}/^{39}\text{Ar}$ dates have lesser quartz content.

Within the Nordrahmen Zone near Mt. Schuhflicker, three of the samples yield similar Oligocene single crystal dates that range from 25.5 ± 0.2 Ma to 33.1 ± 0.2 Ma (n: 36) with weighted mean ages between 27.7 ± 0.4 Ma (n: 8; MSWD: 0.2) and 30.4 ± 0.4 Ma (n: 8; MSWD: 4.3; **Table 3.2**). Of the remaining two samples, one sample (SS21/10) yields slightly older (Eocene-

Oligocene) single crystal dates ranging from c. 27.3–46.2 Ma and has a weighted mean age of 35.8 ± 0.4 Ma (MSWD: 6.0). The last sample (SS 21/11) has dispersed single crystal dates that range between c. 31.3 and c. 83.1 Ma, although, two single crystals record Oligocene dates and have a weighted mean age of 31.7 ± 0.7 Ma (n: 2; MSWD: 0.2; **Table 3.2**).

3.6 Raman spectroscopy of carbonaceous material thermometry

We present new RSCM data from 91 localities that record maximum temperatures between 331 and 537°C. A methodological description for RSCM analysis and a full data table (**Table S3.4**) is available in **Appendix B**. Previously published RSCM data include 29 localities within our study area (Groß et al., 2021; Scharf, Handy, Ziemann, & Schmid, 2013), which reveal temperatures between 347 and 487°C. These temperatures are in general agreement with values reported herein and were integrated with our compilation (for a total n: 120). A rasterized map was created in ESRI ArcMap using the kriging interpolation tool with an output cell size of 200 m. A notable temperature break ($\sim 50^\circ\text{C}$) is present across the continuous greenschist units. Within the Glockner Nappe System, peak temperatures gradually increase toward the southern limit of the study area reaching $>500^\circ\text{C}$ (**Figure 3.9**).

3.7 Discussion

3.7.1 Nordrahen Zone–Glockner Nappe System Boundary

Existing bedrock maps of the northern Tauern Window place the tectonic contact between the Nordhamen Zone and the Glockner Nappe system at the northern limit of our study area, several kilometers north of the mapped continuous greenschist layer (Schmid et al., 2013). As noted, the Nordrahen Zone can be differentiated from the Glockner Nappe System by the

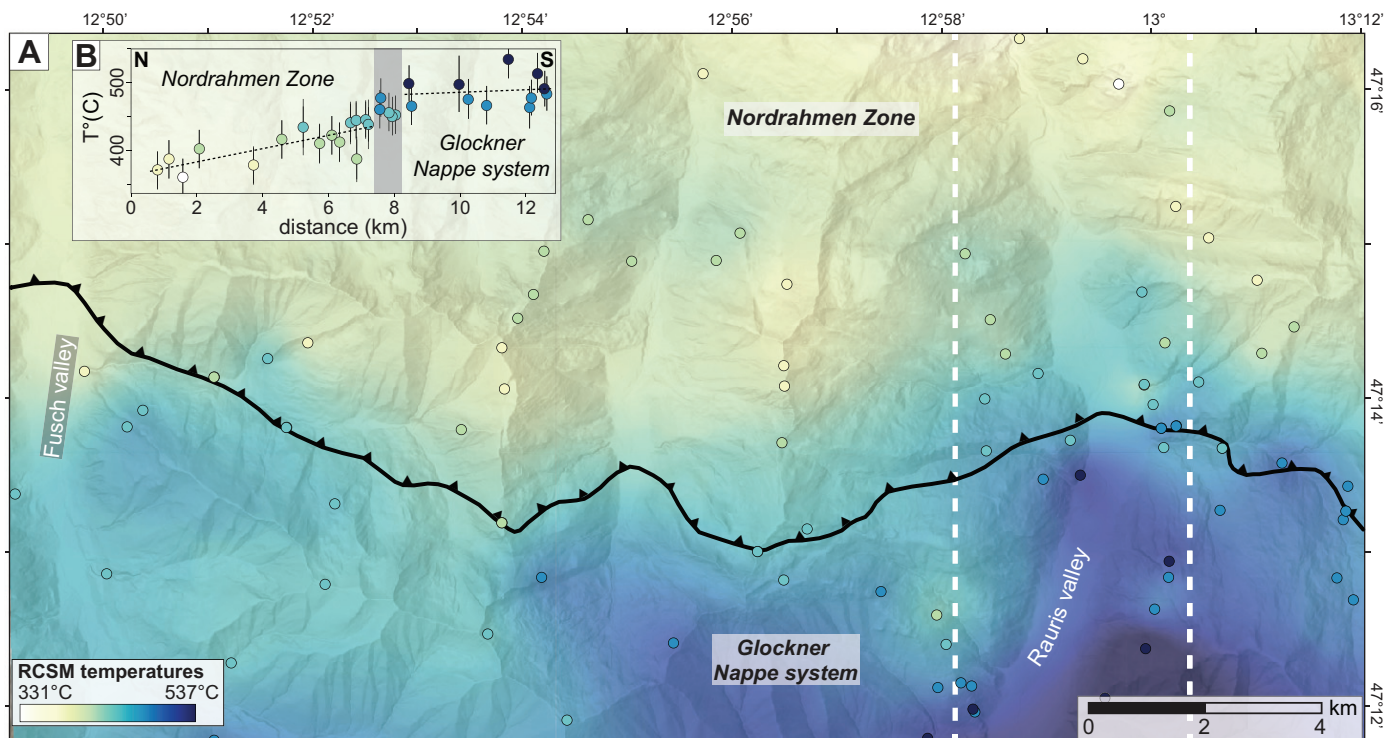


Figure 3.9. (A) Raster map of peak metamorphic temperatures resolved via Raman spectroscopy of carbonaceous material (RSCM). Identical map as Figure 3.1C. Circles denote RSCM sample locations used for the interpolation and are colored to reflect their corresponding temperatures. A significant temperature break ($\sim 50^{\circ}\text{C}$) correlates with the new position of the nappe boundary separating the Glockner Nappe System and the Nordrahmen Zone. RSCM samples distributed around the map extent were included to create the raster. (B) N–S profile of RSCM data surrounding Rauris valley. Profile includes the RSCM samples located between the white dashed lines in [A]. Gray vertical band denotes a 200 m buffer around the nappe boundary. Temperatures in the Nordrahmen Zone gradually increase to $\sim 440^{\circ}\text{C}$ at lower structural levels and temperatures exceeding 500°C are exclusively observed in the Glockner Nappe system. See Table S3.4 for RSCM data.

presence of dam-scale olistoliths and metaradiolarite (Schmid et al., 2013). These olistoliths as well as ultrafine-grained quartzite interpreted as metaradiolarite are exclusively observed structurally above the continuous greenschist, but occur below the previously mapped tectonic contact (**Figure 3.2B and F**). For comparison, if we examine the southern Tauern Window, parts of the Matrei Zone's lower contact are defined by the first occurrence of olistoliths (Frisch et al., 1987; Schmid et al., 2013). Although no obvious thrust structures were observed, intense deformation is localized at the upper limit of the continuous greenschist unit with a deformation gradient toward the hanging wall. It is therefore likely that this unit marks a significant boundary. Additionally, rare N–S trending stretching and mineral lineations were observed in the greenschist. We postulate that earlier fabrics related to N–S thrusting (D1 and D2 of Schmid et al., 2013) have been mostly overprinted by extensional structures, as has been suggested in the southern window where the Glockner Nappe System's upper contact is also defined by an extensional shear zone that is interpreted to overprint a pre-existing thrust (Groß et al., 2022).

Our new compilation of RSCM data also reveals that the greenschist unit coincides with a marked $\sim 50^{\circ}\text{C}$ increase in metamorphic temperatures structurally downward. RSCM temperatures above the greenschist unit reflect temperatures that are indicative of the Nordrahmen Zone ($<450^{\circ}\text{C}$). Elevated RSCM values ($>450^{\circ}\text{C}$) are recorded within the greenschist unit and increase to $>500^{\circ}\text{C}$ at lower structural levels, which is consistent with conditions of upper-to mid-structural levels of the Glockner Nappe System (**Figure 3.9**; Groß et al., 2021; Scharf, Handy, Ziemann, & Schmid, 2013). Together, the RSCM data, localized deformation, and lithologic features (i.e., olistoliths, metaradiolarite) support relocating the tectonic contact of the Nordrahmen Zone and the Glockner Nappe System to coincide with the upper contact of the continuous greenschist unit.

3.7.2 Onset of Top-to-East Extension

Despite the rocks of the Tauern Window recording three main phases of deformation (high-pressure metamorphism during subduction, nappe stacking, and exhumation during W–E extension), all major structures observed in the investigated area (e.g., main foliation, shear sense, folds, shear bands, brittle/ductile faults) can be related to W–E extension combined with top-to-E shearing (**Figure 3.4**). Fabric formation is the earliest structural evidence related to extension, indicated by the pervasive W–E stretching lineation preserved within mylonitic foliation. Elongated white mica that recrystallized during fabric formation consistently record Oligocene $^{40}\text{Ar}/^{39}\text{Ar}$ dates (c. 30 Ma) and provide a time constraint for the onset of W–E extension (**Table 3.2**). DII folding occurred after fabric formation and is compatible with N–S shortening, indicating a component of N–S compression was contemporaneous to the onset of W–E extension.

Interestingly, the Oligocene dates overlap with the youngest radiometric ages interpreted to be related to subduction as well as the oldest radiometric ages of Barrovian metamorphism during nappe stacking (Glodny et al., 2008; Smye et al., 2011). We agree with Glodny et al. (2008) that within the window, a large number of individual post-collisional faults formed at different crustal levels in the Oligocene, at c. 30 Ma. Contrary to the interpretation of Glodny et al. (2008), we attribute these Oligocene dates in the eastern dome to significant horizontal extension. The timing of extension was synchronous with granitoid emplacement and Periadriatic magmatism south of the window at 30–32 Ma, which has been attributed to slab breakoff (Blanckenburg & Davies, 1995). Moreover, detrital studies from the Upper Austrian Northern Alpine Foreland Basin indicate that the onset of exhumation of the Tauern Window and sediment production occurred during the Oligocene (Hülscher et al., 2021). The pre-Miocene story of the Tauern Window, at least

in the east, is now becoming clearer, with overwhelming evidence to suggest substantial exhumation due to extension and erosion at c. 30 Ma.

The Permian to Triassic $^{40}\text{Ar}/^{39}\text{Ar}$ dates reported here are exclusively within quartz-rich phyllites. These micas have random orientations relative to the foliation and are often adjacent to coarse grains of quartz that appear to “protect” pre-existing white mica grains (**Figure 3.8E**; **Figure S3.4**). The morphology of these white mica suggest recrystallization is controlled by strain localization (Barnes et al., 2023). Tabular white mica grains are interpreted to be relict grains from an earlier deformation event, unaffected by Alpine tectonism, and their older $^{40}\text{Ar}/^{39}\text{Ar}$ dates likely reflect a detrital origin.

3.7.3 Progressive Deformation Under Ductile to Brittle-Ductile Conditions

Ductile kinematic indicators suggest that, following fabric formation and mylonitization, progressive deformation continued under a regional W–E extension and N–S shortening. The deformed veins used to quantify the flow parameters related to ductile deformation reveal that pure shear and simple shear contributed relatively equally during this stage of deformation (**Figure 3.5**). In addition, the orientation of DIII is indicative of vertical flattening, which records significant vertical shortening during ductile deformation (**Figure 3.3D**).

The DII and DIII folds are cross-cut by planar shear bands, denoting the latest stage of ductile deformation. Coarse grained white mica developed within these shear bands record Oligocene dates that overlap with the $^{40}\text{Ar}/^{39}\text{Ar}$ dates related to fabric formation (**Table 3.2**). The overprinting structural relationships clearly indicate that mylonitization and the development of shear bands represent the early- and late-stages of ductile deformation, respectively. Therefore,

these results constrain most of the entire phase of ductile deformation to a relatively short time interval during the Oligocene (c. 25–34 Ma).

Brittle-ductile deformation overprints, and mimics the intensity of, ductile structures, suggesting consistent strain localization during progressive cooling. The current orientation of the foliation is related to doming of the Tauern Window (DIV folding), which we interpret to have post-dated brittle-ductile extension. Despite the apparently different fault orientations across the study area, a consistent fault pattern is observed once the data are back-rotated to a pre-DIV orientation (**Table 3.1; Figure 3.7**). Consequently, principal incremental strain axes inferred from brittle-ductile faults before DIV folding are relatively consistent, with a subvertical shortening, and the W–E extension aligned with the stretching lineation (**Figure 3.7**). We interpret our results to be in agreement with previously published results, if fault measurements are rotated relative to the foliation to account for DIV folding (Bertrand et al., 2015). Although we do not directly constrain the timing of brittle-ductile deformation, we can infer brittle-ductile deformation to post-date the Oligocene and it is plausible to assume that they formed during the Miocene following exhumation to shallower crustal levels.

Herein, the orientation of the incremental strain inferred from brittle-ductile faults is consistent with the quantitative analyses of kinematic indicators related during top-to-E ductile flow. These results suggest that the orientation of the incremental regional strain field remained roughly constant during progressive deformation from ductile to brittle-ductile conditions where cooler structures overprinting warmer deformation record exhumation through gradually shallower depths.

Detachment systems are capable of exhuming originally deep-seated rocks to shallower crustal levels. Our new structural observations have striking similarities to the expected styles of

deformation observed in the footwall of classic extensional detachment systems (Davis, 1983; Jolivet et al., 2010; Malavieille, 1993; Wernicke, 1985): (a) strain localization along rheologic contrasts, (b) distributed ductile thinning, (c) a continuum of deformation from ductile to brittle-ductile conditions under an extensional strain field, and (d) relatively rapid exhumation. Details from the extensional detachment model that are missing in our area include a strain gradient that progresses into brittle deformation (cataclasis) and a major low-angle normal fault that would identify the top of the footwall. Additional investigations at higher structural levels were conducted to evaluate whether indeed a detachment plane could be identified.

3.7.4 Schuhflicker Detachment, Katschberg Shear Zone and Katschberg Fault

The ductile to brittle-ductile structures exposed in the northeastern Tauern Window suggests that progressive deformation of the Glockner Nappe System during cooling is related to W–E extension (consistent top-to-E shear; N-S trending veins), N–S shortening (DII folds) and vertical thinning (DIII folds; general shear deformation with a significant pure shear component). However, the pervasive deformation documented between Fusch and Rauris valleys could not be related to any major tectonic contact and therefore the newly mapped structures were compared to those exposed in two N–S profiles conducted at higher structural levels through the Nordrahen Zone across Mt. Schuhflicker and Mt. Saukarkopf to the northeast (**Figure 3.10; Figure 3.11**).

Both sections are characterized by km-scale S-vergent synforms containing dolomite and quartzite with conglomerate layers in the core, which are klippen of Lower Austroalpine Unit (**Figure 3.10A**). The limbs of the synforms belong to the Nordrahen Zone, which mainly consists of calcite marble mylonites (so-called “Klammkalk”), greenschists, graphitic schists and phyllites, discontinuous marble metaconglomerates with mainly dolomite clasts and metasandstones; Peer

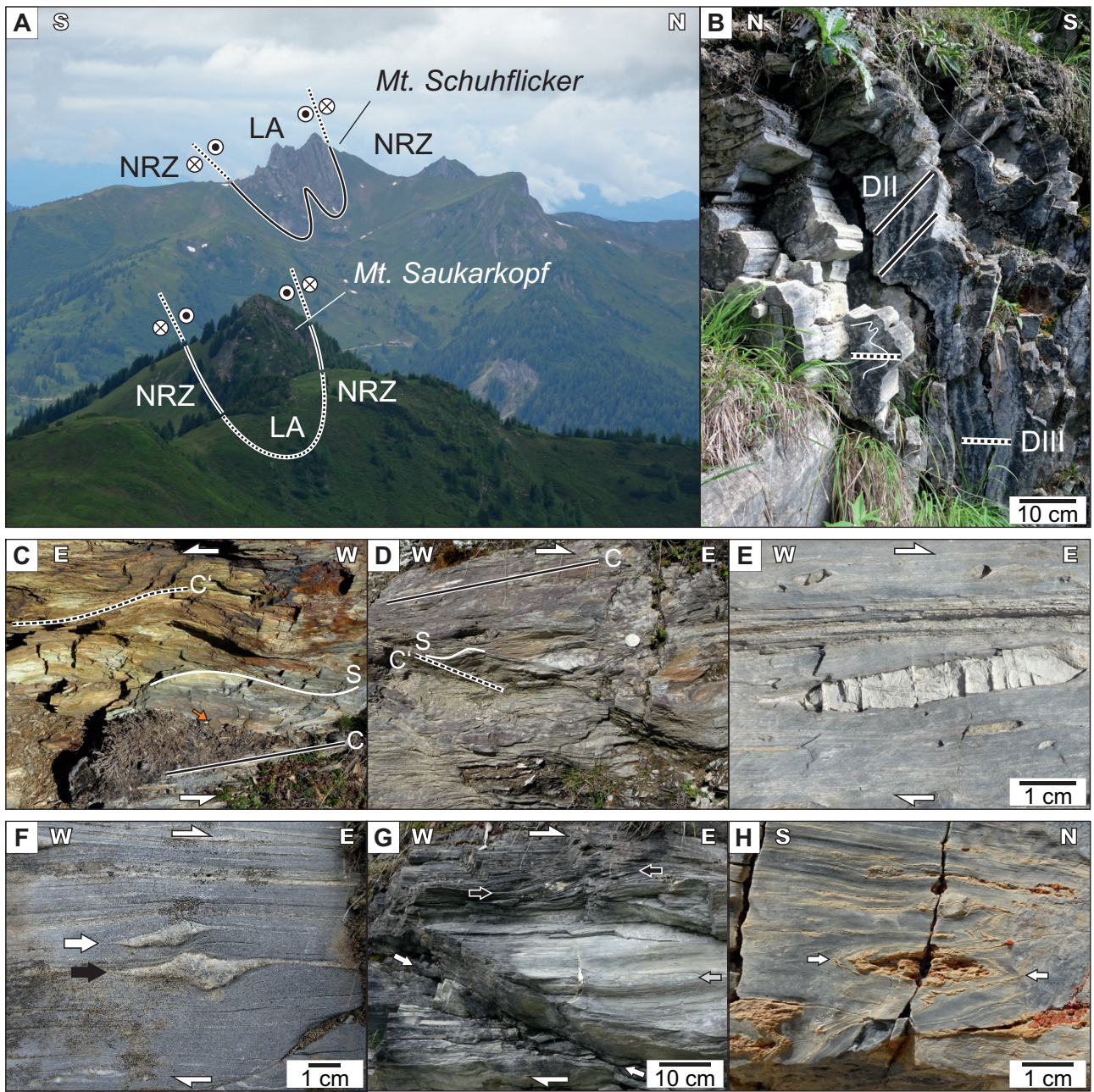


Figure 3.10. (A) View from the peak of Grundegg (2168 m, N 5234327, E 369984) on the S-vergent DII synforms of Saukarkopf (foreground) and Schuhflicker (background). LA - Lower Austroalpine, NRZ - Nordrahmen Zone (Penninic Superunit). Black lines indicate the location of the ultramylonites of the Schuhflicker Detachment. Heads and tails of arrows indicate the apparent dextral (southern upright limb of synforms) and apparent sinistral (northern inverted limb of synforms) displacement of the folded Schuhflicker Detachment. (B) Folded marble mylonites (Klammkalk, NRZ) in the southern upright limb of the Schuhflicker synformal klippe (N 5235273, E 358820). Black lines mark the axial planes ($359^{\circ}/47^{\circ}$) of higher order DII folds (fold axis $275^{\circ}/14^{\circ}$), which have a z-shape looking E. DIII folds have the same fold axis but shallower dipping axial planes ($280^{\circ}/14^{\circ}$) forming type III fold interference patterns (white line). (C) Apparent sinistral shear in quartzitic phyllonites (NRZ) in the northern inverted limb of the Schuhflicker syncline (N 5236095, E 359731). Main foliation dips $356^{\circ}/79^{\circ}$ and records a stretching lineation trending $274^{\circ}/03^{\circ}$. C: black solid line; S: white line; C': dashed black line. POV looking down. The orange arrow points at the coin for scale. (D) Apparent dextral shear in metaconglomerates (NRZ) in the southern upright limb of the Schuhflicker syncline (N 5236115, E 358040). Main foliation dips $002^{\circ}/61^{\circ}$ and records a stretching lineation trending $269^{\circ}/02^{\circ}$. C: black solid line; S: white line; C': dashed black line. The apparent dextral shear sense is confirmed by a quartz sigmoid (left of 2€ coin). POV looking downwards. (E) Brittle boudinage of a dolomite sigmoid in bluish calcite marble mylonites (metaconglomerate, NRZ). Strain shadows and interboudin gaps are filled with white calcite (southern limb of Schuhflicker syncline, N 5235325, E 360397). Main foliation dips $344^{\circ}/65^{\circ}$ with a stretching lineation trending $260^{\circ}/05^{\circ}$. (F) Marble mylonites below the Lower Austroalpine dolomite Saukarkopf synformal klippe with pinch-and-swell deformed calcite veins forming tiled sigmoid (white arrow) and winged inclusion (black arrow). Main foliation dips $352^{\circ}/69^{\circ}$ recording a stretching lineation trending $268^{\circ}/04^{\circ}$ (N 5234929, E 366184). (G) Meter-scale shear band (white arrows $095^{\circ}/33^{\circ}$) and subhorizontal phyllonitic shear zone with a quartz sigmoid (black arrows) cutting the subvertical foliation ($005^{\circ}/82^{\circ}$), which is folded by DIII folds (fold axis $273^{\circ}/03^{\circ}$ marked with gray arrow (N 5235347, E 358704). Note the subvertical quartz vein in the center of the picture, which becomes synthetically sheared close to the shear band. (H) Marble ultramylonites below the Lower Austroalpine Schuhflicker synformal klippe (mylonitic foliation dipping $335^{\circ}/15^{\circ}$). Note the sheath fold outlined by thin yellow dolomitic layers in the blueish marbles. POV looking W into the stretching lineation ($275^{\circ}/08^{\circ}$). The double closure of the sheath fold is indicated by white arrows (N 5235867; 360246).

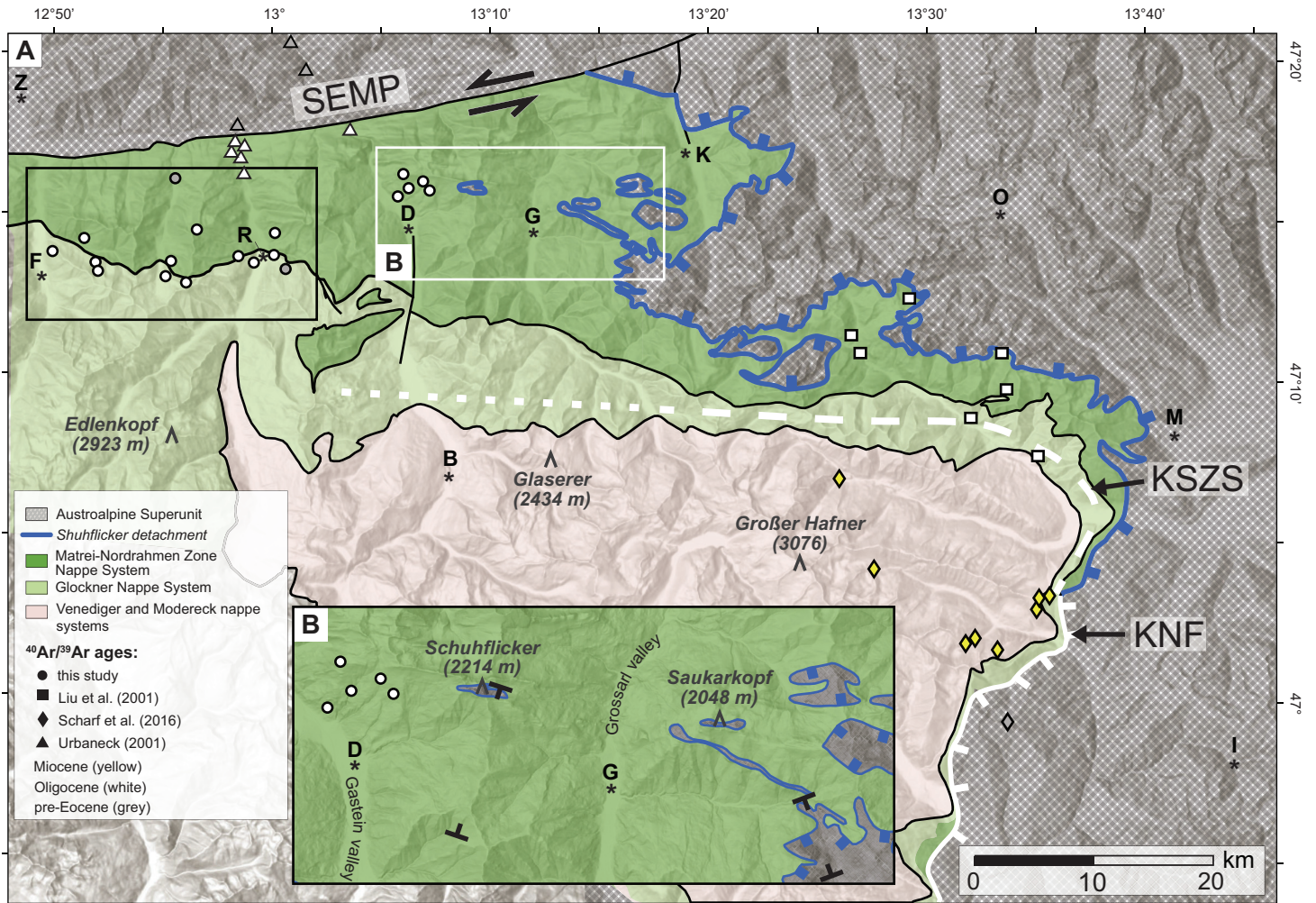


Figure 3.11. (A) Simplified geologic map of the eastern Tauern Window. Study area between Fusch and Rauris valleys (Figure 3.1C) denoted by black box. White box denotes the location of Schuhflicker and Saukarkopf synformal klippen to the east. The upper contact of the Matri-Nordrahmen Zone Nappe System represents the Schuhflicker Detachment. KNF–Katschberg fault. Newly reported and previously published mica dates are also shown. Asterisks show the locations of villages for reference: B - Bad Gastein, D - Dorfgastein, F - Fusch, G - Grossarl, I - Innerkrems, K - Kleinarl, M - Mauterndorf, O - Obertauern, R - Rauris, Z - Zell am See Fusch. (B) Inset of Schuhflicker and Saukarkopf Lower Austroalpine synformal klippen, above the detachment, showing $^{40}\text{Ar}/^{39}\text{Ar}$ sample distribution and N-S traverses discussed in text (defined by T-bars).

and Zimmer (1980) provide detailed lithological descriptions and a map. The ductile to brittle-ductile structures exhibit a progressive deformation history very similar to that of the structures described above from the Glockner Nappe System, but the intensity of deformation increases toward higher structural levels. All lithologies in the Nordrahmen Zone record a metamorphic foliation and a W–E trending stretching lineation. The strongest deformation is observed in the marble mylonites and phyllites/ phyllonites, where isoclinal D_I folds with axes parallel to the stretching lineation are frequently observed. The rocks of the Nordrahmen Zone form tight, upright folds that verge southward with amplitudes and wavelengths on the km-scale and W–E trending fold axes (D_{II} folds, **Figure 3.10A and B**). Therefore, the main foliation is either subvertical or dips steeply toward the north. Since the fold axes of D_{II} are parallel to the stretching lineation, abundant kinematic indicators in the XZ-plane indicate dextral shear in the upright limb and apparent sinistral shear in the inverted limb (**Figure 3.10C and D**). The most frequent shear sense indicators are SCC' fabrics in phyllitic rocks (**Figure 3.10C and D**), sigmoids and boudinage in marble conglomerates (**Figure 3.10E**), and pinch- and-swell boudinaged veins forming sigmoids, asymmetric shear band boudinage and winged inclusions (**Figure 3.10F**). If the D_{II} structures are unfolded, the shear sense is consistently top-to-E. The D_{II} steeply dipping foliation is overprinted by open to tight D_{III} folds with axes parallel to D_{II} folds (and therefore also the stretching lineation) but with subhorizontal axial planes indicating a component of subvertical flattening (**Figure 3.10B**). The amplitude and wavelength of D_{III} folds are only m-scale and are not reflected in the map pattern, which is dominated by D_{II} folding (**Figure 3.11**). All structures are cut by gently E-dipping, m-scale shear bands or subhorizontal intensely-deformed phyllonitic shear zones, where quartz sigmoids, SC and SCC' fabrics indicate top- to-E extension (**Figure 3.10G**). The thickness and spacing of the subhorizontal phyllonitic shear zones show a marked strain

gradient toward the border of the overlying Lower Austroalpine klippen of Mt. Schuhflicker and Mt. Saukarkopf. The subvertical N–S striking quartz veins were emplaced during W–E extension. These veins cut all earlier structures and formed pre-, syn- and post-top-to-E shearing (**Figure 3.10G**). The contact of the Nordrahmen Zone to the overlying Lower Austroalpine synformal klippen is marked by m-scale calcite marble ultramylonite topped by dam- to m-scale dolomite cataclasites (cellular dolomite). Shear sense in the marble ultramylonites is top-to-E. Locally, sheath folds are observed (**Figure 3.10H**).

Similar to the structures in the Glockner Nappe System presented here, the Nordrahmen Zone records progressive W–E extension during N–S shortening. Ductile to brittle-ductile shear sense is unequivocally top-to-E and finite strain records a marked gradient toward the base of the Lower Austroalpine synformal klippen. We therefore suggest that the border of the Nordrahmen Zone to the Lower Austroalpine is a top-to-E detachment zone, which facilitated the beginning of exhumation of the eastern Tauern Window in the Oligocene. Because the easternmost exposure of the detachment system is on Mt. Schuhflicker, we suggest the name Schuhflicker Detachment.

The existence of the Schuhflicker Detachment has important regional implications, mainly concerning the eastern border of the Tauern Window. The E-dipping normal Katschberg Fault has facilitated exhumation of the eastern Tauern Window since the early Miocene, with a total exhumation of ~20 km (Genser & Neubauer, 1989). This suggests that significant exhumation must have occurred during the Oligocene (Bertrand et al., 2017; Glodny et al., 2008). The trace of the ductile shear zone of the Katschberg Fault curves around to the north of the Eastern Tauern Dome, and connects with subvertical shear zones exhibiting dextral shearing, south of the Nordrahmen-Glockner boundary (Scharf, Handy, Favaro, et al., 2013), and separates Oligocene (north) from Miocene (south) cooling and deformation ages (**Figure 3.11**). Therefore, it cannot be

associated with the Oligocene top-to-E deformation regime described in this work. We propose that W–E extension and exhumation of the Tauern Window began in the Oligocene along the Schuhflicker Detachment and later transferred in the Miocene to the Katschberg Fault.

The existence of long-lived extensional structures with similar kinematics and a ductile to brittle evolution that accommodated tens of kilometers of exhumation suggests that the Schuhflicker Detachment, the Katschberg Shear Zone and the Katschberg Fault form a detachment system that we here name the East Tauern Detachment System (ETDS). It is likely that the shear zone localized at the contact between the Nordrahmen Zone and the Glockner Nappe System, overprinting the nappe contact with a top-to-E kinematics and corresponding to a sharp increase in maximum temperature of $\sim 50^{\circ}\text{C}$. In comparison to other detachments systems where deformation progressively migrates toward the hanging wall (Jolivet et al., 2010; Rabillard et al., 2015), as for example, explained by the conceptual rolling hinge model (Axen & Bartley, 1997; Gessner et al., 2001; Le Pourhiet et al., 2004), the ETDS does not show a migration pattern. In contrast deformation localizes both at the contact between the Penninic Superunit and the Austroalpine Superunit, and within the Penninic Superunit at different stages (see also Scharf, Handy, Favaro, et al., 2013). Another difference is that the ETDS is related to extension perpendicular to the regional direction of shortening and not parallel to it (such as the Cyclades: Grasemann et al., 2012; Jolivet et al., 2010; Schneider et al., 2018). Finally, activity along the ETDS started more or less at the same time as the formation and exhumation of the eclogites in the Eclogite Zone (Gleissner et al., 2007; Glodny et al., 2005; Nagel et al., 2013; Smye et al., 2011). We therefore postulate that part of that extension in the middle to upper crust accommodated space laterally in the E–W direction while eclogites exhumed along the slab toward the north (Schmid et al., 2013) and shortening was still occurring along a N–S axis. These implications

require that exhumation occurs in complex three-dimensional systems and should not be viewed only as two-dimensional process.

3.8 Conclusions

Our new structural data provide significant insights into the earliest phase of tectonic evolution of the eastern Tauern Window, specifically regarding the transition from high-pressure metamorphism and nappe stacking to extensional deformation during the Oligocene. Our mapping suggests that the tectonic contact between the Nordrahmen Zone and the Glockner Nappe System should be relocated at the upper contact of the continuous greenschist unit, based on consistent structural and lithological evidence, including olistoliths and metaradiolarites in the hanging wall, as well as a marked break in RSCM temperatures. A significant component of pure shear associated with late-stage eastward-directed ductile flow and progressive deformation from lower to middle crustal levels is compatible with exhumation by extension and ductile thinning. Distributed ductile thinning is a characteristic feature in the footwall of detachment systems, and prompted further investigation at higher structural levels. To the northeast of pervasive eastward ductile flow documented in the Glockner Nappe System, the major Schuhflicker Detachment was discovered at the upper limit of the Nordrahmen Zone. The detachment is defined by a knife-sharp fault surface capped with ultramylonites and cataclasite in the hanging wall. The detachment defines the contact of the Matri-Nordrahmen Zone Nappe System with the Austroalpine Superunit and has likely been overlooked because of the more recognizable Katschberg Fault and shear zone system. Late Oligocene $^{40}\text{Ar}/^{39}\text{Ar}$ dates record fabric formation and provide a minimum time constraint for the onset of regional W–E extension and exhumation, confirmed by sedimentological studies in the foreland basins to the north. Miocene exhumation of the Tauern

Window is dominated by erosion of the domes and a modest amount of tectonic denudation accommodated by the brittle Katschberg Fault and Brenner Fault. Since the Schuhflicker Detachment, the Katschberg Shear Zone, and the Katschberg Fault have facilitated the exhumation of the eastern Tauern Window since the Oligocene for nearly 15 Myr, we propose grouping these significant extensional tectonic contacts into the ETDS

3.9 Acknowledgements

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CHAPTER 4

OLIGO-MIOCENE EXHUMATION HISTORY OF THE EASTERN TAUERN WINDOW RESOLVED VIA AFT THERMAL HISTORY MODELS ACCOUNTING FOR GRAIN- SPECIFIC ANNEALING KINETICS

4.1 Abstract

In the Tauern Window of the Eastern Alps, Miocene exhumation is commonly linked to erosion driven by structural doming and relatively high topography, yet erosion alone cannot account for the observed magnitude of unroofing. Recent work in the eastern Tauern sub-dome identified the Eastern Tauern Detachment System (ETDS), an Oligo-Miocene crustal-scale detachment system, but its contribution to the overall exhumation remains unresolved. We report eleven new apatite fission track (AFT) ages from a north-south transect in the footwall of the Schuhflicker Detachment that yield three distinct age domains: (1) early Miocene dates in the northern limb of the sub-dome, separating younger early Miocene dates in the (2) sub-dome core and (3) the northern edge of the window. Because AFT dates can be biased by partial annealing and kinetic heterogeneity, apatite grain-specific chemistry was quantified via electron microprobe to calculate r_{mr0} , a proxy for annealing kinetics. Thermal history models incorporating r_{mr0} were generated for one representative sample from each of the three domains. Models yield plausible cooling rates in the sub-dome core from c. 11-7 Ma at $\sim 17^{\circ}\text{C}/\text{Myr}$, whereas the northern limb cooled earlier and slightly more slowly (c. 19-13 Ma at $\sim 12^{\circ}\text{C}/\text{Myr}$). Although Miocene cooling in the sub-dome core fits the model of unroofing via erosion during doming, the older AFT ages in the northern limb may record cooling associated with exhumation of the footwall of the Oligocene Schuhflicker Detachment, suggesting ductile thinning and east-directed extension contributed to tectonic exhumation prior to, and synchronous with, Miocene doming. Based on this model, 10 ± 2 km of exhumation has occurred in the eastern Tauern sub-dome since c. 30 Ma, yet it does not account for the >20 km of purported exhumation across the region. These results indicate a complex exhumation history that involves tectonic unroofing and surface processes, and

demonstrate both the utility and limitations of incorporating apatite chemistry into thermal history modeling.

4.2 Introduction

The Tauern Window of the eastern Alps exposes originally deep-seated rocks that have undergone subduction and were later brought back to the surface to form some of the highest peaks in the orogen. Decades of research integrating structural observations with innovative analytical techniques have focused on understanding the mechanisms that contribute to the exhumation of the window and determining the timescales at which these processes operate (e.g., Favaro et al., 2017; Fox et al., 2016; Glodny et al., 2008; Rosenberg et al., 2018; Scharf et al., 2016; Schneider et al., 2013, 2015; Spalding et al., 2025). In particular, low-temperature thermochronology has helped to resolve thermal and temporal aspects of upper crustal processes. Numerous apatite fission track (AFT) studies have been conducted across the tectonic window and generally report dates that are interpreted as cooling ages, and it is widely accepted that the shallow crustal exhumation of the window occurred rapidly during the Miocene (e.g., Bertrand et al., 2017; Eizenhöfer et al., 2023; Foeken et al., 2007; Fügenschuh et al., 1997; Grundmann and Morteani, 1985; Hejl, 1997; Staufenberg, 1987; Schmid et al., 2013; Schneider et al., 2015; Wölfler et al., 2008, 2012). Recent bedrock mapping and structural investigations from the eastern window document an orogen-scale east-directed detachment system (i.e., East Tauern Detachment System, ETDS) that likely began operating during the Oligocene at mid-crustal levels along the Schuhflicker Detachment (Spalding et al., 2025). During progressive eastward extension, deformation was accommodated by the Katchberg Shear Zone System (KSZS) and the Katchberg Normal Fault (KNF) through the Miocene (Schmid et al 2013, 2016; Scharf et al., 2013a; Spalding

et al., 2025). However, the magnitude and timing of exhumation associated with the ETDS remain unresolved.

Fission track thermochronology constrains the cooling of rocks in the upper crust within a temperature interval depending on the mineral (e.g., zircon, apatite, monazite) and its chemical composition. The power of AFT dating for geological investigations derives precisely from its thermal sensitivity. Apatite's partial annealing zone (PAZ) defines the temperature window in which fission tracks begin to accumulate in the crystal, and in rapidly cooled samples AFT ages record the time of cooling through the PAZ (Green et al., 1986). AFT samples with complex thermal histories (e.g., long residence time in the PAZ, repeated heating/cooling), however, may have undergone partial thermal annealing, producing AFT dates that do not necessarily represent the timing of a single, simple cooling event. Laboratory-based experiments have provided valuable insight into these annealing processes and have identified an important correlation between grain-specific chemistry and the particular temperature window that defines the PAZ (e.g., Green et al., 1986; Ketcham et al., 1999; Barbarand et al., 2003). These experiments indicate that although the PAZ for fluorapatite, the most common apatite specimen, is considered to be 60-100°C, the PAZ for all apatite specimens found in nature can range between 50-150°C (e.g., Armstrong, 2005; Barbarand et al., 2003; Fitzgerald and Gleadow, 1990; Gleadow et al., 1986; Green et al., 1989; Ketcham et al., 1999; Laslett et al., 1987). Rocks that contain apatite with different chemical compositions may possess individual apatite that anneal at dissimilar rates and temperatures. Consequently, raw AFT dates may not always be geologically significant and may instead incorporate some grains that have been (partially) thermal annealed, or represent a mixture of information that reflect apatite's variable annealing kinetics.

Interpreting partially annealed AFT ages requires numerical modeling by reconstructing plausible time-temperature (t-T) paths that could produce the sample's single-grain AFT ages and track-length distributions. Moreover, apatite mineral chemistry can serve as a proxy for grain-specific annealing kinetics, which can also be incorporated into the numerical models. Several studies have shown that modelling that accounts for grain-specific annealing kinetics yield detailed and quantitative thermal histories, enabling robust geological interpretations from fewer samples than interpreting raw AFT data alone on many samples (e.g., Ketcham et al., 2000; Issler et al., 2005; Green and Duddy, 2012; Powell et al., 2017; Schneider and Issler, 2019; McDannell et al., 2021; Issler et al., 2022; Spalding et al., 2023).

With the identification of an older extensional detachment system that may be responsible for significant pre-Miocene exhumation of the eastern Tauern Window (Spalding et al., 2025), it is possible that multi-kinetic AFT analysis may be able to resolve this earlier unroofing history. Herein, we present eleven new AFT samples from a N-S transect across the eastern Tauern sub-dome. Our AFT analysis protocol measured grain-specific apatite chemistry to characterize individual apatite annealing kinetics, and this information was incorporated into thermal history models. To our knowledge, this multi-kinetic approach has not yet been applied to AFT thermochronological studies from the Tauern Window, where we intend to identify a cooling signature related to ETDS activity.

4.3 Regional tectonics

The internal structure of the Tauern Window has been classically defined by Schmid et al. (2013) and consists of two elongated, double-plunging anticlines, referred to as the eastern and western Tauern sub-domes, that trend WSW-ENE and WNW-ESE, respectively (**Figure 4.1A**).

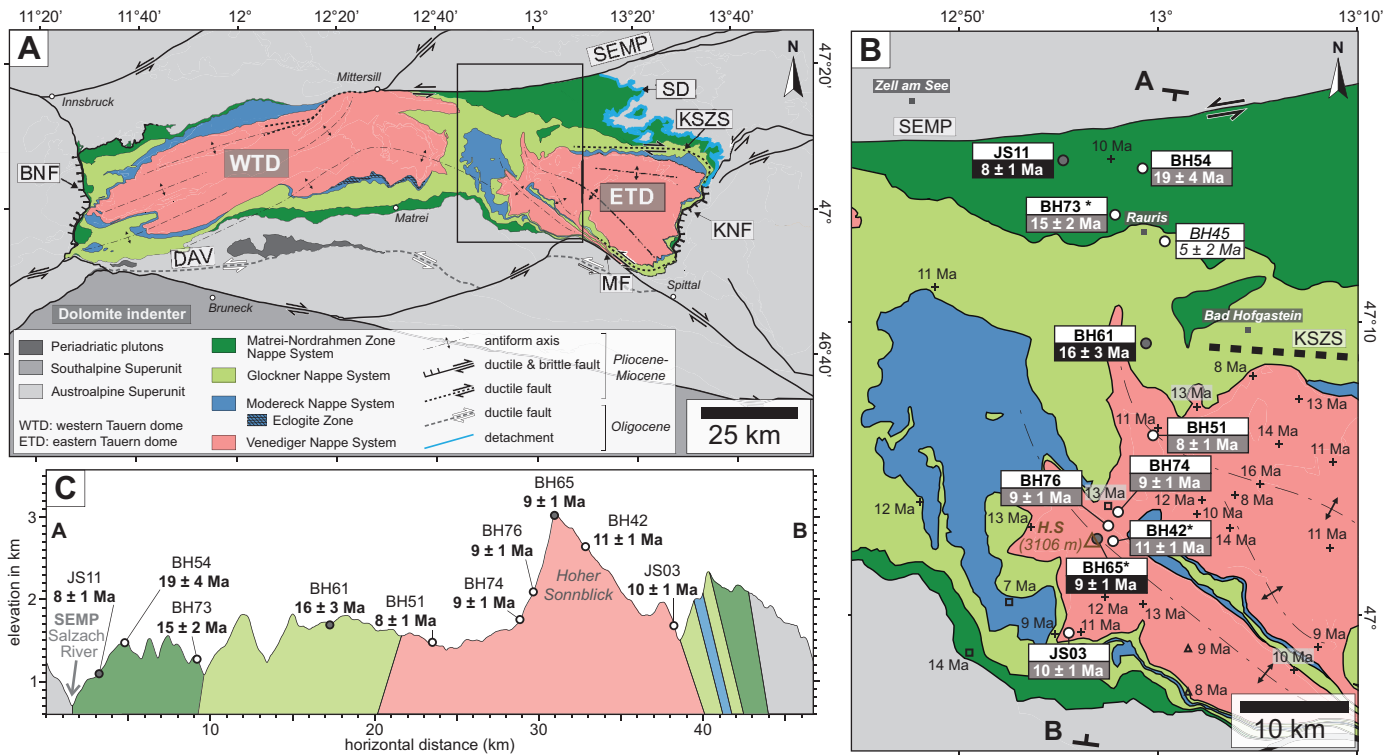


Figure 4.1. A) Simplified geologic map of the Tauern Window (modified from Schmid et al., 2013). Black rectangle denotes the study area. Fault abbreviations are as follows: BNF Brenner Normal Fault; DAV Deferegggen-Antholz-Vals Fault; KNF Katschberg Normal Fault; KSZS Katschberg Shear Zone System; MF Mölltal fault; SEMP Salzach-Ennstal-Mariazell-Puchberg Fault; SD Schuhflicker Detachment (blue). The Eastern Tauern Detachment System comprises the Schuhflicker Detachment, the Katschberg Shear Zone System, and the Katschberg Normal Fault. Units and faults taken from Schmid et al. (2013) and Spalding et al. (2025). B) Geologic map of the study area denoted in A) showing the distribution of AFT samples and their pooled age. Sample names with an asterisk have overly dispersed single-grain AFT ages, and a central age is reported instead. Sample labels with a black background highlight the samples selected for inverse thermal history modeling and the sample with a white background (BH45) was omitted (see text for further explanation). Sample BH65 is from the peak of Hoher Sonnblick (HS). Existing AFT dates : [+] Staufenberg, 1987; [□] Wölfler et al., 2008; [Δ] Wölfler et al., 2012. C) Topographic profile along traverse denoted in [B] projecting AFT samples and pooled/central AFT ages. The profile has a 4x vertical exaggeration.

The cores of the sub-domes expose rocks from the Subpenninic Nappes, derived from European continental crust, which are mantled by the Penninic Nappes, representing the Alpine Tethyan oceanic domain that separated the Eurasian and Adriatic continents in the early Mesozoic era. The Subpenninic Nappes comprise the Venediger Nappe System (VNS), which forms the gneissic cores of the eastern and western sub-domes. The VNS is overlain by the Modereck Nappe System (MNS; **Figure 4.1A**) that defines Europe's distal continental margin. Structurally above the MNS, the Penninic Nappes consists of the Glockner Nappe System (GNS) and the Nordrahen Zone (NRZ), which represent oceanic domains (Valais, Piemont-Liguria) that opened in the Early Cretaceous and mid-Jurassic, respectively. Austroalpine Nappes framing the Tauern Window represent the structure's hanging wall and are comprised of rocks derived from the Adriatic plate.

Penninic and parts of the Subpenninic nappes attained various subduction depths during the Cenozoic although the time when subduction processes terminated is debated (Christensen et al., 1994; Groß et al., 2020; Kurz et al., 2008). Equilibrated eclogite-facies mineral assemblages in the MNS and GNS yield i) Eocene dates via hornblende and phengite $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology (Ratschbacher et al., 2004, Kurz et al., 2008), whereas ii) early Oligocene dates are resolved via multi-mineral Rb-Sr geochronology (Glodny et al., 2005). Within the subduction channel, the NRZ, GNS, and MNS were imbricated over the VNS during nappe stacking ultimately forming the current tectonostratigraphic sequence of the Tauern Window (Kurz et al., 2008, Schmid et al., 2013, Groß et al., 2020a). These rocks were subsequently overprinted by a proposed Barrovian-style metamorphic event at c. 30-25 Ma (Christensen et al., 1994; Cliff et al., 1998; 2015; Inger and Cliff, 1994, Favaro et al., 2015), and eventually greenschist facies retrogression during exhumation.

Major fault systems delimit the Tauern Window and separate the deeply exhumed Penninic rocks from the Austroalpine units in the window's hanging wall. Most notable are broadly N-S striking normal faults that laterally bound the window: the east-dipping Katschberg Fault in the east and the west-dipping Brenner Fault in the west (**Figure 4.1A**), which imparted a pervasive ~E-W stretching lineation in the immediate footwall (Kurz et al., 1998; Ratschbacher et al., 1991; Scharf et al., 2013a, Groß et al., 2020a). Displacement estimates along the eastern Katschberg Fault range from 17 to 29 km (Genser and Neubauer, 1989; Scharf et al., 2013a). The northern limit of the eastern Tauern Window is mostly defined by the ENE-WSW striking, sinistral Salzach-Ennstal-Mariazell-Puchberg Fault (SEMP; Rosenberg & Schneider, 2008; **Figure 4.1A**). The SEMP is interpreted to have operated coevally with the conjugate Periadriatic Fault south of the window, and the combined activity of these faults facilitated east-directed lateral extrusion to the north of the Dolomite Indenter (e.g., Ratschbacher et al., 1989, 1991, Scharf et al., 2013a). The southwestern margin of the window is aligned with the leading edge of the Dolomite Indenter (e.g., Favaro et al., 2017; Schmid et al., 2013; **Figure 4.1A**), colliding with the orogen at c. 23 Ma that marks the latest collisional phase of Alpine orogenesis (Schmid et al., 2013; Rosenberg et al., 2015). Structural evidence suggests that orogen-parallel (E-W) extension was coeval with N-S shortening following crustal indentation (Scharf et al., 2013a). Metamorphic (St+Bt) isograds have concentric patterns that mimic the fold axes of the eastern and western sub-domes and are interpreted to have formed during doming of the Tauern Window during N-S indentation (Bertrand et al., 2017; Schneider et al., 2015; Scharf et al., 2013b; Selverstone et al., 1995).

Miocene apatite and zircon fission track (AFT, ZFT) dates across the Tauern Window have been widely interpreted as cooling dates related to unroofing (e.g., Bertrand et al., 2017; Eizenhöfer et al., 2023; Foeken et al., 2007; Fügenschuh et al., 1997; Grundmann and Morteani,

1985; Hejl, 1997; Keil and Neubauer, 2015; Most, 2001, 2003; Pomella, 2010; Schneider et al., 2015; Staufenberg, 1987; Viola et al., 2001; Wolff et al., 2021; Wölfler et al., 2008, 2012). ZFT dates are systematically older than AFT dates, which is to be expected, as the ZFT system is sensitive at higher temperatures ($240 \pm 60^{\circ}\text{C}$) relative to the AFT system ($110 \pm 60^{\circ}\text{C}$; Yamada et al., 1995; Green et al., 1986). Near our study area in the Rauris Valley, most published AFT dates are from samples of the VNS and range from 16-8 Ma (**Figure 4.1B**; Bertrand et al., 2017; Staufenberg, 1987; Wölfler et al., 2012). There are limited published AFT data reported from the GNS (11 Ma) and the NRZ (10 Ma; Staufenberg, 1987). The paucity of AFT dates in the NRZ and GNS at these localities has been attributed to low U concentrations in the apatite, resulting in imprecise dates that have been deemed insignificant (Stüwe et al., 2005).

The youngest ZFT and AFT dates in the Tauern Window are recorded in the hinge zones of the sub-domes (Most, 2003; Staufenberg, 1987). The dominant mechanisms believed to have contributed to the exhumation of the window are erosion facilitated by the high topography generated from upright folding and tectonic unroofing along the Brenner and Katschberg faults (e.g., Bertrand et al., 2017; Favaro et al., 2017; Frisch et al., 2000; Schmid et al., 2013). To decipher the importance of erosion versus tectonic unroofing on the overall exhumation of the Tauern Window, Favaro et al. (2017) used structural and thermochronological data to retro-deform the nappe systems present in the window and produce 2-D reconstructions of the orogenic crust prior to, during, and following indentation. These results indicate that crustal indentation produced relatively equal amounts of N-S shortening (75 km) as E-W extension (71 km), although exhumation was primarily driven by erosion, and tectonic unroofing along the Brenner and Katschberg faults account for one third of exhumation in the window (Favaro et al., 2017). In another study, Bertrand et al (2017) attempted to quantify the magnitude of exhumation associated

with erosion versus tectonic unroofing by interpreting the spatial distribution of AFT and ZFT cooling dates. Age versus distance profiles perpendicular to the axial trace of the western dome have a "U" shaped pattern with AFT and ZFT ages increasing toward the limbs (north and south). These results support an erosion-dominated model, where maximum exhumation occurred in the hinge zone, and consequently, was the latest to cool across the respective isotherms (Bertrand et al., 2017).

In comparison, proximal to the Brenner and Katschberg faults, young cooling ages (ZFT <10 Ma; AFT <5 Ma) are exclusively observed within mylonitic belts, <20 km from the trace of the faults (Bertrand et al., 2017). Significant widespread exhumation via tectonic unroofing would produce a similar age trend but would likely extend across the window. Instead, these results indicate tectonic unroofing was confined to the immediate footwall of these structures during a late stage of Miocene deformation.

Based on the combined ZFT and AFT dates, Bertrand et al. (2017) estimate exhumation rates of 0.5-0.9 km/Myr in the western dome, and ≤ 0.4 km/Myr in the eastern one between 15-10 Ma, and both sub-domes were exhumed at a similar rate of ≤ 0.5 km/Myr after c. 8 Ma. Taken together, these results predict ~ 7.5 km of total exhumation over the past 15 Myr, however, geobarometric data indicates the VNS was exhumed >20 km since the Oligocene (Bertrand et al., 2017; Fügenschuh et al., 1997; Schmid et al., 2013). To account for the magnitude of unroofing observed in the Tauern Window, exhumation rates need to be higher preceding the Miocene, and alternative mechanisms must have contributed to unroofing of the window (e.g., Glodny et al., 2008; Smye et al., 2011; Nagel et al., 2013; Spalding et al., 2025).

Within the Penninic Nappes south of the western sub-dome, Glodny et al. (2008) reports Oligocene deformation dates (31.2 ± 0.4 Ma via multi-mineral Rb-Sr geochronology) associated

to WSW-ENE trending mylonitic shear zone. In the eastern dome, similar Oligocene white mica $^{40}\text{Ar}/^{39}\text{Ar}$ deformation dates (32-28 Ma) are recorded in the footwall of the top-to-east Schuhflicker Detachment (Spalding et al., 2025). Along the eastern margin of the Tauern Window, the Schuhflicker Detachment is cross-cut by the Katschberg Shear Zone System (KSZS) and the Katschberg Normal Fault (**Figure 4.1A**), which may have been broadly coeval structures (Scharf et al. 2013a). It is proposed that during progressive exhumation, strain was re-localized to different structural levels, and collectively these structures form a crustal-scale, ~E-W-oriented detachment system (i.e., ETDS) that operated from the Oligocene through the Miocene (**Figure 4.1A**). Although the magnitude of exhumation accommodated by the ETDS has not been resolved, investigations from similar styles of detachment systems documented elsewhere have demonstrated that these structures are capable of exhuming deep-seated rocks through the ductile to brittle regimes (e.g., Grasemann et al., 2012; Jolivet et al., 2010; Malavieille, 1993, Scharf et al., 2013a). Recurring Oligocene deformation dates along extensional structures in the Tauern Window (Glodny et al., 2008; Spalding et al., 2025) and sedimentological data from the Northern Alpine Foreland Basin (Hülscher et al., 2021) support an earlier onset for tectonic unroofing related regional ~E-W extension.

4.4 AFT thermochronology

In fission track thermochronology, several different parameters have traditionally been used as proxies that reflect grain-specific track annealing kinetics. D_{par} represents the maximum diameter of fission tracks etch pit, where retentivity increases with D_{par} values (Burtner et al., 1994). Chlorine content is known to increase retentivity, whereas F content decreases retentivity, and both Cl- and F-content have also been used as proxies for annealing kinetics (Bertrand et al.,

2017; Green et al., 1986). Despite D_{par} , Cl- and F-content adequately characterizing some apatite specimens, they are not suitable to represent the full range of compositional variations naturally found in apatite (Carlson et al., 1999; Donelick et al., 2005; Green et al., 1986; Issler et al., 2022; Ketcham et al., 1999).

Laboratory-based annealing experiments on a wide range of apatite specimens reveal that trace amounts of Fe, Mn, Mg, Si, and REE's can significantly increase retentivity (Barbarand et al., 2003; Carlson et al., 1999). The $r_{\text{mr}0}$ parameter was developed by comparing the annealing behavior of various apatite specimens relative to the most retentive apatite specimen found in nature (denoted as $r_{\text{mr}0} = 0$; Carlson et al., 1999). The $r_{\text{mr}0}$ value is calculated through a multi-empirical equation that accounts for all elemental substitutions that are known to influence annealing kinetics in apatite, and several investigations have demonstrated it is a suitable proxy to predict annealing behavior (Issler et al., 2005, 2022; McDannell et al., 2019; Powell et al., 2017, 2019; Schneider and Issler, 2019; Spalding et al., 2023).

Track length distributions within AFT samples can also provide pertinent information regarding the sample's thermal history and indicate possible multi-kinetic populations (Green et al., 1986, 1989). For example, AFT samples that exclusively preserve long (~16-20 μm) track lengths likely underwent rapid cooling, whereas a relatively wider distribution of track lengths may indicate slow cooling across the PAZ. Consequently, increased partial annealing reduces the mean track length and broadens the track length distribution (Green et al., 1989). Bimodal peaks in fission track lengths may represent multiple heating/cooling events, where short track lengths represent an earlier heating event, and those tracks have been partially annealed (Green et al., 1986, 1989). In addition, thermal annealing is an anisotropic process where the rate of annealing

increases for tracks that are misaligned relative to the apatite's crystallographic c-axis (Green et al, 1986).

4.5 New AFT data from the eastern sub-dome

Eleven AFT samples were collected along a ~40 km N-S traverse, perpendicular to the eastern sub-dome's long axis. Sampling targeted various apatite-bearing lithologies and included six samples from the VNS, two samples from the GNS, and three samples from the NRZ (**Figure 4.1A; Table 4.1**). All samples from the NRZ and the GNS were collected in an elevation range of 1100-1700 masl (**Figure 4.1C**); samples from the VNS cross the peak of Hoher Sonnblick, and are from 1460-3080 masl (**Figure 4.C**).

AFT analyses were conducted via the laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) modified- ζ method (Chew and Donelick, 2012; Cogné et al., 2020). The density of fission tracks (N_s), orientation, length, and D_{par} were measured from each sample according to the procedures described in Donelick et al. (2005; **Table S4.1, S4.2**). Following FT analysis, apatite grain-specific chemistry was measured via electron probe microanalysis (EPMA; **Table S4.3**). A detailed description of the AFT LA-ICP-MS and EPMA analytical methods is provided in **Appendix C**. The analyses measured thirteen elements that are known to readily substitute into apatite. The objective was to analyze chemistry on all apatite grains used in measuring AFT dates and track lengths, however, grains that were partially ablated by the laser or are smaller than the probe's beam width (10 μm) could not be analyzed. EPMA analysis yielding low weight percentages (<95 wt%), or low CaO and P_2O_5 values were omitted. For apatite grains successfully analyzed via EPMA, grain-specific chemistry was used to calculate r_{mr0} values (Carlson et al., 1999). Pooled and central ages were calculated for each sample, and pooled ages

systematically yield younger dates (**Table 4.1**). For samples that pass the X^2 test ($X^2 > 5\%$) and have low age dispersion ($< 10\%$), pooled ages are reported (**Figure 4.1**), otherwise central ages are reported. Intra-sample age dispersion can be masked by large uncertainties associated with single-grain AFT ages. To visualize intra-sample age dispersion, AFT ages and their uncertainty ($\pm 1\sigma$) were projected onto radial plots and the data points were color-coded with respect to their corresponding r_{mr0} value (**Figure S4.1**). Finite mixture models are an unbiased statistical method used to identify discrete populations within samples, which serve as a preliminary tool to identify age populations within AFT samples (Galbraith, 2005; Vermeesch, 2018). Despite these efforts, a single age population is discerned for each sample (**Figure S4.1**).

Samples from the VNS yield consistent late Miocene AFT dates between c. 11 and c. 8 Ma (n: 6), whereas samples from the GNS are 16 ± 3 Ma (BH61) and 5 ± 2 Ma (BH45). The Pliocene age from BH45 is derived from the only metabasite in the dataset and is comprised of small and corroded apatite grains. Consequently, AFT and EPMA analyses were successful on only fifteen age-grains and eight length-grains (**Table 4.1, S4.3**). These apatite grains also have low ^{238}U content, and most single-grain AFT dates are 0 Ma or imprecise ($\pm 100\%$ error; **Figure S4.1, S4.2; Table S4.1**). The significantly younger AFT date from sample BH45 likely reflects the poor quality of the sample's data. Consequently, sample BH45 was not considered further in this study. For the NRZ, one sample records a late Miocene date (8 ± 1 Ma), whereas the other two samples have older Miocene dates (c. 19-16 Ma; **Figure 4.1B, Table 4.1**). Overall, track lengths vary by $\sim 6 \mu\text{m}$ within each sample, and average track lengths for all AFT samples are between $13.6 \pm 0.8 \mu\text{m}$ and $14.7 \pm 1.3 \mu\text{m}$, although no sample evinces clear bimodal peaks in track lengths (**Table 4.1; Figure S4.3**).

Table 4.1. Summary of AFT data, eastern Tauern Window, Austria

sample	superunit	nappe	lithology	AFT age grains					AFT length grains				kinetic parameters				UTM coordinates	
				grains	pooled age $\pm 1\sigma$	central age $\pm 1\sigma$	χ^2	disp.	grains	tracks	TL avg.	TL range	D_{par} avg.	D_{par} range	r_{mr0}	r_{mr0}	zone	elev.
				(n)	(Ma)	(Ma)	(%)	(%)	(n)	(n)	(μm)	(μm)	(μm)	(μm)	average	range	33N	(m)
JS11			meta-litharenite	24	7.9$\pm$1.1	9.8$\pm$1.3	18	0	38	56	14.2$\pm$1.6	8.1-17.0	1.83$\pm$0.21	1.08-2.26	0.79$\pm$0.05	0.62-0.86	N 5237057 E 343368	1100
BH54		NRZ	meta-gabbro	27	18.9 $\pm$ 3.9	26.1 $\pm$ 4.9	12	0	4	5	13.6 $\pm$ 0.8	12.5-14.7	1.96 $\pm$ 0.27	1.41-2.59	0.77 $\pm$ 0.02	0.74-0.83	N 5236823 E 348318	1440
BH73*		NRZ	meta-gabbro	22	13.4 $\pm$ 2.0	15.7 $\pm$ 2.6	7	100	21	38	14.7 $\pm$ 1.3	12.6-17.3	2.32 $\pm$ 0.53	1.49-3.51	0.82 $\pm$ 0.03	0.70-0.86	N 5233572 E 346333	1350
<i>BH45</i>		GNS	<i>meta-basite</i>	<i>15</i>	<i>5.4$\pm$1.6</i>	<i>8.8$\pm$2.4</i>	<i>84</i>	<i>0</i>	<i>8</i>	<i>9</i>	<i>14.4$\pm$0.5</i>	<i>13.9-15.2</i>	<i>1.83$\pm$0.28</i>	<i>1.35-2.48</i>	<i>0.83$\pm$0.01</i>	<i>0.82-0.84</i>	<i>N 5231852</i> <i>E 349524</i>	<i>1310</i>
BH61		GNS	meta-gabbro	55	15.7$\pm$2.8	24.8$\pm$3.7	14	0	60	88	14.2$\pm$1.2	11.2-17.3	1.99$\pm$0.24	1.85-2.48	0.80$\pm$0.02	0.74-0.83	N 5225311 E 348189	1680
BH51			ortho-gneiss	35	7.6 $\pm$ 0.8	8.8 $\pm$ 0.9	17	0	16	25	14.7 $\pm$ 1.3	11.0-16.4	1.83 $\pm$ 0.20	1.29-2.20	0.85 $\pm$ 0.01	0.82-0.86	N 5219506 E 348524	1460
BH74			para-gneiss	36	9.3 $\pm$ 0.7	10.1 $\pm$ 0.8	28	0	24	44	14.0 $\pm$ 1.3	9.9-16.0	1.88 $\pm$ 0.17	1.51-2.20	0.83 $\pm$ 0.01	0.81-0.84	N 5214805 E 346069	1720
BH76			ortho-gneiss	28	9.3 $\pm$ 1.4	12.7 $\pm$ 1.8	99	0	22	44	14.2 $\pm$ 1.5	10.2-16.5	1.88 $\pm$ 0.21	1.34-2.22	0.82 $\pm$ 0.01	0.79-0.84	N 5213968 E 345556	2180
BH65*		VNS	ortho-gneiss	39	8.6$\pm$0.7	9.4$\pm$0.8	40	21	18	35	14.5$\pm$1.1	11.9-16.5	1.85$\pm$0.21	1.28-2.28	0.83$\pm$0.01	0.80-0.85	N 5213130 E 344910	3080
BH42*			ortho-gneiss	27	9.2 $\pm$ 1.1	10.7 $\pm$ 1.3	26	19	16	36	14.3 $\pm$ 1.9	8.8-18.7	1.95 $\pm$ 0.20	1.54-2.39	0.83 $\pm$ 0.01	0.79-0.84	N 5212924 E 345606	2680
JS03			meta-gabbro	35	10.0 $\pm$ 0.9	11.9 $\pm$ 1.1	40	0	42	58	14.0 $\pm$ 1.7	8.1-16.9	1.71 $\pm$ 0.15	1.36-2.10	0.85 $\pm$ 0.01	0.80-0.86	N 5206449 E 343118	1580

* Denotes AFT samples where a central age is reported in Figure 4.1. A pooled age is reported for all other samples.

Rows in bold are samples selected for inverse thermal history modeling. Row in italic was omitted from the study. Refer to text for explanation.

Nappe system abbreviations: NRZ (Nordrahmen Zone); GNS (Glockner Nappe System); VNS (Venediger Nappe System).

Other abbreviations: disp. (age dispersion); TL (track lengths); elev. (elevation).

AFT ages show no systematic spatial trend across the eastern Tauern sub-dome. Instead, the data display an apparent "out of sequence" pattern, with older (early Miocene) ages occurring between younger (late Miocene) ages recorded in the sub-dome's core and along the northern margin of the window (**Figure 4.1B**). To explain the earlier cooling signature observed in the sub-dome's northern limb, it is reasonable to assume that different processes may have driven coeval cooling in the core and northern limb of the window during the late Miocene. Accordingly, the AFT data was categorized into three different age domains: i) the late Miocene sample near the northern edge of the window (n: 1); ii) early Miocene samples in the northern limb (n: 3); and iii) late Miocene samples in the sub-dome core (n: 6). To evaluate whether new temporal information related to the window's exhumation could be resolved, one representative sample from each of the age domains was selected for detailed thermal history modeling that account for grain-specific annealing kinetics. Sample selection targeted i) different nappe systems, ii) different apatite-bearing lithologies, iii) samples possessing a high number of apatite grains with well-defined chemistry, and iv) samples with a wide range of single-grain AFT ages and r_{mr0} values.

The late Miocene domain at the northern margin of the Tauern Window comprises a single sample (JS11), which was selected for thermal history modeling. This sample is from a meta-litharenite and the apatite from this sample have the widest range of annealing kinetics (Δr_{mr0} : 0.24; **Table 4.1**). The three samples from the early Miocene domain are metagabbros and comprised of two samples (BH54, BH73) from the NRZ and one sample (BH61) from the GNS. Sample BH73 has the widest range of annealing kinetics (Δr_{mr0} : 0.16) and single-grain AFT dates have 100% age dispersion (**Table 4.1**; **Figure S4.1**). The two other early Miocene AFT samples (BH54, BH61) have similar ranges of annealing kinetics (Δr_{mr0} : 0.09) and have no intra-sample age dispersion (**Table 4.1**; **Figure S4.1**). Apatite from these three samples have low U content,

resulting in large errors associated to single-grain AFT dates (**Table S4.1; Figure S4.2**). Despite sample BH73 possessing a wider range of annealing kinetics and dispersed single-grain AFT dates, its dataset consists of approximately half the number of AFT age- and length-grains as sample BH61 (**Table 4.1**). Furthermore, sample BH73 is from the NRZ, which is already represented by sample JS11 for thermal history modeling for that nappe, whereas sample BH61 is from the GNS. Sample BH61 was selected to represent AFT samples with early Miocene dates due to its relatively larger dataset, and thus AFT samples from all three nappe systems would be represented in thermal history modeling. All AFT samples from the late Miocene domain in the core of the sub-dome are from the VNS (**Figure 4.1B**). The apatite from these six samples share remarkably similar annealing behavior, with r_{mr0} values ranging between 0.79 and 0.86 (**Table 4.1**). Two orthogneiss samples (BH65, BH42) have some intra-sample age dispersion (21% and 19%, respectively) and have the same variation in annealing kinetics (Δr_{mr0} : 0.05; **Table 4.1; Figure S4.1**). Sample BH65 comprises thirteen more AFT-age grains and two more length-grains compared to BH42 (**Table 4.1**). Ultimately, due to its larger dataset and higher degree of intra-sample age dispersion, sample BH65 was selected to represent the late Miocene age population for thermal history modeling.

The representative AFT samples from each age domain are from different nappe system, and from here on, these samples will be referred to by their corresponding nappe. To review, these include: 1) a meta-litharenite from the NRZ (JS11) with a pooled age of 8 ± 1 Ma, at the northern edge of the window, 2) a metagabbro from the GNS (BH61) with a pooled age of 16 ± 3 Ma, in the sub-dome's northern limb, and 3) an orthogneiss from the VNS with a central age of 9 ± 1 Ma, in the core of the sub-dome (**Figure 4.B, Table 4.1**). Confined fission track lengths are similar for the VNS and the GNS samples, with average track lengths of 14.5 ± 1.1 μm and 14.2 ± 1.2 μm , respectively, that range from 11.9-16.5 μm and 11.2-17.3 μm , respectively. Average track lengths

are similar for the NRZ sample ($14.2 \pm 1.6 \mu\text{m}$), however, a wider range of track lengths are observed in this sample ($8.1\text{-}17.0 \mu\text{m}$; **Table 4.1**). The $r_{\text{mr}0}$ values indicate that the NRZ sample should be the most resistant to thermal annealing, with average values of 0.79 ± 0.05 , and to have a wide range of annealing kinetics ($r_{\text{mr}0}$: $0.62\text{-}0.86$; **Table 4.1**). Less retentive annealing kinetics are resolved from the VNS and GNS, with average $r_{\text{mr}0}$ values of 0.83 ± 0.01 and 0.80 ± 0.02 , respectively, that range between $0.80\text{-}0.85$ and $0.74\text{-}0.83$, respectively (**Table 4.1**). To visualize the relationship between the AFT data and grain-specific annealing kinetics, AFT data from the three samples selected for thermal history modeling are plotted in kinetic space (**Figure 4.2**).

For AFT samples that are partially annealed or contain different kinetic populations, apatite grains that are more retentive (lower $r_{\text{mr}0}$) are expected to record older AFT dates and include shorter tracks (partially annealed). In our samples, no obvious relationship between $r_{\text{mr}0}$ and AFT dates or track lengths is present (**Figure 4.2**). The NRZ sample contains four age-grains with less retentive annealing kinetics ($r_{\text{mr}0} < 0.74$), which corresponds to four track lengths (**Figure 4.2C**). Both 'populations' have the same pooled age and share similar track lengths, indicating the more retentive apatite does not record additional information related to an earlier thermal event. Consequently, despite this sample comprising apatite with distinct $r_{\text{mr}0}$ values, it cannot be modeled with multi-kinetic populations as there is no correlation between $r_{\text{mr}0}$ and fission track lengths or single-grain AFT dates (**Figure 4.2C**).

For D_{par} values to mimic the kinetic proxy $r_{\text{mr}0}$, an inverse relationship is expected, however, no correlation is observed with this independent variable either (**Table 4.1**, **Figure S4.4**). Despite $r_{\text{mr}0}$ predicting the NRZ sample to contain the most retentive apatite, D_{par} predicts the same sample to be the least retentive, with an average D_{par} of $1.8 \pm 0.2 \mu\text{m}$ that ranges between $1.1\text{-}2.3 \mu\text{m}$ (**Table 4.1**). By comparing track length orientations relative to the crystallographic c-axis, all

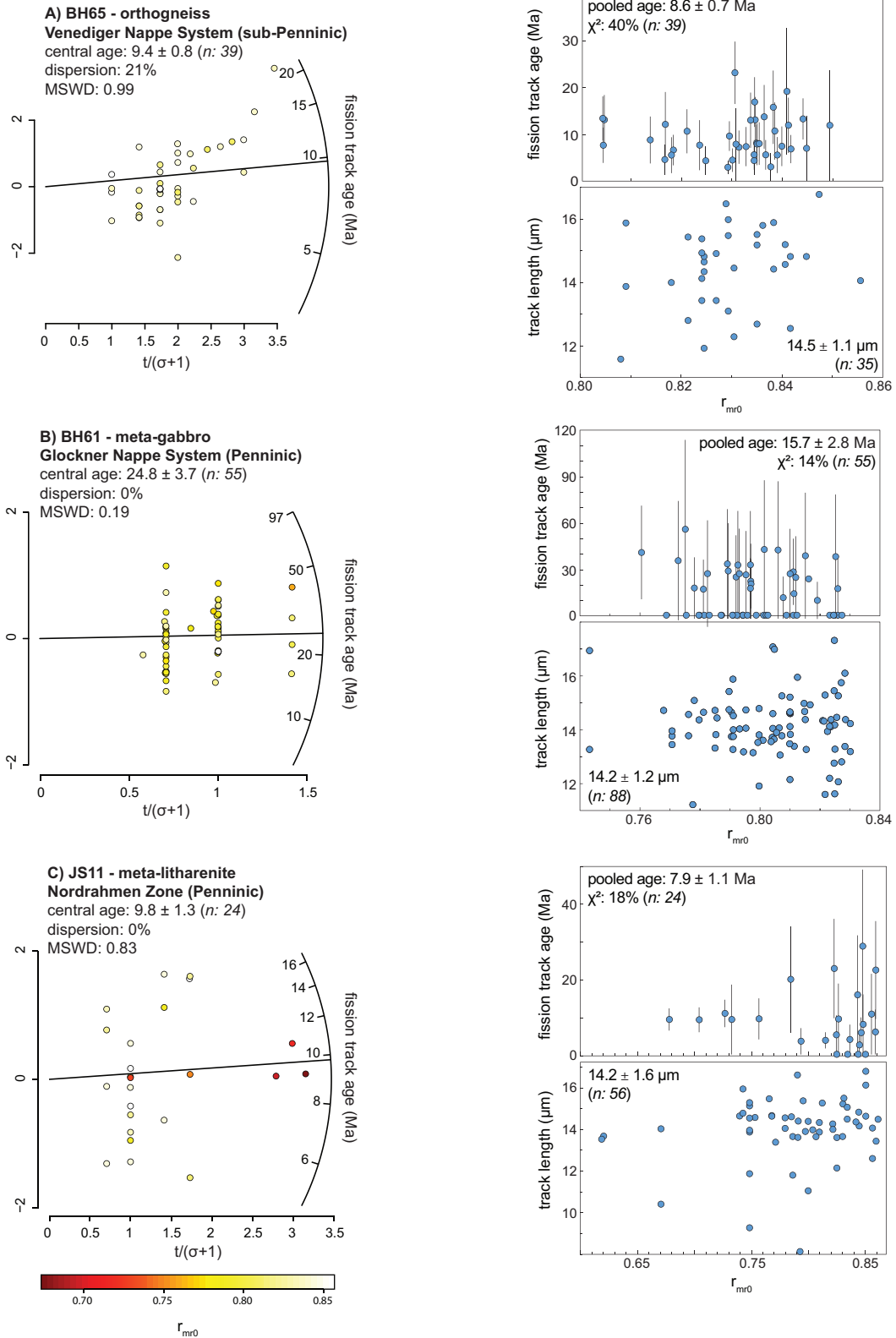


Figure 4.2. AFT radial plots [left column] and single-grain AFT dates and track lengths plotted as a function of the kinetic parameter $r_{\text{mr}0}$ [right column] for the three samples selected for thermal history modeling. Radial plots account for all single-grain AFT ages and their associated error (1σ); more precise ages plot closer to the radial arc. The line in each graph represents the samples' central ages, which is read from its intersection with the radial arc. The assigned colors represent the grains' corresponding $r_{\text{mr}0}$ value where warmer colors represent apatite grains with more retentive annealing kinetics. The VNS sample [A] has overly dispersed single-grain AFT and the central age was used for thermal history modeling. The linear clusters observed in the GNS sample [B] result from a low number of spontaneous fission tracks (see text for further explanation). Radial plots were created using IsoplotR (Vermeesch, 2018). Error bars on fission track dates are 1σ . The $r_{\text{mr}0}$ values derived from grain chemistry measured via EPMA. In the NRZ sample [C], five AFT age-grains and four track lengths have less retentive annealing kinetics, although there is no correlation between $r_{\text{mr}0}$ and their corresponding AFT date or track lengths. All samples pass the χ^2 test. The pooled ages reported for the GNS sample [B] and NRZ sample [C] were used for thermal history modeling.

three samples exhibit the same correlation of progressively shorter track lengths for fission tracks that are increasingly misaligned relative to the c-axis (**Figure S4.4**). To determine the effects of grain chemistry on the kinetic behavior of apatite, different elemental substitutions were compared relative to r_{mr0} on binary plots (**Figure S4.4**). The VNS and GNS samples have no appreciable Cl-content (<0.01 wt%), and Cl-content from the NRZ sample vary between 0-0.48 wt%, however, there is no correlation between Cl-content and r_{mr0} , and instead some of the most retentive grains have the lowest Cl-content (**Figure S4.4**). Apatite grains from all three samples have significant F-content (>1.91 wt%). Interestingly, F-content is distinct for each sample: the GNS sample has the lowest F-content (2.10 ± 0.11 wt%), the VNS sample has intermediate F-content (2.97 ± 0.16 wt%), and the NRZ sample is the most F-rich (3.40 ± 0.23 wt%; **Figure S4.4**; **Table S4.3**). Fluorine-content does not significantly influence annealing kinetics, as the most apparent retentive sample (NRZ) generally has the highest F-content, and, for all three samples, r_{mr0} does not obviously correlate with F-content (**Figure S4.4**). Moreover, there is an inverse correlation between r_{mr0} and Fe-content, indicating Fe increases retentivity (lower r_{mr0} values). A similar, but weaker correlation is observed between r_{mr0} and Mn-content for the VNS and NRZ samples, and between r_{mr0} and Mg-content for the GNS sample (**Figure S4.4**).

4.6 Thermal history modeling

Inverse thermal history modeling was performed using AFTINV (v.6.12; Issler, 1996) for the three AFT samples detailed in this study, focussing on the 30-0 Ma temporal window. Although Raman spectroscopy of carbonaceous material and geothermometry data resolve peak

temperatures of $>500^{\circ}\text{C}$ (Scharf et al., 2013b; Spalding et al., 2025), a lower temperature benchmark ($\geq 250^{\circ}\text{C}$) was used as a constraint for the model start time (at 30 Ma), as higher

temperatures exceed the temperature of the PAZ for all apatite specimens and no meaningful information can be extracted. Despite the Tauern Window likely to have undergone exclusively cooling since the Oligocene, the models are set up to search for random heating and cooling to avoid over-constraining the plausible paths and to maximize the likelihood of resolving new information. Maximum heating and cooling rates are limited to $40^{\circ}\text{C}/\text{Myr}$. Input parameters also require temperatures of $\leq 20^{\circ}\text{C}$ at 0 Ma to represent surface conditions of our AFT samples. The VNS sample (collected from the peak of Hoher Sonnblick) includes additional input constraints that represent published zircon (U-Th)/He (ZHe) and apatite (U-Th)/He (AHe) dates from the same locality, and their corresponding closure temperatures ($180\text{-}200^{\circ}\text{C}$ at 15 Ma, and $60\text{-}80^{\circ}\text{C}$ at 8 Ma, respectively; Wöfler et al., 2012).

AFTINV accounts for individual apatite $r_{\text{mr}0}$ values, requiring a user-defined $r_{\text{mr}0}$ value, and because no sample exhibited multi-kinetic behavior the average $r_{\text{mr}0}$ for each AFT sample was used. Time-temperature pathways are resolved at 1 Myr intervals by randomizing cooling and heating within the limits of the input parameters and recognizing solutions with an acceptable statistical fit between modeled and calculated AFT ages and track lengths. Models are set up to use a non-directed random Monte Carlo (MC) approach to find 300 plausible solutions at the 0.05 significance level. The search space is then redefined to an envelope constraining the 300 MC solutions and AFTINV searches for an additional 300 solutions via a controlled random search function (CRS) with 0.50 statistical significance (McDannell and Issler, 2021). Model AFT ages are calculated for each time-temperature pathway resolved. For the NRZ (JS-11), average model

AFT ages resolved via MC and CRS are within 0.2 Myr of their empirical AFT age (**Figure 4.5**), whereas model ages from the other samples are ≥ 0.5 Myr older than their empirical AFT age: for the GNS sample (BH61), average model ages are 17.3 Ma (MC) and 16.2 Ma (CRS; **Figure 4.4**), and for the VNS sample (BH65), model ages 10.1 Ma (MC) and 12.8 Ma (CRS; **Figure 4.3**).

For each sample, time-temperature pathways predict a single cooling event (**Figure 4.3-4.5**). The CRS results are better constrained in time-temperature space, although, solutions often vary by $>50^{\circ}\text{C}$ for a single time interval. To extract meaningful information from thermal history models we used results from the objective mean function of CRS solutions (**Figure 4.3-4.5**). Model results calculate a maximum annealing temperature which is interpreted as the upper temperature limit of the PAZ. The NRZ sample has the most retentive annealing kinetics ($r_{\text{mr}0}$: 0.79) and consequently resolves the highest annealing temperature (138°C). The GNS and VNS samples have maximum annealing temperatures of 129°C and 118°C , respectively. Towards the end of the model paths, time-temperature pathways exhibit a "plateau" at $\sim 50\text{-}60^{\circ}\text{C}$ (more evident on samples BH61 and JS11), then abruptly diverge towards surface conditions at c. 3 Ma. These temperatures are cooler than the PAZ window, therefore this part of the model is not well constrained, which likely results from the input constraints requiring surface conditions at the end of model run time. The temperature denoted by the isothermal "plateau" on time-temperature pathways is interpreted to represent the lower temperature limit for the PAZ. Solutions from the NRZ and GNS samples converge towards 60°C at 6 Ma and 13 Ma, respectively, whereas solutions from the VNS converge towards 50°C at 7 Ma (**Figure 4.3-4.5**). For all samples, the modeled track length distributions have unimodal peaks at $\sim 14\text{ }\mu\text{m}$ and are broadly consistent with the average measured track lengths ($14.2\text{-}14.5\text{ }\mu\text{m}$; **Figure 4.2-4.5**). Retention ages are calculated from the oldest (shortest) track length and denote the earliest time the AFT sample's thermal history can be resolved. Average

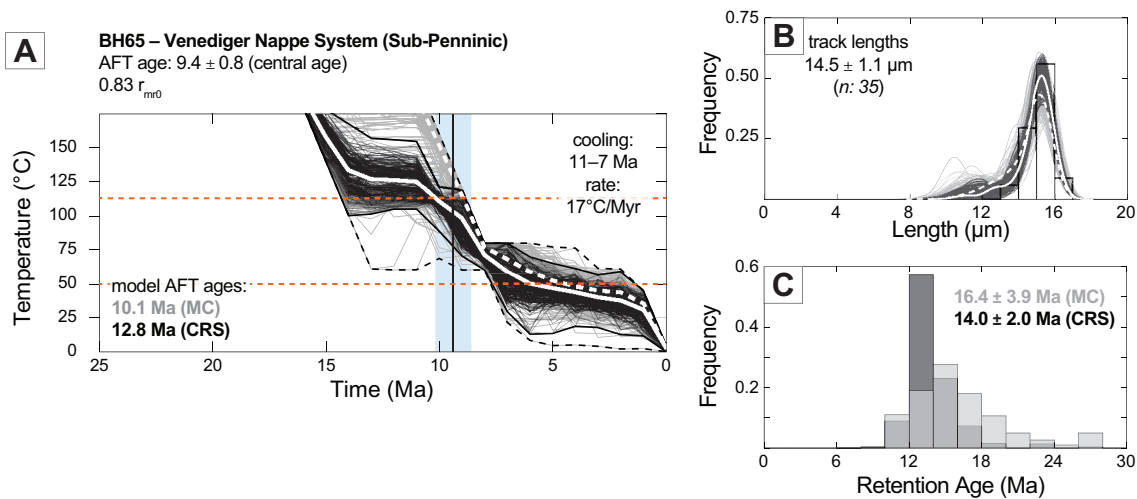


Figure 4.3. AFT inverse thermal history model results for VNS sample BH65 that account for the sample's annealing kinetics, determined by average r_{m0} values. Models created using AFTINV (v. 6.12; Issler, 1996). A) Plausible temperature-time paths. Light grey represents 300 statistically acceptable Monte Carlo solutions (MC) with 0.05 level of significance, and black lines represent 300 statistically acceptable solutions using a controlled random search (CRS) function with 0.5 level of significance. Dashed black lines denote the limits of all solutions. White lines represent the exponential mean function for MC solutions (dashed line) and CRS (solid line). The dashed orange lines denote the upper and lower extent of the PAZ (discussed in text). The vertical black line denotes the sample's calculated AFT central age, and its corresponding error is in blue ($\pm 1\sigma$). The thermal history model predicts cooling from 11–7 Ma at an average rate of 17°C/Myr . B) Diagram comparing measured track length distribution. The histogram reflects measured track lengths, and the faded lines represent the probability density function of calculated track lengths from all solutions found in A (MC: light grey; CRS dark grey). C) Histogram illustrating retention ages from model results. Darker solid bars represent CRS solutions and overlying light grey bars represent MC solutions.

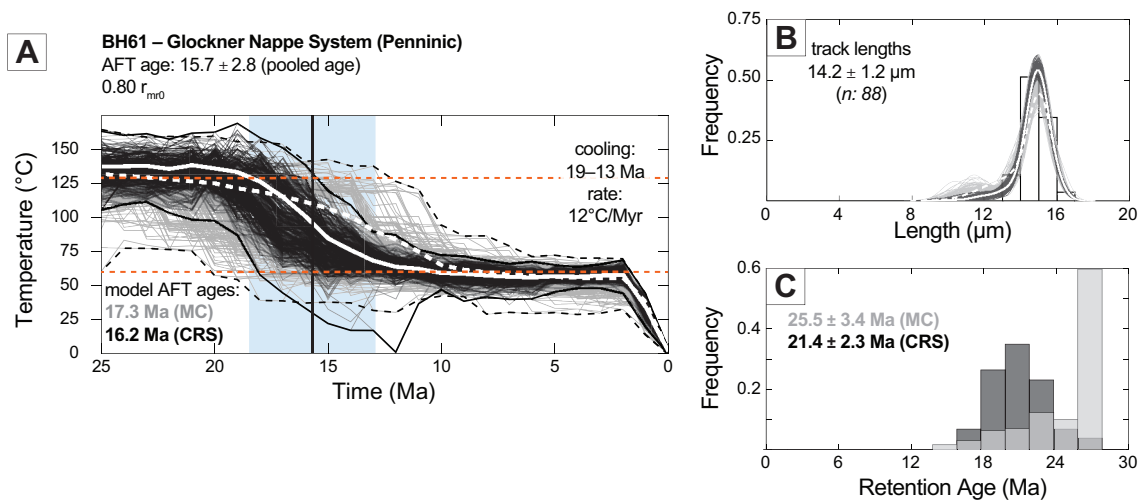


Figure 4.4. AFT inverse thermal history model results for GNS sample BH61 that account for the sample's annealing kinetics, determined by average r_{mr0} values. Refer to Figure 3 for additional details. The vertical black line denotes the sample's calculated AFT pooled age, and its corresponding error is in blue ($\pm 1\sigma$). The thermal history model predicts cooling from 19–13 Ma at an average rate of 12°C/Myr.

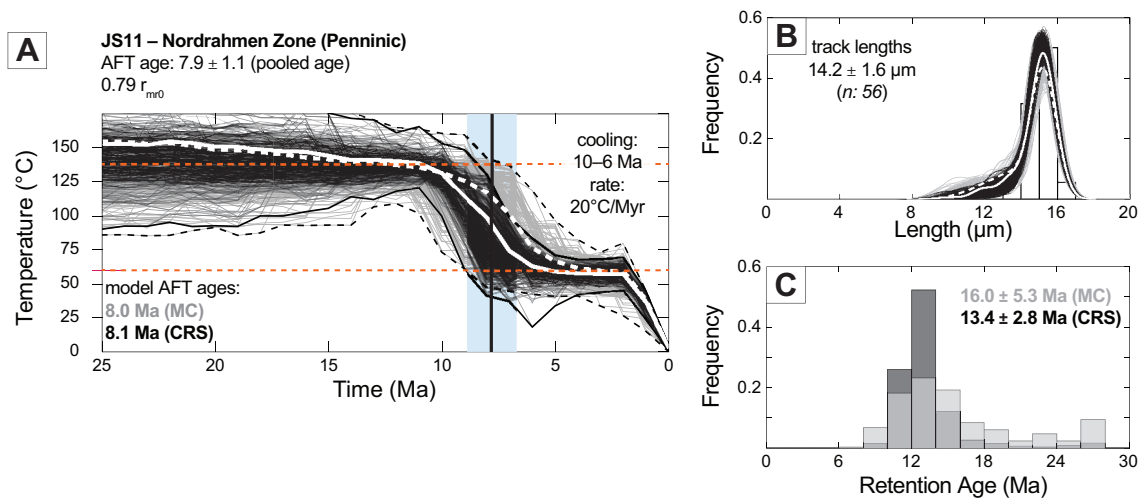


Figure 4.5. AFT inverse thermal history model results for NRZ sample JS11 that account for the samples's annealing kinetics, determined by average r_{mr0} values. Refer to Fig. 3 for additional details. The vertical black line denotes the sample's calculated AFT pooled age, and its corresponding error is in blue ($\pm 1\sigma$). The thermal history model predicts cooling from 10–6 Ma at an average rate of 20°C/Myr.

retention ages are similar for the VNS and NRZ samples (CRS: 12.7 ± 1.3 Ma and 13.4 ± 2.8 Ma, respectively; **Figure 4.3, 4.5**). The average retention ages for the GNS sample are older (CRS: 21.4 ± 2.3 Ma; **Figure 4.4**), which reflects the sample's (older) pooled age. As all samples share similar track length distributions, and thermal history models predict a single accelerated cooling event, retention ages that are slightly older than the sample's AFT age are expected. Notably, the average retention ages consistently pre-date the onset of cooling predicted from the models, which in turn, pre-date the empirical AFT date: the GNS sample predicts an early onset of cooling, at c. 19 Ma, whereas results from the VNS and NRZ samples predict cooling to have initiated at c. 11-10 Ma. Ultimately, model-derived paths require 4-6 Myr for the samples to cool through their respective PAZ's.

4.7 Discussion

4.7.1 Significance of the AFT data

The kinetic parameter r_{mr0} was calculated from apatite grain-specific chemistry to quantify the annealing properties of all apatite specimens within new AFT samples from the eastern Tauern Window. The samples have variable ranges of r_{mr0} values but do not correlate with track lengths or single-grain AFT dates, which implies that even the most retentive apatite grains were completely annealed before their latest cooling through the PAZ (**Table 4.1, Figure 4.2**). The r_{mr0} values were incorporated into AFT thermal history models to resolve more accurate solutions and evaluate whether new information regarding the earlier exhumation history of the eastern window could be resolved.

AFT data and grain chemistry were examined for the three samples selected for thermal history modeling. D_{par} has traditionally been used as a proxy for apatite annealing kinetics (Burtner

et al., 1994), and notably for our apatite specimens the calculated r_{mr0} does not correlate with measured D_{par} . Similarly, halogen concentrations (Cl- and F-content) have also been used as proxies to predict annealing kinetics (Green et al., 1986) although no correlation between r_{mr0} and Cl- or F-content is observed. Instead, r_{mr0} values correlate to Fe-, Mg-, and Mn-content of the apatite (**Figure S4.4**). Laboratory-based annealing experiments have demonstrated that minor cation substitutions may influence apatite's kinetic behavior which can negate the effects of F- and Cl-content and these results highlight the differences between r_{mr0} and other proxies traditionally used to predict apatite's annealing kinetics (Barbarand, 2003; Carlson et al., 1999; Ketcham et al., 1999).

The new AFT data have unimodal populations of fission track lengths ($\sim 14 \mu m$), which is characteristic of rocks that record a single cooling event. Track lengths in our samples are generally distributed across a $\sim 6 \mu m$ range within AFT samples, and shorter track lengths are increasingly misaligned relative to apatite's crystallographic c-axis (**Table 4.1, Figure S4.3**). As the rate of thermal annealing increases for fission tracks that are increasingly misaligned relative to the apatite's c-axis, the scatter of track lengths within AFT samples reflects the anisotropy of thermal annealing within apatite crystals. Moreover, this indicates that the samples have undergone a component of partial annealing that may provide insight into the rate of cooling through the PAZ (Green et al., 1989).

Despite that the thermal history models were tasked to search for random heating and cooling episodes since c. 30 Ma, solutions from all three samples predict a single cooling event, which is consistent with our preliminary interpretations of the AFT data (**Figure 4.3-4.5**). At the start and end of each model, all solutions converge at high and low temperatures, respectively (**Figure 4.3-4.5**). These isothermal plateaus are not geologically significant but instead denote the

temperature limits of these apatite specimens to undergo thermal annealing. The high temperature that defines the start of the models coincides with their respective maximum annealing temperature calculated from thermal history models, which is interpreted to reflect the upper temperature limit of the PAZ, whereas the cooler temperatures defining the end of model times is interpreted as the lower temperature limit of the PAZ. As kinetic behavior influences the temperature range that apatite undergoes thermal annealing, the kinetic parameter r_{mr0} correlates to the PAZ defined by each model. The NRZ sample has the widest range of r_{mr0} values that include the most retentive apatite grains in our dataset, resulting in a PAZ of 60-138°C (ΔT : 78°C; **Figure 4.5**). In comparison, the PAZ of the GNS and VNS samples are defined by a narrower window and a lower temperature: 60-129°C (ΔT : 69°C; GNS; **Figure 4.4**) and 50-118°C (ΔT : 68°C; VNS; **Figure 4.3**), respectively. All models predict the onset of cooling to have begun ~2-3 Myr earlier than their empirical AFT date and require 4-6 Myr to cool through their respective PAZ, which reflects the component of partial annealing evinced in the track length distribution. (**Figure 4.3-4.5**). Because all model results predict a single accelerated cooling event, the rate of cooling across the PAZ can be inferred from the temperatures that define the PAZ and the duration of time the samples require to cool across the PAZ: the VNS and NRZ samples yield similar cooling rates of ~17°C/Myr and ~20°C/Myr, respectively, whereas results from the early Miocene GNS sample yields a slower cooling rate of ~12°C/Myr.

4.7.2 Tectonic interpretation

New AFT dates from the VNS (11-8 Ma; n: 6) are within the lower range of published AFT ages from this nappe system (16-8 Ma; Staufenberg, 1987; Wölfler et al., 2012), and the northernmost AFT sample from the NRZ (8 Ma; JS11) is similar to the only known existing AFT

ages from this part of the window (10 Ma; **Figure 4.1B**; Staufenberg, 1987). No published AFT dates are proximal to the sample localities of the early Miocene AFT dates (19-16 Ma; n: 3) from the NRZ and GNS. The nearest known sample in the GNS records an AFT date of 11 Ma (Staufenberg, 1987) but is >20 km west of our sample traverse (**Figure 4.1B**).

Results from the three samples selected for thermal history modeling can be interpreted in conjunction with the regional geology to predict exhumation rates and mechanisms. A geothermal gradient of the Eastern Alps has been estimated to be $\sim 30^{\circ}\text{C}/\text{km}$, which has been used to determine Miocene exhumation rate in previous AFT studies (Grundmann & Morteani, 1985; Wagner et al., 1977; Bertrand et al., 2017). We note that the paleo-geothermal gradient may have been higher during the early (Oligocene) stages of exhumation due to heat advection from deep-seated rocks quickly brought to the surface (Mancktelow and Grasemann, 1997). In addition, evidence of ductile thinning observed below the Oligocene Schuhflicker Detachment likely increased the geothermal gradient as this process can warp isotherms upwards, and horizontal extension can result in telescoping isotherms (e.g., Ring et al., 1999; Spalding et al., 2025). Nonetheless, the range of temperatures interpreted to define the limits of the PAZ equates to crustal depths of ~ 4.5 - 1.5 km, with exhumation rates calculated from cooling rates (resolved from the thermal history models) on the order of 0.4 km/Myr from 19-13 Ma for the GNS, 0.6 km/Myr from 11-7 Ma for the VNS, and 0.7 km/Myr from 10-6 Ma for the NRZ. If we arbitrarily double the paleo-geothermal gradient ($60^{\circ}\text{C}/\text{km}$) to account for early heat advection or a relatively hotter regime, the PAZ equates to crustal depths of ~ 2 - 1 km and the exhumation rates would decrease by half. Regardless of the paleo-geothermal gradient, the exhumation rates resolved herein align with previously estimated rates for the eastern sub-dome (Bertrand et al., 2017) but are slow relative to exhumation rates documented across other orogens undergoing Tertiary unroofing. For example, exhumation

rates exceeding 5 km/Myr (Zeitler et al., 1993) have been documented in the western Himalayas and similar rates (4.9 km/My) are reported in the central Andes (Göllner et al., 2021), as well as the Basin and Range Province (2-4 km/My; Foster and John, 1999).

A recent tectonic model proposed the onset of E-W extension in the eastern Tauern Window occurred during the Oligocene and early exhumation was facilitated along the Schuhflicker Detachment of the ETDS (Spalding et al., 2025). To evaluate whether a thermal signature related to unroofing of the footwall of the Schuhflicker Detachment can be detected and assess alternative solutions, our thermal history models searched for random heating and cooling episodes since 30 Ma. The earliest evidence of cooling resolved from the thermal history models is from the GNS sample, which predicts cooling below $\sim 129^{\circ}\text{C}$ at c. 19 Ma (**Figure 4.4**). In comparison, thermal history models from the VNS and NRZ predict a later (younger) onset of cooling (c. 11-10 Ma; **Figure 4.3, 4.5**). The GNS sample represents the relatively older age domain in the eastern sub-dome's northern limb, separating younger (late Miocene) age domains in the core of the sub-dome and at the northern edge of the Tauern Window. The intermediate structural position of this age domain, and its discrepant thermal history, suggests different processes may have facilitated its exhumation relative to the VNS and NRZ samples.

In fact, the two AFT samples from the NRZ and GNS (pooled ages of 19 Ma and 16 Ma, respectively; **Figure 4.1B**), may give some insight into the pre- and earliest Miocene history of the sub-dome. The Schuhflicker Detachment was actively extending the crust under brittle-ductile conditions ($300\text{-}250^{\circ}\text{C}$) at c. 30 Ma (Spalding et al., 2025), which represents 10-8 km depths. If we assume the cooling rate ($12^{\circ}\text{C}/\text{my}$) recorded in the GNS sample is projected back from the c. 19-13 Ma window, when the sample cooled through the PAZ ($129\text{-}60^{\circ}\text{C}$), to c. 30 Ma, the time when these rocks were at brittle-ductile conditions, then we calculate ~ 7 km of unroofing since the

late Oligocene. Since c. 13 Ma, there has been only ~2 km of subsequent unroofing, for a total of 9 km of exhumation, which independently aligns with the predicted 10-8 km paleodepth of the current exposure levels of the footwall of the Schuhflicker Detachment of the ETDS (**Figure 4.6**). If we instead use the unroofing rate of 0.4 km/Myr for the eastern sub-dome (this study; Scharf et al., 2013a; Bertrand et al., 2017) since 30 Ma, then 12 km of total exhumation can be achieved. We acknowledge that it is somewhat unrealistic to assume a steady-state geothermal gradient (30°C/km) of an active orogen over 30 Myr timescales, or that exhumation rates were homogeneous across the eastern sub-dome (Bertrand et al., 2017), but this first-order approach allows us to broadly assess the amount of exhumation of the eastern sub-dome, in part attributed to activity along the Schuhflicker Detachment. Further, this exercise demonstrates that Early Miocene AFT ages from the eastern window may be recording pre-doming cooling and unroofing, and utilizing the r_{mr0} approach to AFT dating can help better resolve the sensitivity of the numerical models (**Figure 4.6**). It is proposed that the ETDS was active since c. 30 Ma, initiating along the Schuhflicker Detachment, and during progressive deformation, activating the KSZS, and eventually the KNF (Spalding et al., 2025).

The VNS is the metamorphic gneiss dome, and the deepest nappe system, of the Tauern Window (e.g., Schmid et al., 2013). The onset and rates of cooling resolved from the VNS's thermal history model agree with previously published AFT data, which are interpreted to record the exhumation via erosion that was facilitated by the high topography generated by upright Miocene folding (Bertrand et al., 2017). The five other AFT samples from the VNS reported here share similar AFT dates (11-8 Ma). Notably, the modeled sample from VNS is from the peak of Hoher Sonnblick (3080 m), whereas the other samples from the VNS are distributed across the variable topographic relief of the window, reaching elevations as low as 1460 m (**Figure 4.1C**).

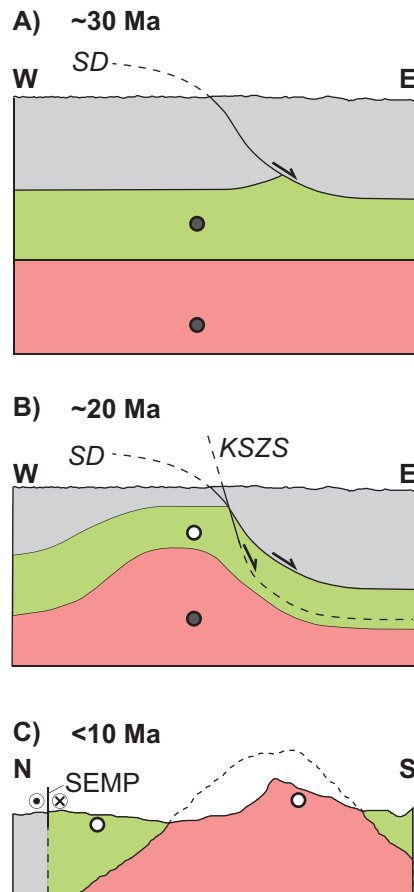


Figure 4.6. Schematic diagram illustrating progressive exhumation since the Oligocene. White circles represent AFT samples that have cooled through the PAZ, and grey circles are at crustal depths that are warmer than the upper limit of the PAZ. Note the change of profile orientation from B to C. A) Onset of exhumation along the Schuhflicker Detachment (SD). All AFT samples are hotter than the PAZ. B) Progressive exhumation along the Schuhflicker Detachments thins the Penninic units with initiation and propagation of Katschberg Shear Zone System (KSZS). AFT samples within the Penninic units have cooled through the PAZ. C) Doming of the Tauern Window facilitates erosion and AFT samples from the Sub-Penninic cool through the PAZ. SEMP: Salzach-Ennstal-Mariazell-Puchberg fault.

As there is no correlation between AFT ages and elevation for the VNS samples, we interpret all samples from the VNS to have cooled due to unroofing via erosion during the doming of the Tauern Window (**Figure 4.6**).

The NRZ sample is the young (late Miocene) age domain at the northern edge of the Tauern Window. This sample was collected at an elevation of 1100 m within the valley slope of the Salzach River, which also coincides with the trace of the SEMP fault. An existing published AFT date from the NRZ records a similar age (10 Ma) and was also sampled from a similar elevation (900 m) within the Rauris Valley (Staufenberg, 1987). It is possible the younger AFT dates from the northern margin of the window adjacent to the SEMP were in fact influenced by deformation and cooling along this strike-slip fault. Positive flower structures and compartmentalized zones of uplift due to small restraining bends are common aspects of crustal-scale strike-slip systems (e.g., Spotila et al., 2001; Blythe et al., 2002; Spotila et al., 2007). Younger late Miocene AFT dates can be predicted along the length of the SEMP fault because of its Neogene history.

4.8 Summary

We report new AFT dates from a N-S traverse transecting the eastern Tauern sub-dome in an effort to retrieve new information related to the exhumation history of the tectonic window. Apatite grain chemistry was measured to assess grain-specific annealing kinetics via the kinetic parameter r_{mr0} , which accounts for all elemental substitutions known to influence the annealing kinetics of apatite (Barbarand et al., 2003; Carlson et al., 1999). Cl- and F-content are often used as proxies to predict apatite's annealing kinetics. However, our results indicate r_{mr0} is not controlled by Cl- and F-concentrations for these apatite specimens, but instead, minor elemental substitutions of Fe, Mn and Mg increased the retentivity of these apatite. Despite some AFT samples preserving

a wide range of r_{mr0} values, there is no correlation between track lengths or single-grain AFT dates with the kinetic parameter r_{mr0} . This suggests that even the most retentive grains were completely annealed before cooling through their respective PAZ temperatures and highlights the limitations of this method for samples that have undergone rapid cooling.

Late Miocene AFT ages from the core of the sub-dome (11-8 Ma; n: 6) and the northern edge of the Tauern Window (8 Ma; n: 1) are concordant with regional AFT studies, and their corresponding numerical models predict similar cooling histories (17°C/Ma from 11-7 Ma, and 20°C/Ma from 10-6 Ma, respectively). Results from the core of the sub-dome are interpreted to record exhumation rates of 0.6 km/Myr via erosion, facilitated by the high topography generated from upright folding, and agree with current tectonic models for the area (**Figure 4.6**; Bertrand et al., 2017; Schmid et al., 2013; Scharf et al., 2013a; Favaro et al., 2015, 2017).

These late Miocene AFT ages are separated by an older age domain in the sub-dome's northern limb with AFT dates (n: 3) of 19-16 Ma. The earliest Miocene AFT age domain corresponds within the footwall of the Schuhflicker Detachment of the ETDS, and integrated exhumation calculations suggest slightly slower unroofing rates (0.4 km/Myr) for 10 ± 2 km of total exhumation since 30 Ma. We interpret part of this crustal unroofing was due to extension along the ETDS (**Figure 4.6**). Our new data cannot account for the proposed >20 km of exhumation since the Oligocene that has been proposed for parts of the Tauern Window (Fügenschuh et al., 1997; Schmid et al., 2013), nor does it support accelerated unroofing during the Oligocene to earliest Miocene (Von Blanckenburg et al., 1989; Bertrand et al., 2017). Additional thermochronological studies with higher sampling density and combined thermochronometers will be necessary to refine these interpretations and explore the role of different tectonic structures in shaping the exhumation history of the eastern dome.

4.9 Acknowledgements

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CHAPTER 5

CONCLUSIONS

5.1 Overview

Understanding mountain building processes requires insight into the mechanisms that exhume rocks during and after collision and compression, and the rates at which they operate. The integration of innovative radiometric dating techniques in geosciences has significantly improved our ability to constrain the timescales over mountain belts are formed and destructed.

The research in this thesis investigated the exhumation histories in two tectonically contrasting orogens: the Peel Plateau, adjacent to the actively converging Mackenzie Mountains in the Canadian Cordillera (Favaro et al., 2015; Gabrielse, 1991; Selverstone, 1988), and the Tauern Window in the Eastern Alps, where regional strain has evolved from N-S compression to E-W extension (Scharf et al., 2013; Schmid et al., 2013). Initially, the objective of this work was to resolve upper crustal exhumation histories by developing AFT thermal history models that account for grain-specific annealing kinetics and interpret the significance of the models alongside new and existing structural data in the context of respective tectonic frameworks. Prior to this work, upper crustal exhumation in both the Peel Plateau and Tauern Window had been largely attributed to erosion (e.g., Bertrand et al., 2017; Hadlari et al., 2009; Issler et al., 2005; Schmid et al., 2013). Although thermal history models confirm that erosion indeed contributed to upper crustal exhumation, discrepancies between the spatial distribution of AFT samples and the onset of cooling predicted by thermal history models suggest underlying structures may have contributed to exhumation or influenced the rate of erosion. In Chapter 2, AFT samples from the Peel Plateau were separated into multi-kinetic populations to produce more robust thermal history models that track the evolution of an overlying Cretaceous foreland basin. During initial field investigation in the Tauern Window, extensive ductile and brittle-ductile structures related to E-W extensional strain were observed and suspected to have formed during exhumation from middle- to upper-

crustal levels. These observations prompted a focused investigation into early exhumation history of the Tauern Window that was presented in Chapter 3. Herein, extensional deformation fabrics were dated via $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology to provide a minimum time constraint for the onset of E-W extensional strain. The upper crustal exhumation history of the Tauern Window resolved via AFT thermal history modeling is presented in Chapter 4. Thermal history models test whether cooling patterns are consistent with erosion facilitated by doming of the Tauern Window, and whether a signature of earlier exhumation can be detected. Collectively, Chapters 2 and 3 document the Tauern Window's exhumation history from middle- to upper-crustal depths. Ultimately, this research demonstrates the power of combining advanced radiometric techniques with structural data to unravel complex exhumation histories.

5.2 Early exhumation of the Tauern Window

Existing tectonic models have attributed the opening of the Tauern Window to erosion facilitated by high topography generated during crustal indentation from the south. The magnitude of exhumation recorded in the Tauern Window, however, cannot be explained by erosion alone, therefore other processes must have contributed to the earlier stages of exhumation at deeper crustal levels (Glodny et al., 2008; Schmid et al., 2013). Herein, structural evidence of deformation related to E-W extensional strain were documented across the study area and the earliest relict is a pervasive stretching lineation overprints the main foliation. Kinematic indicators that record top-to-east ductile flow and strain analysis of N-S oriented veins that evince an eastward rotation were used to quantify strain and reveal that pure shear and simple shear contributed relatively equally to ductile flow. Brittle-ductile faults directly overprint ductile deformation and were thoroughly documented to infer the strain field related to progressive deformation at higher crustal levels.

Brittle-ductile fault measurements were rotated relative to the foliation to obtain their original orientations as the north-dipping foliation is attributed to doming of the Tauern Window, which post-dates the stage of brittle-ductile deformation. Principal strain axes inferred from brittle-ductile faults are consistent with vertical shortening (vertical ϵ_1) and E-W extension (horizontal ϵ_3 parallel to the stretching lineation). Together, the overprinting relationship and a consistent strain field inferred from ductile and brittle-ductile structures suggest that these structures represent a continuum of deformation related to exhumation from the middle to upper crust. A strain field dominated by vertical shortening during horizontal extension is compatible with ductile thinning and is characteristic in the footwall of crustal scale detachments.

To further evaluate this model, I followed the increasing deformation gradient to higher crustal levels. In the northernmost section of the Tauern Window, portions of the hanging wall are preserved along ridges and peaks as klippen. Upon investigating this area, deformation progressively increases towards a knife sharp detachment that defines the contact of these klippen, with ultramylonites capped with cataclasite in the immediate footwall. This newly discovered structure was named the Schuhflicker Detachment, which has likely been overlooked in the past, as most of the Window's northern and eastern margins are overprinted by brittle faults. On a regional scale, the Schuhflicker Detachment is cross-cut by the previously mapped and well-documented Katschberg Shear Zone System and brittle Katschberg Normal Fault that operated at higher crustal levels (e.g., Genser and Neubauer, 1989; Scharf et al., 2013). Collectively, these structures are interpreted to form the Eastern Tauern Detachment System, where the Schuhflicker Detachment developed at middle crustal levels, and during progressive exhumation, W-E extension transferred to the structurally higher Katschberg Shear Zone System and eventually the Katschberg Normal Fault. Furthermore, white mica that is recrystallized within the rock fabric

record Oligocene $^{40}\text{Ar}/^{39}\text{Ar}$ dates and provide a minimum age constraint for the onset of E-W extension. These Oligocene dates overlap with the youngest high pressure (subduction) metamorphic ages recorded in the Tauern Window and indicates that the onset of E-W extension and exhumation was much earlier than previously documented. Combined, this investigation suggests that formation and exhumation of the Tauern Window began markedly earlier than previously documented and was facilitated by tectonic unroofing along a crustal-scale detachment system. These interpretations account for the magnitude of exhumation observed in the Tauern Window that cannot be explained by erosion alone.

In other extensional tectonic settings deformed by detachment systems or metamorphic core complexes (e.g., Basin and Range Province, Cyclades, NW Himalaya), ductile deformation within the footwall of these structures is accommodated by relatively equal contributions of pure shear and simple shear (Ducharme et al., 2024; Furlong and Londe, 1986; Grassemann et al., 1999). Traditional conceptual models of detachment systems, however, predict that successively younger fault surfaces propagate to increasingly shallower crustal levels during progressive exhumation (Lister et al., 1989). The newly proposed Eastern Tauern Detachment System challenges this model, as the initial detachment plane (the Shuhflicker Detachment) occupies a higher crustal level relative to the younger Katschberg Shear Zone System. It is possible that rheologic contrasts (basement-cover contacts), pre-existing tectonic structures, or stress reorganization dictate the localization at which new faults propagate within detachment systems. Moreover, establishing the onset of E-W extension in the Oligocene carries significant geodynamic implications, as it indicates that extensional deformation was coeval with the waning stages of subduction-related processes, as suggested by Glodny et al. (2005, 2008). This temporal overlap implies a more complex interplay between compressional and extensional regimes in the Tauern Window and

underscore the importance of considering overlapping tectonic processes when interpreting orogenic processes. These findings may provide a useful framework for understanding exhumation processes in other extensional orogenic settings.

5.3 Resolving upper-crustal exhumation histories via AFT thermal history modeling

As discussed throughout this work, interpreting AFT dates as simple ages representing cooling through a nominal closure temperature can lead to misguided geological interpretations for samples that have undergone a component of thermal annealing. These studies demonstrate that thermal history models have the capacity of resolving multiple heating/cooling events and can be used to determine the rates of heating and cooling through time. Apatite grain-specific chemistry influences the specific temperature and rate that fission tracks undergo thermal annealing, and the accuracy of thermal history models is dependent on how well the annealing kinetics of the apatite specimens within AFT samples are characterized (Barbarand et al., 2003; Carlson et al., 1999; Ketcham et al., 1999). In the Peel Plateau (Chapter 2) and the Tauern Window (Chapter 4) apatite grain chemistry was used to calculate r_{mr0} values, which served as a proxy for apatite's grain specific annealing kinetics that were integrated into thermal history models which were in turn evaluated within the framework of their respective tectonic histories to improve current exhumation models.

5.3.1 Tauern Window

Erosion facilitated by the high topography generated by collision with crustal indentation has widely been associated to have facilitated upper crustal exhumation in the Tauern Window (Bertrand et al., 2017; Burg et al., 2004; Schmid et al., 2013). Late Miocene AFT dates have been

documented across the Tauern Window and have typically been interpreted as cooling ages (e.g., Bertrand et al., 2017; Staufenberg, 1987; Wölfler et al., 2012). Along a N-S traverse transecting the eastern Tauern sub-dome, eleven new AFT samples were collected across three nappe systems. Late Miocene AFT ages (11-8 Ma) are recorded in the core of the sub-dome (VNS) and towards the northern limit of the Tauern Window (NRZ) which are similar to published AFT ages from this area Staufenberg (1987; Wölfler et al., 2008, 2012). Between these younger age domains, older (early Miocene) AFT ages are recorded on the northern limb of the eastern sub-dome.

One representative AFT sample from each nappe system was selected for thermal history modeling. Despite unsuccessfully defining multi-kinetic AFT populations, apatite grain-specific chemistry was used to calculate the kinetic proxy r_{mr0} that was incorporated into thermal history models to test whether new information regarding upper crustal exhumation, and a signature of the ETDS as identified in Chapter 3, can be discerned. The three models resolve a single cooling event, and all solutions converge at high and low temperatures at the start and end of each model, respectively. These isothermal plateaus are interpreted to denote the PAZ, over which cooling rates of 17-20°C were discerned from the late Miocene age domain, and a slightly slower cooling rate of ~12°C was calculated from the early Miocene age domain. Previous AFT studies have inferred a geothermal gradient of ~30°C/km since the Miocene, which also used here to estimate the rate and magnitude of exhumation (Grundmann & Morteani, 1985; Wagner et al., 1977; Bertrand et al., 2017). The range of temperatures interpreted to define the limits of the PAZ is equivalent to crustal depths of ~4.5-1.5 km. Results from the core of the sub-dome predict exhumation across the PAZ to have occurred 11-7 Ma at a rate of 0.6 km/Myr, and are similar to results from the northern limit of the Tauern Window (0.7 km/Myr from 10-6 Ma). In comparison, model results from the older age domain predicts earlier (19-13 Ma) and slower (0.4 km/Myr) exhumation across

the PAZ. The intermediate structural position of the older (early Miocene) age domain, and its discrepant thermal history, suggests different processes may have facilitated its exhumation relative late Miocene AFT samples.

The five other late Miocene AFT ages from the core of the sub-dome are from the VNS (11-8 Ma). Notably, the modeled sample from VNS is from the peak of Hoher Sonnblick (3080 m), whereas the other samples from the VNS are distributed across the variable topographic relief of the window, reaching elevations as low as 1460 m. As there is no correlation between AFT ages and elevation for the VNS samples, we interpret all samples from the VNS to have cooled due to unroofing via erosion during the doming of the Tauern Window.

The late Miocene AFT age from the northern edge of the Tauern Window (NRZ) was collected at an elevation of 1100 m within the valley slope of the Salzach River, which also coincides with the trace of the SEMP fault. The SEMP is a major structure that extends ~400 km along strike, has accommodated >60 km of displacement and remained active through the Miocene (Decker and Peresson, 1996; Linzer et al., 2002; Schmid et al., 2013). It is possible this younger cooling signature is influenced by deformation and cooling along this strike-slip fault.

During the Oligocene, the Schuhflicker Detachment was operating under brittle-ductile conditions (300-250°C; Spalding et al., 2025), which translates to 10-8 km depths. If we assume the cooling rate inferred from the older age domain (12°C/my) and project it back to c. 30 Ma (the time when these rocks were at brittle-ductile conditions) then we calculate ~9 km of unroofing since the late Oligocene. The older age domain (early Miocene) within the GNS and NRZ are interpreted to record a cooling signature related to exhumation along the ETDS.

To my knowledge, no previous studies have produced AFT thermal history models in the Tauern Window. This work underscores the value of measuring grain-specific chemistry as part of

the AFT analysis protocol, and when paired with thermal history modeling, the data can produce more detailed reconstructions of upper-crustal thermal histories. Furthermore, these results demonstrate how the onset of cooling predicted by thermal history models is better suited to be correlated with a specific exhumation mechanism and exemplifies the usefulness of interpreting models in relation to their tectonic framework.

5.3.2 Peel Plateau

The Phanerozoic rocks in the Peel Plateau are a prospective hydrocarbon reservoir and interest remains in constraining the thermal history of these rocks to assess whether and when the rocks achieved thermal maturation (Hadlari et al., 2009; Lemieux et al., 2009; Pierce and Jones, 2009; Pyle and Jones, 2009). Peak burial temperatures are difficult to resolve using conventional methods, and several unconformities subdivide this rock sequence that represent periods of time where an unknown amount of material had been deposited and eroded. Thermal history models were produced from three AFT samples from Late Devonian and Cretaceous (Albian and Cenomanian) strata to resolve the timing of subsidence and basin inversion of a Cretaceous foreland basin. A regional unconformity separates the Upper Devonian and Lower Cretaceous rocks, and the Late Devonian AFT sample studied is also suited to resolve burial and unroofing of an earlier depo-system. The thermal history model from the Late Devonian AFT sample predicts initial burial temperatures of $\sim 170^{\circ}\text{C}$ during the Late Triassic, followed by exhumation to near-surface conditions prior to renewed Cretaceous subsidence. These results translate to peak burial depths of 4.2-5.7 km and align with existing estimated from nearby basins (e.g., Root, Brackett, and Mackenzie Plain; Issler et al., 2005; Powell et al., 2019). The Cretaceous foreland basin of the Peel Plateau is related to tectonism of the Mackenzie Mountains to the south and basin inversion

is related to lithospheric flexure associated to the northward migration of the Mackenzie Mountains deformation front.

The three AFT samples chosen for thermal history modeling were collected along a ~16 km profile perpendicular to the strike of the Mackenzie Mountains deformation front. The timing of peak burial and the onset of cooling are expected to be progressively younger away from the deformation front, however thermal history model results do not conform to this simplified tectonic scenario. The most proximal (Late-Devonian) and distal (Cenomanian) AFT samples predict peak burial and the onset of cooling to have occurred to during the Palaeocene, whereas the intermediate (Albian) sample is predicted to have achieved peak burial conditions in the Eocene. In addition, the thermal history model from the intermediate sample predicts two pulses of cooling (at 45 Ma and 20 Ma), whereas results from the other samples predict monotonic cooling shortly after reaching peak burial conditions. Published field observations coupled with geophysical data indicate the Albian and Cenomanian sample locations are overlying a buried foreland-vergent duplex structure (Aitken et al., 1982; Lemieux et al., 2009). The Albian sample is above the southern flank of the duplex structure, and the two pulses of cooling predicted from the models are interpreted to reflect progressive growth of the duplex structure. The Cenomanian AFT sample is positioned above the roof thrust of the duplex structure, and the anomalously early onset of cooling predicted from thermal history modeling may be related to nappe stacking. Furthermore, a sub-Cenomanian disconformity is evinced by paleosol documented along the Albian-Cenomanian contact (Hadlari et al., 2014; Pyle and Jones, 2009). This disconformity was integrated into the Albian thermal history model by searching for burial and unroofing from 110 to 97.5 Ma. In addition, the search space defining the limits to solve time-temperature pathways was modified to represent aerial exposure at the start of the Cenomanian. The thermal history

model of the Albian sample, however, does not predict significant cooling prior to the Cenomanian, which suggests that the magnitude of erosion related to the observed disconformity was negligible.

For the three AFT samples, peak burial temperatures of $\sim 85^{\circ}\text{--}90^{\circ}\text{C}$ were predicted for the Cretaceous depo-system. Despite all models resolving similar peak burial temperatures, there is a correlation between the magnitude of burial and AFT sample stratigraphic position, where peak burial temperatures are low for younger strata. This correlation is expected, as new sedimentation contributes to the progressive burial of the underlying rock formations. These results translate to the 2-3 km of burial and subsequent erosion within this foreland basin and are consistent with the published results from the Richardson Mountains, Brackett Basin and Root Basin (Issler et al., 2005; Powell et al., 2019; McKay et al., 2021).

At other localities proximal to the Peel Plateau, similar burial temperatures have been resolved for both Mesozoic and Cretaceous depo-systems via AFT thermal history models. Results presented herein, however, provide a better temporal constraint and yield more accurate burial temperatures. For example, for the earlier depo-system, the timing of peak burial predicted by existing models in the Mackenzie Plain is loosely constrained, varying between 60-150 Myr within individual models, whereas peak burial temperatures vary up to 50°C and are slightly lower than estimates reported here (Powell et al., 2019). Similar temperature and temporal discrepancies are observed for the Cretaceous depo-system. These models account for multi-kinetic AFT population and resolved 300 time-temperature pathways using a Monte Carlo with a statistical significance of 0.05. Our models use the same approach, however, after resolving MC solutions, the search space was redefined by the MC solutions, and an additional 300 time-temperature pathways are resolved through a controlled random search (CRS) with a statistical significance of 0.5 (Issler, 1996; Price, 1977; Willett, 1997; Issler et al., 2022). I think the CRS approach produces better more refined

results and suggest applying this method in future studies. In comparison, AFT thermal history models in the Mackenzie Plain by Enkelmann et al. (2019) resolve significantly higher burial temperatures ($\sim 140^{\circ}\text{C}$) and predict the onset of cooling to have occurred during the Oligocene-Early Miocene, which is not observed elsewhere. The study, however, did not measure apatite grain-chemistry and consequently does not utilize the multi-kinetic approach. Differences between thermal history models presented here and the existing results highlight the usefulness of the kinetic parameter $r_{\text{mr}0}$ and integrating the CRS method into thermal history models.

5.4 Advantages and limitation of $r_{\text{mr}0}$ and multi-kinetic AFT data

Annealing kinetics vary among different apatite specimens and dictate the rate and range of temperatures within which fission tracks are shortened and eventually erased. The resolution of AFT thermal history models reflects how accurately the annealing kinetics of individual apatite grains are characterized. The variables of D_{par} , F- and Cl-content have traditionally been used as kinetic proxies, however laboratory-based experiments have demonstrated that numerous elemental substitutions influence annealing (Barbarand et al., 2003; Carlson et al., 1999; Ketcham et al., 1999). The effects of different elemental substitutions on retentivity have been parametrized to develop the empirical $r_{\text{mr}0}$ equation, which can be used to quantify the annealing kinetics of any apatite specimen by incorporating its measured stoichiometric chemistry into its formula (Carlson et al., 1999; Ketcham et al., 1999).

AFT samples from the Tauern Window and the Peel Plateau were characterized based on their grain-specific $r_{\text{mr}0}$ (derived from grain-specific chemistry) and these data were assessed to determine whether those AFT samples are comprised of multi-kinetic populations. Then, the annealing kinetics defined by $r_{\text{mr}0}$ were integrated into thermal history models. Analysis of the AFT

samples in the Tauern Window indicate the retentivity of these apatite are controlled by minor elemental substitutions of Fe, Mn and Mg, and not influenced by Cl- and F-concentrations. Traditional kinetic proxies would have incorrectly characterized the retentivity of these apatite, exemplifying the utility of the kinetic parameter r_{mr0} .

Within AFT samples from the Peel Plateau, single-grain AFT dates are over-dispersed (i.e., fail the X^2 test), are comprised of apatite with a wide range of annealing kinetics, and single-grain AFT dates correlate to the retentivity predicted by r_{mr0} . In comparison, only one AFT sample from the Tauern Window (JS11 from the Nordrahmen Zone; NRZ) is comprised of apatite with a significant range of r_{mr0} values, but single-grain AFT dates from this sample define a statistically significant age population (i.e., pass the X^2 test) and there was no correlation between retentivity and single-grain AFT dates. The samples from the Peel Plateau are from detrital sedimentary rocks, and the apatite likely originated from various source rocks of different provenances, resulting in heterogenous mineral chemistries. Similarly, the AFT sample from the Tauern Window with variable annealing kinetics has a sedimentary protolith (meta-litharenite) whereas AFT samples sourced from metamorphosed igneous rocks (in the Tauern Window) share comparable annealing kinetics.

Partially annealed AFT samples are ideal for multi-kinetic thermal history modeling as these apatite respond differently to the same thermal events: less retentive apatite (higher r_{mr0} values) anneal at lower temperatures and at a faster rate compared to more retentive apatite grains. As a result, when a rock resides within the PAZ, fission tracks from less retentive apatite experience more extensive track shortening, ultimately reducing the track density and producing younger single-grain AFT ages. AFT samples from the Peel Plateau are partially annealed, as retentive apatite typically record older single grain AFT dates. Prior to thermal history modeling,

multi-kinetic populations were discerned by defining groups of apatite that exhibit distinct annealing behaviors (similar r_{mr0} values) and record similar single-grain AFT dates.

In comparison, for the AFT sample from the Tauern Window with variable annealing kinetics (JS11 from the NRZ), single-grain AFT dates are consistent regardless of r_{mr0} values. This indicates the duration of time that the sample resided in the PAZ was too short to significantly reduce the density of fission tracks. Since all apatite grains record the same age information regardless of annealing kinetics, no multi-kinetic populations could be discerned. For all AFT samples from the Tauern Window, there is, however, a correlation between the orientation and the lengths of fission tracks: fission track lengths are increasingly shorter as they are mis-aligned to the crystallographic c-axis. This correlation reflects the anisotropy of annealing processes, as the rate of thermal annealing increases for tracks that are increasingly mis-aligned to the c-axis. This correlation evinces a short residency within the PAZ that allows a minor component of thermal annealing to produce the observed track length distribution (Gleadow et al., 1986). For the AFT samples in the Tauern Window, average r_{mr0} values were incorporated into AFT thermal history models. The results predict the onset of cooling to have occurred ~2-3 Myr prior to their empirical AFT date and allot 4-6 Myr to cool across their respective PAZ. Results from the Tauern Window highlight the limitation of multi-kinetic AFT thermal history modeling for rapidly exhumed deep-seated rocks.

Contrary to the Tauern Window, partially annealed AFT dates from the Peel Plateau were separated into multi-kinetic populations with statistically significant pooled ages. Different kinetic populations act as independent thermochronometers as their respective PAZ is determined based on the retentivity of the apatite within that population. The practicality of the multi-kinetic approach is illustrated by the results from the oldest AFT sample (Late Devonian) which has

undergone more than one cycle of burial and unroofing. Apatite from this sample can be separated into two kinetic populations: a more retentive population with a Jurassic pooled age, and a less retentive population with a Cretaceous pooled age. Thermal history model results predict significantly higher burial temperatures for the first depo-system, whereas the less retentive population was completely annealed during initial burial but is better suited to resolve the thermal history of the second burial and unroofing event. The utility of incorporating the multi-kinetic approach is further examined by comparing thermal history models for the Albian sample which: i) characterize the apatite as single kinetic population and uses the average r_{mr0} value, and ii) separates the apatite into two kinetic populations and uses a representative r_{mr0} value for each population. The same input constraints were used to produce both models and are defined by realistic cooling and heating rates and the temperatures associated with known geologic events. Overall, time-temperature in the mono-kinetic model encroach on the input constraints and predict burial temperatures that are $\sim 40^{\circ}\text{C}$ hotter than results from the multi-kinetic data. Time-temperature pathways from the mono-kinetic model would have preferentially resolved solutions that are geologically implausible, as the input constraints require surface exposure across the Albian-Cenomanian boundary to explain the paleosols documented in the Peel Plateau (Hadlari et al., 2014; Pyle and Jones, 2009). In comparison, time-temperature pathways from the multi-kinetic model converge to a narrow pathway that do not impede on the input constraints and are deemed more realistic, as the data comprise statistically significant age populations. Interpretations that neglect multi-kinetic populations would significantly overestimate thermal maturation and this comparison exemplifies that accounting for multi-kinetic populations within AFT samples can produce more plausible thermal history models.

Traditionally, the thermal maturation of prospective hydrocarbon reservoirs has relied on peak burial temperature estimates based on the modification of organic material during burial, such as vitrinite reflectance (%Ro; Barker and Pawlewicz, 2005). Organic material is susceptible to recycling which can inaccurately estimate thermal maturation and it cannot not constrain the timing of peak burial, nor does it reveal information regarding multiple burial events (Nzoussi-Mbassani et al., 2005; Nielsen et al., 2017). Thermal history models from multi-kinetic AFT data are a powerful tool for hydrocarbon exploration, as they produce time-resolved solutions and can resolve multiple burial and exhumation events. By accounting for grain-specific annealing kinetics, multi-kinetic models can more accurately reconstruct complex thermal histories, providing critical insights into the timing, duration, and magnitude of heating events that influence the maturation and preservation of hydrocarbons.

It is important to note that defining multi-kinetic populations can be challenging, and particular groups can produce plausible thermal history models. Comparing model results from different groupings to the measured AFT data can help decipher which arrangement of multi-kinetic groupings best represents the AFT sample. Furthermore, thermal history models are themselves interpretations. Therefore, it is important to include realistic time-temperature constraints that represent the region's tectonic history to produce meaningful results. Ultimately, thermal history models from the Peel Plateau and Tauern Window highlight the utility of the kinetic parameter r_{mr0} , as well as the applications and limitations of multi-kinetic AFT populations. The multi-kinetic method is an innovative approach in thermochronology with implications for both academic research and resource exploration.

5.5 Direction for future work

The research in this dissertation exemplifies how complex exhumation histories can be resolved using innovative geo- and thermochronometers and structural data. For future work in the Tauern Window, field investigations mapping the extent of the Schuhflicker Detachment and structures related to the ETDS would contribute to further comprehend its geometry and quantify its contribution to mid- upper- crustal exhumation. Furthermore, to properly assess whether AFT thermal history models truly detect a signature of the ETDS requires a higher sampling density across this structure. As different thermochronometers are sensitive to various temperatures (AHe, ZHe, AFT, ZFT), dating the same sample using multiple techniques would provide multiple time-temperature constraints. AFT thermal history models from the Peel Plateau and the Tauern Window could be refined by dating the same samples via AHe, ZHe and ZFT and incorporating this data as input constraints within the models. Finally, AFT thermal history models presented in this thesis demonstrate that the r_{mr0} parameter is a more accurate proxy for annealing kinetics than D_{par} , F content or Cl content, and should be incorporated into the workflow for future research projects using AFT data in geosciences.

5.6 References

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APPENDIX A

SUPPLEMENTARY INFORMATION FOR CHAPTER 2

Table S2.1. Apatite chemistry for all AFT age and length grains, Peel Plateau, NWT, Canada

Grain #	Na (apfu)	Mg (apfu)	P (apfu)	S (apfu)	Ca (apfu)	Mn (apfu)	Fe (apfu)	As (apfu)	Si (apfu)	Al (apfu)	Sr (apfu)	Y (apfu)	La (apfu)	Ce (apfu)	F (apfu)	Cl (apfu)	OH (apfu)	TOTAL (apfu)	rmr0	Ca SITE 10	P SITE 6	F+Cl+OH 2	TOTAL WT% OX	TOTAL WT% OX
16FNA007A01, Trevor Fm. (chert arenite), 65.50878567, -131.05855233, 398.9 masl																								
AFT Age-Grains																								
1	0.003	0.003	5.967	0.000	9.953	0.000	0.000	0.000	0.000	0.000	0.124	0.000	0.000	0.000	2.282	0.000	0.000	18	0.860	10.080	5.97	2.28	99.14	99.14
3	0.046	0.092	5.894	0.035	9.913	0.013	0.045	0.000	0.000	0.000	0.012	0.010	0.009	0.023	1.464	0.123	0.414	18	0.744	10.160	5.93	2.00	98.75	98.75
4	0.022	0.094	5.980	0.002	9.824	0.026	0.055	0.000	0.000	0.000	0.014	0.008	0.000	0.006	0.998	0.213	0.789	18	0.665	10.050	5.98	2.00	99.44	99.44
5	0.048	0.039	5.918	0.020	9.969	0.027	0.035	0.000	0.000	0.000	0.012	0.004	0.008	0.014	1.048	0.308	0.644	18	0.689	10.150	5.94	2.00	99.17	99.17
7	0.020	0.012	5.956	0.000	9.944	0.021	0.031	0.000	0.000	0.000	0.009	0.019	0.012	0.025	1.167	0.131	0.702	18	0.749	10.090	5.96	2.00	98.47	98.47
9	0.024	0.032	5.941	0.000	10.025	0.008	0.021	0.000	0.000	0.000	0.006	0.007	0.007	0.015	1.902	0.057	0.040	18	0.823	10.140	5.94	2.00	98.46	98.46
15	0.020	0.055	5.886	0.021	10.048	0.004	0.027	0.000	0.000	0.000	0.040	0.005	0.006	0.015	1.327	0.050	0.623	18	0.786	10.220	5.91	2.00	98.22	98.22
17	0.125	0.025	5.788	0.130	9.859	0.012	0.019	0.000	0.000	0.000	0.055	0.007	0.021	0.043	1.383	0.075	0.542	18	0.781	10.170	5.92	2.00	97.62	97.62
19	0.028	0.020	5.856	0.032	10.135	0.003	0.018	0.000	0.000	0.000	0.057	0.000	0.006	0.006	1.509	0.008	0.484	18	0.815	10.270	5.89	2.00	95.81	95.81
20	0.007	0.005	5.999	0.000	9.959	0.000	0.000	0.000	0.000	0.000	0.031	0.004	0.000	0.000	2.102	0.002	0.000	18	0.864	10.000	6	2.10	99.46	99.46
21	0.019	0.043	5.979	0.000	9.904	0.013	0.052	0.000	0.000	0.000	0.007	0.007	0.004	0.006	1.288	0.184	0.528	18	0.718	10.050	5.98	2.00	98.92	98.92
22	0.012	0.004	5.972	0.000	9.828	0.002	0.006	0.000	0.000	0.000	0.221	0.000	0.003	0.000	2.266	0.006	0.000	18	0.845	10.080	5.97	2.27	99.81	99.81
23	0.016	0.020	5.936	0.001	10.023	0.009	0.049	0.000	0.000	0.000	0.008	0.011	0.003	0.011	1.710	0.028	0.262	18	0.783	10.150	5.94	2.00	98.86	98.86
24	0.037	0.056	5.862	0.067	10.010	0.004	0.017	0.000	0.000	0.000	0.024	0.000	0.004	0.006	1.107	0.043	0.850	18	0.789	10.160	5.93	2.00	98.46	98.46
25	0.021	0.049	5.964	0.000	9.936	0.003	0.019	0.000	0.000	0.000	0.047	0.004	0.005	0.010	1.786	0.027	0.187	18	0.824	10.090	5.96	2.00	99.54	99.54
26	0.009	0.005	5.897	0.000	10.209	0.017	0.005	0.000	0.000	0.000	0.006	0.008	0.000	0.000	1.706	0.018	0.276	18	0.838	10.260	5.9	2.00	98.00	98.00
27	0.019	0.016	5.967	0.001	9.935	0.023	0.040	0.000	0.000	0.000	0.010	0.010	0.007	0.015	1.186	0.130	0.685	18	0.738	10.070	5.97	2.00	98.81	98.81
28	0.022	0.014	5.945	0.000	10.007	0.021	0.026	0.000	0.000	0.000	0.011	0.010	0.005	0.018	1.180	0.129	0.691	18	0.760	10.130	5.94	2.00	99.16	99.16
29	0.028	0.021	5.886	0.052	9.941	0.004	0.014	0.000	0.000	0.000	0.079	0.007	0.010	0.021	1.178	0.041	0.781	18	0.795	10.120	5.94	2.00	98.88	98.88
30	0.029	0.000	5.917	0.022	10.079	0.008	0.013	0.000	0.000	0.000	0.008	0.007	0.000	0.006	1.899	0.002	0.099	18	0.843	10.150	5.94	2.00	98.31	98.31
31	0.017	0.057	5.983	0.003	9.827	0.014	0.076	0.000	0.000	0.000	0.012	0.006	0.007	0.015	1.380	0.144	0.475	18	0.684	10.030	5.99	2.00	98.88	98.88
34	0.058	0.029	5.910	0.049	9.915	0.029	0.031	0.000	0.000	0.000	0.009	0.005	0.007	0.012	0.771	0.434	0.795	18	0.636	10.090	5.96	2.00	95.10	95.10
35	0.055	0.038	5.766	0.108	10.092	0.006	0.020	0.000	0.000	0.000	0.038	0.004	0.008	0.016	0.899	0.041	1.060	18	0.778	10.280	5.87	2.00	95.69	95.69
36	0.010	0.005	5.945	0.002	10.103	0.000	0.010	0.000	0.000	0.000	0.004	0.003	0.000	0.000	1.467	0.002	0.531	18	0.832	10.130	5.95	2.00	97.36	97.36
37	0.017	0.003	5.917	0.003	10.103	0.009	0.051	0.000	0.000	0.000	0.004	0.012	0.000	0.003	1.522	0.010	0.468	18	0.775	10.200	5.92	2.00	98.61	98.61
38	0.054	0.033	5.798	0.090	10.056	0.005	0.025	0.000	0.000	0.000	0.043	0.004	0.009	0.020	0.908	0.054	1.038	18	0.766	10.250	5.89	2.00	97.43	97.43
39	0.031	0.045	5.913	0.034	9.942	0.006	0.017	0.000	0.000	0.000	0.048	0.003	0.007	0.018	1.394	0.048	0.558	18	0.801	10.120	5.95	2.00	97.38	97.38
40	0.019	0.014	5.965	0.000	9.937	0.021	0.034	0.000	0.000	0.000	0.007	0.016	0.010	0.019	1.179	0.127	0.694	18	0.747	10.080	5.96	2.00	98.52	98.52
AFT Length-Grains																								
3	0.021	0.020	5.958	0.002	9.966	0.019	0.028	0.000	0.000	0.000	0.007	0.011	0.005	0.016	1.142	0.127	0.731	18	0.756	10.090	5.96	2.00	94.76	94.76
5	0.048	0.094	5.882	0.036	9.930	0.014	0.051	0.000	0.000	0.000	0.012	0.010	0.009	0.023	1.528	0.108	0.364	18	0.741	10.190	5.92	2.00	97.03	97.03
6	0.096	0.025	5.807	0.101	9.894	0.012	0.019	0.000	0.000	0.000	0.064	0.007	0.022	0.049	1.475	0.079	0.446	18	0.787	10.190	5.91	2.00	97.78	97.78
8	0.019	0.058	5.959	0.000	9.906	0.014	0.065	0.000	0.000	0.000	0.010	0.007	0.007	0.014	1.359	0.139	0.502	18	0.706	10.100	5.96	2.00	99.72	99.72
9	0.010	0.003	5.874	0.000	10.224	0.000	0.006	0.000	0.000	0.000	0.078	0.000	0.000	0.000	2.359	0.000	0.000	19	0.856	10.320	5.87	2.36	98.79	98.79
11	0.021	0.014	5.952	0.002	9.975	0.019	0.039	0.000	0.000	0.000	0.007	0.011	0.007	0.016	1.181	0.118	0.701	18	0.742	10.110	5.95	2.00	96.69	96.69
12	0.024	0.013	5.963	0.001	9.948	0.022	0.033	0.000	0.000	0.000	0.007	0.011	0.008	0.017	1.245	0.133	0.622	18	0.751	10.080	5.96	2.00	98.77	98.77
13	0.015	0.073	5.941	0.003	9.937	0.013	0.063	0.000	0.000	0.000	0.013	0.008	0.004	0.009	0.994	0.109	0.897	18	0.688	10.130	5.94	2.00	96.17	96.17
14	0.057	0.095	5.879	0.029	9.934	0.011	0.047	0.000	0.000	0.000	0.016	0.005	0.016	0.034	1.761	0.097	0.143	18	0.763	10.220	5.91	2.00	94.60	94.60

Grain #	Na (apfu)	Mg (apfu)	P (apfu)	S (apfu)	Ca (apfu)	Mn (apfu)	Fe (apfu)	As (apfu)	Si (apfu)	Al (apfu)	Sr (apfu)	Y (apfu)	La (apfu)	Ce (apfu)	F (apfu)	Cl (apfu)	OH (apfu)	TOTAL (apfu)	rmr0	Ca SITE 10	P SITE 6	F+Cl+OH 2	TOTAL WT% OX	TOTAL WT% OX
15	0.054	0.006	5.863	0.014	10.119	0.007	0.012	0.000	0.000	0.000	0.072	0.005	0.012	0.019	1.103	0.006	0.891	18	0.797	10.310	5.88	2.00	97.66	97.66
16	0.015	0.006	5.914	0.003	10.118	0.026	0.014	0.000	0.000	0.000	0.008	0.005	0.004	0.009	1.808	0.036	0.156	18	0.825	10.210	5.92	2.00	96.66	96.66
17	0.017	0.011	5.980	0.000	9.969	0.009	0.026	0.000	0.000	0.000	0.005	0.005	0.004	0.007	0.734	0.022	1.245	18	0.791	10.050	5.98	2.00	99.06	99.06
18	0.020	0.032	5.926	0.000	9.952	0.021	0.050	0.000	0.000	0.000	0.019	0.012	0.016	0.040	1.292	0.105	0.603	18	0.729	10.160	5.93	2.00	98.76	98.76
19	0.025	0.003	5.913	0.043	10.024	0.013	0.013	0.000	0.000	0.000	0.004	0.004	0.004	0.005	1.089	0.159	0.752	18	0.776	10.100	5.96	2.00	98.22	98.22
20	0.015	0.002	5.909	0.021	10.109	0.009	0.008	0.000	0.000	0.000	0.009	0.003	0.005	0.006	1.570	0.014	0.416	18	0.832	10.160	5.93	2.00	98.82	98.82
22	0.107	0.057	5.903	0.018	9.953	0.011	0.047	0.000	0.000	0.000	0.048	0.000	0.000	0.012	1.155	0.006	0.839	18	0.743	10.230	5.92	2.00	95.50	95.50
23	0.035	0.017	5.878	0.032	10.031	0.005	0.020	0.000	0.000	0.000	0.064	0.006	0.009	0.020	0.946	0.024	1.029	18	0.781	10.210	5.91	2.00	98.70	98.70
24	0.018	0.002	5.909	0.016	10.055	0.022	0.043	0.000	0.000	0.000	0.004	0.000	0.012	0.018	1.451	0.194	0.355	18	0.739	10.170	5.92	2.00	94.67	94.67
25	0.051	0.006	5.915	0.052	9.957	0.019	0.017	0.000	0.000	0.000	0.009	0.003	0.005	0.008	1.139	0.092	0.769	18	0.778	10.080	5.97	2.00	99.74	99.74
27	0.058	0.004	5.945	0.006	9.988	0.003	0.016	0.000	0.000	0.000	0.048	0.000	0.007	0.014	1.226	0.002	0.772	18	0.803	10.140	5.95	2.00	97.96	97.96
28	0.020	0.012	5.946	0.000	9.992	0.022	0.036	0.000	0.000	0.000	0.011	0.013	0.006	0.015	1.263	0.119	0.618	18	0.750	10.130	5.95	2.00	98.60	98.60
29	0.030	0.062	5.947	0.000	9.905	0.013	0.041	0.000	0.000	0.000	0.028	0.008	0.013	0.025	1.255	0.145	0.600	18	0.735	10.130	5.95	2.00	98.85	98.85

16FNA006A01, Martin House Fm. (lithic wacke), 65.46295917, -131.125593, 432 masl

AFT Age-Grains

1	0.024	0.008	5.867	0.019	10.190	0.002	0.006	0.000	0.000	0.000	0.045	0.004	0.000	0.004	0.937	0.007	1.057	18	0.810	10.280	5.89	2.00	98.93	98.93
2	0.013	0.006	5.878	0.012	10.193	0.000	0.005	0.000	0.000	0.000	0.057	0.002	0.000	0.000	1.254	0.000	0.746	18	0.824	10.280	5.89	2.00	98.93	98.93
3	0.044	0.021	5.933	0.007	10.046	0.003	0.003	0.000	0.000	0.000	0.030	0.000	0.004	0.012	0.701	0.000	1.299	18	0.825	10.160	5.94	2.00	99.24	99.24
4	0.022	0.036	5.925	0.000	10.009	0.012	0.041	0.000	0.000	0.000	0.013	0.008	0.013	0.022	2.140	0.163	0.000	18	0.773	10.180	5.93	2.30	98.66	98.66
8	0.023	0.000	5.949	0.000	10.079	0.015	0.004	0.000	0.000	0.000	0.003	0.011	0.000	0.000	1.878	0.003	0.118	18	0.850	10.130	5.95	2.00	99.12	99.12
9	0.078	0.063	5.962	0.015	9.709	0.027	0.031	0.000	0.000	0.000	0.012	0.010	0.030	0.072	1.649	0.076	0.275	18	0.772	10.030	5.98	2.00	98.24	98.24
10	0.041	0.040	5.961	0.015	9.841	0.037	0.034	0.000	0.000	0.000	0.012	0.009	0.011	0.025	0.779	0.497	0.725	18	0.596	10.050	5.98	2.00	97.77	97.77
11	0.034	0.055	5.895	0.022	10.008	0.023	0.062	0.000	0.000	0.000	0.008	0.000	0.007	0.011	0.803	0.256	0.941	18	0.622	10.210	5.92	2.00	94.92	94.92
14	0.063	0.005	5.873	0.009	10.153	0.000	0.004	0.000	0.000	0.000	0.044	0.000	0.010	0.026	1.107	0.005	0.888	18	0.813	10.300	5.88	2.00	96.44	96.44
15	0.016	0.002	5.956	0.008	10.031	0.036	0.003	0.000	0.000	0.000	0.006	0.000	0.000	0.000	1.919	0.004	0.077	18	0.844	10.090	5.96	2.00	98.87	98.87
18	0.011	0.056	5.906	0.004	10.073	0.006	0.046	0.000	0.000	0.000	0.009	0.004	0.005	0.010	1.696	0.024	0.281	18	0.786	10.220	5.91	2.00	96.12	96.12
20	0.100	0.035	5.879	0.009	10.042	0.012	0.029	0.000	0.000	0.000	0.062	0.005	0.005	0.020	1.287	0.011	0.702	18	0.776	10.310	5.89	2.00	96.94	96.94
21	0.012	0.004	5.940	0.016	10.024	0.009	0.006	0.000	0.000	0.000	0.029	0.003	0.007	0.008	1.772	0.019	0.209	18	0.842	10.100	5.96	2.00	98.44	98.44
22	0.025	0.004	5.861	0.042	10.129	0.017	0.004	0.000	0.000	0.000	0.002	0.003	0.017	0.017	1.801	0.027	0.173	18	0.840	10.220	5.9	2.00	96.34	96.34
23	0.011	0.003	5.882	0.024	10.170	0.008	0.003	0.000	0.000	0.000	0.007	0.008	0.000	0.010	1.654	0.048	0.298	18	0.837	10.220	5.91	2.00	93.87	93.87
24	0.052	0.022	5.861	0.045	10.055	0.020	0.022	0.000	0.000	0.000	0.016	0.009	0.008	0.019	0.932	0.431	0.637	18	0.681	10.220	5.91	2.00	95.08	95.08
25	0.016	0.008	5.922	0.010	10.046	0.009	0.007	0.000	0.000	0.000	0.007	0.006	0.017	0.030	1.653	0.109	0.238	18	0.821	10.150	5.93	2.00	94.27	94.27
26	0.013	0.004	5.949	0.000	10.021	0.008	0.006	0.000	0.000	0.000	0.037	0.009	0.005	0.016	2.119	0.003	0.000	18	0.853	10.120	5.95	2.12	98.11	98.11
27	0.015	0.011	5.918	0.009	10.107	0.009	0.008	0.000	0.000	0.000	0.003	0.005	0.006	0.014	1.727	0.010	0.263	18	0.839	10.180	5.93	2.00	97.17	97.17
28	0.028	0.002	5.864	0.047	10.075	0.006	0.005	0.000	0.000	0.000	0.011	0.011	0.011	0.035	1.998	0.003	0.000	18	0.853	10.180	5.91	2.00	97.35	97.35
29	0.019	0.002	5.906	0.022	10.128	0.006	0.004	0.000	0.000	0.000	0.007	0.000	0.003	0.007	2.064	0.010	0.000	18	0.857	10.170	5.93	2.07	99.41	99.41
31	0.032	0.004	5.951	0.005	9.916	0.132	0.006	0.000	0.000	0.000	0.005	0.015	0.000	0.004	1.666	0.007	0.327	18	0.780	10.110	5.96	2.00	96.64	96.64
32	0.007	0.009	5.944	0.000	10.105	0.008	0.005	0.000	0.000	0.000	0.010	0.000	0.000	0.000	1.273	0.037	0.689	18	0.820	10.140	5.94	2.00	97.44	97.44
34	0.011	0.003	5.952	0.000	10.018	0.028	0.008	0.000	0.000	0.000	0.007	0.013	0.005	0.015	1.487	0.000	0.513	18	0.820	10.110	5.95	2.00	97.78	97.78
35	0.035	0.006	5.989	0.013	9.916	0.018	0.007	0.000	0.000	0.000	0.007	0.003	0.003	0.007	1.213	0.034	0.753	18	0.808	10.000	6	2.00	97.36	97.36
36	0.036	0.004	5.965	0.001	9.974	0.019	0.005	0.000	0.000	0.000	0.003	0.023	0.004	0.014	1.771	0.000	0.229	18	0.839	10.080	5.97	2.00	97.20	97.20

Grain #	Na (apfu)	Mg (apfu)	P (apfu)	S (apfu)	Ca (apfu)	Mn (apfu)	Fe (apfu)	As (apfu)	Si (apfu)	Al (apfu)	Sr (apfu)	Y (apfu)	La (apfu)	Ce (apfu)	F (apfu)	Cl (apfu)	OH (apfu)	TOTAL (apfu)	rmr0	Ca SITE 10	P SITE 6	F+Cl+OH 2	TOTAL WT% OX	TOTAL WT% OX
37	0.088	0.023	5.958	0.007	9.834	0.011	0.012	0.000	0.000	0.000	0.103	0.002	0.011	0.025	1.335	0.009	0.656	18	0.802	10.110	5.97	2.00	97.01	97.01
38	0.014	0.051	5.939	0.006	9.967	0.021	0.047	0.000	0.000	0.000	0.011	0.011	0.003	0.007	1.056	0.222	0.722	18	0.692	10.130	5.94	2.00	99.29	99.29
39	0.040	0.032	5.901	0.016	9.973	0.015	0.033	0.000	0.000	0.000	0.013	0.006	0.022	0.048	1.364	0.224	0.412	18	0.738	10.180	5.92	2.00	97.09	97.09
40	0.012	0.002	5.973	0.000	9.988	0.011	0.004	0.000	0.000	0.000	0.003	0.029	0.000	0.007	1.593	0.007	0.401	18	0.837	10.060	5.97	2.00	99.31	99.31

AFT Length-Grains

1	0.019	0.008	5.854	0.018	10.234	0.000	0.005	0.000	0.000	0.000	0.043	0.000	0.003	0.004	0.932	0.007	1.061	18	0.813	10.320	5.87	2.00	97.39	97.39
4	0.045	0.026	5.904	0.008	10.103	0.000	0.004	0.000	0.000	0.000	0.027	0.003	0.005	0.014	0.807	0.003	1.190	18	0.819	10.230	5.91	2.00	96.15	96.15
6	0.025	0.002	5.891	0.001	10.191	0.000	0.004	0.000	0.000	0.000	0.038	0.002	0.004	0.007	0.842	0.007	1.151	18	0.818	10.270	5.89	2.00	99.15	99.15
7	0.081	0.064	5.931	0.014	9.795	0.025	0.028	0.000	0.000	0.000	0.009	0.010	0.032	0.070	1.619	0.079	0.303	18	0.775	10.110	5.95	2.00	97.77	97.77
8	0.034	0.037	5.958	0.015	9.859	0.038	0.034	0.000	0.000	0.000	0.011	0.009	0.010	0.024	0.802	0.469	0.729	18	0.609	10.060	5.97	2.00	98.18	98.18
9	0.164	0.115	5.903	0.024	9.844	0.009	0.045	0.000	0.000	0.000	0.049	0.003	0.003	0.012	0.842	0.045	1.113	18	0.721	10.240	5.93	2.00	96.81	96.81
13	0.028	0.006	5.919	0.004	10.086	0.014	0.014	0.000	0.000	0.000	0.011	0.009	0.008	0.014	1.598	0.063	0.339	18	0.814	10.190	5.92	2.00	97.02	97.02
14	0.009	0.013	5.911	0.012	10.074	0.010	0.005	0.000	0.000	0.000	0.005	0.006	0.016	0.028	1.552	0.105	0.344	18	0.818	10.170	5.92	2.00	93.17	93.17
15	0.058	0.023	5.852	0.049	10.064	0.021	0.023	0.000	0.000	0.000	0.013	0.008	0.007	0.019	0.968	0.406	0.626	18	0.687	10.240	5.9	2.00	96.84	96.84
16	0.080	0.012	5.878	0.079	9.899	0.013	0.017	0.000	0.000	0.000	0.021	0.000	0.015	0.029	1.448	0.134	0.418	18	0.786	10.090	5.96	2.00	98.78	98.78
17	0.043	0.031	5.925	0.014	9.959	0.033	0.041	0.000	0.000	0.000	0.007	0.015	0.006	0.016	1.023	0.358	0.618	18	0.656	10.150	5.94	2.00	93.12	93.12
18	0.057	0.035	5.855	0.042	9.987	0.020	0.036	0.000	0.000	0.000	0.015	0.006	0.024	0.046	1.354	0.285	0.361	18	0.714	10.230	5.9	2.00	95.41	95.41
19	0.069	0.011	5.885	0.060	9.931	0.014	0.019	0.000	0.000	0.000	0.023	0.005	0.014	0.031	1.455	0.133	0.412	18	0.783	10.120	5.94	2.00	98.53	98.53
20	0.030	0.007	5.944	0.002	10.046	0.007	0.021	0.000	0.000	0.000	0.006	0.015	0.000	0.005	1.649	0.011	0.340	18	0.819	10.140	5.95	2.00	99.13	99.13
21	0.127	0.096	5.939	0.012	9.856	0.010	0.045	0.000	0.000	0.000	0.034	0.000	0.000	0.009	0.925	0.016	1.059	18	0.734	10.180	5.95	2.00	97.85	97.85
22	0.005	0.005	5.984	0.000	9.982	0.007	0.003	0.000	0.000	0.000	0.013	0.004	0.003	0.013	1.941	0.002	0.057	18	0.856	10.030	5.98	2.00	98.57	98.57
23	0.019	0.003	5.973	0.000	10.011	0.013	0.011	0.000	0.000	0.000	0.004	0.011	0.000	0.000	1.771	0.003	0.226	18	0.837	10.070	5.97	2.00	100.25	100.25
24	0.010	0.007	5.956	0.000	10.022	0.009	0.012	0.000	0.000	0.000	0.015	0.006	0.008	0.013	1.469	0.128	0.403	18	0.804	10.100	5.96	2.00	98.39	98.39
25	0.054	0.072	5.967	0.006	9.827	0.011	0.038	0.000	0.000	0.000	0.053	0.005	0.007	0.014	1.641	0.129	0.230	18	0.766	10.080	5.97	2.00	98.25	98.25
26	0.057	0.004	5.992	0.000	9.906	0.008	0.011	0.000	0.000	0.000	0.000	0.032	0.003	0.006	1.814	0.016	0.169	18	0.836	10.030	5.99	2.00	98.72	98.72
27	0.011	0.002	5.978	0.000	10.014	0.009	0.007	0.000	0.000	0.000	0.003	0.010	0.000	0.000	1.960	0.016	0.024	18	0.851	10.060	5.98	2.00	97.84	97.84
28	0.023	0.008	5.962	0.004	10.009	0.010	0.008	0.000	0.000	0.000	0.012	0.016	0.000	0.000	1.201	0.088	0.711	18	0.800	10.090	5.97	2.00	97.88	97.88
29	0.056	0.002	5.955	0.036	9.896	0.010	0.004	0.000	0.000	0.000	0.008	0.006	0.009	0.022	1.709	0.040	0.251	18	0.834	10.010	5.99	2.00	98.29	98.29
30	0.008	0.002	5.961	0.000	10.031	0.010	0.004	0.000	0.000	0.000	0.002	0.012	0.003	0.016	2.018	0.004	0.000	18	0.856	10.090	5.96	2.02	98.75	98.75
31	0.012	0.007	5.964	0.000	10.043	0.012	0.005	0.000	0.000	0.000	0.006	0.005	0.000	0.003	2.066	0.003	0.000	18	0.855	10.090	5.96	2.07	99.03	99.03
32	0.047	0.003	5.984	0.000	9.926	0.000	0.000	0.000	0.000	0.000	0.014	0.045	0.000	0.004	2.173	0.000	0.000	18	0.861	10.040	5.98	2.17	98.21	98.21
33	0.022	0.000	5.876	0.005	10.034	0.004	0.003	0.000	0.000	0.000	0.105	0.004	0.028	0.060	1.717	0.003	0.280	18	0.836	10.260	5.88	2.00	97.15	97.15

16FNA008B01, Imperial Fm (lithic wacke) 65.41090817, -131.41356184, 722.3 masl

AFT Age-Grains

2	0.010	0.033	5.961	0.000	10.040	0.017	0.007	0.000	0.000	0.000	0.002	0.006	0.002	0.009	1.369	0.037	0.594	18	0.817	10.090	5.96	2.00	99.36	99.36
13	0.019	0.004	5.929	0.003	10.005	0.014	0.048	0.000	0.000	0.000	0.004	0.019	0.007	0.022	1.411	0.095	0.494	18	0.750	10.150	5.93	2.00	98.21	98.21
23	0.030	0.000	5.922	0.000	10.050	0.012	0.004	0.000	0.000	0.000	0.000	0.060	0.004	0.010	1.854	0.009	0.137	18	0.844	10.170	5.92	2.00	97.65	97.65
27	0.115	0.004	5.858	0.094	9.730	0.018	0.020	0.000	0.000	0.000	0.031	0.007	0.033	0.072	1.875	0.073	0.052	18	0.801	10.080	5.95	2.00	97.78	97.78
28	0.018	0.081	5.930	0.015	10.048	0.028	0.018	0.000	0.000	0.000	0.004	0.010	0.000	0.003	1.933	0.007	0.061	18	0.830	10.130	5.94	2.00	97.73	97.73
30	0.087	0.063	5.808	0.108	10.037	0.013	0.010	0.000	0.000	0.000	0.009	0.007	0.003	0.014	1.464	0.104	0.432	18	0.803	10.190	5.92	2.00	99.33	99.33
32	0.006	0.039	5.954	0.000	10.054	0.027	0.000	0.000	0.000	0.000	0.006	0.005	0.006	0.007	1.788	0.029	0.182	18	0.842	10.110	5.95	2.00	99.95	99.95

Grain #	Na (apfu)	Mg (apfu)	P (apfu)	S (apfu)	Ca (apfu)	Mn (apfu)	Fe (apfu)	As (apfu)	Si (apfu)	Al (apfu)	Sr (apfu)	Y (apfu)	La (apfu)	Ce (apfu)	F (apfu)	Cl (apfu)	OH (apfu)	TOTAL (apfu)	rmr0	Ca SITE 10	P SITE 6	F+Cl+OH 2	TOTAL WT% OX	TOTAL WT% OX
33	0.006	0.017	5.953	0.004	10.053	0.007	0.008	0.000	0.000	0.000	0.009	0.009	0.000	0.006	1.364	0.007	0.629	18	0.825	10.100	5.96	2.00	97.97	97.97
37	0.011	0.055	5.908	0.008	10.133	0.012	0.004	0.000	0.000	0.000	0.005	0.006	0.007	0.016	1.542	0.055	0.403	18	0.828	10.200	5.92	2.00	97.76	97.76
40	0.009	0.055	5.981	0.002	10.017	0.008	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.003	1.909	0.008	0.083	18	0.858	10.040	5.98	2.00	99.55	99.55
AFT Length-Grains																								
1	0.012	0.000	5.989	0.000	9.972	0.018	0.005	0.000	0.000	0.000	0.004	0.005	0.000	0.007	1.563	0.042	0.395	18	0.827	10.030	5.99	2.00	99.51	99.51
3	0.034	0.004	5.940	0.003	10.005	0.016	0.011	0.000	0.000	0.000	0.005	0.017	0.012	0.027	1.401	0.394	0.204	18	0.748	10.130	5.94	2.00	98.76	98.76
4	0.019	0.007	5.963	0.000	9.919	0.014	0.048	0.000	0.000	0.000	0.006	0.021	0.010	0.020	1.396	0.084	0.520	18	0.751	10.080	5.96	2.00	99.58	99.58
6	0.014	0.021	5.926	0.006	10.081	0.021	0.022	0.000	0.000	0.000	0.002	0.008	0.003	0.004	1.932	0.004	0.064	18	0.828	10.170	5.93	2.00	96.16	96.16
7	0.089	0.000	5.842	0.108	9.945	0.014	0.016	0.000	0.000	0.000	0.009	0.004	0.007	0.012	1.455	0.096	0.449	18	0.795	10.100	5.95	2.00	99.14	99.14
10	0.013	0.004	5.997	0.002	9.942	0.011	0.005	0.000	0.000	0.000	0.007	0.005	0.006	0.010	1.834	0.004	0.161	18	0.848	10.000	6	2.00	98.47	98.47
11	0.014	0.044	5.895	0.008	10.164	0.015	0.005	0.000	0.000	0.000	0.004	0.004	0.007	0.014	1.657	0.062	0.281	18	0.829	10.230	5.9	2.00	95.50	95.50
12	0.012	0.003	5.977	0.003	9.982	0.013	0.013	0.000	0.000	0.000	0.004	0.006	0.003	0.008	0.974	0.254	0.773	18	0.752	10.050	5.98	2.00	98.84	98.84
13	0.071	0.000	5.847	0.076	9.913	0.024	0.038	0.000	0.000	0.000	0.014	0.008	0.007	0.018	1.129	0.202	0.668	18	0.710	10.170	5.92	2.00	95.13	95.13
14	0.043	0.005	5.954	0.019	9.892	0.030	0.034	0.000	0.000	0.000	0.007	0.007	0.008	0.021	0.993	0.293	0.714	18	0.690	10.060	5.97	2.00	99.31	99.31
15	0.033	0.018	5.827	0.003	10.189	0.009	0.003	0.000	0.000	0.000	0.008	0.017	0.039	0.075	1.843	0.011	0.145	18	0.841	10.380	5.83	2.00	94.45	94.45
17	0.026	0.032	5.916	0.003	10.038	0.017	0.013	0.000	0.000	0.000	0.000	0.054	0.005	0.019	1.757	0.017	0.226	18	0.826	10.170	5.92	2.00	95.62	95.62
18	0.008	0.042	5.924	0.001	10.098	0.008	0.007	0.000	0.000	0.000	0.003	0.018	0.005	0.019	1.811	0.007	0.182	18	0.844	10.170	5.92	2.00	98.27	98.27
19	0.011	0.014	5.963	0.000	9.989	0.028	0.014	0.000	0.000	0.000	0.012	0.013	0.003	0.011	1.598	0.016	0.387	18	0.817	10.080	5.96	2.00	98.88	98.88
20	0.017	0.014	5.907	0.041	10.059	0.014	0.005	0.000	0.000	0.000	0.008	0.000	0.003	0.006	1.253	0.081	0.666	18	0.808	10.120	5.95	2.00	99.30	99.30
21	0.025	0.000	5.952	0.005	9.973	0.059	0.018	0.000	0.000	0.000	0.006	0.013	0.002	0.002	1.497	0.009	0.494	18	0.791	10.110	5.96	2.00	98.57	98.57

Note: Elemental concentrations in atoms per formula unit (apfu) were calculated from weight % oxide using the stoichiometric relationships of *Ketcham.*, (2015), and r_{mr0} was determined using the calculations of *Carlson et al.*, (1999).

Table S2.2. Summary of AFT age data, Peel Plateau, NWT, Canada

Grain #	N _s	W _i (cm ²)	P _i (dmnls)	P _i W _i	one sigma (dmnls)	sP _i ² W _i ²	FT age (Ma)	one sigma (Ma)	Etch Figs.	D _{par} (µm)	U (ppm)	meas. F (apfu)	meas. Cl (apfu)	calc. OH (apfu)	r _{mr0}
16FNA007A01, Trevor Fm. (chert arenite), 65.50878567, -131.05855233, 398.9 masl															
Kinetic population #1 (undefined r_{mr0})															
1592A_1	2	3.398E-05	0.021	7.009E-07	0.001	9.328E-16	35.2	24.9	2	1.58	1	2.28	0.00	0.00	0.86
1592A_9	10	1.213E-05	0.160	1.943E-06	0.011	1.806E-14	63.3	20.5	3	1.74	51	1.90	0.06	0.04	0.82
1592A_19	0	1.456E-05	0.006	8.552E-08	0.000	2.914E-17	0.0	0.0	1	2.21	1	1.51	0.01	0.48	0.82
1592A_20	1	3.883E-05	0.003	1.129E-07	0.000	4.201E-17	108.6	108.8	1	1.95	1	2.10	0.00	0.00	0.86
1592A_22	7	1.213E-05	0.157	1.908E-06	0.006	5.143E-15	45.2	17.2	2	1.47	20	2.27	0.01	0.00	0.84
1592A_25	3	3.106E-05	0.022	6.770E-07	0.001	3.680E-16	54.5	31.5	2	1.60	5	1.79	0.03	0.19	0.82
1592A_30	3	1.456E-05	0.057	8.310E-07	0.002	8.521E-16	44.5	25.7	2	1.70	6	1.90	0.00	0.10	0.84
1592A_13	4	7.766E-06	0.150	1.166E-06	0.023	3.075E-14	42.3	22.1	3	1.87	32				0.83
1592A_3	1	1.213E-05	0.011	1.392E-07	0.000	3.138E-17	88.2	88.3	1	1.87	2	1.46	0.12	0.41	0.74
1592A_4	2	1.747E-05	0.013	2.344E-07	0.001	9.279E-17	104.6	74.1	2	2.14	3	1.00	0.21	0.79	0.66
1592A_5	3	1.941E-05	0.009	1.665E-07	0.000	6.472E-17	218.9	126.9	1	1.82	2	1.05	0.31	0.64	0.69
1592A_15	1	1.747E-05	0.007	1.257E-07	0.000	3.467E-17	97.6	97.7	1	2.24	2	1.33	0.05	0.62	0.79
1592A_21	2	1.699E-05	0.006	9.773E-08	0.000	2.168E-17	248.0	175.8	2	1.74	1	1.29	0.18	0.53	0.72
1592A_23	1	8.736E-06	0.014	1.232E-07	0.001	3.276E-17	99.5	99.7	1	1.32	3	1.71	0.03	0.26	0.78
1592A_24	2	4.368E-05	0.004	1.930E-07	0.000	8.368E-17	126.8	89.9	1	2.08	1	1.11	0.04	0.85	0.79
1592A_26	2	1.165E-05	0.014	1.603E-07	0.000	2.881E-17	152.4	107.9	1	1.60	3	1.71	0.02	0.28	0.84
1592A_27	10	1.359E-05	0.067	9.145E-07	0.002	1.051E-15	133.7	42.6	4	1.91	14	1.19	0.13	0.68	0.74
1592A_28	4	1.456E-05	0.047	6.842E-07	0.002	1.279E-15	71.8	36.1	2	1.77	9	1.18	0.13	0.69	0.76
1592A_29	1	1.019E-05	0.013	1.346E-07	0.001	3.407E-17	91.2	91.3	1	2.10	2	1.18	0.04	0.78	0.79
1592A_34	3	1.456E-05	0.022	3.194E-07	0.001	1.099E-16	115.0	66.6	3	2.13	4	0.77	0.43	0.80	0.64

1592A_35	1	1.456E-05	0.011	1.672E-07	0.000	3.234E-17	73.5	73.5	1	1.81	2	0.90	0.04	1.06	0.78
1592A_36	4	1.747E-05	0.023	4.014E-07	0.001	2.990E-16	122.0	61.3	4	1.59	4	1.47	0.00	0.53	0.83
1592A_37	2	9.707E-06	0.021	2.000E-07	0.001	7.591E-17	122.4	86.8	1	1.84	4	1.52	0.01	0.47	0.77
1592A_38	1	1.213E-05	0.007	8.846E-08	0.000	1.109E-17	138.2	138.3	1	2.79	1	0.91	0.05	1.04	0.77
1592A_39	2	1.165E-05	0.011	1.322E-07	0.000	2.483E-17	184.3	130.5	2	2.19	2	1.39	0.05	0.56	0.80
1592A_40	9	1.213E-05	0.098	1.185E-06	0.005	3.166E-15	93.1	31.4	3	2.01	17	1.18	0.13	0.69	0.75
1592A_16	100	1.747E-05	0.563	9.834E-06	0.017	8.604E-14	124.4	13.2	2	1.77	111				0.84
1592A_33	59	1.165E-05	0.562	6.549E-06	0.017	3.815E-14	110.4	14.9	4	1.80	280				0.83
1592A_7	31	3.883E-05	0.057	2.224E-06	0.003	1.044E-14	170.0	31.7	4	1.98	2	1.17	0.13	0.70	0.75
1592A_2	20	1.359E-05	0.155	2.103E-06	0.011	2.114E-14	116.5	27.3	2	2.02	7943				0.81
pooled (30) Q=33%	291	5.247E-04		3.360E-05		2.184E-13	106.1	6.7		1.89		1.43	0.09	0.51	0.79
Kinetic population #2 (undefined r _{mr0})															
1592A_17	30	1.747E-05	0.080	1.399E-06	0.003	3.688E-15	259.7	49.0	4	2.07	1	1.38	0.07	0.54	0.78
1592A_31	17	2.427E-05	0.019	4.642E-07	0.001	1.579E-16	437.3	107.0	3	2.10	3	1.38	0.14	0.48	0.68
1592A_8	42	7.766E-06	0.190	1.479E-06	0.043	1.139E-13	341.8	94.4	4	1.60	2				0.86
1592A_18	62	7.766E-06	0.190	1.478E-06	0.043	1.138E-13	498.5	130.5	2	1.69	1				0.85
1592A_6	24	1.116E-05	0.080	8.935E-07	0.003	1.505E-15	323.7	67.8	3	1.73	9				0.84
1592A_32	50	8.736E-06	0.190	1.662E-06	0.043	1.439E-13	361.5	97.3	4	1.74	5				0.84
1592A_11	28	5.824E-06	0.080	4.664E-07	0.003	4.100E-16	702.2	136.8	4	1.79	2				0.84
1592A_12	63	1.456E-05	0.190	2.773E-06	0.043	4.005E-13	274.8	71.8	4	1.79	3				0.84
1592A_14	10	1.553E-05	0.013	1.997E-07	0.001	1.185E-16	590.8	189.9	2	2.08	5				0.80
1592A_10	5	1.941E-05	0.017	3.226E-07	0.001	1.957E-16	188.8	84.9	4	2.44	3				0.75
pooled (10) Q=0%	331	1.325E-04		1.114E-05		7.782E-13	357.2	35.0		1.90		1.38	0.11	0.51	0.81
central age								381.5	44.3	dispersion = 35%					
16FNA006A01, Martin House Fm. (lithic wacke), 65.46295917, -131.125593, 432 masl															
Kinetic population #1 (r _{mr0} > 0.81)															
1591A_1	1	3.883E-05	0.007	2.598E-07	0.000	9.816E-17	47.4	47.4	1	2.26	1	0.94	0.01	1.06	0.81
1591A_3	0	3.883E-05	0.004	1.732E-07	0.000	3.374E-17	0.0	0.0	1	1.98	1	0.70	0.00	1.30	0.82
1591A_4	0	2.378E-05	0.017	4.066E-07	0.001	1.741E-16	0.0	0.0	1	1.98	3	2.14	0.16	0.00	0.77
1591A_8	5	2.912E-05	0.033	9.624E-07	0.001	1.101E-15	63.9	28.7	2	1.60	6	1.88	0.00	0.12	0.85

1591A_14	3	1.213E-05	0.098	1.188E-06	0.004	2.166E-15	31.1	18.0	2	2.33	3	1.11	0.00	0.89	0.81
1591A_15	0	1.456E-05	0.017	2.489E-07	0.001	6.521E-17	0.0	0.0	1	1.78	0	1.92	0.00	0.08	0.84
1591A_18	0	1.213E-05	0.004	5.373E-08	0.000	3.820E-18	0.0	0.0	1	1.35	1	1.70	0.02	0.28	0.79
1591A_21	1	9.707E-06	0.010	9.345E-08	0.000	8.059E-18	130.9	131.0	1	1.88	2	1.77	0.02	0.21	0.84
1591A_26	1	1.213E-05	0.016	2.000E-07	0.000	2.136E-17	61.5	61.5	1	1.88	3	2.12	0.00	0.00	0.85
1591A_27	4	9.707E-06	0.074	7.179E-07	0.003	8.140E-16	68.5	34.4	2	1.54	18	1.73	0.01	0.26	0.84
1591A_28	2	1.213E-05	0.053	6.487E-07	0.002	4.053E-16	38.0	26.9	3	1.57	10	2.00	0.00	0.00	0.85
1591A_29	1	1.019E-05	0.060	6.130E-07	0.002	4.809E-16	20.1	20.1	1	1.67	11	2.06	0.01	0.00	0.86
1591A_31	2	1.213E-05	0.210	2.542E-06	0.008	8.578E-15	9.7	6.9	2	1.65	36	1.67	0.01	0.33	0.78
1591A_34	1	1.456E-05	0.030	4.388E-07	0.001	1.238E-16	28.1	28.1	1	1.44	6	1.49	0.00	0.51	0.82
1591A_36	4	9.707E-06	0.142	1.377E-06	0.004	1.300E-15	35.8	17.9	3	1.60	29	1.77	0.00	0.23	0.84
1591A_40	19	1.941E-05	0.294	5.715E-06	0.012	5.379E-14	40.9	9.6	2	1.29	80	1.59	0.01	0.40	0.84
1591A_33	3	7.280E-06	0.098	7.123E-07	0.002	2.964E-16	51.8	30.0	1	1.45	19				0.87
1591A_19	14	1.165E-05	0.146	1.705E-06	0.093	1.165E-12	100.7	69.2	4	1.52	1171				0.86
1591A_16	6	1.844E-05	0.103	1.891E-06	0.004	5.478E-15	39.1	16.0	3	1.60	11				0.86
1591A_7	3	1.747E-05	0.098	1.711E-06	0.002	1.710E-15	21.6	12.5	2	1.61	96				0.85
1591A_17	6	7.280E-06	0.000	0.000E+00	0.000	0.000E+00	0.0	0.0	4	1.77	0				0.84
1591A_30	3	1.019E-05	0.476	4.848E-06	0.121	1.523E-12	7.6	4.8	2	1.77	43				0.84
1591A_13	0	1.213E-05	0.017	2.073E-07	0.001	4.525E-17	0.0	0.0	1	1.96	156				0.82
pooled (23) Q=59%	79	3.635E-04		2.671E-05		2.764E-12	36.4	4.7		1.72		1.66	0.02	0.35	0.83
Kinetic population #2 (r _{mr0} < 0.81)															
1591A_22	4	1.019E-05	0.045	4.588E-07	0.001	1.460E-16	106.8	53.5	2	1.82	8	1.80	0.03	0.17	0.84
1591A_23	9	8.736E-06	0.140	1.226E-06	0.004	1.161E-15	90.1	30.2	3	1.85	27	1.65	0.05	0.30	0.84
1591A_2	1	1.456E-05	0.002	2.252E-08	0.000	1.848E-18	526.7	527.7	1	1.78	0	1.25	0.00	0.75	0.82
1591A_25	26	1.165E-05	0.281	3.268E-06	0.007	7.199E-15	97.6	19.4	3	1.90	51	1.65	0.11	0.24	0.82
1591A_32	1	1.553E-05	0.007	1.139E-07	0.000	2.304E-17	107.6	107.7	1	1.81	1	1.27	0.04	0.69	0.82
1591A_35	1	7.280E-06	0.009	6.896E-08	0.000	2.987E-18	176.7	176.8	1	1.70	2	1.21	0.03	0.75	0.81
1591A_20	4	7.280E-06	0.021	1.514E-07	0.001	2.191E-17	318.4	159.6	1	2.29	4	1.29	0.01	0.70	0.78
1591A_9	5	2.330E-05	0.023	5.400E-07	0.001	2.622E-16	113.4	50.9	2	1.67	5	1.65	0.08	0.28	0.77
1591A_39	6	1.165E-05	0.102	1.192E-06	0.004	2.180E-15	61.9	25.4	3	1.97	20	1.36	0.22	0.41	0.74
1591A_38	1	1.941E-05	0.013	2.475E-07	0.001	1.042E-16	49.7	49.8	1	1.90	2	1.06	0.22	0.72	0.69
1591A_24	3	1.165E-05	0.024	2.820E-07	0.001	5.913E-17	130.1	75.3	3	2.34	5	0.93	0.43	0.64	0.68

1591A_11	1	8.736E-06	0.016	1.363E-07	0.000	1.797E-17	90.0	90.1	1	2.09	3	0.80	0.26	0.94	0.62
1591A_10	4	2.912E-05	0.022	6.276E-07	0.001	3.519E-16	78.3	39.2	3	2.83	4	0.78	0.50	0.72	0.60
1591A_5	18	8.736E-06	0.236	2.060E-06	0.006	2.402E-15	107.1	25.4	3	1.78	46				0.84
1591A_12	17	9.707E-06	0.147	1.422E-06	0.093	8.107E-13	146.1	99.1	3	1.80	35				0.83
1591A_6	17	7.766E-06	0.281	2.181E-06	0.007	3.204E-15	95.6	23.4	2	1.97	32				0.82
1591A_37	4	7.280E-06	0.001	9.933E-09	0.000	7.975E-19	1137.6	1142.3	2	2.00	0	1.33	0.01	0.66	0.80
pooled (16) Q=71%	118	2.053E-04		1.400E-05		8.279E-13	103.3	11.8		1.97		1.29	0.15	0.56	0.77

16FNA008B01, Imperial Fm (lithic wacke) 65.41090817, -131.41356184, 722.3 masl

Kinetic population #1 ($r_{mr0} > 0.79$)

1593A_33	0	5.824E-06	0.007	3.929E-08	0.000	1.680E-18	0.0	0.0	1	1.82	1	1.36	0.01	0.63	0.82
1593A_37	9	8.736E-06	0.140	1.222E-06	0.004	9.787E-16	90.3	30.2	2	1.81	28	1.54	0.06	0.40	0.83
1593A_32	1	7.766E-06	0.103	7.996E-07	0.003	5.273E-16	15.4	15.4	2	1.63	21	1.79	0.03	0.18	0.84
1593A_23	3	7.280E-06	0.105	7.646E-07	0.003	6.104E-16	48.3	27.9	2	1.39	21	1.85	0.01	0.14	0.84
1593A_27	2	7.766E-06	0.107	8.304E-07	0.006	2.431E-15	29.7	21.1	2	1.40	21	1.88	0.07	0.05	0.80
1593A_40	9	1.165E-05	0.119	1.385E-06	0.003	1.613E-15	79.8	26.7	3	1.52	20	1.91	0.01	0.08	0.86
1593A_28	3	8.736E-06	0.083	7.278E-07	0.003	5.295E-16	50.7	29.4	2	1.86	16	1.93	0.01	0.06	0.83
1593A_34	1	5.824E-06	0.090	5.254E-07	0.014	6.617E-15	23.5	23.8	2	1.42	10				0.87
1593A_16	1	7.766E-06	0.164	1.271E-06	0.023	3.274E-14	9.7	9.8	1	1.54	15				0.86
1593A_10	5	7.766E-06	0.452	3.513E-06	0.121	8.823E-13	17.6	9.2	1	1.62	57				0.85
1593A_18	2	7.766E-06	0.131	1.016E-06	0.004	7.574E-16	24.3	17.2	2	1.78	30				0.84
1593A_9	0	7.766E-06	0.030	2.300E-07	0.008	4.166E-15	0.0	0.0	1	1.80	4				0.83
1593A_7	1	9.707E-06	0.050	4.900E-07	0.002	2.586E-16	25.2	25.2	1	2.47	178				0.75
1593A_35	6	1.213E-05	0.229	2.779E-06	0.048	3.325E-13	26.6	12.2	3	2.79	34				0.69
1593A_8	1	7.280E-06	0.020	1.434E-07	0.003	6.225E-16	85.6	86.9	1	1.29	3				0.88
1593A_38	15	9.707E-06	0.385	3.739E-06	0.072	4.936E-13	49.4	15.8	3	1.40	69				0.87
1593A_5	4	5.824E-06	0.133	7.727E-07	0.003	3.579E-16	63.7	31.9	2	1.50	15				0.86
1593A_19	3	7.766E-06	0.088	6.817E-07	0.024	3.528E-14	54.2	34.7	2	1.51	6				0.86
1593A_24	13	1.359E-05	0.385	5.238E-06	0.072	9.689E-13	30.6	10.3	3	1.57	39				0.86
1593A_4	7	7.280E-06	0.229	1.669E-06	0.048	1.200E-13	51.6	22.3	2	1.61	22				0.85
1593A_12	2	7.280E-06	0.088	6.386E-07	0.024	3.097E-14	38.6	29.3	2	1.74	21				0.84
1593A_14	1	5.824E-06	0.050	2.940E-07	0.002	9.307E-17	41.9	41.9	1	1.74	10				0.84
1593A_31	3	7.280E-06	0.088	6.385E-07	0.024	3.096E-14	57.8	37.0	2	1.74	23				0.84
1593A_11	4	5.824E-06	0.107	6.235E-07	0.006	1.371E-15	78.8	39.7	3	1.75	1				0.84
1593A_20	4	5.824E-06	0.133	7.723E-07	0.003	3.576E-16	63.7	31.9	2	1.76	27				0.84

1593A_22	1	7.280E-06	0.039	2.875E-07	0.003	4.319E-16	42.8	43.0	1	1.82	53				0.83
1593A_39	1	9.707E-06	0.035	3.415E-07	0.003	1.050E-15	36.1	36.3	1	1.84	7				0.83
1593A_21	11	7.766E-06	0.200	1.556E-06	0.071	3.015E-13	86.8	40.3	3	1.87	0				0.83
1593A_1	8	9.707E-06	0.135	1.313E-06	0.004	1.562E-15	74.9	26.6	3	1.89	26				0.83
1593A_29	12	1.165E-05	0.200	2.332E-06	0.071	6.773E-13	63.3	28.9	3	1.94	17				0.82
1593A_6	1	5.824E-06	0.040	2.302E-07	0.003	2.770E-16	53.5	53.6	1	1.99	9				0.81
1593A_15	11	7.766E-06	0.219	1.700E-06	0.006	2.040E-15	79.5	24.1	4	2.17	43				0.79
pooled (32) Q=57%	145	2.597E-04		3.856E-05		3.933E-12	46.3	4.6		1.75		1.75	0.03	0.22	0.83

Kinetic population #2 ($r_{mr0} < 0.79$)

1593A_2	12	1.116E-05	0.103	1.151E-06	0.003	1.283E-15	127.6	37.1	3	1.87	20	1.37	0.04	0.59	0.82
1593A_13	5	1.456E-05	0.038	5.475E-07	0.001	2.486E-16	111.9	50.2	2	1.86	7	1.41	0.10	0.49	0.75
1593A_30	8	1.456E-05	0.043	6.269E-07	0.002	4.778E-16	155.8	55.4	4	1.99	8	1.46	0.10	0.43	0.80
1593A_3	5	4.368E-06	0.069	3.008E-07	0.002	1.180E-16	202.2	90.8	2	1.48	15				0.87
1593A_17	1	5.824E-06	0.020	1.146E-07	0.003	3.979E-16	106.9	108.5	1	1.89	56				0.83
1593A_25	20	5.339E-06	0.237	1.267E-06	0.029	2.409E-14	192.2	49.1	3	1.69	47				0.85
1593A_26	12	7.280E-06	0.103	7.499E-07	0.003	5.449E-16	194.8	56.7	4	1.90	11				0.82
1593A_36	12	1.456E-05	0.072	1.047E-06	0.002	5.447E-16	140.1	40.7	3	1.54	14				0.86
pooled (8) Q=89%	75	7.766E-05		5.804E-06		2.770E-14	157.7	19.0		1.78		1.41	0.08	0.51	0.82

Note: N_s is the number of spontaneous fission tracks for each apatite. Ω_i is the area over which tracks are counted, whereas P_i is the $^{238}\text{U}/^{43}\text{Ca}$ ratio. Q represents the X^2 probability for each population. A population passes the X^2 test if $Q > 5\%$. D_{par} is the diameter of the etch figure parallel to the c axis. F, Cl and OH concentrations were calculated from weight % oxide using the stoichiometric relationships of *Ketcham* (2015), and r_{mr0} was determined using the calculations of *Carlson et al.* (1999).

modified zeta: 12.357 ± 0.2251

total decay const: $1.551\text{E-}10$

Table S2.3. Summary of AFT length data, Peel Plateau, NWT, Canada

Grain #	Track	Confined length (mm)	angle to C-axis (degrees)	Etch Figs.	D_{par} (μm)	meas. F (apfu)	meas. Cl (apfu)	calc. OH (apfu)	r_{mr0}
16FNA007A01, Trevor Fm. (chert arenite), 65.50878567, -131.05855233, 398.9 masl									
Kinetic population #1 (undefined r_{mr0})									
3	1	14.72	34.13	4	2.08	1.14	0.13	0.73	0.76
3	2	12.69	87.90	4	2.08	1.14	0.13	0.73	0.76
3	3	16.83	26.99	4	2.08	1.14	0.13	0.73	0.76
5	1	15.36	40.47	4	1.93	1.53	0.11	0.36	0.74
5	2	16.46	48.60	4	1.93	1.53	0.11	0.36	0.74
9	1	13.15	42.94	4	1.45	2.36	0.00	0.00	0.86
9	2	13.03	69.58	4	1.45	2.36	0.00	0.00	0.86
11	1	14.24	55.55	4	2.24	1.18	0.12	0.70	0.74
11	2	15.15	35.47	4	2.24	1.18	0.12	0.70	0.74
12	1	12.66	72.08	4	2.36	1.25	0.13	0.62	0.75
12	2	11.44	61.83	4	2.36	1.25	0.13	0.62	0.75
12	3	13.36	24.68	4	2.36	1.25	0.13	0.62	0.75
12	4	12.22	77.60	4	2.36	1.25	0.13	0.62	0.75
13	1	13.67	47.98	3	1.98	0.99	0.11	0.90	0.69
14	1	15.23	22.74	3	1.97	1.76	0.10	0.14	0.76
14	2	14.67	44.22	3	1.97	1.76	0.10	0.14	0.76
14	3	14.05	40.08	3	1.97	1.76	0.10	0.14	0.76
14	4	11.71	69.40	3	1.97	1.76	0.10	0.14	0.76
14	5	11.91	68.28	3	1.97	1.76	0.10	0.14	0.76
14	6	13.41	41.21	3	1.97	1.76	0.10	0.14	0.76
15	1	12.34	47.75	4	2.84	1.10	0.01	0.89	0.80
15	2	14.70	70.52	4	2.84	1.10	0.01	0.89	0.80
15	3	15.40	17.81	4	2.84	1.10	0.01	0.89	0.80
15	4	13.68	56.26	4	2.84	1.10	0.01	0.89	0.80
15	5	14.08	66.77	4	2.84	1.10	0.01	0.89	0.80
15	6	16.47	43.53	4	2.84	1.10	0.01	0.89	0.80
15	7	13.10	39.78	4	2.84	1.10	0.01	0.89	0.80
15	8	13.83	40.82	4	2.84	1.10	0.01	0.89	0.80
15	9	13.22	67.49	4	2.84	1.10	0.01	0.89	0.80
15	10	13.34	45.19	4	2.84	1.10	0.01	0.89	0.80
16	1	11.71	45.15	4	1.92	1.81	0.04	0.16	0.82
16	2	11.28	84.67	4	1.92	1.81	0.04	0.16	0.82
16	3	13.05	48.78	4	1.92	1.81	0.04	0.16	0.82
16	4	11.85	52.54	4	1.92	1.81	0.04	0.16	0.82
16	5	11.21	81.51	4	1.92	1.81	0.04	0.16	0.82
16	6	10.28	79.34	4	1.92	1.81	0.04	0.16	0.82
16	7	12.13	44.47	4	1.92	1.81	0.04	0.16	0.82
17	1	13.41	72.72	3	2.45	0.73	0.02	1.25	0.79
17	2	13.84	34.42	3	2.45	0.73	0.02	1.25	0.79
17	3	12.95	40.22	3	2.45	0.73	0.02	1.25	0.79
18	1	13.18	61.03	4	2.37	1.29	0.11	0.60	0.73
18	2	11.23	80.88	4	2.37	1.29	0.11	0.60	0.73
19	1	11.90	49.84	3	2.14	1.09	0.16	0.75	0.78

Grain #	Track	Confined length (mm)	angle to C-axis (degrees)	Etch Figs.	D_{par} (μ m)	meas. F (apfu)	meas. Cl (apfu)	calc. OH (apfu)	r_{mr0}
19	2	10.83	63.80	3	2.14	1.09	0.16	0.75	0.78
19	3	13.03	40.65	3	2.14	1.09	0.16	0.75	0.78
19	4	10.07	65.47	3	2.14	1.09	0.16	0.75	0.78
20	1	15.84	43.65	3	1.93	1.57	0.01	0.42	0.83
20	2	11.38	89.88	3	1.93	1.57	0.01	0.42	0.83
22	1	12.01	60.09	4	2.31	1.16	0.01	0.84	0.74
22	2	12.35	42.51	4	2.31	1.16	0.01	0.84	0.74
23	1	10.57	84.92	4	2.27	0.95	0.02	1.03	0.78
23	2	9.57	54.44	4	2.27	0.95	0.02	1.03	0.78
24	1	14.64	58.68	4	2.03	1.45	0.19	0.36	0.74
24	2	12.29	69.67	4	2.03	1.45	0.19	0.36	0.74
24	3	12.33	60.19	4	2.03	1.45	0.19	0.36	0.74
24	4	14.51	54.73	4	2.03	1.45	0.19	0.36	0.74
24	5	11.99	52.82	4	2.03	1.45	0.19	0.36	0.74
25	1	13.27	70.02	2	2.20	1.14	0.09	0.77	0.78
27	1	10.65	53.22	3	2.07	1.23	0.00	0.77	0.80
28	1	14.36	55.86	2	2.08	1.26	0.12	0.62	0.75
29	1	13.59	46.60	4	1.84	1.26	0.14	0.60	0.74
29	2	13.35	69.38	4	1.84	1.26	0.14	0.60	0.74
2	1	14.89	60.64	2	1.54				0.86
7	1	9.49	81.27	3	1.56				0.86
7	2	10.20	60.28	3	1.56				0.86
7	3	12.07	52.15	3	1.56				0.86
7	4	11.67	36.64	3	1.56				0.86
7	5	13.66	55.18	3	1.56				0.86
7	6	9.54	50.43	3	1.56				0.86
7	7	15.93	18.01	3	1.56				0.86
7	8	12.62	46.91	3	1.56				0.86
4	1	10.54	70.26	2	1.78				0.84
4	2	12.43	41.27	2	1.78				0.84
4	3	11.28	44.36	2	1.78				0.84
4	4	15.07	38.17	2	1.78				0.84
1	1	14.85	44.83	4	1.79				0.84
1	2	14.62	41.90	4	1.79				0.84
1	3	13.70	34.12	4	1.79				0.84
1	4	15.58	21.78	4	1.79				0.84
10	1	9.91	66.61	2	1.97				0.82
10	2	13.49	39.77	2	1.97				0.82
21	1	12.55	42.14	3	1.97				0.82
21	2	11.44	59.45	3	1.97				0.82
26	1	14.95	19.28	3	3.86				0.37
Ave		12.99			2.10	1.35	0.08	0.58	0.79
SD		1.74			0.42	0.35	0.06	0.33	0.06

Grain #	Track	Confined length (mm)	angle to C-axis (degrees)	Etch Figs.	D _{par} (μm)	meas. F (apfu)	meas. Cl (apfu)	calc. OH (apfu)	r _{mr0}
Kinetic population #2 (undefined r_{mr0})									
6	1	11.66	23.34	4	2.44	1.47	0.08	0.45	0.79
6	2	15.10	23.24	4	2.44	1.47	0.08	0.45	0.79
8	1	11.55	70.64	3	1.54	1.36	0.14	0.50	0.71
8	2	12.71	50.16	3	1.54	1.36	0.14	0.50	0.71
Ave		12.76			1.99	1.42	0.11	0.47	0.75
SD		1.65			0.52	0.07	0.03	0.03	0.05
16FNA006A01, Martin House Fm. (lithic wacke), 65.46295917, -131.125593, 432 masl									
Kinetic population #1 (r_{mr0} > 0.81)									
32	1	12.59	40.93	4	1.50	2.17	0.00	0.00	0.86
30	1	14.40	24.46	4	1.36	2.02	0.00	0.00	0.86
22	1	9.35	66.27	4	1.75	1.94	0.00	0.06	0.86
31	1	12.46	42.74	4	1.41	2.07	0.00	0.00	0.85
27	1	12.73	43.97	4	1.43	1.96	0.02	0.02	0.85
23	1	11.78	47.92	4	1.61	1.77	0.00	0.23	0.84
33	1	12.69	79.95	4	1.69	1.72	0.00	0.28	0.84
33	2	11.63	69.47	4	1.69	1.72	0.00	0.28	0.84
26	1	14.67	37.04	4	1.75	1.81	0.02	0.17	0.84
29	1	14.74	39.66	4	1.59	1.71	0.04	0.25	0.83
29	2	14.99	42.03	4	1.59	1.71	0.04	0.25	0.83
29	3	11.74	41.37	4	1.59	1.71	0.04	0.25	0.83
20	1	15.24	25.01	4	1.83	1.65	0.01	0.34	0.82
20	2	15.38	18.50	4	1.83	1.65	0.01	0.34	0.82
4	1	14.04	25.10	4	2.33	0.81	0.00	1.19	0.82
13	1	13.60	17.61	4	1.75	1.60	0.06	0.34	0.81
1	1	14.22	27.91	4	1.91	0.93	0.01	1.06	0.81
10	1	16.89	52.98	4	2.72	1.11	0.00	0.89	0.81
11	1	15.42	33.30	4	1.82				0.83
12	1	13.11	38.38	4	1.83				0.83
3	1	13.16	39.22	4	1.98				0.81
Ave		13.56			1.76	1.67	0.01		0.83
SD		1.71			0.31	0.37	0.02		0.02
Kinetic population # 2 (r_{mr0} < 0.81)									
6	1	11.05	53.18	4	1.97	0.84	0.01	1.15	0.82
14	1	10.70	36.19	4	1.60	1.55	0.10	0.34	0.82
14	2	13.67	43.43	4	1.60	1.55	0.10	0.34	0.82
14	3	12.58	66.79	4	1.60	1.55	0.10	0.34	0.82
14	4	12.80	79.11	4	1.60	1.55	0.10	0.34	0.82
24	1	14.21	44.84	4	1.89	1.47	0.13	0.40	0.80
24	2	13.16	43.25	4	1.89	1.47	0.13	0.40	0.80
28	1	11.77	43.36	4	1.58	1.20	0.09	0.71	0.80
28	2	13.70	34.25	4	1.58	1.20	0.09	0.71	0.80
16	1	13.26	47.30	4	2.28	1.45	0.13	0.42	0.79
19	1	14.30	44.10	4	2.21	1.45	0.13	0.41	0.78
7	1	11.99	34.36	4	2.15	1.62	0.08	0.30	0.77
7	2	15.14	3.04	4	2.15	1.62	0.08	0.30	0.77

Grain #	Track	Confined length (mm)	angle to C-axis (degrees)	Etch Figs.	D_{par} (μ m)	meas. F (apfu)	meas. Cl (apfu)	calc. OH (apfu)	r_{mr0}
25	1	13.41	32.14	4	1.48	1.64	0.13	0.23	0.77
21	1	13.06	41.46	4	3.27	0.93	0.02	1.06	0.73
9	1	14.02	36.30	4	2.70	0.84	0.05	1.11	0.72
18	1	14.06	68.32	4	2.50	1.35	0.28	0.36	0.71
18	2	13.17	70.70	4	2.50	1.35	0.28	0.36	0.71
15	1	11.05	62.32	4	2.41	0.97	0.41	0.63	0.69
17	1	13.89	84.12	4	2.52	1.02	0.36	0.62	0.66
8	1	14.77	74.00	4	2.97	0.80	0.47	0.73	0.61
8	2	14.91	78.64	4	2.97	0.80	0.47	0.73	0.61
8	3	15.86	28.44	4	2.97	0.80	0.47	0.73	0.61
2	1	11.42	51.93	4	2.06				0.80
5	1	12.95	51.29	4	2.07				0.80
5	2	9.55	76.15	4	2.07				0.80
34	1	13.86	52.16	4	2.36				0.76
34	2	15.59	9.58	4	2.36				0.76
34	4	13.75	56.14	4	2.36				0.76
34	3	11.97	63.87	4	2.36				0.76
Ave		13.19			2.20	1.26	0.18		0.76
SD		1.50			0.48	0.31	0.15		0.06
16FNA008B01, Imperial Fm (lithic wacke) 65.41090817, -131.41356184, 722.3 masl									
Kinetic population #1 ($r_{mr0} > 0.79$)									
6	1	10.65	72.36	2	1.52	1.93	0.00	0.06	0.83
7	1	15.65	20.81	4	1.94	1.45	0.10	0.45	0.80
10	1	11.49	64.60	1	1.82	1.83	0.00	0.16	0.85
10	2	12.42	51.78	1	1.82	1.83	0.00	0.16	0.85
10	3	11.41	31.47	1	1.82	1.83	0.00	0.16	0.85
11	1	15.03	55.87	3	1.75	1.66	0.06	0.28	0.83
11	2	13.60	49.03	3	1.75	1.66	0.06	0.28	0.83
15	1	12.59	40.51	2	1.74	1.84	0.01	0.15	0.84
17	1	14.05	34.38	3	1.42	1.76	0.02	0.23	0.83
17	2	14.56	27.41	3	1.42	1.76	0.02	0.23	0.83
17	3	11.44	67.34	3	1.42	1.76	0.02	0.23	0.83
18	1	14.46	60.46	3	1.45	1.81	0.01	0.18	0.84
18	2	13.87	50.76	3	1.45	1.81	0.01	0.18	0.84
18	3	12.06	71.15	3	1.45	1.81	0.01	0.18	0.84
18	4	10.66	59.96	3	1.45	1.81	0.01	0.18	0.84
19	1	15.55	31.50	3	1.90	1.60	0.02	0.39	0.82
20	1	15.12	75.09	2	2.10	1.25	0.08	0.67	0.81
20	2	15.83	35.69	2	2.10	1.25	0.08	0.67	0.81
21	1	17.39	45.87	4	1.52	1.50	0.01	0.49	0.79
21	2	13.45	63.05	4	1.52	1.50	0.01	0.49	0.79
2	1	13.16	69.25	4	1.62				0.85
2	2	9.02	59.71	4	1.62				0.85
5	1	13.92	59.38	3	2.13				0.80
5	2	14.91	58.09	3	2.13				0.80
8	1	14.03	42.59	3	1.81				0.83

Grain #	Track	Confined length (mm)	angle to C-axis (degrees)	Etch Figs.	D_{par} (μm)	meas. F (apfu)	meas. Cl (apfu)	calc. OH (apfu)	r_{mr0}
8	2	14.16	61.49	3	1.81				0.83
8	3	12.76	45.34	3	1.81				0.83
8	4	13.41	43.70	3	1.81				0.83
9	1	13.38	54.30	2	1.40				0.87
16	1	14.38	36.70	2	1.82				0.83
16	2	12.07	46.81	2	1.82				0.83
Ave		13.43			1.71	1.68	0.03	0.29	0.83
SD		1.79			0.23	0.20	0.03	0.17	0.02
Kinetic population #2 ($r_{mr0} < 0.79$)									
3	1	11.36	58.83	3	2.33	1.40	0.39	0.20	0.75
4	1	13.89	51.05	4	1.92	1.40	0.08	0.52	0.75
12	1	14.05	44.59	4	1.83	0.97	0.25	0.77	0.75
13	1	14.44	27.33	4	2.43	1.13	0.20	0.67	0.71
13	2	13.02	73.38	4	2.43	1.13	0.20	0.67	0.71
1	1	8.91	63.29	4	1.54	1.56	0.04	0.40	0.83
14	1	13.95	50.43	4	2.55	0.99	0.29	0.71	0.69
Ave		12.80			2.15	1.23	0.21	0.56	0.74
SD		2.00			0.38	0.23	0.12	0.20	0.05

Note: D_{par} is the diameter of the etch figure parallel to the c axis. F, Cl and OH concentrations were calculated via EPMA. R_{mr0} was determined using the calculations of *Carlson et al.* (1999).

Table S2.4. Apatite U-Pb geochronology data, Peel Plateau, NWT, Canada

Grain #	Isotopic Sums: Tera-Wasserburg Discordia					Isotopic Sums: Ages									Isotopic Sums: Pb-corrected Age		
	$^{238}\text{U}/^{206}\text{Pb}$	2σ	$^{207}\text{Pb}/^{206}\text{U}$	2σ	RhoXY	$^{207}\text{Pb}/^{235}\text{U}$	-2σ	$+2\sigma$	$^{206}\text{Pb}/^{238}\text{U}$	-2σ	$+2\sigma$	$^{207}\text{Pb}/^{206}\text{Pb}$	-2σ	$+2\sigma$	Pb corrected (Ma)	-2σ	$+2\sigma$
16FNA007A01, Trevor Fm. (chert arenite), 65.50878567, -131.05855233, 398.9 masl																	
1592A_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_3	3.41	0.21	0.81	0.08	0.20	3575.42	88.23	84.56	1659.28	114.11	113.11	4560.00	0.00	0.00	227.76	227.76	546.77
1592A_4	9.04	0.85	0.51	0.07	0.14	2212.54	94.70	90.48	676.19	67.86	67.51	4281.84	197.14	183.80	324.28	175.65	360.54
1592A_5	3.00	0.22	0.63	0.08	0.21	3451.83	123.46	116.38	1856.52	142.37	140.81	4560.00	159.71	0.00	687.07	687.07	707.94
1592A_6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_10	8.41	0.69	0.37	0.05	0.11	1985.39	115.85	109.60	724.12	65.94	65.61	3791.75	229.72	212.04	469.58	209.02	334.87
1592A_11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_12	1.71	0.92	1.19	0.57	0.53	4644.70	475.85	385.24	2963.14	1347.60	1219.98	4560.00	0.00	0.00	0.00	0.00	0.00
1592A_13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_14	7.80	0.62	0.35	0.05	0.24	2001.33	111.09	105.32	777.61	68.37	68.01	3704.79	205.74	191.47	524.08	211.48	299.61
1592A_15	8.50	0.79	0.37	0.08	0.07	1974.01	184.29	168.94	716.92	71.54	71.14	3787.96	350.18	310.67	465.52	352.18	380.59
1592A_16	23.26	0.75	0.06	0.01	0.08	301.84	26.61	26.26	271.35	15.50	15.48	544.80	235.39	219.20	269.27	30.68	42.23
1592A_17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_25	27.84	2.85	0.28	0.06	0.01	884.78	108.13	102.66	227.50	25.68	25.63	3366.78	339.45	302.63	167.65	72.97	141.88
1592A_26	1.40	0.07	0.82	0.07	0.26	4480.82	87.17	83.58	3483.91	196.15	193.21	4560.00	0.00	0.00	477.91	477.91	923.08
1592A_27	4.14	0.20	0.78	0.07	0.13	3346.09	85.04	81.62	1395.40	89.99	89.36	4560.00	0.00	0.00	242.29	242.29	371.02
1592A_28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_35	6.82	0.47	0.33	0.06	0.05	2065.07	153.39	142.62	881.78	73.36	72.95	3610.95	287.14	260.17	618.42	306.75	348.60
1592A_36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1592A_40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grain #	Isotopic Sums: Tera-Wasserburg Discordia					Isotopic Sums: Ages									Isotopic Sums: Pb-corrected Age		
	²³⁸ U/ ²⁰⁶ Pb	2σ	²⁰⁷ Pb/ ²⁰⁶ U	2σ	RhoXY	²⁰⁷ Pb/ ²³⁵ U	-2σ	+2σ	²⁰⁶ Pb/ ²³⁸ U	-2σ	+2σ	²⁰⁷ Pb/ ²⁰⁶ Pb	-2σ	+2σ	Pb corrected (Ma)	-2σ	+2σ
16FNA006A01, Martin House Fm. (lithic wacke), 65.46295917, -131.125593, 432 masl																	
1591A_1	7.96	0.73	0.57	0.10	0.02	2423.64	151.39	140.88	762.85	76.78	76.32	4434.35	278.28	251.29	316.94	316.94	411.33
1591A_2	1.46	0.15	0.86	0.11	0.21	4475.51	111.17	105.40	3357.16	300.84	293.98	4560.00	0.00	0.00	281.96	281.96	2112.97
1591A_3	5.94	0.58	0.83	0.13	0.00	3052.02	126.25	118.86	1003.49	103.71	102.88	4560.00	0.00	0.00	111.93	111.93	610.61
1591A_4	5.40	0.31	0.70	0.07	0.02	2987.28	88.84	85.12	1095.37	79.97	79.48	4560.00	0.00	0.00	288.90	277.94	352.21
1591A_5	11.85	0.30	0.27	0.02	-0.39	1454.50	58.20	56.58	522.09	29.52	29.45	3330.03	139.59	132.95	393.12	36.02	70.65
1591A_6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1591A_7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1591A_8	4.99	0.18	0.60	0.05	-0.12	2908.14	76.19	73.43	1177.98	68.69	68.32	4503.29	134.06	113.42	462.11	167.90	217.26
1591A_9	10.65	0.69	0.61	0.07	-0.07	2217.78	79.46	76.47	578.71	45.90	45.74	4528.98	166.81	62.03	211.93	124.99	222.99
1591A_10	5.39	0.27	0.73	0.07	-0.10	3029.04	76.65	73.86	1097.06	72.96	72.55	4560.00	0.00	0.00	249.45	200.63	327.53
1591A_11	4.61	0.19	0.71	0.07	-0.02	3149.57	84.89	81.48	1265.25	76.27	75.82	4560.00	0.00	0.00	326.19	309.04	259.20
1591A_12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1591A_13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1591A_14	3.39	0.07	0.11	0.01	-0.47	1729.45	58.14	56.52	1665.76	80.26	79.76	1807.41	150.12	142.91	1650.38	108.34	173.82
1591A_15	0.00	0.00	0.87	0.07	0.96	11095.02	326.73	281.38	39595.62	2048.97	1767.55	4560.00	0.00	0.00	0.00	0.00	0.00
1591A_16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1591A_17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1591A_18	5.82	0.62	0.45	0.09	0.02	2495.87	169.35	156.31	1021.88	111.66	110.70	4088.57	319.96	286.40	575.20	525.98	653.81
1591A_19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1591A_20	8.43	0.46	0.63	0.06	0.03	2462.18	83.72	80.41	722.50	50.05	49.86	4560.00	115.74	0.00	248.74	175.72	216.68
1591A_21	0.93	0.05	0.73	0.07	0.02	4764.93	79.15	76.18	4703.96	250.67	245.88	4560.00	0.00	0.00	1678.49	960.62	2881.51
1591A_22	4.28	0.11	0.56	0.05	-0.17	2990.01	73.64	71.07	1354.35	67.66	67.30	4403.71	125.23	119.69	601.55	188.00	181.48
1591A_23	2.99	0.10	0.18	0.01	0.00	2271.50	68.28	66.06	1857.63	97.19	96.46	2668.25	138.94	132.51	1713.44	233.52	303.27
1591A_24	8.29	0.45	0.68	0.07	-0.05	2548.42	74.61	71.97	733.77	50.45	50.26	4560.00	0.00	0.00	209.23	141.05	236.85
1591A_25	10.84	0.25	0.16	0.01	-0.24	1132.47	49.84	48.65	569.00	29.21	29.15	2467.88	140.29	133.79	502.88	42.96	66.45
1591A_26	1.09	0.02	0.78	0.06	-0.32	4668.62	70.04	67.70	4186.83	159.70	157.75	4560.00	0.00	0.00	892.98	555.44	454.96
1591A_27	6.18	0.27	0.58	0.05	0.09	2668.01	74.76	72.10	967.55	57.96	57.70	4446.24	127.76	122.00	401.34	142.11	193.53
1591A_28	2.03	0.06	0.71	0.06	-0.06	3960.34	73.32	70.76	2580.54	121.37	120.23	4560.00	0.00	0.00	716.16	386.19	421.38
1591A_29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1591A_30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1591A_31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1591A_32	0.62	0.04	0.83	0.08	0.19	5299.08	90.91	87.01	6172.80	334.52	326.06	4560.00	0.00	0.00	0.00	0.00	0.00
1591A_33	7.27	0.17	0.29	0.02	-0.27	1885.99	65.49	63.45	830.85	40.53	40.40	3390.99	135.09	128.85	623.22	74.50	107.93
1591A_34	5.66	0.25	0.57	0.05	-0.08	2736.76	76.41	73.64	1049.14	61.61	61.32	4424.85	139.82	132.96	447.70	193.18	268.31
1591A_35	2.35	0.09	0.81	0.07	-0.08	3946.05	74.66	72.01	2286.38	113.88	112.88	4560.00	0.00	0.00	322.19	322.19	514.04
1591A_36	10.68	0.29	0.32	0.03	-0.07	1649.31	72.95	70.42	577.03	29.46	29.39	3548.63	148.57	141.02	407.93	85.50	65.94
1591A_37	1.33	0.09	0.80	0.07	0.41	4502.22	94.83	90.60	3622.84	229.12	225.12	4560.00	0.00	0.00	628.99	628.99	1082.19
1591A_38	9.49	0.83	0.85	0.33	0.00	2632.33	387.07	324.97	645.96	60.73	60.45	4560.00	0.00	0.00	51.70	51.70	351.32
1591A_39	11.64	0.71	0.59	0.06	0.14	2112.85	82.44	79.22	531.20	38.83	38.72	4488.54	153.14	142.91	204.38	126.33	164.36
1591A_40	9.29	0.46	0.15	0.01	0.11	1198.27	56.55	55.02	659.24	42.29	42.15	2367.09	155.51	147.59	591.50	102.74	155.75

Grain #	Isotopic Sums: Tera-Wasserburg Discordia					Isotopic Sums: Ages										Isotopic Sums: Pb-corrected Age		
	²³⁸ U/ ²⁰⁶ Pb	2σ	²⁰⁷ Pb/ ²⁰⁶ U	2σ	RhoXY	²⁰⁷ Pb/ ²³⁵ U	-2σ	+2σ	²⁰⁶ Pb/ ²³⁸ U	-2σ	+2σ	²⁰⁷ Pb/ ²⁰⁶ Pb	-2σ	+2σ	Pb corrected (Ma)	-2σ	+2σ	
16FNA008B01, Imperial Fm (lithic wacke) 65.41090817, -131.41356184, 722.3 masl																		
1593A_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_3	9.12	0.48	0.30	0.03	0.23	1748.27	89.91	86.10	670.68	52.70	52.48	3490.29	169.95	160.16	485.10	110.95	165.16	
1593A_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_12	0.01	0.00	0.81	0.09	0.98	9964.40	667.82	501.71	32867.01	4187.82	3155.91	4560.00	0.00	0.00	0.00	0.00	0.00	
1593A_13	7.92	0.29	0.44	0.05	0.22	2182.33	102.36	97.45	766.69	56.27	56.02	4035.44	167.85	158.14	440.10	142.93	129.74	
1593A_14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_18	5.50	0.24	0.52	0.05	0.23	2682.34	102.98	98.01	1077.40	82.95	82.42	4298.33	159.25	150.43	520.63	169.62	244.83	
1593A_19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_20	6.61	0.26	0.37	0.04	0.18	2198.78	99.73	95.06	908.46	69.71	69.34	3791.05	169.19	159.41	594.41	120.08	202.81	
1593A_21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_22	0.01	0.00	0.84	0.08	0.70	9587.85	146.60	136.73	30271.45	811.41	763.36	4560.00	0.00	0.00	0.00	0.00	0.00	
1593A_23	5.42	0.19	0.37	0.04	0.28	2390.53	98.65	94.08	1091.58	81.67	81.15	3810.25	157.15	148.67	714.56	127.59	179.30	
1593A_24	0.09	0.03	0.90	0.25	0.65	7372.85	304.76	264.94	16269.13	2324.92	1969.03	4560.00	0.00	0.00	0.00	0.00	0.00	
1593A_25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_27	4.66	0.33	0.66	0.09	0.27	3060.16	130.14	122.30	1252.19	117.75	116.68	4560.00	45.31	0.00	406.95	406.95	444.86	
1593A_28	0.23	0.01	0.87	0.09	0.23	6342.77	110.93	105.18	10757.66	459.90	444.06	4560.00	0.00	0.00	0.00	0.00	0.00	
1593A_29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_30	2.62	0.10	0.72	0.07	0.28	3718.73	106.76	101.42	2085.50	151.88	150.11	4560.00	0.00	0.00	540.14	222.91	398.70	
1593A_31	0.07	0.04	0.82	0.11	0.98	7545.14	688.57	513.28	17814.10	4013.75	3056.38	4560.00	0.00	0.00	0.00	0.00	0.00	
1593A_32	5.52	0.18	0.50	0.05	0.27	2645.63	106.79	101.45	1074.11	82.98	82.45	4245.84	161.77	152.69	542.13	163.68	159.04	
1593A_33	1.01	0.05	0.80	0.09	0.18	4776.54	119.67	113.01	4434.94	298.99	292.22	4560.00	0.00	0.00	811.76	811.76	3748.24	
1593A_34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_37	11.02	0.33	0.16	0.02	0.24	1116.49	76.93	74.12	560.10	45.72	45.56	2456.00	189.09	177.47	495.57	59.55	77.30	
1593A_38	0.16	0.03	1.34	0.51	0.42	7181.37	479.35	387.53	12874.11	1149.22	1055.11	4560.00	0.00	0.00	0.00	0.00	0.00	
1593A_39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1593A_40	3.71	0.11	0.24	0.03	0.25	2337.79	104.88	99.73	1536.84	118.64	117.56	3135.79	177.66	167.11	1275.38	170.11	213.95	

APPENDIX B

SUPPLEMENTARY INFORMATION FOR CHAPTER 3

Introduction

This Appendix includes a description of the methodology for strain analysis from quantitative kinematic indicators, brittle ductile faults, Raman spectroscopy of carbonaceous material (RSCM) and $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology. The supplementary figures include additional field photos (**Figure S3.1**), examples of constructed Mohr circles for quantitative kinematic indicators (**Figure S3.2**), stereoplots of brittle-ductile faults with inferred incremental strain axes (**Figure S3.3**), additional photomicrographs (**Figure S3.4**), and weighted mean diagrams of white mica $^{40}\text{Ar}/^{39}\text{Ar}$ samples (**Figure S3.5**). The accompanying tables include outcrop locations (**Table S3.1**), structural measurements of brittle-ductile faults (**Table S3.2**), $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology (**Table S3.3**) and RSCM data (**Table S3.4**).

Methodology

Strain analysis – quantitative kinematic indicators

N-S striking quartz $\pm$ carbonate $\pm$ dolomite veins served as quantitative kinematic indicators to determine the flow parameters related to ductile deformation. The veins are progressively deformed as their orientation approaches the foliation. Vein quartz evinces subgrain rotation and grain boundary migration and the intensity of recrystallization increases within veins that have a similar orientation relative to the foliation (**Figure S3.8I**; **Figure S3.4B**). Quartz textures indicate deformation within the ductile regime and vein emplacement is interpreted as discrete phases of brittle failure during ductile flow. Older veins are progressively deformed while rotating into the foliation toward the east. A consistent angle of 110° between undeformed veins and the foliation indicates the foliation acted as the fabric attractor and represents a non-rotating plane (a_1) during ductile flow. In addition, the angles between the instantaneous stretching axes (ISA_1 and ISA_2) remained fixed relative to the foliation.

The Mohr circle of Second Kind is constructed by drawing a circle of arbitrary size, where the upper- and lower-most points on the circle's periphery denote maximum and minimum instantaneous stress axes (ISA_1 and ISA_2 , respectively). The position of the fabric attractor (a_1) is positioned using the measured angle between ISA_2 and a_1 ($2\theta = 2 \cdot (110^\circ - 90^\circ) = 40^\circ$). As eigenvectors have no rotational component ($\chi = 0$), the position of a_1 anchors the y-axis. From here, the position of the second eigenvector is determined from the second intersection of the Mohr circle with the y-axis. The pole of the direction of shear (being the fabric attractor; a_1) is positioned on the circle's periphery with the coordinates of (a_2 ; Γ), where Γ defines the effective shear strain. The position of this point represents a stretched line both in strain space and physical space, and serves as an "anchor point" to project deformation in physical space (Simpson and De Paor, 1993). Assuming steady-state conditions, the constructed Mohr circle can be used to visualize finite deformation for veins that have undergone different amounts of rotation by creating an infinitesimal unit square, and a deformed unit square that represent the vein prior- and post-deformation, respectively. Notably, angles are not doubled in physical space, and the x-axis represents the fabric attractor. The veins rotation (Φ) is used to create a reference line from ISA_2 , and its intersection with the y-axis defines the origin of the coordinate system (0,0), and defines the bottom left corners of the undeformed and deformed units. With no volume change, the length of the reference line multiplied by the stretching ratio (s) equates to one "unit" which is used to scale the coordinate system and defines the infinitesimal unit square. The upper right corner is defined by the previously described "anchor" point (a_2 , Γ) on the Mohr circle. From the Mohr

circle, the component of pure shear (k) is measured from the origin to the point $(0, a_1)$ and is transposed on the horizontal axis in physical space to define the bottom right corner of the deformed square unit and complete the parallelogram. The strain axes are determined by projecting a line from the origin to the furthest point on the Mohr circle. The line's first intersection with the Mohr circle denotes ϵ_3 , and its second intersection denotes ϵ_1 , which are used to construct the strain ellipses for rotated veins.

Examples are provided in **Figure S3.2A** for veins that have undergone different amounts of rotation. The stretching ratio is estimated by directly measuring the veins and does not account for any volume change. Results from this study and theoretical values are compared in **Figure S3.2B**.

Incremental strain axes from brittle-ductile faults

Faults with an unambiguous sense of shear were targeted, as each measurement requires the orientation of the fault plane coupled with the slip vector. Outcrops with localized deformation, or undulating foliation, were divided into "areas" that have a homogeneous orientation of the foliation, and structural data from each area were interpreted independently to facilitate the recognition of measurements that potentially reflect structural anisotropies, instead of regional strain. Assuming that paleo-stress axes were parallel to the incremental strain axes, principal directions were calculated in *Tectonics F.P 1.7.5* (Ortner et al., 2002) using the direct inversion method of Angelier (1989, 1990). Structural measurements from all brittle-ductile faults, pre- and post-rotation, along with the orientation of their inferred incremental strain axes are available in **Table S2**.

$^{40}\text{Ar}/^{39}\text{Ar}$ geochronology

White mica $^{40}\text{Ar}/^{39}\text{Ar}$ dates can represent primary crystallization ages, the timing of cooling through a nominal closure temperature, or the timing of recrystallization related to deformation. Most samples exclusively contain white mica that evinces recrystallization by forming elongated bands that define the foliation of the rock. Consequently, $^{40}\text{Ar}/^{39}\text{Ar}$ dates from these samples record the timing of recrystallization related to deformation associated with fabric formation. Similarly, $^{40}\text{Ar}/^{39}\text{Ar}$ dates from white mica developed within shear veins record deformation related top-to-E shearing. Some samples also include tabular white mica grains that do not evince recrystallization and are likely relict grains that pre-date fabric formation. As $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology was conducted on mineral separates, it is impossible to distinguish whether a single-crystal date is related to a recrystallized grain, or, the larger tabular relict grains, however, it is reasonable to assume that the tabular grains were preferentially picked during the mineral separation process due to their larger grain size (**Figure S3.8, Figure S3.A, B**).

Conventional procedures were used to extract white mineral separates from rock samples in preparation for $^{40}\text{Ar}/^{39}\text{Ar}$ dating. For most samples, a mortar and pestle were used to gently crush the rocks, and the material was sieved to target grain sizes of 150-250 μm . For the samples with mica-filled shear veins (JS/22/S23 and JS/22/24) a small chisel was used to target the material from the shear veins. For each sample, seven to nine mineral samples were selected for $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology. All analytical work was performed at the University of Manitoba (Winnipeg, Canada) using a multicollector Thermo Fisher Scientific ARGUSVI mass spectrometer, linked to a stainless steel Thermo Fisher Scientific extraction/purification line and Photon Machines (55 W) Fusions 10.6 CO_2 laser. Argon isotopes (from mass 40 to 37) were measured using Faraday detectors with low noise $1 \times 10^{12} \Omega$ resistors and mass 36 was measured using a compact discrete

dynode (CDD) detector. The sensitivity for argon measurements is $\sim 6.312 \times 10^{17}$ moles/fA as determined from measured aliquots of Fish Canyon Sanidine (Dazé et al., 2003; Kuiper et al., 2008). Standards and unknowns were placed in 2 mm deep wells in 18 mm diameter aluminium disks, with standards placed strategically so that the lateral neutron flux gradients across the disk could be evaluated. Planar regressions were fit to the standard data, and the $^{40}\text{Ar}/^{39}\text{Ar}$ neutron fluence parameter, J , interpolated for the unknowns. Uncertainties in J are estimated at 0.1-0.2% (1σ), based on Monte Carlo error analysis of the planar regressions (Best et al., 1995). All samples were irradiated for a duration of 72 h in the cadmium-lined, in-core CLICIT facility of the Oregon State University TRIGA reactor. Irradiated samples were placed in a Cu sample tray, with a KBr cover slip, in a stainless-steel high vacuum extraction line and baked with an infrared lamp for 24 h. Single crystals were either fused or step-heated for ~ 40 s per step using the laser, and reactive gases were removed, after ~ 3 min, by three NP-10 SAES getters (two at room temperature and one at $\sim 450^\circ\text{C}$) prior to being admitted to the ARGUSVI mass spectrometer by expansion. Five argon isotopes were measured simultaneously over a period of 6 min. Measured isotope abundances were corrected for extraction-line blanks, which were determined before every sample analysis. Line blanks averaged ~ 6.04 fA for mass 40 and ~ 0.02 fA for mass 36. Mass discrimination was monitored by online analysis of air pipettes based on a power law relationship (Renne et al., 2009) which gave during two separate sessions ($D = 1.01055 \pm 0.00255$ and 1.00657 ± 0.00229 per amu), based on a total of 309 aliquots interspersed with the unknowns. A value of 295.5 was used for the atmospheric $^{40}\text{Ar}/^{39}\text{Ar}$ ratio (Steiger and Jäger, 1977) for the purposes of routine measurement of mass spectrometer discrimination using air aliquots, and correction for atmospheric argon in the $^{40}\text{Ar}/^{39}\text{Ar}$ age calculation. Corrections are made for neutron-induced ^{40}Ar from potassium, ^{39}Ar and ^{36}Ar from calcium, and ^{36}Ar from chlorine (Roddick, 1983; Renne et al., 1998; Renne and Norman, 2001). Data collection was performed using Pychron (Ross, 2017) and data reduction, error propagation, age calculation and plotting were performed using *MassSpec* software (version 8.091; Deino, 2013). The decay constants used were those recommended by Steiger and Jäger (1977).

Prior to calculating weighted mean ages for each sample, imprecise single crystal ages were omitted, and ages with a small error (<1 m.y.) were inflated to 1 Ma, as the analytical errors are likely underestimated. Weighted mean $^{40}\text{Ar}/^{39}\text{Ar}$ dates were calculated in *IsoplotR* (Vermeesch, 2018), and Chauvenets's criterion (Ludwig, 2003) was used to identify anomalous single crystal dates, which were omitted from the weighted mean calculations (**Table 3.1**). For samples with dispersed single crystal $^{40}\text{Ar}/^{39}\text{Ar}$, a range of ages is reported instead (**Table 3.1**). Weighted mean diagrams (**Figure S3.5**) were created in *IsoplotR* (Vermeesch, 2018).

Raman spectroscopy of carbonaceous material

Graphitization is a temperature-based reaction that describes the reorganization of carbon atoms within carbonaceous material (CM) into layered crystal planes (Teichmüller, 1987). The ordering of carbon atoms can be measured via Raman spectroscopy (RS) to derive temperatures related to graphitization. Graphitization is an irreversible reaction and therefore is not affected by retrogression metamorphism (French, 1964; Landis, 1971; Quinn and Glass, 1958). RSCM can serve as a thermometer related to peak metamorphic conditions and has proven useful in understanding the thermal structure of the Tauern Window (e.g. Scharf et al., 2013; Groß et al., 2020). Numerous calibrations have been used in literature to derive peak temperatures from the Raman spectra (e.g. Groß et al., 2020; Scharf et al., 2013). Calibrations are sensitive to slightly different temperatures and comparative studies have demonstrated discrepancies in RSCM values

for the calibrations (Lünsdorf et al., 2017). The RSCM data presented herein uses the calibration of Lünsdorf et al. (2017) as it is suitable for a wide temperature range (160-600°C) and uses an automatic curve-fitting approach and a reference series that allows laboratories to generate its own calibration curve. This method eliminates the error introduced by operator biases and variable analytical conditions across different laboratories and is best suited to interpret RSCM temperatures from different studies (Lünsdorf et al., 2017).

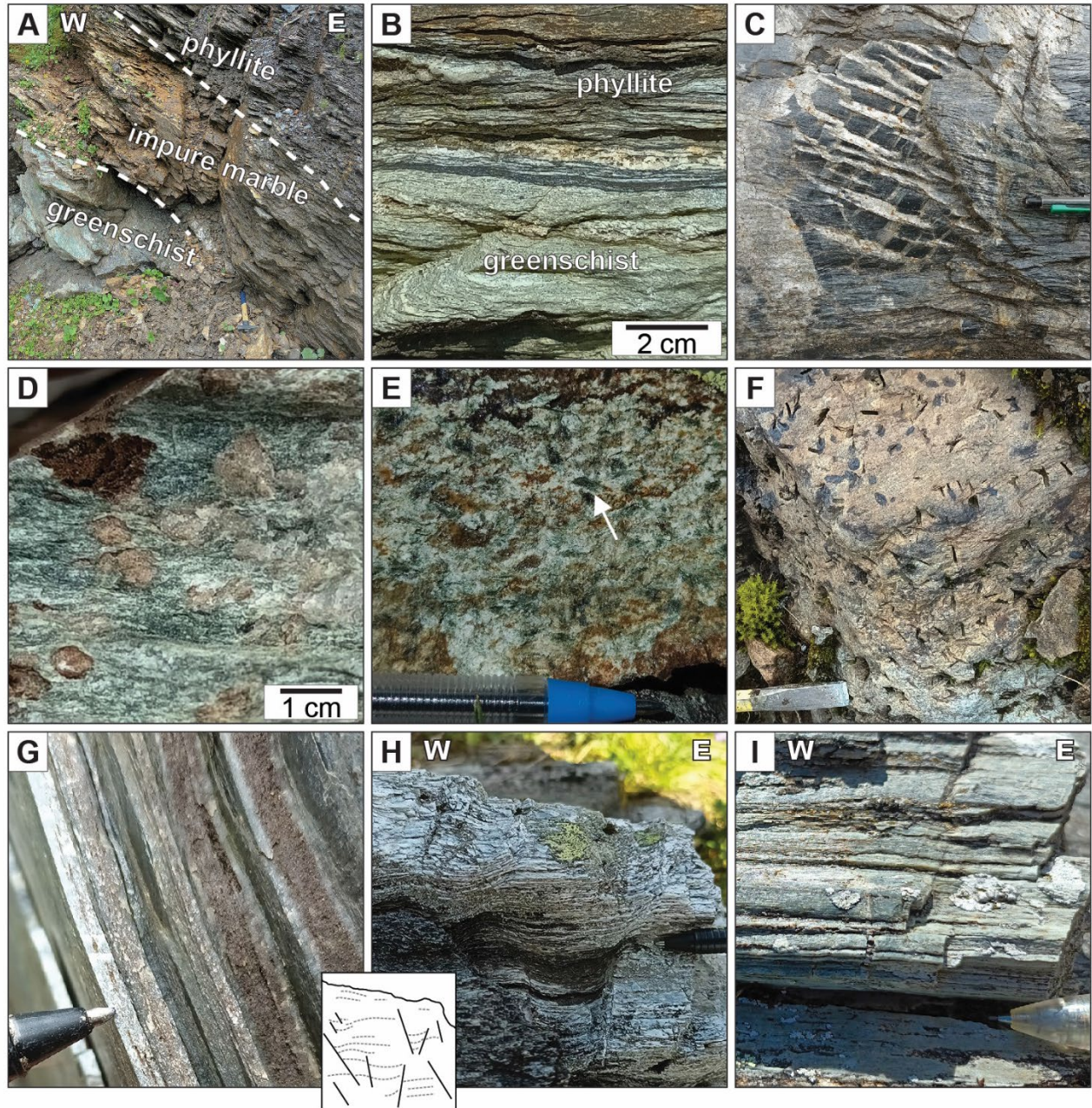


Figure S3.1A. Representative photos of the lithologies observed in the study area. (A) Upper contact of the continuous greenschist unit. Meter-thick package of quartz-rich impure marble separates the greenschist from overlying graphitic phyllite (N 5232073, E341896). (B) Contact separating greenschist (bottom) with quartz-rich phyllite (top). Quartz-rich layers form white banded layers within phyllite (N 5231382, 342898). (C) Graphite phyllite crosscut by a network of cm-thick quartz-mica shear veins (N 5232333, E 342923). (D) Metagabbro lens within greenschist in southwestern limit of the study area. Large (~0.5 cm), pink prismatic minerals are carbonates that are likely replacing plagioclase (N 5232355, E 336734). (E) Coarse grained metagabbro at the base of a greenschist lens in northeast of the study area. Chlorite is likely replacing clinopyroxene (white arrow). Calcite and albite comprises lighter material in the groundmass (N 5234705, E 344655). (F) Weathered metagabbro in the south of the study area. Cm-long acicular voids likely represent dissolved amphiboles (N 5229909, E 342164). (G) Cm-thick layers of fine-grained quartzite interbedded with impure (brown) marble (N 5234312, E 343514). (H) Ultrafine grained quartzite interpreted as metaradiolarite. Penetrative foliation showing drag along conjugate shear bands as shown in line drawing (N 5234443; E 341241). (I) Light green, ultrafine grained quartzite interpreted as metaradiolarite. Penetrative W-E stretching lineation forms L-tectonite (N 5234227, E344594).

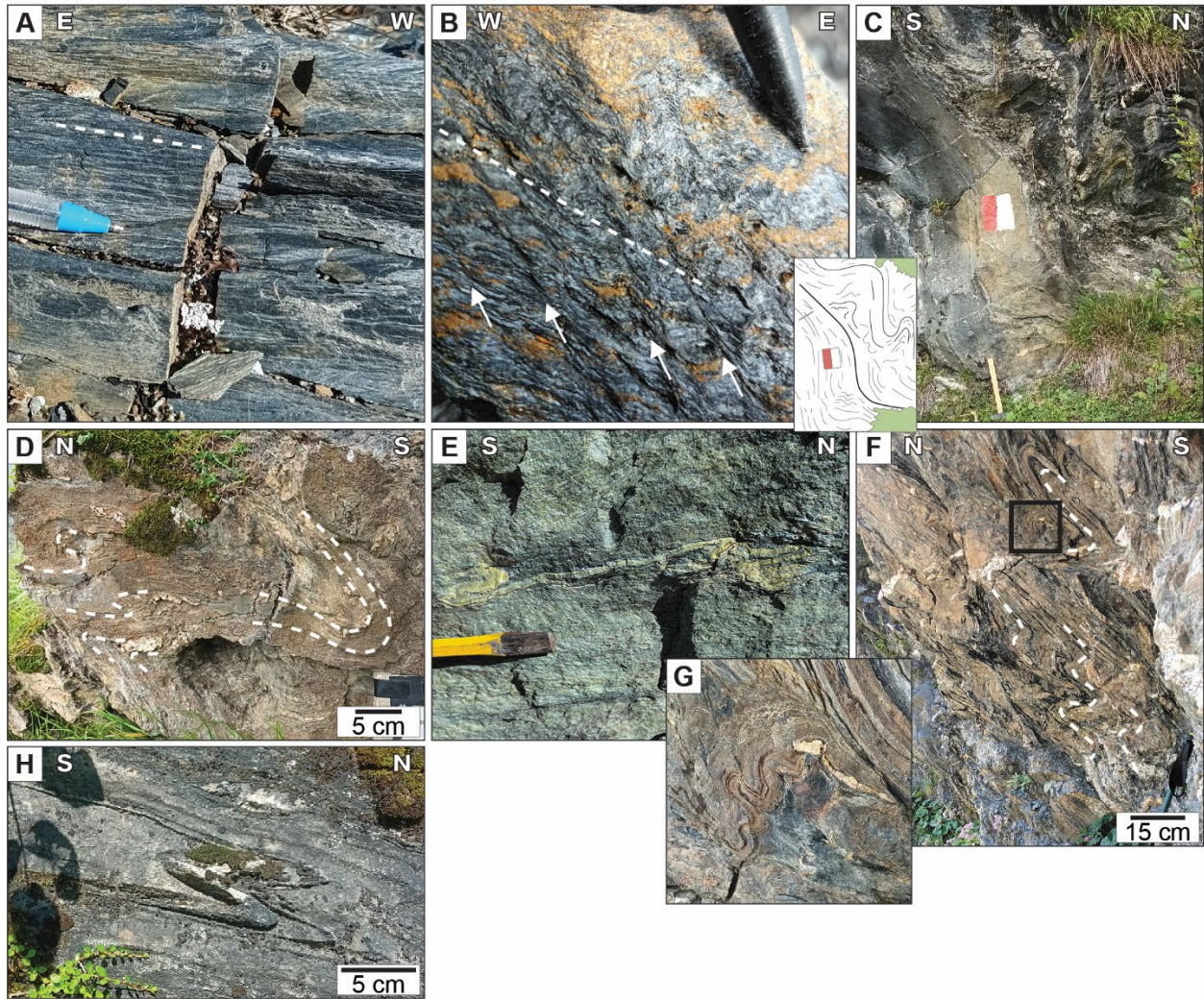


Figure S3.1B. Examples of folds and axial plane cleavage. Representative photos (A) Pervasive E-W crenulation aligned with the axis (dashed white line) of a DII fold (N 5229797, E 341078). (B) Axial plane cleavage (white arrows) within graphitic phyllite with oxidized layers within the foliation (white dashed line; N 5230468, E 341574). (C) Impure marble showing meter-scale DII folding. Parasitic folding on northern limb has a Z geometry, as shown in line diagram (N 5231183, E 341782). (D) DIII fold train within impure marble (N 5233277; E 338842). (E) Greenschist with compositional banding. Bright green layer is epidote and forms DI folds (N 5231546, E 345083). (F) Impure marble with asymmetric DII fold train forming an S geometry. (G) Black box in [F] positioned at the hinge of synformal S fold showing higher order parasitic folds with an M geometry (N 5233142, E 344030). (H) Refolded DIII fold within impure marble (N 5231142, E 341546).

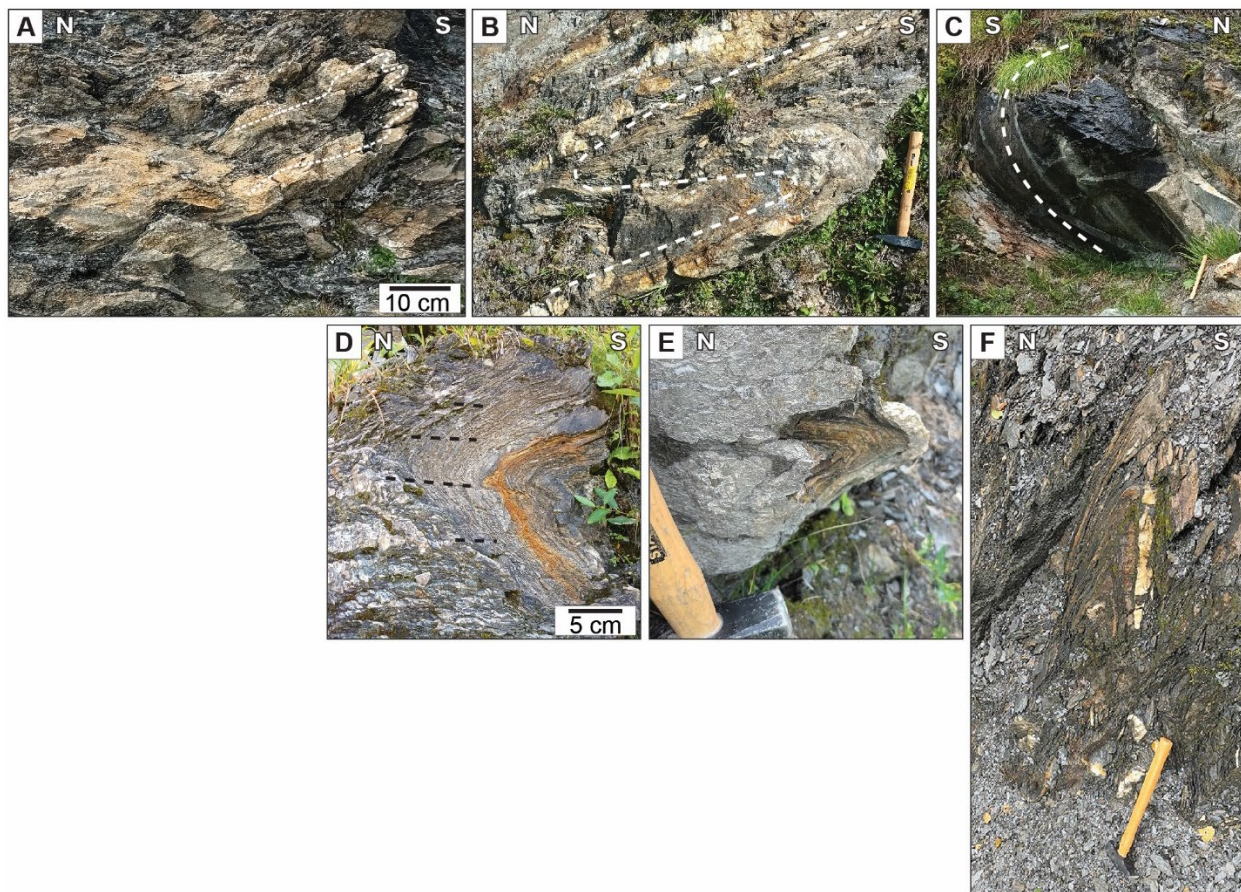


Figure S3.1C. Examples of folds. (A) Impure marble layer with a DIII fold that is refolded (white dashed line; N 5230685, E 340572). (B) Train of DIII folds within impure marble (white dashed line; N 5233808, E 338082). (C) Meter-scale DIII fold within impure marble. Fold profile highlighted by white dashed line (N 5231183, E 341782). (D) DIII fold within phyllite. Axial plane cleavage highlighted by black dashed lines (N 5233894, 343034). (E) DIII fold within impure marble (N 5233375, E 341939). (F) DII fold within impure marble (N 5232700, E 336394).

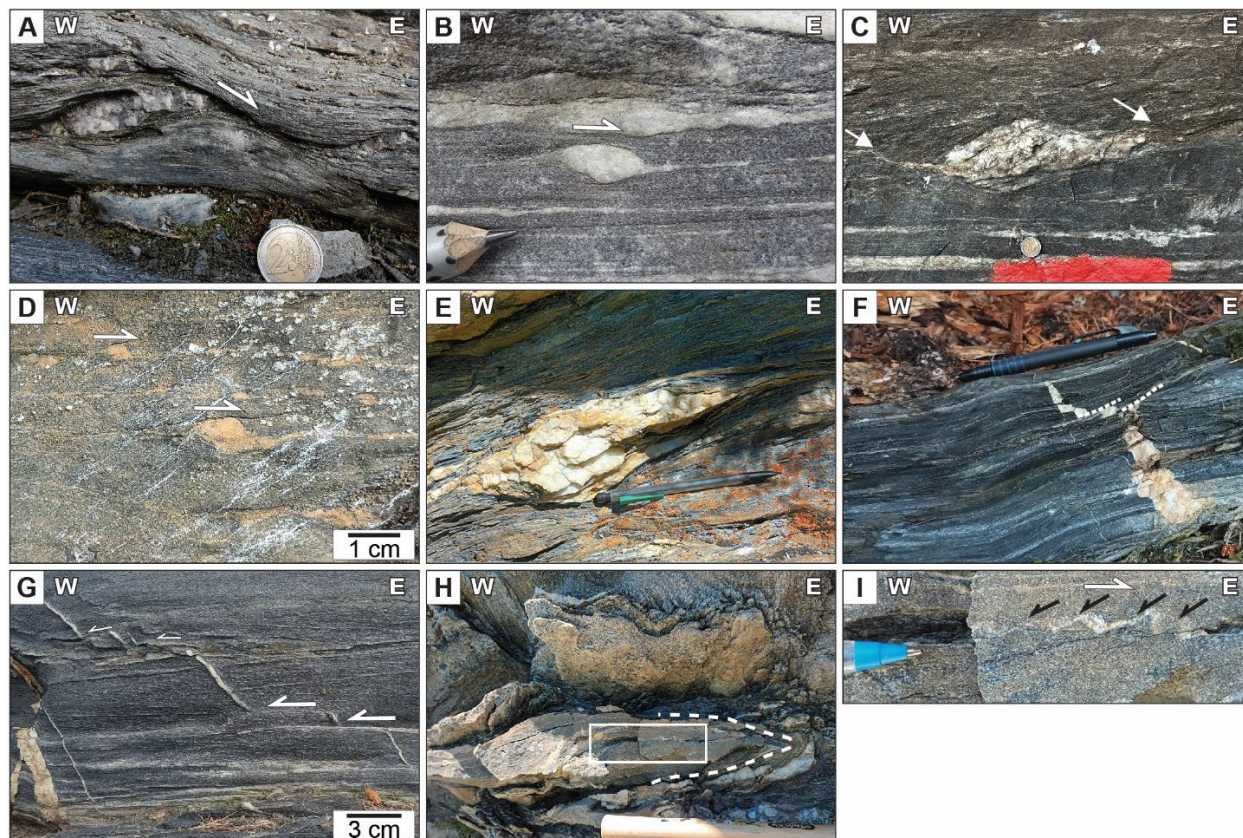


Figure S3.1D. Examples of kinematic indicators. (A) Impure marble with vein-boudinage cross-cut by E-dipping shear band (N 5232098, E 347579). (B) Calcite layer forming winged inclusion within impure marble (N 5232440, E 349447). (C) Vein boudinage within impure marble. E-dipping shear bands denoted by white arrows (N 5234285, E 348580). (D) Series of winged inclusions showing top-to-E kinematics within impure marble (N 5230612, E 342976). (E) Boudinaged calcite vein within impure marble interbedded with phyllite (N 5231913, E 343267). (F) Calcite vein progressively offset by west-dipping shear bands (white dashed lines) showing top-to-W kinematics. Foliation is dipping to the south and likely represents the inverted limb of a DII fold. The overturned foliation results in an apparent reverse sense of shear compared to dominant top-to-E sense of shear (N 5234357, E 343134). (G) Impure marble interbedded with thin beds of phyllite. Calcite vein oblique to the foliation is systematically offset along layers of phyllite. Foliation is dipping to the south and likely represents the inverted limb of a DII fold. The overturned foliation results in an apparent reverse sense of shear compared to dominant top-to-E sense of shear (N 5234357, E 343134). (H) DIII fold within impure marble. (I) Inset denoted by white box in [H]. Calcite vein offset along antithetic fractures (black arrows) with synthetic rotation showing top-to-E sense of shear (N 5230851, E 340739).

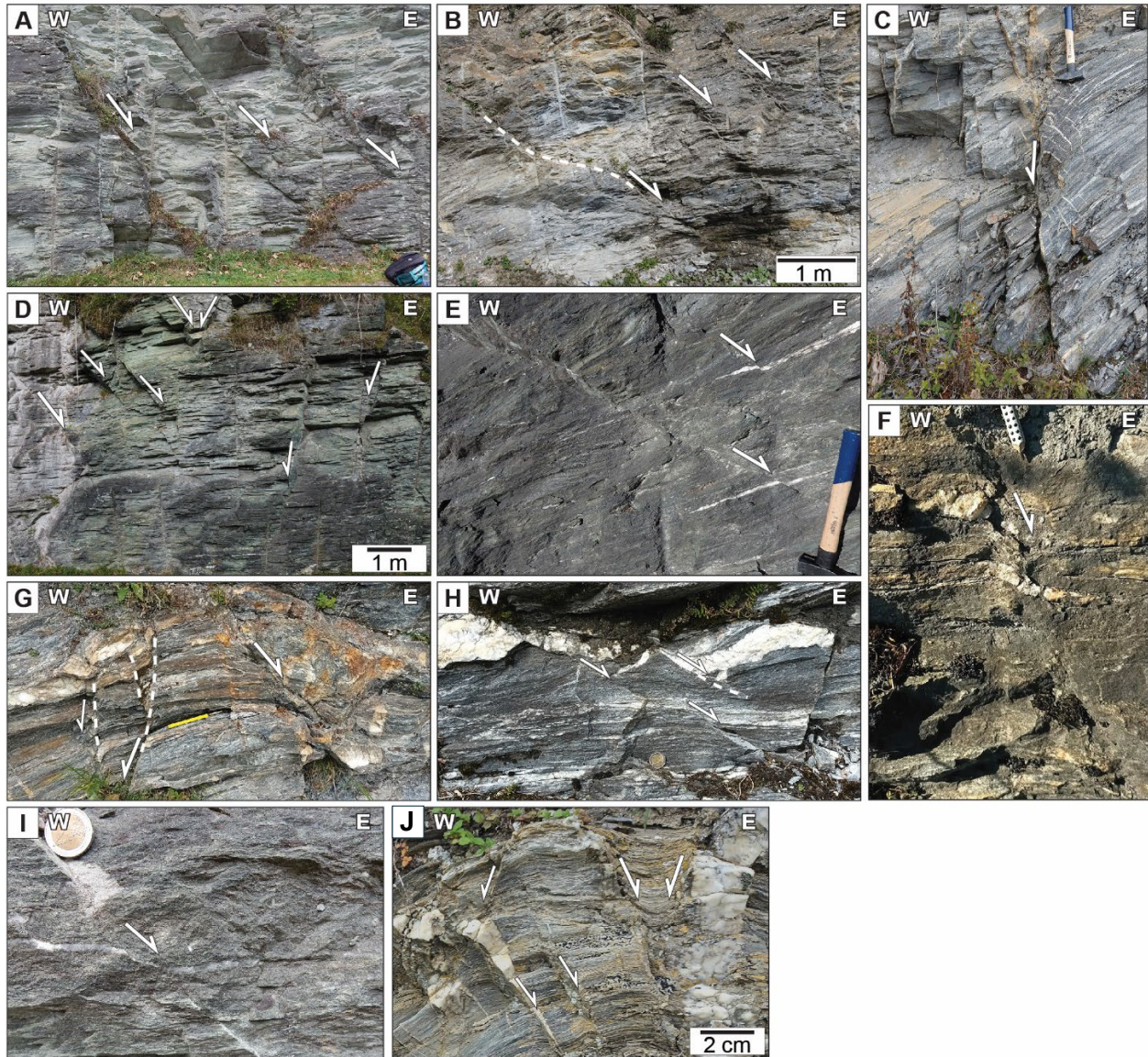


Figure S3.1E. Examples of brittle-ductile faults. (A) Meter-scale E-dipping brittle-ductile normal faults crosscutting greenschist (N 5232527, E 348755). (B) Meter-scale E-dipping brittle-ductile normal faults crosscutting impure marble (N 5232493, E 346899). (C) Steeply dipping brittle-ductile fault. Foliation drag and tension gash structures developed along the fault surface show the faults kinematics (N 5234353, E 348515). (D) E- and W-dipping brittle-ductile normal faults that locally form conjugate sets (N 5232527, E 348755). (E) Greenschist with brittle-ductile normal faults offsetting boudinaged foliation-parallel calcite veins (N 5231546, E 345083). (F) E-dipping normal fault with foliation drag (N 5233808, E 338082). (G) Conjugate set of brittle-ductile faults within impure marble. Fault kinematics evinced by foliation drag (N 5233808, E 338082). (H) Impure marble with E-dipping brittle-ductile faults (N 5234285, E 348580). (I) Greenschist with E-dipping brittle-ductile fault. Foliation-parallel quartz vein is dragged along the surface (N 5232527, E 348755). (J) E- and W- dipping brittle ductile faults that locally form conjugate sets. Intense foliation drag, and quartz-calcite veins often develop along fault surfaces (N 5234526, E 344302).

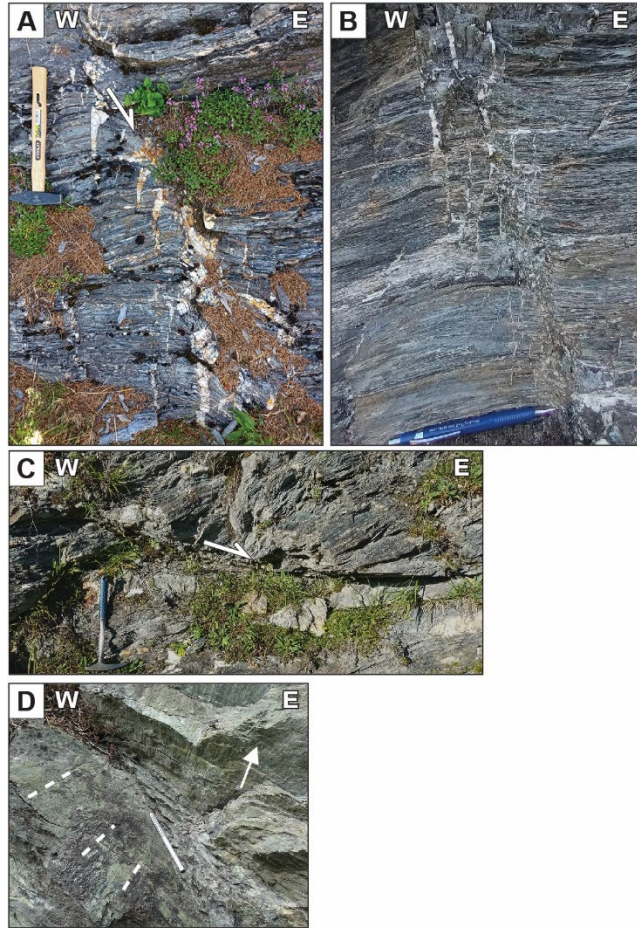
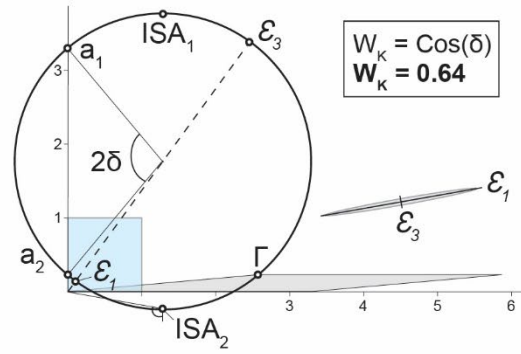
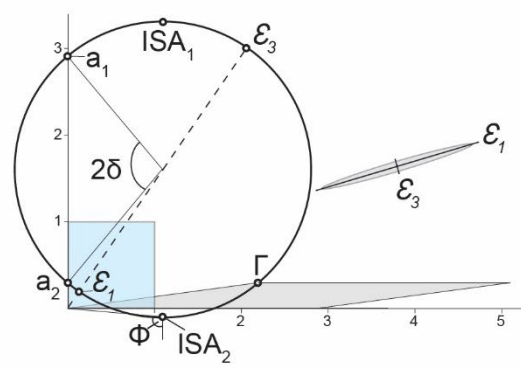


Figure S3.1F. Examples of brittle-ductile faults. (A) Impure marble with E-dipping brittle-ductile normal fault. Fault kinematics evinced by tension gash structures and foliation drag (N 5233808, E 338082). (B) E-dipping brittle-ductile normal fault with tension gash structures in a phyllite (N 5234526, E 344302). (C) Low-angle E-dipping normal fault crosscutting impure marble (N 5233808, E 338082). (D) Conjugate fault planes within greenschist. White arrow denotes direction of displacement evinced by stair-stepping and dashed lines are aligned with striations (N 5232527, E 348755).

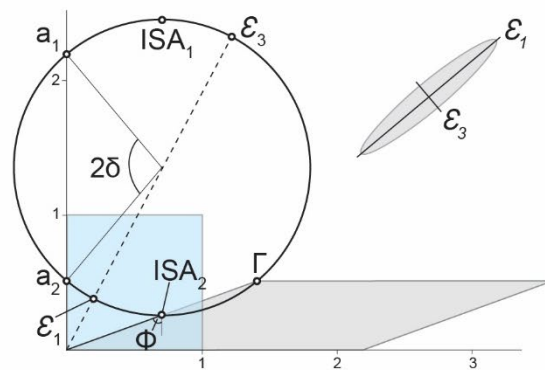
Vein 1



Vein 2



Vein 3



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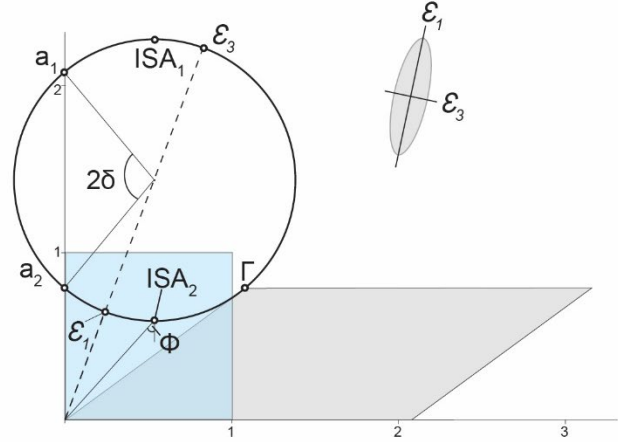
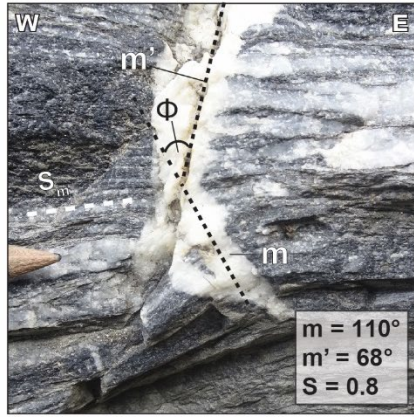
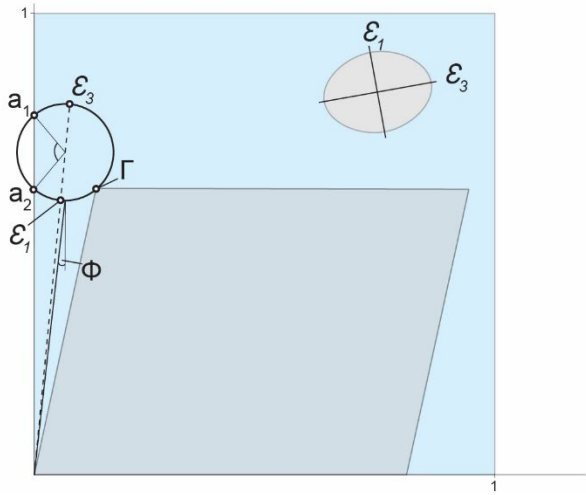
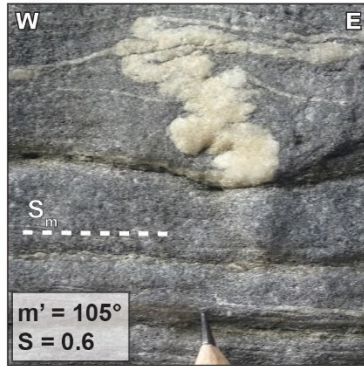
Vein 4**Vein 5**

Figure S3.2A. A) Mohr circles of Second Kind in strain space and physical space for five veins that have been progressively rotated into the top-to-east direction of shear. The instantaneous stretching axis (ISA_1 and ISA_2), the eigenvectors (a_1 and a_2) and the kinematic vorticity number (W_k) are fixed under steady-state ductile flow. Consequently, the constructed Mohr circles are identical to **Figure S5**. ISA_2 represents the original vein orientation (m) and is $\sim 110^\circ$ relative to the foliation (S_m). The original opening angle of veins (m) is shown in **vein 4** in the extension gash at its tip which represents later reactivation. The rotation of the veins is the difference between the veins current orientation (m') and its original opening angle ($\Phi = m - m'$) and is used to define the origin of the coordinate system $(0,0)$ and to project the deformed veins from strain space to physical space. The stretching ratio (S) estimates the amount of shortening/stretching of the deformed vein and is used to define one unit square (blue box). The grey polygon is the deformed unit square and represents the rotated vein and is constructed by projecting coordinates in strain space into physical space. The strain ellipse is defined by a line connecting the origin $(0,0)$ to the furthest point on the Mohr circle, where the first intersection denotes ϵ_3 and the second intersection denotes ϵ_1 . A full description of the construction of the Mohr circle is available in the **methodology** section of the supplementary files. The locations of the five deformed veins presented are: vein 1; N 5232527, E 348755. Vein 2; N 5232098, E 347579. Vein 3; N 5234285, E 348580. Vein 4; N 5232440, E 349447. Vein 5; N 5232440, E 349447.

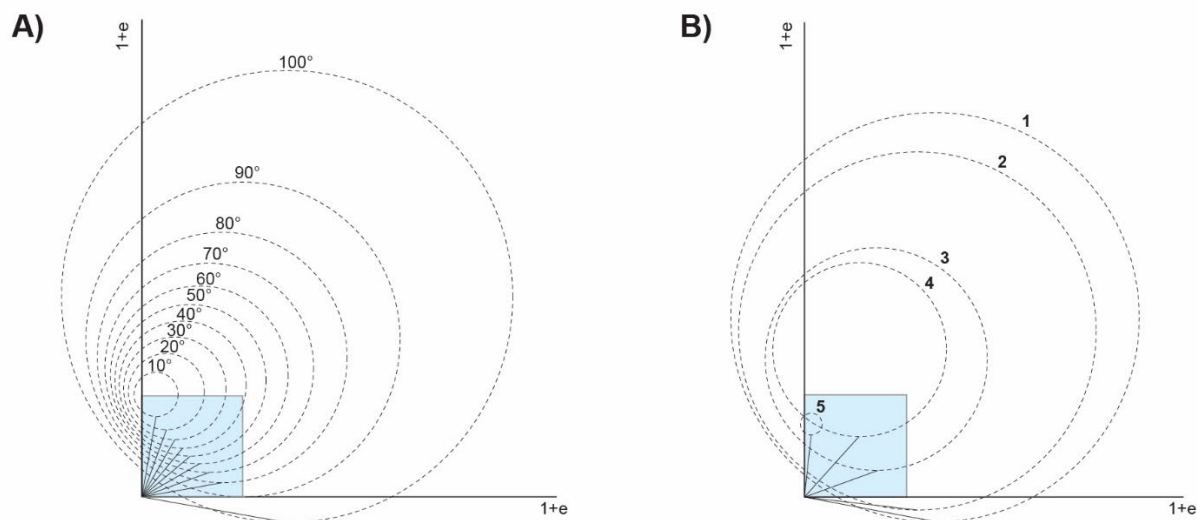


Figure S3.2B. A) Mohr circle of Second Kind showing a forward model of finite deformation for veins that have been progressively rotated by 10° increments. Results are for veins opening at 110° (m) relative to the foliation and assume steady-state ductile flow with no volume change. B) Mohr circle of second kind compiling the results from the five deformed veins presented in **Figure S3.2A**. Each Mohr circle is scaled relative to its respective undeformed unit square.

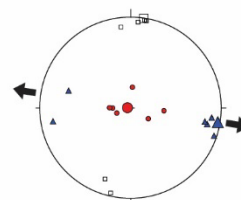
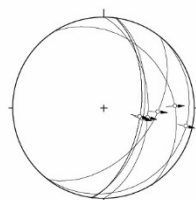
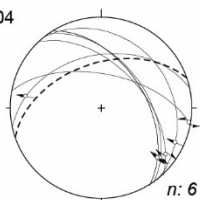
Fault measurements and foliation

Rotated fault measurements

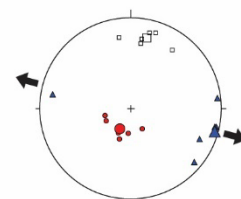
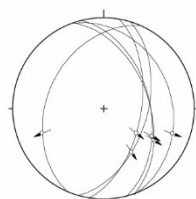
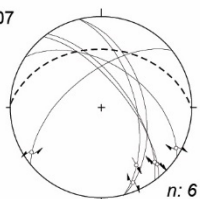
Strain axes

• ϵ_1 □ ϵ_2 ▲ ϵ_3

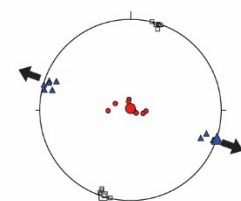
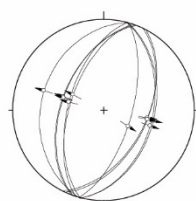
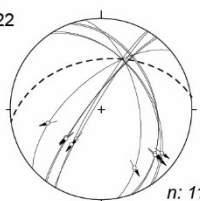
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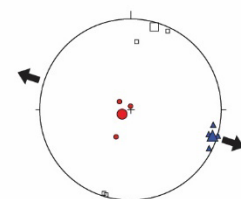
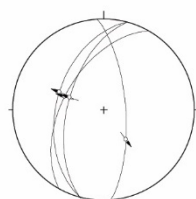
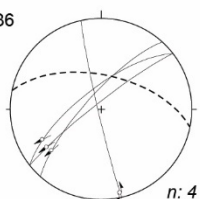
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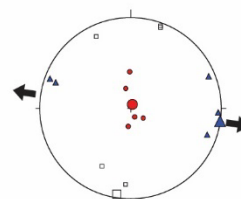
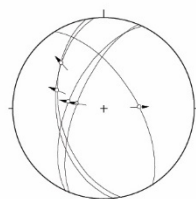
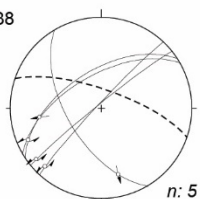
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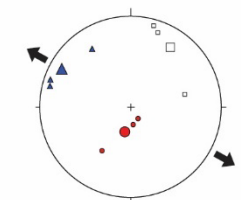
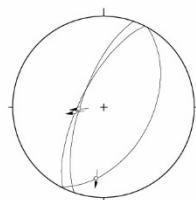
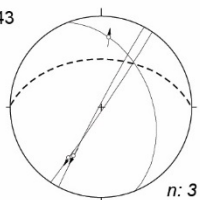
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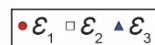


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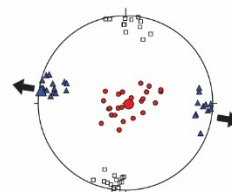
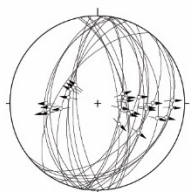
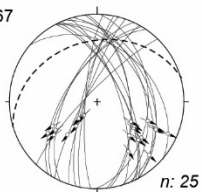
Fault measurements and foliation

Rotated fault measurements

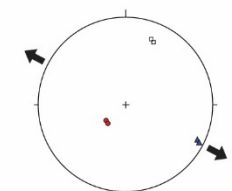
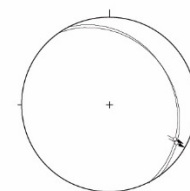
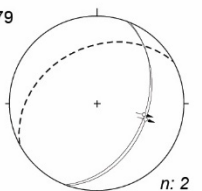
Strain axes



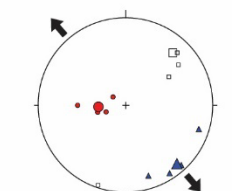
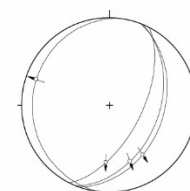
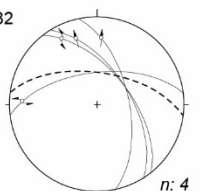
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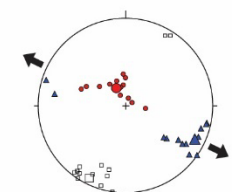
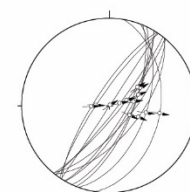
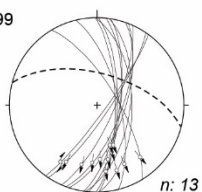
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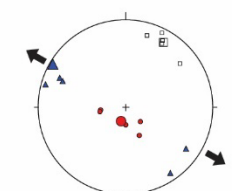
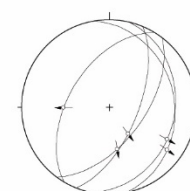
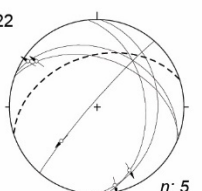
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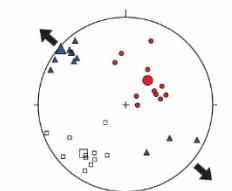
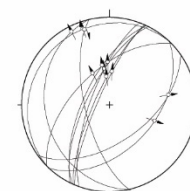
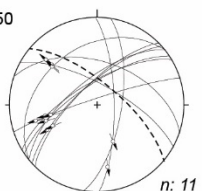
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JS-22-122



JS-22-150



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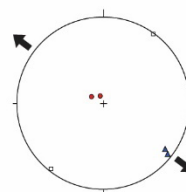
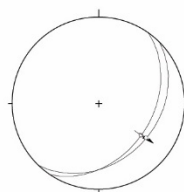
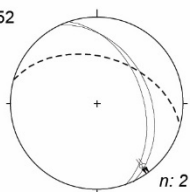
Fault measurements and foliation

Rotated fault measurements

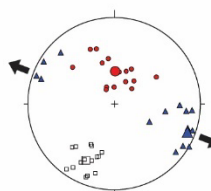
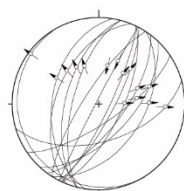
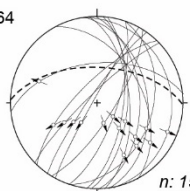
Strain axes



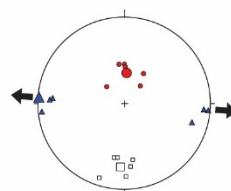
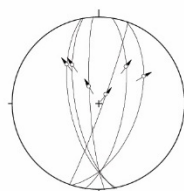
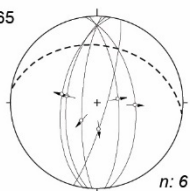
JS-22-152



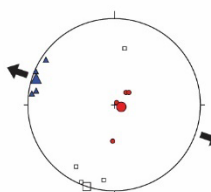
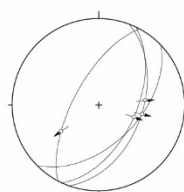
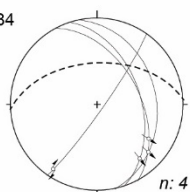
JS-22-164



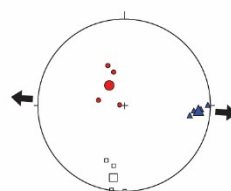
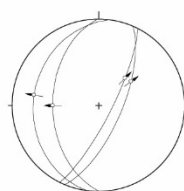
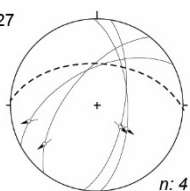
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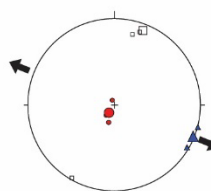
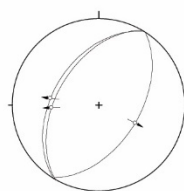
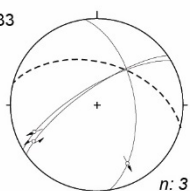
JS-22-184



JS-22-227



JS-22-233



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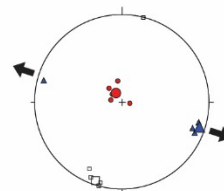
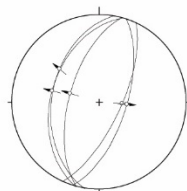
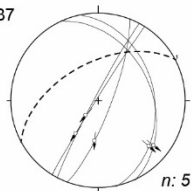
Fault measurements and foliation

Rotated fault measurements

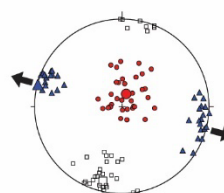
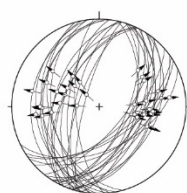
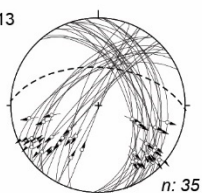
Strain axes



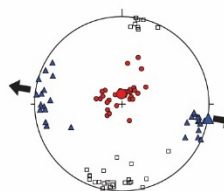
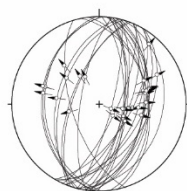
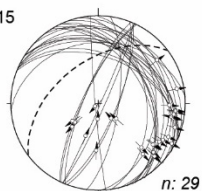
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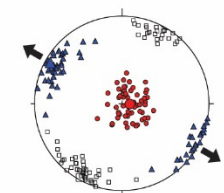
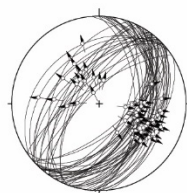
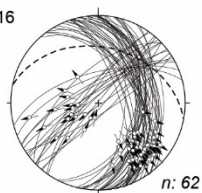
S13



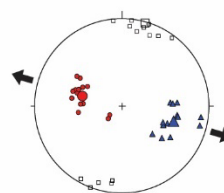
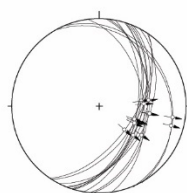
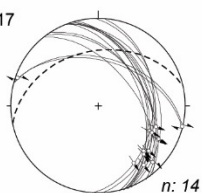
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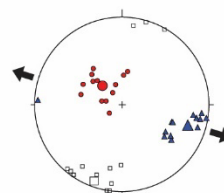
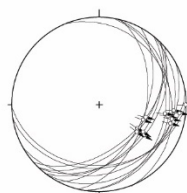
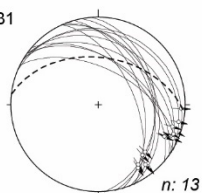
S16



S17



S31



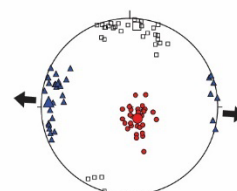
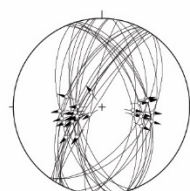
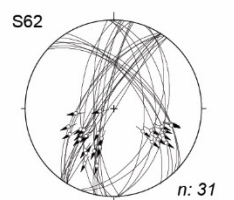
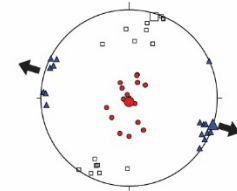
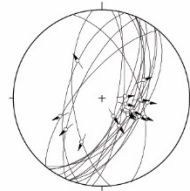
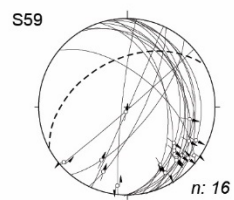
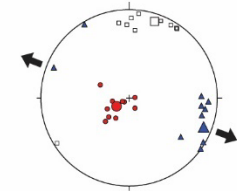
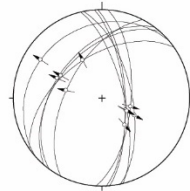
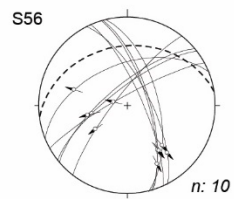
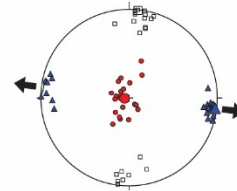
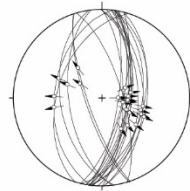
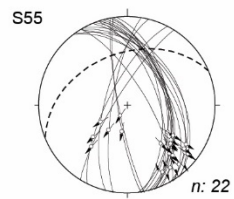
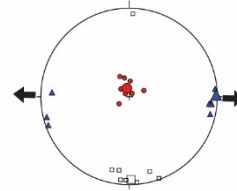
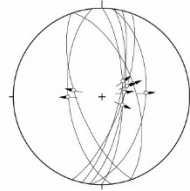
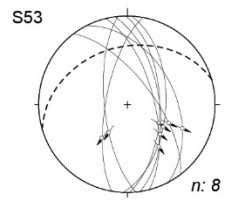
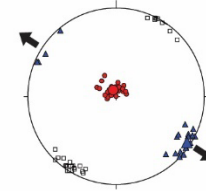
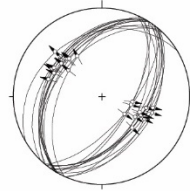
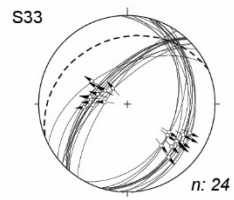
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Fault measurements
and foliation

Rotated fault
measurements

Strain axes

• ϵ_1 □ ϵ_2 ▲ ϵ_3



Continued on the next page

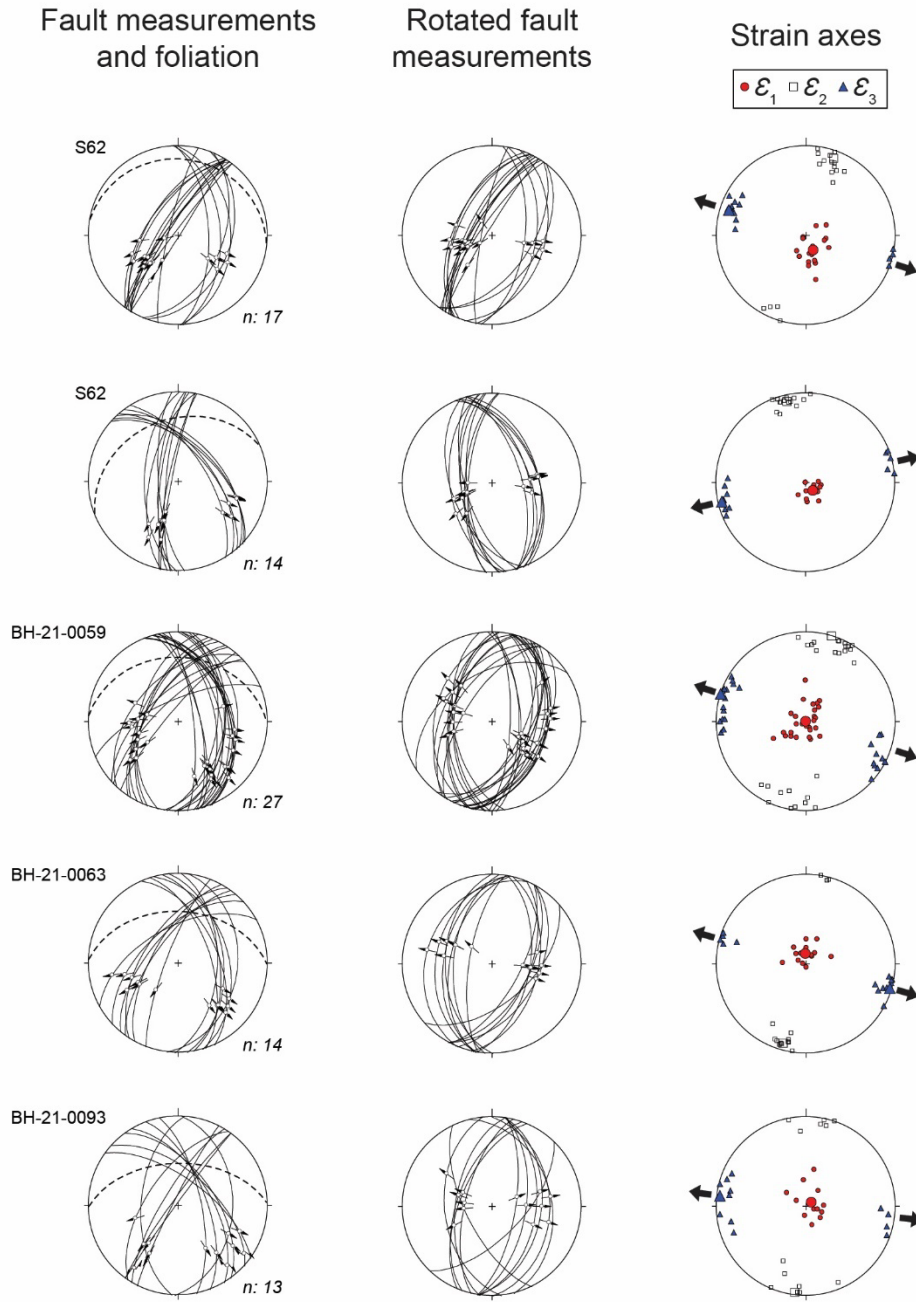


Figure S3.3. Stereoplots of brittle-ductile faults and strain axes. First column are the fault measurements and corresponding slip vectors. Dashed line is a representative foliation measurement for the locality. In the second column, stereoplots are rotated relative to the foliation. The third column shows strain axes for each measurement. Larger symbols represent average strain axes (reported in **Table 3.1**).

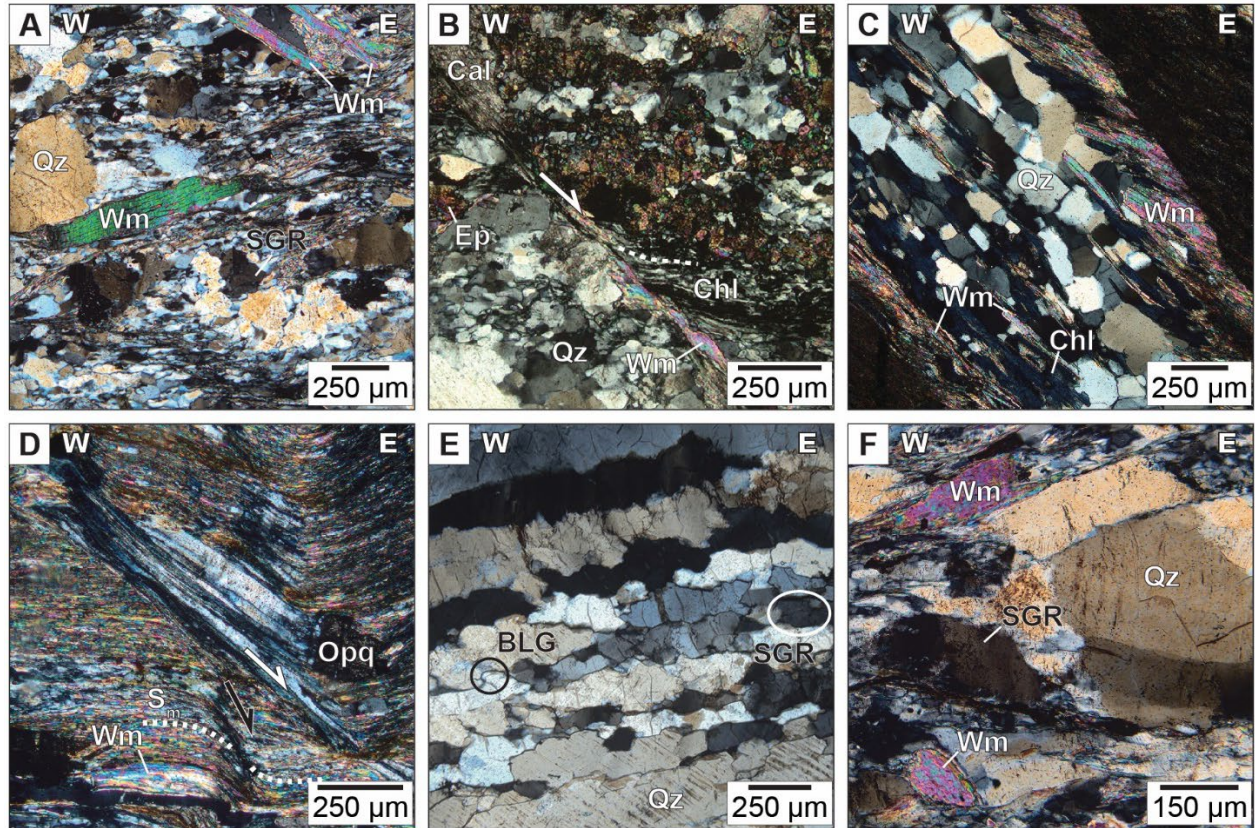


Figure S3.4A. (A) Quartz-rich phyllite with tabular white mica oriented at a high angle relative to the foliation (top right) and forming mica fish (center). Quartz recrystallizing via subgrain rotation (N 5237057, E 343368). (B) E-dipping shear band in greenschist. White mica developed along the shear band and displacement is evinced by minor foliation drag within chlorite (white dashed line; N 5232464, E 338715). (C) Shear vein within graphitic phyllite. Most of the vein consists of elongated quartz that are aligned with the vein orientation and is recrystallized via grain boundary migration. White mica and chlorite define the vein margin. Some tabular white micas are preserved within the vein and are aligned with the vein fabric (N 5232334, E 342923). (D) E-dipping shear veins within phyllite. The dashed white line defines the foliation (S_m) and highlights the foliation drag along the older shear band (black arrow) that is crosscut by a later shear band (white arrow). Ribboned quartz developed in the strain shadow of opaque mineral (Opq) evinced top-to-E sense of displacement (N 5234313, E 343514). (E) Strong shape-preferred orientation of quartz. Quartz recrystallizes via bulging grain boundaries and subgrain rotation (N 5234849, E 342457). (F) Phyllite with large relict quartz grains recrystallizing via subgrain rotation. Tabular white mica proximal to large quartz grains are deformed but not recrystallized (N 5237057, E 343368). Mineral abbreviations follow Whitney and Evans (2010). BLG: bulging; SGR: subgrain rotation.

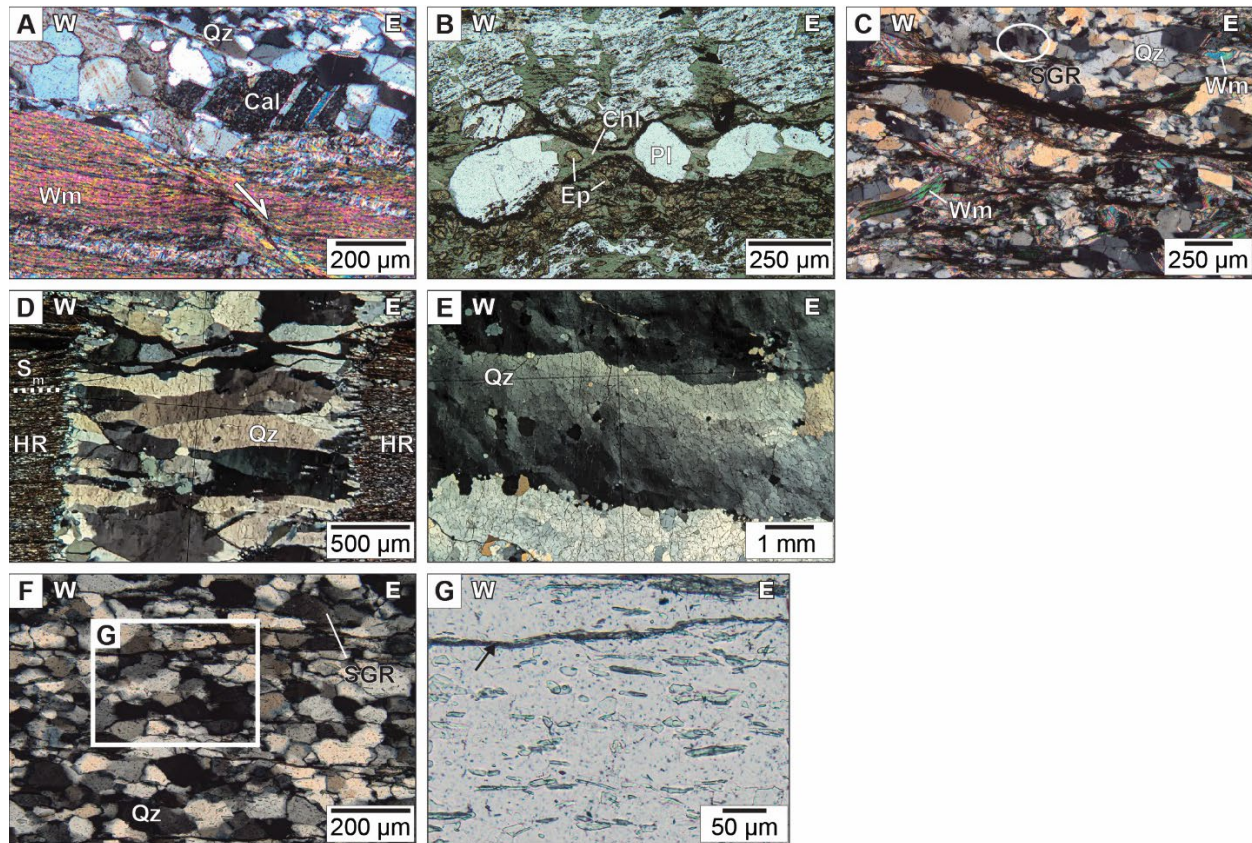


Figure S3.4B. (A) Impure marble with microlithon of white mica (bottom) preserving a discrete E-dipping shear band. Minor foliation drag preserved in the fabric of the white mica (N 5234114, E 344472). (B) Greenschist with pinch-and-swell structure defined by coarse plagioclase and chlorite defining the “necks” of the structure (N 5231178, E 343821). (C) Phyllite with quartz grains recrystallizing via subgrain rotation. Blocky white mica have various orientations and are deformed but do not evince recrystallization (N 5231702, E 349384). (D) Quartz vein that is oriented perpendicular to the foliation of the host rock (S_m). Vein texture consists of tabular quartz crystals that are mostly oriented perpendicular to the direction of vein opening. Reduced grain size along the vein margin (N 5234526, E 344302). (E) Photomicrograph of the interior of a foliation-parallel quartz vein. Large quartz grains that span the entire frame of view are recrystallized via grain boundary migration and exhibits undulous extinction. Quartz grains have a shape-preferred orientation that is parallel to the foliation (N 5234526, E 344302). (F) Quartz mylonite with foliation defined by a shape-preferred orientation of quartz. Quartz is dynamically recrystallized via subgrain rotation. (N 5233821, E 344210). (G) Inset from [F] showing dissolution-reprecipitation parallel to the foliation (black arrow) and acicular actinolite and tremolite (green) that parallel the E-W stretching lineation. Mineral abbreviations follow Whitney and Evans (2010). HR: host rock; BLG: bulging; SGR: subgrain rotation.

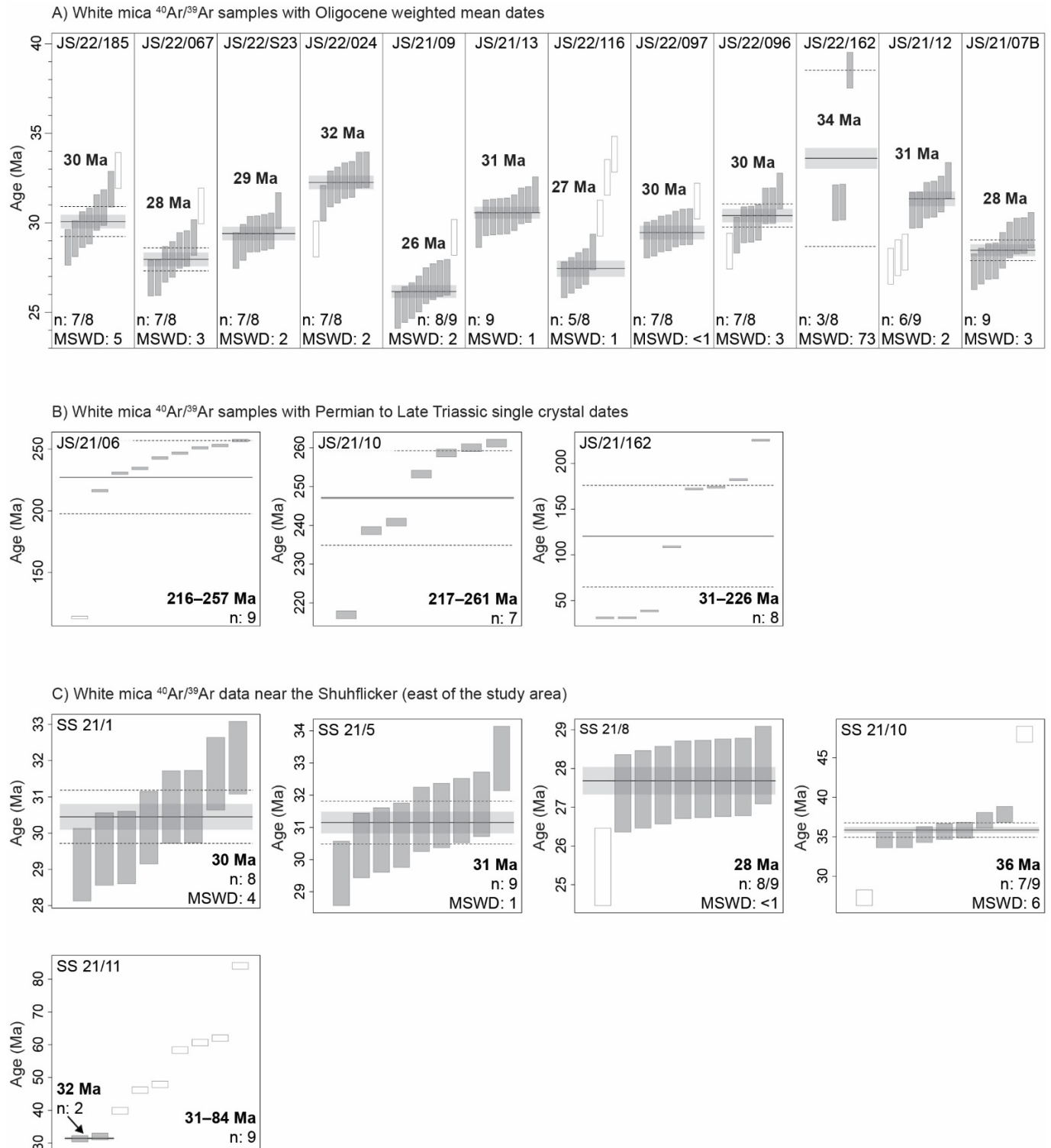


Figure S3.5. Weighted mean diagrams for all white mica $^{40}\text{Ar}/^{39}\text{Ar}$ samples. Empty boxes denotes grains that were omitted. Single-grain crystals with errors (1σ) of <1 Myr were inflated to 1 Ma. For sample JS-22-162, three single crystals yielded Oligocene dates (A) and all dates are shown in (B).

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Table S3.1: Outcrop summary table, Tauern Window, Austria

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
JS-22-001	graphite phyllite	329	42	242	3	5232759	342122
JS-22-002	graphite phyllite	347	52	283	29	5232041	342129
JS-22-003	graphite phyllite	353	47	-	-	5232294	342092
JS-22-004	graphite phyllite - marble	338	30	279	20	5232073	341896
JS-22-005	metagabbro	334	46	273	27	5231701	341786
JS-22-006	graphite phyllite	303	34	-	-	5231346	341819
JS-22-007	impure marble	353	42	289	22	5234518	343102
JS-22-008	phyllite (+/- chlorite)	7	49	291	16	5234831	343466
JS-22-009	impure marble and meta-sandstone	349	81	265	31	5234959	343647
JS-22-010	graphite phyllite	332	48	284	37	5234632	343139
JS-22-011	impure marble	147	34	99	19	5231142	341546
JS-22-012	marble	11	54	289	10	5231127	341374
JS-22-013	impure marble	342	39	286	24	5231116	341281
JS-22-014	very impure marble	353	51	282	21	5231196	341233
JS-22-015	graphite phyllite	332	69	266	47	5231348	341112
JS-22-016	greenschist - impure marble	359	46	86	3	5231421	341039
JS-22-017	graphite phyllite	6	34	293	11	5231234	340997
JS-22-018	impure marble	318	21	279	17	5231160	340982
JS-22-019	very impure marble	338	41	259	9	5231067	340966
JS-22-020	impure marble	342	28	274	11	5231197	341032
JS-22-021	greenschist	341	46	261	11	5232062	342562
JS-22-022	greenschist	352	44	296	28	5232191	342632
JS-22-023	graphite phyllite	328	40	-	-	5232433	342800
JS-22-024	graphite phyllite	322	66	285	61	5232334	342923
JS-22-025	graphite phyllite	329	48	276	33	5232265	342992

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
JS-22-026	very impure marble	21	59	298	11	5231935	342783
JS-22-027	graphite phyllite	343	44	274	19	5232173	343189
JS-22-028	impure marble	315	21	268	15	5231913	343267
JS-22-029	graphite phyllite	343	39	286	24	5232188	343406
JS-22-030	graphite phyllite	12	52	284	3	5232623	343243
JS-22-031	graphite phyllite	344	46	293	33	5232683	343197
JS-22-032	graphite phyllite	3	38	283	7	5233242	343467
JS-22-033	graphite phyllite	313	11	279	9	5233012	343259
JS-22-034	graphite phyllite and meta-sandstone	331	61	270	41	5232388	343370
JS-22-035	greenschist	355	64	271	12	5233386	337091
JS-22-036	phyllite (+/- chlorite)	12	59	287	9	5233262	336654
JS-22-037	greenschist	344	52	263	12	5233274	336985
JS-22-038	graphite phyllite	19	73	109	0	5233060	337334
JS-22-039	greenschist	355	61	-	-	5232967	337442
JS-22-040	greenschist	359	59	274	9	5232888	337511
JS-22-041	graphite phyllite	9	52	280	33	5232453	337881
JS-22-042	very impure marble	348	41	273	12	5232643	336995
JS-22-043	impure marble	1	41	289	15	5232608	337158
JS-22-044	impure marble	4	49	287	15	5232521	337453
JS-22-045	graphite phyllite	262	81	-	-	5230578	341682
JS-22-046	graphite phyllite	2	59	281	14	5230468	341574
JS-22-047	graphite phyllite	19	21	-	-	5230376	341607
JS-22-048	graphite phyllite	342	52	265	16	5230322	341402
JS-22-049	graphite phyllite	332	11	282	7	5230096	341329
JS-22-050	graphite phyllite	144	6	-	-	5229960	341317
JS-22-051	graphite phyllite	2	49	284	14	5229572	341406
JS-22-052	graphite phyllite	228	54	284	37	5229408	341539
JS-22-053	phyllite	331	32	291	26	5229411	341747

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
JS-22-054	graphite phyllite	311	39	273	33	5229751	342287
JS-22-055	metagabbro	319	40	260	24	5229841	342526
JS-22-056	phyllite (+/- chlorite)	349	54	282	29	5234842	344671
JS-22-056B	chlorite schist	352	60	284	33	5234745	344631
JS-22-057	mica schist-quartzite	318	35	278	28	5234734	344647
JS-22-058	metagabbro	342	41	-	-	5234705	344655
JS-22-059	marble	333	71	258	37	5234481	344670
JS-22-059B	phyllite	6	28	288	6	5234413	344668
JS-22-059C	chlorite schist	324	21	282	16	5234317	344608
JS-22-060	impure marble	291	31	263	28	5234228	344594
JS-22-061	impure marble	303	19	267	16	5234048	344398
JS-22-062	pure-ish marble	344	46	271	16	5233851	344231
JS-22-063	phyllite	354	74	277	37	5233558	344239
JS-22-064	graphite phyllite	332	29	293	23	5233912	343965
JS-22-065	impure marble	22	36	297	4	5234015	343794
JS-22-066	phyllite	292	49	305	48	5233383	338308
JS-22-067	impure marble	324	26	282	20	5233808	338082
JS-22-068	impure marble	177	35	268	6	5233478	338646
JS-22-069	very impure marble	299	29	285	28	5233675	338719
JS-22-070	very impure marble	337	21	279	12	5233983	338566
JS-22-071	impure marble	89	17	90	17	5233542	338874
JS-22-072	impure marble	339	49	289	37	5233373	339196
JS-22-073	impure marble	9	40	282	3	5233278	338843
JS-22-074	graphite phyllite	321	11	261	6	5229797	341078
JS-22-075	impure marble	9	39	305	20	5229957	340777
JS-22-076	impure marble	328	34	287	27	5230851	340739
JS-22-077	impure marble	352	41	273	8	5231091	340675
JS-22-078	graphite phyllite	264	52	272	52	5231380	340740

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
JS-22-079	impure marble	342	41	282	24	5231589	340224
JS-22-080	phyllite	328	39	281	29	5231690	340523
JS-22-081	greenschist	337	56	-	-	5231946	340397
JS-22-082	graphite phyllite	1	61	275	7	5232982	338282
JS-22-083	greenschist	358	44	300	27	5232633	338231
JS-22-084	greenschist	12	56	287	8	5232575	338499
JS-22-085	graphite phyllite	356	29	283	9	5232357	338078
JS-22-086	phyllite	343	41	283	23	5232855	338467
JS-22-087	greenschist	354	39	294	22	5233652	336843
JS-22-088	phyllite	352	44	280	16	5233670	336597
JS-22-089	graphite phyllite	345	50	278	25	5232183	338627
JS-22-090	very impure marble	337	40	280	25	5232127	338395
JS-22-091	impure marble	329	34	294	29	5231857	338754
JS-22-092	graphite phyllite	321	41	266	26	5231480	338905
JS-22-093	graphite phyllite	9	31	295	10	5231379	338465
JS-22-094	impure marble	5	44	281	5	5231709	338985
JS-22-095	phyllite	318	42	282	36	5231932	338965
JS-22-096	phyllite-chlorite schist	9	51	77	25	5232058	338836
JS-22-097	greenschist	347	51	-	-	5232464	338715
JS-22-098	graphite phyllite	341	42	273	19	5232621	338965
JS-22-099	graphite phyllite	14	60	285	2	5234849	342457
JS-22-100	graphite phyllite	23	66	101	24	5234231	342555
JS-22-101	impure marble	16	59	91	23	5234006	342450
JS-22-102	graphite phyllite	343	49	276	24	5232992	342033
JS-22-103	very impure marble	291	41	282	41	5233375	341940
JS-22-104	greenschist	19	31	79	17	5232355	336734
JS-22-105	greenschist	335	19	272	9	5232518	336777
JS-22-106	graphite phyllite	348	34	282	15	5231103	338694

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
JS-22-107	impure marble	6	36	280	3	5231793	338202
JS-22-108	graphite phyllite	345	56	279	31	5231905	337970
JS-22-109	graphite phyllite	2	51	79	15	5232281	337375
JS-22-110	graphite phyllite	358	60	275	11	5232528	337003
JS-22-111	chlorite schist	312	36	255	22	5232411	336443
JS-22-112	greenschist	275	31	270	31	5231176	344427
JS-22-113	graphite phyllite	355	36	286	15	5230690	343509
JS-22-114	greenschist	325	11	274	7	5230797	343699
JS-22-115	greenschist	332	52	283	40	5231009	343667
JS-22-116	greenschist	333	39	279	25	5231178	343821
JS-22-117	impure marble	227	21	298	7	5231354	343867
JS-22-118	greenschist	324	11	272	7	5231521	340897
JS-22-119	greenschist	342	19	288	11	5231586	340866
JS-22-120	graphite phyllite	352	69	263	2	5231778	340823
JS-22-121	graphite phyllite	11	45	286	4	5232051	340866
JS-22-122	very impure marble	349	40	301	29	5232302	340823
JS-22-123	impure marble	336	31	282	20	5232568	340800
JS-22-124	impure marble	11	36	308	18	5232829	340828
JS-22-125	marble	342	55	269	23	5232875	340590
JS-22-126	impure marble	344	60	270	25	5232900	340370
JS-22-127	graphite phyllite	341	76	267	48	5233684	343025
JS-22-128	phyllite	358	74	280	36	5233894	343034
JS-22-129	impure marble	18	33	316	17	5233264	343681
JS-22-130	graphite phyllite	324	36	286	30	5233142	343814
JS-22-131	impure marble	337	51	292	41	5233142	344030
JS-22-132	graphite phyllite	319	28	268	18	5233712	337858
JS-22-133	impure marble	348	19	43	11	5232995	338737
JS-22-134	graphite phyllite	351	54	285	29	5232864	339049

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
JS-22-135	impure marble	274	42	302	39	5232985	339635
JS-22-136	graphite phyllite	345	56	268	18	5232989	339879
JS-22-137	graphite phyllite (+/- impure marble)	8	71	288	27	5232700	336394
JS-22-138	impure marble	357	66	281	29	5232977	336391
JS-22-139	phyllite	8	48	280	2	5233545	336484
JS-22-140	marble	5	59	289	22	5233574	336131
JS-22-141	graphite phyllite	332	61	274	44	5230902	339382
JS-22-142	very impure marble	321	47	283	40	5231106	339547
JS-22-143	graphite phyllite	12	71	306	50	5230513	340338
JS-22-144	graphite phyllite	332	39	271	21	5230618	340040
JS-22-145	graphite phyllite	4	31	281	4	5230717	339717
JS-22-146	graphite phyllite	328	28	256	9	5231035	339112
JS-22-147	graphite phyllite	223	51	279	35	5230481	341938
JS-22-148	graphite phyllite	332	67	269	47	5230508	342153
JS-22-149	graphite phyllite	29	44	104	14	5230718	342263
JS-22-150	impure marble	5	44	289	13	5231184	341782
JS-22-151	graphite phyllite	331	36	280	25	5231585	344057
JS-22-152	phyllite	342	54	275	28	5231793	344181
JS-22-153	impure marble	342	52	270	22	5233098	344266
JS-22-154	phyllite	358	72	283	39	5233315	344241
JS-22-155	impure marble	11	61	286	9	5232879	344317
JS-22-156	graphite phyllite	351	41	290	23	5232642	344193
JS-22-157	graphite phyllite	352	31	272	6	5232371	344125
JS-22-158	graphite phyllite	339	68	289	58	5232139	344163
JS-22-159	greenschist	243	39	-	-	5231590	343004
JS-22-160	greenschist	341	53	-	-	5231393	343102
JS-22-161	chlorite schist	345	44	285	26	5231382	342898
JS-22-162	phyllite	314	34	290	32	5231461	342695

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
JS-22-163	graphite phyllite	4	74	283	30	5232100	343153
JS-22-164	phyllite	1	61	283	20	5234526	344302
JS-22-165	impure marble	352	54	279	22	5234268	344244
JS-22-166	impure marble	334	46	273	27	5234168	343898
JS-22-167	phylite	1	46	284	13	5234765	343758
JS-22-168	graphite phyllite	359	16	273	1	5230377	342406
JS-22-169	graphite phyllite	12	34	88	9	5230239	342571
JS-22-170	graphite phyllite	328	51	282	41	5230293	342835
JS-22-171	impure marble	343	29	265	7	5230613	342976
JS-22-172	graphite phyllite	299	26	275	24	5230410	343011
JS-22-173	graphite phyllite	322	34	279	26	5230109	342743
JS-22-174	impure marble	7	46	283	6	5230800	342593
JS-22-175	impure marble	5	41	86	8	5231690	339192
JS-22-176	graphite phyllite	324	46	261	25	5232355	339722
JS-22-177	greenschist	8	49	93	6	5232165	339923
JS-22-178	impure marble	25	51	-	-	5230959	341164
JS-22-179	graphite phyllite	36	66	99	45	5230459	340620
JS-22-180	graphite phyllite	331	49	270	29	5230581	341120
JS-22-181	graphite phyllite	27	46	106	11	5230282	340885
JS-22-182	chlorite schist	339	34	295	26	5230209	341199
JS-22-183	marble	35	29	91	17	5231714	340038
JS-22-184	greenschist	35	29	91	17	5234529	344417
JS-22-185	impure marble	315	27	284	24	5234114	344472
JS-22-185B	impure marble	322	41	273	30	5234104	344457
JS-22-186	phyllite	351	41	293	25	5233821	344210
JS-22-187	graphite phyllite	337	61	260	22	5234996	341413
JS-22-188	marble	181	84	92	6	5234673	341359
JS-22-189	graphite phyllite	42	44	-	-	5234485	341274

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
JS-22-190	impure marble	22	59	294	3	5234444	341241
JS-22-191	impure marble	29	59	300	2	5234207	341079
JS-22-192	impure marble	6	71	284	23	5234021	340964
JS-22-193	graphite phyllite	34	50	117	8	5233861	340880
JS-22-194	graphite phyllite	352	76	264	9	5233519	340972
JS-22-195	impure marble	11	54	284	4	5233370	340898
JS-22-196	impure marble	11	69	94	17	5233920	340629
JS-22-197	graphite phyllite	12	46	286	4	5234099	340339
JS-22-198	graphite phyllite	356	81	273	36	5233604	340337
JS-22-199	graphite phyllite	308	21	254	13	5233355	340160
JS-22-200	graphite phyllite	351	44	281	18	5233265	339908
JS-22-201	impure marble	274	34	272	34	5234357	343134
JS-22-202	impure marble	3	46	287	14	5234207	343280
JS-22-203	impure marble	5	51	284	11	5234313	343514
JS-22-204	graphite phyllite	351	47	304	36	5234594	343659
JS-22-205	graphite phyllite	12	46	-	-	5231264	342266
JS-22-206	graphite phyllite	29	39	114	4	5230972	342316
JS-22-207	impure marble	332	28	-	-	5231693	343460
JS-22-208	graphite phyllite	343	64	279	42	5231760	343804
JS-22-209	phyllite	318	69	264	57	5232092	343746
JS-22-210	graphite phyllite	329	32	260	13	5232000	343570
JS-22-211	graphite phyllite	329	70	250	27	5232927	341633
JS-22-212	graphite phyllite	322	41	285	35	5232772	341454
JS-22-213	impure marble	347	41	276	16	5232640	341329
JS-22-214	graphite phyllite	301	28	279	26	5232370	341292
JS-22-215	graphite phyllite	9	72	285	18	5232162	341316
JS-22-216	chlorite schist	352	51	275	15	5231979	341581
JS-22-217	phyllite	289	30	255	26	5230039	341623

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
JS-22-218	greenschist	338	31	272	14	5229907	341897
JS-22-219	metagabbro	348	42	276	16	5229909	342164
JS-22-220	greenschist	239	29	284	21	5229799	341601
JS-22-221	impure marble	334	36	293	29	5230685	340572
JS-22-222	graphite phyllite	331	34	-	-	5230742	340285
JS-22-223	graphite phyllite	38	29	91	19	5230899	340115
JS-22-224	graphite phyllite	341	69	268	38	5233062	336876
JS-22-225	greenschist - graphite phyllite	316	46	271	36	5233070	337076
JS-22-226	graphite phyllite	22	41	90	18	5232801	336928
JS-22-227	impure marble	3	76	273	1	5232895	336680
JS-22-228	impure marble	1	54	291	25	5231529	339611
JS-22-229	impure marble	359	54	298	34	5231443	339324
JS-22-230	graphite phyllite	321	64	260	45	5232347	340314
JS-22-231	graphite phyllite	343	24	292	16	5232568	340218
JS-22-232	graphite phyllite	342	59	275	33	5232586	340141
JS-22-233	impure marble	7	57	281	7	5233626	335985
JS-22-234	graphite phyllite	294	84	267	83	5232631	342667
JS-22-235	graphite phyllite	333	49	261	19	5231534	342429
JS-22-236	very impure marble	332	46	284	35	5232233	342678
JS-22-237	very impure marble	349	56	278	26	5234415	348528
S6	phyllite (+/- impure marble)	355	34	270	12	5231702	349384
S7	impure marble	336	52	277	34	5232098	347579
S8	greenschist	353	39	284	12	5233572	346333
S9	phyllite	355	48	-	-	5232492	346792
S10	phyllite (+/- impure marble)	8	62	285	22	5237057	343368
S13	graphite phyllite	3	69	283	23	5233132	336324
S15	impure marble	338	49	281	32	5232438	346549
S16	greenschist	349	32	284	15	5232527	348755

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
S17	impure marble	358	34	281	7	5232440	349447
S18	phyllite	351	20	282	7	5233242	349185
S20	impure marble	352	36	269	30	5233503	349166
S22	graphite phyllite	311	30	287	32	5233558	349040
S23	graphite phyllite	249	41	252	31	5233721	348800
S25	impure marble	131	21	272	6	5232197	350205
S27	greenschist	9	26	274	1	5231699	350577
S29	greenschist	335	17	272	7	5231542	350870
S30	impure marble	11	19	286	8	5231652	350907
S31	phyllite	7	45	296	19	5231771	350889
S32	impure marble	42	52	119	11	5231939	350938
S33	greenschist	341	31	277	14	5231395	350915
S34	graphite phyllite	327	41	293	38	5234231	348663
S35	phyllite	332	39	-	-	5234251	348663
S36	marble	319	31	284	34	5234267	348623
S37	phyllite	343	51	289	24	5234285	348602
S38	marble	321	12	282	16	5234285	348580
S39	impure marble	344	39	309	33	5234323	348536
S40	impure marble	9	62	295	28	5234353	348515
S41	impure marble	342	41	272	11	5234425	348468
S42	phyllite	1	81	276	16	5234502	348485
S43	phyllite	351	52	331	48	5234709	348621
S44	impure marble	2	64	277	15	5234876	348953
S45	impure marble	7	58	279	9	5234940	349277
S46	impure marble	352	41	287	27	5234947	349349
S47	impure marble	348	42	272	10	5234973	349359
S48	impure marble	343	54	273	33	5235253	349091
S49	impure marble	289	29	277	19	5235278	349031

outcrop	lithology	representative fabric				UTM Coordinates	
		foliation		stretching lineation		Zone 33N	
		dip dir.	dip	azimuth	plunge	Northing	Easting
S52	graphite phyllite	315	52	239	31	5236469	348922
S53	impure marble	346	45	273	17	5233500	336812
S54	impure marble/phyllite	342	24	277	11	5233584	337417
S55	greenschist	353	33	283	16	5232148	346861
S56	greenschist	352	33	281	11	5232201	346837
S57	marble	348	33	284	14	5232246	346808
S58	graphite phyllite	2	55	277	8	5232481	346630
S59	impure marble	348	56	273	21	5232494	346899
S60	graphite phyllite	322	41	244	11	5233100	346628
S61	graphite phyllite	322	51	257	29	5233386	347272
S62	greenschist	342	21	300	16	5231547	345083
S64	greenschist	346	31	292	19	5231596	345328
S65	impure marble	321	8	297	8	5231800	345583
S66	greenschist	342	49	289	35	5231750	345907
S67	greenschist	344	39	274	15	5231786	346303
S68	greenschist (+/- impure marble)	353	28	278	10	5231897	346400
S69	greenschist	349	29	285	13	5231949	346608
BH-21-0059	greenschist	3	29	277	9	5232615	348633
BH-21-0063	phyllite	350	32	266	4	5232591	348691
BH-21-0093	greenschist	358	56	271	5	5231074	347192

Locations, representative measurement of the main fabric and lithology of all outcrops visited in the study area. No stretching lineation was observed from 19 localities.

Table S3.2: Brittle-ductile fault measurements and inferred strain axes, Tauern Window, Austria

outcrop	structural measurements						rotated measurements				strain axis					
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)
JS-22-004	341/49	6	55	48	128	14	98	54	105	53	269	74	102	15	10	3
			47	52	122	11	90	50	102	49	248	77	97	11	5	6
			11	59	100	3	58	26	88	23	122	71	260	14	353	12
			348	41	279	17	132	9	102	8	95	60	286	30	193	4
			58	50	133	20	97	57	104	56	270	71	100	18	9	3
			52	24	114	9	128	46	94	40	5	72	108	4	200	18
			58	50	133	20	97	57	104	56	270	71	100	18	9	3
JS-22-007	002/36	6	51	68	136	13	71	49	122	35	200	61	102	5	9	29
			76	51	157	11	107	51	148	43	243	65	130	10	36	22
			76	59	149	26	100	56	127	53	254	67	114	19	18	14
			54	65	136	17	76	48	120	39	206	65	102	6	9	24
			34	51	119	7	70	26	110	21	150	69	280	14	14	15
			321	59	237	10	293	37	248	28	185	67	83	5	351	22
JS-22-022	352/44	11	301	84	220	55	288	59	297	59	87	80	291	9	200	4
			300	81	220	48	285	58	284	58	106	82	285	8	14	0
			308	79	231	49	291	51	289	51	142	90	290	1	19	1
			56	45	126	19	105	44	102	44	94	84	284	6	193	1
			58	46	131	17	104	45	109	45	133	85	287	5	16	2
			80	56	150	27	106	65	123	64	263	74	111	15	18	7
			72	40	129	24	118	51	100	50	17	81	110	1	200	9
			70	41	130	23	116	50	102	50	19	83	110	0	200	7
			126	49	187	30	139	84	212	70	294	52	153	31	50	19
			307	79	230	48	290	52	287	52	138	90	289	2	18	1
			319	62	255	40	285	32	288	32	291	71	107	18	197	1
JS-22-036	012/59	4	322	84	235	28	299	53	289	53	251	83	116	5	25	5
			312	76	230	30	285	57	290	57	2	87	107	1	196	3
			322	71	243	28	285	46	292	46	306	78	107	12	198	4
			257	87	167	7	86	70	143	57	208	62	100	9	5	26
			327	56	246	13	258	49	291	44	348	72	92	5	184	17
			239	59	166	26	58	61	88	58	187	74	67	8	335	14

outcrop	structural measurements						rotated measurements				strain axis							
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)		
JS-22-038	019/73	5	313	86	224	12	292	66	281	65	127	76	289	14	20	4	85	
			321	86	232	10	295	58	281	57	155	82	290	6	20	6	83	
			330	60	261	32	263	46	317	32	359	57	109	13	206	30	-47	
JS-22-043	001/46	3	69	44	6	24	119	47	186	22	213	42	327	24	77	39	-31	
			298	88	210	38	289	69	265	68	147	78	285	9	16	8	81	
			124	88	213	34	297	68	260	64	172	74	289	7	20	14	74	
JS-22-067	344/31	25	62	44	135	15	94	46	126	42	187	72	290	4	20	17	-67	
			41	36	114	12	90	31	104	30	119	71	279	18	11	6	-78	
			92	41	129	35	116	57	105	57	322	80	112	9	203	5	84	
			72	69	148	33	84	71	134	62	230	60	99	20	0	20	-69	
			66	61	133	36	84	61	109	59	229	73	92	13	359	11	-77	
			301	61	241	42	281	42	270	41	235	82	95	6	4	5	82	
			304	60	237	34	283	40	260	37	220	75	91	10	359	12	72	
			314	80	232	38	307	54	259	43	193	64	285	1	16	26	57	
			299	79	222	48	290	59	262	55	154	74	279	9	11	13	75	
			69	36	114	27	106	44	95	43	48	83	281	4	190	6	81	
			281	79	224	70	272	67	303	63	63	68	282	18	187	13	-77	
			284	76	220	60	273	63	281	63	83	75	276	15	185	3	-87	
			74	44	111	38	102	52	82	50	346	80	94	3	184	10	77	
			64	66	126	47	79	65	85	64	250	73	81	16	349	3	-87	
			295	61	235	42	274	45	266	44	220	85	90	3	360	4	84	
			63	39	116	26	100	43	97	43	85	85	278	5	188	1	88	
			274	79	223	73	266	70	309	64	55	63	278	20	181	17	-72	
			84	59	136	45	99	69	101	69	276	69	100	21	8	1	-89	
			62	66	123	48	77	63	80	63	250	74	78	15	347	2	-88	
			82	59	120	53	97	68	70	65	300	68	90	19	183	10	79	
			289	79	226	67	280	63	297	62	77	74	285	15	193	7	-82	
			31	19	108	4	125	22	102	21	90	62	289	27	195	8	68	
			30	12	99	4	143	24	94	16	73	55	289	29	189	17	44	
			95	24	107	24	131	45	90	37	38	67	291	7	197	22	58	
			26	15	94	6	137	22	88	15	69	54	282	31	182	16	44	
JS-22-079	332/36	2	112	44	104	44	63	27	118	16	231	67	116	10	22	21	-38	
			110	41	108	41	56	26	120	12	222	66	117	7	24	23	-29	

outcrop	structural measurements						rotated measurements				strain axis							
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)		
JS-22-082	008/60	4	78	60	4	25	117	60	183	35	270	45	162	17	57	40	-41	
			58	59	342	22	113	43	160	32	255	63	147	9	53	25	-52	
			52	59	332	16	111	38	146	32	250	71	137	8	45	17	-61	
			353	60	273	16	274	13	290	13	303	76	108	13	199	3	-75	
JS-22-099	015/60	13	115	69	204	5	115	69	60	56	360	64	102	6	194	25	63	
			113	68	197	13	113	68	69	61	354	71	103	6	195	18	70	
			120	72	206	14	120	72	81	67	346	72	113	11	205	14	75	
			121	75	57	58	121	75	57	58	356	60	107	11	202	27	62	
			304	80	273	78	304	80	273	78	296	49	128	40	33	6	84	
			123	90	58	89	123	90	58	89	307	60	123	30	213	1	89	
			303	76	268	73	303	76	268	73	291	45	130	43	30	9	81	
			130	81	73	73	130	81	73	73	340	66	122	20	217	14	76	
			128	84	217	12	128	84	77	80	323	65	124	23	216	8	82	
			130	70	115	69	130	70	115	69	333	79	127	10	217	5	85	
			129	62	111	61	129	62	111	61	23	83	125	2	214	7	81	
			111	55	101	55	111	55	101	55	65	83	288	5	197	4	84	
100	41	99	41	100	41	99	41	98	71	279	19	189	0	89				
JS-22-122	342/41	5	24	34	304	6	104	26	119	25	134	70	294	19	26	6	-76	
			311	85	226	43	301	51	269	47	178	73	286	5	17	16	69	
			21	44	307	15	80	26	126	19	154	60	292	23	30	18	-47	
			84	44	153	19	113	63	144	59	263	67	124	18	29	14	-75	
			92	31	167	9	127	58	169	50	260	66	146	10	51	22	-64	
JS-22-150	040/70	11	89	74	170	28	133	47	109	44	53	77	303	5	211	12	73	
			326	71	252	39	297	69	352	56	72	60	314	15	216	25	-63	
			342	84	255	29	316	58	333	57	94	79	322	8	230	8	-81	
			318	71	243	37	294	76	355	64	81	57	310	23	210	22	-67	
			329	69	258	40	295	66	350	52	65	60	314	11	218	27	-60	
			29	71	312	32	314	10	341	9	346	49	156	41	250	5	-63	
			321	66	258	45	290	72	358	50	63	51	314	15	213	35	-54	
			315	71	244	44	294	79	5	59	77	51	314	24	209	29	-61	
			99	67	156	52	145	55	80	32	32	51	295	6	200	38	40	
			321	34	310	34	256	67	342	11	22	23	116	10	229	65	-11	
			19	49	311	24	256	28	333	7	355	41	127	37	239	27	-15	

outcrop	structural measurements						rotated measurements				strain axis							
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)		
JS-22-152	016/45	2	71	46	147	14	125	38	127	38	299	77	127	12	36	1	-88	
			65	39	142	10	134	33	126	32	338	83	128	6	218	4	83	
JS-22-164	002/56	15	314	71	243	43	279	45	302	43	335	73	108	12	200	12	-73	
			316	81	239	54	292	49	317	46	0	75	121	8	213	13	-73	
			299	86	218	66	284	66	340	51	41	62	301	5	208	28	-59	
			94	61	124	58	118	76	42	45	353	46	95	11	194	42	47	
			122	74	162	70	303	76	14	53	336	32	98	40	222	34	-55	
			109	71	131	70	297	87	24	45	342	34	91	26	210	45	-45	
			82	41	118	35	133	59	71	38	26	53	290	5	196	37	46	
			305	82	230	61	285	58	329	49	28	67	120	1	209	23	-63	
			97	65	139	58	116	80	39	53	344	49	95	18	198	35	54	
			89	49	132	40	127	66	68	50	9	59	109	6	201	30	57	
			62	46	127	24	123	47	89	41	50	68	289	12	195	18	65	
			85	59	153	32	115	68	88	66	331	75	109	11	201	10	79	
			79	15	112	13	164	54	93	24	58	42	314	15	208	44	30	
			109	36	137	33	146	72	81	53	20	57	128	11	224	31	57	
			354	52	290	30	238	8	306	3	311	37	117	53	216	7	-22	
JS-22-165	009/34	6	276	61	282	61	260	68	326	45	1	53	95	3	187	37	-50	
			279	56	284	56	258	62	321	41	353	52	94	9	191	36	-48	
			82	54	94	53	109	52	59	39	33	56	274	18	174	27	54	
			85	70	80	70	99	66	37	46	2	55	265	5	171	34	52	
			273	76	220	68	266	82	330	72	43	68	273	15	178	16	-73	
			106	81	176	65	110	86	39	79	314	68	106	20	198	10	80	
JS-22-184	357/50	4	62	49	124	29	111	48	85	45	44	74	281	9	188	13	72	
			72	48	142	21	115	55	109	55	49	87	293	1	203	3	86	
			125	84	214	11	298	66	235	46	182	55	278	4	10	34	52	
			78	32	133	20	136	53	102	47	50	72	304	5	211	17	68	
JS-22-227	003/50	4	88	61	129	54	113	68	53	52	342	57	93	13	190	30	57	
			99	64	133	59	117	78	44	54	338	49	94	21	198	33	55	
			308	61	233	26	269	46	270	46	276	86	90	4	179	0	-89	
			332	56	256	20	277	25	279	25	281	65	98	25	188	1	-88	
JS-22-233	015/49	3	329	72	247	22	301	45	278	43	217	78	110	4	19	12	73	
			325	74	240	17	300	50	267	45	197	73	105	1	15	17	67	

outcrop	structural measurements						rotated measurements				strain axis							
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)		
			82	54	153	25	123	51	117	51	339	86	120	3	210	3	86	
JS-22-237	332/54	5	302	88	215	53	286	44	284	44	280	80	105	10	14	1	88	
			78	36	132	23	115	70	93	68	317	73	110	16	202	7	82	
			111	78	185	52	285	62	287	62	100	82	286	8	195	1	-89	
			65	39	129	20	108	65	95	64	309	79	105	10	195	5	84	
			298	86	221	72	280	45	310	41	349	70	113	11	206	16	-67	
S13	003/54	35	82	59	112	55	114	64	47	39	345	50	84	7	180	39	45	
			94	39	148	25	138	63	103	59	352	68	126	16	220	15	73	
			93	48	116	46	129	67	60	40	358	47	99	9	197	41	44	
			111	89	200	45	285	76	313	74	93	59	291	30	196	7	-83	
			118	89	207	33	289	71	272	70	119	65	285	24	17	6	84	
			314	86	226	29	297	55	275	53	159	77	288	8	19	10	77	
			297	84	215	54	283	67	322	61	71	64	296	19	199	17	-72	
			312	85	227	44	294	56	300	56	99	80	297	10	206	3	-86	
			288	72	220	49	266	68	310	60	54	63	281	19	184	19	-70	
			306	78	226	38	283	56	289	56	90	79	285	10	195	3	-87	
			309	58	258	45	262	44	307	34	1	64	106	7	199	25	-54	
			71	31	112	24	144	49	83	29	32	54	291	8	195	35	40	
			71	23	104	20	154	49	83	20	39	45	295	14	192	42	27	
			92	32	111	31	145	60	76	31	22	46	291	0	201	44	37	
			81	54	115	49	118	61	56	40	352	53	90	6	184	37	47	
			88	29	129	23	148	57	93	42	26	60	123	4	215	30	53	
			49	44	132	7	124	36	112	35	91	78	297	11	206	5	81	
			54	52	136	10	112	40	112	40	119	84	292	6	22	1	-89	
			72	47	129	31	123	52	84	45	8	69	105	3	196	21	63	
			73	61	142	32	108	58	87	57	319	75	100	12	191	9	79	
			62	56	135	23	109	48	97	47	0	84	103	1	193	6	82	
			68	64	145	24	102	56	102	56	281	80	102	10	12	0	-90	
			71	52	144	21	117	53	106	53	327	82	113	7	202	5	83	
			299	76	230	55	277	61	319	53	51	65	294	12	198	21	-66	
			319	81	236	36	296	48	289	48	166	86	293	2	22	3	86	
			309	52	253	35	253	43	294	35	347	67	96	8	189	22	-57	
						336	59	259	21	278	23	283	23	287	67	101	23	192

outcrop	structural measurements						rotated measurements				strain axis						
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	
			319	53	238	11	258	35	261	35	268	79	80	11	169	2	-88
			321	60	241	17	270	35	269	35	266	79	89	11	359	1	89
			61	42	129	19	128	44	98	40	38	74	292	4	201	15	67
			328	54	244	9	263	28	263	28	264	72	83	18	173	0	-90
			324	61	243	16	274	33	270	33	263	77	91	13	1	2	86
			315	74	230	18	285	47	262	45	185	78	94	0	4	12	74
			67	47	136	21	122	49	100	47	13	79	112	2	201	11	75
			52	53	126	20	110	39	95	38	60	80	282	7	191	7	79
S15	323/50	29	82	44	136	30	105	78	111	78	281	66	106	24	14	1	-89
			89	34	139	24	115	74	129	73	284	70	118	20	25	4	-86
			58	46	134	15	92	67	122	63	231	73	100	12	6	12	-77
			67	37	126	21	103	66	101	66	287	78	103	12	193	1	89
			71	28	122	18	113	63	98	62	324	80	109	9	199	6	83
			33	33	101	14	99	47	77	45	35	77	270	8	178	11	75
			77	21	119	16	121	61	96	58	354	78	114	6	204	11	77
			43	18	119	5	119	49	105	48	60	81	294	5	203	7	81
			27	31	95	12	101	44	73	40	37	71	268	12	175	14	69
			61	42	132	17	97	66	117	65	246	76	102	12	10	8	-81
			65	41	127	22	99	68	101	68	276	76	100	14	9	1	-89
			33	29	108	8	104	46	88	45	53	79	278	8	186	8	79
			114	88	201	57	284	50	278	50	250	85	101	4	11	3	86
			265	87	223	86	253	64	318	41	8	51	276	2	185	38	-46
			53	24	116	12	113	54	95	53	20	82	287	0	196	8	79
			58	41	133	12	96	64	123	61	231	75	104	9	12	12	-77
			113	73	139	71	291	63	326	59	57	72	301	8	208	16	-73
			24	43	92	20	83	44	62	42	30	75	254	11	162	10	75
			111	72	182	45	289	65	256	61	155	73	280	10	12	14	75
			34	36	100	16	95	48	73	46	28	78	266	7	174	10	75
			24	34	96	12	96	42	74	40	43	73	266	13	173	11	73
			23	17	80	9	121	43	63	27	30	52	273	19	171	31	41
			98	71	131	68	278	72	333	61	55	62	292	16	195	22	-67
			22	46	99	14	78	43	74	43	67	79	257	11	166	2	87
			356	31	54	18	106	28	40	12	19	43	246	36	135	25	26

outcrop	structural measurements						rotated measurements				strain axis							
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)		
			292	76	230	62	268	38	288	36	309	70	98	17	190	10	-74	
			295	76	227	57	272	36	281	35	292	71	97	18	188	5	-82	
			296	75	235	61	272	34	288	33	302	68	100	20	192	8	-77	
			114	84	181	75	286	53	309	51	16	78	114	2	204	12	-76	
			71	65	142	35	93	52	110	51	199	81	100	1	9	9	-79	
			94	65	152	49	111	65	98	65	307	74	108	15	199	5	84	
			102	47	138	41	131	57	100	52	11	74	119	5	210	15	72	
			317	60	290	57	291	46	328	39	19	69	128	7	221	20	-62	
			90	49	142	36	121	51	109	51	15	84	116	1	206	6	82	
			82	48	153	20	117	46	135	45	190	80	305	4	36	9	-77	
			102	46	145	37	132	56	110	54	7	79	124	5	214	10	78	
			83	35	108	32	133	39	86	29	49	60	288	16	190	24	50	
			118	49	133	48	139	66	86	53	9	61	121	12	217	26	62	
			338	66	258	21	318	39	275	31	238	63	115	15	19	22	54	
			314	73	265	65	298	58	329	54	62	74	310	6	218	15	-72	
			87	38	147	21	131	43	128	43	118	83	310	7	219	1	88	
			95	50	146	37	124	55	111	54	349	83	119	5	209	6	83	
			104	39	140	33	139	52	110	48	35	75	127	0	217	15	71	
			88	55	143	40	115	55	105	54	335	84	111	4	201	4	84	
			89	54	142	40	116	54	104	54	346	83	112	4	202	6	83	
			68	50	146	14	105	39	132	36	169	71	299	12	32	14	-68	
			101	52	167	27	126	60	148	58	265	77	133	9	42	10	-79	
			89	44	150	25	126	48	127	48	150	87	306	2	36	1	-89	
			306	76	263	71	293	65	339	56	65	65	309	12	214	22	-66	
			305	80	238	66	295	68	328	65	87	68	304	18	210	12	-77	
			316	80	246	63	305	62	322	61	97	76	310	12	218	8	-82	
			323	79	259	66	311	58	330	56	86	78	318	7	226	9	-80	
			71	31	129	18	135	32	113	30	93	68	303	19	209	10	71	
			86	26	128	20	148	37	111	31	77	65	308	16	212	18	59	
			89	45	139	33	125	48	110	47	45	82	298	2	207	7	80	
			100	46	143	37	130	55	108	53	12	79	122	4	212	11	77	
			310	89	221	46	305	73	271	70	144	65	297	22	31	10	79	
316	85	230	38	308	67	266	60	168	67	295	15	29	18	70				

outcrop	structural measurements						rotated measurements				strain axis					
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)
S16	012/36	62	329	80	246	33	318	56	275	47	205	68	301	2	31	22
			322	84	242	58	313	63	311	63	134	77	313	13	42	0
			332	74	261	49	317	49	305	48	234	84	132	1	42	6
			105	55	143	49	126	64	92	59	347	70	115	13	208	15
			55	39	133	10	113	26	122	26	129	65	299	24	31	4
			62	54	102	47	95	39	70	36	36	72	262	13	169	12
			73	45	142	20	115	39	124	39	143	78	299	11	30	5
			66	55	138	24	97	42	116	40	154	77	287	9	18	10
			73	49	140	24	110	42	119	41	144	80	294	8	24	5
			345	61	322	59	323	32	345	30	4	68	156	19	249	10
			74	60	149	25	99	50	127	47	195	76	291	1	21	14
			78	34	129	23	133	36	110	34	82	71	300	15	207	11
			78	32	125	23	136	36	106	32	77	68	300	16	205	14
			90	51	133	42	120	53	94	50	12	77	109	2	199	12
			91	52	130	45	119	54	89	50	8	75	107	2	198	15
			73	37	131	22	126	35	112	34	94	73	298	15	206	6
			331	71	280	61	314	47	328	46	26	82	141	4	230	8
			131	86	207	74	308	77	1	69	103	59	320	25	222	16
			147	80	193	76	326	74	12	68	119	62	337	23	239	15
			136	80	207	62	316	79	334	79	130	60	319	29	226	3
			116	45	157	37	141	62	123	61	348	76	135	12	226	7
			82	32	117	27	137	38	97	30	62	64	295	16	199	20
			145	88	228	74	320	68	349	65	114	69	328	17	234	11
			72	51	143	21	107	42	124	41	164	78	295	8	26	9
			72	70	152	26	90	56	129	49	205	69	105	4	13	21
			54	52	122	26	90	33	101	32	114	72	276	18	8	5
			49	47	124	15	93	26	111	25	123	64	284	24	17	8
			72	64	144	33	94	52	114	50	198	80	102	1	12	10
			77	42	135	26	121	40	112	40	96	79	297	10	206	4
			68	47	130	26	109	38	107	38	105	78	288	12	197	1
			79	54	127	43	109	49	89	47	23	80	281	2	190	9
			53	55	133	14	85	34	119	29	148	65	285	19	20	16
			59	51	138	14	96	35	124	32	152	68	292	17	26	13

outcrop	structural measurements						rotated measurements				strain axis						
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	
S17	348/37	14	73	44	116	35	107	52	83	50	289	43	86	44	188	12	75
			70	37	110	30	113	47	83	42	295	49	86	37	187	15	69
			54	45	120	22	95	42	99	42	273	54	99	36	6	2	-87
			52	55	116	32	83	48	87	48	261	48	87	42	354	3	-87
			68	32	119	22	118	43	99	41	299	53	101	35	197	9	76
			15	44	104	1	67	19	99	16	233	76	98	10	6	10	-60
			16	47	289	3	61	21	105	15	227	73	104	10	11	14	-48
			71	41	143	15	109	49	130	47	286	46	129	41	28	11	-76
			73	40	132	24	111	50	111	50	291	46	111	44	201	0	90
			88	35	135	26	123	54	113	53	304	42	114	47	209	5	84
			57	45	136	11	97	44	125	41	273	51	123	35	22	15	-69
			94	37	148	24	125	57	133	57	303	38	132	51	37	4	-86
			70	49	137	25	101	54	116	53	279	42	115	47	16	8	-81
			76	45	135	28	108	55	111	55	287	41	111	49	18	2	-88
s31	007/45	13	66	56	139	24	104	46	109	46	283	50	109	40	16	3	-87
			74	48	146	19	118	47	122	47	298	49	122	41	30	2	-88
			36	47	114	13	102	21	100	21	282	75	100	15	190	0	88
			33	38	107	12	129	18	95	16	322	76	96	10	187	10	58
			66	35	141	10	134	38	124	38	314	58	125	32	217	4	82
			27	56	111	8	68	19	101	16	235	76	100	10	8	10	-58
			86	35	135	25	139	49	105	44	322	47	109	38	212	17	67
			36	29	114	6	151	23	105	17	343	71	107	11	200	16	47
			41	49	116	17	100	25	98	25	279	71	98	19	188	0	88
			24	15	93	6	179	31	90	1	10	59	273	4	181	31	2
			31	19	102	6	171	28	96	8	3	63	99	3	190	27	17
			69	39	142	14	129	41	122	40	309	55	123	35	214	3	85
			79	37	148	15	134	46	126	46	315	50	127	40	220	4	84
			312	60	266	50	300	38	288	37	253	81	113	7	22	5	81
			322	60	299	58	314	35	314	35	316	81	134	9	224	0	-90
			313	58	280	53	300	36	298	36	295	82	119	8	28	1	88
			104	30	142	24	126	49	136	49	265	82	131	5	40	5	-84
			108	44	141	39	121	63	127	63	295	71	124	19	32	2	-87
			93	38	134	31	114	54	122	53	275	80	117	9	27	4	-85

outcrop	structural measurements					rotated measurements					strain axis					
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)
S33	338/26	24	86	30	128	23	115	45	118	45	233	90	117	1	26	1
			104	44	124	42	119	62	100	61	317	71	112	18	204	8
			304	72	274	69	295	51	308	51	78	80	301	7	210	7
			313	60	280	56	301	37	303	37	311	83	122	7	212	1
			109	29	128	28	129	50	116	49	355	81	123	5	213	7
			333	55	303	51	330	29	314	28	295	73	139	15	47	6
			311	62	272	56	299	40	296	40	278	86	118	4	27	1
			119	42	128	42	130	64	106	62	331	68	122	19	215	10
			317	66	300	65	309	42	318	42	22	85	134	2	223	5
			108	26	125	25	131	47	113	45	18	81	122	2	212	8
			87	24	119	21	121	40	108	39	56	82	294	4	203	7
			104	33	127	31	124	52	113	52	335	80	119	8	210	6
			312	64	289	62	302	42	310	41	5	85	126	3	216	4
			313	64	288	62	303	41	309	41	359	85	127	3	216	4
			108	29	119	29	129	50	104	47	8	77	117	4	207	12
			97	24	115	23	126	43	103	40	36	78	294	3	203	12
			311	67	301	67	302	45	319	43	41	81	131	0	220	9
			317	71	318	71	310	47	329	46	64	80	320	2	229	10
S53	344/35	8	76	65	143	40	91	71	112	70	233	79	94	9	3	7
			264	69	213	59	249	67	281	62	4	76	256	4	165	13
			89	60	121	56	103	74	54	66	335	70	95	10	188	17
			82	60	132	48	98	70	79	70	313	80	95	8	186	6
			53	66	114	47	72	59	67	58	45	86	251	3	160	2
			280	70	217	51	264	59	269	59	306	86	85	3	175	3
			93	54	122	50	110	71	68	64	347	73	102	8	193	16
			63	45	113	33	97	49	85	48	69	75	273	13	182	6
			259	82	213	78	251	77	322	55	18	54	268	14	170	32
			83	52	124	44	104	71	67	66	326	72	97	12	189	13
			71	61	152	15	90	70	148	56	211	61	105	9	9	27
			58	52	139	12	89	56	128	49	181	70	282	4	13	20
			67	54	145	15	93	63	137	55	202	69	105	3	13	21
			61	39	130	16	104	50	113	50	139	81	287	8	17	5
			54	41	129	13	99	48	114	47	142	76	284	11	16	8

outcrop	structural measurements						rotated measurements				strain axis							
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)		
S55	338/41	22	76	51	129	37	101	66	87	66	309	81	98	8	188	5	84	
			59	72	139	28	74	71	116	64	206	70	83	11	349	16	-73	
			79	54	138	36	100	70	102	70	277	78	101	12	10	1	-89	
			59	44	128	19	98	52	108	52	141	82	281	6	11	5	-84	
			53	49	124	21	89	51	102	51	136	81	273	7	4	6	-82	
			69	51	138	24	97	62	119	60	213	80	102	4	11	10	-79	
			284	69	237	61	261	51	295	46	337	70	93	9	186	17	-68	
			81	59	139	41	98	75	90	75	284	73	97	17	187	2	88	
			279	76	216	61	263	59	291	56	2	76	271	0	180	14	-75	
			72	51	124	38	98	64	80	63	327	81	94	6	184	7	82	
			261	81	191	65	252	75	303	66	30	66	262	15	166	18	-72	
			72	54	133	34	96	66	98	66	268	82	96	8	5	1	-89	
			74	52	132	34	99	66	95	66	286	82	98	8	187	1	88	
			297	72	227	46	277	45	272	45	264	77	95	13	4	2	87	
			302	79	221	38	287	48	259	45	223	71	97	11	4	15	70	
S56	352/33	10	322	74	257	56	311	47	299	46	230	84	125	1	35	6	82	
			320	71	256	52	307	45	294	44	241	83	121	4	30	6	81	
			338	51	286	38	319	20	302	19	294	61	127	28	34	5	74	
			74	69	146	39	87	68	117	65	244	67	96	19	1	11	-78	
			76	61	139	40	94	63	106	62	258	74	98	15	7	5	-84	
			73	71	153	27	85	69	140	57	225	59	103	17	5	25	-64	
			331	81	285	77	325	51	333	50	87	85	329	3	238	5	-85	
			308	79	233	53	298	57	282	56	151	79	292	9	23	7	81	
			63	69	140	31	78	62	118	56	213	68	92	12	358	19	-69	
			66	76	145	38	76	70	117	64	227	64	88	20	352	16	-73	
S59	332/45	16	77	36	136	20	112	62	119	62	260	85	114	4	24	3	-87	
			90	40	128	34	115	71	85	68	330	74	109	12	201	10	79	
			81	53	150	25	101	76	147	70	247	67	109	17	14	14	-76	
			116	76	200	23	294	67	229	45	180	54	274	3	6	36	50	
			130	70	206	34	310	68	246	48	195	56	291	4	23	34	53	
			40	60	126	7	71	54	113	46	160	66	265	7	358	23	-62	
			72	52	150	15	96	70	148	60	221	66	109	10	14	22	-67	
			78	18	116	14	130	52	96	47	51	71	298	8	205	17	67	

outcrop	structural measurements						rotated measurements				strain axis							
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)		
S52	352/45	10	114	89	192	85	285	57	327	49	20	67	119	4	209	22	-64	
			62	35	101	28	107	55	67	47	19	68	274	6	181	21	64	
			89	24	119	21	127	59	93	54	29	74	297	0	206	16	71	
			59	30	130	11	112	51	116	51	132	82	293	7	23	3	-87	
			72	34	132	19	112	59	113	59	246	90	112	1	22	1	-90	
			92	35	133	28	120	68	104	67	325	79	116	10	207	5	84	
			276	85	187	11	264	63	204	45	156	57	65	1	334	33	52	
			92	26	137	19	126	61	122	61	332	86	125	3	215	2	88	
S62	010/16	17	307	79	231	51	303	72	250	62	174	65	291	12	26	21	68	
			303	64	239	42	295	59	254	51	196	70	102	1	11	20	66	
			305	61	248	44	296	55	264	51	210	74	106	4	14	16	71	
			283	81	211	63	280	81	236	77	119	66	275	22	9	9	81	
			113	49	120	49	125	54	101	52	48	77	297	5	206	12	75	
			111	41	111	41	127	46	97	42	64	69	295	13	201	16	68	
			305	79	227	47	301	73	242	59	175	62	287	12	23	25	64	
			122	89	211	40	301	85	219	55	167	48	283	21	28	35	55	
			307	86	223	57	305	79	245	69	161	63	295	19	31	18	72	
			302	81	225	54	299	75	244	66	161	65	288	16	23	19	70	
			302	81	257	77	299	75	323	74	100	71	303	17	210	6	-84	
			301	61	262	55	292	56	286	56	233	87	110	2	19	2	87	
			302	73	237	54	297	68	259	63	169	73	288	9	20	15	74	
			88	62	128	55	97	60	104	60	217	86	99	2	8	3	-87	
			89	41	119	37	108	41	106	41	106	73	287	17	197	0	89	
			87	51	131	42	100	49	116	48	148	78	286	9	17	8	-80	
			302	76	234	56	297	71	258	65	162	71	289	12	22	14	74	
			281	64	208	30	262	51	229	46	175	72	70	5	338	17	68	
			58	64	125	39	74	63	97	61	209	77	81	8	348	10	-79	
			53	59	123	29	73	56	104	52	177	75	84	1	354	15	-71	
			282	81	203	51	274	65	251	63	127	76	268	11	359	9	80	
			42	56	105	34	66	48	80	47	121	81	252	6	342	7	-81	
			338/31	14	281	84	202	60	274	68	270	68	99	76	273	14	3	2
	266	72			199	50	254	65	245	65	86	78	252	11	342	3	86	
	49	61			113	38	68	56	84	55	174	82	74	1	343	8	-81	

outcrop	structural measurements						rotated measurements				strain axis							
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)		
			274	72	196	33	261	61	219	54	145	69	248	5	339	20	67	
			275	79	199	52	266	67	248	66	108	76	262	13	352	6	83	
			277	74	204	46	265	62	243	60	133	78	259	7	350	9	79	
			271	59	214	42	250	52	247	52	220	90	69	2	338	1	88	
			47	51	106	33	75	47	82	47	106	82	258	7	348	4	-85	
			44	54	107	32	70	48	83	47	121	80	255	7	345	7	-81	
BH-21-0059	003/29	27	75	70	148	39	87	64	122	59	234	67	100	16	5	15	-73	
			80	56	150	27	101	55	135	49	224	71	116	6	23	18	-68	
			84	76	163	36	92	73	148	62	242	57	109	24	9	22	-68	
			74	42	132	25	108	41	116	41	149	83	292	5	23	4	-84	
			78	70	149	42	90	65	121	62	243	68	100	18	6	13	-76	
			92	34	108	33	128	43	87	35	34	67	286	7	193	21	58	
			69	43	105	37	103	39	82	37	38	77	272	8	180	10	74	
			73	39	98	36	111	38	77	34	33	71	272	10	178	16	63	
			90	47	72	46	115	52	52	30	360	52	263	5	168	37	39	
			77	51	147	23	102	49	133	45	210	73	117	1	26	17	-68	
			283	54	237	43	262	54	269	54	60	81	265	8	174	4	-86	
			304	63	283	61	286	52	319	47	42	72	301	3	210	17	-68	
			302	63	231	33	284	53	253	48	165	73	270	5	1	16	69	
			290	59	228	38	271	55	255	54	124	79	265	9	355	7	81	
			293	60	245	49	274	54	283	54	70	81	278	8	187	4	-85	
			297	56	274	54	275	49	307	45	23	73	290	1	199	17	-68	
			68	41	138	16	105	37	127	35	167	75	297	10	29	11	-72	
			68	43	118	31	102	39	98	39	84	82	280	7	190	2	87	
			77	44	134	28	108	44	116	44	170	86	292	2	22	4	-85	
			316	71	253	53	303	53	293	53	153	81	299	7	29	5	84	
			318	62	263	47	300	45	293	44	233	86	117	2	27	3	85	
			99	47	146	36	122	56	123	56	297	80	122	10	32	1	-89	
			92	46	148	30	117	52	130	51	254	81	123	6	32	7	-82	
			97	54	144	43	116	61	113	61	298	75	115	15	204	1	89	
			310	80	235	56	302	64	286	63	136	71	297	18	28	6	83	
			313	49	293	47	283	36	314	32	354	70	122	12	215	15	-64	
			337	70	268	45	327	45	295	40	233	73	131	3	40	16	66	

outcrop	structural measurements						rotated measurements				strain axis							
	rep. foliation	faults (n)	fault plane		slip vector		fault plane		slip vector		ϵ_1		ϵ_2		ϵ_3		pitch	
			dip dir. (°)	dip (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)	az. (°)	pl. (°)		
BH-21-0063	002/42	14	306	68	244	49	282	51	298	50	38	81	289	3	198	8	-80	
			317	58	258	39	281	37	293	37	316	77	107	11	198	6	-81	
			291	79	219	58	279	69	311	66	74	66	288	20	193	12	-77	
			331	57	260	26	293	28	282	27	272	69	106	21	14	5	80	
			310	63	242	36	280	45	280	45	275	87	100	3	10	0	89	
			303	58	252	45	270	47	297	43	1	76	103	3	193	14	-71	
			299	66	241	50	275	55	297	52	40	77	284	6	192	11	-76	
			92	54	144	41	118	64	93	62	324	72	110	15	202	10	78	
			97	34	125	31	139	54	92	44	25	65	118	2	209	25	59	
			84	48	120	42	119	56	76	47	1	68	101	4	192	22	62	
			74	43	131	27	119	47	101	45	32	81	291	2	200	9	77	
			72	60	138	36	100	55	96	55	293	83	98	7	189	2	88	
			80	52	136	35	113	55	96	54	335	80	106	7	197	8	80	
			66	53	136	24	103	47	109	47	177	87	286	1	16	3	-86	
BH-21-0093	359/51	13	306	84	221	42	289	58	288	58	111	82	289	8	19	0	89	
			274	56	210	33	244	66	265	64	39	72	250	15	157	9	-81	
			297	85	211	38	283	65	277	65	110	75	282	15	12	2	87	
			301	76	215	16	278	57	243	51	161	72	265	4	356	17	69	
			304	61	253	49	264	46	306	38	355	66	104	8	197	22	-58	
			306	88	218	46	293	61	296	61	105	79	294	11	203	2	-89	
			42	59	126	10	90	36	106	35	128	73	278	15	10	8	-77	
			54	57	126	25	99	44	90	44	61	83	275	6	184	4	84	
			59	60	140	15	98	49	114	48	187	82	285	1	14	8	-79	
			36	65	113	26	76	34	81	34	88	74	259	16	349	3	-86	
			92	39	119	36	134	62	73	43	13	56	110	5	202	34	50	
			69	64	141	33	99	59	88	59	301	80	95	9	185	4	84	
			78	69	147	43	99	69	69	66	305	69	91	18	185	11	78	

Complete data table related to **Table 3.1**. az = azimuth; pl. = plunge Rotated fault measurements and inferred strain axes for each structural measurement. Corresponding stereoplots are available in **Figure S3.3**.

Table S3.3. Analytical results for white mica total fusion $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology for samples from the Tauern Window, Austria

sample	age (Ma)	$\pm 1\sigma$	^{40}Ar (fA)	$\pm 1\sigma$	^{39}Ar (fA)	$\pm 1\sigma$	^{38}Ar (fA)	$\pm 1\sigma$	^{37}Ar (fA)	$\pm 1\sigma$	^{36}Ar (fA)	$\pm 1\sigma$	Ca/K	$\pm 1\sigma$	Cl/K	$\pm 1\sigma$	% $^{40}\text{Ar}^*$	$^{40}\text{Ar}^*/^{39}\text{Ar}_K$	$\pm 1\sigma$
JS/21/10 <i>quartz-rich phyllite; J: $1.40E^{-2} \pm 8.92E^{-6}$ (1σ)</i>																			
01A	216.93	0.15	319.322	0.064	33.956	0.016	0.423	0.015	0.068	0.014	0.029	0.001	0.012	0.003	0.001	0.001	97.245	9.141	0.007
01B	238.63	0.13	485.591	0.094	46.593	0.017	0.593	0.015	0.075	0.013	0.046	0.001	0.009	0.002	0.002	0.001	97.115	10.117	0.006
01C	240.83	0.20	238.952	0.066	22.865	0.015	0.291	0.016	0.043	0.013	0.017	0.000	0.011	0.004	0.002	0.002	97.807	10.217	0.009
01D	260.03	0.21	390.098	0.090	33.484	0.019	0.419	0.015	0.052	0.014	0.062	0.001	0.009	0.003	0.001	0.001	95.243	11.091	0.010
01E	253.22	0.52	121.381	0.042	10.144	0.014	0.157	0.015	0.000	0.013	0.040	0.001	0.000	0.008	0.008	0.004	90.130	10.780	0.024
01F	261.20	0.13	613.025	0.093	53.240	0.019	0.668	0.016	0.089	0.014	0.065	0.001	0.010	0.002	0.001	0.001	96.831	11.145	0.006
01G	258.68	0.07	1075.812	0.142	96.620	0.022	1.165	0.015	0.079	0.012	0.030	0.001	0.005	0.001	0.000	0.000	99.100	11.030	0.003
JS/22/185 <i>marble mylonite; J: $1.42E^{-2} \pm 1.16E^{-5}$ (1σ)</i>																			
01A	28.64	0.32	23.205	0.032	11.970	0.013	0.150	0.016	0.028	0.015	0.033	0.000	0.059	0.032	0.000	0.004	58.155	1.126	0.013
01B	29.63	0.25	13.505	0.034	9.260	0.014	0.107	0.016	0.000	0.013	0.009	0.000	0.000	0.037	0.000	0.005	80.021	1.166	0.010
01C	32.93	0.16	15.630	0.033	11.194	0.013	0.103	0.014	0.025	0.014	0.004	0.000	0.057	0.032	0.000	0.004	92.970	1.297	0.006
01D	29.12	0.24	8.942	0.033	7.433	0.013	0.089	0.015	0.000	0.013	0.001	0.000	0.000	0.043	0.000	0.006	95.320	1.146	0.009
01E	30.59	0.20	12.068	0.034	9.609	0.014	0.094	0.015	0.005	0.013	0.002	0.000	0.012	0.034	0.000	0.004	95.965	1.204	0.008
01F	29.83	0.20	17.172	0.034	12.718	0.015	0.169	0.015	0.000	0.013	0.007	0.000	0.000	0.026	0.003	0.003	87.024	1.174	0.008
01G	31.89	0.34	8.269	0.035	5.969	0.014	0.083	0.015	0.019	0.014	0.003	0.000	0.080	0.062	0.005	0.008	90.716	1.256	0.013
01H	30.86	0.32	10.088	0.034	6.817	0.013	0.090	0.014	0.011	0.014	0.006	0.000	0.040	0.052	0.002	0.006	82.170	1.215	0.013
JS/22/067 <i>marble mylonite; J: $1.43E^{-2} \pm 2.26E^{-5}$ (1σ)</i>																			
01A	27.96	0.22	8.953	0.033	7.868	0.014	0.079	0.015	0.000	0.014	0.001	0.000	0.000	0.028	0.000	0.005	96.404	1.096	0.008
01B	26.92	0.35	19.216	0.030	9.571	0.014	0.121	0.016	0.015	0.014	0.031	0.000	0.025	0.023	0.000	0.005	52.573	1.055	0.014
01C	30.95	0.20	17.953	0.030	12.153	0.013	0.166	0.015	0.040	0.014	0.011	0.000	0.051	0.018	0.004	0.004	82.260	1.214	0.008
01D	26.94	0.17	11.819	0.035	10.606	0.015	0.131	0.016	0.000	0.014	0.002	0.000	0.000	0.021	0.000	0.004	94.818	1.056	0.007
01E	29.19	0.14	16.302	0.033	13.127	0.016	0.167	0.014	0.013	0.014	0.004	0.000	0.015	0.017	0.001	0.003	92.229	1.145	0.005
01F	28.57	0.23	9.659	0.034	7.669	0.013	0.093	0.016	0.000	0.013	0.004	0.000	0.000	0.027	0.000	0.006	89.004	1.120	0.009
01G	27.69	0.25	8.451	0.034	7.314	0.014	0.098	0.016	0.000	0.015	0.002	0.000	0.000	0.032	0.004	0.006	94.012	1.085	0.010
01H	28.46	0.10	21.375	0.032	18.098	0.014	0.214	0.016	0.031	0.014	0.004	0.000	0.027	0.013	0.000	0.002	94.551	1.116	0.004
JS/22/S23 <i>graphite phyllite; J: $1.42E^{-2} \pm 1.16E^{-5}$ (1σ)</i>																			
01A	29.55	0.04	99.104	0.039	80.597	0.022	1.005	0.016	0.010	0.013	0.019	0.000	0.002	0.004	0.001	0.001	94.432	1.160	0.002
01B	29.39	0.16	34.742	0.036	23.171	0.017	0.303	0.016	0.041	0.014	0.027	0.000	0.042	0.015	0.002	0.002	77.018	1.154	0.006
01C	28.91	0.05	50.263	0.036	42.376	0.020	0.504	0.016	0.000	0.013	0.007	0.000	0.000	0.008	0.000	0.001	95.750	1.135	0.002
01D	65.58	72.15	0.000	0.032	0.025	0.012	0.009	0.017	0.017	0.014	0.000	0.000	17.269	16.089	1.062	2.071	0.000	2.601	2.913
01E	30.69	0.06	36.209	0.033	29.141	0.016	0.306	0.016	0.000	0.013	0.003	0.000	0.000	0.011	0.000	0.002	97.078	1.205	0.003
01F	29.47	0.15	15.023	0.034	12.537	0.015	0.169	0.015	0.018	0.014	0.002	0.000	0.034	0.028	0.004	0.003	96.648	1.157	0.006
01G	29.37	0.08	31.166	0.034	26.105	0.016	0.339	0.015	0.024	0.014	0.004	0.000	0.022	0.013	0.002	0.002	96.653	1.153	0.003
01H	28.45	0.10	29.943	0.033	24.655	0.016	0.273	0.016	0.000	0.014	0.008	0.000	0.000	0.014	0.000	0.002	92.006	1.116	0.004
JS/22/024 <i>graphite phyllite; J: $1.43E^{-2} \pm 1.16E^{-5}$ (1σ)</i>																			

sample	age (Ma)	$\pm 1\sigma$	^{40}Ar (fA)	$\pm 1\sigma$	^{39}Ar (fA)	$\pm 1\sigma$	^{38}Ar (fA)	$\pm 1\sigma$	^{37}Ar (fA)	$\pm 1\sigma$	^{36}Ar (fA)	$\pm 1\sigma$	Ca/K	$\pm 1\sigma$	Cl/K	$\pm 1\sigma$	% $^{40}\text{Ar}^*$	$^{40}\text{Ar}^*/^{39}\text{Ar}_K$	$\pm 1\sigma$
01A	31.90	0.07	36.715	0.035	27.995	0.015	0.372	0.016	0.013	0.014	0.006	0.000	0.011	0.012	0.003	0.002	95.522	1.252	0.003
01B	32.36	0.06	47.782	0.035	36.128	0.017	0.461	0.015	0.000	0.014	0.006	0.000	0.000	0.010	0.001	0.001	96.099	1.270	0.002
01C	32.97	0.06	53.716	0.039	39.737	0.018	0.510	0.017	0.025	0.014	0.008	0.000	0.015	0.009	0.002	0.001	95.800	1.294	0.002
01D	32.43	0.04	73.970	0.040	56.131	0.020	0.668	0.015	0.032	0.014	0.008	0.000	0.014	0.006	0.000	0.001	96.645	1.272	0.002
01E	32.95	0.10	29.957	0.036	21.966	0.016	0.272	0.015	0.000	0.013	0.005	0.000	0.000	0.015	0.000	0.002	94.892	1.293	0.004
01F	29.10	0.05	45.568	0.037	38.947	0.018	0.466	0.015	0.000	0.014	0.004	0.000	0.000	0.009	0.000	0.001	97.581	1.141	0.002
01G	31.10	0.06	46.505	0.036	36.914	0.017	0.433	0.016	0.020	0.014	0.005	0.000	0.013	0.010	0.000	0.001	96.927	1.220	0.002
01H	32.11	0.05	61.916	0.038	47.669	0.021	0.575	0.015	0.008	0.014	0.006	0.000	0.004	0.007	0.000	0.001	97.085	1.260	0.002
JS/21/09 <i>phyllite; J: $1.40E^{-2} \pm 8.92E^{-6}$ (1σ)</i>																			
01A	26.89	0.04	66.463	0.036	59.370	0.021	0.722	0.015	0.085	0.013	0.008	0.000	0.009	0.001	0.000	0.001	96.015	1.074	0.002
01B	25.65	0.03	103.545	0.038	97.042	0.026	1.195	0.015	0.067	0.012	0.011	0.000	0.004	0.001	0.001	0.000	96.054	1.024	0.001
01C	26.02	0.03	86.766	0.045	80.083	0.029	0.977	0.016	0.098	0.013	0.010	0.000	0.007	0.001	0.001	0.001	95.951	1.039	0.001
01D	25.43	0.03	144.482	0.088	135.625	0.074	1.668	0.015	0.087	0.013	0.019	0.000	0.004	0.001	0.001	0.000	95.384	1.016	0.001
01E	29.19	0.04	145.107	0.069	116.575	0.048	1.416	0.015	0.104	0.014	0.028	0.000	0.005	0.001	0.000	0.000	93.783	1.167	0.001
01F	26.96	0.04	141.156	0.087	121.743	0.068	1.490	0.014	0.083	0.013	0.031	0.000	0.004	0.001	0.001	0.000	92.953	1.077	0.001
01G	26.49	0.04	96.708	0.059	87.495	0.047	1.074	0.015	0.054	0.014	0.012	0.000	0.003	0.001	0.001	0.000	95.791	1.058	0.002
01H	25.11	0.03	103.433	0.045	99.134	0.031	1.209	0.016	0.209	0.013	0.011	0.000	0.013	0.001	0.001	0.000	96.144	1.003	0.001
01I	26.71	0.03	131.241	0.072	117.485	0.061	1.406	0.016	0.054	0.014	0.017	0.000	0.002	0.001	0.000	0.000	95.561	1.067	0.001
JS/21/13 <i>greenschist; J: $1.40E^{-2} \pm 8.91E^{-6}$ (1σ)</i>																			
01A	30.57	0.06	54.704	0.037	43.435	0.017	0.524	0.015	2.345	0.013	0.006	0.000	0.343	0.002	0.000	0.001	97.177	1.224	0.002
01B	30.95	0.06	61.043	0.036	47.212	0.018	0.535	0.016	5.376	0.013	0.012	0.000	0.725	0.002	0.000	0.001	95.837	1.239	0.002
01C	30.32	0.05	91.247	0.045	71.556	0.023	0.886	0.015	21.045	0.016	0.032	0.000	1.876	0.002	0.001	0.001	95.145	1.214	0.002
01D	31.02	0.04	87.423	0.044	68.137	0.026	0.836	0.016	7.354	0.016	0.014	0.000	0.688	0.001	0.001	0.001	96.798	1.242	0.002
01E	30.36	0.05	80.104	0.040	63.526	0.024	0.776	0.016	8.091	0.014	0.015	0.000	0.813	0.001	0.001	0.001	96.388	1.215	0.002
01F	29.62	0.07	50.386	0.039	40.742	0.021	0.487	0.016	7.388	0.015	0.013	0.000	1.158	0.002	0.000	0.001	95.823	1.185	0.003
01G	30.39	0.07	61.259	0.039	47.272	0.025	0.609	0.015	10.504	0.015	0.021	0.000	1.421	0.002	0.003	0.001	93.852	1.216	0.003
01H	31.58	0.07	45.398	0.037	34.557	0.018	0.440	0.015	0.785	0.015	0.006	0.000	0.145	0.003	0.002	0.001	96.274	1.264	0.003
01I	30.29	0.05	66.556	0.043	53.436	0.025	0.675	0.016	5.808	0.014	0.010	0.000	0.696	0.002	0.002	0.001	97.342	1.212	0.002
JS/22/116 <i>greenschist; J: $1.42E^{-2} \pm 1.17E^{-3}$ (1σ)</i>																			
01A	27.34	0.15	20.333	0.034	15.784	0.014	0.209	0.015	0.031	0.014	0.011	0.000	0.049	0.022	0.003	0.003	83.539	1.075	0.006
01B	27.56	0.84	2.593	0.029	2.182	0.013	0.063	0.016	0.496	0.014	0.002	0.000	5.770	0.165	0.049	0.021	91.119	1.084	0.033
01C	26.82	0.39	4.454	0.032	4.069	0.014	0.065	0.016	0.068	0.014	0.001	0.000	0.422	0.086	0.011	0.011	96.408	1.054	0.015
01D	32.55	0.64	3.888	0.031	2.916	0.013	0.042	0.017	0.636	0.014	0.003	0.000	5.547	0.128	0.007	0.017	96.059	1.282	0.026
01E	27.07	0.68	25.020	0.033	7.314	0.015	0.092	0.014	1.282	0.013	0.063	0.001	4.462	0.048	0.000	0.006	31.090	1.064	0.027
01F	30.27	0.70	5.198	0.035	3.036	0.012	0.059	0.015	0.106	0.014	0.006	0.000	0.891	0.117	0.020	0.014	69.637	1.191	0.028
01G	28.38	0.82	24.801	0.035	6.474	0.013	0.090	0.015	1.402	0.012	0.064	0.001	5.523	0.050	0.000	0.007	29.108	1.116	0.032
01H	33.84	0.45	6.841	0.033	4.804	0.013	0.045	0.015	1.675	0.013	0.007	0.000	8.914	0.074	0.000	0.009	93.407	1.333	0.018
JS/22/097 <i>greenschist; J: $1.42E^{-2} \pm 1.17E^{-3}$ (1σ)</i>																			
01A*	31.22	0.12	24.767	0.037	18.720	0.014	0.254	0.016	0.226	0.013	0.007	0.000	0.303	0.017	0.004	0.003	92.751	1.226	0.005
01B	29.14	0.14	18.366	0.034	15.151	0.015	0.203	0.015	0.003	0.013	0.003	0.000	0.005	0.022	0.003	0.003	94.450	1.144	0.005

sample	age (Ma)	$\pm 1\sigma$	^{40}Ar (fA)	$\pm 1\sigma$	^{39}Ar (fA)	$\pm 1\sigma$	^{38}Ar (fA)	$\pm 1\sigma$	^{37}Ar (fA)	$\pm 1\sigma$	^{36}Ar (fA)	$\pm 1\sigma$	Ca/K	$\pm 1\sigma$	Cl/K	$\pm 1\sigma$	% $^{40}\text{Ar}^*$	$^{40}\text{Ar}^*/^{39}\text{Ar}_K$	$\pm 1\sigma$
01C	29.38	0.08	37.355	0.037	30.299	0.018	0.392	0.014	0.000	0.013	0.008	0.000	0.000	0.011	0.002	0.001	93.640	1.153	0.003
01D	29.65	0.12	25.731	0.034	19.733	0.015	0.256	0.016	0.102	0.014	0.010	0.000	0.130	0.018	0.002	0.002	89.372	1.164	0.005
01E	29.77	0.07	45.282	0.039	34.930	0.017	0.454	0.014	0.002	0.013	0.015	0.000	0.001	0.009	0.002	0.001	90.263	1.169	0.003
01F	29.04	0.14	16.013	0.034	13.489	0.014	0.148	0.015	0.013	0.013	0.002	0.000	0.024	0.025	0.000	0.003	96.110	1.140	0.005
01G	29.44	0.13	19.664	0.030	15.990	0.014	0.205	0.016	0.000	0.013	0.004	0.000	0.000	0.021	0.002	0.003	94.061	1.156	0.005
01H	29.79	0.09	31.241	0.035	24.135	0.016	0.298	0.018	0.007	0.012	0.010	0.000	0.007	0.012	0.000	0.002	90.442	1.170	0.004
JS/22/096 <i>phyllite (+/- chlorite schist); J: $1.43E^{-2} \pm 2.27E^{-5}$ (1σ)</i>																			
01A	29.90	0.19	11.695	0.033	9.617	0.013	0.104	0.017	0.176	0.013	0.002	0.000	0.284	0.022	0.000	0.005	96.357	1.171	0.007
01B	28.42	0.29	7.047	0.033	6.080	0.013	0.068	0.016	0.090	0.014	0.001	0.000	0.229	0.035	0.000	0.007	96.079	1.113	0.012
01C	30.97	0.29	9.868	0.030	7.144	0.014	0.082	0.015	0.462	0.013	0.005	0.000	1.009	0.029	0.000	0.006	87.867	1.213	0.012
01D	31.79	0.21	13.040	0.034	9.655	0.014	0.105	0.015	0.136	0.014	0.004	0.000	0.220	0.022	0.000	0.005	92.292	1.246	0.008
01E	30.95	0.20	13.020	0.034	9.996	0.014	0.117	0.016	0.190	0.013	0.003	0.000	0.296	0.020	0.000	0.005	93.162	1.213	0.008
01F	29.32	0.17	13.997	0.035	11.441	0.014	0.164	0.015	0.188	0.015	0.003	0.000	0.256	0.020	0.006	0.004	93.893	1.148	0.007
01G	30.03	0.39	5.163	0.033	4.324	0.014	0.043	0.015	0.110	0.013	0.000	0.000	0.399	0.046	0.000	0.010	98.567	1.176	0.015
01H	29.93	0.39	5.896	0.033	4.615	0.013	0.053	0.014	0.023	0.013	0.002	0.000	0.077	0.044	0.000	0.009	91.816	1.172	0.016
JS/22/162 <i>quartz-rich phyllite ($\pm$ marble); J: $1.43E^{-2} \pm 2.26E^{-5}$ (1σ)</i>																			
01A	108.84	0.30	33.900	0.037	7.595	0.013	0.110	0.016	0.002	0.014	0.003	0.000	0.003	0.030	0.007	0.006	97.801	4.362	0.012
01B	182.41	0.34	66.064	0.038	8.745	0.014	0.122	0.016	0.008	0.014	0.003	0.000	0.015	0.025	0.005	0.005	98.858	7.462	0.015
01C	38.54	0.19	16.372	0.033	10.180	0.015	0.100	0.016	0.000	0.013	0.003	0.000	0.000	0.021	0.000	0.005	94.244	1.515	0.007
01D	31.17	0.41	5.330	0.034	4.268	0.014	0.046	0.015	0.009	0.012	0.000	0.000	0.032	0.045	0.000	0.010	97.947	1.222	0.016
01E	225.63	0.37	85.521	0.041	9.094	0.014	0.104	0.016	0.000	0.014	0.002	0.000	0.000	0.024	0.000	0.005	99.435	9.344	0.016
01F	172.26	0.70	28.203	0.032	3.835	0.012	0.076	0.015	0.046	0.012	0.004	0.000	0.189	0.051	0.022	0.012	95.631	7.027	0.030
01G	174.16	1.08	90.215	0.041	6.266	0.013	0.101	0.016	0.000	0.014	0.154	0.001	0.000	0.035	0.000	0.007	49.409	7.109	0.046
01H	31.13	0.18	15.211	0.030	11.405	0.015	0.137	0.015	0.000	0.013	0.004	0.000	0.000	0.019	0.000	0.004	91.616	1.221	0.007
JS/21/12 <i>graphite phyllite; J: $1.39E^{-2} \pm 1.02E^{-5}$ (1σ)</i>																			
01A	31.33	0.25	12.181	0.033	9.110	0.015	0.119	0.014	0.014	0.012	0.002	0.000	0.030	0.027	0.003	0.004	94.425	1.262	0.010
01B	30.73	0.19	18.921	0.032	13.460	0.015	0.158	0.016	0.023	0.013	0.007	0.000	0.033	0.019	0.000	0.004	88.086	1.237	0.008
01C	30.71	0.11	30.318	0.032	22.092	0.015	0.257	0.014	0.012	0.014	0.010	0.000	0.010	0.012	0.000	0.002	90.164	1.236	0.004
01D	28.05	0.10	25.088	0.035	21.374	0.015	0.247	0.016	0.024	0.013	0.003	0.000	0.021	0.012	0.000	0.002	96.227	1.129	0.004
01E	31.27	0.23	13.938	0.030	10.157	0.013	0.144	0.018	0.000	0.014	0.004	0.000	0.000	0.027	0.006	0.005	91.850	1.259	0.009
01F	32.38	0.07	49.178	0.038	35.805	0.016	0.399	0.015	0.015	0.015	0.007	0.000	0.008	0.008	0.000	0.001	95.039	1.304	0.003
01G	28.37	0.08	63.671	0.032	47.741	0.017	0.598	0.016	0.003	0.013	0.030	0.000	0.001	0.006	0.001	0.001	85.648	1.141	0.003
01H	27.58	0.09	34.426	0.035	28.628	0.015	0.333	0.015	0.009	0.013	0.008	0.000	0.006	0.009	0.000	0.002	92.346	1.110	0.004
01I	31.61	0.22	21.691	0.034	14.187	0.014	0.171	0.015	0.019	0.013	0.012	0.000	0.026	0.017	0.000	0.003	83.340	1.273	0.009
JS/21/07B <i>marble mylonite; J: $1.39E^{-2} \pm 1.02E^{-5}$ (1σ)</i>																			
01A	29.04	0.13	24.168	0.030	18.849	0.014	0.232	0.016	0.000	0.013	0.007	0.000	0.000	0.014	0.001	0.002	91.224	1.169	0.005
01B	27.84	0.18	13.906	0.035	11.868	0.016	0.143	0.015	0.013	0.012	0.002	0.000	0.020	0.020	0.000	0.004	95.671	1.120	0.007
01C	27.88	0.16	17.640	0.032	14.072	0.014	0.200	0.015	0.044	0.013	0.006	0.000	0.060	0.018	0.006	0.003	89.557	1.122	0.006
01D	28.47	0.12	21.274	0.033	18.050	0.013	0.198	0.015	0.000	0.013	0.001	0.000	0.000	0.014	0.000	0.002	97.272	1.146	0.005
01E	29.59	0.15	21.397	0.035	16.327	0.014	0.231	0.015	0.009	0.014	0.006	0.000	0.011	0.016	0.006	0.003	90.963	1.191	0.006

sample	age (Ma)	$\pm 1\sigma$	^{40}Ar (fA)	$\pm 1\sigma$	^{39}Ar (fA)	$\pm 1\sigma$	^{38}Ar (fA)	$\pm 1\sigma$	^{37}Ar (fA)	$\pm 1\sigma$	^{36}Ar (fA)	$\pm 1\sigma$	Ca/K	$\pm 1\sigma$	Cl/K	$\pm 1\sigma$	% $^{40}\text{Ar}^*$	$^{40}\text{Ar}^*/^{39}\text{Ar}_K$	$\pm 1\sigma$
01F	29.30	0.15	20.012	0.034	15.297	0.015	0.200	0.015	0.000	0.013	0.006	0.000	0.000	0.017	0.003	0.003	90.203	1.179	0.006
01G	29.27	0.12	24.810	0.036	19.583	0.016	0.220	0.014	0.026	0.013	0.005	0.000	0.026	0.013	0.000	0.002	93.041	1.178	0.005
01H	27.59	0.14	21.505	0.034	17.872	0.014	0.241	0.015	0.014	0.014	0.005	0.000	0.015	0.015	0.004	0.002	92.321	1.110	0.006
01I	27.27	0.27	9.324	0.034	7.763	0.014	0.097	0.014	0.002	0.015	0.003	0.000	0.005	0.037	0.001	0.005	91.415	1.097	0.011
JS/21/06 <i>quartz-rich phyllite ($\pm$ marble); J: $1.40E^{-2} \pm 8.91E^{-6}$ (1σ)</i>																			
01C	246.81	0.14	373.277	0.097	35.077	0.017	0.437	0.015	0.046	0.013	0.016	0.000	0.008	0.002	0.001	0.001	98.678	10.497	0.007
01D	242.87	0.18	262.155	0.068	25.097	0.016	0.303	0.015	0.087	0.012	0.010	0.000	0.021	0.003	0.000	0.002	98.812	10.317	0.008
01E	230.53	0.17	260.452	0.079	26.396	0.016	0.335	0.016	0.052	0.013	0.009	0.000	0.012	0.003	0.002	0.002	98.948	9.759	0.007
01F	234.44	0.08	1156.889	0.229	114.865	0.030	1.401	0.015	0.068	0.014	0.049	0.001	0.003	0.001	0.000	0.000	98.689	9.936	0.004
01G	113.43	0.63	19.039	0.034	3.939	0.012	0.081	0.015	0.018	0.014	0.002	0.000	0.028	0.022	0.025	0.011	96.162	4.646	0.027
01H	252.97	0.17	404.405	0.111	36.516	0.019	0.429	0.015	0.019	0.014	0.035	0.001	0.003	0.002	0.000	0.001	97.356	10.778	0.008
01I	251.11	0.27	186.479	0.054	16.908	0.015	0.237	0.014	0.000	0.014	0.019	0.000	0.000	0.005	0.005	0.002	96.991	10.692	0.012
01J	257.03	0.11	587.278	0.087	52.828	0.019	0.663	0.015	0.047	0.013	0.025	0.000	0.005	0.002	0.001	0.001	98.657	10.963	0.005
01K	216.32	0.10	410.762	0.070	44.657	0.017	0.538	0.016	0.044	0.015	0.010	0.000	0.006	0.002	0.000	0.001	99.199	9.121	0.005
SS 21/1 <i>marble mylonite; J: $1.39E^{-2} \pm 1.02E^{-5}$ (1σ)</i>																			
01A	29.13	0.34	9.028	0.033	6.840	0.013	0.068	0.016	0.075	0.013	0.003	0.000	0.215	0.037	0.000	0.007	88.940	1.173	0.014
01B	31.64	0.44	5.986	0.032	4.498	0.014	0.057	0.016	0.052	0.014	0.001	0.000	0.228	0.061	0.002	0.010	95.859	1.275	0.018
01C	30.73	0.33	7.523	0.030	6.261	0.015	0.062	0.016	0.027	0.013	0.000	0.000	0.086	0.041	0.000	0.007	103.106	1.238	0.013
01D	32.08	0.43	6.116	0.029	4.489	0.015	0.054	0.015	0.038	0.013	0.001	0.000	0.167	0.056	0.000	0.010	94.956	1.293	0.017
01E	29.56	0.23	11.884	0.037	9.501	0.013	0.126	0.014	0.111	0.013	0.002	0.000	0.230	0.027	0.004	0.004	95.214	1.190	0.009
01F	29.60	0.54	4.558	0.033	3.714	0.014	0.055	0.016	0.038	0.014	0.000	0.000	0.205	0.073	0.008	0.013	97.175	1.192	0.022
01G	30.72	0.19	15.279	0.031	12.153	0.015	0.160	0.016	0.059	0.014	0.001	0.000	0.096	0.022	0.004	0.004	98.506	1.237	0.008
01I	30.15	0.26	9.366	0.030	7.501	0.014	0.126	0.016	0.020	0.015	0.001	0.000	0.054	0.040	0.014	0.006	97.329	1.214	0.011
SS 21/5 <i>greenschist; J: $1.39E^{-2} \pm 1.02E^{-5}$ (1σ)</i>																			
01A	31.25	0.23	12.318	0.032	9.405	0.013	0.141	0.016	0.026	0.013	0.001	0.000	0.055	0.028	0.009	0.005	96.195	1.259	0.009
01B	30.44	0.23	11.965	0.034	9.472	0.013	0.120	0.015	0.021	0.013	0.001	0.000	0.043	0.026	0.002	0.004	97.146	1.226	0.009
01C	31.72	0.17	15.643	0.029	11.888	0.015	0.156	0.015	0.015	0.013	0.001	0.000	0.025	0.023	0.003	0.004	97.203	1.278	0.007
01D	30.61	0.22	11.397	0.033	9.095	0.013	0.100	0.015	0.018	0.013	0.000	0.000	0.039	0.028	0.000	0.005	98.447	1.233	0.009
01E	29.57	0.17	15.970	0.031	12.960	0.014	0.139	0.016	0.000	0.013	0.001	0.000	0.000	0.020	0.000	0.004	96.687	1.190	0.007
01F	33.14	0.20	15.044	0.031	10.653	0.015	0.141	0.015	0.000	0.013	0.002	0.000	0.000	0.025	0.004	0.004	94.677	1.336	0.008
01G	30.76	0.16	18.485	0.034	14.227	0.015	0.174	0.015	0.036	0.014	0.003	0.000	0.050	0.019	0.001	0.003	95.438	1.239	0.007
01H	31.52	0.17	15.906	0.033	12.172	0.015	0.111	0.015	0.025	0.014	0.001	0.000	0.040	0.022	0.000	0.004	97.259	1.270	0.007
01I	31.37	0.14	22.930	0.033	17.131	0.015	0.224	0.017	0.018	0.012	0.004	0.000	0.020	0.014	0.003	0.003	94.479	1.264	0.006
SS 21/8 <i>phyllite; J: $1.39E^{-2} \pm 7.47E^{-6}$ (1σ)</i>																			
01A	27.73	0.11	22.184	0.033	19.743	0.014	0.237	0.015	0.000	0.014	0.000	0.000	0.000	0.014	0.000	0.002	99.388	1.116	0.005
01B	27.36	0.14	17.894	0.035	15.861	0.015	0.181	0.015	0.010	0.013	0.001	0.000	0.012	0.017	0.000	0.003	97.643	1.101	0.006
01C	28.09	0.10	23.412	0.033	20.274	0.015	0.246	0.018	0.020	0.013	0.001	0.000	0.019	0.013	0.000	0.003	97.943	1.130	0.004
01D	27.57	0.13	17.384	0.034	15.031	0.015	0.198	0.016	0.000	0.014	0.002	0.000	0.000	0.019	0.003	0.003	95.999	1.109	0.005
01E	27.78	0.13	18.957	0.032	16.603	0.014	0.227	0.015	0.000	0.014	0.001	0.000	0.000	0.017	0.005	0.003	97.954	1.117	0.005
01F	27.46	0.08	32.612	0.032	28.507	0.017	0.358	0.015	0.030	0.013	0.003	0.000	0.021	0.009	0.002	0.001	96.651	1.105	0.003

sample	age (Ma)	$\pm 1\sigma$	^{40}Ar (fA)	$\pm 1\sigma$	^{39}Ar (fA)	$\pm 1\sigma$	^{38}Ar (fA)	$\pm 1\sigma$	^{37}Ar (fA)	$\pm 1\sigma$	^{36}Ar (fA)	$\pm 1\sigma$	Ca/K	$\pm 1\sigma$	Cl/K	$\pm 1\sigma$	% $^{40}\text{Ar}^*$	$^{40}\text{Ar}^*/^{39}\text{Ar}_K$	$\pm 1\sigma$
01G	27.76	0.23	37.643	0.035	19.841	0.016	0.242	0.015	0.000	0.013	0.052	0.001	0.000	0.013	0.000	0.002	58.918	1.117	0.009
01H	27.71	0.08	32.192	0.034	28.078	0.015	0.335	0.016	0.035	0.015	0.002	0.000	0.025	0.010	0.000	0.002	97.307	1.115	0.003
01I	25.46	0.16	17.591	0.031	15.441	0.014	0.170	0.017	0.000	0.014	0.006	0.000	0.000	0.019	0.000	0.003	89.941	1.024	0.006
SS 21/10 <i>graphite phyllite; J: $1.39\text{E}^{-2} \pm 7.47\text{E}^{-6}$ (1σ)</i>																			
01A	35.83	0.27	13.614	0.034	8.698	0.015	0.091	0.015	0.074	0.013	0.004	0.000	0.174	0.031	0.000	0.005	92.378	1.445	0.011
01B	35.65	0.33	11.380	0.031	6.837	0.012	0.072	0.015	0.009	0.014	0.005	0.000	0.026	0.041	0.000	0.006	86.434	1.437	0.014
01C	34.61	0.46	8.916	0.034	5.230	0.013	0.077	0.014	0.028	0.013	0.005	0.000	0.108	0.051	0.007	0.008	81.913	1.395	0.019
01D	35.27	0.27	12.813	0.033	8.116	0.014	0.067	0.015	0.000	0.014	0.004	0.000	0.000	0.035	0.000	0.005	90.141	1.422	0.011
01E	47.98	0.25	19.232	0.033	9.301	0.013	0.125	0.016	0.061	0.014	0.004	0.000	0.133	0.031	0.004	0.005	93.960	1.941	0.010
01F	27.26	0.17	19.808	0.031	15.761	0.015	0.201	0.016	0.020	0.013	0.008	0.000	0.026	0.017	0.002	0.003	87.320	1.097	0.007
01G	37.06	0.37	15.021	0.031	7.510	0.014	0.079	0.015	0.046	0.013	0.013	0.000	0.125	0.036	0.000	0.006	74.807	1.495	0.015
01H	34.60	0.44	15.151	0.033	6.922	0.013	0.064	0.016	0.018	0.012	0.018	0.000	0.052	0.037	0.000	0.007	63.776	1.395	0.018
01I	37.83	0.95	11.039	0.032	3.180	0.014	0.018	0.016	0.046	0.014	0.021	0.000	0.294	0.090	0.000	0.014	43.998	1.526	0.039
SS 21/11 <i>graphite phyllite; J: $1.39\text{E}^{-2} \pm 7.51\text{E}^{-6}$ (1σ)</i>																			
01A	39.82	0.47	25.520	0.033	8.741	0.014	0.119	0.015	0.011	0.014	0.039	0.001	0.025	0.034	0.002	0.005	55.068	1.606	0.019
01B	84.09	0.35	53.021	0.038	11.879	0.014	0.143	0.014	0.002	0.013	0.041	0.001	0.003	0.022	0.000	0.003	77.023	3.435	0.015
01C	58.37	0.36	30.777	0.033	9.805	0.014	0.117	0.015	0.000	0.014	0.025	0.000	0.000	0.030	0.000	0.005	75.483	2.367	0.015
01D	32.00	0.30	10.293	0.035	7.104	0.014	0.095	0.015	0.000	0.014	0.004	0.000	0.000	0.040	0.004	0.006	88.996	1.288	0.012
01E	31.31	0.43	8.432	0.033	5.406	0.013	0.075	0.017	0.022	0.013	0.005	0.000	0.085	0.049	0.005	0.009	80.868	1.260	0.018
01F	46.16	0.36	35.234	0.035	11.720	0.014	0.149	0.015	0.033	0.014	0.045	0.001	0.059	0.025	0.000	0.004	62.112	1.866	0.015
01G	47.88	0.44	37.278	0.037	10.785	0.014	0.135	0.016	0.065	0.015	0.055	0.001	0.125	0.029	0.000	0.004	56.056	1.936	0.018
01H	60.68	0.36	26.266	0.034	8.444	0.014	0.119	0.015	0.000	0.013	0.018	0.000	0.000	0.032	0.005	0.005	79.229	2.462	0.015
01I	62.04	0.65	36.223	0.035	7.612	0.013	0.101	0.016	0.015	0.014	0.058	0.001	0.041	0.038	0.000	0.006	52.967	2.518	0.027

Greyed out rows represent grains that are omitted from the weighted mean age or age range reported in Table 3.2.

Table S3.4: Compiled RSCM data, Tauern Window, Austria

sample	T _P (°C)	1σ (°C)	lithology	UTM coordinates Zone 33N		reference
				Easting	Northing	
BH/20/02	468	28	dark phyllite, graphitic	347300	5232126	<i>this study</i>
BH/20/06	459	28	impure marble, graphitic	347636	5232581	<i>this study</i>
BH/20/17	515	29	black phyllite, graphitic	346285	5228801	<i>this study</i>
BH/20/22	461	28	dark phyllite, graphitic	345329	5230839	<i>this study</i>
BH/20/47	469	28	black phyllite, graphitic	349402	5231702	<i>this study</i>
BH/20/52	390	28	black slate, graphitic	347902	5237115	<i>this study</i>
BH/20/53	363	28	black slate, graphitic	348323	5236804	<i>this study</i>
BH/20/77	482	28	dark phyllite, graphitic	351399	5229252	<i>this study</i>
BH/20/78.5	381	28	dark slate, graphitic	348966	5235331	<i>this study</i>
BH/21/29	390	28	black phyllite, graphitic	343368	5237057	<i>this study</i>
BH/21/34	482	28	black phyllite, graphitic	350156	5232246	<i>this study</i>
BH/21/35	452	28	black phyllite, graphitic	349447	5232440	<i>this study</i>
BH/21/36	450	28	black phyllite, graphitic	349186	5233235	<i>this study</i>
BH/21/40	425	28	black phyllite, graphitic	348795	5233712	<i>this study</i>
BH/21/45	447	28	black phyllite, graphitic	348535	5233223	<i>this study</i>
BH/21/46	441	36	black phyllite, graphitic	348635	5232981	<i>this study</i>
BH/21/47	480	28	black phyllite, graphitic	348725	5232696	<i>this study</i>
BH/21/51	453	28	black phyllite, graphitic	348749	5232466	<i>this study</i>
BH/21/53	467	34	impure marble, graphitic	350870	5231553	<i>this study</i>
BH/21/54	464	29	black phyllite, graphitic	350904	5231654	<i>this study</i>
BH/21/57	464	28	impure marble, graphitic	350935	5231950	<i>this study</i>
BH/21/58	437	30	black phyllite, graphitic	348536	5234323	<i>this study</i>
BH/21/60	392	28	black phyllite, graphitic	349349	5234947	<i>this study</i>
BH/21/61	405	28	black phyllite, graphitic	348922	5236469	<i>this study</i>
BH/21/62	417	28	black phyllite, graphitic	337435	5233605	<i>this study</i>
BH/21/63	447	28	black phyllite, graphitic	336575	5233234	<i>this study</i>
BH/21/64	454	37	black phyllite, graphitic	336382	5233042	<i>this study</i>
BH/21/66	516	29	black phyllite, graphitic	347971	5229503	<i>this study</i>
BH/21/67	537	29	black phyllite, graphitic	348471	5230078	<i>this study</i>
BH/21/69	469	28	black phyllite, graphitic	348591	5230545	<i>this study</i>
BH/21/70	500	42	black phyllite, graphitic	348779	5231111	<i>this study</i>
BH/21/71	478	29	black phyllite, graphitic	348767	5230920	<i>this study</i>
BH/21/73	455	28	black phyllite, graphitic	346630	5232481	<i>this study</i>
BH/21/74	448	28	black phyllite, graphitic	346628	5233100	<i>this study</i>
BH/21/77	443	28	black phyllite, graphitic	347272	5233386	<i>this study</i>
BH/21/79	438	33	black phyllite, graphitic	344467	5231608	<i>this study</i>
BH/22/12	438	28	black phyllite, graphitic	352306	5230012	<i>this study</i>
BH/22/14	465	28	black phyllite, graphitic	350777	5230862	<i>this study</i>
BH/22/17	467	28	black phyllite, graphitic	350967	5230596	<i>this study</i>
BH/22/25	413	28	black phyllite, graphitic	343759	5235149	<i>this study</i>
BH/22/33	487	28	black phyllite, graphitic	351331	5228782	<i>this study</i>
BH/22/38	414	28	black phyllite, graphitic	352371	5232172	<i>this study</i>
BH/22/39	461	28	black phyllite, graphitic	352172	5230726	<i>this study</i>
BH/22/40	415	28	black phyllite, graphitic	352305	5231507	<i>this study</i>

sample	T _p	1σ	lithology	UTM coordinates Zone 33N		reference
	(°C)	(°C)		Easting	Northing	
BH/22/41	391	38	black phyllite, graphitic	352373	5232789	<i>this study</i>
BH/22/42	403	28	black phyllite, graphitic	349948	5233558	<i>this study</i>
BH/22/43	402	28	impure marble, graphitic	350341	5233862	<i>this study</i>
BH/22/53	413	28	black phyllite, graphitic	341950	5235357	<i>this study</i>
BH/22/61	415	28	black phyllite, graphitic	346888	5233628	<i>this study</i>
BH/22/64	331	27	impure marble, graphitic	363393	5241072	<i>this study</i>
BH/22/65	419	28	black phyllite, graphitic	346438	5234833	<i>this study</i>
BH/22/66	413	28	impure marble, graphitic	346718	5234041	<i>this study</i>
BH/22/67	394	28	black phyllite, graphitic	359825	5233007	<i>this study</i>
BH/22/68	389	28	black phyllite, graphitic	360384	5235462	<i>this study</i>
BH/22/69	382	28	black phyllite, graphitic	360337	5235737	<i>this study</i>
BH/22/70	364	28	dark dolomite, graphitic	360097	5236036	<i>this study</i>
BH/22/71	391	28	black phyllite, graphitic	360070	5234570	<i>this study</i>
BH/22/72	379	28	black phyllite, graphitic	354575	5238294	<i>this study</i>
BH/22/73	396	33	impure marble, graphitic	349915	5234429	<i>this study</i>
BH/22/76	402	28	impure marble, graphitic	351861	5234614	<i>this study</i>
JS/22/02	409	29	black phyllite, graphitic	343466	5234831	<i>this study</i>
JS/22/03	470	28	black phyllite, graphitic	341281	5231116	<i>this study</i>
JS/22/07	456	30	black phyllite, graphitic	341539	5229408	<i>this study</i>
JS/22/08	386	28	black phyllite, graphitic	344239	5233558	<i>this study</i>
JS/22/09	434	29	black phyllite, graphitic	338082	5233808	<i>this study</i>
JS/22/10	398	28	black phyllite, graphitic	338566	5233983	<i>this study</i>
JS/22/11	438	32	black phyllite, graphitic	338282	5232982	<i>this study</i>
JS/22/12	443	28	black phyllite, graphitic	338836	5232058	<i>this study</i>
JS/22/14	404	28	phyllite, graphitic	342457	5234849	<i>this study</i>
JS/22/15	434	28	black phyllite, graphitic	338694	5231103	<i>this study</i>
JS/22/16	440	28	phyllit, grafitisch?	343867	5231354	<i>this study</i>
JS/22/17	425	28	black phyllite, graphitic	340823	5231778	<i>this study</i>
JS/22/18	411	28	black phyllite, graphitic	340370	5232900	<i>this study</i>
JS/22/19	400	28	black phyllite, graphitic	344241	5233315	<i>this study</i>
JS/22/20	422	28	phyllite, graphitic	344193	5232642	<i>this study</i>
JS/22/21	377	28	black phyllite, graphitic	344302	5234526	<i>this study</i>
JS/22/22	483	28	black phyllite, graphitic	342835	5230293	<i>this study</i>
JS/22/23	435	30	black phyllite, graphitic	340620	5230459	<i>this study</i>
JS/22/24	401	28	phyllite, graphitic	341413	5234996	<i>this study</i>
JS/22/25	405	28	black phyllite, graphitic	341274	5234485	<i>this study</i>
JS/22/26	403	28	black phyllite, graphitic	341079	5234207	<i>this study</i>
JS/22/27	390	28	black phyllite, graphitic	340880	5233861	<i>this study</i>
JS/22/28	389	28	black phyllite, graphitic	340898	5233370	<i>this study</i>
Sch-16-1	489	26	black phyllite, graphitic	343284	5228203	<i>this study</i>
Vo2	526	26	black phyllite, graphitic	349016	5228644	<i>this study</i>
W3/16	502	26	black phyllite, graphitic	345840	5229078	<i>this study</i>
W4/16	480	26	black phyllite, graphitic	346382	5229687	<i>this study</i>
W5/16	493	26	black phyllite, graphitic	346391	5229411	<i>this study</i>
W6	495	26	black phyllite, graphitic	345511	5228431	<i>this study</i>
W7	501	26	black phyllite, graphitic	347745	5232163	<i>this study</i>
W8/16	477	26	black phyllite, graphitic	345623	5228456	<i>this study</i>

sample	T_p	1σ	lithology	UTM coordinates Zone 33N		reference
	(°C)	(°C)		Easting	Northing	
PG39	437	26	N/A	337547	5230198	Groß et al., 2021
PG145	447	43	N/A	335503	5228892	Groß et al., 2021
PG176	456	23	N/A	344171	5231007	Groß et al., 2021
PG178	486	20	N/A	346282	5228797	Groß et al., 2021
PG180	486	25	N/A	346412	5229377	Groß et al., 2021
PG182	427	28	N/A	345987	5230543	Groß et al., 2021
PG185	466	31	N/A	346255	5229728	Groß et al., 2021
PG188	390	33	N/A	348534	5233216	Groß et al., 2021
PG189	463	28	N/A	348903	5232718	Groß et al., 2021
PG190	374	27	N/A	347153	5237375	Groß et al., 2021
PG192	347	25	N/A	347033	5237617	Groß et al., 2021
PG194	453	27	N/A	346090	5230190	Groß et al., 2021
PG195	467	28	N/A	345978	5229679	Groß et al., 2021
PG206	470	36	N/A	337318	5229283	Groß et al., 2021
PG243	467	27	N/A	337102	5228465	Groß et al., 2021
PG247	472	40	N/A	337196	5229119	Groß et al., 2021
PG250	442	26	N/A	336089	5231300	Groß et al., 2021
PG258	487	30	N/A	338268	5228220	Groß et al., 2021
PG291	440	26	N/A	335023	5232280	Groß et al., 2021
PG293	397	20	N/A	335891	5233717	Groß et al., 2021
AS93	348	3	N/A	354507	5238060	Scharf et al., 2013
AS94	437	9	N/A	357338	5230633	Scharf et al., 2013
AS95	382	11	N/A	364098	5236864	Scharf et al., 2013
AS-GrA312	406	6	N/A	363004	5232689	Scharf et al., 2013
AS-GrA313	404	6	N/A	362974	5232733	Scharf et al., 2013
AS-GrA314	360	3	N/A	363568	5237522	Scharf et al., 2013
AS-Gas320	436	6	N/A	356929	5229053	Scharf et al., 2013
AS-Gas321	400	6	N/A	357043	5234616	Scharf et al., 2013
AS-Gas322	413	6	N/A	354577	5235692	Scharf et al., 2013

RSCM data used for interpolated raster in **Figure 3.8**. Samples distributed beyond the map extent are greyed out.

APPENDIX C

SUPPLEMENTARY INFORMATION FOR CHAPTER 4

Methodology

AFT LA-ICPMS analysis

AFT analyses were conducted via the laser ablation-inductively coupled plasma-mass spectrometry (LA-ICPMS modified- ζ method; Chew and Donelick, 2012; Cogné et al., 2020) by GeoSep Services, Inc (Moscow, USA). Apatite grains were separated from rock material using standard mineral separation techniques and, apatite separates were mounted in epoxy, polished using 3.0 and 0.3 μm grit. A single grain mount was used for each AFT sample. The mounts were etched in 5.5 N HNO_3 for 20 s at 21°C to reveal all natural fission-tracks intersecting the polished grain surface. AFT dates, length, and D_{par} data were measured following the procedures described in Donelick et al. (2005), and locations of each age-grain on the mount were recorded. When feasible, 40 apatite grains were used to calculate single-grain AFT dates. Spontaneous tracks (N_s) were first counted in unpolarized light at 2000x magnification using a Zeiss Axioplan microscope. Following this, the apatite mounts were irradiated using fission fragments from a ^{252}Cf source in a vacuum chamber to enhance the number of confined fission-tracks (CFT) available for measurement (e.g., Donelick and Miller, 1991). The irradiated apatite grain mounts were then re-etched under the same conditions to reveal a new set of horizontal CFT within the exposed apatite grains. These confined tracks were viewed and measured in both unpolarized and polarized light at 2000x magnification using the Zeiss Axioplan microscope. Only natural, horizontal, fully confined fission-tracks in apatite with clearly visible ends were considered candidates for length measurement. The length and crystallographic orientation of each fission-track were determined using a digitizing tablet interfaced with a personal computer. Once analytical measurements were completed for AFT analyses (N_s counts and CFT measurements), an Agilent 7700x ICPMS equipped with a New Wave Nd-YAG 213 nm laser ablation system housed at Washington State

University (Pullman, USA) was used to measure isotopic data necessary for all apatite FT calculations. Data were collected for the following isotopic masses: ^{43}Ca , ^{147}Sm , ^{204}Pb , ^{206}Pb , ^{207}Pb , ^{232}Th , and ^{238}U (45 scans over 45 s). Each analysis consisted of a 6 s integration on peaks with the laser shutter closed (for background measurements) followed by the shutter opening and the laser ablating apatite for the remainder of the analysis. A 20 s delay occurred between analyses. The beam diameter was 20 μm and the frequency was set at 5 Hz at 8 J/cm², yielding ablation pits ~16-18 μm deep. The ^{238}U concentrations were determined for the track count areas on each age-grain by measuring the ablation pits depth-weighted $^{238}\text{U}/^{43}\text{Ca}$ ratio from a fixed laser point (^{232}Th and ^{147}Sm were also measured). The volume of ablated material was estimated using ^{43}Ca , presuming Ca content respects apatite's stoichiometry. The AFT dates were calculated using the LA-ICPMS ζ -calibration approach (Chew and Donelick, 2012; Cogné et al., 2020; Donelick et al., 2005; Vermeesch, 2017) based on the Durango apatite reference monitor (31.44 ± 0.18 Ma, McDowell et al., 2005). Complete data tables of the AFT age analysis and track lengths for the 11 AFT samples presented are available in **Tables S1** and **S2**, respectively.

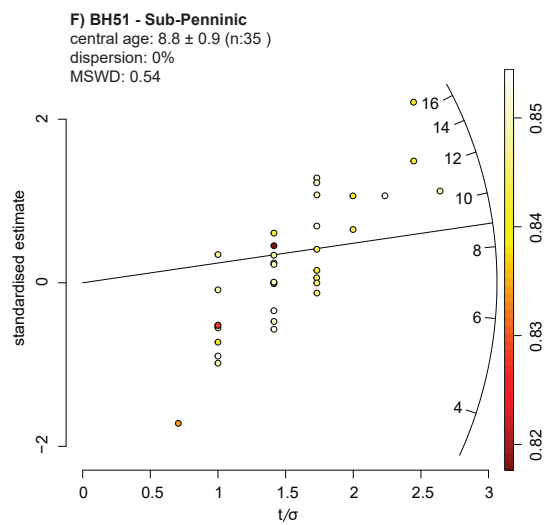
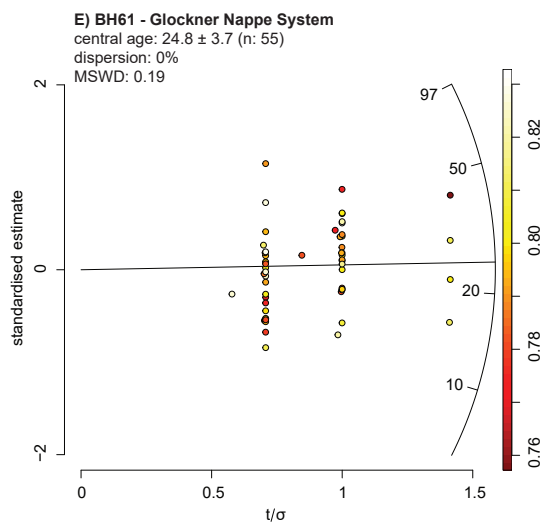
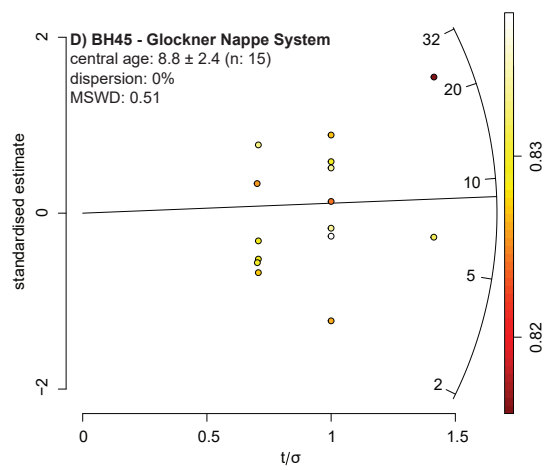
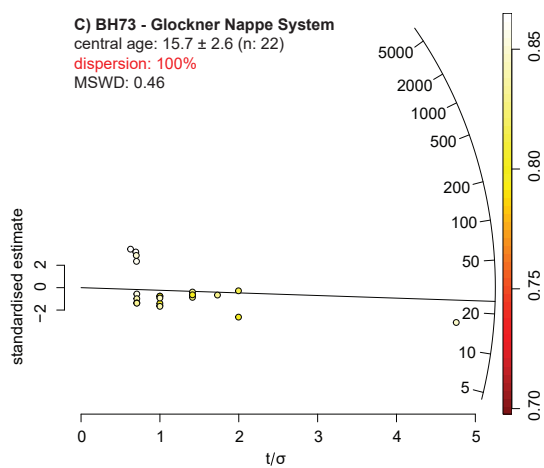
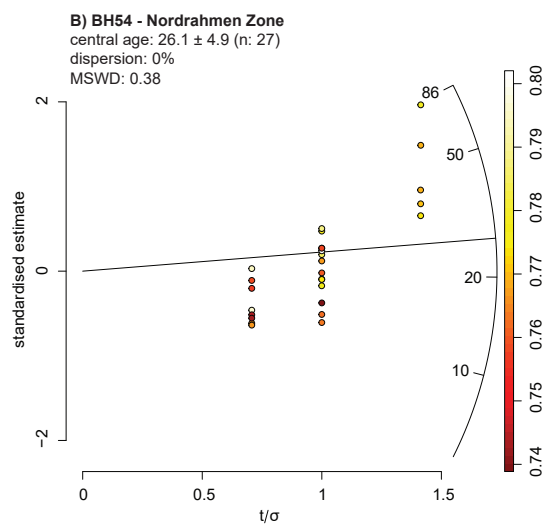
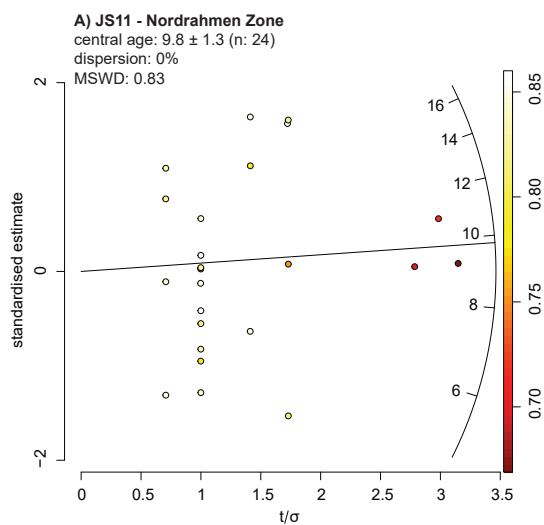
4.5.2 Mineral chemistry: electron probe microanalysis

The same grain mounts that were used for the AFT LA-ICPMS method were also used to measure apatite grain chemistry via electron probe microanalysis (EPMA). The analyses were conducted with a JEOL JXA-8230 equipped with 5 tunable wavelength dispersive spectrometers at the University of Ottawa (Ottawa, Canada). The locations of the apatite grains on their respective mounts (documented during AFT analysis) were used to target all grains utilized as AFT age- and length-grains. To avoid chemical zonation and obtain the most representative chemical data, spot analyses for EPMA were placed adjacent to LA-ICPMS ablation pits for the apatite age-grains.

Thirteen elements (F, Na, Mg, P, S, Cl, Ca, Mn, Fe, Sr, Y, La, Ce) were measured in wt%. The microprobe was operating at 15 keV with a takeoff angle of 40° and used a beam width of 10 µm for all elements. A beam current of 10 nA was used to measure Ca, F, P, Fe and Na and a beam current of 20 nA was used for all other analyses. The analysis of each element was allotted a 40 s counting time, except F which was allotted 80 s of counting time. The intensity data were corrected for Time Dependent Intensity (TDI) loss (or gain) using a self-calibrated correction for Ca, F, P, Fe, and Na. The standards included fluorapatite (Durango) for P, Ca, and F, celestine (MM-1) for S and Sr, diopside for Mg, albite (MM-1) for Na, hematite (MM-1) for Fe, tephrioite (HM-1) for Mn, YAG (MM-1) for Y, tugtupite for Cl, CePO₄ for Ce and LaPO₄ for La. Oxygen was calculated by cation stoichiometry and included in the matrix correction and oxygen equivalent from halogens (F/Cl/Br/I), was subtracted in the matrix correction. Apatite chemistry was converted from wt% to a.p.f.u. using the stoichiometric formula by Ketcham (2015) and the data are available in **Table S4.3**). Halogens (F + Cl + OH) occupy 2 a.p.f.u. following apatite's stoichiometry, and F-Cl content was used to calculate OH.

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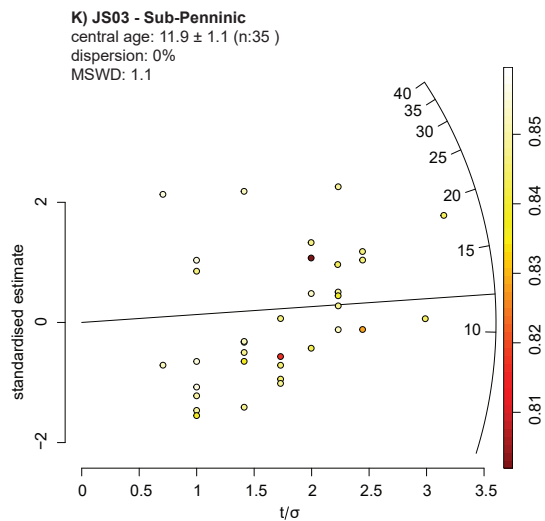
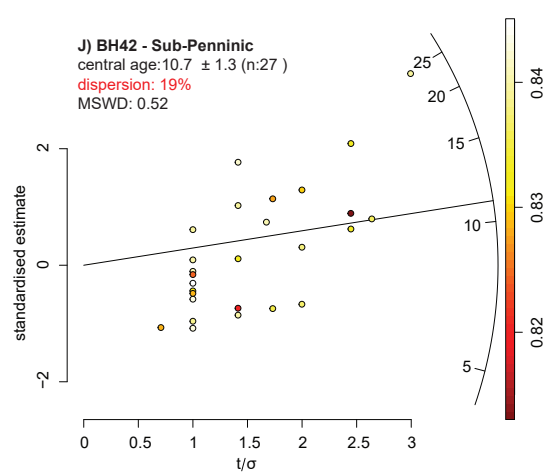
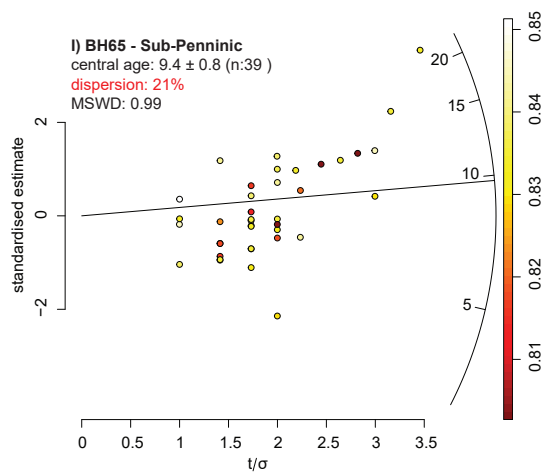
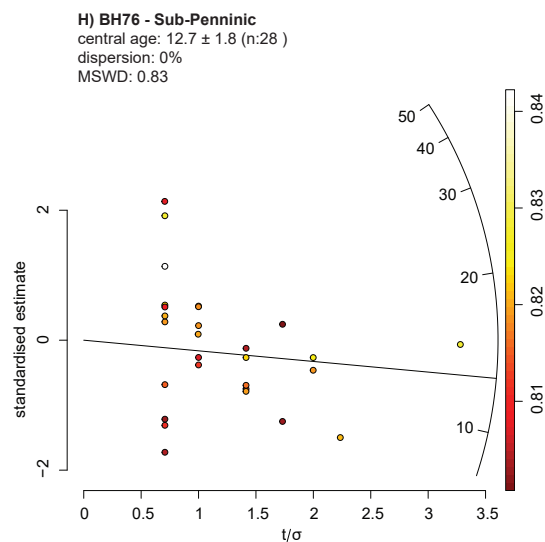
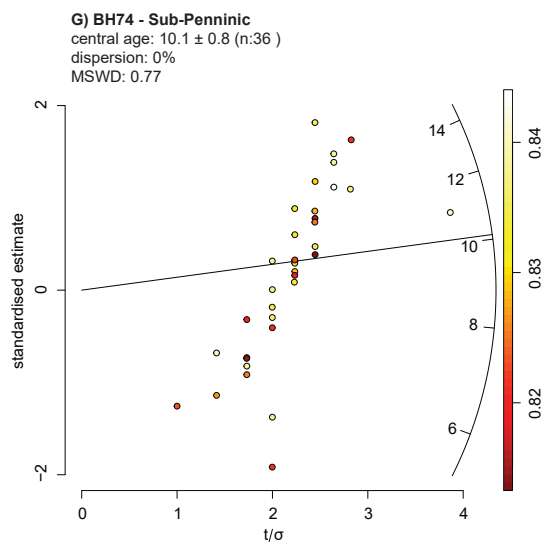
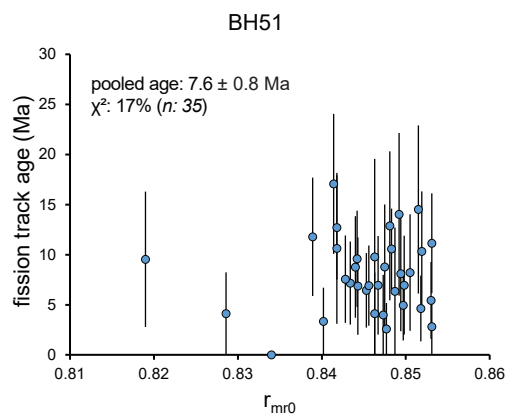
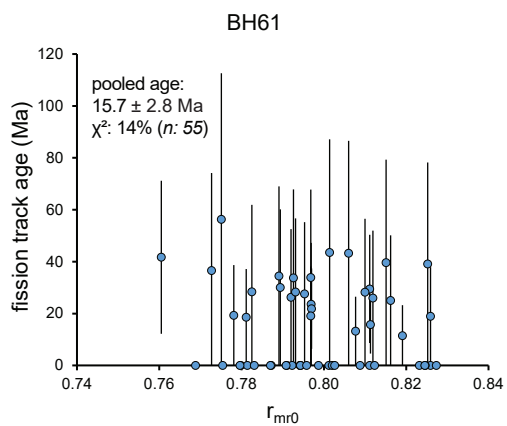
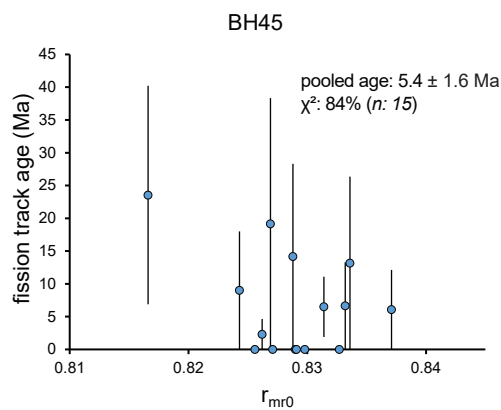
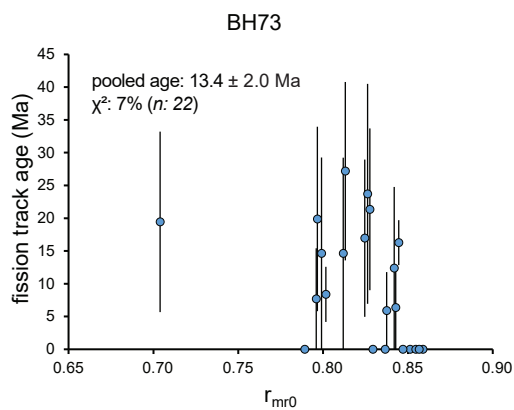
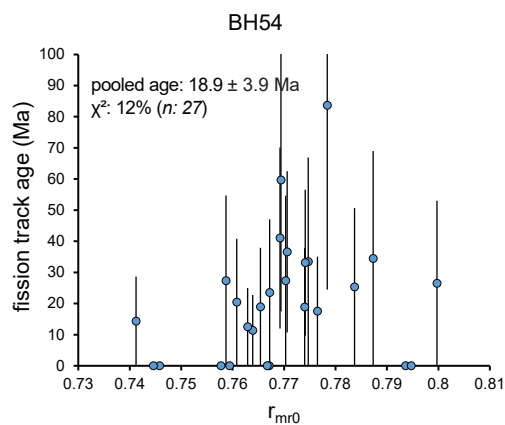
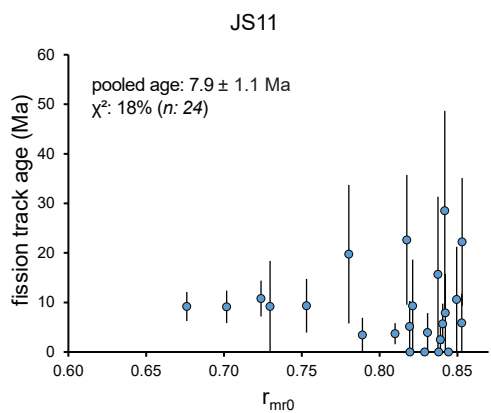


Figure S4.1. Radial plots of the 11 AFT samples collected in the ETD, see Figure 4.1 for sample locations. Radial plots account for all single-grain AFT ages and their associated error (1σ) and more precise ages plot closer to the radial arc. The line in each graph represents the samples' central ages, which is read from its intersection with the radial arc. The assigned colors represent the grains' corresponding *rmr0* value and warmer colors represent apatite grains with more retentive annealing kinetics.



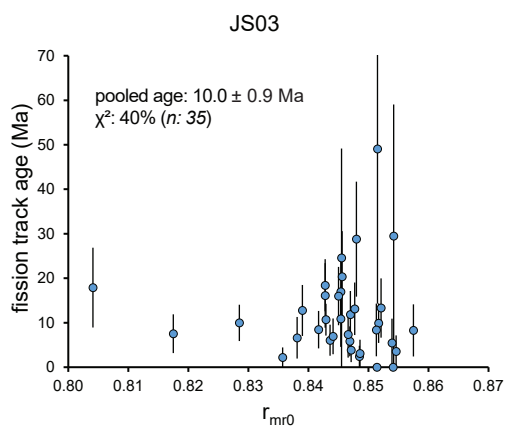
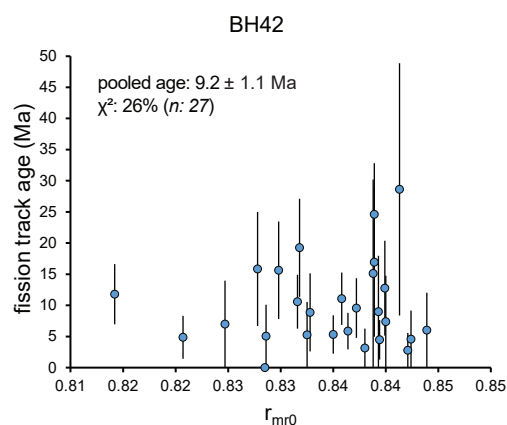
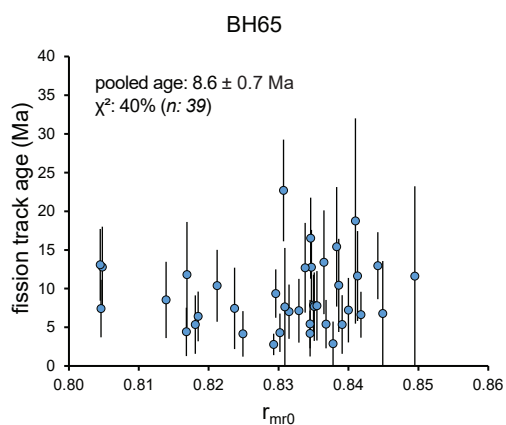
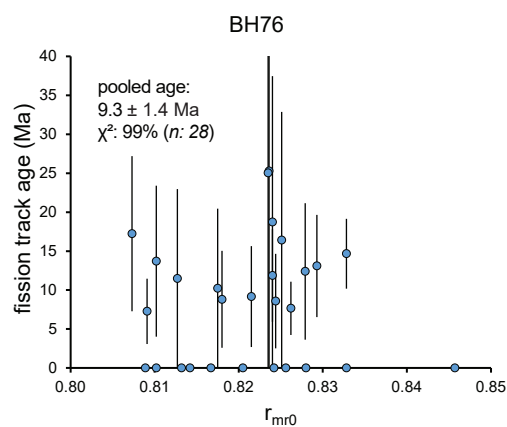
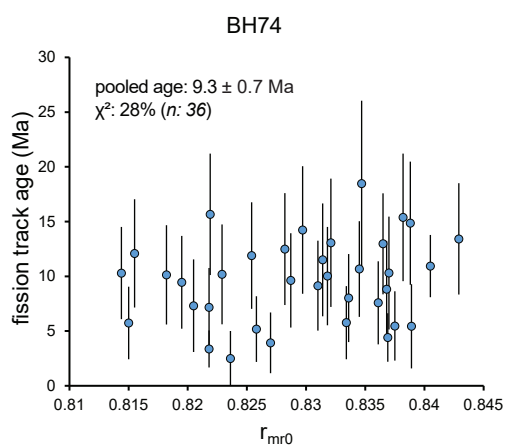
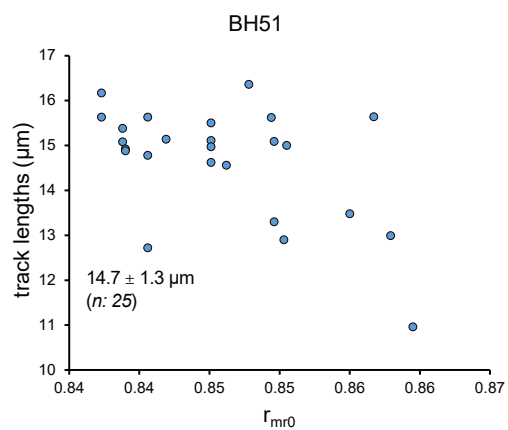
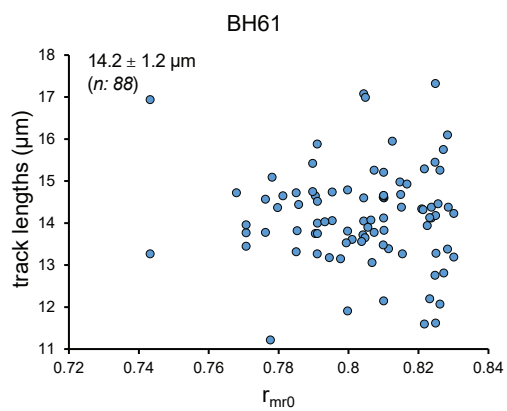
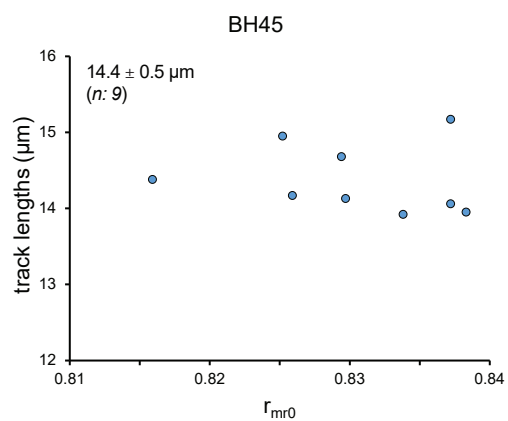
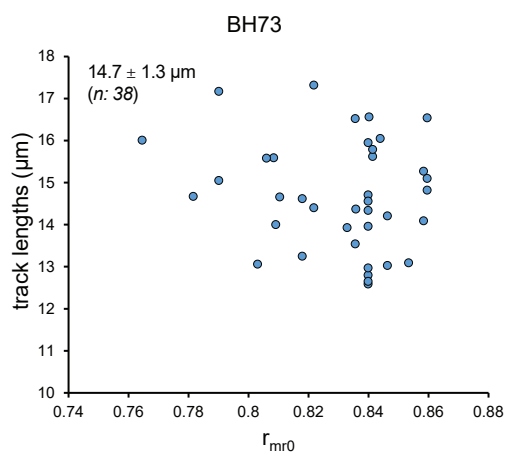
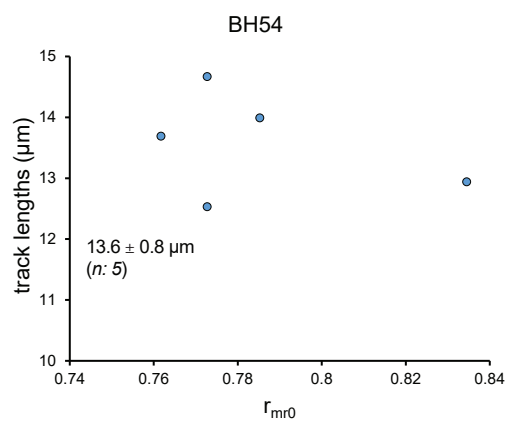
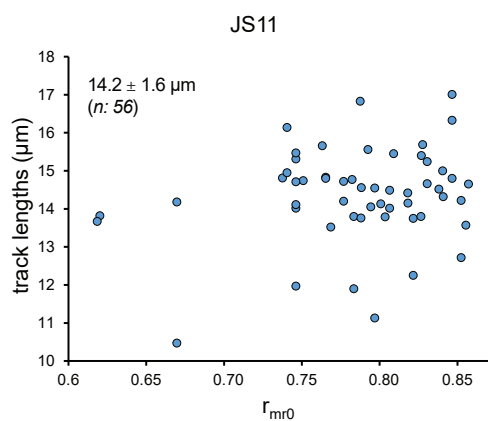


Figure S4.2. Single-grain AFT dates plotted as a function of the kinetic parameter r_{mr0} . Error bars on fission track dates are 1σ . The r_{mr0} values derived from grain chemistry measured via EPMA.



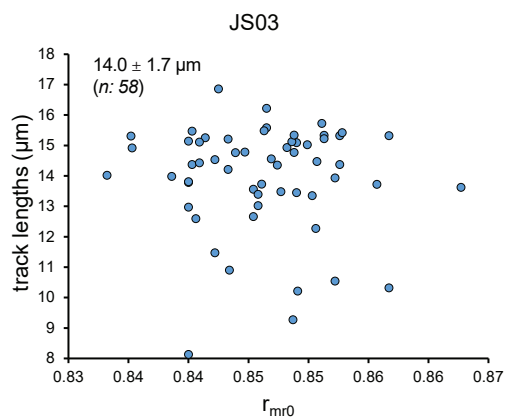
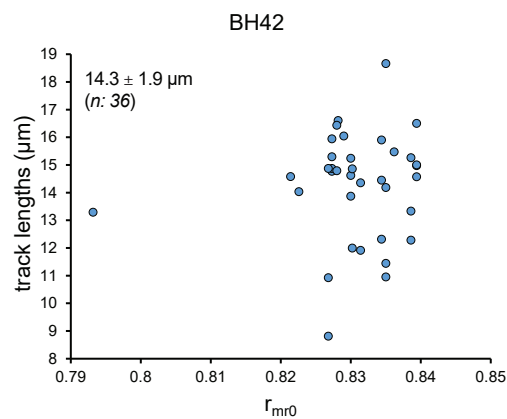
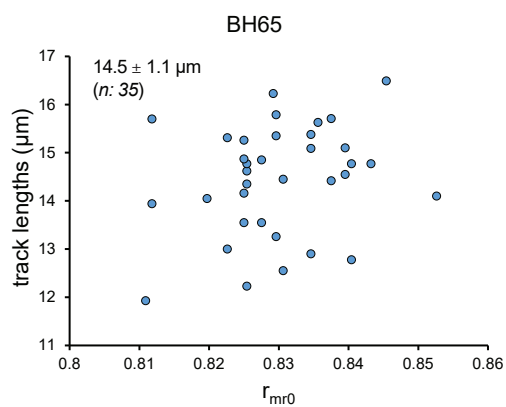
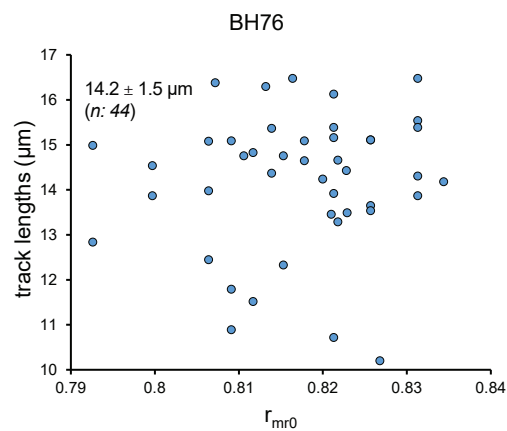
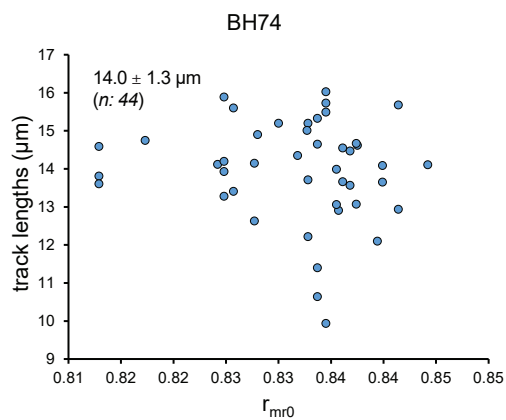


Figure S4.3. Fission track lengths plotted as a function of the kinetic parameter r_{mr0} . Error bars on fission track dates are 1σ . The r_{mr0} values derived from grain chemistry measured via EPMA.

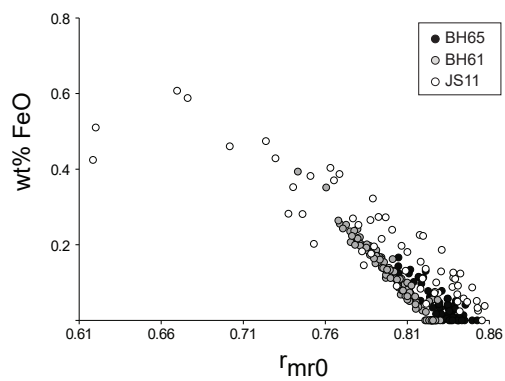
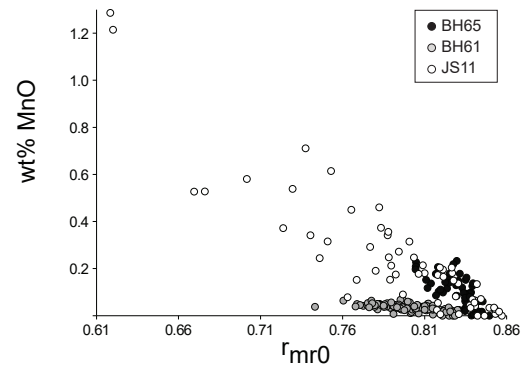
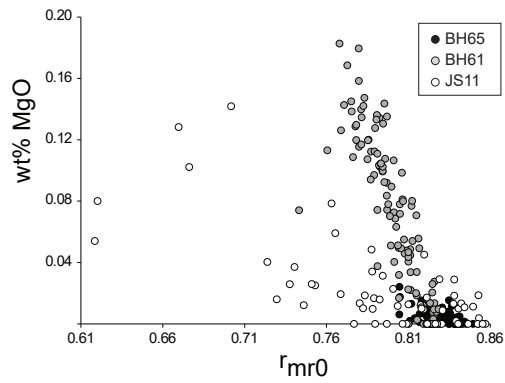
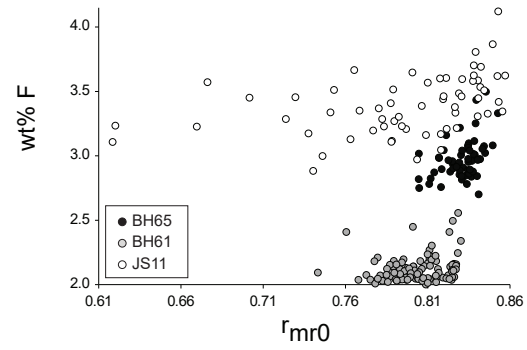
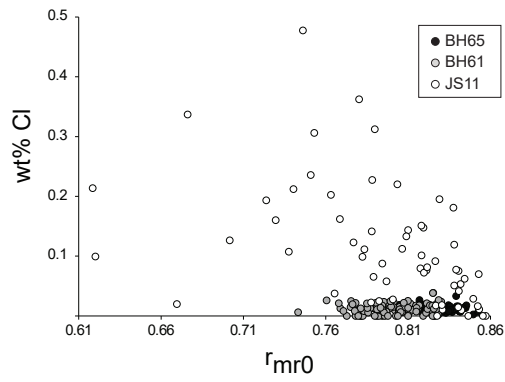
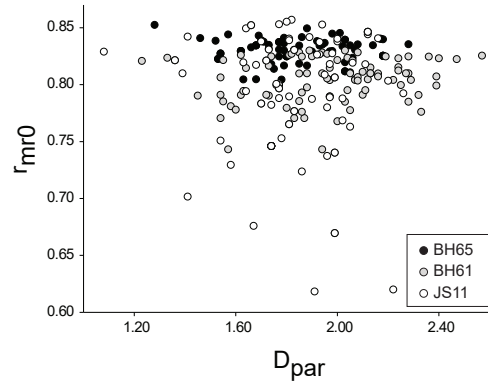
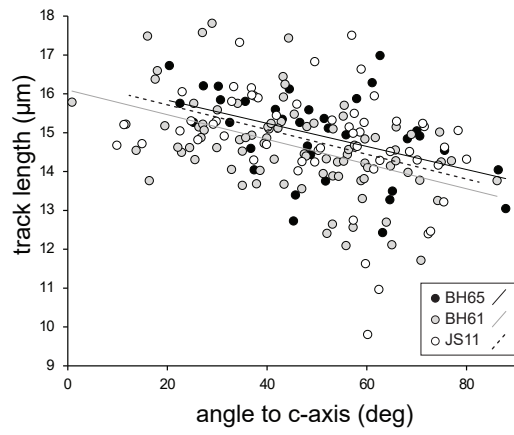


Figure S4.4. Binary plots comparing track lengths and c-axis orientations, r_{mr0} values and D_{par} , and various elemental composition to r_{mr0} values for the three AFT samples selected for inverse thermal history modeling.

Table S4.1. Summary of AFT age data, Tauern Window, Austria

Grain No.	N _s	$\Omega^{\prime}$ (cm ²)	P _i (dmnls)	P _i Ω _i (dmnls)	One sigma (dmnls)	$\sigma P_i^2 \Omega W_i^2$ (Ma)	FT age (Ma)	One sigma (Ma)	Etch Figs.	D _{par} (μm)	U (ppm)	F (apfu)	Cl (apfu)	OH (apfu)	r _{mr0}
JS11, Nordrahn Zone - Penninic, meta-litharenite. UTM zone 33N, 5237057N, 343368E, 1100 masl															
1	1	2.912E-05	0.031	9.004E-07	0.001	1.382E-15	9.2	9.2	2	1.58	8	1.87	0.05	0.09	0.73
3	1	2.427E-05	0.037	8.873E-07	0.002	1.386E-15	9.3	9.3	2	1.72	9	2.00	0.02	0.00	0.82
5	3	1.747E-05	0.384	6.717E-06	0.011	3.757E-14	3.7	2.1	1	1.39	83	1.97	0.04	0.00	0.81
9	10	3.883E-05	0.232	8.994E-06	0.007	7.190E-14	9.2	2.9	4	1.67	65	1.92	0.10	0.00	0.68
10	2	2.427E-05	0.024	5.794E-07	0.001	3.987E-16	28.5	20.2	2	1.89	5	1.89	0.02	0.09	0.84
12	2	1.941E-05	0.043	8.363E-07	0.001	6.989E-16	19.8	14.0	2	1.96	11	1.88	0.11	0.01	0.78
15	2	3.883E-05	0.075	2.898E-06	0.003	1.421E-14	5.7	4.0	1	1.81	32	1.93	0.02	0.05	0.84
16	1	2.427E-05	0.087	2.106E-06	0.003	3.981E-15	3.9	3.9	2	1.73	22	1.90	0.00	0.09	0.83
17	1	3.883E-05	0.027	1.048E-06	0.002	5.505E-15	7.9	7.9	1	1.41	5	1.96	0.00	0.04	0.84
18	3	2.039E-05	0.055	1.116E-06	0.003	4.238E-15	22.2	12.9	2	1.77	10	1.83	0.00	0.17	0.85
19	1	3.883E-05	0.062	2.393E-06	0.003	1.337E-14	3.5	3.5	2	1.97	17	1.88	0.02	0.10	0.79
20	1	2.427E-05	0.058	1.402E-06	0.002	2.101E-15	5.9	5.9	2	1.94	15	2.27	0.02	0.00	0.85
22	0	2.912E-05	0.019	5.389E-07	0.001	2.991E-16	0.0	0.0	1	1.70	5	2.04	0.04	0.00	0.84
23	0	3.106E-05	0.095	2.950E-06	0.003	9.150E-15	0.0	0.0	1	2.12	27	1.86	0.02	0.12	0.84
25	1	3.106E-05	0.108	3.339E-06	0.003	8.618E-15	2.5	2.5	1	1.81	25	2.05	0.02	0.00	0.84
26	1	2.718E-05	0.029	7.791E-07	0.001	8.101E-16	10.6	10.6	2	1.64	8	2.02	0.01	0.00	0.85
31	1	2.427E-05	0.066	1.606E-06	0.002	3.032E-15	5.1	5.2	1	2.06	16	1.90	0.04	0.06	0.82
32	3	2.427E-05	0.109	2.651E-06	0.003	5.679E-15	9.4	5.4	3	1.78	27	1.95	0.09	0.00	0.75
33	0	1.941E-05	0.005	9.800E-08	0.000	1.692E-17	0.0	0.0	1	1.08	1	1.93	0.06	0.02	0.83
36	3	3.398E-05	0.032	1.095E-06	0.001	1.247E-15	22.6	13.1	4	1.68	8	1.94	0.02	0.04	0.82
37	0	3.883E-05	0.004	1.553E-07	0.000	7.439E-17	0.0	0.0	1	1.63	1	1.89	0.02	0.09	0.82
38	9	3.398E-05	0.240	8.166E-06	0.032	1.186E-12	9.1	3.3	4	1.41	129	1.90	0.04	0.06	0.70
39	1	2.427E-05	0.022	5.273E-07	0.001	2.925E-16	15.7	15.7	1	1.93	5	1.89	0.05	0.06	0.84
40	9	3.883E-05	0.178	6.895E-06	0.006	5.631E-14	10.8	3.6	4	1.86	94	1.81	0.06	0.14	0.72
Q=18%	56	6.950E-04		5.868E-05		1.429E-12	7.9	1.1		1.73		1.94	0.04	0.05	0.81

Grain	N _s	Ω^2	P _i	P _i Ω _i	One sigma	$\sigma P_i^2 \Omega W_i^2$	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
BH54, Nordrahn Zone - Penninic, meta-gabbro. UTM zone 33N, 5236823N, 348318E, 1440 masl															
2	0	3.883E-05	0.012	4.735E-07	0.000	8.334E-17	0.0	0.0	1	1.52	3	1.36	0.04	0.60	0.77
3	1	2.427E-05	0.010	2.468E-07	0.000	2.152E-17	33.4	33.4	1	1.72	2	1.26	0.04	0.70	0.77
4	1	2.427E-05	0.017	4.048E-07	0.000	4.620E-17	20.4	20.4	1	1.71	3	0.90	0.05	1.05	0.76
5	0	2.330E-05	0.010	2.315E-07	0.000	1.857E-17	0.0	0.0	1	2.04	2	1.25	0.04	0.71	0.76
8	1	2.427E-05	0.012	3.022E-07	0.000	3.748E-17	27.3	27.3	1	1.63	3	1.35	0.04	0.62	0.77
10	2	2.039E-05	0.010	1.966E-07	0.000	1.366E-17	83.6	59.2	1	1.77	2	1.45	0.05	0.50	0.78
11	2	2.427E-05	0.011	2.761E-07	0.000	2.339E-17	59.6	42.2	2	2.16	2	1.17	0.04	0.79	0.77
12	1	1.747E-05	0.019	3.260E-07	0.000	4.850E-17	25.3	25.3	1	1.41	4	1.25	0.04	0.71	0.78
13	0	1.747E-05	0.011	1.899E-07	0.000	1.469E-17	0.0	0.0	1	1.52	2	1.33	0.04	0.63	0.79
14	1	2.427E-05	0.010	2.394E-07	0.000	1.877E-17	34.5	34.5	1	1.77	2	1.25	0.04	0.71	0.79
18	2	2.427E-05	0.017	4.018E-07	0.000	1.291E-16	41.1	29.1	1	1.76	3	1.19	0.06	0.75	0.77
19	1	3.883E-05	0.011	4.359E-07	0.000	1.061E-16	19.0	19.0	1	2.46	2	1.20	0.04	0.76	0.77
20	1	3.883E-05	0.015	5.773E-07	0.000	1.159E-16	14.3	14.3	1	1.85	3	1.22	0.04	0.73	0.74
22	0	2.912E-05	0.013	3.806E-07	0.000	7.448E-17	0.0	0.0	2	2.07	3	1.32	0.05	0.64	0.79
24	1	2.427E-05	0.013	3.116E-07	0.000	3.523E-17	26.5	26.5	2	2.15	3	1.42	0.02	0.56	0.80
25	1	3.883E-05	0.019	7.281E-07	0.000	1.802E-16	11.4	11.4	1	1.86	3	1.30	0.04	0.66	0.76
26	0	3.398E-05	0.012	4.114E-07	0.000	6.865E-17	0.0	0.0	1	2.06	3	1.18	0.04	0.78	0.75
27	0	3.106E-05	0.014	4.349E-07	0.000	9.680E-17	0.0	0.0	1	1.97	3	1.25	0.05	0.69	0.74
28	1	3.883E-05	0.011	4.374E-07	0.000	1.199E-16	18.9	18.9	1	2.13	2	1.19	0.04	0.77	0.77
29	2	2.912E-05	0.017	4.983E-07	0.000	1.519E-16	33.1	23.4	2	2.22	4	1.23	0.05	0.72	0.77
30	1	3.398E-05	0.014	4.714E-07	0.000	2.425E-16	17.5	17.5	2	1.73	3	1.21	0.04	0.75	0.78
32	1	3.883E-05	0.017	6.617E-07	0.000	2.055E-16	12.5	12.5	2	2.12	3	1.25	0.04	0.71	0.76
34	0	2.912E-05	0.009	2.642E-07	0.000	2.801E-17	0.0	0.0	1	2.09	2	1.19	0.04	0.77	0.76
35	1	2.330E-05	0.013	3.020E-07	0.000	6.145E-17	27.3	27.3	1	2.59	3	1.25	0.04	0.70	0.76
37	1	2.912E-05	0.012	3.514E-07	0.000	6.901E-17	23.5	23.5	1	1.92	3	1.23	0.04	0.73	0.77
38	0	3.106E-05	0.016	4.887E-07	0.000	6.891E-17	0.0	0.0	1	2.17	3	1.25	0.05	0.70	0.77
39	2	3.883E-05	0.012	4.510E-07	0.000	1.198E-16	36.6	25.9	2	1.95	2	1.21	0.04	0.75	0.77
Q=18%	24	7.902E-04		1.049E-05		2.200E-15	18.9	3.9		1.94		1.25	0.04	0.71	0.77

Grain	N _s	Ω^2	P _i	P _i Ω _i	One sigma	$\sigma P_i^2 \Omega W_i^2$	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
BH73, Nordrahn Zone - Penninic, meta-gabbro. UTM zone 33N, 5233572N, 346333E, 1350 masl															
11	1	3.883E-05	0.033	1.298E-06	0.001	1.351E-15	6.4	6.4	1	2.56	7	0.19	0.03	1.78	0.84
13	0	3.106E-05	0.000	2.140E-10	0.000	3.376E-20	0.0	0.0	1	2.18	0	0.15	0.00	1.85	0.86
14	1	4.854E-05	0.012	5.653E-07	0.000	3.580E-16	14.6	14.6	1	1.95	3	0.14	0.11	1.75	0.81
16	2	3.883E-05	0.022	8.497E-07	0.001	6.440E-16	19.4	13.8	2	2.18	5	0.16	0.36	1.48	0.70
18	3	3.883E-05	0.030	1.160E-06	0.001	1.110E-15	21.4	12.3	2	2.16	7	0.17	0.07	1.76	0.83
19	0	3.398E-05	0.009	2.946E-07	0.000	9.549E-17	0.0	0.0	1	2.16	2	1.81	0.02	0.16	0.85
20	0	3.398E-05	0.016	5.332E-07	0.000	2.592E-16	0.0	0.0	1	2.33	4	0.19	0.05	1.76	0.84
23	0	3.883E-05	0.023	9.062E-07	0.001	6.275E-16	0.0	0.0	1	1.84	6	0.24	0.15	1.60	0.79
24	4	3.883E-05	0.102	3.946E-06	0.003	1.225E-14	8.4	4.2	3	2.14	23	0.21	0.14	1.65	0.80
25	0	4.854E-05	0.000	4.323E-09	0.000	4.215E-19	0.0	0.0	1	1.49	0	0.23	0.00	1.77	0.85
26	0	4.854E-05	0.000	1.014E-09	0.000	8.081E-20	0.0	0.0	1	1.68	0	0.13	0.01	1.86	0.86
27	2	3.883E-05	0.025	9.749E-07	0.001	7.542E-16	16.9	12.0	2	1.72	4	0.18	0.08	1.74	0.82
28	1	3.398E-05	0.017	5.648E-07	0.000	2.529E-16	14.6	14.6	1	1.58	4	0.13	0.10	1.77	0.80
29	4	4.854E-05	0.025	1.215E-06	0.001	1.375E-15	27.2	13.6	2	1.73	5	0.20	0.10	1.71	0.81
30	0	3.883E-05	0.024	9.395E-07	0.001	7.936E-16	0.0	0.0	1	2.14	5	0.24	0.07	1.69	0.83
31	23	1.310E-05	0.891	1.168E-05	0.024	9.537E-14	16.3	3.4	4	1.88	52	1.66	0.01	0.33	0.84
32	0	4.854E-05	0.000	1.841E-09	0.000	1.333E-19	0.0	0.0	1	1.91	0	0.20	0.00	1.80	0.85
34	1	4.854E-05	0.022	1.074E-06	0.001	1.380E-15	7.7	7.7	1	1.66	5	0.13	0.14	1.73	0.80
37	1	3.883E-05	0.017	6.673E-07	0.001	3.915E-16	12.4	12.4	1	2.17	4	0.14	0.06	1.79	0.84
38	1	3.883E-05	0.036	1.404E-06	0.001	1.666E-15	5.9	5.9	1	1.73	9	0.20	0.07	1.74	0.84
39	2	3.883E-05	0.018	6.965E-07	0.001	4.301E-16	23.7	16.8	2	2.70	5	0.23	0.07	1.70	0.83
40	2	3.883E-05	0.021	8.308E-07	0.001	5.325E-16	19.9	14.1	1	1.87	4	0.16	0.14	1.70	0.80
Q=7%	48	8.644E-04		2.961E-05		1.196E-13	13.4	2.0		1.99		0.32	0.08	1.60	0.82
*BH45, Glockner Nappe System - Penninic, meta-basite. UTM zone 33N, 5231852N, 349524E, 1310 masl															
2	2	2.912E-05	0.087	2.545E-06	0.002	4.000E-15	6.5	4.6	2	1.84	0	1.23	0.00	0.77	0.83
4	0	1.941E-05	0.016	3.202E-07	0.003	2.908E-15	0.0	0.0	1	2.07	1	1.32	0.00	0.68	0.83
5	2	2.184E-05	0.032	7.013E-07	0.000	1.180E-16	23.5	16.7	2	1.81	0	1.25	0.00	0.75	0.82
6	1	2.912E-05	0.020	5.836E-07	0.000	1.119E-16	14.2	14.2	1	1.82	0	1.23	0.00	0.76	0.83
7	1	2.427E-05	0.038	9.181E-07	0.001	1.800E-16	9.0	9.0	1	1.95	0	1.31	0.00	0.69	0.82
9	1	1.941E-05	0.022	4.311E-07	0.000	6.416E-17	19.2	19.2	1	1.62	0	1.33	0.00	0.67	0.83
12	0	2.912E-05	0.047	1.366E-06	0.001	5.833E-16	0.0	0.0	1	1.56	0	1.21	0.01	0.78	0.83

Grain	N _s	Ω^2	P _i	P _i Ω _i	One sigma	$\sigma P_i^2 \Omega W_i^2$	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
15	1	3.883E-05	0.035	1.363E-06	0.001	5.096E-16	6.1	6.1	1	1.69	0	1.37	0.00	0.63	0.84
17	1	3.883E-05	0.032	1.245E-06	0.001	9.420E-16	6.6	6.6	1	1.79	0	1.29	0.00	0.71	0.83
18	0	2.912E-05	0.038	1.098E-06	0.001	2.576E-16	0.0	0.0	1	1.38	0	1.19	0.00	0.81	0.83
19	0	2.039E-05	0.057	1.155E-06	0.009	3.165E-14	0.0	0.0	1	1.62	0	1.27	0.01	0.72	0.83
20	1	4.854E-05	0.074	3.570E-06	0.001	2.630E-15	2.3	2.3	1	1.44	0	1.21	0.00	0.79	0.83
21	0	3.883E-05	0.021	8.192E-07	0.000	1.708E-16	0.0	0.0	1	1.35	0	1.29	0.00	0.71	0.83
22	0	2.912E-05	0.006	1.748E-07	0.000	1.412E-17	0.0	0.0	1	1.83	0	1.28	0.00	0.72	0.83
24	1	2.912E-05	0.022	6.271E-07	0.000	1.518E-16	13.2	13.2	1	1.52	0	1.28	0.00	0.71	0.83
Q=84%	11	4.451E-04		1.692E-05		4.429E-14	5.4	1.6		1.69		1.27	0.00	0.73	0.83
BH61, Glockner Nappe System - Penninic, meta-gabbro. UTM zone 33N, 5225311N, 348189E, 1680 masl															
1	1	1.941E-05	0.011	2.110E-07	0.000	1.712E-17	39.1	39.1	1	1.33	2	1.32	0.01	0.67	0.83
2	2	2.912E-05	0.014	3.955E-07	0.000	4.391E-17	41.7	29.5	2	2.04	2	1.27	0.01	0.73	0.76
5	1	2.912E-05	0.008	2.435E-07	0.000	2.111E-17	33.9	33.9	1	2.22	2	1.13	0.00	0.86	0.80
6	2	2.912E-05	0.019	5.594E-07	0.000	1.080E-16	29.5	20.9	2	2.29	2	1.16	0.00	0.83	0.81
8	1	3.883E-05	0.008	3.180E-07	0.000	6.199E-17	26.0	26.0	1	2.24	2	1.18	0.00	0.82	0.81
9	1	2.427E-05	0.008	1.906E-07	0.000	1.373E-17	43.3	43.3	1	2.32	1	1.04	0.00	0.96	0.81
10	1	2.427E-05	0.009	2.080E-07	0.000	1.583E-17	39.7	39.7	1	1.62	2	1.15	0.00	0.84	0.82
11	1	3.883E-05	0.009	3.499E-07	0.000	4.666E-17	23.6	23.6	1	1.97	2	1.05	0.00	0.95	0.80
13	2	3.883E-05	0.019	7.551E-07	0.000	1.355E-16	21.9	15.5	3	2.47	2	1.12	0.00	0.88	0.80
14	0	2.912E-05	0.009	2.670E-07	0.000	4.161E-17	0.0	0.0	1	1.57	1	1.08	0.00	0.92	0.77
15	0	2.912E-05	0.013	3.779E-07	0.002	4.100E-15	0.0	0.0	1	1.94	1	1.11	0.00	0.88	0.79
18	0	4.854E-05	0.008	3.695E-07	0.000	8.002E-17	0.0	0.0	1	1.77	2	1.06	0.00	0.94	0.81
22	0	4.854E-05	0.012	5.775E-07	0.000	1.113E-16	0.0	0.0	1	2.07	3	1.19	0.00	0.81	0.81
23	1	2.912E-05	0.006	1.892E-07	0.000	1.393E-17	43.6	43.6	2	2.28	2	1.12	0.00	0.87	0.80
24	1	2.912E-05	0.010	2.990E-07	0.000	2.767E-17	27.6	27.6	2	1.94	3	1.15	0.01	0.84	0.80
25	1	2.378E-05	0.030	7.175E-07	0.006	1.725E-14	11.5	11.7	2	1.54	2	1.08	0.00	0.92	0.82
26	1	2.427E-05	0.009	2.256E-07	0.002	2.844E-15	36.6	37.6	1	1.63	0	1.12	0.00	0.88	0.77
27	1	2.912E-05	0.005	1.464E-07	0.000	2.102E-17	56.3	56.3	2	2.10	1	1.08	0.00	0.91	0.78
28	1	2.912E-05	0.015	4.450E-07	0.001	1.471E-15	18.6	18.6	2	1.76	2	1.11	0.00	0.89	0.78
29	1	3.883E-05	0.007	2.746E-07	0.000	1.530E-16	30.1	30.1	1	2.25	1	1.18	0.00	0.82	0.79

Grain	N _s	Ω^2	P _i	P _i Ω_i	One sigma	$\sigma P_i^2 \Omega W_i^2$	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
30	0	2.912E-05	0.007	1.931E-07	0.000	3.698E-17	0.0	0.0	1	1.77	2	1.27	0.01	0.73	0.82
31	0	2.039E-05	0.007	1.412E-07	0.000	2.103E-17	0.0	0.0	1	1.64	1	1.15	0.00	0.85	0.79
32	1	3.883E-05	0.011	4.273E-07	0.000	1.731E-16	19.3	19.3	2	1.85	0	1.07	0.00	0.93	0.78
33	0	3.883E-05	0.004	1.566E-07	0.000	4.780E-17	0.0	0.0	1	1.23	1	1.09	0.00	0.91	0.78
34	0	1.747E-05	0.010	1.700E-07	0.000	2.448E-17	0.0	0.0	1	1.55	2	1.16	0.01	0.83	0.80
35	0	3.398E-05	0.004	1.341E-07	0.000	2.259E-16	0.0	0.0	2	1.85	1	1.08	0.00	0.92	0.79
36	0	4.854E-05	0.001	6.243E-08	0.000	7.355E-18	0.0	0.0	1	1.94	0	1.16	0.00	0.84	0.83
37	1	4.854E-05	0.005	2.443E-07	0.001	9.777E-16	33.8	34.0	2	1.58	1	1.11	0.00	0.89	0.79
38	0	2.912E-05	0.007	2.119E-07	0.000	4.195E-17	0.0	0.0	1	1.73	2	1.12	0.00	0.88	0.79
39	1	2.378E-05	0.012	2.919E-07	0.000	6.492E-17	28.3	28.3	1	1.45	1	1.17	0.00	0.83	0.81
40	1	2.912E-05	0.011	3.145E-07	0.000	7.093E-17	26.3	26.3	1	2.05	1	1.13	0.00	0.86	0.79
41	1	3.883E-05	0.016	6.234E-07	0.000	3.225E-16	13.3	13.3	2	2.19	0	1.13	0.00	0.87	0.81
42	0	1.553E-05	0.009	1.391E-07	0.013	3.819E-14	0.0	0.0	2	1.74	0	1.11	0.00	0.88	0.82
43	0	1.747E-05	0.002	3.427E-08	0.000	9.710E-19	0.0	0.0	2	1.80	0	1.15	0.00	0.85	0.79
44	1	1.941E-05	0.015	2.917E-07	0.001	4.181E-16	28.3	28.4	1	1.90	2	1.15	0.00	0.85	0.79
45	0	2.912E-05	0.004	1.166E-07	0.001	6.788E-16	0.0	0.0	1	2.16	1	1.18	0.00	0.82	0.81
46	2	3.883E-05	0.027	1.049E-06	0.001	2.592E-15	15.7	11.2	1	1.85	1	1.08	0.01	0.91	0.81
47	0	3.883E-05	0.010	3.882E-07	0.000	1.333E-16	0.0	0.0	1	1.87	2	1.16	0.01	0.84	0.79
48	0	3.398E-05	0.011	3.700E-07	0.000	1.345E-16	0.0	0.0	1	1.54	3	1.13	0.00	0.87	0.80
49	0	3.883E-05	0.010	3.769E-07	0.000	1.505E-16	0.0	0.0	1	1.83	2	1.06	0.00	0.94	0.78
50	1	2.427E-05	0.010	2.392E-07	0.000	4.458E-17	34.5	34.5	1	2.06	1	1.17	0.00	0.83	0.79
51	0	2.912E-05	0.016	4.554E-07	0.001	3.135E-16	0.0	0.0	1	1.72	4	1.19	0.00	0.81	0.78
52	0	2.427E-05	0.004	9.771E-08	0.000	8.478E-18	0.0	0.0	1	1.54	1	1.11	0.00	0.89	0.79
53	0	2.039E-05	0.009	1.829E-07	0.002	1.232E-15	0.0	0.0	1	2.10	2	1.14	0.00	0.86	0.79
54	1	2.427E-05	0.014	3.294E-07	0.000	7.834E-17	25.1	25.1	1	2.07	2	1.13	0.00	0.87	0.82
55	1	3.883E-05	0.007	2.910E-07	0.005	3.373E-14	28.4	33.6	2	2.00	1	1.08	0.00	0.92	0.78
56	0	3.398E-05	0.007	2.546E-07	0.000	6.057E-17	0.0	0.0	1	1.60	2	1.11	0.00	0.89	0.80
57	0	3.883E-05	0.004	1.551E-07	0.000	3.187E-17	0.0	0.0	1	1.81	1	1.15	0.00	0.85	0.80
58	0	3.883E-05	0.008	3.286E-07	0.000	1.228E-16	0.0	0.0	1	1.62	2	1.14	0.00	0.86	0.80
59	0	3.883E-05	0.007	2.912E-07	0.000	1.110E-16	0.0	0.0	1	1.73	2	1.05	0.01	0.94	0.78

Grain	N _s	Ω^2	P _i	P _i Ω _i	One sigma	$\sigma P_i^2 \Omega W_i^2$	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
60	0	1.456E-05	0.009	1.330E-07	0.000	2.048E-17	0.0	0.0	1	2.08	2	1.17	0.00	0.83	0.83
61	0	3.398E-05	0.005	1.807E-07	0.000	6.224E-17	0.0	0.0	1	2.00	1	1.08	0.00	0.91	0.82
62	0	2.912E-05	0.005	1.599E-07	0.000	3.410E-17	0.0	0.0	1	1.55	1	1.06	0.00	0.94	0.78
63	1	3.883E-05	0.011	4.358E-07	0.000	1.617E-16	19.0	19.0	1	1.82	1	1.13	0.00	0.87	0.83
64	1	1.941E-05	0.022	4.329E-07	0.001	1.312E-16	19.1	19.1	2	1.89	2	1.09	0.00	0.91	0.80
Q=14%	32	1.706E-03		1.682E-05		1.070E-13	15.7	2.8		1.86		1.13	0.00	0.87	0.80

BH51, Venediger Nappe System - Sub-Penninic, ortho-gneiss. UTM zone 33N, 5219506N, 348524E, 1460 masl

1	2	3.883E-05	0.052	2.012E-06	0.001	9.073E-16	8.2	5.8	2	2.03	11	1.74	0.00	0.26	0.85
2	3	4.854E-05	0.040	1.925E-06	0.001	1.019E-15	12.9	7.4	3	2.20	8	1.81	0.00	0.19	0.85
3	3	4.854E-05	0.079	3.853E-06	0.001	3.648E-15	6.4	3.7	2	1.71	17	1.69	0.00	0.31	0.85
4	0	4.854E-05	0.140	6.789E-06	0.003	1.732E-14	0.0	0.0	1	1.86	22	1.67	0.00	0.33	0.83
5	3	4.854E-05	0.035	1.708E-06	0.001	1.116E-15	14.5	8.4	2	1.91	7	1.76	0.00	0.24	0.85
7	1	4.854E-05	0.060	2.927E-06	0.001	3.164E-15	2.8	2.8	2	1.73	13	1.80	0.00	0.20	0.85
8	6	4.854E-05	0.060	2.903E-06	0.001	4.315E-15	17.1	7.0	4	1.85	12	1.78	0.00	0.22	0.84
9	3	4.854E-05	0.049	2.399E-06	0.001	3.241E-15	10.3	6.0	3	2.17	11	1.84	0.00	0.16	0.85
10	2	3.883E-05	0.062	2.406E-06	0.001	1.594E-15	6.9	4.9	2	1.96	13	1.76	0.00	0.23	0.84
11	2	3.883E-05	0.061	2.380E-06	0.001	1.783E-15	6.9	4.9	3	1.87	12	1.73	0.01	0.27	0.85
12	2	4.854E-05	0.069	3.338E-06	0.001	2.644E-15	5.0	3.5	1	1.88	14	1.84	0.00	0.16	0.85
14	3	4.854E-05	0.058	2.828E-06	0.001	3.806E-15	8.8	5.1	3	1.99	13	1.64	0.00	0.36	0.84
15	2	3.883E-05	0.078	3.042E-06	0.002	6.471E-15	5.4	3.8	3	1.66	15	1.74	0.00	0.26	0.85
17	6	4.854E-05	0.080	3.898E-06	0.001	4.137E-15	12.7	5.2	4	2.05	17	1.68	0.00	0.31	0.84
18	3	4.854E-05	0.071	3.459E-06	0.002	1.006E-14	7.2	4.1	2	2.07	16	1.76	0.01	0.23	0.84
19	2	3.106E-05	0.056	1.733E-06	0.001	1.149E-15	9.5	6.8	2	1.92	12	1.74	0.00	0.25	0.82
20	3	4.854E-05	0.074	3.587E-06	0.002	5.971E-15	6.9	4.0	4	1.96	16	1.76	0.00	0.24	0.85
21	2	3.883E-05	0.061	2.375E-06	0.002	4.954E-15	7.0	4.9	1	1.82	13	1.71	0.00	0.29	0.85
22	7	4.854E-05	0.113	5.466E-06	0.002	1.331E-14	10.6	4.0	3	1.57	23	1.69	0.00	0.31	0.85
23	4	4.854E-05	0.058	2.805E-06	0.001	4.463E-15	11.8	5.9	2	1.89	11	1.70	0.00	0.30	0.84
24	2	4.854E-05	0.074	3.570E-06	0.001	3.753E-15	4.6	3.3	2	2.19	16	1.93	0.00	0.07	0.85
25	3	3.883E-05	0.045	1.767E-06	0.001	2.031E-15	14.0	8.1	3	2.03	11	1.71	0.00	0.29	0.85
26	2	4.854E-05	0.039	1.881E-06	0.001	2.996E-15	8.8	6.2	2	1.90	7	1.67	0.00	0.33	0.85
27	2	3.883E-05	0.052	2.038E-06	0.001	1.726E-15	8.1	5.7	3	1.89	11	1.73	0.00	0.26	0.85
28	1	4.854E-05	0.043	2.072E-06	0.001	1.134E-15	4.0	4.0	1	1.86	7	1.74	0.00	0.26	0.85

Grain	N _s	Ω^2	P _i	P _i Ω _i	One sigma	$\sigma P_i^2 \Omega W_i^2$	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
29	3	4.854E-05	0.068	3.282E-06	0.001	4.314E-15	7.6	4.4	2	1.48	14	1.81	0.00	0.19	0.84
30	1	4.368E-05	0.073	3.193E-06	0.001	2.409E-15	2.6	2.6	3	1.61	14	1.71	0.00	0.29	0.85
32	2	4.854E-05	0.032	1.554E-06	0.001	9.369E-16	10.6	7.5	3	1.98	7	1.68	0.00	0.32	0.84
33	1	4.854E-05	0.041	2.009E-06	0.002	5.846E-15	4.1	4.1	1	1.61	14	1.76	0.00	0.24	0.85
34	5	4.854E-05	0.076	3.708E-06	0.001	4.047E-15	11.1	5.0	3	1.82	16	1.83	0.00	0.17	0.85
35	1	2.427E-05	0.054	1.302E-06	0.001	6.796E-16	6.4	6.4	1	2.03	11	1.80	0.00	0.20	0.85
36	1	4.854E-05	0.051	2.468E-06	0.001	3.054E-15	3.4	3.4	1	1.48	15	1.72	0.00	0.27	0.84
37	1	4.854E-05	0.041	2.009E-06	0.001	1.237E-15	4.1	4.1	1	1.41	13	1.51	0.02	0.48	0.83
38	1	2.912E-05	0.029	8.454E-07	0.000	1.804E-16	9.8	9.8	1	1.92	6	1.80	0.00	0.20	0.85
39	4	4.854E-05	0.071	3.448E-06	0.001	3.907E-15	9.6	4.8	4	1.80	17	1.64	0.00	0.36	0.84
Q=17%	89	1.565E-03		9.698E-05		1.333E-13	7.6	0.8		1.70		1.74	0.00	0.26	0.85

BH74, Venediger Nappe System - Sub-Penninic, para-gneiss. UTM zone 33N, 5214805N, 346069E, 1720 masl

1	5	4.854E-05	0.084	4.080E-06	0.001	4.097E-15	10.1	4.5	4	1.83	18	1.45	0.00	0.55	0.82
2	6	4.854E-05	0.055	2.682E-06	0.001	3.422E-15	18.5	7.6	3	1.68	11	1.45	0.00	0.55	0.83
3	2	3.883E-05	0.108	4.211E-06	0.002	3.733E-15	3.9	2.8	3	1.67	23	1.49	0.00	0.51	0.83
4	6	4.854E-05	0.085	4.102E-06	0.002	6.105E-15	12.1	4.9	4	1.95	18	1.49	0.00	0.51	0.82
5	5	3.883E-05	0.081	3.162E-06	0.002	4.932E-15	13.1	5.9	4	1.76	18	1.46	0.00	0.54	0.83
6	6	4.854E-05	0.086	4.170E-06	0.002	1.109E-14	11.9	4.9	4	1.73	18	1.54	0.00	0.46	0.83
7	6	4.854E-05	0.096	4.648E-06	0.002	6.714E-15	10.7	4.4	4	1.85	21	1.53	0.00	0.47	0.83
8	5	4.854E-05	0.085	4.122E-06	0.001	4.812E-15	10.0	4.5	3	1.89	19	1.52	0.00	0.47	0.83
9	5	3.883E-05	0.092	3.590E-06	0.001	3.339E-15	11.5	5.2	3	1.78	20	1.56	0.00	0.43	0.83
10	6	4.854E-05	0.082	3.970E-06	0.002	9.743E-15	12.5	5.1	4	1.88	18	1.44	0.00	0.55	0.83
11	5	4.854E-05	0.093	4.519E-06	0.003	2.369E-14	9.1	4.1	3	1.91	17	1.49	0.00	0.51	0.83
13	3	4.854E-05	0.093	4.536E-06	0.002	5.904E-15	5.5	3.2	3	1.64	21	1.54	0.00	0.45	0.84
14	1	3.883E-05	0.085	3.305E-06	0.002	4.729E-15	2.5	2.5	1	1.51	18	1.43	0.00	0.57	0.82
15	6	4.854E-05	0.072	3.483E-06	0.001	3.331E-15	14.2	5.8	4	2.02	15	1.51	0.00	0.49	0.83
16	4	4.854E-05	0.095	4.609E-06	0.002	5.334E-15	7.2	3.6	4	2.00	20	1.56	0.00	0.43	0.82
17	4	4.854E-05	0.090	4.361E-06	0.002	6.949E-15	7.6	3.8	4	1.80	20	1.58	0.00	0.42	0.84
18	3	3.883E-05	0.087	3.390E-06	0.002	4.432E-15	7.3	4.2	3	1.67	19	1.50	0.00	0.50	0.82
19	3	4.854E-05	0.089	4.302E-06	0.001	4.694E-15	5.8	3.3	3	1.69	19	1.47	0.00	0.53	0.83
20	5	4.854E-05	0.088	4.293E-06	0.001	4.847E-15	9.6	4.3	4	2.01	19	1.42	0.00	0.58	0.83
21	15	4.854E-05	0.234	1.134E-05	0.004	3.657E-14	10.9	2.8	4	1.95	51	1.59	0.00	0.41	0.84
22	4	4.854E-05	0.202	9.818E-06	0.004	4.381E-14	3.4	1.7	3	1.99	44	1.41	0.00	0.58	0.82

Grain	N _s	$\Omega^{\prime}$	P _i	P _i Ω _i	One sigma	$\sigma P_i^2 \Omega W_i^2$	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
23	4	4.854E-05	0.085	4.123E-06	0.002	1.008E-14	8.0	4.0	3	1.73	18	1.48	0.00	0.52	0.83
26	5	4.854E-05	0.090	4.372E-06	0.002	7.302E-15	9.5	4.2	3	2.02	20	1.51	0.00	0.49	0.82
27	5	4.854E-05	0.084	4.058E-06	0.001	4.679E-15	10.2	4.6	4	1.85	18	1.46	0.00	0.54	0.82
28	4	3.883E-05	0.083	3.209E-06	0.001	3.257E-15	10.3	5.2	3	1.92	18	1.56	0.00	0.44	0.84
29	3	4.854E-05	0.089	4.323E-06	0.003	1.497E-14	5.7	3.3	3	1.62	19	1.45	0.00	0.54	0.82
30	8	4.854E-05	0.105	5.096E-06	0.003	2.508E-14	13.0	4.6	4	1.62	22	1.49	0.00	0.51	0.84
31	4	3.883E-05	0.193	7.484E-06	0.003	9.692E-15	4.4	2.2	4	1.66	4	1.41	0.00	0.59	0.84
32	2	3.883E-05	0.078	3.043E-06	0.001	2.416E-15	5.4	3.8	4	1.73	11	1.57	0.00	0.42	0.84
33	8	4.854E-05	0.087	4.222E-06	0.001	4.136E-15	15.7	5.5	4	1.95	19	1.46	0.00	0.54	0.82
34	7	4.854E-05	0.089	4.311E-06	0.001	4.317E-15	13.4	5.1	2	2.14	19	1.59	0.00	0.40	0.84
35	6	4.854E-05	0.099	4.817E-06	0.002	6.402E-15	10.3	4.2	4	1.88	24	1.48	0.00	0.52	0.81
36	3	4.854E-05	0.099	4.786E-06	0.002	5.864E-15	5.2	3.0	4	1.67	23	1.51	0.00	0.48	0.83
38	7	3.883E-05	0.100	3.894E-06	0.001	3.391E-15	14.9	5.6	3	1.94	22	1.54	0.00	0.45	0.84
39	4	4.854E-05	0.077	3.747E-06	0.001	3.500E-15	8.8	4.4	2	1.72	17	1.46	0.00	0.54	0.84
40	7	4.854E-05	0.077	3.760E-06	0.001	4.154E-15	15.4	5.8	4	1.90	17	1.48	0.00	0.52	0.84
Q=28%	182	1.660E-03		1.619E-04		3.115E-13	9.3	0.7		1.82		1.50	0.00	0.50	0.83

BH76, Venediger Nappe System - Sub-Penninic, ortho-gneiss. UTM zone 33N, 5213968N, 345556E, 2180 masl

1	1	4.854E-05	0.010	5.034E-07	0.001	1.618E-15	16.4	16.5	4	1.95	23	1.06	0.01	0.94	0.82
2	2	4.368E-05	0.028	1.206E-06	0.000	2.575E-16	13.7	9.7	3	1.77	1	1.05	0.00	0.95	0.81
3	2	3.883E-05	0.048	1.877E-06	0.001	6.051E-16	8.8	6.2	2	1.84	0	1.09	0.01	0.90	0.81
4	1	4.854E-05	0.007	3.265E-07	0.000	1.938E-17	25.3	25.3	1	1.71	0	1.28	0.01	0.71	0.82
5	1	3.883E-05	0.008	3.295E-07	0.000	6.569E-17	25.1	25.1	1	1.66	2	1.09	0.01	0.91	0.82
7	4	4.854E-05	0.057	2.785E-06	0.001	2.779E-15	11.9	5.9	3	2.15	13	1.12	0.02	0.86	0.82
8	0	4.854E-05	0.004	1.851E-07	0.000	2.880E-17	0.0	0.0	1	1.40	1	1.19	0.00	0.80	0.82
9	4	4.854E-05	0.052	2.525E-06	0.001	1.739E-15	13.1	6.6	4	1.94	12	1.20	0.01	0.79	0.82
10	2	3.883E-05	0.050	1.928E-06	0.001	2.351E-15	8.6	6.1	2	2.20	8	1.15	0.02	0.84	0.82
11	0	3.883E-05	0.045	1.762E-06	0.001	8.476E-16	0.0	0.0	1	2.16	10	1.13	0.02	0.85	0.81
12	0	4.854E-05	0.003	1.282E-07	0.000	1.993E-17	0.0	0.0	1	1.81	1	1.08	0.01	0.91	0.82
13	5	4.854E-05	0.111	5.401E-06	0.002	6.610E-15	7.7	3.4	4	1.96	25	1.10	0.01	0.89	0.82
14	1	2.427E-05	0.033	8.087E-07	0.000	1.173E-16	10.2	10.2	1	1.94	1	1.22	0.02	0.76	0.81
15	0	2.912E-05	0.025	7.267E-07	0.001	4.193E-16	0.0	0.0	1	1.60	5	1.08	0.01	0.90	0.82
16	0	2.427E-05	0.007	1.627E-07	0.000	4.810E-18	0.0	0.0	1	1.93	5	1.13	0.02	0.85	0.82
17	1	3.106E-05	0.023	7.202E-07	0.000	9.263E-17	11.5	11.5	1	1.68	1	1.08	0.01	0.91	0.81

Grain	N _s	$\Omega^{\prime}$	P _i	P _i Ω _i	One sigma	$\sigma P_i^2 \Omega W_i^2$	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
18	0	2.912E-05	0.000	1.301E-08	0.000	1.381E-18	0.0	0.0	1	2.21	0	1.08	0.02	0.90	0.81
19	0	2.427E-05	0.001	1.806E-08	0.000	7.184E-19	0.0	0.0	1	1.73	0	1.40	0.01	0.58	0.83
20	1	2.912E-05	0.015	4.410E-07	0.000	3.935E-17	18.7	18.7	1	1.82	0	1.08	0.02	0.90	0.82
21	2	1.747E-05	0.076	1.334E-06	0.001	3.859E-16	12.4	8.8	2	1.57	5	1.10	0.01	0.89	0.82
22	0	3.883E-05	0.003	1.338E-07	0.000	1.580E-17	0.0	0.0	1	1.62	1	1.04	0.01	0.95	0.81
23	3	4.854E-05	0.030	1.438E-06	0.000	3.601E-16	17.2	10.0	1	1.63	0	1.09	0.01	0.90	0.80
24	0	3.883E-05	0.001	5.502E-08	0.000	2.714E-18	0.0	0.0	1	1.34	0	1.54	0.03	0.43	0.84
25	0	2.912E-05	0.053	1.542E-06	0.001	1.058E-15	0.0	0.0	1	1.80	11	1.17	0.01	0.82	0.80
27	2	3.883E-05	0.046	1.805E-06	0.001	1.276E-15	9.2	6.5	1	1.62	12	1.22	0.03	0.76	0.82
28	11	4.368E-05	0.142	6.197E-06	0.006	7.746E-14	14.7	4.5	3	1.85	91	1.24	0.00	0.76	0.83
29	0	4.854E-05	0.065	3.168E-06	0.001	2.494E-15	0.0	0.0	1	1.89	15	1.15	0.02	0.83	0.81
30	3	4.854E-05	0.070	3.412E-06	0.001	2.888E-15	7.3	4.2	2	1.92	14	1.03	0.02	0.95	0.80
Q=99%	46	1.082E-03		4.093E-05		1.036E-13	9.3	1.4		1.81		1.15	0.01	0.84	0.82
BH65,Venediger Nappe System - Sub-Penninic, ortho-gneiss. UTM zone 33N, 5213130N, 344910E, 3080 masl															
1	4	2.912E-05	0.085	2.466E-06	0.002	2.554E-15	13.4	6.7	3	1.79	18	1.52	0.00	0.48	0.84
2	2	2.427E-05	0.092	2.222E-06	0.002	2.075E-15	7.4	5.3	1	2.06	21	1.50	0.00	0.50	0.82
3	3	4.854E-05	0.095	4.587E-06	0.001	5.002E-15	5.4	3.1	3	1.95	20	1.57	0.00	0.43	0.84
4	4	4.854E-05	0.087	4.206E-06	0.001	4.386E-15	7.9	3.9	2	1.73	19	1.65	0.00	0.35	0.84
5	7	4.854E-05	0.093	4.534E-06	0.002	6.742E-15	12.8	4.8	3	2.14	20	1.56	0.00	0.44	0.83
6	4	4.368E-05	0.118	5.155E-06	0.002	6.141E-15	6.4	3.2	4	1.85	25	1.56	0.01	0.44	0.82
7	5	4.368E-05	0.091	3.985E-06	0.001	3.785E-15	10.4	4.6	4	1.72	19	1.68	0.00	0.31	0.82
8	3	2.427E-05	0.087	2.100E-06	0.002	1.342E-15	11.8	6.8	3	1.79	20	1.58	0.01	0.41	0.82
9	6	4.854E-05	0.080	3.879E-06	0.002	6.789E-15	12.8	5.2	4	1.68	17	1.46	0.00	0.54	0.80
10	2	3.883E-05	0.097	3.753E-06	0.002	5.935E-15	4.4	3.1	2	1.88	20	1.57	0.00	0.43	0.82
11	4	4.854E-05	0.097	4.716E-06	0.002	7.108E-15	7.0	3.5	3	1.73	21	1.52	0.00	0.47	0.83
12	1	4.854E-05	0.025	1.220E-06	0.001	4.842E-15	6.8	6.8	1	1.98	18	1.58	0.00	0.42	0.84
13	3	3.883E-05	0.149	5.780E-06	0.002	8.182E-15	4.3	2.5	3	1.79	33	1.58	0.01	0.41	0.83
14	1	3.883E-05	0.028	1.083E-06	0.000	2.430E-16	7.6	7.6	2	1.77	1	1.60	0.00	0.40	0.83
15	4	4.854E-05	0.245	1.188E-05	0.004	3.893E-14	2.8	1.4	3	1.97	56	1.50	0.00	0.50	0.83
16	2	4.854E-05	0.082	3.977E-06	0.002	7.005E-15	4.2	2.9	2	1.77	41	1.57	0.00	0.43	0.82
17	3	4.368E-05	0.054	2.379E-06	0.001	1.963E-15	10.4	6.0	2	1.52	11	1.56	0.00	0.43	0.84
18	3	4.854E-05	0.071	3.440E-06	0.001	2.489E-15	7.2	4.2	3	2.18	16	1.49	0.00	0.51	0.84
19	2	3.883E-05	0.102	3.944E-06	0.002	5.005E-15	4.2	3.0	3	1.93	22	1.53	0.00	0.47	0.83

Grain	N _s	$\Omega^{\prime}$	P _i	P _i Ω _i	One sigma	$\sigma P_i^2 \Omega W_i^2$	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
20	3	3.883E-05	0.089	3.474E-06	0.002	4.193E-15	7.1	4.1	3	1.66	19	1.50	0.00	0.49	0.83
21	3	4.854E-05	0.067	3.234E-06	0.002	6.073E-15	7.7	4.4	3	1.94	14	1.50	0.00	0.50	0.84
22	4	2.184E-05	0.098	2.144E-06	0.003	4.988E-15	15.4	7.7	4	1.92	20	1.67	0.00	0.33	0.84
23	3	3.398E-05	0.085	2.905E-06	0.002	3.524E-15	8.5	4.9	3	1.75	19	1.50	0.00	0.50	0.81
25	2	2.912E-05	0.106	3.085E-06	0.002	4.359E-15	5.4	3.8	2	1.70	23	1.74	0.01	0.25	0.84
26	9	4.854E-05	0.118	5.737E-06	0.002	1.345E-14	13.0	4.3	4	1.57	25	1.60	0.00	0.40	0.84
27	1	2.912E-05	0.099	2.876E-06	0.002	3.199E-15	2.9	2.9	1	1.71	23	1.58	0.00	0.41	0.84
28	4	3.106E-05	0.092	2.844E-06	0.001	1.806E-15	11.6	5.8	4	1.79	20	1.57	0.00	0.42	0.84
29	3	4.854E-05	0.094	4.578E-06	0.002	7.751E-15	5.4	3.1	2	1.85	20	1.62	0.01	0.38	0.83
30	2	3.883E-05	0.023	8.811E-07	0.000	2.314E-16	18.8	13.3	2	1.46	6	1.44	0.00	0.56	0.84
31	5	3.883E-05	0.084	3.255E-06	0.008	9.686E-14	12.7	5.8	3	2.02	117	1.48	0.00	0.52	0.83
32	9	4.854E-05	0.164	7.953E-06	0.003	1.667E-14	9.4	3.1	4	1.98	38	1.51	0.00	0.49	0.83
33	5	4.854E-05	0.129	6.241E-06	0.003	1.483E-14	6.6	3.0	3	1.86	27	1.56	0.00	0.43	0.84
34	4	4.854E-05	0.092	4.456E-06	0.002	6.774E-15	7.4	3.7	4	1.63	20	1.58	0.01	0.42	0.80
35	12	4.854E-05	0.090	4.369E-06	0.002	6.056E-15	22.7	6.6	4	2.07	20	1.47	0.00	0.52	0.83
36	8	4.854E-05	0.104	5.056E-06	0.003	2.007E-14	13.1	4.6	4	1.78	23	1.46	0.00	0.53	0.80
37	10	4.854E-05	0.103	5.001E-06	0.002	7.746E-15	16.5	5.2	4	2.05	23	1.59	0.00	0.41	0.83
38	1	4.854E-05	0.015	7.115E-07	0.000	1.027E-16	11.6	11.6	1	1.88	1	1.60	0.00	0.40	0.85
39	2	3.883E-05	0.080	3.094E-06	0.001	2.682E-15	5.3	3.8	2	1.74	19	1.44	0.00	0.56	0.82
40	3	3.883E-05	0.082	3.190E-06	0.001	2.955E-15	7.8	4.5	4	2.08	18	1.58	0.00	0.41	0.84
Q=40%	156	1.625E-03		1.504E-04		3.448E-13	8.6	0.7		1.84		1.55	0.00	0.44	0.83

BH42,Venediger Nappe System - Sub-Penninic, ortho-gneiss. UTM zone 33N, 5212924N, 345606E, 2680 masl

1	2	4.854E-05	0.038	1.865E-06	0.001	7.429E-16	8.9	6.3	2	1.84	8	1.52	0.00	0.48	0.83
2	1	4.854E-05	0.023	1.120E-06	0.000	3.579E-16	7.4	7.4	3	1.89	5	1.48	0.00	0.52	0.84
3	1	2.427E-05	0.023	5.473E-07	0.000	1.034E-16	15.1	15.1	2	2.08	5	1.49	0.00	0.51	0.84
4	4	4.854E-05	0.116	5.641E-06	0.002	1.284E-14	5.9	2.9	3	1.77	25	1.45	0.00	0.55	0.84
5	1	3.883E-05	0.077	2.977E-06	0.001	2.687E-15	2.8	2.8	3	1.75	15	1.66	0.00	0.34	0.84
19	2	4.854E-05	0.012	5.768E-07	0.000	1.284E-16	28.6	20.3	2	1.88	2	1.53	0.00	0.47	0.84
20	6	3.883E-05	0.066	2.576E-06	0.001	1.892E-15	19.2	7.9	4	1.57	14	1.61	0.00	0.39	0.83
21	4	2.427E-05	0.087	2.113E-06	0.001	1.065E-15	15.6	7.8	4	1.90	18	1.55	0.00	0.44	0.83
22	7	4.854E-05	0.108	5.223E-06	0.003	2.047E-14	11.1	4.2	4	1.98	28	1.49	0.00	0.50	0.84
23	6	4.854E-05	0.097	4.694E-06	0.002	6.284E-15	10.6	4.3	4	2.07	1	1.45	0.00	0.54	0.83
24	6	4.854E-05	0.087	4.205E-06	0.002	6.994E-15	11.8	4.8	4	1.83	19	1.40	0.00	0.59	0.81

Grain	N _s	Ω^z	P _i	P _i Ω _i	One sigma	$\sigma P_i^2 \Omega W_i^2$	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
25	1	2.427E-05	0.074	1.806E-06	0.001	6.733E-16	4.6	4.6	1	1.87	16	1.48	0.00	0.51	0.84
26	4	4.854E-05	0.071	3.456E-06	0.001	2.823E-15	9.6	4.8	4	2.03	13	1.56	0.00	0.44	0.84
27	1	3.106E-05	0.038	1.184E-06	0.001	2.994E-16	7.0	7.0	1	1.60	16	1.48	0.00	0.51	0.82
28	3	3.398E-05	0.057	1.945E-06	0.009	8.981E-14	12.7	7.6	4	1.85	3	1.54	0.00	0.46	0.84
29	1	3.883E-05	0.024	9.203E-07	0.000	2.874E-16	9.0	9.0	1	1.92	5	1.48	0.00	0.52	0.84
30	9	4.854E-05	0.062	3.022E-06	0.001	4.088E-15	24.6	8.2	4	2.00	12	1.49	0.00	0.51	0.84
31	2	4.854E-05	0.076	3.699E-06	0.002	6.951E-15	4.5	3.2	2	2.35	17	1.48	0.00	0.52	0.84
32	1	4.854E-05	0.032	1.569E-06	0.001	1.498E-15	5.3	5.3	1	1.85	19	1.53	0.00	0.46	0.83
33	1	3.883E-05	0.035	1.374E-06	0.001	5.179E-16	6.0	6.0	1	2.30	7	1.58	0.00	0.41	0.84
34	1	2.912E-05	0.091	2.638E-06	0.001	1.717E-15	3.1	3.1	1	1.96	18	1.59	0.00	0.41	0.84
35	3	4.854E-05	0.032	1.566E-06	0.000	5.881E-16	15.8	9.1	2	2.14	7	1.43	0.00	0.56	0.83
36	0	4.854E-05	0.047	2.290E-06	0.001	1.641E-15	0.0	0.0	1	1.54	10	1.50	0.00	0.50	0.83
37	3	4.854E-05	0.096	4.652E-06	0.001	5.017E-15	5.3	3.1	3	2.04	22	1.48	0.00	0.52	0.84
38	2	4.854E-05	0.020	9.767E-07	0.000	3.132E-16	16.9	12.0	1	1.89	4	1.51	0.00	0.49	0.84
39	1	4.854E-05	0.034	1.636E-06	0.001	7.632E-16	5.1	5.1	2	2.23	7	1.43	0.00	0.57	0.83
40	2	3.883E-05	0.088	3.401E-06	0.002	7.141E-15	4.9	3.4	2	1.86	17	1.44	0.00	0.56	0.82
Q=26%	75	1.138E-03		6.767E-05		1.777E-13	9.2	1.1		1.93	12.333	1.50	0.00	0.49	0.83

JS03, Venediger Nappe System - Sub-Penninic, meta-gabbro. UTM zone 33N, 5206449N, 343118E, 1580 masl

1	5	4.854E-05	0.072	3.491E-06	0.002	9.998E-15	11.8	5.3	3	1.83	18	1.78	0.02	0.21	0.85
2	6	3.883E-05	0.075	2.922E-06	0.002	8.029E-15	17.0	7.0	3	1.74	19	1.66	0.00	0.33	0.85
3	3	4.854E-05	0.068	3.292E-06	0.002	1.043E-14	7.5	4.4	3	1.80	19	1.66	0.00	0.34	0.82
5	3	4.368E-05	0.094	4.091E-06	0.003	1.291E-14	6.1	3.5	2	1.52	23	1.81	0.00	0.18	0.84
6	0	4.854E-05	0.022	1.081E-06	0.001	9.795E-16	0.0	0.0	2	1.64	5	1.81	0.00	0.19	0.85
7	1	3.883E-05	0.088	3.422E-06	0.003	1.059E-14	2.4	2.4	1	1.86	24	1.80	0.00	0.20	0.85
8	2	4.854E-05	0.052	2.500E-06	0.002	5.493E-15	6.6	4.7	2	1.70	15	1.79	0.00	0.20	0.84
9	3	4.854E-05	0.088	4.265E-06	0.003	1.765E-14	5.8	3.4	2	1.55	20	1.75	0.00	0.25	0.85
11	2	2.184E-05	0.091	1.996E-06	0.003	3.608E-15	8.3	5.9	2	1.59	23	2.00	0.01	0.00	0.86
12	10	4.854E-05	0.092	4.485E-06	0.003	1.581E-14	18.4	5.9	4	1.67	23	1.92	0.03	0.05	0.84
13	4	3.398E-05	0.054	1.846E-06	0.002	3.560E-15	17.9	9.0	3	1.81	15	1.92	0.03	0.05	0.80
14	2	2.912E-05	0.077	2.252E-06	0.002	4.213E-15	7.3	5.2	2	1.58	18	1.90	0.05	0.05	0.85
15	9	3.883E-05	0.179	6.966E-06	0.005	4.072E-14	10.7	3.6	4	2.10	45	1.96	0.04	0.00	0.84
16	1	3.398E-05	0.068	2.319E-06	0.002	4.268E-15	3.6	3.6	2	1.77	16	1.91	0.03	0.06	0.85
17	1	2.039E-05	0.074	1.513E-06	0.002	2.038E-15	5.5	5.5	1	1.77	18	1.91	0.01	0.09	0.85

Grain	N _s	Ω ²	P _i	P _i Ω _i	One sigma	σP _i ² ΩW _i ²	FT age	One sigma	Etch	D _{par}	U	F	Cl	OH	r _{mr0}
No.		(cm ²)	(dmnls)		(dmnls)		(Ma)	(Ma)	Figs.	(μm)	(ppm)	(apfu)	(apfu)	(apfu)	
18	4	3.883E-05	0.042	1.622E-06	0.001	2.841E-15	20.4	10.2	4	1.92	11	1.76	0.00	0.24	0.85
19	4	3.398E-05	0.073	2.483E-06	0.002	5.081E-15	13.3	6.7	4	1.78	19	1.83	0.01	0.16	0.85
20	1	2.912E-05	0.092	2.683E-06	0.003	5.906E-15	3.1	3.1	1	1.68	22	1.75	0.00	0.24	0.85
21	5	2.912E-05	0.049	1.434E-06	0.001	1.755E-15	28.8	12.9	4	1.63	12	1.83	0.01	0.17	0.85
22	2	1.941E-05	0.017	3.360E-07	0.001	1.526E-16	49.1	34.7	2	1.73	4	1.92	0.01	0.07	0.85
24	1	2.912E-05	0.012	3.361E-07	0.000	1.339E-16	24.6	24.6	1	1.63	1	1.73	0.00	0.26	0.85
25	3	3.106E-05	0.074	2.283E-06	0.002	4.278E-15	10.9	6.3	3	1.68	20	1.75	0.00	0.25	0.85
26	5	4.368E-05	0.072	3.148E-06	0.002	1.009E-14	13.1	5.9	4	1.81	18	1.77	0.01	0.22	0.85
27	5	4.854E-05	0.086	4.170E-06	0.003	1.473E-14	9.9	4.4	3	1.58	21	1.87	0.00	0.13	0.85
28	5	4.854E-05	0.067	3.236E-06	0.002	1.014E-14	12.8	5.7	3	1.87	18	1.77	0.01	0.22	0.84
29	3	4.854E-05	0.074	3.580E-06	0.002	1.048E-14	6.9	4.0	2	1.59	18	1.87	0.00	0.13	0.84
30	6	3.883E-05	0.080	3.099E-06	0.002	7.818E-15	16.0	6.6	4	1.43	22	1.90	0.00	0.09	0.85
31	5	4.854E-05	0.053	2.562E-06	0.002	1.061E-14	16.1	7.2	4	1.36	15	1.74	0.02	0.24	0.84
32	1	4.854E-05	0.077	3.732E-06	0.002	1.291E-14	2.2	2.2	1	1.87	20	1.72	0.03	0.25	0.84
33	2	3.883E-05	0.051	1.977E-06	0.002	3.534E-15	8.4	5.9	3	1.53	14	1.88	0.01	0.11	0.85
35	0	4.368E-05	0.000	1.894E-08	0.000	1.433E-18	0.0	0.0	1	1.43	0	1.93	0.02	0.04	0.85
36	6	4.854E-05	0.103	4.975E-06	0.003	2.115E-14	10.0	4.1	4	1.42	23	1.75	0.08	0.17	0.83
37	4	4.854E-05	0.081	3.920E-06	0.002	1.431E-14	8.4	4.2	3	1.71	20	1.80	0.01	0.20	0.84
39	1	4.854E-05	0.006	2.798E-07	0.000	1.903E-16	29.5	29.5	1	1.44	2	1.92	0.01	0.08	0.85
40	2	4.854E-05	0.088	4.293E-06	0.002	1.431E-14	3.9	2.7	2	1.46	23	1.75	0.00	0.25	0.85
Q=40%	117	1.403E-03		9.661E-05		3.007E-13	10.0	0.9		1.67	17.104	1.82	0.01	0.16	0.84

Sample headers highlighted in blue are selected for thermal history modeling. * Denotes AFT sample omitted from the study.

Note: N_s is the number of spontaneous fission tracks for each apatite. Ω_i is the area over which tracks are counted, whereas P_i is the ²³⁸U/⁴³Ca ratio.

Q represents the χ² probability for each population. A population passes the chi-squared test if χ² > 5%. D_{par} is the diameter of the etch figure parallel to the c-axis. F, Cl and OH concentrations were calculated via EPMA. R_{mr0} was determined using the calculations of *Carlson et al.* (1999).

modified zeta: 8.2727 ± 0.1407

total decay const: 1.551E-10

Table S4.2. Summary of AFT length data, Tauern Window, Austria

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D_{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r_{mr0}
JS11, Norddrahmen Zone - Penninic, meta-litharenite.									
UTM zone 33N, 5237057N, 343368E, 1100 masl									
1	1	16.33	49.54	4	2.12	1.79	0.00	0.21	0.85
1	2	14.80	65.96	4	2.12	1.79	0.00	0.21	0.85
1	3	17.01	56.96	4	2.12	1.79	0.00	0.21	0.85
2	1	14.32	26.08	4	2.16	1.83	0.01	0.16	0.84
3	1	14.22	14.89	4	1.66	1.97	0.00	0.03	0.85
3	2	12.72	75.41	4	1.66	1.97	0.00	0.03	0.85
6	1	11.13	59.70	4	1.77	1.75	0.02	0.24	0.80
6	2	14.55	22.52	4	1.77	1.75	0.02	0.24	0.80
7	1	14.52	58.61	4	2.00	1.98	0.01	0.01	0.84
8	1	15.40	38.19	4	1.93	1.81	0.01	0.19	0.83
9	1	14.65	56.43	2	1.82	1.96	0.00	0.04	0.86
10	1	14.05	50.25	4	1.64	1.74	0.03	0.24	0.79
11	1	13.80	37.29	2	1.70	1.83	0.03	0.14	0.78
11	2	11.90	72.32	2	1.70	1.83	0.03	0.14	0.78
12	1	15.45	61.50	4	1.95	1.73	0.04	0.23	0.81
13	1	14.42	31.40	4	2.11	1.71	0.04	0.25	0.82
14	1	13.75	49.54	4	1.36	1.78	0.02	0.20	0.82
14	2	12.25	57.27	4	1.36	1.78	0.02	0.20	0.82
15	1	8.14	69.44	2	1.81	1.78	0.09	0.13	0.79
16	1	14.83	52.99	1	1.81	1.95	0.01	0.04	0.77
16	2	14.80	29.75	1	1.81	1.95	0.01	0.04	0.77
17	1	15.56	22.93	4	2.26	1.79	0.01	0.20	0.79
18	1	14.66	71.51	3	1.83	1.86	0.01	0.14	0.83
18	2	15.24	45.95	3	1.83	1.86	0.01	0.14	0.83
19	1	13.82	80.01	2	2.22	1.73	0.03	0.24	0.62
20	1	14.13	75.56	2	1.76	1.95	0.01	0.04	0.80
21	1	15.00	57.45	4	2.00	1.74	0.00	0.25	0.84
22	1	13.52	46.19	2	2.02	1.81	0.05	0.14	0.77
23	1	15.66	36.84	4	2.05	1.70	0.06	0.25	0.76
24	1	14.56	78.30	4	1.77	1.69	0.07	0.25	0.79
26	1	14.02	68.57	4	1.99	1.83	0.03	0.14	0.81
26	2	14.49	57.22	4	1.99	1.83	0.03	0.14	0.81
27	1	15.69	33.26	4	1.98	1.76	0.00	0.24	0.83
28	1	16.83	34.45	4	1.90	1.85	0.01	0.14	0.79
29	1	14.77	59.42	4	1.74	1.79	0.03	0.18	0.78
30	1	14.15	58.07	4	1.97	1.63	0.03	0.34	0.82
31	1	14.74	71.18	2	1.54	1.80	0.07	0.13	0.75
32	1	13.67	74.31	4	1.91	1.70	0.06	0.24	0.62
33	1	14.02	64.69	4	1.74	1.64	0.14	0.22	0.75
33	2	14.11	50.67	4	1.74	1.64	0.14	0.22	0.75
33	3	15.31	32.89	4	1.74	1.64	0.14	0.22	0.75
33	4	9.31	60.15	4	1.74	1.64	0.14	0.22	0.75
33	5	11.97	72.77	4	1.74	1.64	0.14	0.22	0.75

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D _{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r _{mr0}
33	6	14.71	11.26	4	1.74	1.64	0.14	0.22	0.75
33	7	15.47	36.91	4	1.74	1.64	0.14	0.22	0.75
34	1	13.76	46.97	4	2.02	1.69	0.04	0.27	0.79
35	1	14.18	9.83	4	1.99	1.76	0.01	0.23	0.67
35	2	10.47	62.41	4	1.99	1.76	0.01	0.23	0.67
36	1	14.81	24.70	4	1.96	1.72	0.03	0.25	0.74
37	1	13.80	70.10	4	1.92	1.84	0.03	0.13	0.83
38	1	14.95	41.85	4	1.99	1.58	0.06	0.36	0.74
38	2	16.14	58.86	4	1.99	1.58	0.06	0.36	0.74
39	1	14.20	39.85	3	1.83	1.75	0.04	0.22	0.78
39	2	14.72	29.18	3	1.83	1.75	0.04	0.22	0.78
40	1	13.57	61.39	4	1.80	1.80	0.00	0.20	0.86
41	1	13.79	62.61	4	2.20	1.61	0.06	0.32	0.80
Ave.		14.16			1.87	1.77	0.04	0.19	0.79
SD		1.61			0.19	0.10	0.04	0.08	0.05
BH54, Nordrahn Zone - Penninic, meta-gabbro.									
UTM zone 33N, 5236823N, 348318E, 1440 masl									
1	1	12.94	40.98	4	2.16	1.28	0.00	0.72	0.83
5	1	13.99	58.94	4	2.08	1.35	0.04	0.60	0.79
6	1	13.69	58.01	4	2.23	1.16	0.04	0.80	0.76
7	1	14.67	27.88	4	2.08	1.27	0.04	0.69	0.77
7	2	12.53	59.23	4	2.08	1.27	0.04	0.69	0.77
Ave.		13.56			2.13	1.27	0.03	0.70	0.79
SD		0.85			0.07	0.07	0.02	0.07	0.03
BH73, Nordrahn Zone - Penninic, meta-gabbro.									
UTM zone 33N, 5233572N, 346333E, 1350 masl									
1	1	15.59	30.62	4	2.33	0.14	0.14	1.72	0.81
2	1	15.10	57.89	4	1.91	0.17	0.00	1.83	0.86
2	2	16.54	63.20	4	1.91	0.17	0.00	1.83	0.86
2	3	14.82	33.85	4	1.91	0.17	0.00	1.83	0.86
3	1	13.93	71.58	4	3.18	0.16	0.03	1.81	0.83
4	1	16.56	55.14	4	2.71	0.14	0.05	1.81	0.84
5	1	14.37	62.08	3	1.55	0.17	0.05	1.78	0.84
6	1	16.01	26.02	2	2.28	0.49	0.21	1.30	0.76
7	1	13.06	77.02	2	2.67	0.28	0.13	1.59	0.80
8	1	15.62	28.07	3	2.91	0.15	0.03	1.82	0.84
8	2	15.79	40.72	3	2.91	0.15	0.03	1.82	0.84
9	1	13.25	75.76	4	2.81	0.11	0.11	1.78	0.82
9	2	14.62	24.68	4	2.81	0.11	0.11	1.78	0.82
10	1	15.58	36.91	1	2.94	0.16	0.12	1.72	0.81
11	1	13.03	64.19	2	2.62	0.20	0.01	1.80	0.85
11	2	14.21	50.23	2	2.62	0.20	0.01	1.80	0.85
12	1	14.67	55.79	4	2.76	0.13	0.24	1.63	0.78
13	1	14.09	29.33	3	3.13	0.19	0.00	1.81	0.86
13	2	15.27	52.73	3	3.13	0.19	0.00	1.81	0.86
14	1	13.09	47.86	1	2.78	0.19	0.00	1.80	0.85

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D _{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r _{mr0}
15	1	16.05	51.79	2	2.15	0.18	0.03	1.79	0.84
16	1	14.00	46.32	3	2.83	0.14	0.13	1.73	0.81
17	1	16.52	54.20	2	2.90	0.13	0.07	1.80	0.84
17	2	13.54	33.94	2	2.90	0.13	0.07	1.80	0.84
18	1	14.66	41.68	3	3.04	0.21	0.08	1.71	0.81
19	1	14.71	57.13	3	2.01	1.42	0.00	0.57	0.84
19	2	12.80	55.36	3	2.01	1.42	0.00	0.57	0.84
19	3	12.59	87.82	3	2.01	1.42	0.00	0.57	0.84
19	4	12.65	65.78	3	2.01	1.42	0.00	0.57	0.84
19	5	15.95	50.12	3	2.01	1.42	0.00	0.57	0.84
19	6	14.56	34.94	3	2.01	1.42	0.00	0.57	0.84
19	7	12.97	74.91	3	2.01	1.42	0.00	0.57	0.84
19	8	14.34	18.43	3	2.01	1.42	0.00	0.57	0.84
19	9	13.96	31.29	3	2.01	1.42	0.00	0.57	0.84
20	1	14.40	57.56	1	3.51	0.24	0.05	1.71	0.82
20	2	17.32	31.78	1	3.51	0.24	0.05	1.71	0.82
21	1	15.05	48.39	2	3.15	0.15	0.23	1.62	0.79
21	2	17.17	60.11	2	3.15	0.15	0.23	1.62	0.79
Ave.		14.70			2.56	0.47	0.06	1.47	0.83
SD		1.29			0.52	0.54	0.07	0.51	0.02

*BH45, Glockner Nappe System - Penninic, meta-basite.

UTM zone 33N, 5231852N, 349524E, 1310 masl

3	1	14.13	87.60	4	2.11	1.20	0.00	0.79	0.83
4	1	14.06	49.90	4	2.06	1.32	0.00	0.68	0.84
4	2	15.17	41.59	4	2.06	1.32	0.00	0.68	0.84
5	1	13.95	39.52	4	2.20	1.37	0.00	0.63	0.84
6	1	14.95	50.18	4	2.02	1.20	0.00	0.80	0.83
7	1	14.68	63.86	4	1.78	1.33	0.00	0.67	0.83
9	1	13.92	48.23	4	2.48	1.27	0.00	0.73	0.83
11	1	14.38	63.30	4	2.06	1.23	0.00	0.77	0.82
12	1	14.17	68.90	4	2.03	1.34	0.00	0.66	0.83
Ave.		14.38			2.09	1.29	0.00	0.71	0.83
SD		0.45			0.18	0.06	0.00	0.06	0.01

BH61, Glockner Nappe System - Penninic, meta-gabbro.

UTM zone 33N, 5225311N, 348189E, 1680 masl

1	1	14.38	61.70	4	2.03	1.12	0.00	0.88	0.82
1	2	14.12	24.45	4	2.03	1.12	0.00	0.88	0.82
2	1	14.60	53.19	4	2.28	1.07	0.00	0.93	0.80
2	2	14.05	13.70	4	2.28	1.07	0.00	0.93	0.80
3	1	13.27	58.80	4	2.40	1.07	0.00	0.92	0.82
4	1	15.88	17.55	4	2.24	1.13	0.00	0.87	0.79
4	2	13.27	16.36	4	2.24	1.13	0.00	0.87	0.79
5	1	13.72	59.61	4	2.04	1.08	0.00	0.92	0.80
6	1	13.94	56.07	4	2.11	1.10	0.00	0.90	0.82
7	1	13.27	86.13	4	2.39	1.15	0.00	0.84	0.74
7	2	16.94	44.27	4	2.39	1.15	0.00	0.84	0.74

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D_{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r_{mr0}
8	1	13.61	60.13	4	2.16	1.30	0.00	0.70	0.80
9	1	13.65	64.74	4	2.12	1.09	0.00	0.91	0.80
10	1	13.83	51.88	4	1.96	1.11	0.00	0.88	0.81
10	2	14.60	40.39	4	1.96	1.11	0.00	0.88	0.81
12	1	14.07	56.33	4	2.36	1.13	0.00	0.87	0.81
13	1	13.18	43.39	4	1.86	1.07	0.00	0.92	0.79
14	1	13.39	53.18	4	1.86	1.13	0.00	0.87	0.81
15	1	14.79	42.84	4	2.13	1.09	0.00	0.90	0.80
15	2	13.81	25.49	4	2.13	1.09	0.00	0.90	0.80
15	3	11.91	51.98	4	2.13	1.09	0.00	0.90	0.80
16	1	14.98	45.42	4	2.05	1.17	0.00	0.83	0.81
17	1	14.44	36.91	4	2.27	1.09	0.00	0.90	0.79
18	1	14.34	59.60	4	2.33	1.03	0.00	0.97	0.82
19	1	13.82	41.41	4	1.86	1.12	0.00	0.88	0.79
21	1	16.10	17.98	4	1.88	1.16	0.00	0.84	0.83
21	2	13.38	54.31	4	1.88	1.16	0.00	0.84	0.83
23	1	14.65	26.31	4	2.57	1.03	0.00	0.96	0.78
24	1	13.75	54.12	4	2.08	1.06	0.01	0.93	0.79
24	2	14.65	40.16	4	2.08	1.06	0.01	0.93	0.79
25	1	11.22	70.83	4	1.97	1.14	0.00	0.86	0.78
26	1	11.62	64.99	4	1.97	1.12	0.00	0.87	0.82
26	2	14.18	57.50	4	1.97	1.12	0.00	0.87	0.82
27	1	14.37	39.89	4	1.76	1.12	0.00	0.88	0.78
28	1	13.28	70.60	4	1.99	1.14	0.01	0.85	0.83
29	1	13.48	68.25	4	1.78	1.20	0.01	0.79	0.81
29	2	14.62	42.17	4	1.78	1.20	0.01	0.79	0.81
30	1	13.77	55.34	4	2.15	1.04	0.00	0.96	0.77
30	2	13.96	47.45	4	2.15	1.04	0.00	0.96	0.77
30	3	13.45	51.22	4	2.15	1.04	0.00	0.96	0.77
31	1	14.32	34.46	4	2.06	1.12	0.01	0.87	0.82
32	1	13.75	74.91	4	1.77	1.13	0.00	0.86	0.79
32	2	14.00	22.84	4	1.77	1.13	0.00	0.86	0.79
32	3	14.52	74.58	4	1.77	1.13	0.00	0.86	0.79
34	1	17.08	27.01	4	2.11	1.11	0.00	0.89	0.80
35	1	14.72	11.65	4	2.14	1.14	0.01	0.86	0.77
36	1	15.09	30.02	4	1.98	1.04	0.01	0.95	0.78
37	1	12.07	57.24	4	2.14	1.11	0.00	0.89	0.83
37	2	15.26	34.05	4	2.14	1.11	0.00	0.89	0.83
38	1	14.93	55.27	3	2.14	1.13	0.01	0.87	0.82
39	1	13.06	46.93	4	2.06	1.11	0.00	0.89	0.81
40	1	11.60	55.80	4	2.22	1.03	0.00	0.97	0.82
40	2	15.29	0.86	4	2.22	1.03	0.00	0.97	0.82
41	1	12.81	59.08	4	2.21	1.16	0.01	0.83	0.83
42	1	13.19	37.84	4	1.85	1.25	0.01	0.75	0.83
42	2	14.23	39.38	4	1.85	1.25	0.01	0.75	0.83
43	1	13.32	59.44	4	1.64	1.11	0.01	0.88	0.79

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D _{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r _{mr0}
43	2	14.72	27.10	4	1.64	1.11	0.01	0.88	0.79
44	1	17.32	28.92	4	2.15	1.11	0.00	0.89	0.82
45	1	14.13	22.08	4	2.36	1.12	0.01	0.87	0.82
45	2	12.20	63.90	4	2.36	1.12	0.01	0.87	0.82
46	1	15.95	43.18	2	1.92	1.24	0.00	0.76	0.81
47	1	14.06	65.70	2	2.29	1.07	0.00	0.93	0.80
47	2	14.74	40.76	2	2.29	1.07	0.00	0.93	0.80
48	1	13.53	38.55	4	1.88	1.13	0.01	0.86	0.80
49	1	15.26	25.28	4	2.18	1.12	0.01	0.88	0.81
49	2	13.78	76.97	4	2.18	1.12	0.01	0.88	0.81
50	1	16.99	15.99	4	2.22	1.13	0.00	0.87	0.80
51	1	15.75	43.58	4	2.11	1.13	0.00	0.86	0.83
52	1	13.90	47.81	4	1.97	1.18	0.00	0.82	0.81
53	1	12.76	74.19	4	2.13	1.16	0.01	0.84	0.82
53	2	15.45	37.38	4	2.13	1.16	0.01	0.84	0.82
54	1	14.03	35.03	4	1.94	1.13	0.00	0.86	0.79
55	1	14.38	35.68	4	2.13	1.08	0.00	0.92	0.82
56	1	14.65	65.86	4	1.98	1.06	0.00	0.94	0.81
56	2	15.21	55.47	4	1.98	1.06	0.00	0.94	0.81
56	3	14.12	29.87	4	1.98	1.06	0.00	0.94	0.81
56	4	14.66	47.94	4	1.98	1.06	0.00	0.94	0.81
57	1	13.78	65.80	2	2.20	1.08	0.01	0.92	0.78
57	2	14.57	27.35	2	2.20	1.08	0.01	0.92	0.78
58	1	12.15	53.10	4	2.17	1.08	0.00	0.92	0.81
59	1	13.15	35.03	4	2.25	1.10	0.00	0.90	0.80
60	1	14.46	68.90	4	2.15	1.14	0.00	0.85	0.83
61	1	14.38	26.72	4	1.99	1.37	0.01	0.62	0.83
62	1	13.56	32.84	4	2.09	1.14	0.00	0.86	0.80
63	1	14.75	49.38	4	1.91	1.11	0.00	0.89	0.79
63	2	15.42	43.27	4	1.91	1.11	0.00	0.89	0.79
64	1	14.68	19.45	3	2.26	1.10	0.00	0.90	0.81
Ave.		14.16			2.08	1.12	0.00		0.80
SD		1.16			0.18	0.06	0.00		0.02

BH51, Venediger Nappe System - Sub-Penninic, ortho-gneiss. UTM zone 33N, 5219506N, 348524E, 1460 masl

1	1	15.62	19.64	4	1.88	1.96	0.00	0.03	0.85
2	1	12.99	65.84	4	1.78	2.11	0.00	0.00	0.86
3	1	16.36	67.06	4	1.67	1.72	0.00	0.28	0.85
4	1	13.48	71.57	4	1.74	1.84	0.00	0.15	0.86
5	1	12.90	60.04	4	1.76	1.70	0.00	0.29	0.85
6	1	10.96	51.81	4	1.29	1.95	0.00	0.04	0.86
7	1	15.08	56.39	4	1.65	1.75	0.00	0.25	0.84
7	2	15.38	34.25	4	1.65	1.75	0.00	0.25	0.84
8	1	15.50	58.12	4	2.10	1.64	0.00	0.36	0.85
8	2	14.62	23.72	4	2.10	1.64	0.00	0.36	0.85
8	3	15.11	51.15	4	2.10	1.64	0.00	0.36	0.85

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D_{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r_{mr0}
8	4	14.97	38.02	4	2.10	1.64	0.00	0.36	0.85
9	1	13.30	40.95	4	1.68	1.74	0.00	0.26	0.85
9	2	15.09	65.28	4	1.68	1.74	0.00	0.26	0.85
12	1	15.63	14.98	4	1.90	1.66	0.00	0.34	0.84
12	2	12.72	66.80	4	1.90	1.66	0.00	0.34	0.84
12	3	14.78	37.15	4	1.90	1.66	0.00	0.34	0.84
14	1	14.92	63.98	4	1.60	1.63	0.00	0.37	0.84
14	2	14.88	41.64	4	1.60	1.63	0.00	0.37	0.84
15	1	15.64	23.82	4	1.70	1.90	0.00	0.10	0.86
16	1	15.14	51.71	4	2.15	1.74	0.00	0.26	0.84
17	1	15.00	74.17	4	1.73	1.74	0.00	0.26	0.85
20	1	16.17	74.88	4	1.69	1.76	0.00	0.24	0.84
20	2	15.63	9.10	4	1.69	1.76	0.00	0.24	0.84
21	1	14.56	43.89	4	1.70	1.78	0.00	0.22	0.85
Ave.		14.66			1.79	1.75	0.00	0.25	0.85
SD		1.26			0.20	0.12	0.00	0.11	0.01
BH74, Venediger Nappe System - Sub-Penninic, para-gneiss.									
UTM zone 33N, 5214805N, 346069E, 1720 masl									
1	1	14.90	33.48	4	1.84	1.50	0.00	0.50	0.83
3	1	14.12	50.19	4	2.20	1.45	0.00	0.55	0.82
4	1	14.35	39.24	4	2.07	1.50	0.00	0.50	0.83
5	1	15.49	88.25	4	2.12	1.50	0.00	0.50	0.83
5	2	16.03	52.66	4	2.12	1.50	0.00	0.50	0.83
5	3	9.94	76.39	4	2.12	1.50	0.00	0.50	0.83
5	4	15.73	24.36	4	2.12	1.50	0.00	0.50	0.83
6	1	14.65	33.78	4	1.89	1.52	0.00	0.48	0.83
11	1	13.57	71.60	4	1.98	1.56	0.00	0.44	0.84
11	2	14.47	35.06	4	1.98	1.56	0.00	0.44	0.84
12	1	12.91	39.02	4	2.01	1.47	0.00	0.53	0.84
13	1	15.68	61.77	4	2.07	1.53	0.00	0.47	0.84
13	2	12.94	65.50	4	2.07	1.53	0.00	0.47	0.84
14	1	14.11	46.19	4	1.77	1.56	0.00	0.44	0.84
15	1	13.06	49.19	4	2.03	1.48	0.00	0.52	0.84
15	2	13.99	54.56	4	2.03	1.48	0.00	0.52	0.84
16	1	13.65	34.41	4	1.98	1.50	0.00	0.50	0.84
16	2	14.09	39.92	4	1.98	1.50	0.00	0.50	0.84
18	1	14.75	55.40	4	1.75	1.50	0.00	0.50	0.82
19	1	14.15	59.96	4	1.92	1.43	0.00	0.57	0.83
19	2	12.63	46.87	4	1.92	1.43	0.00	0.57	0.83
21	1	14.62	43.66	4	1.59	1.56	0.00	0.43	0.84
22	1	14.67	44.12	4	2.05	1.47	0.00	0.53	0.84
22	2	13.07	70.35	4	2.05	1.47	0.00	0.53	0.84
23	1	14.55	40.99	4	2.13	1.50	0.00	0.50	0.84
23	2	13.66	60.15	4	2.13	1.50	0.00	0.50	0.84
25	1	15.89	67.49	4	1.72	1.44	0.00	0.56	0.82
25	2	13.28	61.50	4	1.72	1.44	0.00	0.56	0.82

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D _{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r _{mr0}
25	3	13.93	50.11	4	1.72	1.44	0.00	0.56	0.82
25	4	14.20	53.87	4	1.72	1.44	0.00	0.56	0.82
26	1	13.81	47.86	4	1.76	1.43	0.00	0.57	0.81
26	2	13.61	63.54	4	1.76	1.43	0.00	0.57	0.81
26	3	14.59	26.57	4	1.76	1.43	0.00	0.57	0.81
27	1	11.40	51.72	4	2.01	1.43	0.00	0.57	0.83
27	2	15.33	9.95	4	2.01	1.43	0.00	0.57	0.83
27	3	10.64	61.82	4	2.01	1.43	0.00	0.57	0.83
28	1	12.22	59.50	4	1.92	1.50	0.00	0.50	0.83
28	2	13.71	60.54	4	1.92	1.50	0.00	0.50	0.83
28	3	15.20	39.36	4	1.92	1.50	0.00	0.50	0.83
29	1	15.01	32.09	4	2.13	1.46	0.00	0.54	0.83
30	1	15.60	33.71	4	2.10	1.51	0.00	0.49	0.83
30	2	13.41	66.62	4	2.10	1.51	0.00	0.49	0.83
31	1	12.10	68.75	4	2.20	1.48	0.00	0.52	0.84
32	1	15.20	47.41	4	1.82	1.52	0.00	0.48	0.83
Ave.		13.98			1.96	1.48	0.00	0.51	0.83
SD		1.33			0.15	0.04	0.00	0.04	0.01

BH76, Venediger Nappe System - Sub-Penninic, ortho-gneiss.

UTM zone 33N, 5213968N, 345556E, 2180 masl

1	1	15.37	38.45	4	1.87	1.15	0.02	0.83	0.81
1	2	14.37	30.15	4	1.87	1.15	0.02	0.83	0.81
2	1	14.18	52.69	4	1.95	1.49	0.02	0.49	0.83
3	1	16.30	18.81	4	2.13	1.11	0.02	0.87	0.81
4	1	10.72	60.99	4	2.15	1.24	0.03	0.73	0.82
4	2	16.13	39.24	4	2.15	1.24	0.03	0.73	0.82
4	3	15.16	56.08	4	2.15	1.24	0.03	0.73	0.82
4	4	13.92	52.00	4	2.15	1.24	0.03	0.73	0.82
4	5	15.39	15.42	4	2.15	1.24	0.03	0.73	0.82
5	1	16.38	26.84	4	2.18	1.02	0.02	0.96	0.81
7	1	11.52	88.66	4	1.93	1.07	0.02	0.92	0.81
7	2	14.83	35.25	4	1.93	1.07	0.02	0.92	0.81
9	1	14.99	5.75	4	2.19	1.15	0.02	0.83	0.79
9	2	12.84	53.58	4	2.19	1.15	0.02	0.83	0.79
10	1	15.54	39.35	4	1.97	1.29	0.01	0.70	0.83
10	2	16.48	42.08	4	1.97	1.29	0.01	0.70	0.83
10	3	15.39	60.54	4	1.97	1.29	0.01	0.70	0.83
10	4	14.31	75.68	4	1.97	1.29	0.01	0.70	0.83
10	5	13.87	74.97	4	1.97	1.29	0.01	0.70	0.83
11	1	10.20	60.51	4	1.98	1.24	0.03	0.73	0.83
12	1	14.65	49.49	4	2.16	1.07	0.02	0.91	0.82
12	2	15.09	20.79	4	2.16	1.07	0.02	0.91	0.82
13	1	14.66	30.39	4	1.96	1.10	0.01	0.90	0.82
13	2	13.29	24.10	4	1.96	1.10	0.01	0.90	0.82
14	1	14.24	64.44	4	1.91	1.11	0.01	0.88	0.82
15	1	13.49	40.93	4	1.68	1.28	0.01	0.71	0.82

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D _{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r _{mr0}
16	1	13.46	65.35	4	2.22	1.15	0.03	0.82	0.82
19	1	16.48	30.95	4	1.89	1.08	0.01	0.91	0.82
23	1	14.43	23.43	4	1.91	1.15	0.01	0.84	0.82
25	1	14.76	56.77	4	1.92	1.09	0.00	0.90	0.82
25	2	12.33	46.54	4	1.92	1.09	0.00	0.90	0.82
27	1	14.76	49.09	4	1.59	1.12	0.01	0.87	0.81
28	1	14.54	44.43	4	2.05	1.10	0.04	0.87	0.80
28	2	13.87	70.76	4	2.05	1.10	0.04	0.87	0.80
31	1	15.11	65.89	4	1.72	1.17	0.00	0.82	0.83
31	2	13.65	48.76	4	1.72	1.17	0.00	0.82	0.83
31	3	13.54	54.03	4	1.72	1.17	0.00	0.82	0.83
31	4	15.11	21.81	4	1.72	1.17	0.00	0.82	0.83
33	1	11.79	53.43	4	2.01	1.07	0.01	0.91	0.81
33	2	15.09	13.77	4	2.01	1.07	0.01	0.91	0.81
33	3	10.89	76.49	4	2.01	1.07	0.01	0.91	0.81
34	1	12.45	59.44	4	1.92	1.08	0.01	0.91	0.81
34	2	13.98	57.89	4	1.92	1.08	0.01	0.91	0.81
34	3	15.08	28.09	4	1.92	1.08	0.01	0.91	0.81
Ave.		14.20			1.97	1.16	0.02	0.82	0.82
SD		1.52			0.15	0.10	0.01	0.10	0.01
BH65,Venediger Nappe System - Sub-Penninic, ortho-gneiss.									
UTM zone 33N, 5213130N, 344910E, 3080 masl									
2	1	14.55	70.01	4	2.03	1.81	0.00	0.18	0.84
2	2	15.10	41.63	4	2.03	1.81	0.00	0.18	0.84
5	1	14.77	46.52	4	2.17	1.57	0.00	0.43	0.84
5	2	12.78	64.61	4	2.17	1.57	0.00	0.43	0.84
10	1	15.70	30.19	4	2.03	1.49	0.00	0.50	0.81
10	2	13.94	48.71	4	2.03	1.49	0.00	0.50	0.81
11	1	16.49	62.64	4	2.01	1.86	0.01	0.14	0.85
12	1	11.93	63.13	4	2.05	1.46	0.00	0.53	0.81
14	1	14.10	36.73	4	1.28	1.74	0.00	0.26	0.85
21	1	14.77	25.24	4	1.69	1.59	0.00	0.40	0.84
24	1	14.42	70.60	4	1.77	1.52	0.00	0.48	0.84
24	2	15.71	27.21	4	1.77	1.52	0.00	0.48	0.84
25	1	12.55	87.84	4	1.83	1.51	0.00	0.49	0.83
25	2	14.45	55.82	4	1.83	1.51	0.00	0.49	0.83
27	1	14.35	68.10	4	2.18	1.51	0.00	0.49	0.83
27	2	12.23	45.27	4	2.18	1.51	0.00	0.49	0.83
27	3	14.62	52.27	4	2.18	1.51	0.00	0.49	0.83
27	4	14.77	32.50	4	2.18	1.51	0.00	0.49	0.83
32	1	14.16	48.08	4	1.80	1.57	0.00	0.43	0.83
32	2	13.55	86.34	4	1.80	1.57	0.00	0.43	0.83
32	3	14.87	51.42	4	1.80	1.57	0.00	0.43	0.83
32	4	15.26	22.49	4	1.80	1.57	0.00	0.43	0.83
33	1	13.26	51.72	4	1.62	1.69	0.01	0.31	0.83
33	2	15.79	61.05	4	1.62	1.69	0.01	0.31	0.83

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D _{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r _{mr0}
33	3	15.35	30.62	4	1.62	1.69	0.01	0.31	0.83
36	1	15.63	44.44	4	2.28	1.53	0.00	0.47	0.84
39	1	16.23	20.38	4	1.90	1.57	0.00	0.42	0.83
40	1	12.90	45.66	4	1.68	1.56	0.00	0.44	0.83
40	2	15.38	57.93	4	1.68	1.56	0.00	0.44	0.83
40	3	15.09	48.34	4	1.68	1.56	0.00	0.44	0.83
43	1	14.85	43.02	4	1.54	1.54	0.00	0.46	0.83
43	2	13.55	37.37	4	1.54	1.54	0.00	0.46	0.83
45	1	14.05	75.56	4	2.03	1.60	0.00	0.40	0.82
46	1	15.31	35.61	4	1.53	1.57	0.01	0.42	0.82
46	2	13.00	65.11	4	1.53	1.57	0.01	0.42	0.82
Ave.		14.44			1.85	1.58	0.00	0.41	0.83
SD		1.14			0.25	0.10	0.00	0.10	0.01

BH42,Venediger Nappe System - Sub-Penninic, ortho-gneiss.

UTM zone 33N, 5212924N, 345606E, 2680 masl

12	1	13.29	41.50	4	1.83	1.40	0.00	0.60	0.79
20	1	14.77	36.36	4	2.13	1.50	0.00	0.50	0.83
20	2	15.29	75.71	4	2.13	1.50	0.00	0.50	0.83
20	3	14.87	47.06	4	2.13	1.50	0.00	0.50	0.83
20	4	15.94	39.38	4	2.13	1.50	0.00	0.50	0.83
22	1	14.58	61.58	4	2.06	1.45	0.01	0.55	0.82
30	1	16.60	21.11	4	1.64	1.54	0.00	0.45	0.83
31	1	10.95	62.74	4	2.05	1.50	0.00	0.49	0.84
31	2	18.66	56.66	4	2.05	1.50	0.00	0.49	0.84
31	3	11.44	66.13	4	2.05	1.50	0.00	0.49	0.84
31	4	14.18	58.57	4	2.05	1.50	0.00	0.49	0.84
32	1	8.81	59.28	4	2.05	1.44	0.00	0.55	0.83
32	2	10.92	75.29	4	2.05	1.44	0.00	0.55	0.83
32	3	14.87	34.23	4	2.05	1.44	0.00	0.55	0.83
33	1	16.04	31.23	4	2.15	1.48	0.00	0.52	0.83
37	1	14.35	48.69	4	1.99	1.52	0.00	0.48	0.83
37	2	11.91	42.79	4	1.99	1.52	0.00	0.48	0.83
41	1	14.45	69.37	4	2.39	1.44	0.00	0.56	0.83
41	2	15.90	84.15	4	2.39	1.44	0.00	0.56	0.83
41	3	12.31	76.14	4	2.39	1.44	0.00	0.56	0.83
43	1	15.26	46.94	4	1.96	1.54	0.00	0.46	0.84
43	2	12.28	61.81	4	1.96	1.54	0.00	0.46	0.84
43	3	13.33	78.45	4	1.96	1.54	0.00	0.46	0.84
46	1	15.24	52.90	4	2.25	1.47	0.00	0.53	0.83
46	2	14.62	69.81	4	2.25	1.47	0.00	0.53	0.83
46	3	13.87	59.02	4	2.25	1.47	0.00	0.53	0.83
52	1	16.43	72.00	4	1.75	1.44	0.00	0.56	0.83
52	2	14.79	55.45	4	1.75	1.44	0.00	0.56	0.83
57	1	11.99	62.26	4	1.78	1.48	0.00	0.52	0.83
57	2	14.86	52.10	4	1.78	1.48	0.00	0.52	0.83
58	1	14.97	9.70	4	2.07	1.47	0.00	0.53	0.84

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D _{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r _{mr0}
58	2	14.57	33.49	4	2.07	1.47	0.00	0.53	0.84
58	3	15.00	65.34	4	2.07	1.47	0.00	0.53	0.84
58	4	16.50	30.60	4	2.07	1.47	0.00	0.53	0.84
61	1	14.03	63.22	4	2.06	1.46	0.00	0.54	0.82
62	1	15.47	24.76	4	1.89	1.50	0.00	0.50	0.84
Ave.		14.26			2.05	1.48	0.00	0.52	0.83
SD		1.93			0.18	0.04	0.00	0.04	0.01

JS03, Venediger Nappe System - Sub-Penninic, meta-gabbro.

UTM zone 33N, 5206449N, 343118E, 1580 masl

2	1	14.35	49.66	2	1.84	1.66	0.00	0.34	0.85
3	1	13.35	61.94	4	1.97	1.73	0.00	0.27	0.85
4	1	9.27	66.73	4	1.83	1.73	0.00	0.27	0.85
5	1	14.37	23.69	4	1.75	1.66	0.00	0.34	0.84
5	2	15.47	57.28	4	1.75	1.66	0.00	0.34	0.84
6	1	12.97	83.86	2	1.85	1.67	0.00	0.33	0.84
6	2	13.78	73.30	2	1.85	1.67	0.00	0.33	0.84
6	3	15.14	35.94	2	1.85	1.67	0.00	0.33	0.84
6	4	13.81	85.05	2	1.85	1.67	0.00	0.33	0.84
7	1	14.93	50.11	4	1.72	1.66	0.00	0.34	0.85
8	1	15.72	46.38	4	1.79	1.72	0.00	0.28	0.85
9	1	16.22	37.44	4	1.83	1.79	0.00	0.21	0.85
9	2	15.58	76.22	4	1.83	1.79	0.00	0.21	0.85
10	1	15.25	47.16	4	1.72	1.65	0.00	0.35	0.84
11	1	13.93	68.79	3	1.78	1.79	0.00	0.21	0.85
11	2	10.54	64.59	3	1.78	1.79	0.00	0.21	0.85
12	1	13.45	28.04	3	1.58	1.70	0.00	0.30	0.85
12	2	15.09	43.50	3	1.58	1.70	0.00	0.30	0.85
13	1	13.72	35.12	4	2.04	1.83	0.00	0.17	0.86
14	1	13.62	46.17	4	2.01	1.98	0.01	0.02	0.86
15	1	10.90	39.43	4	1.80	1.78	0.00	0.22	0.84
16	1	13.73	48.22	3	1.74	1.75	0.00	0.25	0.85
17	1	15.48	33.71	4	1.51	1.65	0.00	0.35	0.85
18	1	15.33	81.69	4	1.76	1.73	0.01	0.26	0.85
18	2	15.22	36.29	4	1.76	1.73	0.01	0.26	0.85
19	1	13.98	47.17	4	1.86	1.65	0.00	0.35	0.84
20	1	14.53	22.99	4	1.75	1.71	0.00	0.29	0.84
20	2	11.47	65.64	4	1.75	1.71	0.00	0.29	0.84
21	1	15.31	32.62	2	1.69	1.67	0.00	0.33	0.84
22	1	14.56	23.55	4	1.63	1.68	0.00	0.32	0.85
23	1	14.76	65.36	3	1.75	1.62	0.00	0.38	0.84
24	1	14.02	67.11	3	1.56	1.63	0.00	0.37	0.83
25	1	12.59	65.54	4	1.89	1.72	0.00	0.28	0.84
26	1	15.21	13.47	4	1.55	1.63	0.00	0.37	0.84
26	2	14.21	37.13	4	1.55	1.63	0.00	0.37	0.84
27	1	15.32	49.43	4	1.48	1.78	0.00	0.22	0.85
27	2	14.37	49.43	4	1.48	1.78	0.00	0.22	0.85

Grain No.	Track No.	Track length (μm)	Angle to C-axis (degrees)	Etch Figs.	D _{par} (μm)	F (apfu)	Cl (apfu)	OH (apfu)	r _{mr0}
28	1	12.27	34.78	4	1.70	1.78	0.00	0.22	0.85
29	1	10.21	63.09	2	1.66	1.74	0.01	0.26	0.85
30	1	15.02	13.28	4	1.56	1.73	0.00	0.27	0.85
31	1	15.12	46.58	3	1.69	1.73	0.00	0.27	0.85
32	1	14.43	32.12	3	1.85	1.66	0.00	0.34	0.84
32	2	15.11	28.54	3	1.85	1.66	0.00	0.34	0.84
33	1	14.78	46.32	4	1.84	1.69	0.00	0.32	0.84
34	1	10.32	62.22	4	1.93	1.87	0.00	0.13	0.86
34	2	15.32	13.21	4	1.93	1.87	0.00	0.13	0.86
35	1	13.48	43.32	3	1.78	1.70	0.00	0.30	0.85
36	1	12.66	54.81	4	1.62	1.66	0.00	0.34	0.85
36	2	13.56	53.90	4	1.62	1.66	0.00	0.34	0.85
37	1	15.42	36.97	2	1.81	1.80	0.00	0.20	0.85
38	1	14.77	71.53	4	1.75	1.77	0.00	0.23	0.85
38	2	15.34	45.84	4	1.75	1.77	0.00	0.23	0.85
39	1	8.13	49.87	4	1.71	1.61	0.00	0.39	0.84
40	1	16.86	17.47	3	1.55	1.67	0.00	0.34	0.84
41	1	14.92	43.03	3	1.64	0.53	0.01	1.46	0.84
42	1	14.47	27.19	3	1.69	1.72	0.00	0.28	0.85
43	1	13.02	74.69	4	1.79	1.67	0.00	0.34	0.85
43	2	13.39	34.43	4	1.79	1.67	0.00	0.34	0.85
Ave.		13.97			1.75	1.69	0.00	0.30	0.85
SD		1.74			0.13	0.17	0.00	0.17	0.01

Sample headers highlighted in blue are selected for thermal history modeling.

* Denotes AFT sample omitted from the study.

Note: D_{par} is the diameter of the etch figure parallel to the c axis. F, Cl and OH concentrations were calculated via EPMA. R_{mr0} was determined using the calculations of Carlson *et al.* (1999)

Table S4.3. Apatite chemistry of AFT age and length grains, Tauern Window, Austria

Grain No.	Na (apfu)	Mg (apfu)	P (apfu)	S (apfu)	Ca (apfu)	Mn (apfu)	Fe (apfu)	Sr (apfu)	Y (apfu)	La (apfu)	Ce (apfu)	F (apfu)	Cl (apfu)	OH (apfu)	Total (apfu)	Total Wt% O	r _{mr0}
JS11, Norddrahmen Zone - Penninic, meta-litharenite. UTM zone 33N, 5237057N, 343368E, 1100 masl																	
AFT Age-Grains																	
1	0.031	0.004	5.917	0.039	9.617	0.078	0.061	0.000	0.010	0.002	0.023	1.867	0.046	0.087	17.9	98.4	0.73
3	0.065	0.005	5.866	0.001	9.864	0.029	0.020	0.005	0.019	0.005	0.023	2.005	0.023	0.000	18.1	96.0	0.82
5	0.055	0.003	5.831	0.000	9.637	0.027	0.027	0.000	0.051	0.000	0.019	1.971	0.043	0.000	18.0	96.2	0.81
9	0.042	0.026	6.008	0.000	9.649	0.076	0.084	0.000	0.027	0.000	0.009	1.918	0.097	0.000	18.0	99.2	0.68
10	0.050	0.003	5.979	0.000	9.734	0.019	0.003	0.001	0.035	0.013	0.021	1.894	0.015	0.090	17.9	99.3	0.84
12	0.048	0.004	5.888	0.001	9.801	0.029	0.037	0.000	0.029	0.015	0.031	1.879	0.108	0.013	18.0	96.0	0.78
15	0.093	0.003	6.029	0.000	9.671	0.009	0.007	0.003	0.020	0.010	0.031	1.931	0.022	0.048	17.9	98.7	0.84
16	0.020	0.002	5.992	0.000	9.925	0.001	0.026	0.007	0.011	0.000	0.004	1.904	0.003	0.093	18.0	100.4	0.83
17	0.027	0.003	6.018	0.000	9.836	0.000	0.017	0.024	0.010	0.000	0.002	1.955	0.003	0.042	18.0	100.2	0.84
18	0.016	0.001	6.018	0.000	9.890	0.001	0.004	0.009	0.010	0.000	0.000	1.828	0.003	0.169	18.0	99.3	0.85
19	0.043	0.004	6.010	0.000	9.685	0.022	0.046	0.001	0.024	0.007	0.023	1.877	0.019	0.105	17.9	99.6	0.79
20	0.041	0.005	6.045	0.002	9.772	0.004	0.005	0.015	0.010	0.002	0.000	2.266	0.021	0.000	18.2	96.6	0.85
22	0.027	0.005	6.026	0.000	9.844	0.007	0.016	0.001	0.002	0.004	0.001	2.043	0.035	0.000	18.0	96.2	0.84
23	0.017	0.003	6.004	0.003	9.892	0.010	0.008	0.003	0.003	0.004	0.001	1.861	0.018	0.121	18.0	100.1	0.84
25	0.042	0.001	6.023	0.000	9.838	0.010	0.016	0.002	0.010	0.000	0.000	2.050	0.022	0.000	18.0	98.6	0.84
26	0.017	0.003	6.058	0.001	9.757	0.005	0.012	0.004	0.002	0.000	0.004	2.015	0.008	0.000	17.9	101.5	0.85
31	0.048	0.002	5.947	0.001	9.859	0.030	0.016	0.000	0.015	0.016	0.029	1.900	0.044	0.056	18.0	96.8	0.82
32	0.137	0.007	5.967	0.005	9.574	0.091	0.030	0.000	0.055	0.008	0.023	1.945	0.091	0.000	18.0	96.4	0.75
33	0.132	0.008	6.001	0.005	9.764	0.012	0.011	0.005	0.012	0.007	0.014	1.925	0.058	0.017	18.0	96.3	0.83
36	0.071	0.003	5.957	0.002	9.835	0.003	0.032	0.005	0.014	0.000	0.010	1.937	0.023	0.041	18.0	98.9	0.82
37	0.027	0.012	5.921	0.000	9.984	0.001	0.032	0.011	0.008	0.000	0.000	1.891	0.021	0.088	18.1	97.6	0.82
38	0.145	0.037	6.013	0.004	9.541	0.086	0.067	0.000	0.047	0.001	0.011	1.900	0.037	0.063	18.0	96.7	0.70
39	0.023	0.003	6.021	0.000	9.856	0.006	0.012	0.002	0.005	0.004	0.003	1.893	0.051	0.056	18.0	100.4	0.84
40	0.049	0.010	5.941	0.000	9.919	0.055	0.069	0.001	0.022	0.000	0.002	1.805	0.057	0.138	18.1	97.4	0.72
AFT Length-Grains																	
1	0.040	0.000	5.926	0.002	9.945	0.000	0.007	0.020	0.009	0.000	0.006	1.794	0.000	0.206	18.0	98.9	0.85
2	0.000	0.000	5.986	0.000	9.976	0.006	0.013	0.015	0.006	0.000	0.000	1.832	0.012	0.157	18.0	100.2	0.84
3	0.014	0.000	5.922	0.000	10.100	0.005	0.007	0.027	0.011	0.000	0.000	1.967	0.005	0.029	18.1	98.4	0.85
6	0.025	0.000	5.868	0.000	10.056	0.013	0.039	0.005	0.035	0.004	0.010	1.747	0.017	0.236	18.1	98.6	0.80

7	0.025	0.007	5.876	0.000	10.035	0.005	0.018	0.021	0.020	0.000	0.004	1.979	0.015	0.006	18.1	97.9	0.84
8	0.057	0.000	5.910	0.000	9.927	0.026	0.011	0.002	0.061	0.005	0.015	1.807	0.005	0.188	18.1	98.8	0.83
9	0.018	0.000	5.938	0.000	10.098	0.000	0.005	0.008	0.014	0.000	0.002	1.956	0.000	0.045	18.1	98.9	0.86
10	0.024	0.008	5.976	0.000	9.875	0.039	0.031	0.005	0.021	0.000	0.007	1.737	0.025	0.238	18.0	99.2	0.79
11	0.064	0.005	5.664	0.000	9.775	0.057	0.022	0.000	0.185	0.014	0.034	1.825	0.034	0.141	18.1	95.7	0.78
12	0.029	0.000	5.878	0.000	10.018	0.031	0.019	0.003	0.016	0.013	0.030	1.731	0.039	0.230	18.1	98.2	0.81
13	0.044	0.003	5.943	0.000	9.898	0.025	0.012	0.003	0.022	0.008	0.023	1.706	0.044	0.251	18.0	99.4	0.82
14	0.029	0.000	5.949	0.000	9.744	0.025	0.006	0.003	0.030	0.055	0.134	1.778	0.024	0.198	18.0	97.9	0.82
15	0.049	0.000	5.922	0.000	9.896	0.031	0.028	0.002	0.025	0.013	0.028	1.784	0.091	0.125	18.1	98.3	0.79
16	0.024	0.015	5.967	0.000	9.904	0.064	0.052	0.006	0.017	0.000	0.003	1.953	0.011	0.037	18.1	100.2	0.77
17	0.045	0.004	5.885	0.000	9.985	0.025	0.039	0.000	0.032	0.008	0.020	1.792	0.007	0.201	18.1	98.9	0.79
18	0.008	0.000	5.957	0.000	10.038	0.020	0.018	0.006	0.011	0.000	0.000	1.859	0.005	0.136	18.1	99.4	0.83
19	0.027	0.020	5.964	0.000	9.777	0.174	0.072	0.005	0.017	0.000	0.002	1.734	0.029	0.238	18.1	99.9	0.62
20	0.037	0.006	5.991	0.000	9.872	0.045	0.034	0.004	0.021	0.000	0.005	1.955	0.008	0.038	18.0	99.4	0.80
21	0.012	0.000	5.976	0.000	9.959	0.008	0.010	0.004	0.000	0.003	0.006	1.743	0.004	0.253	18.0	101.0	0.84
22	0.030	0.005	5.911	0.018	9.946	0.022	0.055	0.004	0.008	0.007	0.020	1.814	0.047	0.139	18.1	98.9	0.77
23	0.015	0.020	5.912	0.000	10.052	0.011	0.058	0.005	0.008	0.000	0.010	1.696	0.059	0.245	18.1	98.9	0.76
24	0.056	0.003	5.910	0.000	9.875	0.036	0.026	0.000	0.043	0.009	0.027	1.688	0.066	0.246	18.1	99.0	0.79
26	0.037	0.000	5.944	0.000	9.935	0.026	0.028	0.004	0.011	0.011	0.022	1.826	0.032	0.142	18.0	99.2	0.81
27	0.016	0.000	5.895	0.000	10.016	0.022	0.015	0.003	0.040	0.000	0.007	1.760	0.000	0.240	18.1	97.8	0.83
28	0.033	0.012	5.912	0.000	10.064	0.050	0.038	0.004	0.020	0.000	0.003	1.851	0.007	0.143	18.1	98.7	0.79
29	0.054	0.003	5.902	0.000	9.841	0.067	0.026	0.002	0.049	0.009	0.027	1.794	0.029	0.178	18.1	98.3	0.78
30	0.005	0.003	5.982	0.000	10.005	0.008	0.022	0.002	0.000	0.000	0.002	1.629	0.029	0.342	18.0	99.8	0.82
31	0.040	0.007	5.928	0.000	9.986	0.046	0.055	0.004	0.027	0.000	0.006	1.804	0.068	0.128	18.1	99.2	0.75
32	0.040	0.014	5.933	0.000	9.837	0.189	0.061	0.000	0.017	0.003	0.010	1.700	0.063	0.237	18.1	98.2	0.62
33	0.043	0.003	5.823	0.000	9.787	0.036	0.041	0.002	0.101	0.007	0.028	1.636	0.140	0.225	18.0	98.7	0.75
34	0.048	0.009	5.932	0.000	10.013	0.052	0.025	0.005	0.023	0.000	0.006	1.692	0.041	0.267	18.1	98.5	0.79
35	0.074	0.033	5.910	0.000	9.846	0.077	0.088	0.000	0.049	0.003	0.012	1.763	0.006	0.231	18.1	98.3	0.67
36	0.042	0.007	5.934	0.000	9.789	0.103	0.040	0.003	0.035	0.009	0.024	1.715	0.031	0.254	18.0	99.2	0.74
37	0.031	0.000	5.908	0.000	9.943	0.030	0.010	0.004	0.026	0.012	0.031	1.840	0.027	0.133	18.1	98.4	0.83
38	0.041	0.010	5.945	0.000	9.942	0.050	0.051	0.004	0.023	0.003	0.007	1.580	0.062	0.358	18.1	97.8	0.74
39	0.058	0.000	5.918	0.000	9.943	0.043	0.039	0.000	0.034	0.004	0.009	1.749	0.036	0.215	18.1	97.9	0.78
40	0.013	0.000	5.953	0.000	10.071	0.002	0.000	0.016	0.011	0.000	0.000	1.800	0.000	0.200	18.1	99.2	0.86
41	0.032	0.003	5.908	0.000	9.925	0.036	0.013	0.003	0.015	0.015	0.035	1.614	0.064	0.322	18.1	98.9	0.80

BH54, Nordrahn Zone - Penninic, meta-gabbro. UTM zone 33N, 5236823N, 348318E, 1440 masl

AFT Age-Grains

2	0.013	0.044	5.950	0.000	9.992	0.008	0.044	0.005	0.011	0.007	0.009	1.357	0.039	0.604	18.1	100.1	0.77
3	0.013	0.058	5.990	0.000	9.898	0.007	0.034	0.003	0.011	0.004	0.009	1.256	0.044	0.699	18.0	102.2	0.77
4	0.008	0.050	5.970	0.000	9.971	0.005	0.034	0.003	0.010	0.001	0.008	0.905	0.048	1.047	18.1	98.6	0.76
5	0.007	0.043	5.880	0.000	10.182	0.007	0.046	0.002	0.008	0.006	0.009	1.250	0.038	0.712	18.2	99.6	0.76
8	0.005	0.050	6.020	0.000	9.835	0.004	0.043	0.007	0.010	0.004	0.004	1.346	0.037	0.617	18.0	103.6	0.77
10	0.000	0.048	6.020	0.000	9.848	0.008	0.038	0.005	0.008	0.003	0.010	1.447	0.055	0.499	18.0	102.2	0.78
11	0.015	0.056	5.970	0.000	9.970	0.006	0.034	0.005	0.012	0.003	0.006	1.167	0.043	0.790	18.1	99.8	0.77
12	0.008	0.044	5.970	0.000	9.975	0.009	0.028	0.003	0.010	0.003	0.013	1.249	0.041	0.711	18.1	100.8	0.78
13	0.011	0.050	6.040	0.000	9.783	0.004	0.025	0.007	0.009	0.009	0.009	1.334	0.041	0.626	17.9	101.9	0.79
14	0.007	0.045	6.010	0.000	9.898	0.003	0.028	0.001	0.006	0.001	0.007	1.253	0.040	0.707	18.0	101.4	0.79
18	0.023	0.029	5.930	0.000	10.059	0.007	0.033	0.003	0.016	0.012	0.017	1.187	0.058	0.755	18.1	99.1	0.77
19	0.021	0.054	5.980	0.001	9.923	0.006	0.039	0.004	0.009	0.006	0.010	1.203	0.040	0.757	18.0	101.4	0.77
20	0.008	0.054	5.970	0.000	9.942	0.006	0.055	0.005	0.012	0.004	0.005	1.222	0.045	0.733	18.1	99.7	0.74
22	0.011	0.056	5.980	0.002	9.952	0.002	0.024	0.004	0.012	0.000	0.007	1.315	0.046	0.639	18.1	100.4	0.79
24	0.005	0.045	6.030	0.000	9.828	0.002	0.028	0.007	0.008	0.001	0.008	1.421	0.024	0.555	18.0	101.6	0.80
25	0.006	0.039	5.980	0.000	9.934	0.005	0.045	0.003	0.010	0.003	0.012	1.301	0.040	0.659	18.0	100.9	0.76
26	0.003	0.051	6.030	0.000	9.773	0.008	0.051	0.005	0.011	0.003	0.015	1.178	0.038	0.784	18.0	102.6	0.75
27	0.007	0.048	6.000	0.000	9.865	0.008	0.053	0.007	0.008	0.007	0.007	1.255	0.053	0.693	18.0	102.0	0.74
28	0.004	0.049	5.990	0.000	9.912	0.008	0.033	0.005	0.010	0.002	0.009	1.194	0.041	0.765	18.0	101.0	0.77
29	0.007	0.056	5.890	0.000	10.173	0.005	0.034	0.006	0.008	0.000	0.007	1.230	0.046	0.724	18.2	98.2	0.77
30	0.013	0.049	6.010	0.000	9.890	0.006	0.033	0.003	0.006	0.000	0.004	1.215	0.037	0.748	18.0	101.1	0.78
32	0.013	0.048	5.950	0.000	10.015	0.012	0.041	0.002	0.008	0.006	0.002	1.252	0.040	0.708	18.1	99.4	0.76
34	0.010	0.050	6.030	0.000	9.796	0.011	0.042	0.005	0.006	0.007	0.007	1.193	0.040	0.768	18.0	100.9	0.76
35	0.004	0.046	5.930	0.000	10.062	0.005	0.046	0.003	0.014	0.001	0.011	1.252	0.044	0.704	18.1	98.7	0.76
37	0.000	0.043	6.000	0.000	9.892	0.010	0.039	0.003	0.008	0.004	0.009	1.232	0.042	0.727	18.0	101.7	0.77
38	0.014	0.036	6.040	0.000	9.771	0.013	0.037	0.004	0.013	0.005	0.010	1.249	0.050	0.702	17.9	99.7	0.77
39	0.009	0.053	6.070	0.000	9.711	0.009	0.035	0.003	0.007	0.005	0.007	1.213	0.038	0.749	17.9	102.7	0.77

AFT Length-Grains																	
1	0.004	0.001	6.040	0.002	9.892	0.001	0.000	0.001	0.001	0.000	0.000	1.282	0.003	0.716	17.9	103.9	0.83
5	0.016	0.058	5.990	0.000	9.916	0.009	0.029	0.003	0.012	0.007	0.009	1.351	0.045	0.605	18.0	100.7	0.79
6	0.012	0.044	6.030	0.001	9.822	0.003	0.041	0.003	0.008	0.004	0.006	1.156	0.044	0.800	18.0	102.4	0.76
7	0.021	0.054	5.970	0.000	9.939	0.008	0.036	0.004	0.011	0.006	0.007	1.268	0.038	0.693	18.1	102.3	0.77

BH73, Nordrahnmen Zone - Penninic, meta-gabbro. UTM zone 33N, 5233572N, 346333E, 1350 masl

AFT Age-Grains																	
11	0.015	0.005	5.910	0.004	10.190	0.000	0.008	0.002	0.008	0.000	0.003	0.193	0.025	1.782	18.1	97.0	0.84
13	0.016	0.003	5.940	0.003	10.138	0.000	0.000	0.003	0.000	0.000	0.000	0.147	0.004	1.849	18.1	95.5	0.86
14	0.017	0.017	6.010	0.008	9.919	0.005	0.017	0.001	0.007	0.003	0.000	0.141	0.109	1.751	18.0	97.5	0.81
16	0.617	0.019	5.940	0.011	9.801	0.001	0.005	0.001	0.008	0.000	0.001	0.162	0.360	1.479	18.4	96.5	0.70
18	0.037	0.020	5.970	0.007	10.034	0.003	0.011	0.000	0.010	0.000	0.004	0.174	0.065	1.760	18.1	97.1	0.83
19	0.001	0.002	5.950	0.000	10.108	0.011	0.000	0.002	0.005	0.000	0.000	1.813	0.023	0.164	18.1	97.3	0.85
20	0.004	0.015	5.950	0.006	10.076	0.002	0.009	0.001	0.008	0.003	0.000	0.194	0.046	1.761	18.1	100.4	0.84
23	0.016	0.023	6.010	0.006	9.911	0.005	0.021	0.000	0.010	0.001	0.000	0.244	0.153	1.603	18.0	95.8	0.79
24	0.000	0.017	5.970	0.002	10.031	0.003	0.017	0.002	0.007	0.001	0.001	0.210	0.144	1.646	18.0	97.5	0.80
25	0.007	0.010	5.980	0.000	10.037	0.000	0.001	0.001	0.001	0.000	0.001	0.226	0.004	1.770	18.0	99.3	0.85
26	0.019	0.035	5.970	0.001	10.064	0.000	0.000	0.011	0.001	0.000	0.000	0.132	0.005	1.863	18.1	97.6	0.86
27	0.010	0.024	5.960	0.003	10.064	0.005	0.011	0.000	0.006	0.000	0.001	0.177	0.084	1.739	18.1	97.6	0.82
28	0.417	0.021	5.930	0.005	9.935	0.000	0.009	0.002	0.006	0.000	0.001	0.130	0.104	1.766	18.3	99.0	0.80
29	0.116	0.021	5.960	0.007	10.003	0.004	0.012	0.000	0.009	0.000	0.000	0.196	0.095	1.709	18.1	97.7	0.81
30	0.009	0.015	5.990	0.005	9.992	0.002	0.008	0.000	0.007	0.000	0.001	0.243	0.071	1.687	18.0	96.2	0.83
31	0.002	0.004	6.020	0.002	9.947	0.004	0.004	0.004	0.001	0.000	0.001	1.663	0.009	0.329	18.0	95.7	0.84
32	0.000	0.002	5.930	0.000	10.155	0.002	0.009	0.004	0.001	0.005	0.000	0.201	0.001	1.798	18.1	97.8	0.85
34	0.024	0.017	5.980	0.005	9.979	0.003	0.023	0.001	0.007	0.002	0.001	0.129	0.145	1.726	18.0	98.9	0.80
37	0.020	0.010	6.000	0.003	9.953	0.006	0.000	0.000	0.010	0.006	0.002	0.145	0.064	1.792	18.0	96.9	0.84
38	0.014	0.015	6.080	0.005	9.766	0.003	0.002	0.000	0.010	0.000	0.002	0.196	0.069	1.736	17.9	96.7	0.84
39	0.020	0.013	6.030	0.003	9.896	0.006	0.009	0.001	0.007	0.000	0.000	0.228	0.071	1.702	18.0	95.5	0.83
40	0.031	0.023	5.990	0.006	9.962	0.009	0.020	0.000	0.008	0.002	0.000	0.160	0.139	1.702	18.0	97.7	0.80

AFT Length-Grains																	
1	0.013	0.012	6.060	0.009	9.792	0.007	0.013	0.004	0.012	0.000	0.005	0.141	0.138	1.721	17.9	101.8	0.81
2	0.000	0.000	6.020	0.003	9.945	0.000	0.000	0.006	0.000	0.000	0.000	0.169	0.000	1.831	18.0	100.3	0.86
3	0.007	0.014	6.010	0.010	9.925	0.002	0.016	0.003	0.009	0.000	0.004	0.162	0.032	1.806	18.0	100.6	0.83
4	0.005	0.006	6.000	0.008	9.970	0.004	0.007	0.002	0.006	0.000	0.002	0.137	0.051	1.813	18.0	100.1	0.84
5	0.013	0.008	5.990	0.007	9.997	0.004	0.009	0.000	0.008	0.000	0.000	0.168	0.050	1.782	18.0	100.0	0.84

6	0.008	0.017	6.020	0.007	9.888	0.007	0.017	0.004	0.009	0.000	0.004	0.487	0.209	1.305	18.0	100.1	0.76
7	0.000	0.020	5.950	0.006	10.088	0.005	0.015	0.002	0.005	0.000	0.003	0.275	0.131	1.593	18.1	98.1	0.80
8	0.005	0.011	6.000	0.006	9.962	0.005	0.008	0.005	0.008	0.000	0.000	0.146	0.032	1.822	18.0	100.1	0.84
9	0.008	0.016	6.010	0.007	9.917	0.004	0.013	0.004	0.008	0.000	0.003	0.113	0.112	1.775	18.0	100.5	0.82
10	0.009	0.018	6.030	0.005	9.864	0.004	0.019	0.002	0.009	0.000	0.003	0.164	0.118	1.719	18.0	100.4	0.81
11	0.007	0.052	6.010	0.002	9.956	0.000	0.007	0.008	0.000	0.000	0.000	0.196	0.005	1.799	18.0	96.8	0.85
12	0.000	0.006	6.050	0.006	9.831	0.007	0.014	0.005	0.008	0.000	0.000	0.125	0.245	1.630	17.9	100.3	0.78
13	0.000	0.000	5.990	0.000	10.007	0.000	0.000	0.007	0.000	0.000	0.000	0.186	0.002	1.812	18.0	100.0	0.86
14	0.005	0.000	5.990	0.000	10.014	0.000	0.004	0.004	0.000	0.000	0.000	0.191	0.004	1.805	18.0	100.4	0.85
15	0.010	0.012	5.970	0.006	10.025	0.000	0.007	0.006	0.007	0.000	0.003	0.178	0.027	1.795	18.0	99.3	0.84
16	0.011	0.018	6.050	0.007	9.830	0.005	0.016	0.006	0.007	0.000	0.004	0.143	0.126	1.732	17.9	100.0	0.81
17	0.008	0.007	5.970	0.007	10.040	0.006	0.007	0.003	0.008	0.000	0.000	0.134	0.066	1.800	18.0	98.9	0.84
18	0.014	0.015	5.960	0.007	10.032	0.005	0.021	0.003	0.011	0.000	0.004	0.211	0.081	1.708	18.1	99.4	0.81
19	0.004	0.000	5.950	0.002	10.124	0.003	0.000	0.005	0.000	0.000	0.000	1.425	0.004	0.572	18.1	100.0	0.84
20	0.016	0.019	5.920	0.007	10.122	0.006	0.015	0.002	0.009	0.000	0.006	0.240	0.054	1.706	18.1	98.9	0.82
21	0.014	0.010	5.960	0.012	10.057	0.004	0.010	0.004	0.014	0.000	0.005	0.147	0.229	1.624	18.1	99.5	0.79

***BH45, Glockner Nappe System - Penninic, meta-basite. UTM zone 33N, 5231852N, 349524E, 1310 masl**

AFT Age-Grains

2	0.009	0.000	5.990	0.000	10.017	0.002	0.000	0.002	0.000	0.000	0.002	1.228	0.002	0.770	18.0	100.7	0.83
4	0.000	0.001	6.050	0.000	9.862	0.003	0.008	0.000	0.000	0.005	0.000	1.317	0.003	0.680	17.9	101.2	0.83
5	0.006	0.000	6.020	0.002	9.917	0.004	0.013	0.001	0.000	0.000	0.000	1.251	0.002	0.746	18.0	101.6	0.82
6	0.004	0.000	6.040	0.005	9.894	0.009	0.000	0.000	0.000	0.002	0.000	1.235	0.004	0.762	17.9	101.8	0.83
7	0.000	0.000	6.000	0.002	9.993	0.007	0.008	0.000	0.001	0.002	0.000	1.307	0.001	0.692	18.0	101.9	0.82
9	0.004	0.000	6.010	0.003	9.952	0.000	0.009	0.004	0.001	0.001	0.000	1.331	0.000	0.669	18.0	101.7	0.83
12	0.048	0.004	5.960	0.004	10.057	0.002	0.000	0.001	0.002	0.002	0.003	1.210	0.006	0.784	18.1	100.6	0.83
15	0.000	0.000	6.010	0.001	9.964	0.006	0.000	0.000	0.001	0.000	0.001	1.368	0.001	0.631	18.0	102.0	0.84
17	0.006	0.000	5.990	0.000	10.012	0.005	0.000	0.002	0.000	0.000	0.000	1.288	0.001	0.711	18.0	102.0	0.83
18	0.006	0.001	6.030	0.000	9.917	0.005	0.000	0.000	0.000	0.000	0.000	1.189	0.001	0.810	18.0	101.5	0.83
19	0.019	0.000	6.020	0.000	9.943	0.001	0.002	0.000	0.000	0.000	0.000	1.274	0.009	0.717	18.0	101.4	0.83
20	0.000	0.000	6.030	0.000	9.910	0.002	0.005	0.000	0.000	0.000	0.000	1.213	0.001	0.786	18.0	102.8	0.83
21	0.009	0.000	6.000	0.001	9.978	0.004	0.004	0.000	0.001	0.000	0.000	1.293	0.000	0.707	18.0	102.1	0.83
22	0.000	0.000	6.030	0.000	9.919	0.002	0.002	0.000	0.001	0.003	0.000	1.277	0.001	0.723	18.0	102.0	0.83
24	0.005	0.000	6.030	0.000	9.927	0.001	0.001	0.001	0.001	0.001	0.000	1.284	0.002	0.715	18.0	102.2	0.83

AFT Length-Grains																	
3	0.010	0.000	6.060	0.003	9.829	0.003	0.000	0.003	0.001	0.000	0.000	1.203	0.003	0.794	17.9	102.6	0.83
4	0.001	0.001	6.040	0.003	9.900	0.000	0.000	0.000	0.001	0.001	0.000	1.322	0.001	0.677	17.9	100.9	0.84
5	0.004	0.000	5.910	0.001	10.211	0.003	0.000	0.000	0.000	0.001	0.000	1.373	0.002	0.625	18.1	100.3	0.84
6	0.000	0.000	6.040	0.001	9.887	0.008	0.003	0.001	0.003	0.002	0.000	1.201	0.001	0.798	17.9	102.2	0.83
7	0.000	0.001	5.950	0.000	10.109	0.003	0.006	0.001	0.001	0.000	0.001	1.330	0.000	0.670	18.1	101.3	0.83
9	0.002	0.000	6.010	0.002	9.974	0.002	0.000	0.000	0.002	0.000	0.002	1.265	0.000	0.735	18.0	102.5	0.83
11	0.002	0.001	6.030	0.002	9.891	0.003	0.013	0.002	0.003	0.001	0.003	1.231	0.002	0.767	18.0	102.2	0.82
12	0.006	0.000	6.000	0.002	9.971	0.005	0.009	0.002	0.001	0.000	0.000	1.339	0.001	0.661	18.0	102.5	0.83

BH61, Glockner Nappe System - Penninic, meta-gabbro. UTM zone 33N, 5225311N, 348189E, 1680 masl

AFT Age-Grains																	
1	0.003	0.001	5.994	0.003	9.982	0.002	0.008	0.006	0.002	0.000	0.001	1.320	0.011	0.669	18.0	100.9	0.83
2	0.014	0.028	5.939	0.002	9.955	0.009	0.049	0.003	0.010	0.006	0.008	1.267	0.007	0.726	18.1	101.9	0.76
5	0.015	0.021	5.953	0.000	9.934	0.006	0.019	0.002	0.015	0.007	0.012	1.131	0.005	0.864	18.0	100.9	0.80
6	0.004	0.012	5.920	0.001	10.056	0.003	0.012	0.001	0.014	0.008	0.011	1.164	0.004	0.832	18.1	101.4	0.81
8	0.003	0.019	5.927	0.000	10.010	0.007	0.010	0.004	0.014	0.008	0.006	1.182	0.003	0.815	18.1	100.6	0.81
9	0.005	0.024	5.929	0.000	10.019	0.006	0.010	0.002	0.013	0.007	0.009	1.043	0.002	0.955	18.1	101.9	0.81
10	0.019	0.005	5.963	0.000	9.966	0.001	0.008	0.013	0.012	0.004	0.012	1.154	0.004	0.842	18.0	101.3	0.82
11	0.007	0.034	5.961	0.000	9.923	0.007	0.016	0.002	0.013	0.004	0.011	1.050	0.003	0.946	18.0	101.2	0.80
13	0.016	0.019	5.887	0.000	10.105	0.010	0.018	0.003	0.014	0.000	0.015	1.115	0.003	0.882	18.1	98.3	0.80
14	0.017	0.032	5.907	0.000	10.044	0.007	0.037	0.004	0.013	0.007	0.004	1.077	0.004	0.919	18.1	99.5	0.77
15	0.013	0.029	5.926	0.000	9.975	0.008	0.025	0.003	0.016	0.005	0.012	1.113	0.004	0.883	18.1	99.6	0.79
18	0.003	0.012	5.916	0.000	10.071	0.006	0.009	0.003	0.010	0.005	0.011	1.061	0.002	0.937	18.1	101.3	0.81
22	0.000	0.011	5.951	0.000	9.962	0.005	0.012	0.004	0.014	0.005	0.010	1.187	0.005	0.809	18.0	102.4	0.81
23	0.010	0.010	5.939	0.000	9.993	0.002	0.018	0.005	0.015	0.002	0.008	1.122	0.004	0.874	18.0	102.2	0.80
24	0.000	0.036	5.981	0.000	9.880	0.009	0.020	0.002	0.010	0.003	0.012	1.154	0.007	0.839	18.0	101.7	0.80
25	0.009	0.000	6.031	0.000	9.898	0.004	0.004	0.010	0.002	0.000	0.000	1.080	0.000	0.920	18.0	101.5	0.82
26	0.007	0.043	5.944	0.000	9.886	0.006	0.036	0.005	0.015	0.000	0.013	1.120	0.000	0.880	18.0	99.2	0.77
27	0.008	0.036	5.979	0.000	9.873	0.006	0.033	0.006	0.011	0.000	0.009	1.083	0.004	0.913	18.0	100.7	0.78
28	0.004	0.035	5.965	0.000	9.890	0.005	0.031	0.004	0.013	0.004	0.008	1.110	0.000	0.890	18.0	99.8	0.78
29	0.007	0.029	5.902	0.000	10.018	0.007	0.026	0.007	0.018	0.003	0.010	1.181	0.004	0.815	18.1	99.3	0.79
30	0.008	0.000	6.030	0.000	9.846	0.003	0.007	0.006	0.005	0.000	0.005	1.265	0.005	0.730	17.9	101.3	0.82
31	0.000	0.025	5.963	0.000	9.915	0.005	0.024	0.006	0.015	0.003	0.007	1.146	0.000	0.854	18.0	100.4	0.79
32	0.007	0.030	5.964	0.000	9.884	0.006	0.031	0.006	0.012	0.002	0.009	1.068	0.000	0.932	18.0	100.6	0.78
33	0.014	0.030	5.872	0.000	10.166	0.007	0.030	0.006	0.011	0.002	0.006	1.085	0.003	0.912	18.2	98.6	0.78

34	0.006	0.019	5.918	0.000	10.057	0.005	0.018	0.005	0.011	0.003	0.007	1.159	0.007	0.835	18.1	99.2	0.80
35	0.000	0.028	5.912	0.000	10.067	0.007	0.023	0.007	0.011	0.000	0.007	1.076	0.000	0.924	18.1	98.7	0.79
36	0.000	0.007	5.953	0.000	10.068	0.003	0.000	0.024	0.005	0.000	0.000	1.158	0.004	0.839	18.1	100.1	0.83
37	0.000	0.026	5.908	0.000	10.047	0.006	0.022	0.006	0.014	0.003	0.008	1.108	0.003	0.889	18.1	98.8	0.79
38	0.014	0.035	5.894	0.000	10.055	0.006	0.022	0.006	0.014	0.004	0.009	1.122	0.000	0.878	18.1	98.6	0.79
39	0.013	0.010	5.942	0.000	10.025	0.004	0.012	0.006	0.012	0.002	0.007	1.169	0.004	0.828	18.1	99.3	0.81
40	0.010	0.027	5.872	0.000	10.171	0.007	0.023	0.007	0.010	0.000	0.008	1.134	0.003	0.863	18.2	98.6	0.79
41	0.000	0.011	5.999	0.000	9.858	0.004	0.013	0.009	0.014	0.000	0.006	1.131	0.004	0.865	18.0	101.2	0.81
42	0.000	0.005	6.001	0.000	9.909	0.003	0.000	0.006	0.007	0.002	0.005	1.114	0.004	0.882	18.0	100.9	0.82
43	0.000	0.035	5.899	0.000	10.080	0.004	0.026	0.004	0.010	0.002	0.008	1.146	0.003	0.851	18.1	99.2	0.79
44	0.004	0.027	5.925	0.000	10.021	0.005	0.024	0.006	0.011	0.003	0.007	1.149	0.003	0.849	18.1	99.0	0.79
45	0.011	0.020	5.937	0.000	10.032	0.007	0.010	0.005	0.010	0.000	0.007	1.179	0.003	0.818	18.1	99.7	0.81
46	0.011	0.008	5.983	0.000	9.941	0.006	0.007	0.014	0.011	0.000	0.006	1.085	0.006	0.910	18.0	100.8	0.81
47	0.000	0.025	5.972	0.000	9.893	0.007	0.023	0.005	0.011	0.005	0.009	1.158	0.005	0.837	18.0	100.3	0.79
48	0.008	0.017	5.943	0.000	10.038	0.002	0.018	0.004	0.009	0.000	0.005	1.126	0.003	0.871	18.1	100.4	0.80
49	0.016	0.034	5.975	0.000	9.869	0.004	0.029	0.005	0.014	0.000	0.012	1.065	0.000	0.935	18.0	100.1	0.78
50	0.000	0.025	5.906	0.000	10.049	0.005	0.028	0.004	0.015	0.004	0.009	1.166	0.004	0.830	18.1	98.6	0.79
51	0.000	0.046	5.909	0.000	9.996	0.006	0.034	0.005	0.011	0.005	0.009	1.191	0.003	0.807	18.1	99.6	0.78
52	0.004	0.026	5.927	0.000	10.018	0.006	0.021	0.006	0.011	0.002	0.007	1.108	0.002	0.890	18.1	98.9	0.79
53	0.000	0.023	5.984	0.000	9.812	0.006	0.028	0.006	0.016	0.004	0.012	1.140	0.004	0.856	17.9	100.9	0.79
54	0.006	0.014	5.972	0.000	9.917	0.005	0.006	0.005	0.013	0.003	0.009	1.131	0.004	0.866	18.0	100.3	0.82
55	0.010	0.036	5.990	0.000	9.862	0.007	0.028	0.007	0.012	0.000	0.007	1.083	0.000	0.917	18.0	100.1	0.78
56	0.013	0.016	5.904	0.000	10.088	0.004	0.016	0.006	0.012	0.004	0.008	1.108	0.000	0.892	18.1	99.2	0.80
57	0.006	0.028	5.863	0.000	10.131	0.004	0.022	0.005	0.016	0.004	0.009	1.150	0.000	0.850	18.1	98.6	0.80
58	0.005	0.018	5.935	0.000	10.029	0.005	0.020	0.009	0.011	0.004	0.006	1.136	0.004	0.861	18.1	100.4	0.80
59	0.008	0.036	5.946	0.000	9.905	0.008	0.030	0.008	0.017	0.003	0.009	1.050	0.007	0.943	18.0	97.8	0.78
60	0.000	0.000	5.920	0.000	10.167	0.002	0.000	0.031	0.000	0.000	0.000	1.169	0.002	0.829	18.1	99.3	0.83
61	0.000	0.000	5.993	0.000	10.008	0.003	0.000	0.008	0.000	0.000	0.000	1.085	0.003	0.912	18.0	100.3	0.82
62	0.008	0.037	5.968	0.000	9.878	0.007	0.026	0.005	0.014	0.004	0.009	1.058	0.002	0.940	18.0	100.7	0.78
63	0.000	0.003	5.980	0.000	9.957	0.003	0.000	0.008	0.010	0.000	0.005	1.134	0.000	0.866	18.0	100.2	0.83
64	0.007	0.023	5.978	0.000	9.877	0.005	0.019	0.006	0.013	0.005	0.008	1.091	0.002	0.907	18.0	100.6	0.80

AFT Length-Grains

1	0.000	0.000	5.994	0.000	9.947	0.002	0.000	0.046	0.003	0.000	0.006	1.117	0.002	0.882	18.0	102.5	0.82
2	0.017	0.008	5.914	0.000	10.093	0.004	0.013	0.002	0.011	0.001	0.008	1.072	0.002	0.926	18.1	99.0	0.80
3	0.000	0.001	6.033	0.001	9.893	0.004	0.007	0.003	0.000	0.000	0.003	1.071	0.004	0.925	17.9	102.3	0.82
4	0.019	0.018	5.983	0.000	9.892	0.001	0.026	0.005	0.011	0.003	0.006	1.127	0.005	0.868	18.0	102.2	0.79
5	0.001	0.012	5.951	0.000	10.021	0.005	0.014	0.003	0.008	0.001	0.006	1.081	0.004	0.916	18.0	101.5	0.80

6	0.011	0.004	5.937	0.000	10.047	0.004	0.000	0.006	0.010	0.000	0.007	1.100	0.005	0.896	18.1	101.0	0.82
7	0.024	0.019	5.871	0.000	10.108	0.006	0.057	0.001	0.013	0.001	0.012	1.155	0.002	0.844	18.2	97.7	0.74
8	0.009	0.027	5.907	0.005	10.047	0.008	0.023	0.001	0.012	0.003	0.005	1.296	0.004	0.700	18.1	101.3	0.80
9	0.010	0.020	5.872	0.000	10.118	0.004	0.012	0.002	0.016	0.004	0.015	1.085	0.004	0.911	18.1	99.1	0.80
10	0.001	0.000	5.944	0.000	10.047	0.004	0.012	0.002	0.008	0.001	0.008	1.114	0.003	0.883	18.1	98.7	0.81
12	0.003	0.020	5.929	0.001	10.068	0.001	0.015	0.001	0.009	0.000	0.005	1.126	0.002	0.873	18.1	101.1	0.81
13	0.019	0.032	5.936	0.000	10.001	0.004	0.019	0.002	0.011	0.004	0.003	1.074	0.003	0.923	18.1	101.7	0.79
14	0.005	0.005	5.955	0.000	10.023	0.006	0.010	0.005	0.009	0.001	0.003	1.126	0.002	0.872	18.0	102.1	0.81
15	0.013	0.022	5.949	0.000	9.978	0.008	0.016	0.001	0.010	0.001	0.006	1.094	0.004	0.901	18.0	102.2	0.80
16	0.012	0.005	5.992	0.000	9.872	0.004	0.009	0.002	0.015	0.000	0.013	1.166	0.005	0.829	18.0	101.8	0.81
17	0.007	0.031	5.850	0.001	10.218	0.007	0.027	0.004	0.008	0.000	0.009	1.094	0.002	0.904	18.2	99.6	0.79
18	0.000	0.000	5.930	0.000	10.123	0.000	0.000	0.041	0.001	0.006	0.000	1.031	0.002	0.967	18.1	99.8	0.82
19	0.015	0.030	5.947	0.000	9.986	0.005	0.028	0.004	0.009	0.002	0.004	1.121	0.004	0.876	18.1	101.4	0.79
21	0.000	0.000	6.010	0.000	9.959	0.003	0.000	0.012	0.000	0.000	0.000	1.161	0.001	0.838	18.0	103.1	0.83
23	0.005	0.029	5.971	0.002	9.914	0.007	0.027	0.002	0.013	0.005	0.003	1.033	0.004	0.964	18.0	102.4	0.78
24	0.012	0.033	5.983	0.000	9.849	0.006	0.021	0.002	0.013	0.004	0.010	1.064	0.006	0.930	18.0	102.5	0.79
25	0.011	0.032	5.944	0.001	9.929	0.009	0.033	0.004	0.011	0.005	0.007	1.139	0.002	0.859	18.0	102.5	0.78
26	0.000	0.002	5.990	0.000	9.970	0.001	0.000	0.029	0.002	0.008	0.002	1.124	0.002	0.874	18.0	102.5	0.82
27	0.004	0.041	5.905	0.000	9.974	0.007	0.031	0.005	0.017	0.000	0.010	1.119	0.000	0.881	18.1	98.0	0.78
28	0.004	0.000	5.980	0.000	10.009	0.000	0.000	0.039	0.000	0.000	0.000	1.141	0.011	0.848	18.0	99.3	0.83
29	0.007	0.006	5.992	0.000	9.911	0.004	0.014	0.008	0.012	0.000	0.004	1.201	0.007	0.792	18.0	99.4	0.81
30	0.006	0.036	5.993	0.000	9.833	0.006	0.034	0.006	0.013	0.002	0.008	1.035	0.002	0.963	18.0	100.1	0.77
31	0.000	0.000	5.952	0.000	10.054	0.003	0.003	0.014	0.005	0.000	0.000	1.125	0.006	0.869	18.1	97.6	0.82
32	0.000	0.010	5.847	0.002	10.190	0.006	0.025	0.006	0.015	0.004	0.009	1.133	0.003	0.864	18.2	96.7	0.79
34	0.006	0.004	5.953	0.000	10.026	0.006	0.014	0.030	0.005	0.000	0.003	1.111	0.003	0.886	18.1	98.6	0.80
35	0.008	0.048	5.843	0.000	10.136	0.006	0.039	0.006	0.015	0.004	0.010	1.138	0.006	0.856	18.2	96.6	0.77
36	0.011	0.033	5.950	0.002	9.961	0.008	0.029	0.005	0.010	0.003	0.004	1.042	0.006	0.952	18.0	98.7	0.78
37	0.000	0.000	6.010	0.000	9.957	0.002	0.000	0.016	0.000	0.000	0.000	1.113	0.000	0.888	18.0	98.9	0.83
38	0.011	0.013	5.970	0.000	9.970	0.005	0.005	0.006	0.009	0.002	0.005	1.129	0.005	0.866	18.0	99.2	0.82
39	0.014	0.021	5.937	0.000	10.012	0.005	0.011	0.006	0.014	0.003	0.006	1.107	0.004	0.889	18.1	98.2	0.81
40	0.000	0.000	6.034	0.000	9.905	0.003	0.000	0.009	0.000	0.000	0.000	1.028	0.003	0.969	17.9	98.8	0.82
41	0.000	0.000	5.958	0.000	10.070	0.000	0.000	0.035	0.000	0.000	0.000	1.161	0.006	0.833	18.1	99.1	0.83
42	0.000	0.002	5.962	0.000	9.997	0.004	0.000	0.007	0.012	0.000	0.006	1.247	0.007	0.747	18.0	100.4	0.83
43	0.008	0.027	5.942	0.000	9.955	0.006	0.027	0.005	0.013	0.003	0.010	1.112	0.006	0.882	18.0	100.1	0.79
44	0.003	0.000	5.942	0.000	10.063	0.003	0.000	0.007	0.010	0.000	0.007	1.108	0.000	0.892	18.1	99.6	0.82
45	0.012	0.004	5.904	0.002	10.091	0.002	0.000	0.009	0.014	0.004	0.011	1.121	0.005	0.874	18.1	98.0	0.82
46	0.000	0.014	5.920	0.000	10.013	0.004	0.013	0.010	0.016	0.004	0.010	1.236	0.003	0.761	18.1	99.9	0.81

47	0.010	0.024	5.976	0.000	9.935	0.005	0.020	0.004	0.009	0.002	0.003	1.070	0.002	0.929	18.0	98.5	0.80
48	0.000	0.013	5.915	0.000	10.082	0.005	0.019	0.006	0.010	0.000	0.007	1.131	0.007	0.862	18.1	97.6	0.80
49	0.012	0.014	5.967	0.000	9.936	0.005	0.011	0.006	0.013	0.005	0.007	1.117	0.006	0.877	18.0	98.3	0.81
50	0.006	0.018	5.946	0.000	9.989	0.004	0.015	0.007	0.011	0.000	0.006	1.131	0.003	0.866	18.0	99.3	0.80
51	0.000	0.002	5.952	0.000	10.108	0.002	0.000	0.008	0.000	0.000	0.000	1.134	0.003	0.863	18.1	100.1	0.83
52	0.009	0.013	5.964	0.000	9.944	0.007	0.016	0.007	0.010	0.005	0.006	1.176	0.002	0.822	18.0	99.3	0.81
53	0.004	0.007	5.901	0.000	10.135	0.005	0.000	0.009	0.010	0.000	0.007	1.155	0.005	0.840	18.1	97.8	0.82
54	0.006	0.027	5.921	0.000	10.040	0.005	0.023	0.005	0.011	0.000	0.008	1.133	0.004	0.864	18.1	98.6	0.79
55	0.005	0.009	5.982	0.000	9.897	0.006	0.004	0.010	0.012	0.002	0.007	1.081	0.004	0.916	18.0	99.9	0.82
56	0.011	0.011	6.025	0.000	9.798	0.006	0.008	0.005	0.017	0.002	0.010	1.063	0.000	0.937	17.9	101.0	0.81
57	0.006	0.028	5.865	0.000	10.118	0.005	0.033	0.004	0.014	0.003	0.009	1.078	0.006	0.916	18.1	97.6	0.78
58	0.007	0.012	5.948	0.000	10.016	0.004	0.009	0.007	0.013	0.000	0.008	1.079	0.004	0.917	18.0	98.2	0.81
59	0.016	0.020	5.910	0.000	10.065	0.003	0.019	0.006	0.012	0.004	0.009	1.102	0.000	0.898	18.1	99.3	0.80
60	0.008	0.002	5.923	0.000	10.095	0.003	0.000	0.007	0.010	0.000	0.008	1.144	0.004	0.852	18.1	98.9	0.83
61	0.000	0.002	5.957	0.000	10.022	0.000	0.008	0.007	0.008	0.000	0.006	1.368	0.008	0.624	18.0	99.9	0.83
62	0.013	0.013	5.966	0.000	9.934	0.006	0.016	0.004	0.013	0.003	0.010	1.136	0.000	0.864	18.0	98.1	0.80
63	0.010	0.032	5.971	0.000	9.826	0.008	0.023	0.007	0.015	0.003	0.012	1.111	0.000	0.889	18.0	100.6	0.79
64	0.000	0.018	5.976	0.000	9.893	0.004	0.006	0.007	0.013	0.000	0.008	1.096	0.002	0.902	18.0	100.8	0.81

BH51, Venediger Nappe System - Sub-Penninic, ortho-gneiss. UTM zone 33N, 5219506N, 348524E, 1460 masl

AFT Age-Grains

1	0.018	0.000	6.000	0.017	9.973	0.008	0.000	0.004	0.005	0.003	0.005	1.739	0.003	0.258	18.0	101.3	0.85
2	0.087	0.000	5.980	0.123	9.963	0.005	0.003	0.011	0.001	0.000	0.002	1.807	0.004	0.189	18.0	101.7	0.85
3	0.012	0.001	5.960	0.019	10.066	0.008	0.003	0.009	0.002	0.002	0.005	1.690	0.003	0.308	18.1	102.5	0.85
4	0.015	0.004	5.980	0.021	9.998	0.009	0.011	0.005	0.003	0.007	0.007	1.667	0.003	0.331	18.0	101.6	0.83
5	0.011	0.001	6.020	0.005	9.905	0.003	0.001	0.037	0.002	0.003	0.000	1.761	0.004	0.235	18.0	102.3	0.85
7	0.013	0.003	5.970	0.016	10.046	0.009	0.000	0.008	0.001	0.001	0.002	1.799	0.002	0.199	18.1	100.8	0.85
8	0.028	0.001	6.020	0.018	9.892	0.011	0.008	0.009	0.002	0.002	0.006	1.776	0.002	0.223	18.0	101.8	0.84
9	0.002	0.001	6.000	0.016	9.951	0.003	0.005	0.026	0.002	0.003	0.004	1.840	0.001	0.159	18.0	103.6	0.85
10	0.014	0.001	6.010	0.014	9.947	0.009	0.006	0.008	0.003	0.000	0.005	1.765	0.004	0.232	18.0	102.8	0.84
11	0.010	0.000	5.990	0.019	9.981	0.010	0.002	0.006	0.003	0.003	0.002	1.728	0.006	0.267	18.0	101.7	0.85
12	0.001	0.000	5.960	0.001	9.964	0.002	0.002	0.116	0.001	0.003	0.004	1.840	0.003	0.157	18.1	100.4	0.85
14	0.009	0.002	5.980	0.020	10.004	0.014	0.000	0.004	0.001	0.003	0.005	1.640	0.005	0.356	18.0	102.0	0.84
15	0.010	0.001	6.010	0.016	9.931	0.003	0.000	0.012	0.002	0.000	0.005	1.740	0.002	0.259	18.0	101.5	0.85
17	0.009	0.001	6.030	0.015	9.898	0.013	0.005	0.003	0.002	0.000	0.007	1.684	0.003	0.313	18.0	103.1	0.84
18	0.010	0.000	5.970	0.016	10.041	0.002	0.009	0.016	0.004	0.001	0.007	1.764	0.006	0.230	18.1	101.1	0.84
19	0.002	0.001	5.950	0.020	10.047	0.008	0.028	0.006	0.002	0.000	0.015	1.743	0.003	0.254	18.1	101.3	0.82

20	0.015	0.001	5.950	0.021	10.092	0.007	0.006	0.003	0.001	0.003	0.008	1.763	0.002	0.235	18.1	102.6	0.85
21	0.016	0.002	6.040	0.028	9.863	0.007	0.000	0.008	0.002	0.004	0.006	1.712	0.002	0.286	17.9	101.6	0.85
22	0.021	0.000	6.010	0.021	9.930	0.007	0.000	0.011	0.002	0.003	0.002	1.691	0.003	0.307	18.0	103.7	0.85
23	0.016	0.001	5.970	0.014	10.032	0.008	0.008	0.012	0.001	0.007	0.007	1.699	0.003	0.298	18.1	101.4	0.84
24	0.000	0.000	5.940	0.004	10.080	0.003	0.008	0.046	0.001	0.000	0.000	1.931	0.002	0.067	18.1	100.7	0.85
25	0.017	0.000	5.950	0.020	10.078	0.003	0.001	0.022	0.002	0.001	0.003	1.710	0.003	0.287	18.1	102.3	0.85
26	0.013	0.003	6.020	0.024	9.897	0.009	0.000	0.005	0.003	0.002	0.004	1.666	0.001	0.333	18.0	102.3	0.85
27	0.018	0.002	6.040	0.019	9.858	0.007	0.001	0.009	0.002	0.000	0.006	1.734	0.002	0.265	17.9	102.5	0.85
28	0.004	0.000	5.990	0.000	9.919	0.002	0.001	0.094	0.002	0.000	0.002	1.739	0.004	0.257	18.0	101.8	0.85
29	0.001	0.000	5.980	0.000	9.898	0.003	0.006	0.134	0.002	0.000	0.000	1.810	0.002	0.188	18.0	101.7	0.84
30	0.009	0.000	5.940	0.005	10.095	0.004	0.002	0.042	0.001	0.007	0.001	1.713	0.001	0.286	18.1	101.6	0.85
32	0.027	0.003	6.030	0.020	9.871	0.011	0.004	0.004	0.004	0.000	0.009	1.677	0.003	0.320	18.0	102.2	0.84
33	0.019	0.000	6.000	0.020	9.968	0.003	0.006	0.016	0.002	0.001	0.001	1.759	0.004	0.237	18.0	101.7	0.85
34	0.004	0.000	5.990	0.001	9.972	0.005	0.002	0.030	0.003	0.000	0.002	1.828	0.003	0.169	18.0	101.4	0.85
35	0.020	0.000	6.010	0.016	9.916	0.012	0.002	0.013	0.001	0.001	0.007	1.801	0.003	0.196	18.0	101.5	0.85
36	0.005	0.003	5.970	0.017	10.022	0.013	0.007	0.007	0.002	0.003	0.004	1.722	0.004	0.274	18.0	101.7	0.84
37	0.023	0.003	6.050	0.018	9.824	0.011	0.007	0.009	0.003	0.001	0.007	1.509	0.017	0.475	17.9	97.3	0.83
38	0.011	0.001	5.990	0.021	9.983	0.008	0.007	0.008	0.003	0.003	0.006	1.800	0.003	0.197	18.0	101.3	0.85
39	0.015	0.003	6.020	0.016	9.886	0.011	0.000	0.008	0.004	0.008	0.007	1.641	0.002	0.358	18.0	102.1	0.84

AFT Length-Grains

1	0.033	0.002	5.990	0.014	9.961	0.012	0.007	0.007	0.005	0.004	0.016	1.964	0.001	0.035	18.0	101.5	0.85
2	0.023	0.002	5.980	0.010	10.000	0.011	0.002	0.005	0.003	0.006	0.011	2.106	0.002	0.000	18.1	101.0	0.86
3	0.014	0.001	6.030	0.019	9.872	0.006	0.002	0.026	0.002	0.004	0.008	1.720	0.002	0.279	18.0	101.9	0.85
4	0.000	0.001	5.960	0.016	10.080	0.010	0.000	0.008	0.003	0.001	0.004	1.844	0.003	0.153	18.1	101.7	0.86
5	0.011	0.001	6.030	0.018	9.895	0.006	0.000	0.013	0.001	0.000	0.004	1.705	0.002	0.294	18.0	102.4	0.85
6	0.014	0.000	5.980	0.012	10.003	0.007	0.000	0.030	0.003	0.000	0.000	1.954	0.001	0.045	18.0	101.4	0.86
7	0.018	0.000	6.030	0.016	9.870	0.003	0.012	0.033	0.001	0.000	0.004	1.749	0.001	0.250	18.0	102.8	0.84
8	0.027	0.000	6.030	0.040	9.863	0.008	0.000	0.011	0.002	0.005	0.009	1.641	0.003	0.357	18.0	102.4	0.85
9	0.026	0.000	6.000	0.018	9.965	0.010	0.000	0.006	0.002	0.001	0.000	1.742	0.003	0.256	18.0	101.7	0.85
12	0.007	0.004	6.020	0.019	9.915	0.011	0.005	0.006	0.002	0.006	0.003	1.657	0.002	0.342	18.0	102.9	0.84
14	0.019	0.001	5.970	0.017	10.037	0.009	0.005	0.007	0.003	0.003	0.009	1.630	0.003	0.367	18.1	101.7	0.84
15	0.003	0.001	6.010	0.017	9.933	0.004	0.002	0.008	0.004	0.000	0.012	1.900	0.002	0.098	18.0	102.1	0.86
16	0.021	0.001	6.030	0.019	9.881	0.007	0.008	0.012	0.002	0.001	0.005	1.736	0.004	0.260	18.0	103.0	0.84
17	0.016	0.001	6.020	0.021	9.905	0.007	0.000	0.016	0.002	0.004	0.007	1.740	0.002	0.258	18.0	102.4	0.85
20	0.016	0.001	6.000	0.021	9.949	0.008	0.013	0.007	0.001	0.000	0.002	1.760	0.002	0.237	18.0	102.2	0.84
21	0.002	0.001	5.970	0.002	10.019	0.004	0.007	0.031	0.002	0.000	0.000	1.775	0.002	0.222	18.0	101.5	0.85

BH74, Venediger Nappe System - Sub-Penninic, para-gneiss. UTM zone 33N, 5214805N, 346069E, 1720 masl

AFT Age-Grains

1	0.023	0.004	6.040	0.020	9.827	0.012	0.015	0.006	0.004	0.005	0.007	1.448	0.002	0.550	17.9	102.3	0.82
2	0.032	0.003	5.980	0.021	9.981	0.011	0.000	0.004	0.007	0.005	0.008	1.449	0.002	0.549	18.0	100.7	0.83
3	0.024	0.003	6.000	0.022	9.936	0.020	0.005	0.006	0.006	0.003	0.014	1.488	0.003	0.509	18.0	101.3	0.83
4	0.020	0.005	6.020	0.024	9.859	0.017	0.015	0.009	0.010	0.008	0.015	1.488	0.000	0.512	18.0	101.2	0.82
5	0.021	0.003	6.010	0.017	9.914	0.015	0.001	0.007	0.006	0.007	0.012	1.455	0.002	0.542	18.0	101.6	0.83
6	0.025	0.008	6.040	0.023	9.815	0.016	0.009	0.008	0.006	0.006	0.015	1.540	0.002	0.458	17.9	101.9	0.83
7	0.021	0.001	6.020	0.017	9.905	0.007	0.006	0.006	0.005	0.002	0.006	1.526	0.001	0.473	18.0	101.4	0.83
8	0.027	0.002	5.990	0.022	9.961	0.015	0.004	0.007	0.008	0.005	0.014	1.524	0.003	0.472	18.0	101.8	0.83
9	0.014	0.002	6.020	0.017	9.884	0.012	0.008	0.010	0.008	0.002	0.013	1.563	0.002	0.435	18.0	102.7	0.83
10	0.022	0.005	6.050	0.020	9.794	0.014	0.005	0.007	0.007	0.004	0.015	1.445	0.002	0.554	17.9	101.5	0.83
11	0.020	0.003	6.010	0.024	9.919	0.015	0.004	0.007	0.006	0.006	0.011	1.487	0.003	0.509	18.0	101.1	0.83
13	0.016	0.000	5.970	0.027	9.994	0.012	0.001	0.012	0.007	0.015	0.017	1.544	0.002	0.454	18.0	101.2	0.84
14	0.013	0.002	6.010	0.016	9.916	0.009	0.011	0.007	0.006	0.008	0.010	1.431	0.001	0.568	18.0	101.9	0.82
15	0.003	0.002	6.010	0.015	9.925	0.008	0.009	0.007	0.006	0.009	0.015	1.513	0.002	0.486	18.0	102.3	0.83
16	0.030	0.003	5.990	0.017	9.944	0.019	0.012	0.007	0.007	0.005	0.013	1.564	0.003	0.433	18.0	102.1	0.82
17	0.018	0.003	5.990	0.017	9.956	0.017	0.003	0.005	0.007	0.001	0.009	1.582	0.002	0.416	18.0	101.9	0.84
18	0.013	0.002	6.010	0.017	9.912	0.009	0.016	0.015	0.006	0.000	0.006	1.498	0.003	0.499	18.0	102.0	0.82
19	0.017	0.001	6.010	0.019	9.922	0.011	0.003	0.009	0.005	0.000	0.010	1.466	0.001	0.533	18.0	102.3	0.83
20	0.032	0.003	6.060	0.019	9.788	0.018	0.002	0.007	0.005	0.001	0.008	1.424	0.001	0.576	17.9	101.8	0.83
21	0.010	0.000	6.040	0.017	9.857	0.005	0.004	0.017	0.004	0.000	0.001	1.590	0.004	0.406	17.9	101.6	0.84
22	0.022	0.003	6.030	0.021	9.843	0.014	0.009	0.009	0.005	0.008	0.011	1.415	0.003	0.583	18.0	101.8	0.82
23	0.024	0.000	6.090	0.017	9.718	0.014	0.002	0.008	0.007	0.001	0.006	1.476	0.001	0.523	17.9	101.6	0.83
26	0.017	0.004	6.010	0.019	9.903	0.016	0.014	0.009	0.006	0.006	0.011	1.507	0.002	0.491	18.0	101.8	0.82
27	0.019	0.003	6.000	0.020	9.914	0.015	0.009	0.007	0.007	0.007	0.011	1.459	0.003	0.538	18.0	101.1	0.82
28	0.020	0.001	6.020	0.011	9.898	0.015	0.002	0.008	0.007	0.003	0.005	1.557	0.003	0.440	18.0	100.8	0.84
29	0.018	0.004	6.020	0.022	9.854	0.018	0.014	0.010	0.007	0.006	0.013	1.454	0.001	0.545	18.0	101.7	0.82
30	0.018	0.000	6.060	0.034	9.789	0.010	0.001	0.010	0.008	0.000	0.016	1.489	0.002	0.509	17.9	101.2	0.84
31	0.000	0.000	6.010	0.000	9.966	0.007	0.001	0.007	0.000	0.002	0.001	1.410	0.005	0.586	18.0	101.9	0.84
32	0.002	0.000	6.010	0.000	9.928	0.007	0.004	0.040	0.000	0.003	0.000	1.573	0.002	0.425	18.0	102.5	0.84
33	0.028	0.003	6.040	0.026	9.831	0.018	0.009	0.010	0.003	0.000	0.008	1.456	0.001	0.543	18.0	101.3	0.82
34	0.012	0.001	6.050	0.012	9.837	0.007	0.002	0.005	0.004	0.005	0.004	1.594	0.004	0.403	17.9	101.8	0.84
35	0.021	0.001	6.000	0.021	9.932	0.012	0.019	0.004	0.007	0.000	0.009	1.478	0.003	0.519	18.0	101.7	0.81
36	0.017	0.003	6.010	0.025	9.913	0.013	0.010	0.007	0.008	0.004	0.012	1.513	0.002	0.484	18.0	101.5	0.83
38	0.018	0.001	5.980	0.017	10.008	0.015	0.000	0.002	0.006	0.005	0.007	1.544	0.002	0.454	18.0	100.8	0.84

39	0.011	0.000	5.990	0.025	9.970	0.009	0.000	0.005	0.008	0.009	0.021	1.462	0.002	0.537	18.0	101.8	0.84
40	0.020	0.000	6.040	0.012	9.864	0.007	0.000	0.010	0.007	0.007	0.008	1.477	0.002	0.521	18.0	102.0	0.84

AFT Length-Grains

1	0.015	0.002	6.000	0.013	9.949	0.011	0.009	0.013	0.005	0.006	0.007	1.500	0.002	0.497	18.0	102.0	0.83
3	0.007	0.000	6.050	0.009	9.810	0.011	0.010	0.010	0.006	0.006	0.013	1.448	0.002	0.549	17.9	102.2	0.82
4	0.026	0.003	6.030	0.017	9.853	0.014	0.004	0.006	0.005	0.007	0.014	1.500	0.003	0.498	18.0	101.4	0.83
5	0.019	0.002	5.990	0.015	9.980	0.010	0.004	0.007	0.006	0.006	0.007	1.503	0.001	0.496	18.0	101.4	0.83
6	0.006	0.005	6.030	0.015	9.840	0.015	0.003	0.005	0.006	0.009	0.020	1.517	0.002	0.481	17.9	101.6	0.83
11	0.023	0.005	5.940	0.022	10.093	0.018	0.001	0.005	0.009	0.003	0.010	1.561	0.002	0.437	18.1	100.0	0.84
12	0.027	0.001	6.030	0.022	9.866	0.010	0.000	0.007	0.006	0.001	0.020	1.467	0.002	0.531	18.0	102.0	0.84
13	0.025	0.000	5.980	0.019	9.999	0.005	0.000	0.006	0.007	0.005	0.006	1.526	0.002	0.473	18.0	101.6	0.84
14	0.005	0.001	6.050	0.008	9.857	0.005	0.000	0.013	0.004	0.000	0.001	1.559	0.004	0.437	17.9	101.9	0.84
15	0.017	0.000	6.030	0.000	9.855	0.010	0.000	0.059	0.000	0.000	0.000	1.477	0.003	0.520	18.0	102.1	0.84
16	0.006	0.001	5.970	0.005	10.051	0.006	0.002	0.006	0.001	0.000	0.000	1.499	0.002	0.499	18.0	101.3	0.84
18	0.017	0.002	5.990	0.018	9.947	0.019	0.014	0.005	0.007	0.005	0.016	1.500	0.002	0.498	18.0	101.7	0.82
19	0.023	0.001	6.040	0.024	9.818	0.013	0.004	0.006	0.010	0.010	0.020	1.430	0.004	0.566	17.9	101.4	0.83
21	0.015	0.000	5.950	0.018	10.078	0.010	0.004	0.007	0.007	0.003	0.005	1.564	0.002	0.435	18.1	101.5	0.84
22	0.009	0.001	6.030	0.014	9.857	0.007	0.000	0.032	0.006	0.002	0.006	1.468	0.004	0.529	18.0	101.1	0.84
23	0.020	0.000	6.040	0.015	9.836	0.011	0.001	0.007	0.007	0.008	0.009	1.501	0.002	0.496	17.9	102.3	0.84
25	0.016	0.002	6.010	0.026	9.895	0.014	0.007	0.008	0.014	0.007	0.017	1.437	0.002	0.561	18.0	101.7	0.82
26	0.026	0.006	6.050	0.018	9.785	0.019	0.014	0.009	0.006	0.004	0.017	1.427	0.001	0.572	17.9	102.1	0.81
27	0.032	0.000	6.040	0.015	9.848	0.010	0.000	0.008	0.005	0.009	0.011	1.425	0.003	0.572	18.0	101.6	0.83
28	0.033	0.003	6.080	0.015	9.738	0.021	0.000	0.008	0.006	0.004	0.009	1.503	0.001	0.496	17.9	102.9	0.83
29	0.010	0.000	6.010	0.013	9.941	0.008	0.004	0.011	0.007	0.000	0.010	1.455	0.002	0.543	18.0	101.0	0.83
30	0.013	0.006	6.030	0.015	9.842	0.014	0.010	0.008	0.006	0.008	0.009	1.509	0.002	0.489	17.9	102.3	0.83
31	0.014	0.001	6.030	0.021	9.870	0.007	0.000	0.009	0.006	0.006	0.005	1.482	0.001	0.517	18.0	101.2	0.84
32	0.009	0.003	6.010	0.019	9.900	0.011	0.008	0.009	0.007	0.005	0.011	1.521	0.002	0.477	18.0	102.5	0.83

BH76, Venediger Nappe System - Sub-Penninic, ortho-gneiss. UTM zone 33N, 5213968N, 345556E, 2180 masl

AFT Age-Grains

1	0.007	0.002	6.040	0.013	9.892	0.004	0.001	0.004	0.001	0.000	0.000	1.057	0.006	0.937	17.9	101.6	0.82
2	0.021	0.005	5.980	0.000	9.978	0.005	0.011	0.001	0.019	0.000	0.009	1.050	0.002	0.948	18.0	98.8	0.81
3	0.000	0.003	6.040	0.000	9.857	0.007	0.006	0.027	0.001	0.003	0.000	1.095	0.010	0.895	17.9	101.4	0.81
4	0.004	0.003	6.030	0.001	9.871	0.011	0.006	0.035	0.001	0.006	0.000	1.277	0.015	0.709	18.0	100.6	0.82
5	0.002	0.003	6.010	0.000	9.955	0.009	0.002	0.001	0.008	0.000	0.002	1.087	0.008	0.905	18.0	102.3	0.82
7	0.023	0.000	5.970	0.004	10.029	0.007	0.001	0.003	0.013	0.000	0.001	1.120	0.021	0.859	18.1	101.2	0.82

8	0.005	0.000	6.010	0.001	9.948	0.006	0.007	0.003	0.007	0.000	0.000	1.195	0.003	0.803	18.0	101.2	0.82
9	0.000	0.001	5.990	0.000	9.969	0.005	0.002	0.031	0.004	0.001	0.003	1.203	0.009	0.788	18.0	101.9	0.82
10	0.012	0.000	6.000	0.000	9.967	0.008	0.002	0.006	0.006	0.000	0.001	1.145	0.019	0.836	18.0	100.8	0.82
11	0.010	0.000	6.010	0.011	9.935	0.003	0.009	0.005	0.013	0.000	0.004	1.130	0.018	0.852	18.0	101.4	0.81
12	0.005	0.001	6.040	0.000	9.898	0.005	0.000	0.002	0.003	0.000	0.001	1.084	0.007	0.909	17.9	102.3	0.82
13	0.008	0.000	6.020	0.000	9.921	0.007	0.000	0.004	0.007	0.000	0.000	1.099	0.014	0.888	18.0	102.3	0.82
14	0.049	0.000	5.990	0.013	9.926	0.004	0.008	0.011	0.009	0.011	0.019	1.219	0.018	0.763	18.0	100.6	0.81
15	0.000	0.002	6.010	0.000	9.927	0.006	0.004	0.027	0.002	0.004	0.000	1.083	0.012	0.905	18.0	101.2	0.82
16	0.000	0.003	5.970	0.000	10.028	0.006	0.000	0.020	0.003	0.000	0.004	1.132	0.021	0.847	18.0	101.2	0.82
17	0.008	0.000	6.000	0.000	9.964	0.006	0.011	0.003	0.011	0.000	0.000	1.078	0.009	0.913	18.0	100.1	0.81
18	0.000	0.003	6.030	0.000	9.891	0.012	0.007	0.019	0.001	0.000	0.000	1.082	0.023	0.896	18.0	102.6	0.81
19	0.005	0.003	6.040	0.003	9.852	0.010	0.005	0.014	0.004	0.000	0.003	1.402	0.015	0.584	17.9	103.3	0.83
20	0.000	0.001	6.020	0.000	9.915	0.007	0.000	0.010	0.004	0.000	0.001	1.079	0.023	0.898	18.0	102.0	0.82
21	0.016	0.003	5.990	0.001	9.996	0.002	0.000	0.006	0.006	0.002	0.001	1.104	0.010	0.886	18.0	102.1	0.82
22	0.016	0.001	6.070	0.000	9.796	0.003	0.009	0.002	0.006	0.000	0.000	1.039	0.010	0.951	17.9	103.2	0.81
23	0.010	0.002	6.020	0.000	9.888	0.009	0.012	0.043	0.000	0.001	0.000	1.086	0.011	0.903	18.0	101.2	0.80
24	0.004	0.000	5.920	0.005	10.168	0.004	0.000	0.005	0.004	0.003	0.002	1.540	0.028	0.433	18.1	97.7	0.84
25	0.026	0.001	6.000	0.014	9.915	0.005	0.014	0.009	0.007	0.008	0.014	1.165	0.015	0.820	18.0	100.9	0.80
27	0.013	0.001	6.020	0.007	9.924	0.006	0.007	0.004	0.008	0.000	0.000	1.218	0.026	0.757	18.0	101.8	0.82
28	0.010	0.000	6.030	0.000	9.889	0.008	0.000	0.005	0.018	0.005	0.000	1.238	0.002	0.760	18.0	101.3	0.83
29	0.025	0.000	6.030	0.014	9.853	0.007	0.012	0.007	0.019	0.000	0.008	1.153	0.016	0.831	18.0	101.6	0.81
30	0.004	0.002	6.050	0.006	9.836	0.005	0.011	0.004	0.005	0.000	0.005	1.026	0.022	0.952	17.9	102.7	0.80

AFT Length-Grains

1	0.025	0.000	6.000	0.017	9.918	0.015	0.002	0.009	0.011	0.004	0.017	1.149	0.019	0.832	18.0	101.9	0.81
2	0.002	0.000	6.050	0.000	9.843	0.004	0.005	0.003	0.007	0.005	0.001	1.492	0.020	0.488	17.9	101.5	0.83
3	0.019	0.000	6.070	0.001	9.797	0.008	0.005	0.001	0.008	0.002	0.000	1.107	0.023	0.870	17.9	103.0	0.81
4	0.006	0.000	5.950	0.000	10.089	0.003	0.005	0.002	0.010	0.001	0.000	1.241	0.030	0.729	18.1	101.2	0.82
5	0.029	0.000	5.930	0.000	10.126	0.006	0.006	0.002	0.012	0.000	0.002	1.019	0.021	0.960	18.1	100.8	0.81
6	0.024	0.001	6.020	0.000	9.901	0.008	0.005	0.003	0.009	0.000	0.002	1.066	0.016	0.918	18.0	102.8	0.81
9	0.030	0.001	6.010	0.017	9.887	0.009	0.021	0.012	0.019	0.001	0.004	1.148	0.019	0.833	18.0	101.0	0.79
10	0.005	0.000	5.980	0.000	10.045	0.007	0.000	0.003	0.003	0.000	0.000	1.294	0.009	0.697	18.0	100.6	0.83
11	0.010	0.000	6.000	0.002	9.977	0.004	0.000	0.003	0.008	0.000	0.000	1.240	0.030	0.731	18.0	101.5	0.83
12	0.014	0.003	6.070	0.000	9.799	0.008	0.000	0.003	0.013	0.000	0.001	1.074	0.017	0.909	17.9	102.6	0.82
13	0.000	0.002	5.940	0.000	10.117	0.007	0.000	0.019	0.001	0.000	0.000	1.097	0.008	0.896	18.1	99.9	0.82
14	0.016	0.001	6.050	0.000	9.837	0.006	0.001	0.003	0.020	0.006	0.000	1.110	0.005	0.885	17.9	101.7	0.82
15	0.003	0.001	6.010	0.000	9.945	0.008	0.005	0.001	0.010	0.000	0.003	1.279	0.012	0.709	18.0	101.2	0.82
16	0.003	0.001	5.940	0.000	10.141	0.001	0.003	0.001	0.006	0.000	0.000	1.149	0.029	0.823	18.1	98.9	0.82

19	0.005	0.003	6.060	0.000	9.828	0.010	0.002	0.010	0.005	0.000	0.000	1.077	0.008	0.915	17.9	103.1	0.82
23	0.001	0.002	6.000	0.000	9.941	0.007	0.000	0.032	0.002	0.000	0.003	1.155	0.010	0.835	18.0	102.8	0.82
25	0.017	0.001	5.990	0.000	9.972	0.006	0.005	0.004	0.016	0.000	0.007	1.091	0.004	0.905	18.0	101.0	0.82
27	0.013	0.001	5.990	0.000	9.981	0.010	0.007	0.004	0.013	0.001	0.002	1.120	0.015	0.865	18.0	102.2	0.81
28	0.008	0.000	6.010	0.012	9.933	0.004	0.014	0.008	0.017	0.000	0.007	1.096	0.037	0.867	18.0	101.1	0.80
31	0.014	0.001	6.040	0.000	9.843	0.004	0.000	0.024	0.007	0.005	0.000	1.174	0.003	0.823	17.9	101.1	0.83
33	0.003	0.001	6.000	0.000	9.938	0.007	0.008	0.026	0.004	0.003	0.001	1.073	0.014	0.913	18.0	102.2	0.81
34	0.004	0.002	6.010	0.000	9.930	0.007	0.011	0.013	0.002	0.000	0.000	1.077	0.011	0.911	18.0	102.5	0.81

BH65,Venediger Nappe System - Sub-Penninic, ortho-gneiss. UTM zone 33N, 5213130N, 344910E, 3080 masl

AFT Age-Grains

1	0.047	0.003	5.959	0.010	9.905	0.011	0.000	0.004	0.023	0.000	0.007	1.517	0.003	0.480	18.0	99.7	0.84
2	0.033	0.002	6.010	0.006	9.779	0.016	0.009	0.001	0.021	0.006	0.014	1.499	0.003	0.498	17.9	102.1	0.82
3	0.026	0.001	6.000	0.000	9.923	0.013	0.003	0.002	0.016	0.000	0.005	1.565	0.002	0.433	18.0	100.8	0.84
4	0.048	0.002	5.958	0.003	9.938	0.022	0.002	0.004	0.017	0.004	0.010	1.647	0.003	0.350	18.0	100.4	0.84
5	0.026	0.004	6.024	0.006	9.782	0.009	0.005	0.004	0.025	0.003	0.008	1.557	0.003	0.440	17.9	100.9	0.83
6	0.068	0.002	5.899	0.031	9.951	0.015	0.014	0.003	0.025	0.005	0.007	1.559	0.006	0.435	18.1	99.4	0.82
7	0.040	0.001	5.968	0.007	9.884	0.014	0.018	0.006	0.021	0.005	0.007	1.681	0.004	0.315	18.0	100.2	0.82
8	0.075	0.002	5.942	0.049	9.784	0.012	0.016	0.004	0.024	0.004	0.013	1.584	0.008	0.409	18.0	100.3	0.82
9	0.011	0.004	5.947	0.004	9.931	0.032	0.017	0.003	0.015	0.004	0.014	1.455	0.002	0.542	18.0	101.1	0.80
10	0.007	0.000	5.984	0.007	9.879	0.025	0.016	0.006	0.012	0.002	0.003	1.570	0.004	0.426	18.0	101.4	0.82
11	0.029	0.002	6.000	0.007	9.835	0.025	0.000	0.004	0.017	0.004	0.007	1.521	0.004	0.475	18.0	101.8	0.83
12	0.007	0.000	6.032	0.000	9.871	0.002	0.000	0.032	0.003	0.001	0.002	1.576	0.004	0.420	18.0	102.0	0.84
13	0.046	0.002	5.950	0.030	9.868	0.019	0.005	0.002	0.024	0.003	0.008	1.584	0.005	0.411	18.0	101.2	0.83
14	0.057	0.000	5.967	0.019	9.922	0.003	0.011	0.005	0.016	0.000	0.003	1.596	0.003	0.400	18.0	101.5	0.83
15	0.027	0.000	5.981	0.003	9.869	0.012	0.006	0.005	0.023	0.007	0.013	1.501	0.004	0.495	18.0	101.5	0.83
16	0.041	0.000	5.939	0.008	9.977	0.023	0.008	0.002	0.019	0.003	0.009	1.565	0.003	0.432	18.1	100.5	0.82
17	0.003	0.000	6.005	0.000	9.919	0.000	0.006	0.047	0.000	0.004	0.000	1.565	0.003	0.432	18.0	102.6	0.84
18	0.000	0.000	6.016	0.000	9.902	0.001	0.001	0.047	0.002	0.000	0.001	1.486	0.004	0.510	18.0	102.0	0.84
19	0.003	0.002	5.969	0.000	10.043	0.004	0.008	0.009	0.001	0.000	0.002	1.527	0.005	0.468	18.0	101.0	0.83
20	0.035	0.000	6.006	0.005	9.797	0.017	0.001	0.003	0.029	0.002	0.009	1.504	0.001	0.494	17.9	100.7	0.83
21	0.019	0.000	5.977	0.005	9.918	0.004	0.004	0.017	0.009	0.008	0.007	1.501	0.002	0.497	18.0	101.7	0.84
22	0.031	0.000	6.030	0.003	9.777	0.014	0.004	0.004	0.023	0.003	0.006	1.667	0.004	0.329	17.9	99.2	0.84
23	0.063	0.001	6.013	0.009	9.751	0.019	0.014	0.001	0.023	0.000	0.013	1.499	0.004	0.496	17.9	101.9	0.81
25	0.032	0.000	5.970	0.022	9.913	0.018	0.004	0.000	0.016	0.000	0.012	1.742	0.010	0.248	18.0	99.4	0.84
26	0.003	0.000	6.056	0.000	9.814	0.002	0.002	0.030	0.003	0.000	0.000	1.597	0.004	0.399	17.9	102.2	0.84
27	0.038	0.000	6.027	0.004	9.786	0.013	0.001	0.005	0.018	0.006	0.005	1.583	0.003	0.413	17.9	101.2	0.84

28	0.041	0.001	5.963	0.009	9.964	0.008	0.000	0.007	0.014	0.000	0.004	1.573	0.002	0.425	18.0	100.8	0.84
29	0.030	0.000	5.996	0.004	9.886	0.013	0.006	0.005	0.013	0.005	0.008	1.615	0.005	0.380	18.0	101.6	0.83
30	0.000	0.000	5.999	0.000	9.984	0.003	0.000	0.005	0.000	0.004	0.000	1.439	0.002	0.558	18.0	100.0	0.84
31	0.028	0.000	5.994	0.003	9.865	0.014	0.001	0.004	0.016	0.003	0.013	1.481	0.004	0.516	18.0	100.1	0.83
32	0.029	0.003	5.983	0.001	9.809	0.012	0.005	0.006	0.015	0.014	0.025	1.508	0.004	0.489	18.0	102.2	0.83
33	0.031	0.000	5.998	0.006	9.865	0.003	0.001	0.008	0.017	0.006	0.006	1.564	0.002	0.435	18.0	101.3	0.84
34	0.023	0.006	6.014	0.007	9.773	0.029	0.023	0.008	0.011	0.000	0.008	1.576	0.005	0.419	17.9	101.8	0.80
35	0.020	0.003	6.015	0.008	9.826	0.020	0.002	0.005	0.011	0.004	0.003	1.475	0.002	0.523	17.9	101.5	0.83
36	0.027	0.002	6.039	0.011	9.747	0.027	0.020	0.005	0.011	0.004	0.006	1.465	0.002	0.533	17.9	102.3	0.80
37	0.027	0.001	6.022	0.014	9.752	0.011	0.006	0.004	0.019	0.000	0.011	1.586	0.003	0.411	17.9	102.5	0.83
38	0.000	0.000	5.998	0.003	9.970	0.000	0.000	0.006	0.005	0.000	0.000	1.603	0.001	0.396	18.0	102.3	0.85
39	0.022	0.004	6.034	0.005	9.742	0.029	0.007	0.004	0.014	0.002	0.010	1.436	0.002	0.562	17.9	102.0	0.82
40	0.022	0.002	6.029	0.000	9.785	0.023	0.000	0.001	0.019	0.004	0.015	1.584	0.004	0.411	17.9	102.1	0.84

AFT Length-Grains

2	0.024	0.001	5.973	0.007	9.906	0.020	0.007	0.000	0.020	0.003	0.008	1.814	0.005	0.182	18.0	100.8	0.84
5	0.032	0.000	5.925	0.000	9.936	0.005	0.000	0.003	0.043	0.006	0.013	1.570	0.005	0.425	18.0	101.1	0.84
10	0.026	0.003	5.953	0.006	9.938	0.017	0.019	0.005	0.012	0.003	0.009	1.494	0.004	0.503	18.0	101.0	0.81
11	0.047	0.000	5.980	0.021	9.833	0.009	0.006	0.007	0.015	0.003	0.019	1.855	0.005	0.140	18.0	100.3	0.85
12	0.018	0.001	5.958	0.004	9.947	0.021	0.017	0.002	0.017	0.004	0.005	1.463	0.002	0.535	18.0	101.5	0.81
14	0.011	0.000	6.028	0.000	9.886	0.004	0.000	0.011	0.005	0.000	0.003	1.741	0.002	0.258	18.0	101.6	0.85
21	0.018	0.000	5.973	0.006	9.958	0.009	0.000	0.004	0.012	0.000	0.008	1.593	0.004	0.404	18.0	102.2	0.84
24	0.033	0.001	5.954	0.033	9.897	0.011	0.000	0.015	0.003	0.001	0.010	1.518	0.003	0.479	18.0	101.0	0.84
25	0.022	0.001	5.952	0.009	9.949	0.021	0.002	0.004	0.013	0.006	0.009	1.510	0.004	0.487	18.0	100.6	0.83
27	0.024	0.003	6.043	0.002	9.722	0.025	0.005	0.005	0.013	0.007	0.014	1.509	0.004	0.487	17.9	102.2	0.83
32	0.033	0.000	5.990	0.004	9.831	0.020	0.009	0.004	0.023	0.006	0.011	1.566	0.004	0.430	18.0	100.7	0.83
33	0.009	0.001	5.984	0.001	9.914	0.033	0.007	0.008	0.009	0.000	0.012	1.686	0.005	0.309	18.0	101.8	0.83
36	0.038	0.001	5.957	0.006	9.945	0.007	0.003	0.001	0.022	0.002	0.007	1.527	0.003	0.470	18.0	101.1	0.84
39	0.037	0.001	5.917	0.009	10.028	0.019	0.006	0.001	0.018	0.007	0.013	1.574	0.003	0.423	18.1	100.3	0.83
40	0.032	0.002	5.994	0.000	9.948	0.003	0.008	0.002	0.013	0.001	0.003	1.559	0.002	0.439	18.0	101.7	0.83
43	0.019	0.002	5.978	0.006	9.863	0.031	0.002	0.004	0.011	0.005	0.013	1.536	0.004	0.460	18.0	101.2	0.83
45	0.041	0.002	5.962	0.007	9.923	0.016	0.016	0.004	0.017	0.004	0.008	1.597	0.005	0.398	18.0	101.7	0.82
46	0.028	0.003	6.008	0.006	9.812	0.020	0.011	0.003	0.020	0.005	0.011	1.570	0.005	0.425	17.9	100.6	0.82

BH42,Venediger Nappe System - Sub-Penninic, ortho-gneiss. UTM zone 33N, 5212924N, 345606E, 2680 masl

AFT Age-Grains

1	0.006	0.000	6.020	0.002	9.912	0.004	0.008	0.015	0.010	0.004	0.004	1.520	0.005	0.476	18.0	100.1	0.83
2	0.000	0.000	6.030	0.000	9.883	0.004	0.000	0.041	0.003	0.001	0.000	1.478	0.003	0.519	18.0	100.4	0.84
3	0.002	0.001	6.010	0.000	9.917	0.006	0.000	0.051	0.001	0.003	0.000	1.486	0.003	0.512	18.0	100.6	0.84
4	0.002	0.000	6.070	0.001	9.784	0.007	0.001	0.035	0.004	0.001	0.000	1.446	0.003	0.551	17.9	102.4	0.84
5	0.000	0.000	6.030	0.000	9.884	0.007	0.005	0.033	0.000	0.001	0.002	1.656	0.003	0.341	18.0	101.6	0.84
19	0.001	0.001	6.030	0.002	9.885	0.003	0.002	0.033	0.002	0.000	0.000	1.530	0.002	0.467	18.0	101.4	0.84
20	0.031	0.000	6.000	0.005	9.937	0.003	0.011	0.012	0.010	0.007	0.007	1.607	0.004	0.389	18.0	100.7	0.83
21	0.012	0.000	6.050	0.017	9.799	0.010	0.009	0.022	0.009	0.004	0.004	1.555	0.004	0.441	17.9	102.8	0.83
22	0.017	0.001	6.050	0.000	9.812	0.014	0.000	0.005	0.015	0.004	0.012	1.493	0.004	0.503	17.9	101.3	0.84
23	0.029	0.000	6.000	0.002	9.934	0.017	0.000	0.005	0.022	0.006	0.008	1.453	0.004	0.543	18.0	101.5	0.83
24	0.015	0.001	6.030	0.008	9.828	0.018	0.013	0.005	0.016	0.008	0.019	1.403	0.003	0.594	18.0	100.4	0.81
25	0.013	0.000	6.040	0.001	9.862	0.000	0.000	0.015	0.004	0.000	0.000	1.481	0.005	0.514	17.9	102.3	0.84
26	0.011	0.000	6.000	0.000	9.910	0.009	0.002	0.054	0.006	0.002	0.003	1.560	0.004	0.436	18.0	102.5	0.84
27	0.033	0.000	6.040	0.004	9.833	0.013	0.009	0.004	0.016	0.002	0.006	1.484	0.003	0.513	18.0	100.5	0.82
28	0.046	0.002	6.000	0.034	9.930	0.006	0.000	0.010	0.014	0.002	0.003	1.541	0.004	0.455	18.0	101.3	0.84
29	0.010	0.000	6.040	0.000	9.845	0.005	0.000	0.039	0.001	0.000	0.000	1.479	0.003	0.518	17.9	101.0	0.84
30	0.007	0.000	6.040	0.007	9.840	0.006	0.000	0.026	0.014	0.001	0.005	1.487	0.003	0.510	17.9	101.1	0.84
31	0.002	0.000	5.930	0.000	10.126	0.005	0.000	0.040	0.003	0.000	0.002	1.476	0.003	0.521	18.1	99.6	0.84
32	0.006	0.000	6.030	0.000	9.877	0.006	0.009	0.016	0.002	0.002	0.001	1.534	0.003	0.464	18.0	101.1	0.83
33	0.020	0.000	5.990	0.023	9.969	0.003	0.000	0.019	0.008	0.009	0.007	1.584	0.004	0.413	18.0	100.9	0.84
34	0.025	0.000	5.990	0.007	9.958	0.009	0.003	0.007	0.020	0.007	0.013	1.589	0.004	0.407	18.0	100.6	0.84
35	0.023	0.001	6.030	0.003	9.854	0.024	0.000	0.007	0.015	0.008	0.008	1.434	0.004	0.562	18.0	101.9	0.83
36	0.006	0.000	6.030	0.002	9.841	0.006	0.008	0.063	0.005	0.006	0.000	1.499	0.004	0.498	18.0	102.3	0.83
37	0.010	0.000	6.000	0.000	9.912	0.002	0.003	0.073	0.004	0.000	0.000	1.477	0.002	0.522	18.0	101.0	0.84
38	0.004	0.002	6.050	0.001	9.793	0.006	0.000	0.054	0.004	0.001	0.001	1.505	0.003	0.491	17.9	101.1	0.84
39	0.052	0.001	6.000	0.044	9.886	0.010	0.003	0.003	0.024	0.005	0.015	1.429	0.004	0.567	18.0	101.1	0.83
40	0.038	0.001	6.030	0.003	9.851	0.013	0.010	0.004	0.025	0.001	0.009	1.442	0.003	0.555	18.0	100.4	0.82

AFT Length-Grains

11	0.006	0.002	6.650	0.002	9.168	0.009	0.034	0.014	0.006	0.003	0.000	1.399	0.002	0.599	17.9	99.2	0.79
19	0.012	0.000	6.060	0.000	9.793	0.014	0.008	0.008	0.013	0.003	0.006	1.497	0.002	0.501	17.9	101.4	0.83
21	0.035	0.001	6.010	0.004	9.885	0.018	0.007	0.002	0.029	0.002	0.012	1.447	0.008	0.545	18.0	98.8	0.82
29	0.031	0.000	6.000	0.001	9.925	0.009	0.009	0.023	0.020	0.000	0.002	1.544	0.003	0.454	18.0	101.0	0.83
30	0.021	0.002	6.020	0.000	9.877	0.009	0.002	0.016	0.019	0.000	0.009	1.501	0.005	0.494	18.0	100.2	0.84

31	0.026	0.002	6.020	0.008	9.890	0.017	0.004	0.003	0.015	0.002	0.012	1.444	0.004	0.552	18.0	101.7	0.83
32	0.012	0.001	6.020	0.009	9.869	0.020	0.003	0.005	0.010	0.008	0.012	1.481	0.003	0.515	18.0	100.7	0.83
36	0.036	0.000	6.000	0.007	9.925	0.014	0.004	0.003	0.018	0.003	0.007	1.517	0.004	0.479	18.0	100.5	0.83
40	0.007	0.000	5.970	0.005	10.015	0.012	0.000	0.003	0.021	0.005	0.011	1.437	0.003	0.560	18.0	100.4	0.83
42	0.050	0.000	5.990	0.056	9.933	0.003	0.002	0.018	0.010	0.001	0.003	1.541	0.003	0.456	18.0	99.9	0.84
45	0.000	0.001	6.020	0.000	9.910	0.007	0.008	0.023	0.003	0.001	0.002	1.471	0.003	0.526	18.0	102.0	0.83
51	0.016	0.001	6.050	0.007	9.819	0.012	0.006	0.008	0.007	0.000	0.004	1.437	0.002	0.561	17.9	101.8	0.83
56	0.031	0.001	6.010	0.004	9.923	0.019	0.002	0.001	0.017	0.000	0.007	1.476	0.004	0.520	18.0	101.6	0.83
57	0.011	0.000	6.050	0.000	9.853	0.006	0.000	0.016	0.000	0.003	0.001	1.467	0.003	0.530	17.9	102.9	0.84
60	0.044	0.000	6.010	0.056	9.869	0.012	0.009	0.009	0.010	0.001	0.014	1.459	0.005	0.537	18.0	100.9	0.82
61	0.013	0.002	6.010	0.000	9.945	0.007	0.003	0.012	0.010	0.000	0.005	1.496	0.004	0.499	18.0	100.9	0.84

JS03, Venediger Nappe System - Sub-Penninic, meta-gabbro. UTM zone 33N, 5206449N, 343118E, 1580 masl

AFT Age-Grains

1	0.019	0.002	5.960	0.006	10.048	0.011	0.001	0.002	0.015	0.007	0.006	1.775	0.017	0.208	18.1	98.5	0.85
2	0.061	0.004	6.000	0.012	9.951	0.004	0.000	0.024	0.002	0.000	0.000	1.664	0.004	0.332	18.0	97.9	0.85
3	0.068	0.007	6.030	0.015	9.826	0.018	0.018	0.003	0.015	0.005	0.008	1.660	0.004	0.336	18.0	97.9	0.82
5	0.026	0.002	5.990	0.009	9.956	0.017	0.005	0.004	0.010	0.008	0.002	1.812	0.003	0.185	18.0	100.2	0.84
6	0.029	0.002	5.990	0.002	9.980	0.008	0.001	0.010	0.000	0.008	0.000	1.811	0.001	0.188	18.0	100.8	0.85
7	0.052	0.004	6.000	0.011	9.956	0.011	0.001	0.002	0.012	0.000	0.001	1.801	0.002	0.197	18.0	100.3	0.85
8	0.067	0.005	6.010	0.009	9.915	0.008	0.010	0.015	0.008	0.000	0.002	1.793	0.003	0.204	18.0	98.6	0.84
9	0.041	0.002	6.040	0.015	9.839	0.013	0.000	0.000	0.016	0.006	0.004	1.748	0.002	0.251	18.0	100.1	0.85
11	0.031	0.003	5.990	0.001	9.984	0.009	0.001	0.002	0.013	0.002	0.005	2.003	0.010	0.000	18.1	98.9	0.86
12	0.051	0.002	5.970	0.007	10.011	0.022	0.004	0.000	0.017	0.000	0.009	1.922	0.027	0.051	18.1	98.1	0.84
13	0.030	0.001	6.050	0.005	9.798	0.002	0.045	0.022	0.000	0.000	0.000	1.925	0.026	0.049	17.9	98.8	0.80
14	0.098	0.006	6.070	0.003	9.819	0.009	0.000	0.004	0.000	0.000	0.001	1.903	0.049	0.048	18.0	99.7	0.85
15	0.116	0.006	5.970	0.023	9.968	0.016	0.001	0.005	0.013	0.001	0.008	1.962	0.044	0.000	18.1	96.8	0.84
16	0.028	0.001	6.050	0.006	9.834	0.008	0.000	0.005	0.005	0.001	0.003	1.912	0.025	0.063	17.9	100.8	0.85
17	0.054	0.002	6.000	0.007	9.953	0.008	0.001	0.006	0.004	0.005	0.005	1.905	0.008	0.087	18.0	96.2	0.85
18	0.012	0.001	5.990	0.008	9.974	0.013	0.003	0.004	0.016	0.001	0.008	1.756	0.005	0.239	18.0	98.0	0.85
19	0.045	0.002	6.060	0.009	9.803	0.008	0.000	0.007	0.007	0.004	0.004	1.834	0.005	0.161	17.9	97.9	0.85
20	0.045	0.000	6.000	0.007	9.958	0.009	0.000	0.006	0.013	0.001	0.006	1.754	0.002	0.244	18.0	100.3	0.85
21	0.046	0.001	6.010	0.004	9.923	0.007	0.004	0.021	0.004	0.000	0.000	1.829	0.005	0.166	18.0	99.5	0.85
22	0.054	0.003	6.070	0.005	9.789	0.009	0.003	0.007	0.012	0.003	0.000	1.920	0.007	0.073	17.9	96.9	0.85
24	0.036	0.000	5.990	0.003	9.962	0.004	0.003	0.037	0.002	0.000	0.000	1.733	0.004	0.263	18.0	98.7	0.85
25	0.054	0.001	5.990	0.008	9.963	0.012	0.001	0.004	0.018	0.002	0.005	1.751	0.004	0.245	18.0	98.5	0.85
26	0.026	0.000	6.050	0.006	9.833	0.014	0.000	0.004	0.007	0.003	0.009	1.773	0.006	0.222	17.9	96.4	0.85

27	0.050	0.002	5.970	0.008	10.022	0.011	0.000	0.002	0.014	0.006	0.010	1.865	0.003	0.131	18.1	97.9	0.85
28	0.087	0.005	6.040	0.010	9.818	0.012	0.006	0.004	0.011	0.000	0.002	1.769	0.007	0.225	18.0	97.9	0.84
29	0.039	0.005	5.990	0.011	9.956	0.020	0.005	0.003	0.012	0.000	0.002	1.870	0.002	0.129	18.0	100.6	0.84
30	0.056	0.002	5.980	0.010	9.978	0.014	0.007	0.001	0.013	0.002	0.008	1.903	0.004	0.093	18.1	99.8	0.85
31	0.053	0.002	6.030	0.007	9.833	0.012	0.000	0.002	0.020	0.007	0.013	1.742	0.021	0.238	18.0	98.0	0.84
32	0.119	0.003	6.050	0.008	9.790	0.011	0.003	0.002	0.016	0.001	0.002	1.723	0.026	0.251	18.0	98.6	0.84
33	0.031	0.003	5.980	0.008	9.994	0.016	0.001	0.004	0.012	0.002	0.009	1.883	0.005	0.112	18.0	100.4	0.85
35	0.056	0.002	6.030	0.002	9.882	0.006	0.002	0.003	0.000	0.001	0.000	1.934	0.022	0.044	18.0	99.9	0.85
36	0.139	0.007	6.020	0.009	9.834	0.013	0.001	0.002	0.017	0.008	0.003	1.751	0.080	0.170	18.0	96.0	0.83
37	0.029	0.004	5.990	0.006	9.963	0.014	0.006	0.000	0.015	0.009	0.007	1.800	0.005	0.195	18.0	100.6	0.84
39	0.047	0.001	6.030	0.026	9.852	0.010	0.000	0.003	0.015	0.004	0.005	1.915	0.009	0.075	18.0	100.2	0.85
40	0.022	0.001	6.000	0.018	9.960	0.009	0.002	0.006	0.013	0.004	0.000	1.746	0.003	0.251	18.0	101.7	0.85

AFT Length-Grains

2	0.000	0.000	6.000	0.002	9.975	0.009	0.000	0.022	0.003	0.000	0.000	1.661	0.002	0.337	18.0	99.0	0.85
3	0.006	0.000	5.950	0.009	10.087	0.009	0.000	0.018	0.008	0.000	0.000	1.731	0.000	0.269	18.1	98.0	0.85
4	0.008	0.000	5.970	0.007	10.034	0.012	0.000	0.007	0.009	0.000	0.003	1.726	0.003	0.271	18.0	98.1	0.85
5	0.011	0.000	5.940	0.006	10.097	0.016	0.003	0.007	0.017	0.000	0.006	1.662	0.000	0.338	18.1	98.9	0.84
6	0.010	0.000	5.970	0.008	10.032	0.008	0.008	0.009	0.005	0.000	0.002	1.671	0.000	0.329	18.0	99.9	0.84
7	0.005	0.000	6.010	0.009	9.957	0.008	0.000	0.010	0.000	0.000	0.000	1.656	0.000	0.344	18.0	100.6	0.85
8	0.006	0.000	5.960	0.007	10.071	0.007	0.000	0.009	0.005	0.000	0.000	1.717	0.000	0.283	18.1	98.4	0.85
9	0.011	0.000	5.950	0.007	10.070	0.013	0.004	0.008	0.014	0.000	0.009	1.785	0.000	0.215	18.1	97.7	0.85
10	0.023	0.002	6.000	0.008	9.920	0.017	0.000	0.005	0.017	0.003	0.011	1.649	0.002	0.348	18.0	99.7	0.84
11	0.006	0.000	5.970	0.006	10.042	0.009	0.000	0.011	0.010	0.003	0.008	1.789	0.002	0.209	18.1	98.2	0.85
12	0.008	0.000	6.020	0.006	9.905	0.008	0.000	0.014	0.005	0.002	0.008	1.701	0.000	0.299	18.0	99.1	0.85
13	0.008	0.000	5.960	0.011	10.055	0.004	0.000	0.045	0.000	0.000	0.000	1.834	0.000	0.166	18.1	99.2	0.86
14	0.000	0.000	5.930	0.009	10.122	0.000	0.000	0.044	0.000	0.000	0.000	1.977	0.007	0.016	18.1	97.6	0.86
15	0.036	0.000	5.960	0.067	10.026	0.011	0.006	0.008	0.010	0.000	0.010	1.783	0.000	0.217	18.1	98.0	0.84
16	0.007	0.000	5.990	0.011	9.988	0.008	0.005	0.007	0.010	0.000	0.004	1.753	0.002	0.245	18.0	98.2	0.85
17	0.011	0.000	6.020	0.009	9.916	0.009	0.000	0.010	0.004	0.002	0.009	1.648	0.000	0.352	18.0	99.4	0.85
18	0.010	0.000	5.920	0.013	10.148	0.005	0.000	0.025	0.000	0.000	0.000	1.733	0.005	0.262	18.1	97.7	0.85
19	0.021	0.000	5.930	0.009	10.115	0.015	0.004	0.005	0.014	0.004	0.009	1.648	0.005	0.348	18.1	98.8	0.84
20	0.018	0.000	5.980	0.024	10.003	0.014	0.004	0.006	0.012	0.000	0.005	1.710	0.000	0.291	18.0	98.9	0.84
21	0.017	0.000	6.000	0.011	9.939	0.017	0.007	0.005	0.016	0.005	0.008	1.670	0.002	0.329	18.0	99.4	0.84
22	0.011	0.000	5.940	0.010	10.094	0.010	0.000	0.008	0.017	0.000	0.006	1.682	0.002	0.317	18.1	99.4	0.85
23	0.018	0.000	5.950	0.004	10.071	0.011	0.000	0.007	0.013	0.000	0.006	1.618	0.000	0.383	18.1	98.6	0.84
24	0.024	0.000	5.930	0.014	10.109	0.017	0.007	0.005	0.016	0.000	0.007	1.632	0.002	0.366	18.1	98.8	0.83
25	0.015	0.000	6.000	0.009	9.941	0.007	0.009	0.017	0.005	0.000	0.000	1.715	0.000	0.285	18.0	99.9	0.84

26	0.019	0.000	5.950	0.018	10.081	0.012	0.000	0.005	0.018	0.000	0.008	1.630	0.000	0.370	18.1	98.2	0.84
27	0.010	0.000	6.000	0.008	9.970	0.008	0.000	0.008	0.010	0.000	0.004	1.778	0.000	0.222	18.0	99.6	0.85
28	0.009	0.000	5.980	0.006	9.993	0.011	0.000	0.011	0.011	0.004	0.006	1.779	0.002	0.219	18.0	98.3	0.85
29	0.010	0.000	5.970	0.011	10.054	0.012	0.000	0.007	0.003	0.000	0.000	1.737	0.007	0.256	18.1	98.2	0.85
30	0.016	0.000	5.980	0.013	10.009	0.009	0.000	0.011	0.004	0.002	0.005	1.731	0.000	0.269	18.0	98.8	0.85
31	0.014	0.000	6.010	0.009	9.933	0.011	0.000	0.008	0.017	0.002	0.006	1.731	0.000	0.269	18.0	100.0	0.85
32	0.017	0.002	6.020	0.010	9.879	0.020	0.000	0.010	0.010	0.004	0.008	1.656	0.002	0.342	18.0	99.4	0.84
33	0.027	0.000	6.010	0.031	9.898	0.014	0.000	0.003	0.018	0.003	0.009	1.685	0.000	0.315	18.0	99.9	0.84
34	0.000	0.000	5.960	0.005	10.080	0.008	0.000	0.011	0.006	0.000	0.006	1.872	0.003	0.126	18.1	99.5	0.86
35	0.014	0.000	5.980	0.009	10.010	0.011	0.000	0.008	0.009	0.003	0.003	1.696	0.000	0.304	18.0	99.6	0.85
36	0.011	0.000	5.990	0.000	9.988	0.012	0.000	0.004	0.008	0.000	0.004	1.658	0.005	0.337	18.0	98.7	0.85
37	0.015	0.000	5.960	0.008	10.067	0.009	0.000	0.012	0.008	0.000	0.005	1.796	0.000	0.204	18.1	99.3	0.85
38	0.020	0.000	5.960	0.009	10.044	0.014	0.000	0.007	0.011	0.003	0.009	1.768	0.000	0.232	18.1	99.1	0.85
39	0.009	0.000	6.010	0.014	9.941	0.010	0.004	0.007	0.009	0.003	0.003	1.614	0.000	0.386	18.0	98.2	0.84
40	0.018	0.000	5.960	0.005	10.050	0.017	0.000	0.007	0.018	0.005	0.007	1.665	0.000	0.335	18.1	98.5	0.84
41	0.014	0.000	5.940	0.006	10.101	0.011	0.000	0.008	0.018	0.000	0.009	0.530	0.007	1.463	18.1	98.6	0.84
42	0.006	0.000	5.970	0.006	10.049	0.006	0.000	0.025	0.002	0.000	0.002	1.717	0.000	0.283	18.1	99.3	0.85
43	0.014	0.000	5.970	0.006	10.026	0.011	0.000	0.006	0.011	0.004	0.009	1.665	0.000	0.335	18.1	99.6	0.85

Sample headers highlighted in blue were selected for thermal history modeling.

*AFT sample omitted from the study

Note: Elemental concentrations were calculated from weight % oxide and converted to atoms per formula unit (apfu) using the stoichiometric relationships of Ketcham, (2015). Rmr0 was determined using the calculations of Carlson et al., (1999). Sample headers highlighted in blue were selected for thermal history modeling.

*AFT sample omitted from the study