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**EPISODIC SEDIMENTATION ON AN EARLY SILURIAN,
STORM-DOMINATED CARBONATE RAMP,
ANTICOSTI ISLAND, QUEBEC.**

by
Terry Sami

A Thesis
submitted to the School of Graduate Studies and Research
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in the Department of Geology,
Ottawa-Carleton Geoscience Centre,
University of Ottawa,
Ottawa, Ontario

Abstract

The 150 to 160 metre thick lowest Silurian (Rhuddanian) Becscie Formation represents continuous deposition on a shallow, open-marine carbonate ramp across the Ordovician-Silurian boundary. The Becscie Formation contains five lithofacies and is separated into four informal members. The sequence reflects deposition on a generally quiet, shallow marine ramp punctuated by short-lived, episodic, high energy events. These events produced individual storm units, or tempestites, which occur as fining-upwards sequences ranging from 5 to 80 cm thick. A complete, ideal storm deposit consists of a sharp scoured base overlain by bio/intraclastic rudstone grading upwards into medium grainstone, finely laminated calcisiltite and mudstone, or shale. Deposition progressed from a carbonate mud-dominated ramp in the lower two members to a shale-dominated ramp in the upper two members. Palaeocurrents and sedimentary structures demonstrate that the tempestites were deposited within a combined-flow regime, probably as a result of cyclonic storms.

The tempestites display lateral and vertical variations which were used to construct proximity trends for the Becscie Formation. The lateral proximity trends, lithofacies distribution, and palaeocurrent data indicate that the Anticosti Basin deepened to the southeast and shallowed towards a proposed northeast-southwest oriented shoreline to the northwest. The vertical proximity trends and lithofacies changes enable the recognition of third-order eustatic sea level changes. After an initial deepening at the base of the formation, a shallowing-deepening cycle dominates the sequence. Several higher order fluctuations are superimposed on this cycle. The resolution of fluctuations observed in tempestite proximity trends is an order of magnitude higher than those identified by facies or faunal methods.

Resumé

La Formation de Becscie, d'âge Silurien Inférieur (Rhuddanian) est une séquence d'environ 150 à 160 m d'épaisseur qui a été déposée sur une rampe calcaire peu profonde. Cette séquence traverse de façon continue la limite entre l'Ordovicien et le Silurien. La séquence se divise en quatre membres informels comprenant au total cinq lithofaciès. La sédimentation sur une rampe à faible énergie a été ponctuée d'évènements épisodiques de courte durée et à haut niveau d'énergie. Ces évènements ont produit des "tempestites", de 5 à 80 cm en épaisseur, qui sont généralement granoclassés. La séquence idéale d'une tempestite comprend une base érodée bien définie recouverte par des rudstones bio/intraclastiques qui passent graduellement à des grainstones, puis à des calcisiltites finement laminées. La séquence est recouverte de calcaire micritique ou de schiste argileux. Les deux membres inférieurs de la séquence ont été déposés sur une rampe dominée par des boues micritiques, tandis que les deux membres supérieurs ont été déposés sur une rampe dominée par des boues argileuses. Les paléocourants et les structures sédimentaires démontrent que les tempestites ont été déposés par un régime hydrodynamique combiné, probablement causé par des tempêtes cycloniques.

Les tempestites de la Formation de Becscie montrent des variations latérales et verticales qui ont été utilisées pour construire des courbes de proximalité. Les variations latérales des courbes de proximalité, la distribution des lithofaciès, et les paléocourants indiquent que la partie profonde du bassin se situe au sud-est, tandis que la partie peu profonde est située au nord-ouest. L'ancienne ligne de rivage était orientée nord-est/sud-ouest. Les variations verticales des courbes de proximalité et les changements verticaux de lithofaciès ont permis d'identifier trois ordres de changements paléobathymétriques dans le bassin. Après une transgression initiale à la base de la formation, un cycle de régression-transgression a dominé la séquence. Plusieurs fluctuations secondaires et tertiaires sont superposées sur ce cycle. Les fluctuations enregistrées par les courbes de proximalité ont une résolution plus élevée que celles identifiées à partir d'autres méthodes (e.g. lithofaciès, faune).

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Introduction

This study was undertaken to gain a better understanding of the sedimentology and stratigraphy of the Becscie Formation exposed on Anticosti Island. This interval of the Anticosti sequence is of particular importance as it contains the Ordovician-Silurian boundary. While a large body of work has been done on the biostratigraphy of the Becscie sequence, only a few workers have addressed the sedimentology.

Eighty-two stratigraphic sections were measured, covering most known major outcrops of the Becscie Formation on Anticosti Island. These were combined into four composite sections marking the major outcrop regions (Appendix I). The sections were examined on a centimetre scale in order to obtain as much information on the tempestite-dominated sequence as possible (detailed composite sections are included with the thesis at the University of Ottawa and are available upon request). The various sections were correlated using sedimentary packages since no marker units were identified. The composite sections are generally reliable with the exception of the R. Prinsta-Reef Point section which contains a large proportion of covered intervals. Over 2000 individual tempestite beds were identified. Several hundred acetate peels and thin sections were prepared from field samples to aid petrographic descriptions. Throughout the text the term 'mudstone' is used to describe a very fine-grained limestone with few fossils, following Dunham's classification.

The tempestite beds were treated statistically by computer in order to generate tempestite proximity trends for the various composite sections (Appendix II). Several different parameters were run for each section and were subsequently combined to form a single proximity curve for each section. Over 350 palaeocurrent measurements were taken on a variety of storm-related sedimentary structures and used to generate rose diagrams.

The Becscie sequence was deposited on the inner to outer part of a storm-dominated, muddy carbonate to shaley ramp. The ramp shallowed northwestwards with a northeast-southwest oriented shoreline and deepened southeastwards towards the partially-opened Iapetus Ocean. Variations in the vertical sequence indicate a transgressive-regressive-transgressive cycle with superimposed lower-order fluctuations. The tempestite proximality trends proved useful in providing information on sea-level fluctuations, basin geometry and palaeogeography, and possible climatic-storm variations through time. The results correspond with those obtained from lithofacies analysis signifying their viability for analysis of storm-dominated basins, particularly where lithofacies or palaeontological information is lacking.

This study provides another clue in unraveling the palaeogeography of eastern North America, and in particular that of the Anticosti Basin.

PART I

General Setting and Stratigraphy

Location

Anticosti Island is located in the Gulf of St. Lawrence, eastern Canada, about 30 km south of the north shore of Québec and 75 km northeast of the Gaspé peninsula (49° 04' - 49°57' latitude, 64°32' - 61°41' longitude). The island is 222 km in length and 56 km at its widest point (Fig. 1). Situated to the north of the Logan Line, on the eastern part of the St. Lawrence platform, the island's strata were spared the stresses of the Taconic Orogeny. The Anticosti sequence consists of up to 1100 m of undeformed, fossiliferous limestone, shale, and minor siliciclastic sediments (Petryk 1981a). The strata strike northwest-southeast, and dip an average of 2° to the southwest.

Regional Palaeogeography

Ranging from Upper Ordovician (Ashgill) to Lower Silurian (Llandovery/Wenlock?), the exposed Anticosti sequence is unique in that it represents one of the best exposures of continuous shallow-water deposition across the Ordovician-Silurian boundary in North America (Barnes 1988, Lespérance 1981). During the Early Silurian, the Anticosti Basin was situated at palaeolatitudes of 15 to 20° S (Ziegler *et al.* 1977, 1979, Scotese *et al.* 1985), placing it within a dry, warm zone at a time when much of the Laurentia craton was covered by shallow, epeiric seas (Ziegler *et al.* 1977). The basin was located on the northwest margin of the Iapetus Ocean, which is believed to have been open from the late Proterozoic until possibly the late Silurian-early Devonian (Ziegler *et al.* 1977, Mason 1988) (Fig. 2). The Anticosti strata were deposited at a time of global sea-level fluctuations associated with glacial-climatic episodes in North Africa (Harobrey 1985). The Early Silurian was marked by the onset of an eustatic sea-level rise related to melting of the North African continental ice sheet (Ziegler *et al.* 1979).

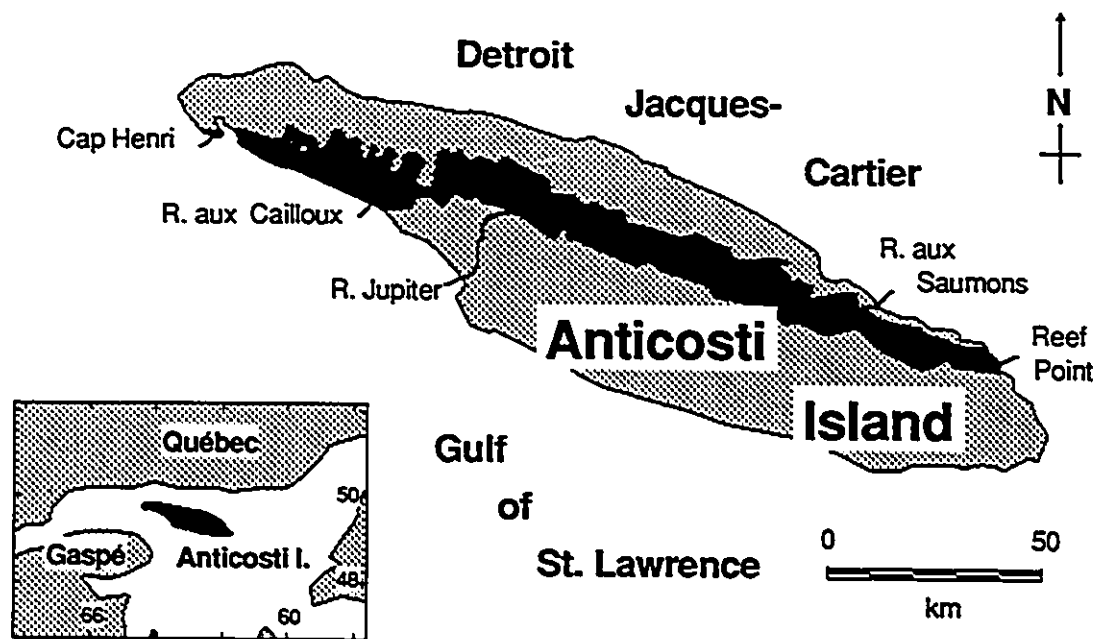


Figure 1: Location map of Anticosti Island showing distribution of the Becscie Formation and significant outcrop localities (modified from Petryk 1981a).

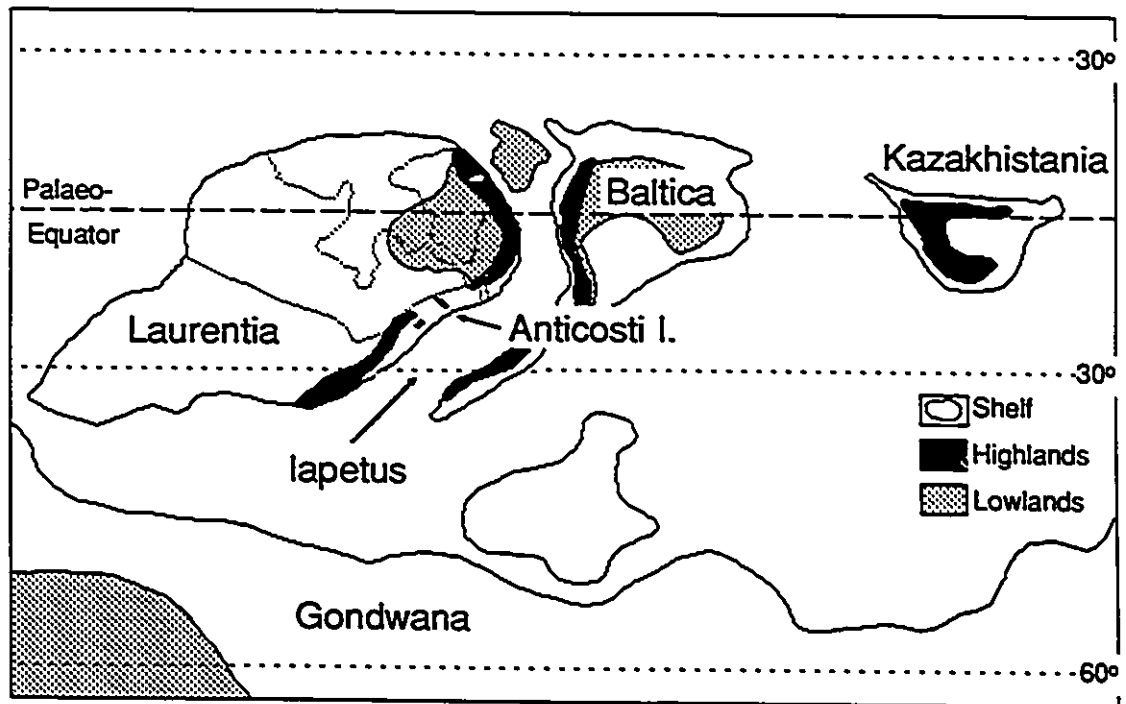


Figure 2: Early Silurian palaeogeography showing location of Anticosti Island on the eastern edge of Laurentia and bordering on northeast edge of the Iapetus Ocean. The location of significant land masses is shown by the stippling patterns (modified from Johnson 1987 and Ziegler *et al.* 1977).

Since tectonic influences on the Anticosti Basin are small or absent, the palaeo-bathymetric changes reported through Ordovician and Silurian strata have been interpreted as probably glacio-eustatic in nature (Petryk 1981b).

Although the Anticosti basin experienced several sea-level lowstands, there is no evidence of supratidal or intertidal exposure, with deposition being restricted to shallow, open-marine subtidal conditions. The abundance of lime mudstone/packstone, diverse open-marine biota, whole fossils, upward-fining storm sequences, bioturbation, and the absence of any slope breaks, reefal margin, or slope and basin sediments corresponds to Read's (1985) definition of a homoclinal ramp, with an inferred palaeoslope of 1 to 2'. This quiet, low-energy environment was interrupted by short-lived, episodic, high-energy storm conditions (Petryk 1981a). A deeper ramp interpretation is consistent with the lack of evidence for supratidal or intertidal environments.

Previous Work

Richardson (1857) and Billings (1857) were the first to map and subdivide the Anticosti sequence based on lithostratigraphy and biostratigraphy respectively. Six divisions, A to F, were defined spanning the Ashgill to late Llandovery. Schuchert and Twenhofel (1910) introduced formal formation names based on lithostratigraphic work on coastal exposures. This set up a framework on which Twenhofel continued to elaborate for the next few years (1921, 1928). Bolton (1961, 1970, 1972) mapped the interior of the island and refined Twenhofel's subdivisions based on lithostratigraphy and biostratigraphy, together with Copeland (1970, 1973, 1974). The six formations were placed into precise faunal zones. Petryk's (1981a, 1981b) work involved reinterpretation of formation boundaries and subdivisions based on extensive litho-stratigraphic and basinal analysis. Johnson *et al.* (1981) proposed sea-level fluctuations for the Anticosti sequence using brachiopod communities, based on Cocks and Copper's (1981) stratigraphic work on eastern regions of the island. This work on

the sedimentology and stratigraphy has been continued by Long and Copper (1987a, 1987b). They are currently involved with stratigraphic re-interpretation of various parts of the sequence, including the Becscie Formation (Copper and Long, in press). In addition, a large body of work has been carried out on the biostratigraphy of the Anticosti sequence, particularly in faunal changes across the Ordovician-Silurian boundary (Lespérance 1981, Barnes 1988).

Stratigraphy

According to Petryk (1981a), the Anticosti sequence is composed of six formations distributed between two groups, the Upper Ordovician Vauréal and Ellis Bay formations in the Jolliet Group, and the Lower Silurian Becscie, Gun River, Jupiter and Chicotte formations in the Anticosti Group (Fig. 3).

Bolton (1972) first subdivided the Becscie Formation into two transitional, lower and upper members (Fig. 4). Due to the difficulty in mapping Bolton's biostratigraphically-defined members, Petryk (1981a) proposed a revised informal four-fold lithostratigraphic subdivision for this formation. The present study closely follows Petryk's framework with some minor member boundary changes. The members have been defined on the basis of lithologic variations and shifts in tempestite proximity (Sami & Desrochers 1989b). Copper and Long (in press) have placed the upper two members in the newly proposed Merrimack Formation on the basis of lithologic and palaeontologic changes. I have retained Petryk's subdivisions for the sake of simplicity and the sedimentologic relationships between member 3 and lower members.

The Becscie Formation contains 150 to 160 metres of predominantly limestone, with minor shale and siliciclastics (Sami & Desrochers 1989b). Although the thickness of the formation is relatively uniform across the island, the thicknesses of the members show east-west variations.

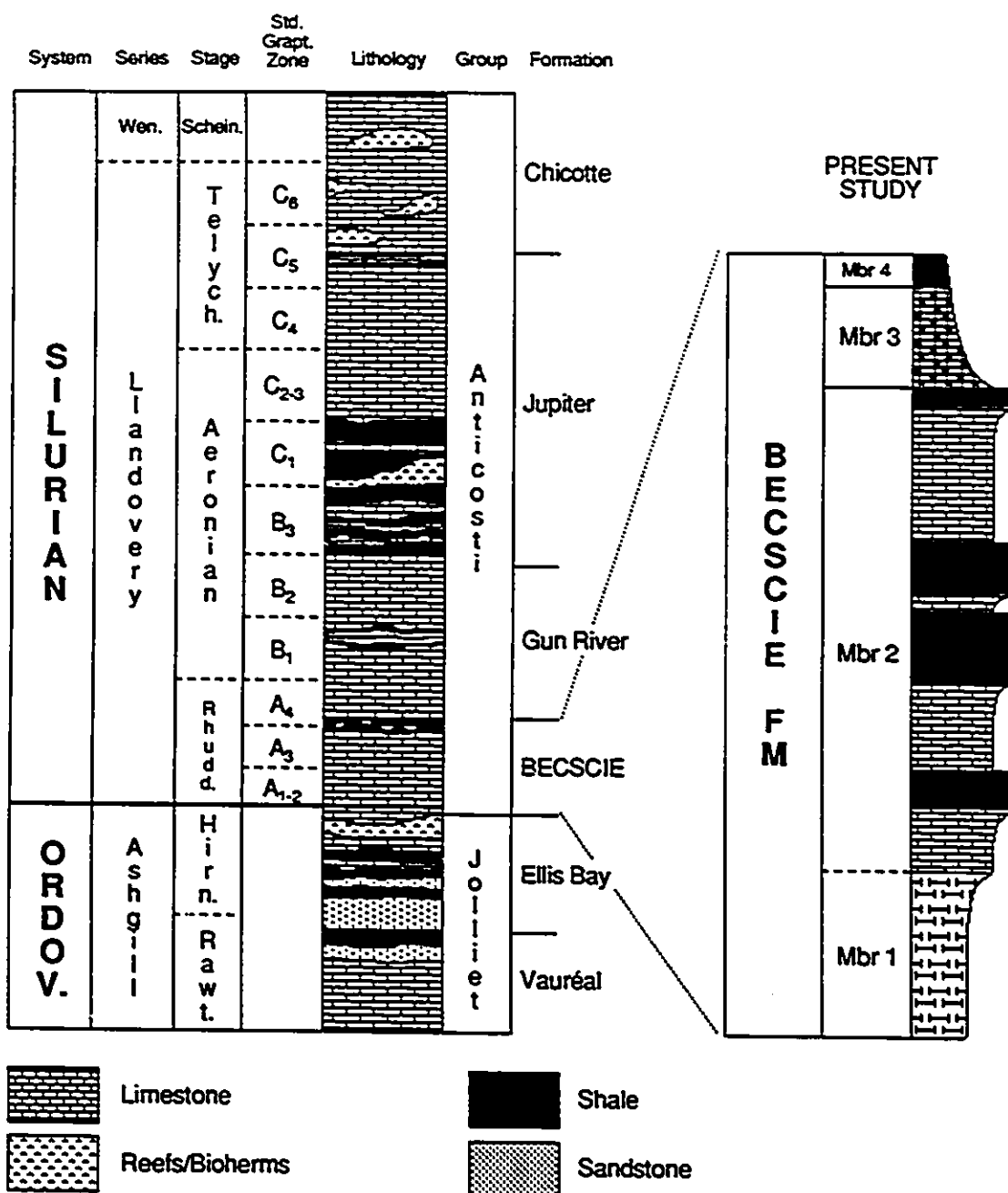


Figure 3: Stratigraphic subdivisions and nomenclature of the Anticosti (left) and Becscie (right) sequences, showing age and lithofacies relationships. Lithologic legend applies to Anticosti sequence only. Lithologic symbols for the Becscie sequence are found in Fig. 5. The Anticosti sequence is modified from Petryk 1981a. The Becscie sequence is from the present study.

Richardson 1857	Schuchert & Twenhofel 1910	Twenhofel 1928	Bolton 1972	Petryk 1981a	Copper & Long (in press)	Sami (present study)		
D4	GUN RIVER	GUN RIVER	GUN RIVER		GUN RIVER	GUN RIVER		
D3			BECSCIE Upper Member	Mbr 4	Merrimack	Mbr 4		
				Mbr 3		Mbr 3		
D2				BECSCIE Lower Member	BECSCIE	BECSCIE	BECSCIE	Mbr 2
D1								
C14	D3	D3						
C13	D2	D2						
C12	D1	D1		Mbr 1		Mbr 1		
C11	ELLIS BAY	ELLIS BAY	ELLIS BAY	ELLIS BAY	ELLIS BAY	ELLIS BAY		

Figure 4: Tabular comparison of previously defined divisions of the Becscie Formation (modified from Petryk 1981a) with subdivisions used in the present study.

The Ellis Bay-Becscie contact is placed at the top of the bioherms in member 7 of the Ellis Bay Formation, and the onset of mudstones characteristic of the Becscie Formation (Plate V f). Where the bioherms are absent, the contact is placed at the top of member 6 of the Ellis Bay Formation. Petryk (1981a) suggested using an oncolite-rich, platform bed as the boundary in the absence of bioherms, but difficulties in establishing a time marker on this unit across the island made such a definition inconsistent. The contact is transitional over a few metres, consisting of interbedded mudstones and coarse, encrinitic reef-derived grainstones. The Ordovician-Silurian boundary has been placed within the upper portion of this transitional zone by McCracken & Barnes (1981) and Nowlan (1982) on the basis of conodonts, and by Cocks & Copper (1981) based on brachiopods. The remainder of the formation is Rhuddanian in age (Fig. 3).

Member 1 (including the transition zone) ranges from 6 to 34 metres thick from east to west and contains lithofacies 2. The member 1 to member 2 transition is marked by a gradual increase in coarse tempestite units, coinciding with a transition to lithofacies 4 (Figs. 3 & 5). The transition is gradual and difficult to map lithologically, necessitating the use of proximity trends for precise location (Sami & Desrochers 1989a, 1989b). Member 2 varies from 90 to 120 metres in thickness from west to east and includes lithofacies 4 and 5 (Fig. 5). Member 2 is terminated by the onset of shaley deposition (lithofacies 3). Lithologically members 2 and 3 are very similar, apart from an increase in shale due to an upwards deepening. Member 3 is 20 to 25 metres thick and is composed of lithofacies 3. However, poor exposure in the east prevents the identification of any east-west trends (Fig. 5). A further deepening and subsequent loss of tempestite units marks the beginning of member 4. This member thins from 8 to 3.3 metres from west to east. Lithofacies 1 which makes up the member is dominantly shale and the upper contact with the clean, dense lime mudstone of the Gun River Formation is sharp and easily recognized (Plate V e).

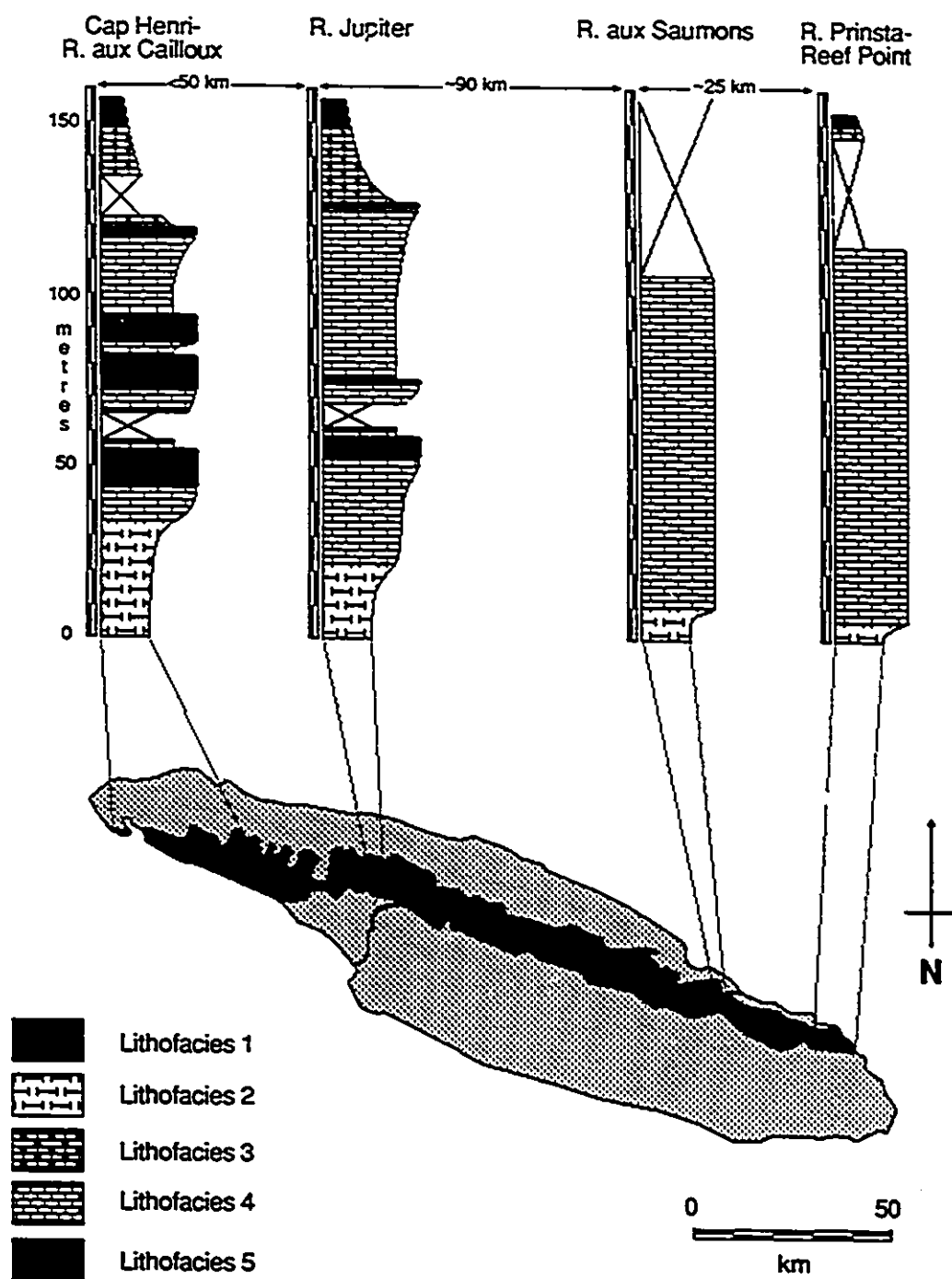


Figure 5: Location map of composite sections showing distribution and thicknesses of recognized lithofacies. Covered intervals of less than 5 metres are not shown.

Johnson *et al.* (1981) have set a late Rhuddanian (A₃- A₄) age for members 3 and 4 based on brachiopods. This is also supported by the brachiopod work of Copper (1981) and the conodont work of Barnes (1988), providing an upper age constraint for the Becscie Formation.

Lithofacies and Environments

Rock Types

Eighty-six sections and one core were measured, spanning the island from west to east (Appendix I), these were subsequently combined into four composite sections representing the four main regions of Becscie outcrop: Cap Henri to Rivière Cailloux, Rivière Jupiter, Rivière aux Saumons, and Rivière Prinsta to Reef point (Fig. 5).

These sequences are composed of a variety of limestone rock types which, despite their gradational relationships, are attributable to several distinct end members.

Mudstone: Two types of mudstone are recognizable. Both are composed of dense micrite and microspar. The dominant distinguishing feature is the presence of faint lamination. In both cases, the nature of the mudstone is difficult to determine due to the fine grain size involved. A peloidal texture may be locally discernable, particularly within burrows. The recrystallization of micrite to microspar and pseudospar is pervasive and obscures the original texture of the mud. The mudstones are often separated from other beds by thin, shaley beds or seams, usually less than 1 cm thick. Microstylolites and solution seams increase towards these shaley contacts, suggesting that diagenetic enhancement of bedding has occurred (Wanless 1979).

The laminated mudstones are slightly coarser due to the presence of quartz silt, which aids in defining the lamination (Plate II a, b). Fossils, if present, are commonly fragmented and show some alignment parallel to lamination. The basal contacts are

usually sharp but may be irregular. Individual beds fine-upwards, with decreasing silt and fossil content. Bioturbation is highly variable, with some units heavily burrowed but others undisturbed. The burrow-fill is often silt-poor in comparison to the surrounding mudstone. Geopetal structures and cement-filled shelter porosity may be present. Individual beds range in thickness from 2 to 10 cm. Unlaminated mudstones lack quartz silt but show an increased clay content (Plate I a, b). Apart from burrows these mudstones appear featureless. *In situ* fossils are present, including brachiopods, cyclocrinids, and bryozoans. Sponge spicules are present in some units. The basal contacts are primarily gradational from underlying coarser units. The bedding thickness varies from 2 to 15 cm.

Packstone/Wackestone: As with the mudstones, there are two types of packstone/wackestone differentiated by the presence of lamination and quartz silt. Packstones are more common than wackestones due to the abundance of fossil material within the sequence. In both types of packstone, the matrix is similar to that described for the mudstones mentioned above.

Laminated packstones are marked by a high fossil (5-25%) and quartz silt (~5%) content (Plate II c, d). The fossil material is disarticulated but usually unfragmented. Most of the fossil material, including brachiopods, crinoids, bryozoans, trilobites, and gastropods, is less than 1 mm in size, while the quartz silt is less than 0,05 mm in diameter and sub-angular. Elongate shelly fossil material generally shows good orientation parallel to lamination. Burrows are present but not pervasive. The laminated packstones occur as tabular beds and small channel-fills and vary in thickness from 2 to 5 cm. Basal contacts are commonly sharp and may be erosional. The unlaminated packstone is low in silt content (<1%) and shows a lower (5-10%) fossil content than the laminated packstone (Plate I c, d). Most fossils are *in situ*, slightly transported or re-mobilized and tend to be larger than in the laminated packstones. Beds vary in

thickness from 1 to 5 cm and commonly occur as isolated depression-fills in discontinuous beds. The basal contacts are sharp or gradational in nature.

Argillaceous Mudstone/Packstone: These rocks are similar to the previously mentioned mudstones and packstones, but are distinguished on the basis of a significantly increased (up to 15%) shale content (Plate I e, f). The mudstones and packstones occur in lenticular to nodular beds within a green, calcareous shale which may be up to 80 cm thick. The quartz silt content is low, apart from some local accumulations. Solution seams and microstylolites are abundant throughout the units. *In situ* brachiopods, corals and stromatoporoids are abundant in the packstones and within the shale, and form biostromes locally within distinct fossil-rich horizons. Bioturbation is intense, with trace fossils associated to the *Cruziana* ichnofacies, and is possibly responsible for the disarticulation of shelly faunas.

Laminated Calcisiltite: These fine-grained grainstones are composed of silt-sized fossil debris and quartz silt and show very well-defined lamination (Plate II e, f). The fossils present include disarticulated ostracode shells (0,1 to 0,25 mm) and micritized crinoid fragments (0,05 to 0,25 mm) and some minor coarser fragments. In places, the crinoid material is indistinguishable from peloids. The quartz silt (0,05 to 0,1 mm in size) is angular to subrounded and, together with oriented ostracode shells, defines the lamination. The quartz silt constitutes 5 to 20% of the sedimentary grains. Internal stratification includes horizontal, subhorizontal and ripple cross-lamination and hummocky/swaley cross-lamination. This internal lamination is commonly truncated by overlying lamination. Some individual beds show a sand-sized lag at the base and fine upwards. This corresponds to an upwards increase in micrite and ostracode shells and decrease in silt. Individual laminae show a similar fining-upward trend. The basal contacts are generally sharp and irregular, with isolated intraclasts and coarser bioclasts resting on the contacts. Some bed tops show interference and/or small wave ripples with

internal cross-lamination. The beds range in thickness from 5 to 40 cm, with amalgamation resulting in an increase up to 100 cm. Bioturbation is rare and restricted to the top few centimetres when present.

Medium-Fine Grained Grainstone: Allochems are abundant and diverse in this rock type, including crinoid plates, ostracode shells, brachiopod fragments and minor amounts of trilobite and bryozoan fragments and peloids (Plate III a, b). The allochems range in size from 0,1 to 1,0 mm. The shelly fossils are disarticulated but usually neither fragmented nor rounded. The quartz silt content is moderate to low (<5%). Well-rounded intraclasts of mudstone, packstone and calcisiltite, up to 30 mm in size, are present at the base of some beds. Coral and stromatoporoid pebbles are also present locally.

Lamination is faint or absent, being defined by the orientation of elongate grains. Most beds exhibit normal grading and good sorting. The micrite content tends to increase upwards and locally becomes abundant enough to constitute a packstone. The basal contacts are sharp above finer units and gradational above coarser units. The bed thickness varies from 2 to 20 cm.

Bio/Intraclastic Rudstone: The ratio of intraclasts to bioclasts varies widely in this rock type, from exclusively intraclastic (Plate III e, f) to exclusively bioclastic (Plate III c, d) without any change in nature of the clasts. The grain-size distribution is bimodal, with a coarse bio/intraclastic fraction making up the framework of the rock type and a fine bioclastic fraction constituting the matrix. Intraclasts range in size from 1 mm to 3 cm and are composed of all the finer-grained lithologies, from mudstone to grainstone, indicating some early seafloor lithification. These intraclasts are mostly rounded, discoid to tabular in shape and can be imbricated. Some of the mudstone clasts are highly irregular and some show evidence of borings and truncated grains. The bioclasts consist of tabulate coral and stromatoporoid cobbles up to 20 cm in diameter and large

pentamerid brachiopod shells up to several centimeters in length. The fine-grained matrix is a well packed grainstone containing all major fossil types seen: brachiopods, crinoids, bryozoans, trilobites, coral and stromatoporoid fragments and some peloids. The micrite content increases upwards, developing locally into a packstone. The quartz silt content is usually less than 1% but locally rises to 5%. A faint, normal grading is present locally. Geopetal and infiltration textures are common. The basal contacts are always sharp and erosive and in some cases possess a channel morphology.

Sedimentary Package

As mentioned above, these rock types are intergradational end-members, resulting in a suite of intermediate types. The different rock types are sedimentologically related in an ideal sequence. This sequence, or parts of it, is found throughout the numerous studied sections. It is characterized by an upwards-fining transition from coarser to finer rock types. This produces a gradational stacking, from base to top, of: bio/intraclastic rudstone, medium to fine-grained grainstone, laminated calcisiltite, packstone, and mudstone. This fining-upward sequence is interbedded with unlaminated mudstones packstones and shales (Fig. 6, Plate VI a-f). This ideal sequence is rarely complete, but occurs more commonly as a partial or truncated sequence. The ideal sequence is interpreted as having been deposited by a waning-flow current associated with storm sedimentation, thus making the dominant sedimentary package a tempestite sequence. The unlaminated fine-grained interbeds are interpreted as a result of the intervening fairweather sedimentation.

This interpretation accounts for the erosive nature of many coarser units and the abundance of large intraclasts and bioclasts. The quartz silt is closely associated with tempestite units and usually absent from the fair-weather units indicating that siliciclastic influx was storm-controlled. The lamination is also restricted to tempestite units. The fairweather units tend to contain autochthonous or par-autochthonous faunas

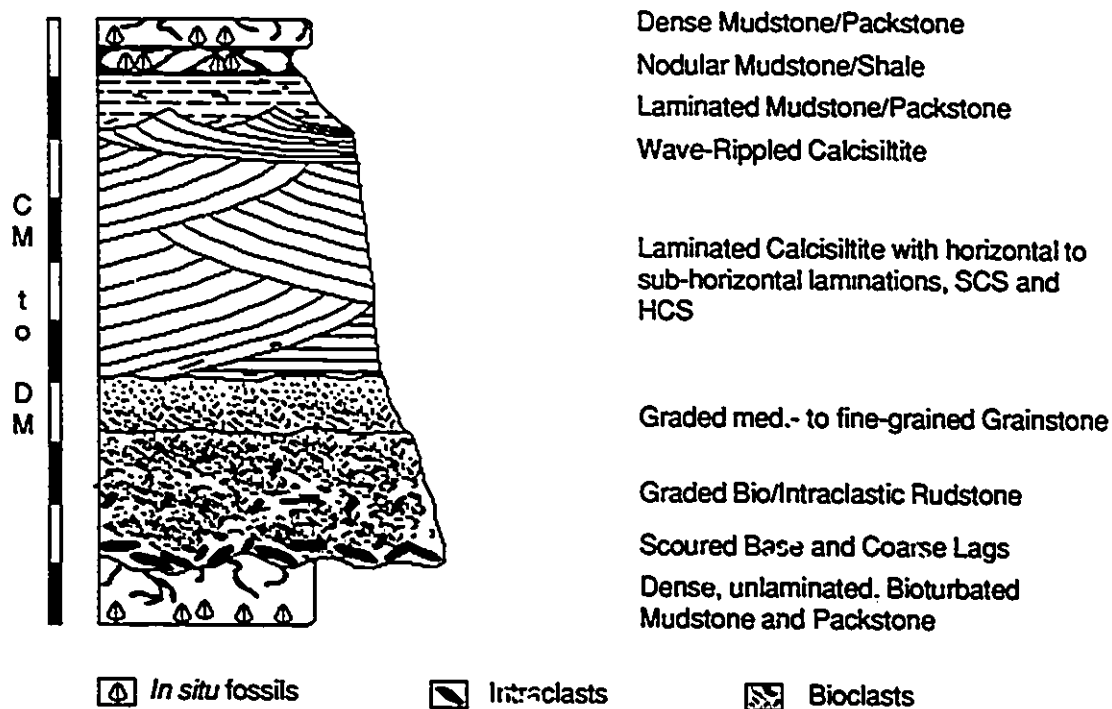


Figure 6:

Idealized Becscie tempestite sequence, showing vertical relationships between observed rock types and general fining-upwards trend. Dense mudstone and packstone represent the interbedded fairweather rock types.

and show extensive bioturbation while tempestite beds are dominated by disarticulated allochems and only minor burrowing. The intervals between storms were marked by the formation of hard or firm grounds, leading to the widespread formation of intraclasts with subsequent storm-generated scouring.

Tempestite units are ubiquitous throughout the sequence and form the dominant sedimentary package. The sequence can be divided into five distinct lithofacies based on variations in the nature of the tempestite package. The contacts between the lithofacies are generally gradational, making precise separation difficult. Their distinction becomes clearer with the implementation of tempestite proximity trends (Sami & Desrochers 1989a, 1989b). Proximity trends and their uses will be discussed in detail in Part II.

Lithofacies 1 (LF1)

Description: Green-grey shales make up 30 to 70% of this lithofacies, the remainder including unlaminated, argillaceous mudstones and packstones and rare, laminated, argillaceous packstones and calcisiltites (Plate IV a, b). The shale content increases upwards to the exclusion of tempestites and fairweather muddy carbonate sediments. Bedding is lenticular to nodular, usually less than 10 cm in thickness with abundant solution seams at the contacts. *In situ* fauna, including tabulate corals, stromatoporoids and brachiopods, is abundant and decreases in occurrence upwards. Some of these occur in distinct, fossil-rich horizons (Plate XI c). Clean micrite and tempestite units are rare and occur mostly at the base. The facies varies from 3,3 to 8 metres in thickness and displays no distinct sedimentary structures. The lower contact is gradational with lithofacies 3, while the upper contact with Gun River mudstones is sharp (Fig. 3, Plate Ve).

Interpretation: Lithofacies 1 represents predominantly fair-weather deposition from suspension with only minor, distal tempestite occurrence. The presence of *Stricklandia*

to *Clorinda* brachiopod communities indicates depths of 75 to 120 metres (Copper & Long, in press), and thus effectively below storm-wave base (Fig. 7). Fine-grained fairweather sedimentation was dominated by settling of siliciclastic sediments out of suspension, with very little carbonate mud being deposited. As such, energy levels were very low, with the exception of the occasional high-energy storm introducing shallower-water sediments. Diagenetic effects are important in defining the nodular bedding within the sequence, as evidenced by the pervasiveness of solution seams and microstylolites (Wanless 1979). The upwards decrease in fossil content, increase in shale, and decrease in tempestite frequency indicate a deepening upwards trend during deposition of LF1. Micritic sedimentation was re-initiated with deposition of the basal Gun River Formation.

Lithofacies 2 (LF2)

Description: Light to dark grey un laminated and laminated mudstones dominate lithofacies 2, with minor amounts of un laminated and laminated packstones, laminated calcisiltites, and fine-grained grainstones (Plate IV c, d). The shale content is generally below 2%. Bedding is dominantly planar and laterally continuous, with irregular surfaces due to extensive bioturbation and sediment loading. Unlaminated packstones occur as small lenticular patches between mudstone units. Bed thickness ranges from 2 to 10 cm. Thin (<0,5 cm) shale drapes separate mudstone units with micro-stylolitic to solution-seamed contacts. *In situ* tabulate coral heads and brachiopods are present, commonly located above packstone or grainstone units, but the overall fossil content is low. Laminated rock types exhibit sharp bases and some show wave-rippled tops, with wavelengths up to 45 cm. Oriented elongate fossils, such as nautiloids, crinoid stems, and bryozoans, are common (Plate XI a, b).

The lithofacies thickness decreases from 34 metres in the west to 6 metres in the east (Fig. 5). Both the lower and upper contacts are gradational. The lower contact is

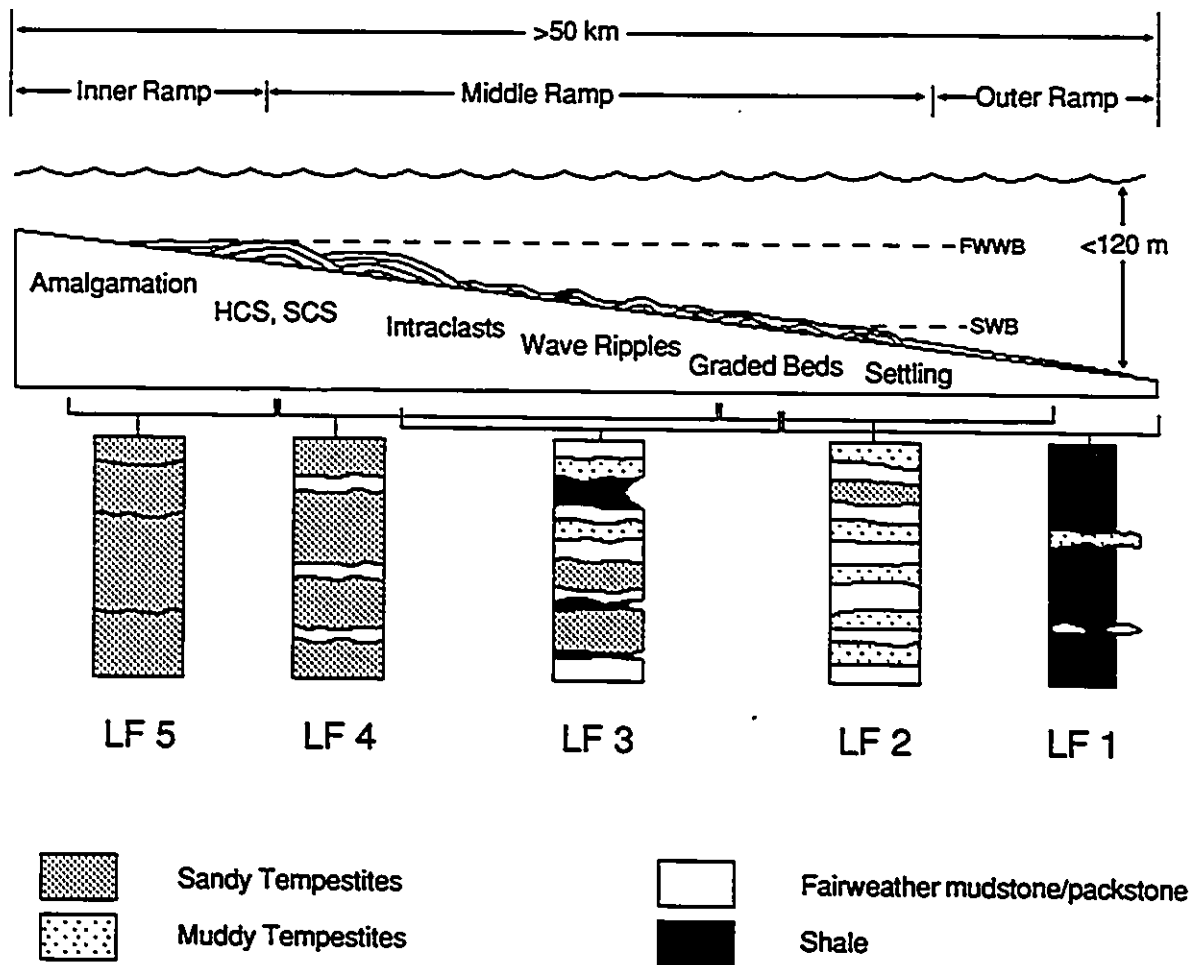


Figure 7: Depositional profile for the Becscie sequence showing lateral relationships between lithofacies types. Of particular note is the overlapping of the depositional environments of LF 1, LF 2, LF 3, and LF 4 and the sedimentary features associated with the lithofacies (adapted from Handford 1986).

characterized by an increase in carbonate mud content and a decrease in sediment derived from the biohermal member of the Ellis Bay Formation, while the upper contact has a reverse trend, with an increase in tempestite units. The mudstone content decreases upwards, with a gradual increase in calcisiltite and grainstone. The actual contacts are defined using sharp shifts in tempestite proximality trends (Sami & Desrochers 1989a).

Interpretation: The sediment alternates between fairweather unlaminated mudstones and packstones and distal, laminated mudstone and packstone tempestites. This corresponds with the upper portion of the ideal tempestite sequence (Fig. 6). The presence of *in situ* tabulate corals, stromatoporoids and cyclocrinid, calcareous algae, sets a lower depth limit of 100 metres (Beadle & Johnson 1986). The majority of beds are interpreted to have been deposited below storm-wave base (Fig. 7). The presence of rippled tempestites, however, indicates that deposition occurred above storm-wave base at times, up to about 70 metres. The clay content of the mudstones is very low but increases towards bedding contacts with the appearance of microstylolites. This suggests that the shale interbeds are diagenetically enhanced bedding planes. The intense bioturbation and presence of *in situ* fossils within the unlaminated mudstones and packstones indicate that they are depositional and not diagenetic.

Low-energy conditions prevailed during deposition of LF2 resulting in sedimentation due to the settling out of carbonate mud and minor shale from suspension. The sharp bases and grading of laminated units suggests physical sedimentation from low energy, episodic, waning flows, rather than erosion. Sediment transport was not extensive as evidenced by the lack of shallow-water faunas, but sufficient to produce a slight difference between fairweather and storm-derived mudstones, the most noticeable difference in the latter being the presence of lamination and quartz silt. The 2 metre thick transitional zone at the base of LF2 marks an abrupt

deepening from shallow subtidal carbonates of the Ellis Bay to deep ramp environments, marked by the transition from bioherms through encrinitic debris to mudstones. This was followed by a gradual shallowing which is marked by an increase in tempestite units, first distal then increasingly proximal, continuing up into lithofacies 4. With the lateral thinning of lithofacies 2 to the east, there is a concurrent decrease in tempestite units, the eastern exposures being dominated by unlaminated mudstones and shales. The thinning may be due to an increase in depth to the east, with the subsequent decrease of sediment introduced by storm currents giving rise to a thinner sequence.

Lithofacies 3 (LF3)

Description: This lithofacies contains sub-equal amounts of blue-green, argillaceous tempestites and interbedded mudstones, packstones and shale (Plate IV e, f). The shale content is locally as high as 30%. The bedding is nodular to lenticular with poor lateral continuity. Bed thicknesses range from 2 to 40 cm, usually within the same bed, due to highly irregular bedding surfaces. The coarse units have sharp eroded bases and show good grading. Sedimentary structures present include hummocky cross-stratification, wave ripples, channels, gutters, and coarse-grained ripples (wavelength= 45-80 cm). The fossil content is generally high and increases upwards.

The lithofacies varies between 18 and 28 metres in thickness, but poor exposure prevents identification of east-west trends (Fig.5). *In situ* fauna and shale increase upwards, while tempestite unit frequency decreases and units become more distal in nature. Tabulate coral and stromatoporoid colonies decrease in size and abundance eastwards. This is also accompanied by an eastwards increase in shale content and nodular bedding and a decrease in mudstone and tempestite abundance. Lithofacies 3 overlies, and is gradational from lithofacies 4 and grades upwards into lithofacies 1 with increasing shale content.

Interpretation: Lithofacies 3 is transitional between underlying lithofacies 4 and overlying lithofacies 1, but is distinct enough from both to be separated. The lower part of LF3 resembles lithofacies 4 and the upper part of LF3 resembles lithofacies 2, but with increased shale content, both within and between beds. In terms of depositional environments LF3 overlaps lithofacies 2 and lithofacies 4, but within a siliciclastic rather than carbonate-dominated regime (Fig. 7). Water depths inferred from *Pentamerus* to *Stricklandia* brachiopod communities (Copper & Long, in press) were 40 to 75 metres (overlapping LF2 & LF4). The coarser rock types at the base of LF3 were deposited above storm-wave base (equivalent to LF 4), and locally show the complete tempestite sequence. The fine-grained rock types abundant in the upper part of LF3 were deposited below storm-wave base (equivalent to LF 2), and represent fairweather settling from suspension. Low to very low energy conditions were episodically interrupted by high to moderate energy storm conditions. These trends suggest that lithofacies 3 represents an upwards and possibly eastwards-deepening interval, though lateral control is poor.

Lithofacies 4 (LF4)

Description: Lithofacies 4 contains, in decreasing amounts, laminated calcisiltites, bio/intraclastic rudstones, medium to fine-grained grainstones and laminated mudstones/packstones interbedded with nodular to irregularly-bedded, unlaminated mudstones/ packstones (Plate V a, b). Although the quartz silt content is high, the shale content is very low (<1%) and restricted to shale seams within nodular mudstones and interbed solution seams. The bedding is tabular to lenticular, with poor lateral continuity, and 5 to 50 cm thick, with individual beds being highly variable. Sharp eroded bases are abundant, as are channels, hummocky and swaley cross-stratification (HCS and SCS), lenses of micro-hummocky lamination, wave and interference ripples, gutters, ball and pillow structures, coarse-grained ripples and slump beds (Plates VII-X).

The fossil content is very high with faunas being mostly allocthonous, but *in situ* tabulate corals and stromatoporoids locally form biostromes. The lithofacies thickness is highly variable (dependant on occurrences of lithofacies 5), but in general the complete package varies from 90 to 125 metres and increases to the east (Fig. 5). LF4 overlies and grades upwards from lithofacies 2 with an increase in coarse rock types and grades upwards into lithofacies 3 with increased shale content. In the western exposures, LF4 locally grades internally into lithofacies 5, with a decrease in mudstone content.

Interpretation: The fairweather mudstones and packstones interbedded with the full range of tempestite rock types suggest a low- energy ramp punctuated by high-energy, erosive, storm currents (Fig. 7). The complete tempestite sequence can be observed, from coarse base to muddy top (Fig. 6). The abundance of wave-formed structures and excellent preservation of tempestites indicate deposition above storm-wave base but below fairweather-wave base (Walker 1985a). Water depths were about 30 to 70 metres based on location to other lithofacies, being shallower than for lithofacies 1, 2 and 3, but deeper than for lithofacies 5. There is an increase in bed thickness and coarseness, and a decrease in bioturbation and *in situ* fauna relative to lithofacies representing deeper environments (LF1-3). The abundance of intraclasts indicates the pervasiveness of early lithification in this environment or possibly a derivation from adjacent shallower environments. The abundance of erosional structures (gutters, channels, intraclasts) produced a very irregular depositional surface, reflected in the lenticular bedding morphologies (Plate VII f). The overall vertical trend is upwards-shallowing followed by gradual upwards-deepening. Up to four secondary shallowing-upwards cycles may be seen within lithofacies 4, terminating with lithofacies 5 in the westernmost Becscie exposures. The lateral variations in tempestite frequency, coarseness, and thickness suggest an eastward deepening.

Lithofacies 5 (LF5)

Description: Two rock types dominate lithofacies 5; quartz silt-rich laminated calcisilites, and medium to coarse-grained laminated grainstones, with minor intraclasts (Plate V c, d). The bedding consists of thick amalgamated beds, up to 80 cm thick, with no intervening mudstones or packstones (Plate VI e). The bedding is lenticular and highly irregular, with poor lateral continuity. The amalgamated contacts are sharp and usually overlain by thin fossil lags. The lamination is very well developed due to the high quartz silt content. Other sedimentary structures include grading, hummocky and swaley cross-stratification, and possibly channels (Plates VI, VII and X). The fossil content is high with no evidence of *in situ* material.

Lithofacies 5 is only present in western exposures, with a pinching out observed to the east, from 15 to 2 metres (Fig. 5). It grades into lithofacies 4 with the preservation of interbedded mudstones.

Interpretation: Equivalent to Dott and Bourgeois' (1982) M-cutout and lag-type storm units, this lithofacies represents the shallowest environments observed in the Beccscie Formation. Deposition occurred above storm-wave base and probably near fairweather-wave base, from 10 to 30 metres depth (Walker 1985a) (Fig. 7). Lithofacies 5 is exclusively composed of tempestite sequences, mostly from the basal portion, signifying very high energy levels (Fig. 6). The lack of intraclasts may suggest that their formation was restricted to deeper parts of the ramp or that they were effectively removed. Alternatively, it may be that intervals between storms were too short to allow the required early lithification. The absence of interbedded mudstone is probably due to removal by erosion rather than lack of deposition. Both hummocky and swaley cross-stratification are distinctly present but show no consistent vertical or lateral trends, preventing any environmental distinction such as that done by Tillman (1989). Lithofacies 5 decreases in thickness upwards from the first occurrence, indicating upwards

deepening. The absence of this lithofacies to the east also suggests an eastward deepening.

Depositional Interpretation

Ramps may be subdivided into several zones based on dominant energy levels and processes (Harms *et al.* 1982). These zones, nearshore, inner, middle and outer ramps, are not fixed but vary with size and slope of the particular shelf (Fig. 7). The nearshore environment is not represented by Becscie sediments and will not be discussed here. On the inner ramp, extending from 10 to 30 metres water depth, wave and tidal processes are dominant and energy levels are commonly high (Tillman 1985). The middle ramp, 30 to 100 metres water depth, is characterized by generally low energy conditions punctuated by episodic, short-lived high-energy storm events. Storm waves play an important role in substrate modification within this zone (Walker 1985a). On the outer ramp, 100 to 300 metres deep, energy levels are predominantly low, with storm currents being restricted to the strongest storms (Walker 1985a).

The five lithofacies suggest that fairweather deposition occurred on a low-energy, muddy to shaley, carbonate ramp from 10 metres, down to 120 metres depth (Figs. 8 & 9). Two depositional processes were involved, the settling of fines from suspension during fairweather periods, and high-energy physical sedimentation from waning flows and from suspension during episodic storms. These short-lived, high-energy events caused extensive re-mobilization of sediments and basinward transport of both coarse and fine sediments. The quartz silt is exclusively found in storm units and represents material introduced onto the ramp but derived from another environment, most likely wind-blown.

The evidence for storm-induced sedimentation is extensive, including: hummocky and swaley cross-stratification; amalgamation; grading; interference ripples; gutters; and subtidal intraclasts (Einsele & Seilacher 1982, Kreisa 1981). The presence

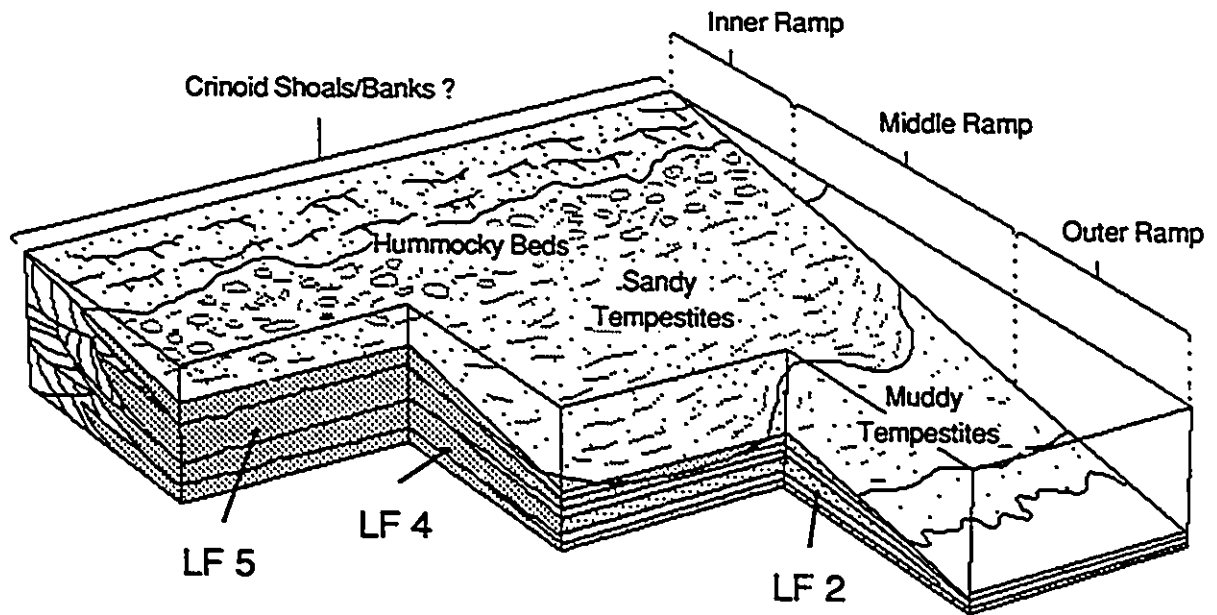


Figure 8: Block diagram illustrating the distribution of depositional environments and their associated lithofacies for a carbonate mud-dominated ramp. The crinoid shoal/bank environment is inferred as a source of the abundant carbonate sand and is not observed within the Becscie sequence. For lithologic symbols see Fig. 7. This depositional model is proposed for the lower part of the Becscie sequence, where lime mud is abundant (adapted from Handford 1986).

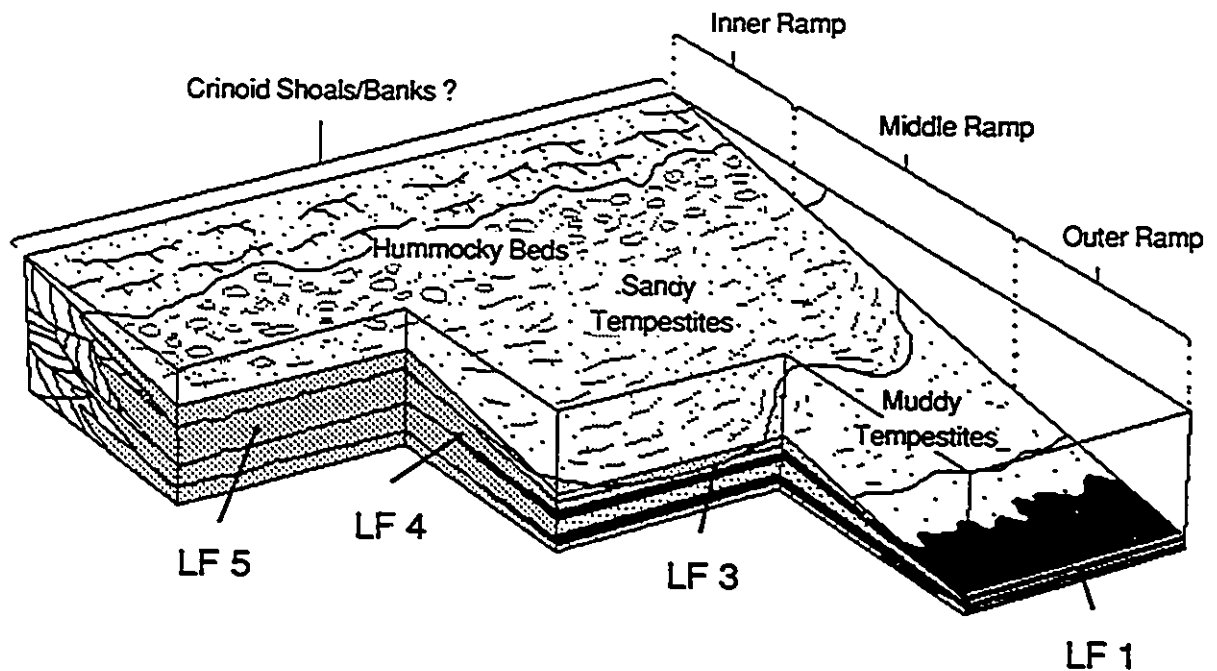


Figure 9: Block diagram illustrating the distribution of depositional environments and their associated lithofacies for a shale-dominated ramp. The crinoid shoal/bank environment is inferred as a source of the abundant carbonate sand and is not observed within the Becscie sequence. For lithologic symbols see Fig. 7. This depositional model is proposed for the upper part of the Becscie sequence, where lime mud is rare (adapted from Handford 1986).

of both wave-generated and current-generated features suggests a combined-flow storm regime (Nøttvedt & Kreisa 1987, Swift 1985).

The observed lithofacies reflect ramp subdivisions and their changing depths and related processes (Figs. 7, 8, & 9). In order of decreasing depth, the lithofacies and their environments are as follows:

- LF 1** - Rare, thin distal tempestites interbedded with fairweather shales,
deposition by settling from suspension on outer ramp, 75-120 m depth
- LF 2** - Thin distal tempestites interbedded with fairweather mudstones,
deposition by settling and episodic waning flow on middle to outer ramp,
70-100 m depth
- LF 3** - Thin to thick, shaley tempestites interbedded with fairweather shales and
argillaceous mudstones, deposition by settling and episodic waning flows
on middle to outer ramp, 40-75 m depth
- LF 4** - Medium to thick, coarse tempestites interbedded with fairweather
mudstones, deposition by settling and episodic high energy waning flows
on inner to outer shelf, 30-70 m depth
- LF 5** - Thick, amalgamated tempestites deposited by high-energy storm waves
on inner shelf, 10-30 m depth

The distribution of these lithofacies is illustrated in figures 7, 8, and 9. The vertical succession of these lithofacies can be used to infer relative sea-level changes based on a muddy ramp model. The lithofacies, when they are all present, occur in the following sequence from base to top (Fig. 5): LF 2, LF 4, LF 5, LF 4, LF 3 and LF 1. The transition zone at the base of lithofacies 2 marks the latest Ordovician-early Silurian transgression from shallow subtidal to the outer ramp environment of lithofacies 2. The transition from lithofacies 2 to lithofacies 4 marks a shallowing-

upwards event, or regression; which is continued with the transition to lithofacies 5. The upwards-shallowing marks a shift from deep-water, outer ramp, carbonate mud sedimentation into shallow water, inner ramp, tempestite-dominated sedimentation. The upwards shift from lithofacies 4 to lithofacies 3 and subsequently, lithofacies 1 represents an upward deepening or transgressive event from the shallow inner ramp to a shale-dominated, deep, outer ramp. The overlying Gun River mudstones mark a re-establishment of muddy, deep-water carbonate sedimentation. Superimposed on this transgressive-regressive-transgressive sequence are the secondary upwards-shallowing cycles represented by the occurrences of lithofacies 5 (Fig. 5).

The transition from muddy (carbonate) to shaley (siliciclastic) and subsequently back to muddy (carbonate) deep-water sedimentation marks a significant change in the nature of fairweather sediments. Assuming a sedimentological control, such as depth of deposition, there should be no significant overlap between muddy and shaley deep-water lithofacies. A substantial overlap exists between lithofacies 1, 2, 3, and 4 indicating that the controls may have been related to sediment source and/or processes. The deep-water carbonate muds were most likely derived from shallower-water production on what is commonly referred to as the "subtidal carbonate factory" (James 1984) and introduced into deeper waters from suspension. The introduction of these fines into suspension may have been related to storm or fairweather processes. As long as the zone of carbonate production is at optimal depths then the influx of carbonate mud to the outer ramp is sufficient to effectively dilute siliciclastic input and produce a muddy sequence. If the marine transgression is rapid enough and sediment production cannot keep up, the supply of carbonate mud to the outer shelf will fall drastically, and a shale-dominated outer ramp sequence will result. The author proposes that the shift from a muddy outer ramp at the base of the Becscie Formation to a shaley outer ramp at the top of the same formation was due to rapid sea-level rise from the middle Becscie upwards (Figs. 8 & 9). When carbonate production finally caught up, in the lower Gun

River Formation, a muddy outer ramp was re-established.

The lateral changes in lithofacies patterns and thicknesses may be used to infer the palaeogeometry of the ramp. Lithofacies 1, 2, and 5 all thin to the east, lithofacies 4 thickens, and not enough information is available on lithofacies 3. The absence of lithofacies 5 in the east suggests an eastwards deepening. The thinning of lithofacies 1 and 2 to the east is related to the loss of tempestite units in the deeper waters of the eastern ramp, and a decrease in available micrite, forming a condensed sequence. Storm-dominated ramps show maximum sediment accumulation somewhere in the middle ramp where depths are sufficient to minimize erosion and shallow enough to receive abundant sediment (Aigner 1985). This would explain the apparent thickening of lithofacies 4 to the east, due to a relative increase in erosion to the west with shallowing. The depositional model for the Lower Silurian Becscie Formation can thus be summarized as a shallow to deep-water, low-energy carbonate ramp subject to short-lived, episodic high-energy storm sedimentation (Figs. 8 & 9). The lateral changes in the Becscie sequence indicate an eastwards deepening, while the vertical succession indicates a sequence of deepening-shallowing-deepening for the early Silurian (Rhuddanian A₁ to A₄).

Part II

Storm Sedimentology

Introduction

The study of the geological effects of intense storms began in 1961 with the work of Hayes (1967) on hurricanes Carla and Cindy, along the Texas Gulf coast. The reported effects included extensive shoreline modification and the deposition of a widespread graded sand unit on the shallow shelf, covering the previously muddy sea floor. Hayes (*ibid.*) invoked deposition of the unit by a density current initiated through ebbing of the storm surge, which was reported to be up to 7m. The preservation potential of the unit was high, due to its deposition within a low-energy environment. Hayes thus concluded that hurricanes play an important role in sediment transport and mixing in nearshore environments.

Since this pioneering study, many of Hayes' conclusions have proven to be incorrect. The nearshore environment recovered from the hurricane effects quite rapidly and Hayes' sand layer had been rendered unrecognizable by intense bioturbation in only twenty years (McGowen 1981 in Dott 1983). Hayes' interpretation of a storm surge ebb as the transport mechanism has also been questioned (Walker 1985a), and now seems unlikely in view of proposed shelf responses to storms. Yet Hayes' conclusion that storms play an important role in shelf sedimentation still holds true. Since then storm deposits have been reported from all time periods in the geological record (Allen 1982).

The processes which operate on modern shelves are still being studied in an effort to better understand the geological record. There are as many theories on shelf and storm sedimentation as there are workers, with a broad division often biased by whether they study modern or ancient shelf sediments. As such, many of the current theories are still unproven and subject to re-interpretation. Despite this, they represent a significant advance since Hayes first addressed the topic.

Episodic Sedimentation

The notion of episodic accumulation of sediments is not new, dating back to the original ideas on catastrophic processes proposed in the early days of geology. The response to this dominantly creationist belief was the theory of Uniformitarianism, which proposed that the processes affecting the Earth were relatively constant, and that change occurred slowly and continuously. Applied to sedimentology, this meant that sediment accumulation was continuous, with few breaks. Some geologists (Ager 1980) have proposed that the breaks in the geological record may actually represent more time than the preserved rocks. This view poses the question of whether ordinary day-to-day processes acting uniformly through time or extraordinary processes acting sporadically are more important in the geological record. The dilemma is over continuous vs. episodic processes (Dott 1983). The concept of dynamic equilibrium, in which change is gradual rather than abrupt, strongly governs most geological studies. Often when changes are present a cyclicity is inferred. This is really only an extension of uniformitarianism in that it involves uniform change with uniform repetition. Ager (p.35 1980) describes the geological record as “a lot of holes tied together with sediments”, in an effort to show that the processes acting on the record are episodic and non-continuous and that the gaps represent more time than the preserved strata. An episodic event is often taken to be synonymous with “rare” event, and thus unlikely to occur. On a geological time scale, events which seem impossible by human standards become possible, and improbable events become inevitable (Dott 1983). Yet are rare events really important in the geological record? Goodwin and Anderson (1985) have developed the idea of Punctuated Aggradational Cycles, episodic stratigraphic intervals, along the same lines as the theories of Punctuated Equilibrium in evolutionary biology. On a larger scale Vail *et al.* (1977) have constructed sea level curves which chart major changes, often abrupt, affecting sea levels through geological time. Both these examples serve to show that events which occur at infrequent intervals may be used to obtain

information about the rock record.

The impact that rare events have on the geologic record is dependant on the volume of the deposit, the frequency of the event and the degree of subsequent modification, such as bioturbation, winnowing, scour and diagenesis. There exists a great variation in the duration and frequency of episodic events, from hours to days, and in the order of 400 to 15,000 years for major storms (Walker 1984) to millions of years for transgressive-regressive cycles (Dott 1983). Events which recur from several days to millions of years may be of greater than normal intensity, as in storms, or less than normal intensity, as in non-deposition. Sedimentary boundaries define these episodes, and most records are a combination of both processes. These processes may do a lot of work and modify sediments extensively, but unless they are preserved within the sediments they will have no bearing on the geological record. High-energy events, although rare by human standards, have a preservation potential disproportionate to their frequency and duration, and thus much of the stratigraphic record may contain units of a cataclysmic nature (Kreisa 1981). Preservation potential is therefore one of the most important factors governing the distribution and recognition of event deposits. Preservation potential is strongest below base level, so that episodes such as river floods, which deposit material above base level have a lower preservational potential than marine shelf storms, which deposit below wave base. Yet this is not absolute, since these deposits may also undergo uplift, regressions, and diagenetic and biogenic modification. Bioturbation is especially important on shallow shelves, where energy levels are low and faunas abundant. The importance of bioturbation in erasing storm deposits was demonstrated by McGowen (1981 in Dott 1983). The degree of bioturbation reflects the number of burrowing organisms, the time interval between storms, and any substrate modification produced by the storm. Brandt (1986) proposes that changes in the frequency of storm deposits through the geological record may be due in part to changes in the number of infauna. This may account for an abrupt

decrease in preserved storm beds since the Jurassic, which coincides with an explosion of infaunal species.

Episodic events which strongly affect shallow shelves include: (i) cyclonic storms, (ii) mid-latitude winter storms, (iii) seismic shocks (tsunamis), (iv) volcanic ashfalls, and (v) turbidity currents (Dott 1983, Seilacher 1982). Due to the shallow shelf setting of the Anticosti sequence, the discussion will be limited to storms on shallow shelves, including tropical hurricanes (cyclones) and intense winter storms.

Shallow Shelf Storm Processes

Modern shelves range from the low water line down to 550 metres depth at the shelf-slope break, and average about 130 metres deep. They are subdivided into four main types, dependent on processes affecting the shelf, (i) storm-dominated, (ii) tide-dominated, (iii) wave-dominated, and (iv) oceanic current-dominated (Walker 1984, Johnson and Baldwin 1985). Storm-dominated shelves account for 80% of all modern shelf types, illustrating their importance. It seems reasonable to assume that their importance can be projected backwards in the geological record, as basic shelf processes should not have changed significantly. Shelves can be subdivided into three or four zones: the nearshore, the inner shelf, the middle shelf and the outer shelf, with the middle zone sometimes omitted (Tillman 1985, Harms *et al.* 1982). The ranges of each zone are not fixed but vary, depending on the size and slope of the particular shelf. Each zone is characterized by different dominant processes, with considerable overlap. Storm-generated currents affect all shelf zones (Tillman 1985).

Seaward of the 10 m isobath on modern, storm-dominated shelves, there is no fairweather sediment transport, only peak and waning storm regimes (Swift and Niederoda 1985). As such the bedforms on these shelf floors are predominantly storm-produced. Fairweather wave base is defined as the effective limit for fairweather

waves feeling bottom, where the background sediment becomes predominantly muddy, separating environments dominated by day-to-day processes from those which are normally quiet and sediment is only moved by storms (Walker 1985a). Storms can be divided into several stages: (i) Pre-storm, with gentle winds and small surface waves (fairweather conditions); (ii) Storm growth, a rapid increase in wind strength and consequently wave size and period; (iii) Full storm, in which wind and waves become constant for a significant period; (iv) Storm decay, wind speed and waves are restored to pre-storm state; and (v) Post-storm, fairweather state.

Three major storm processes are active during these stages (Aigner 1985, Allen 1982): (i) Barometric effect: water levels at the coast are raised or lowered due to a gradient in atmospheric pressure induced by the storm, producing coastal set-up or set-down, (ii) Wind effects: wind tractive forces produce onshore wind drift currents in nearshore surface waters further enhancing coastal set-up; this motion is compensated by a near-bottom gradient current flowing offshore in response to the water column tilt, (iii) Wave effects: storm waves set up oscillatory bottom flows superimposed on the unidirectional wind-induced flows. These processes initiate various types of water movement. Wind-driven currents are the result of wind shear stress on the water surface, they are usually unidirectional, very extensive and subject to coriolis forces. Oscillatory wave drift results in orbital motion, which is translated into a back and forth motion at the bottom. Storm surge, or set-up is due to barometric and wind traction effects (Fig. 10). This system of currents is complicated by the presence of coriolis forces (Fig. 11). In the northern hemisphere, currents are deflected to the right, in the south, to the left. This veering increases with depth, and so the resultant flow on shelf bottoms is often 90° from the dominant wind direction. The result is that the gradient current due to coastal set-up veers to the side and flows parallel to the coast as a geostrophic current (Swift and Niederoda 1985). An increase in the wind strength causes an increase in the velocity of the geostrophic current. The near-bottom flow,

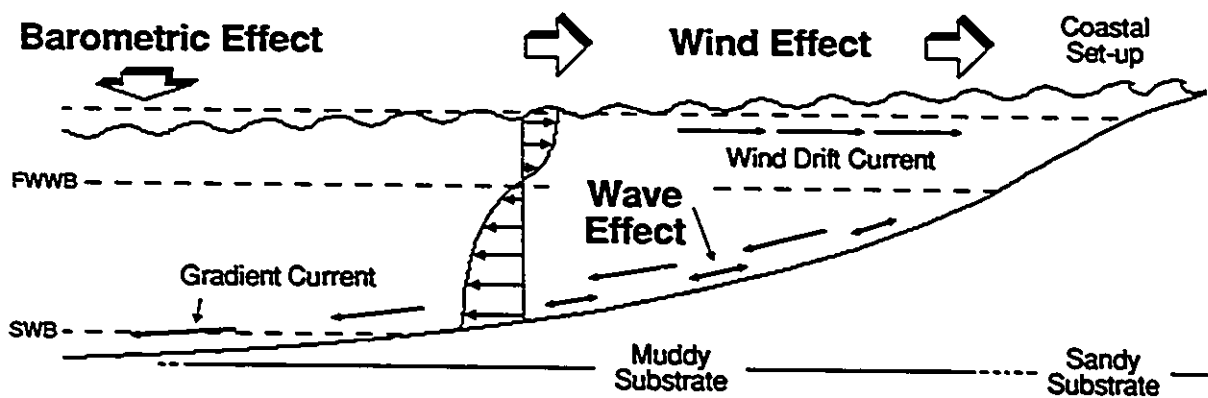


Figure 10: Offshore profile showing a summary of shallow shelf storm processes:

Barometric effect, inducing coastal set-up; Wind effect, producing a wind drift current; and Wave effect, forming an oscillatory component. the gradient current is a result of the combination of these effects. FWWB = Fairweather wave base, SWB = Storm wave base (modified from Aigner 1985, Walker 1984).

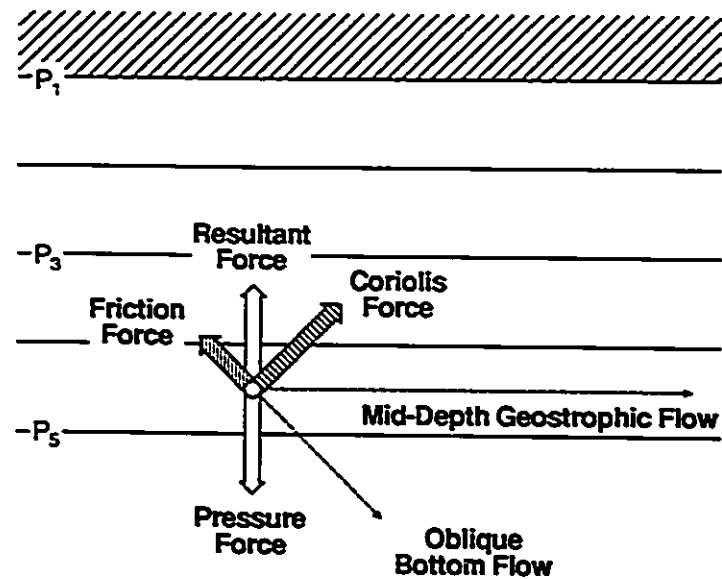


Figure 11: The balance of forces, in plan view, for the nearshore seafloor of the Anticosti Basin. P_1 , P_2 , and P_3 represent isobars of equal pressure. The hashed pattern represents the proposed shoreline. The pressure force is modified by coriolis to produce an alongshore-directed geostrophic flow (counterclockwise rotation for the southern hemisphere). This flow is modified by friction force at the seafloor to produce an oblique offshore-directed bottom flow (modified from Swift *et al.* 1986a).

however, experiences bottom friction and due to the resulting force veers obliquely offshore. As the strength of the current increases, the offshore deflection of the bottom flow becomes more pronounced. A dynamic equilibrium is eventually attained, with the shelf itself acting to contain the flow, and the storm surge travels along the shore as a shelf wave. Storm surge ebb may also contribute to the relaxation of the set-up, but it has been shown to be minor (up to 3000 times weaker) compared to geostrophic currents (Walker 1984, Swift and Niederoda 1985, Swift *et al.* 1986a). Storms crossing the Anticosti ramp from east to west, in the Early Silurian, would therefore have produced a southward-directed downwelling which would have been deflected into an eastwards-travelling geostrophic core flow and a southeastwards-directed bottom flow (Fig. 12).

The nearshore zone is dominated by the onshore-directed wind drift currents forming spillover lobes and skeletal banks. Offshore zones are dominated by seaward transport of coastal sediments by bottom gradient and geostrophic currents (Aigner 1985, Swift *et al.* 1986b). Several mechanisms have been proposed to account for transport of sediment from the shoreface to offshore zones (summaries in Aigner 1985, Allen 1982, Walker 1985a, Swift 1985): Wind drift currents; Rip currents; Combined storm wave/density currents; Combined wave-induced current with storm-ebb current; Storm surge ebb currents; Purely wave-induced currents; Storm-induced bottom currents with storm wave liquifaction; Storm waves with tidal ebb currents; Storm waves alone; Incremental storm flows; Combined geostrophic/oscillatory storm wave currents. Combined geostrophic/oscillatory currents (Swift *et al.* 1983, Swift 1985, Swift and Niederoda 1985, Swift *et al.* 1986a, Aigner 1985, Allen 1982) and combined storm wave/density currents (Hamblin and Walker 1979, Walker 1985a, Walker 1985b) have received the most widespread support. Combined-flows contain two components, a high frequency ($6-12\text{ s}^{-1}$) wave orbital component superimposed on a slowly varying unidirectional component (Swift *et al.* 1986a). These combined-flows are very effective

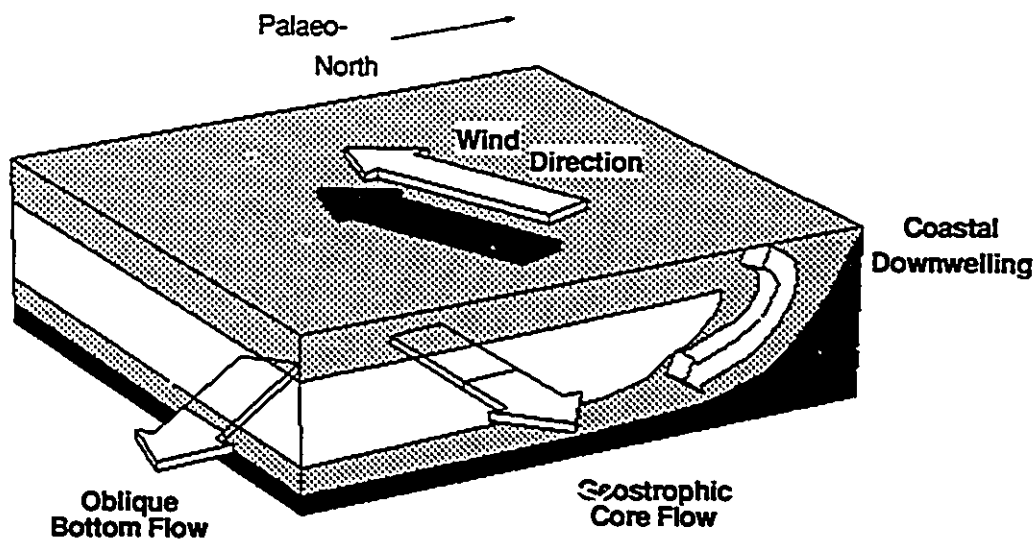


Figure 12: Block diagram illustrating the proposed flow regimes active on the Anticosti ramp during the Early Silurian. Coastal downwelling, induced by east-west travelling storms resulted in eastwards-directed geostrophic flow and southeastwards-directed bottom flow. Based on forces illustrated in Fig. 11 and palaeogeographical reconstructions (modified from Swift and Rice 1984).

sediment transporters due to intense bottom shear stress, often transporting up to ten times the amount of sediment of strictly unidirectional currents (Swift and Niederoda 1985). The oscillatory component entrains and disperses grains as a sustained load above the bed while the unidirectional component provides the net offshore transport (Allen 1982). Such combined-flows with velocities of 1 m/s in shallow water acting in one direction for a day may move up to 1000 tons/m/day of fine sand up to tens of kilometres (McCave 1984). Combined- flows are effective sediment transporters in that they are more efficient than either oscillatory or unidirectional currents alone. Wave orbital currents create a thin transient boundary layer which is more effective than the thick boundary of the mean flow in entraining sediment. When a wave orbital component and a mean flow component coexist near the bottom they interact in a non-linear way due to the turbulence generated by the combined-flow. The resulting boundary shear stresses are greater than the sum of each component alone. In addition, turbulent eddies, due to acceleration and deceleration of the flow, are very strong and enable a higher ratio of suspended to bedload sediment. The turbulence resembles the upper flow regime, but with lower actual velocities. Swift and Niederoda (1985) stated that there is little evidence to suggest that turbidity currents can be initiated on modern shelves. Turbidity currents are driven by a positive-feedback mechanism of autosuspension. The flow becomes self-sustaining when it attains a velocity sufficient so that turbulence is intense enough to suspend grains and the density of the suspension is in turn sufficient to drive the flow. Initiation occurs when the sediment travels fast enough to exceed the critical value for autosuspension. Studies of modern shelf conditions show that flows are unlikely to achieve autosuspension (Swift and Niederoda 1985). Turbidity currents require densities in excess of 1 g/cc; a concentration of several orders higher than densities actually observed. Walker (1985b), in his work on ancient shallow shelf facies, believed that density currents can be initiated on shelves during storms due to extreme conditions. It may be that storm-generated density currents settle sediments in a

way that is indistinguishable from sediments raining out of a waning geostrophic current (Walker 1985b); as such it is best not to dismiss such a mechanism.

The effect of storm processes on shoreface and shallow shelf sediments can be summarized in several steps. On the shoreface, sand and mud are introduced by alongshore currents. During the storm, gradient currents move large quantities of fine sand out of the surf zone into the zone of coastal downwelling. The combined-flow currents carry sediments obliquely down the shoreface onto the inner shelf. Erosion due to accelerating storm currents ceases when the boundary layer reaches flow capacity (Swift and Rice 1984). The wave-orbital component decreases rapidly and results in a loss of competence depositing sediment from a waning current.

There are two main storm types which produce this range of effects, tropical cyclonic and intense mid-latitude winter storms (Swift and Niederoda 1985). These storm types differ greatly in intensity, duration and scale of effects. Cyclones are storm systems which originate in the tropics and have winds in excess of 35 m/s. They are commonly less than 100 km in diameter and travel at velocities of 10-15 m/s, with high intensities being due to their areal concentration. Mid-latitude winter storms are commonly 200-500 km in diameter and travel at velocities of 2-5 m/s (Swift and Niederoda 1985). Cyclones may be less efficient in coupling with the water column due to their high intensities and velocities. As a result they may not have sufficient time to transfer turbulent motion downwards from wind-stressed surface to bottom. In addition, they also occur in the late summer to early autumn when the water column is highly thermally stratified and the buoyancy of the light, warm surface water further hinders the transfer of turbulence (Swift *et al.* 1983, Swift and Niederoda 1985). Cyclones are effective in coastal setup, they generate short-lived, intense coastal flows, but are unable to generate the vast, sustained geostrophic flows characteristic of intense winter storms. Winter storms affect a wider area and occur at times when thermal stratification is poor,

as a result they generate strong downwelling currents and geostrophic currents which can flow for several 1000 km as topographically trapped shelf waves until they dissipate due to frictional drag (Swift *et al.* 1986a). The approach paths of the two storm types may also differ, due to different regions of generation, and may be reflected in the resulting flow directions and sedimentation patterns.

Shallow Shelf Storm Sedimentation

The early stages in storm development are marked by intense erosion and the suspension of large amounts of sediment. The currents eventually stop accelerating and a dynamic equilibrium is reached, where the amount of sediment deposited equals the amount of sediment entrained. As the storm currents reach deeper water and the flows become less competent deposition occurs on a larger scale. The resulting sediment package reflects deposition from a waning current (Figs. 6 & 13). Oscillatory currents can remain effective up to a depth of 200 m (Kreisa 1981). A storm regime as described in the previous chapter will produce a wide range of strata types, including: (i) cross beds, multi-event beds deposited on the shoreface under high energies; (ii) hummocky beds, single event suspension beds deposited by storm flows with a high ratio of oscillatory to unidirectional flow components; (iii) graded beds, single event beds deposited from waning combined currents with relatively dense near bottom suspensions; and (iv) lag strata, multi-event beds resulting from reworking of sediments (Swift *et al.* 1986b). Net scour and deposition are non-uniform across the shelf due to topographic irregularities. This causes velocity fluctuations, with deposition occurring as currents decelerate over highs and erosion in troughs as currents accelerate. A positive-feedback mechanism is initiated as the bedforms get larger. This enables the formation of thick storm beds which cannot be accounted for by simple accumulation from suspension (Swift and Rice 1984).

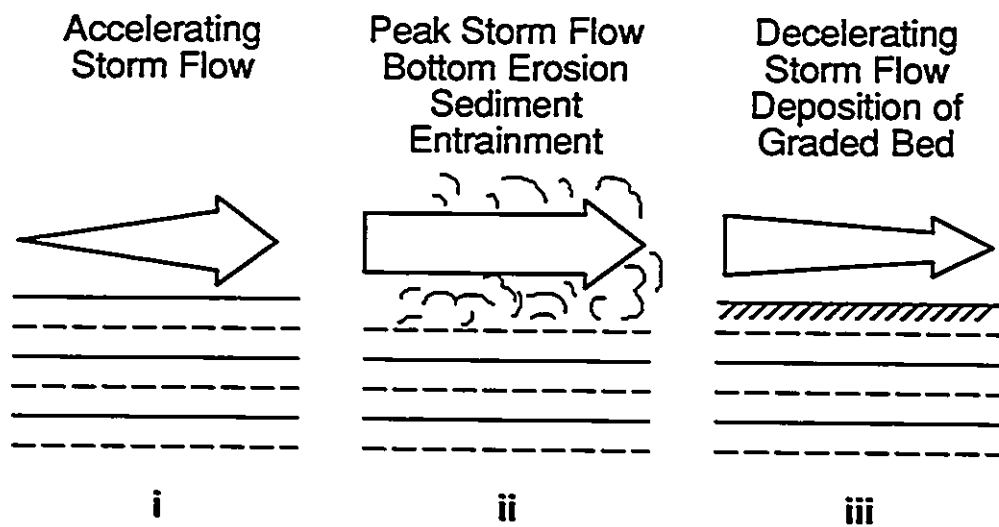


Figure 13: Model for the deposition of graded tempestite beds from waning storm flows and the response of the seafloor to the different storm stages: (i) Storm growth; (ii) Full storm; and (iii) Storm decay. The thickness of the arrows reflects current strength and competence (modified from Swift and Rice 1984).

Tempestite Morphology and Sedimentary Structures

There are numerous sedimentary features which serve as useful criteria in the identification of storm beds. This assemblage includes: interbedded coarse and fine beds, graded beds, scoured bases and burrowed tops, thick and thin lenticular beds, infiltration textures, hummocky cross-stratification, laminated beds with upwardly thinning laminae, pot and gutter casts, lag-suspension couplets, reworked, par-autochthonous faunas, and escape burrows, in a distinctive vertical sequence of structures reflecting deposition from a waning flow (Kreisa 1981)(Fig. 14).

Each shelf zone is characterized by distinctive deposits: (i) Inner zone: thick allochthonous, hummocky sands and thin autochthonous muds, sharp erosional bases. The beds are thick since deposition occurs for long periods and they are located near the source of sediment. Lags are common due to the high degree of erosion and reworking. Most coarse beds are not graded due to constant conditions through most of the period of deposition; (ii) Middle zone: characterized by thin, graded sandy beds since regime of deposition is short and occurs during a period of waning currents; (iii) Outer zone: graded muddy beds, thin and often bioturbated. Two types of storm deposit have been described, graded units and hummocky units (Fig. 14). In the Becscie sequence however, both types are gradational and are part of the ideal tempestite sequence (Fig. 6).

Graded Units: Graded beds represent sediments deposited during single storm events and commonly occur in characteristic horizontal and vertical sequences (Kreisa 1981). These sequences represent the onset (erosion), culmination (winnowing) and waning (deposition) of storms (Seilacher 1982). Storm-related processes generate many structures and textures within the vertical sequence which provide criteria for recognizing storm-graded beds, even when complete sequences are absent. These sequences may occur in both siliciclastic and carbonate facies. Aigner (1982) described

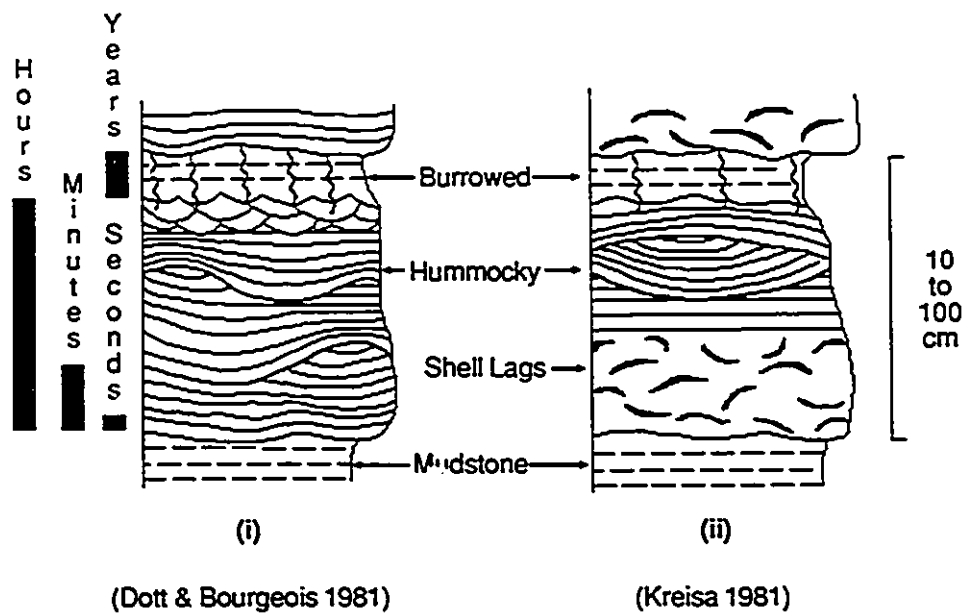


Figure 14: Simplified comparison of (i) predominantly hummocky and (ii) predominantly graded tempestite sequences. The time scales for each portion of the sequence are represented to the left (modified from Dott 1983).

such a vertical sequence in carbonates and proposed an ideal sequence for these "tempestites". The main criteria for identifying these tempestites are (i) sharp erosional base, often showing sole marks such as grooves, tool marks, and gutter casts and/or lenticular shell/intraclast lags, (ii) massive or graded sand, often with reworked shell material, (iii) plane or low angle lamination, may be hummocky cross-stratification, (iv) wave ripple cross-lamination and wave ripples, (v) bioturbated, muddy interval with diffuse top (Swift 1985, Aigner 1985). Other features include, common lenticular bedding, escape traces, ball and pillow structures, hardgrounds and condensed horizons (Walker 1985a, Kreisa 1981).

Most of these structures show the effects of both oscillatory (wave ripples and cross-lamination) and unidirectional (gutter casts, tool marks) components of flow. Evidence of unidirectional traction transport is rare, but climbing ripple lamination (similar to HCS but on a smaller scale- "microhummocky cross-lamination") may occur. The sediments are commonly well-sorted and show a polymodal distribution from shell material to fine sand and silt to muds so that intervals may appear to have sharp contacts.

The restriction of bioturbation to bed tops, the presence of escape traces, infiltration textures, and predominantly par-autochthonous to autochthonous shell assemblages in the sequences support a single-event interpretation (Kreisa 1981, Kreisa and Bambach 1982). Shell material may be abundant, and represent *in situ* reworking, winnowing, or current deposition (Johnson and Baldwin 1985). This shell material is usually well preserved due to rapid burial and the resulting lack of biogenic degradation. Little fragmentation occurs because there is no consistent high energy. Storm flows are periodic and short lived locally and as such are not very effective agents of shell breakage. The net result is that storms preserve rather than destroy loose fossils, by burying and protecting them from fairweather processes and early diagenesis (Kreisa

1981). The lag deposits are often composed of shell material which has undergone winnowing but usually little mixing and transport, unless close to shore.

The majority of tempestite beds in the Becscie sequence are graded (Fig. 6). Complete fining-upwards sequences are rarely represented, with most beds showing only partial sequences. In most cases the fining is rather abrupt, due to grain size sorting, so that the tempestites are separated into discrete parts (Plate VI a-d). These graded beds are laterally variable in thickness, have sharp scoured bases, and exhibit all the structures commonly attributed to storm-influenced deposition: sharp bases, grading, shell and intraclast lags, gutters, HCS, interference and wave ripples, and coarse-grained ripples (Plates VI-X).

Hummocky Units: Hummocky beds are characterised by the presence of hummocky cross-stratification within a vertical sequence. Hummocky cross-stratification (HCS) was defined by Harms *et al.* (1975) as exhibiting the following features: lower bounding surface is erosional and commonly dips at angles less than 15°; laminae above bounding surfaces are parallel to the surface but may thin or thicken laterally; dip directions of boundaries are random; bases of HCS beds are sharp and may show tool marks; wavelengths vary from 1-5m, and amplitudes are a few tens of centimetres; and they occur in a three-dimensional pattern of hummocks and swales (Plate VII a-c, e). An idealized tempestite sequence (similar to that of graded beds) has been proposed (Dott and Bourgeois 1982, 1983, Walker *et al.* 1983). This sequence contains hummocky-cross-lamination, planar lamination, cross-lamination, and bioturbated mudstones in a distinct vertical zonation (Fig. 14). The different units reflect the change in storm processes active at time of deposition (Johnson and Baldwin 1985): Eroded base, (storm erosion); horizontal lamination and HCS (main storm deposition); wave ripple and cross-lamination, (waning storm deposition); bioturbated mud (final suspension deposition and possibly fairweather deposition). A similar type of structure

has been observed in lenses of fine sandstone with curved laminations, internal truncations and wavelengths from 10-100 cm (Plate VII d). Dott and Bourgeois (1982) referred to these structures as micro-hummocky cross-lamination, interpreting them as wave-formed analogues to starved current ripples, formed during low sand supply. Greenwood and Sherman (1986) consider them to be actual HCS, as the original report of HCS included wavelengths as low as 10 cm.

Despite their abundance in the geological record, the origin of HCS is still unclear, partly due to the ambiguity of proposed modern examples. Hamblin and Walker (1979), in one of the first interpretations of a sequence containing HCS, suggested that HCS forms between fairweather wave base and storm wave base due to emplacement of sand by turbidity currents and subsequent storm wave reworking. Dott and Bourgeois (1982) and Dott (1983) interpret HCS as a scouring phenomenon, with storm waves sculpting the sediment into a pattern of hummocks and swales and a subsequent draping of these forms by sediment coming out of suspension, whereas Walker *et al.* (1983) consider HCS to be an actively growing bedform.

Allen (1985) examined the processes which are active on modern shelves and concluded that combined-flows are necessary to cause the enhancement of bed shear stress required to form HCS and prevent substantial migration of the bedforms. Random dip directions, wave ripples and cross-laminations all indicate an oscillatory component, while irregular basal erosional surfaces, basal sole marks, gutter casts and primary current lineation indicate a unidirectional component of flow, supporting a combined-flow origin. Swift *et al.* (1983) proposed that they form under combined-flow storm currents in which wave orbital motion is dominant. The hummocks are supplied with sediment from suspension and growth alternates with erosion producing the truncated surfaces (Swift 1985). Greenwood and Sherman (1986) observed actively growing bedforms with little or no lateral migration, developing under the influence of combined

longshore and oscillatory flows, which they believed to be HCS. This occurrence would place HCS in a combined-flow regime, between upper planar bed and wave ripples.

Some disagreement exists as to which types of storms are more important for production of HCS. Marsaglia and Klein (1983) and Klein and Marsaglia (1987) propose that winter storms are more likely to produce HCS than hurricanes. Duke (1985) contends that hurricanes seem to be more effective. Swift and Nummedal (1987) suggest that there is no preference of one type or the other since they both affect the water column with similar processes and produce similar effects.

In summary, hummocky and swaley cross-stratification appear to be diagnostic of inner shelf storm deposits. This is not to indicate that they do not form in other zones, but that their preservation potential is greatest between fairweather and storm wave bases, where day-to-day processes are minimal. Their origin is still uncertain, but combined-flows seem most reasonable in that they are in agreement with processes observed on modern shelves. Hummocky, swaley, and microhummocky beds are abundant in the Becscie sequence, particularly in lithofacies 4 and 5 (Plate VII). They occur in laterally continuous to lenticular beds which may show amalgamation (Plate VI e). They are composed of calcisiltites, are very well-laminated, commonly have interference or wave-rippled tops, and generally occur within a graded unit. Swaley cross-stratification is similar to HCS but with a greater percentage of preserved swales. Tillman (1989) contends that they are two distinct bedforms which can be distinguished on the basis of form (swaley vs. hummocky), grain size (SCS is coarser grained), bed thickness (SCS being thicker), amalgamation (common in SCS), stratigraphic position (SCS occurring above HCS and below foreshore), and environments of deposition (SCS occurring shorewards of HCS, in the middle to upper shoreface, as compared to the inner shelf to lower shoreface for HCS). In the Becscie sequence such a distinction is not observed, with the two bedforms commonly being interbedded.

Gutters and Gutter Casts: Storm-surge scour channels and gutter marks both result from the intense scouring of the shelf floor during the peak storm stage. The most common forms for gutter casts are symmetrical to asymmetrical, sinuous to straight and usually around a meter in length and several centimetres in depth and width (Whitaker 1973). They may have eroded into firm cohesive mud or a sandy substrate by water moving along helicoidal paths. They occur dominantly in carbonate lithologies. Their interior surfaces may show toolmarks obliquely arranged, indicating a helicoidal path, or parallel to the alignment of the gutters. The tool marks are commonly bidirectional, indicating an oscillatory component to flow, and the fill may show current ripples aligned across the gutter, and/or imbrication, indicating a unidirectional component of flow, therefore a combined-flow (Aigner 1985). Gutter casts are common on storm bed bases; they reflect the selective erosion of cohesive sediments by high velocity currents (Johnson and Baldwin 1985). Gutters may experience episodic activation and fill, allowing preferential colonization or sediment trapping (Goldring and Aigner 1982).

Gutters and gutter casts can be found throughout lithofacies 4 and the coarser portions of lithofacies 2 and 3 of the Becscie sequence, on extensive, well-exposed bedding planes (Plate VIII a-d). They vary widely in morphology and substrate-fill combinations (Fig. 15). They occur most frequently in mudstone and fine grainstone or calcisiltite substrates, with any of the observed rock types composing the fill. Some gutters show evidence of a delayed-fill, such as borings and/or burrows and colonization of gutter surfaces by attached organisms (tabulate corals, stromatoporoids, brachiopods, bryozoans) (Plate VIII e, f). This would indicate that the storm which infills a gutter is distinct from that which formed the gutter. They vary from several tens of centimetres to several metres in length and from 5 to 50 centimetres in width. They are linear to sinuous and commonly bifurcate. The larger gutters show greater (>1m) spacing, while narrow gutters may be only centimetres apart. All observed occurrences form distinctly guttered horizons which are laterally traceable.

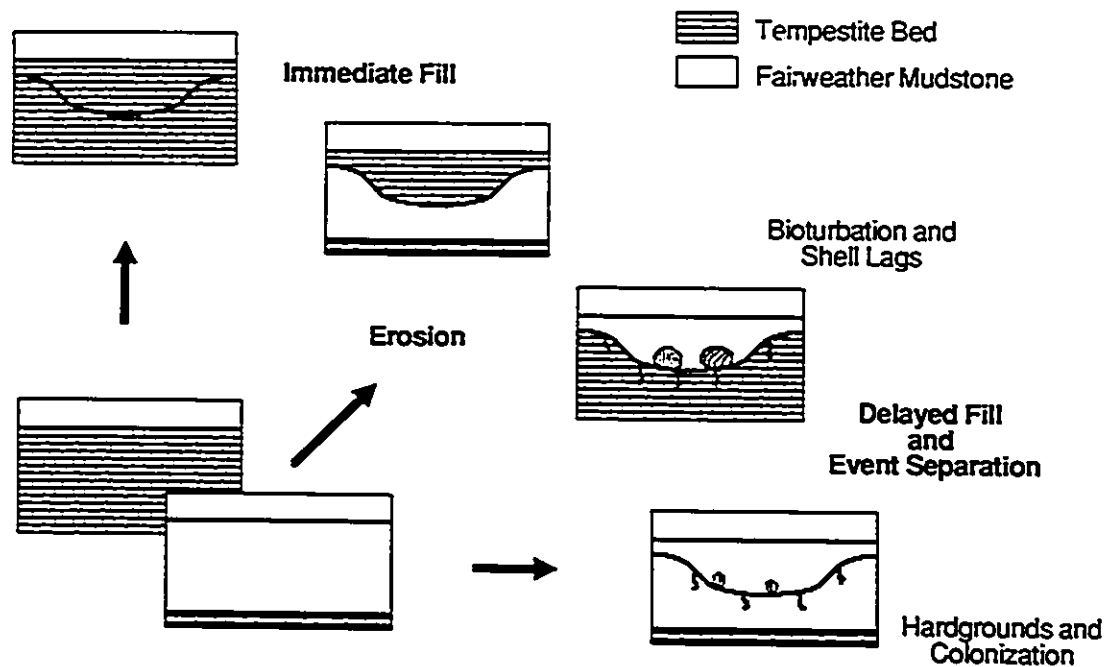


Figure 15: The four main gutter types observed in the Becscie sequence, showing the different substrate/fill combinations formed in response to different physical and biological processes. When the fill is immediate, coarse tempestites dominate the fill. When fill is delayed, burrowing of the gutter and the formation of fossil lags occurs. With increased delay hardgrounds may form and be subject to boring and attaching organisms. These are eventually infilled by fairweather mudstones (modified from Goldring and Aigner 1982).

Interference Ripples: Interference ripples provide further evidence of a multidirectional storm regime. The pattern of ripple crests represents the presence of multidirectional oscillatory currents, indicative of storm flows (Allen 1982). The two sets are believed to have formed simultaneously.

Interference ripples in the Becscie sequence generally occur on the tops of laminated mudstone/ packstone, calcisiltite and fine grainstone units, commonly topping hummocky cross-stratified sequences (Plate VII e). Their wavelengths range from 5 to 10 centimetres, with ripple-crests being perpendicular to slightly oblique. Their morphology is rectangular to inequant-hexagonal in form, and some grade laterally into symmetrical wave ripples of similar wavelengths (Plate IX a-d). This is particularly common on the flanks of three-dimensional, hummocky surfaces.

Shell Lags and Condensation Horizons: Condensation horizons and shell lags are quite common in storm beds and reflect intense winnowing and reworking of sediments. Condensation horizons form through the repeated reworking of quiet-water sediments by rare, higher-energy events, resulting in the removal of fines and the accumulation of shelly and coarse clastic material (Gebhard 1982). This leaves a thin bed of mixed material representing a large time interval. Shell lags form through dynamic (transport, concentration, winnowing) or static (suffocation and rapid burial of *in situ* faunas) processes, the former producing thick beds and the latter creating thin beds (Dott 1983). The actual transport and mixing of faunas is rare in storm beds except in the nearshore environment where erosion is extensive (Kreisa 1981).

Dynamic shell lags are common within lithofacies 5 and coarser portions of lithofacies 4. They are usually thick, 5 to 45 centimetres, and laterally discontinuous. Some seem to be controlled by the distribution of depressions or channels. Condensation horizons and static shell lags are common within the finer lithofacies (LF1, LF2, LF3) where thin tempestites are covered by thick muddy or shaley units. Most

unlaminated packstone occurrences are actually condensation horizons or static shell lags. They are generally thin, 2 to 5 centimetres thick, contain *in situ* faunas and form shallow depression-fills (Plates V a, VII f, XI c, d).

Coarse-Grained Ripples: Wave-formed, coarse-grained ripples (CGR) having wavelengths of 25 to 300 centimetres and amplitudes of 5 to 35 centimetres are reported to share a close association, and possibly a common origin with hummocky cross-stratification (Leckie 1988, Swift *et al.* 1983, Nøttvedt & Kreisa 1987). The difference lies with component grain size. While HCS is restricted to fine sand and silt-sized grains, CGR form with medium to very coarse, pebbly sand. Although the mechanisms are the same, sediment size governs the resulting bedforms. Modern CGR crests trend parallel to local shorelines and bathymetry, and thus may aid in basinal reconstruction in ancient sequences (Leckie 1988).

Symmetrical and asymmetrical, coarse-grained ripples with wavelengths of 45 to 85 centimetres and amplitudes of 5 to 10 centimetres are common throughout the Becscie sequence. They are composed of medium to coarse-grained grainstones and coarse bio/intraclastic rudstones. They are slightly sinuous to straight, show no bifurcation and range from symmetrical to slightly asymmetrical (Plate IX e). The internal stratification of asymmetrical CGR consists of poorly-defined low-angle crossbeds (Plate IX f). Coarse fossil debris may be locally concentrated in the ripple troughs.

Scoured Bases: Sharp, scoured bases are characteristic of storm-deposited beds (Aigner 1985). The sharpness of these surfaces may be due to erosion prior to deposition, or to an abrupt change in grain size (depositional). Selective erosion of the substrate may produce irregular surfaces, gutters, scours, or channels, depending on the force and nature of the eroding current.

Scoured bases are present throughout the Becscie sequence, associated with

tempestite units. These bases are often regular to slightly irregular and represent both erosional and depositional regimes. Some sharp bases are locally highly sculptured and irregular and show discoloration and possible borings. These surfaces are developed exclusively in dense, unlaminated mudstone which commonly occurs as irregular intraclasts in overlying beds (Plate VI f). These irregular surfaces are likely the result of storm scouring and accentuation of burrowed sediments, due to the selective erosion of the less cohesive burrow-fills. The retention of these intricate surfaces in intraclasts suggests early lithification and possible formation of firm- or hardgrounds. Due to the fine-grained texture, borings are difficult to confirm, but the presence of numerous sharp-walled excavations indicates some degree of cohesiveness.

Tempestite Proximity Trends

Introduction

Tempestite units may differ in appearance from the ideal sequence in several ways, due to incompleteness and amalgamation. Factors which affect the sedimentary record of storms (Fig. 16) include: storm duration, storm intensity, storm nature, depth of deposit, and distance of deposit from the source of sediment (or shoreline) (Allen 1982). These variations are easily observed and may be used to plot trends through storm-influenced sequences.

Aigner (1985) contends that variations in tempestite morphology are useful in establishing proximity trends, being defined by changes in distance from shore and depth-related parameters. These parameters reflect the sedimentologic character of tempestites and include: grain size, unit frequency, bed thickness, amalgamation occurrence, presence of cross-lamination, degree of bioturbation, bedding style and fossil assemblage (Fig. 17). Variations in these parameters produce both lateral and

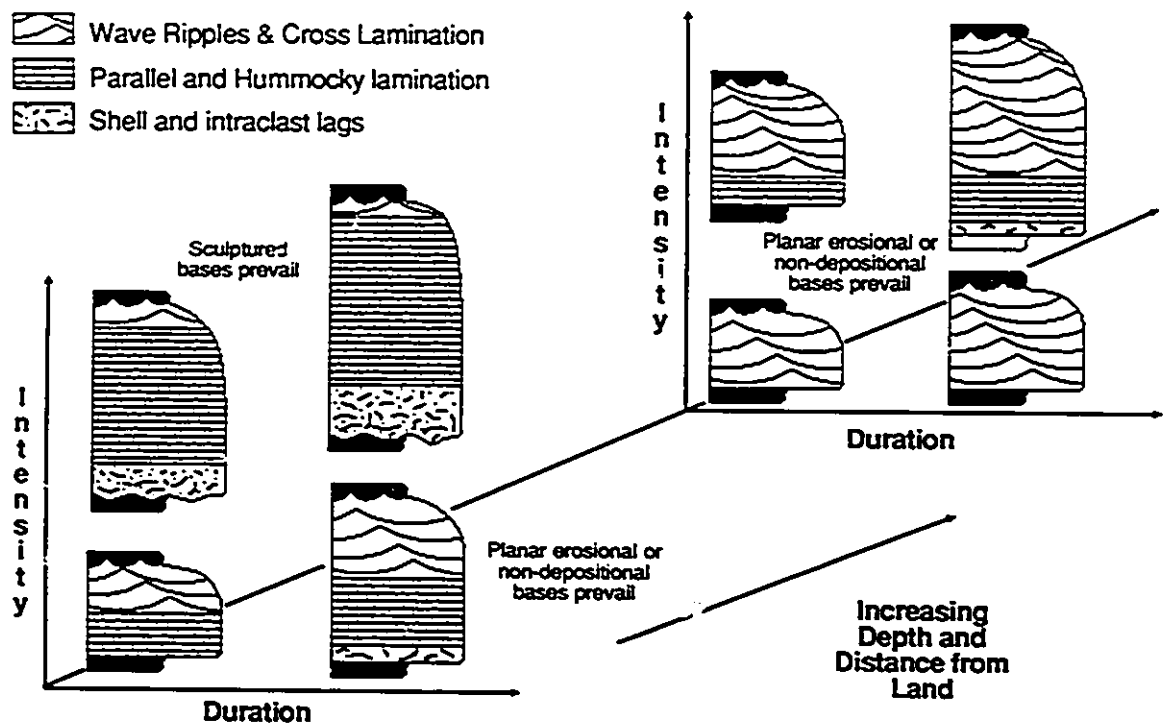


Figure 16: Three-dimensional graphical representation expressing the character of storm layers as a function of storm duration and intensity, and water depth and distance from land. The storm sequences react similarly to changes in different parameters, thus rendering identification of the controlling factors difficult (modified from Allen 1982).

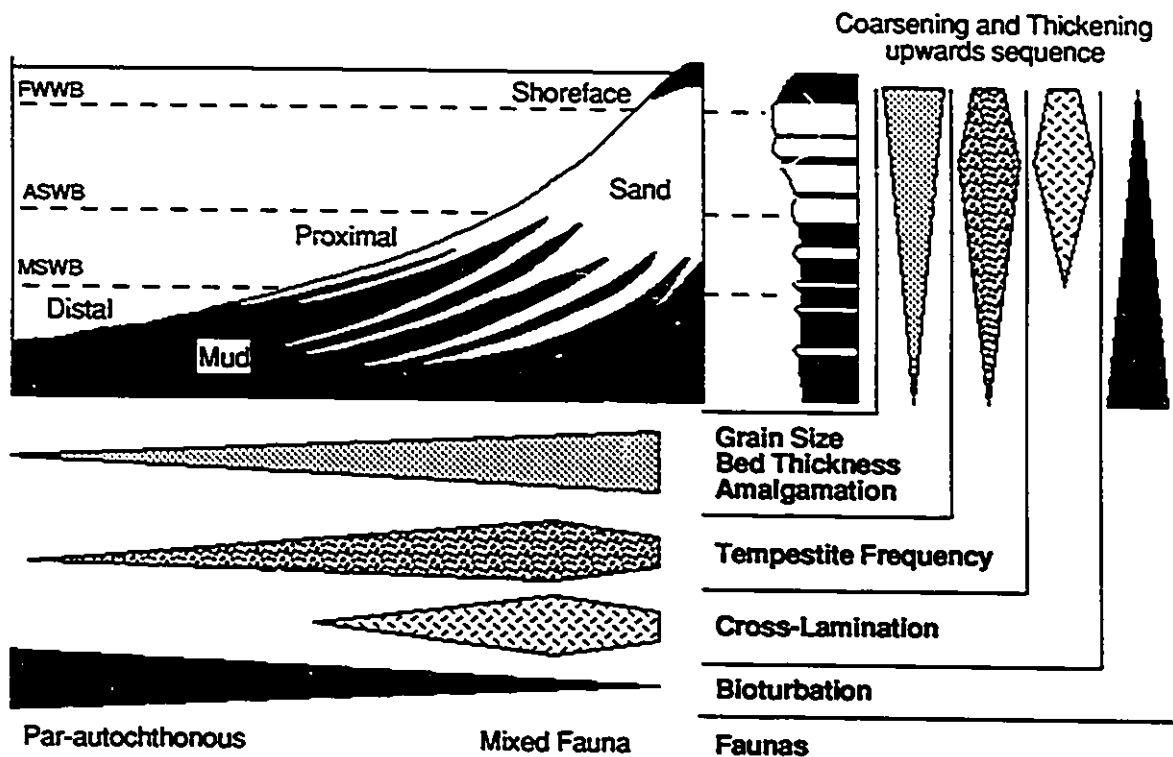


Figure 17: Variations in tempestite proximality parameters which can be used to generate proximality curves. Parameter variations are represented laterally against a depositional profile and vertically against a shallowing-upwards sequence. Distal to proximal nature of tempestite units is then based on relative changes in these proximality parameters. FWWB=Fairweather wave base, ASWB=Average storm wave base, MSWB=Major storm wave base. (modified from Aigner 1985).

vertical trends within a sequence and are meant to reflect relative depth and proximity changes. This enables tempestites to be described as relatively proximal to distal in nature, with no indication of absolute depths or depth changes. In recent literature, proximality trends have been used to infer relative sea-level changes and basin morphology (Aigner 1985, Brett *et al.* 1986, Easthouse & Driese 1988, Driese 1988, Baarli 1988, Brookfield & Brett 1988). This method is very useful and powerful, particularly with lateral trends, in defining basinal morphology and sediment dispersal patterns (Gagan *et al.* 1988). Bathymetric profiles, inferred from vertical sequences, however, are more complex and less straightforward in interpretation, particularly when the parameters measured are not exclusively controlled by depth and distance to shore. Tempestites vary according to storm intensity, duration, and path as well as depth. This is not a problem for lateral trends since individual storm units will vary with depth regardless of the other factors, but it does cause difficulties with vertical trends since a change in tempestite morphology may be produced by a change in storm nature rather than depth. The result is that vertical trends are a combination of all factors affecting tempestite deposition and not exclusively depth. As such, care should be taken in assuming that a vertical sequence can be translated into a bathymetric profile and the subsequent construction of tempestite-based sea-level curves. This assumes that the other factors remain constant through time, an unlikely event in view of the Earth's climatic history. Before this may be done with confidence, the importance of the various factors affecting storms should be extensively modelled.

Variations in tempestite sequences that are used to infer proximality trends are summarized in Aigner (1985) for recent sediments (Fig. 17). For ancient sequences of graded and hummocky tempestites, similar variations are inferred. These variations include the following: (i) The ratio of tempestite to fairweather beds decreases basinwards as the capacity of storm-induced flow to transport sand decreases towards deeper, offshore waters. On the inner ramp amalgamation reworks, obliterates, and/or

combines units so that their apparent number decreases; in addition the tempestites are thicker, reducing the number in any given measured interval. Basinwards, there is a decrease in frequency due to the reduction of sand influx with increasing distance, due to the decrease in wave effects, paralleled by a decrease in erosion and formation of shell lags. These variations produce a maximum tempestite frequency in the inner to middle ramp; (ii) The occurrence of cross-lamination shows a similar trend since its preservation potential in nearshore environments is poor due to erosion and the oscillatory component of flow decreases shelfwards; (iii) Grain size, bed thickness and amalgamation all decrease basinwards due to decreases in storm current strength with increasing depth and distance from shore; (iv) Bioturbation of tempestite units increases with increasing depth; and (v) With increasing depth, tempestite faunas shift from mixed to par-autochthonous to autochthonous, reflecting a decrease in the ability of storm currents to transport shelly material. In general, nearshore tempestite sequences are characterized by amalgamated, erosively bounded, bioclastic, and 5-130 cm thick tempestite beds with no fairweather interbeds. Proximal tempestite sequences contain a large number of complete tempestite beds, ranging from 5-100 cm in thickness, interbedded with fairweather beds. Distal tempestite sequences are composed primarily of fairweather units interbedded with 4-10 cm thick, very fine grained, tempestite beds having basal, conformable or eroded surfaces, internal planar lamination grading up rarely into cross-lamination, and contain predominantly par-autochthonous fauna. Like graded tempestite beds, hummocky tempestite beds show variations in their ideal sequence. Most variations are a result of differences in distance from shore and depth. Proximal, shallow deposits show a high degree of amalgamation and little mud, beds are thick, composed almost exclusively of HCS and bases are erosion surfaces. As beds become more distal they become thinner, microhummocky lenses are more frequent, and the percentage of interbedded mudstone increases (Johnson and Baldwin 1985).

Proximality Parameters and Trends

For the present study several proximality parameters were used, including: (a) tempestite frequency per metre; (b) maximum tempestite thickness per metre; (c) mean tempestite thickness per metre; (d) combined tempestite frequency and mean thickness per metre; (e) combined intraclastic tempestite frequency and mean thickness per 5 metres; and (f) percentage tempestites per metre. Other parameters were tested but did not provide any definitive results. These parameters were plotted against the four composite stratigraphic sections with the aid of a computer (Appendix II) and the results are shown in figures 18 through 25. The horizontal scale for each of the parameters is retained for each of the four sections to better illustrate the trends. Both lateral and vertical trends may be described from these plots.

Lateral Trends: The frequency plots (Plots a in Figs. 18, 20, 22, & 24) show a slight decrease eastwards, indicating a possible decrease in proximality to the east. Tempestite frequency, however, is not directly related to proximality as mentioned previously, but also depends on the thickness of the tempestites, as this will affect the number that may fit in each metre. As proximality increases, so does bed thickness (Plots b and c in Figs. 18, 20, 22, & 24). Yet, as beds become thicker there can be fewer in each metre, giving an anomalously low frequency. This apparent anomaly can be corrected for by combining the two parameters (frequency and mean thickness) to give a better indication of proximality (Plots d in Figs. 19, 21, 23, & 25).

These combined parameters display similar but more pronounced east-west trends than the mean and maximum thickness plots. These trends show an eastwards decrease in proximality as all the parameters decrease eastwards. The proximality peaks are more numerous and better pronounced to the west reflecting larger and more frequent energy-level fluctuations. Many of the sharp shifts of these parameters to the west reflect the presence of lithofacies 5.

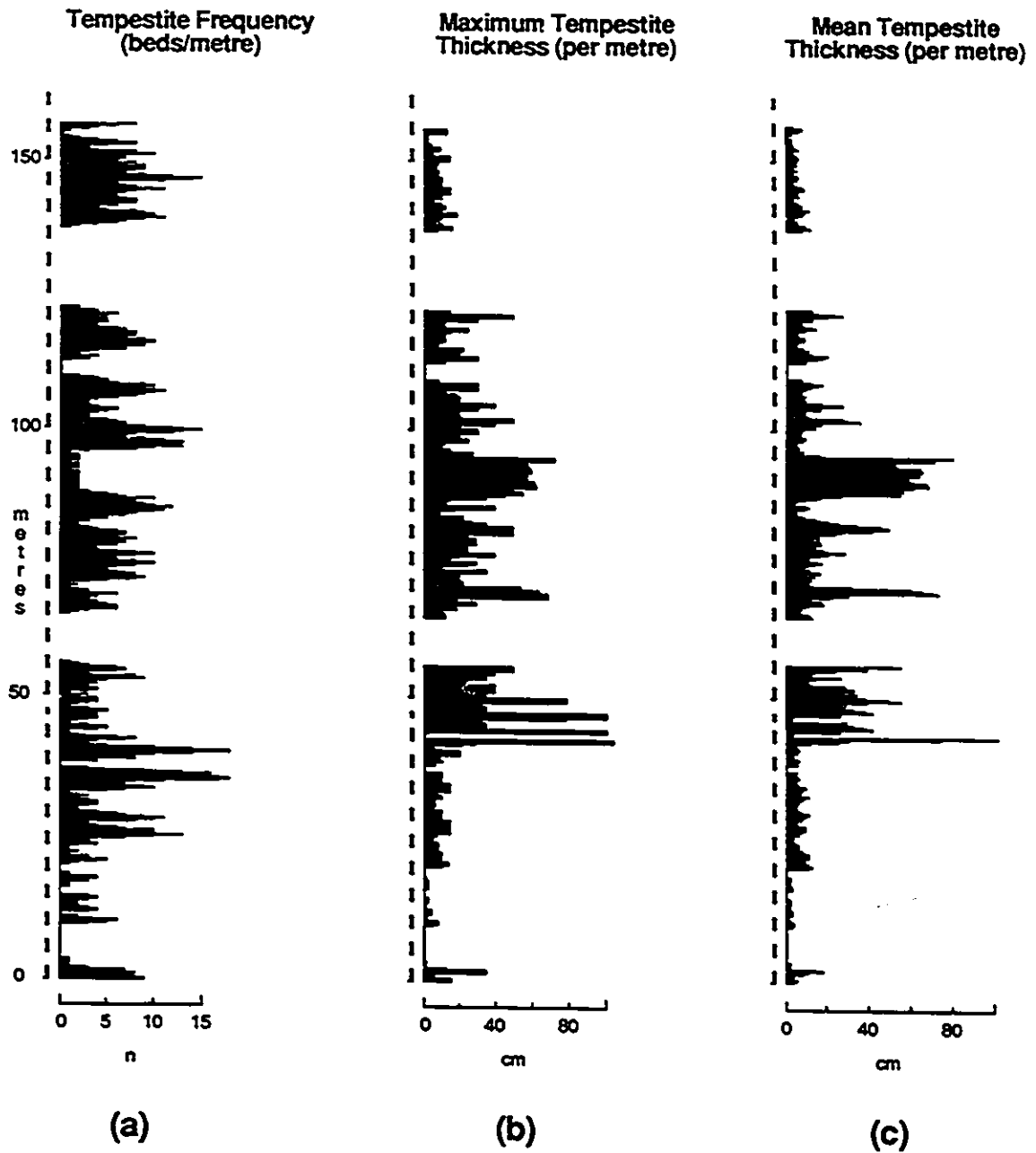


Figure 18: Variations in tempestite proximity parameters: (a) Tempestite frequency per metre; (b) Maximum tempestite thickness per metre; and (c) Mean tempestite thickness per metre, plotted against the Cap Henri-R. aux Cailloux section.

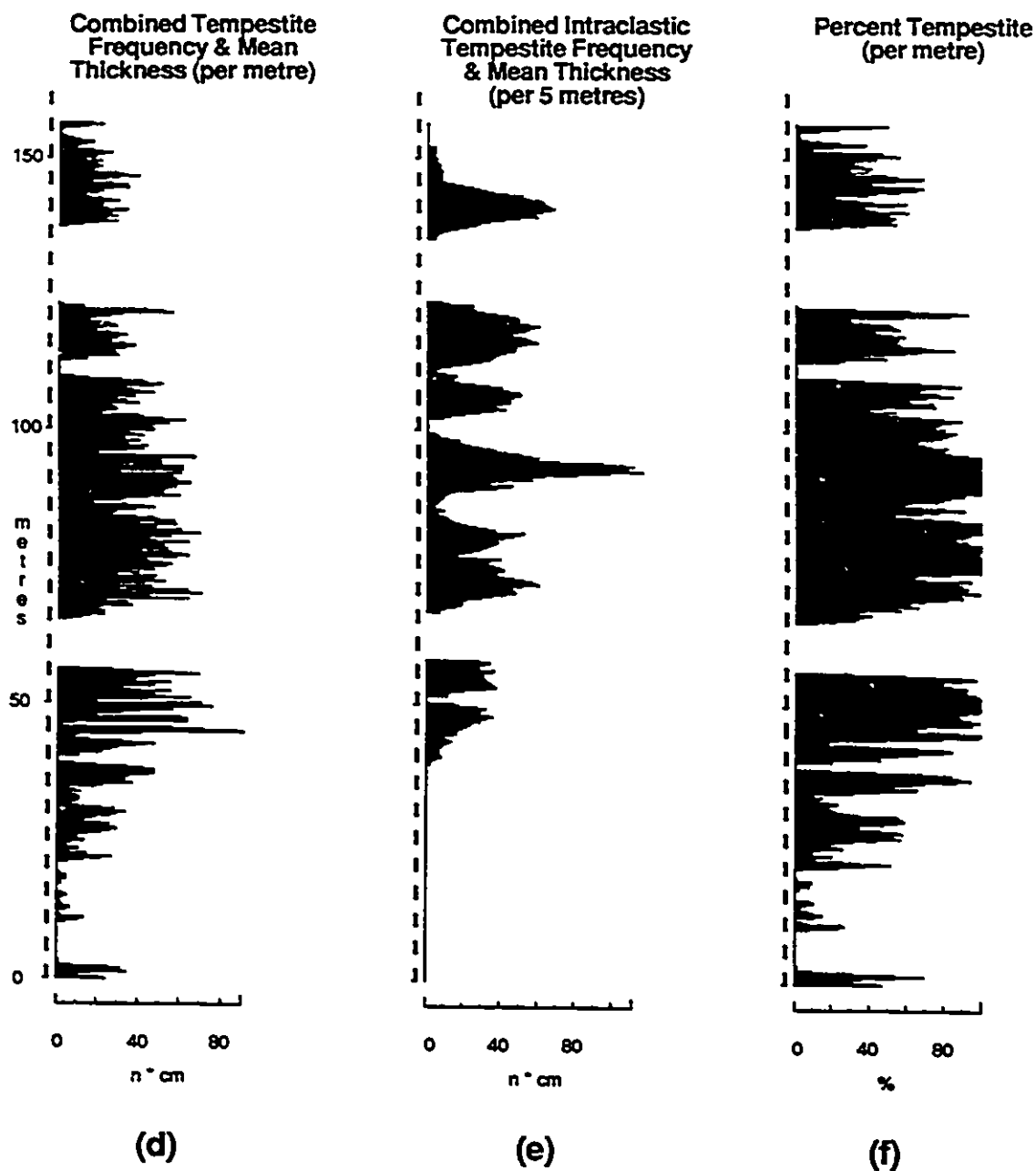


Figure 19: Variations in tempestite proximality parameters: (d) Combined tempestite frequency and mean thickness per metre; (e) Combined intraclastic tempestite frequency and mean thickness per 5 metres; and (f) Percentage tempestite per metre, plotted against the Cap Henri-R. aux Cailloux section.

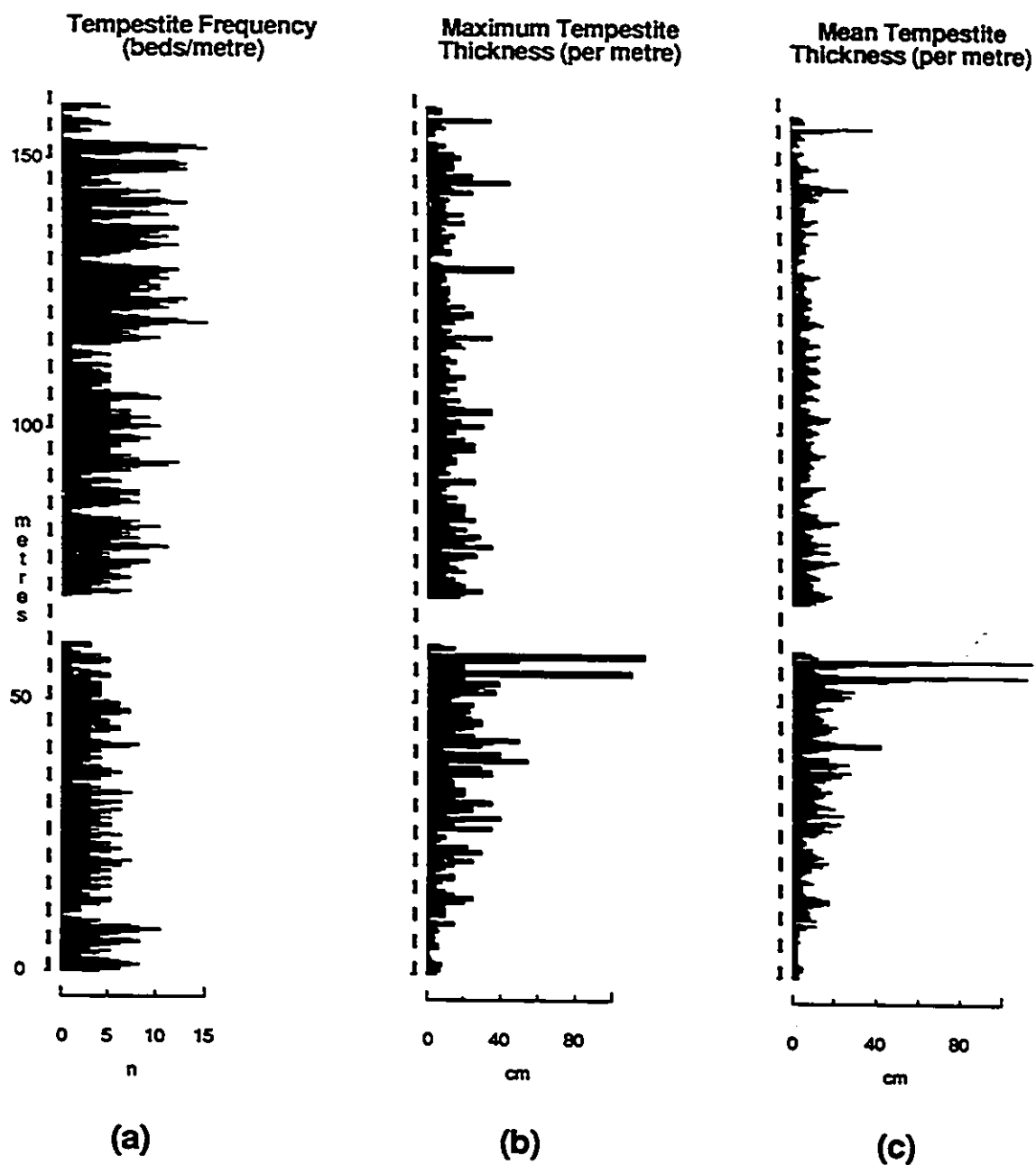


Figure 20: Variations in tempestite proximity parameters: (a) Tempestite frequency per metre; (b) Maximum tempestite thickness per metre; and (c) Mean tempestite thickness per metre, plotted against the R. Jupiter section.

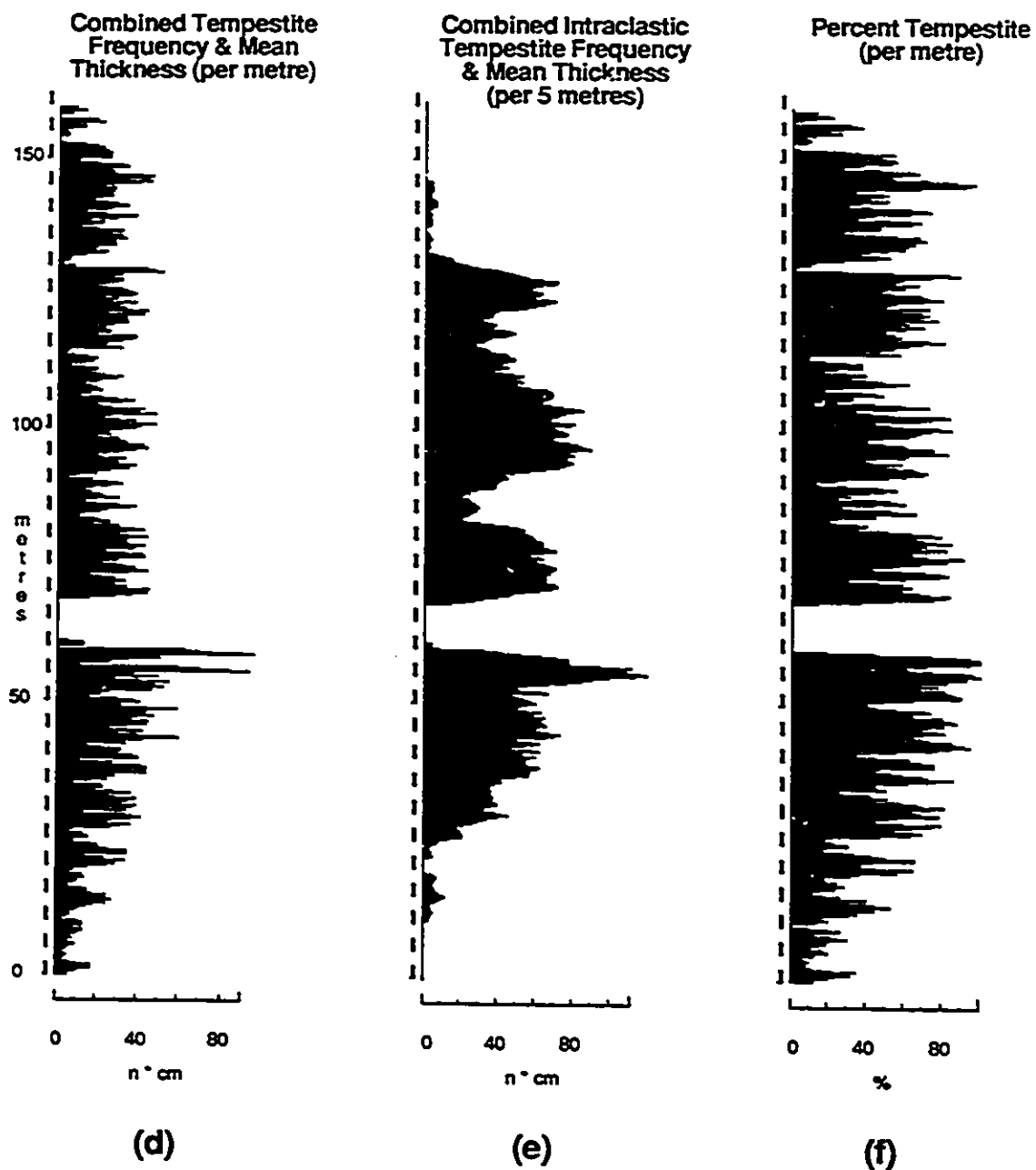


Figure 21: Variations in tempestite proximality parameters: (d) Combined tempestite frequency and mean thickness per metre; (e) Combined intraclastic tempestite frequency and mean thickness per 5 metres; and (f) Percentage tempestite per metre, plotted against the R. Jupiter section.

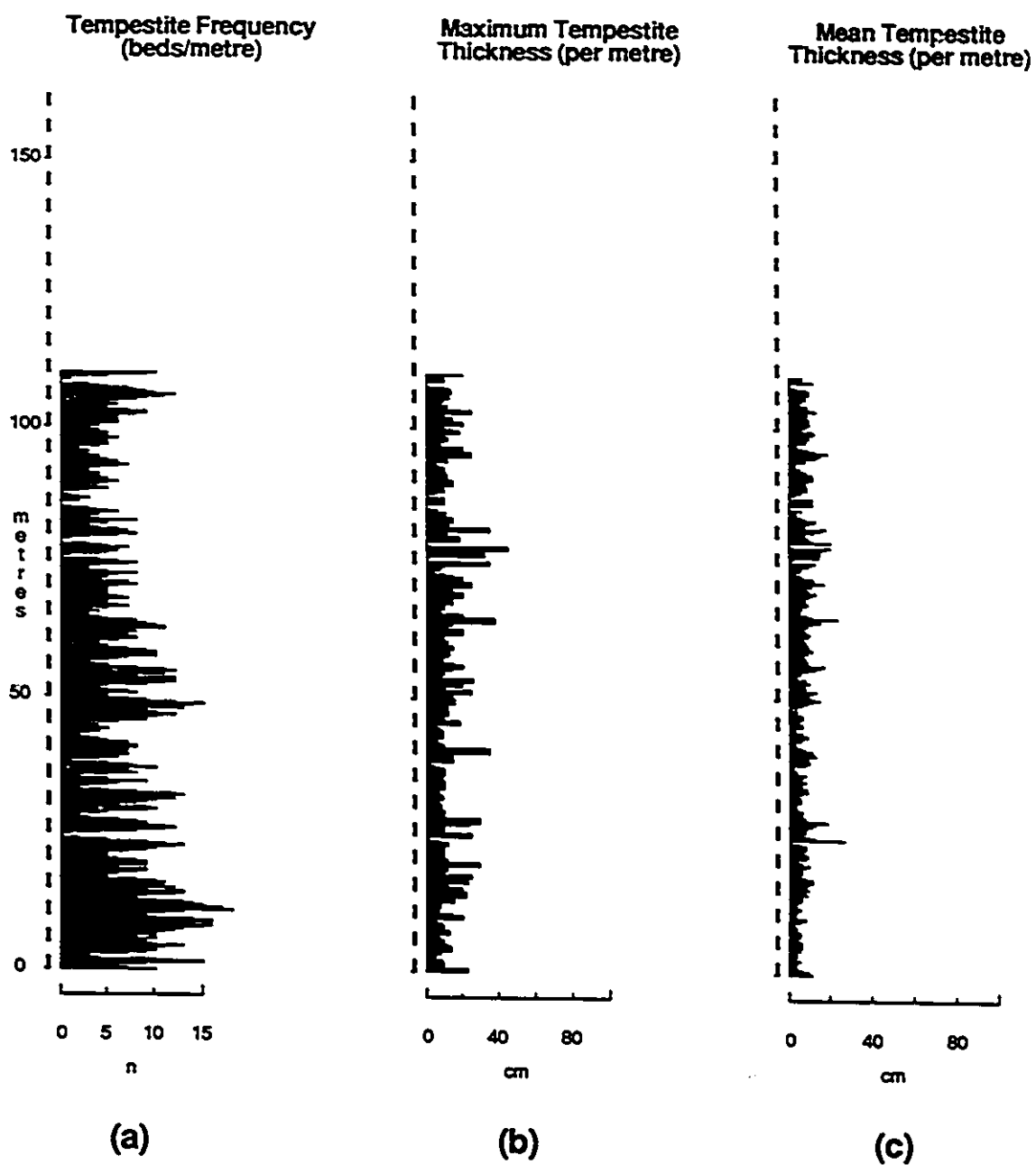


Figure 22: Variations in tempestite proximity parameters: (a) Tempestite frequency per metre; (b) Maximum tempestite thickness per metre; and (c) Mean tempestite thickness per metre, plotted against the R. aux Saumons section.

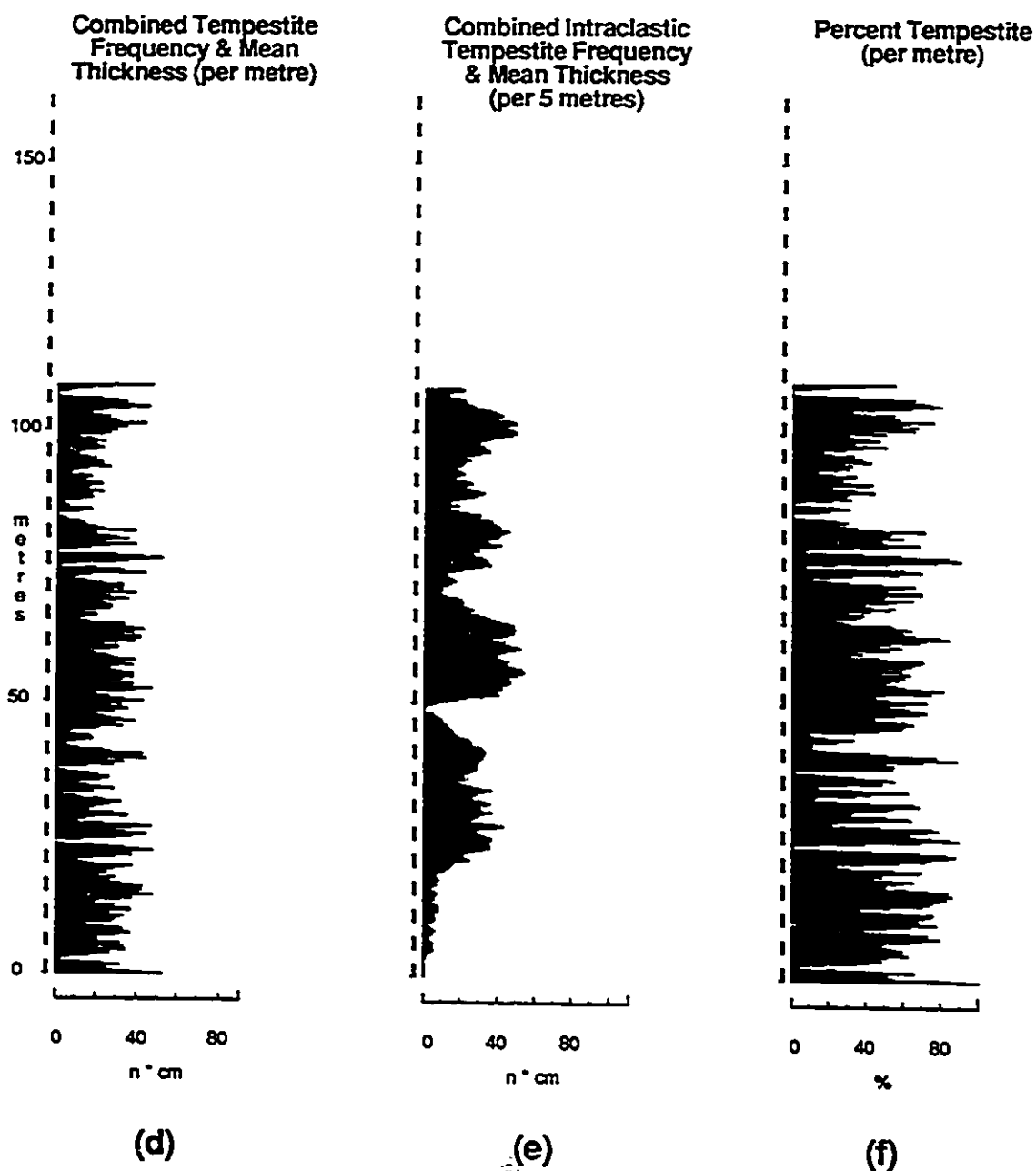


Figure 23: Variations in tempestite proximity parameters: (d) Combined tempestite frequency and mean thickness per metre; (e) Combined intraclastic tempestite frequency and mean thickness per 5 metres; and (f) Percentage tempestite per metre, plotted against the R. aux Saumons section.

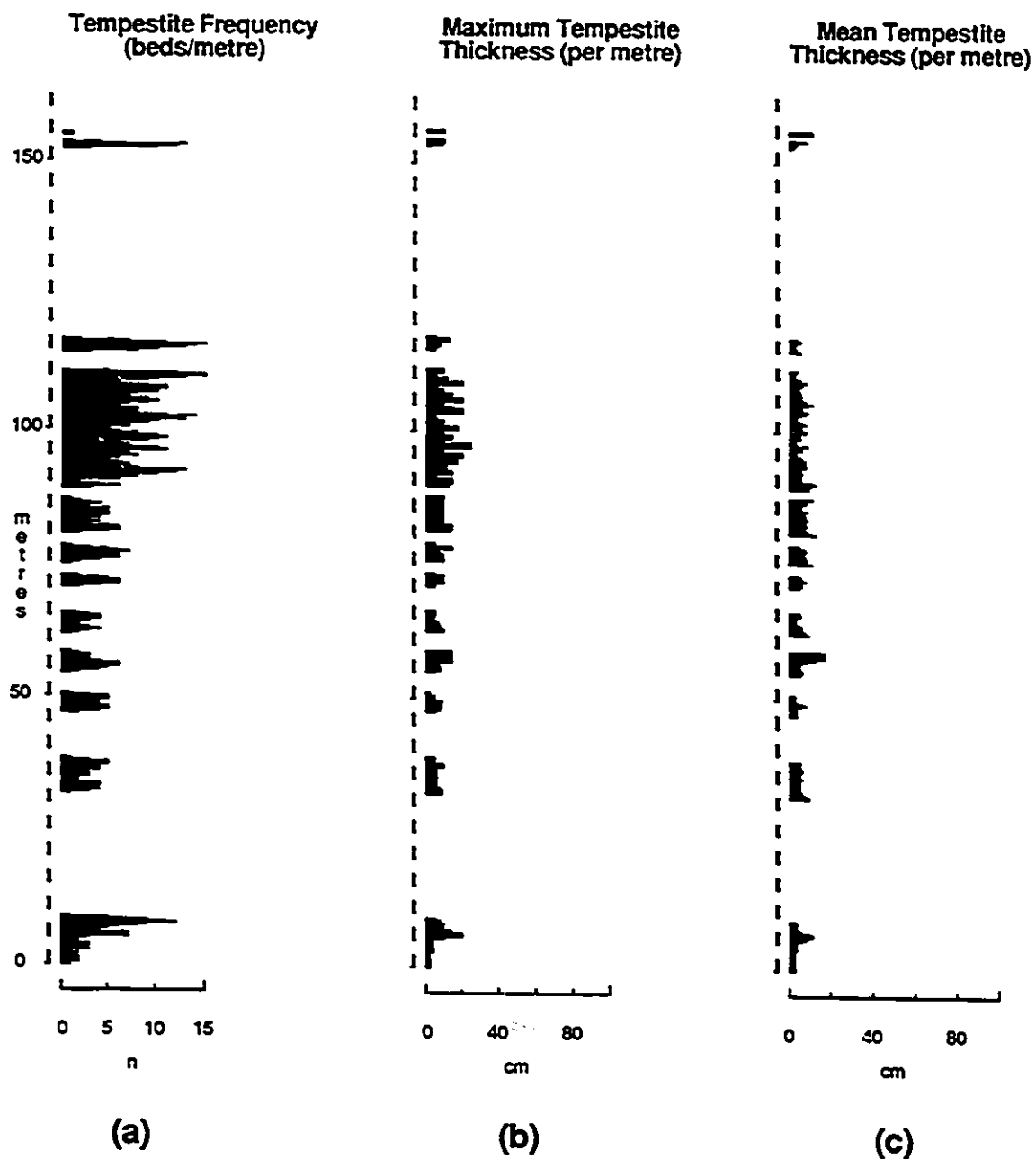


Figure 24: Variations in tempestite proximity parameters: (a) Tempestite frequency per metre; (b) Maximum tempestite thickness per metre; and (c) Mean tempestite thickness per metre, plotted against the R. Prinsta-Reef Point section.

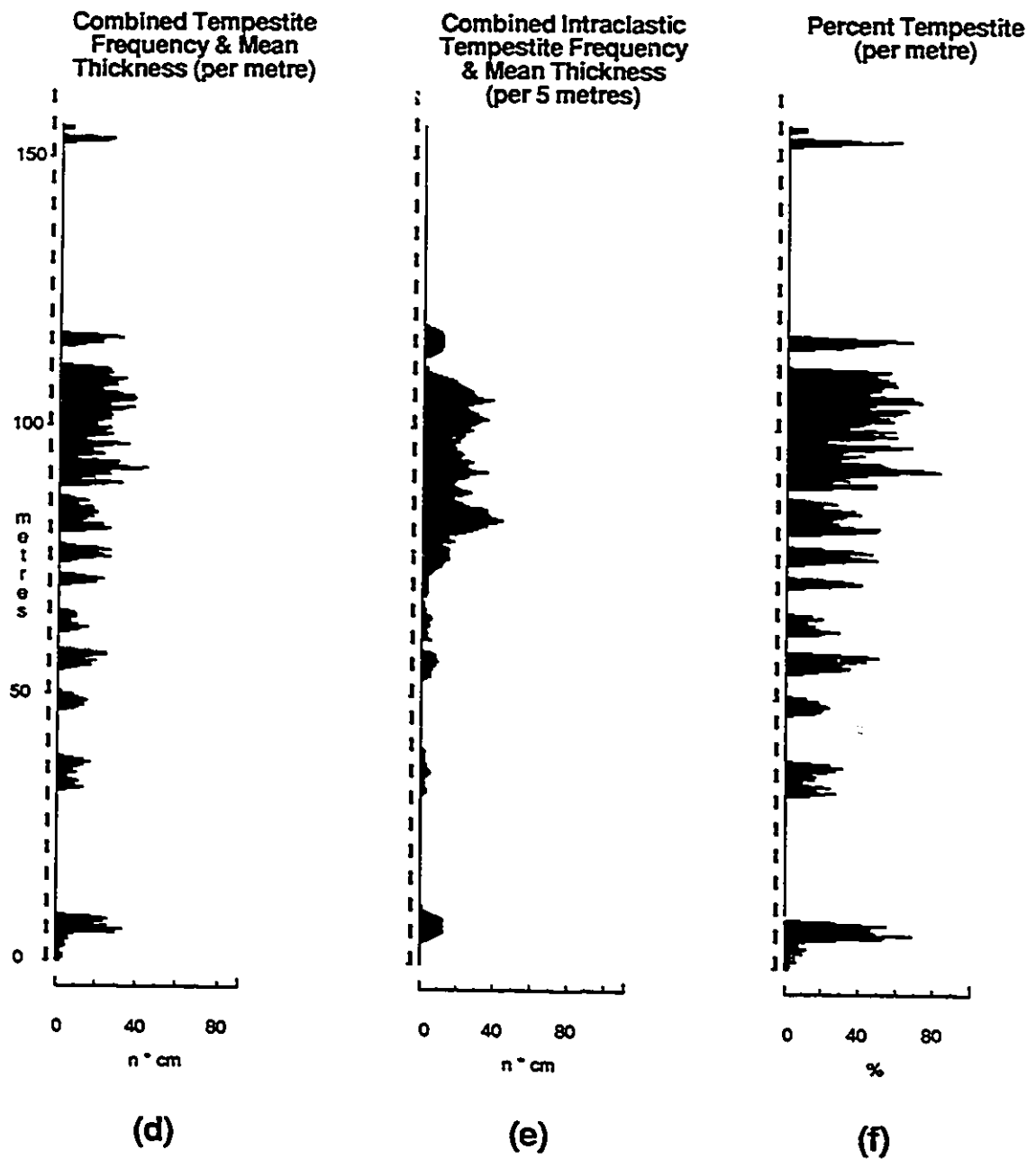


Figure 25: Variations in tempestite proximity parameters: (d) Combined tempestite frequency and mean thickness per metre; (e) Combined intraclastic tempestite frequency and mean thickness per 5 metres; and (f) Percentage tempestite per metre, plotted against the R. Prinsta-Reef Point section.

The intraclastic mean-frequency plots (Plots e in Figs. 19, 21, 23, & 25) are different in appearance from the previous plots in having a lower resolution, as they are plotted for every 5 metre rather than every 1 metre interval. These plots pick up only the coarser proximality fluctuations. They do not exactly match the other curves since intraclasts are absent in the shallowest and the deeper lithofacies, being good proximality indicators for the median water depths. They also indicate an eastwards decrease in proximality.

The percentage plots (Plots f in Figs. 19, 21, 23, & 25) show the best definition of proximality peaks. Up to 60 distinct proximality fluctuations may be distinguished within these plots, showing an average spacing of 2 to 3 metres. The percent of tempestite units decreases to the east indicating decreasing proximality.

In summary, all proximality parameters indicate an eastward deepening. Some parameters, (Plots a, d, & e in Figs. 18, 19, 20 & 21) show an apparent increase in proximality from the Cap Henri section to the R. Jupiter section at several stratigraphic intervals, the opposite of the overall observed trend of eastwards deepening. This slight discrepancy is due to the optimal zone for these proximality indicators lying slightly basinwards of the shallowest tempestites, producing anomalous trends (Fig. 17).

Vertical Trends: In order to interpret the vertical proximality trends the various proximality plots were combined by computer into one curve for each section (Fig. 26). These combined curves give a more accurate indication of relative proximality for each section. The vertical fluctuations are used to infer lateral shifts of depositional environments through time, analogous to the lateral trends. The vertical sequence is similar for the four sections and consists of an upwards-shallowing followed by an upwards-deepening. The initial deepening event which occurred at the base of the Becscie Formation is poorly represented due to the scale of the plots but is clearly seen in the uncombined plots (Figs. 18 to 25). The only difference between the sections is

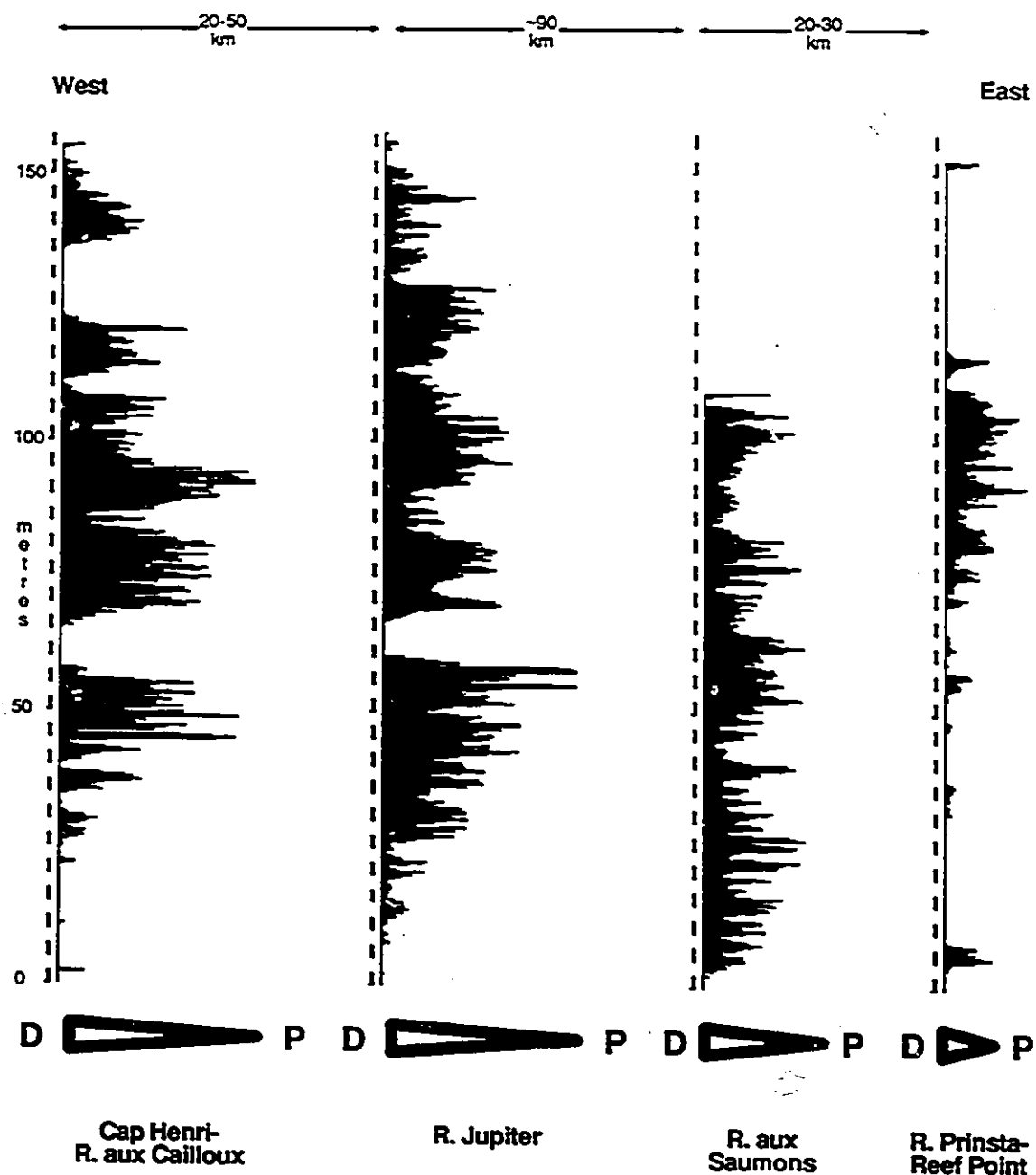


Figure 26: A comparison of the combined tempestite proximity trends for each of the four composite sections showing vertical and lateral changes. P=Proximal, D=Distal, so that each plot shows increased relative proximity to the right. All the plots are to the same horizontal scale for comparison. Combination of the parameters was by computer with each parameter weighted to give the best separation of peaks

that in eastern sections, the upwards-shallowing occurs lower down in the section than in the west (Fig. 26), due to the condensed nature of the eastern sections resulting from a decrease in the number of tempestite beds. Up to 60 distinct smaller-scale fluctuations are superimposed on this overall trend.

Both the lateral and vertical variations in tempestite proximity demonstrate trends similar to those seen in the lithofacies distributions (Part I), supporting the use of tempestite proximity trends for basin analysis.

Proximity Fluctuations

Up to three orders of tempestite proximity fluctuation can be distinguished in the combined curves (Fig. 27). The three orders reflect different processes which produce changes in tempestite proximity on different scales.

The third-order curves, represented by the proximity curves (Fig. 26) display up to 60 distinct fluctuations. It should be noted that these fluctuations do not simply reflect the presence and absence of individual tempestite beds but rather a statistical treatment of the up to 1000 individual tempestite beds per section. Adopting a time span of about 5 million years for the duration of the Rhuddanian (based on biostratigraphic ranges) these fluctuations may be occurring on a scale of every 80,000 to 100,000 years. This scale of fluctuation is of a greater scale than that normally observed for eustatic sea-level changes (Read and Goldammer 1988). With such a rapid fluctuation it becomes difficult to separate the influences on tempestite proximity of depth and distance changes from those due to periodic climatic changes (*e.g.* Milankovitch cycles); as such, the third-order curves may not represent sea-level fluctuations. A clear distinction between these factors influencing tempestite proximity is beyond the scope of this study, requiring extensive field observation and experimental modelling.

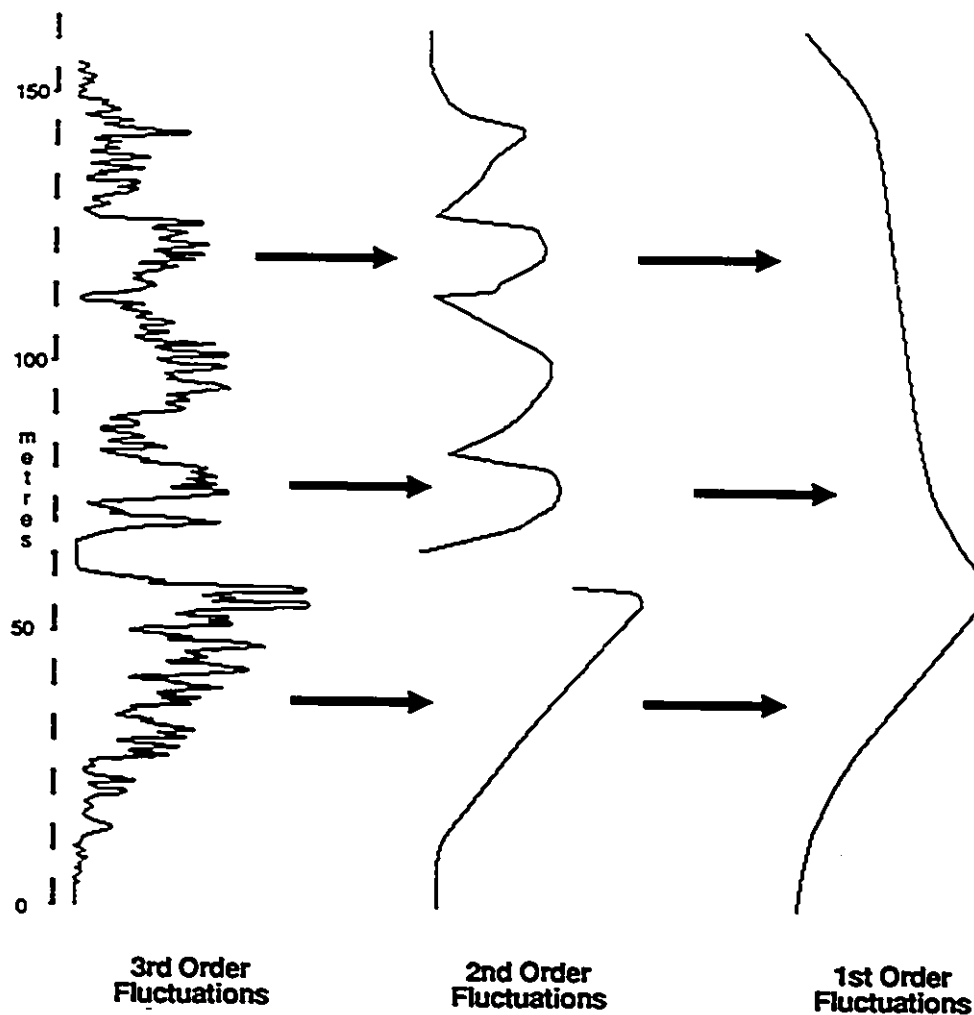


Figure 27: The breakdown of combined tempestite proximity trends into decreasing orders of fluctuation. Third-order curves are simplified versions of the combined proximity plots. The lower order curves are derived directly from the higher order curves. This example is from the R. Jupiter section.

Up to 5 proximity fluctuations can be identified in the second-order curves (Fig. 28), giving an average cycle period of approximately 1 million years. Given such a period, these fluctuations may represent eustatic or non-eustatic changes in sea-level. Insufficient data on sea-level fluctuations at this scale in other Lower Silurian basins prevents any conclusions on whether the fluctuations are intrinsically or extrinsically controlled. Nevertheless, these fluctuations are important in that they represent a resolution of sea-level change not always seen in lithologic and palaeontologic indicators.

The first order curves show a gradual shallowing-deepening cycle, occurring over a period of 5 million years, following the initial deepening at the base of the Becscie Formation (Fig. 29). These curves correlate closely with published North American Early Silurian third-order eustatic sea-level curves (Johnson 1987). This would suggest that this scale of fluctuation is a result of eustatic sea-level changes.

The third-, second-, and first-order Becscie tempestite proximity curves would therefore correspond to Vail *et al.*'s (1977) fifth-, fourth, and third-order sea-level curves respectively, assuming they represent actual relative sea-level changes.

Proximity curves may also be used to better define the member boundaries. As previously described, the member contacts are commonly gradational and difficult to define consistently using the lithofacies contacts. Some specific abrupt shifts in the proximity curves are correlatable and, together with the lithofacies information, can help to precisely place the member contacts within the four sections (Fig. 30).

Palaeocurrent Indicators

Palaeocurrent indicators are abundant in the Becscie sequence and include: (i) gutters and gutter casts; (ii) oriented elongate fossils (Dixon 1970); (iii) symmetrical

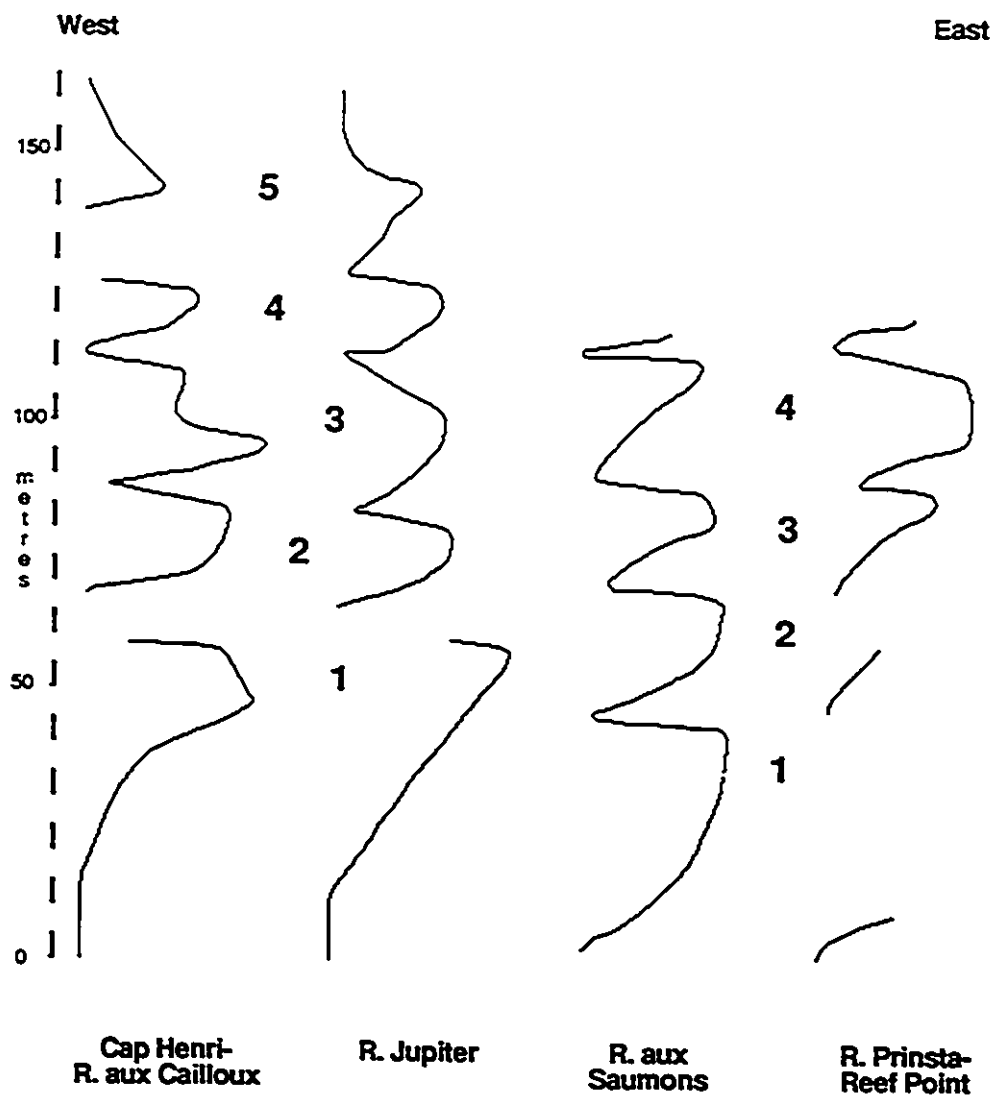


Figure 28: Correlation of second-order tempestite proximity fluctuations between the four Becscie composite sections. Up to 5 distinct events may be recognized. These events show a downwards shift in the two eastern sections, with the fifth event not represented. Proximality increases to the right within each curve.

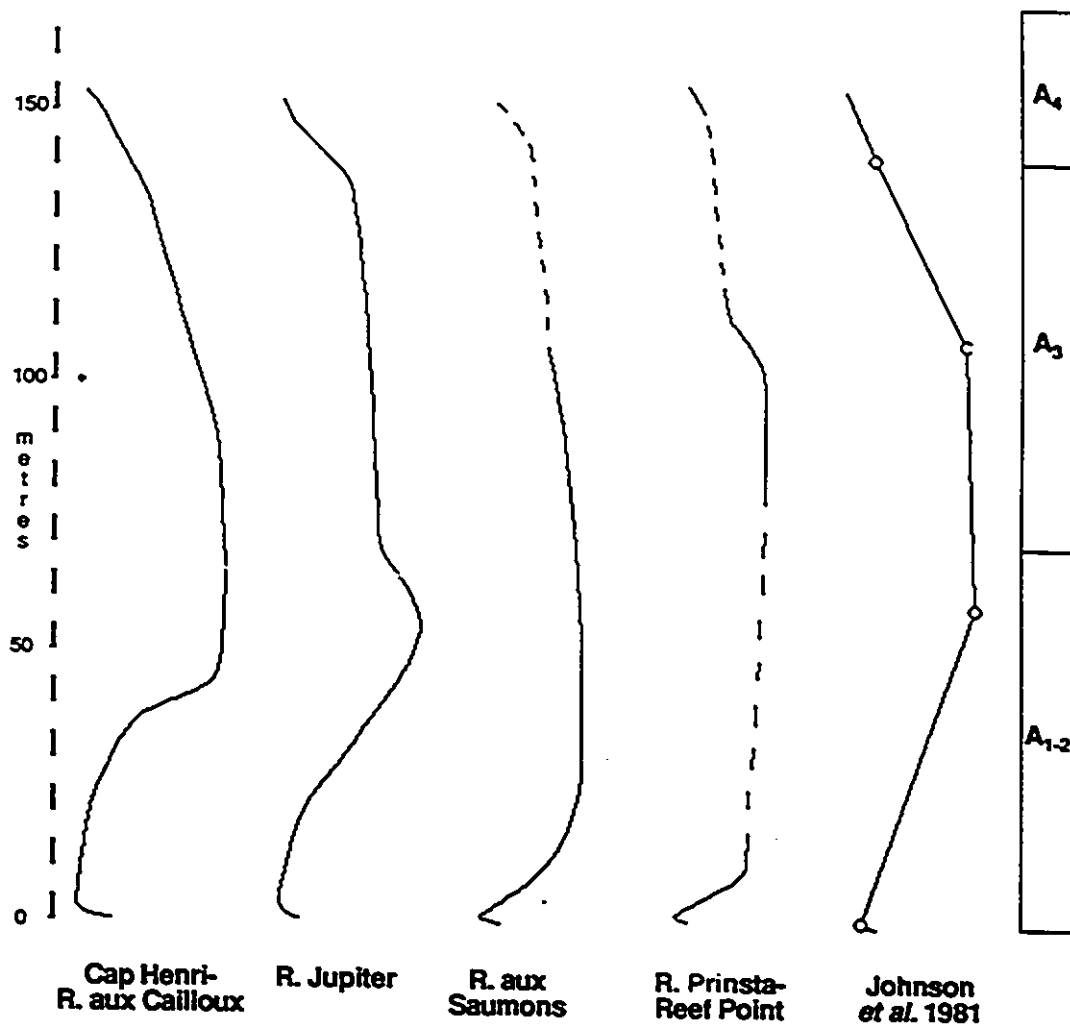


Figure 29: Correlation of first-order proximity fluctuations of the four Becscie composite sections and a published Early Silurian eustatic sea level curve based on brachiopod communities (Johnson *et al.* 1981). A₁₋₂, A₃, and A₄ represent standard graptolite zones of the Rhuddanian stage. One distal-proximal-distal fluctuation is observed following an initial deepening event (poorly defined due to scale). Proximity curves increase in proximity to the right, sea level curve shallows to the right.

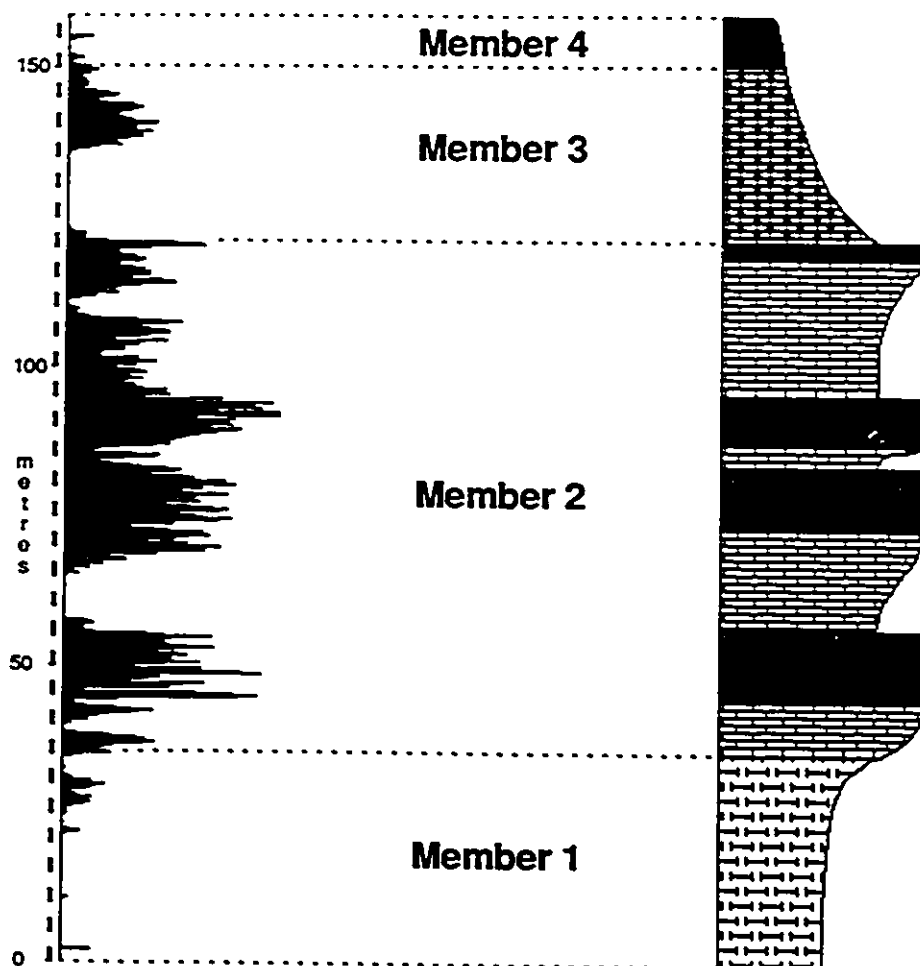


Figure 30: The use of tempestite proximity trends in defining member boundaries, using the Cap Henri-R. aux Cailloux section as an example (proximity increasing to the right). The proximity peaks used for marking the member boundaries are correlatable between the four sections. Lithologic symbols are the same as those used in Fig. 5.

coarse-grained ripples (CGR); (iv) symmetrical wave and interference ripples; (v) asymmetrical coarse-grained ripples (CGR); and (vi) slumped-bed axes. Rose diagrams representing the palaeocurrent measurements and their distribution are illustrated in figures 31 and 32. There are two dominant palaeocurrent directions; a unidirectional heading of 95 to 105° and a bidirectional heading of 30/210° to 40/220°. The east-west variations in the two dominant palaeocurrent directions are minor (Figs. 31 & 32). The unidirectional indicators (asymmetrical CGR and slump bed axes) show a slight clockwise rotation westwards and the bidirectional indicators a slight counterclockwise rotation westwards. There are no discernable vertical trends, with palaeocurrent values overlapping throughout the sequence. The range of features represents both current- and wave-formed structures, suggesting a combined-flow regime for the Becscie sequence.

Basin Analysis

Basin Geometry and Palaeogeography

The various proximity trends indicate that the Anticosti platform deepened eastwards in the Early Silurian during deposition of the Becscie Formation suggesting that the palaeoshoreline lay to the northwest. The palaeocurrent data suggest that unidirectional currents were oriented both to the southeast and the northeast, and that bidirectional currents were oriented northeast-southwestwards. Combining these two sources of information, a sketch of the storm-flow dynamics may be constructed for the Anticosti platform in the Early Silurian (Fig. 33). Storm tracks, inferred from palaeoreconstructions and climatic models (Ziegler *et al.* 1977, Barron 1989), are shown moving from east to west with a polewards deflection. This path accounts for the bidirectional palaeocurrents observed, oriented parallel to the maximum wind-wave energy (Figs. 31 & 32). In response to the induced pressure gradients unidirectional

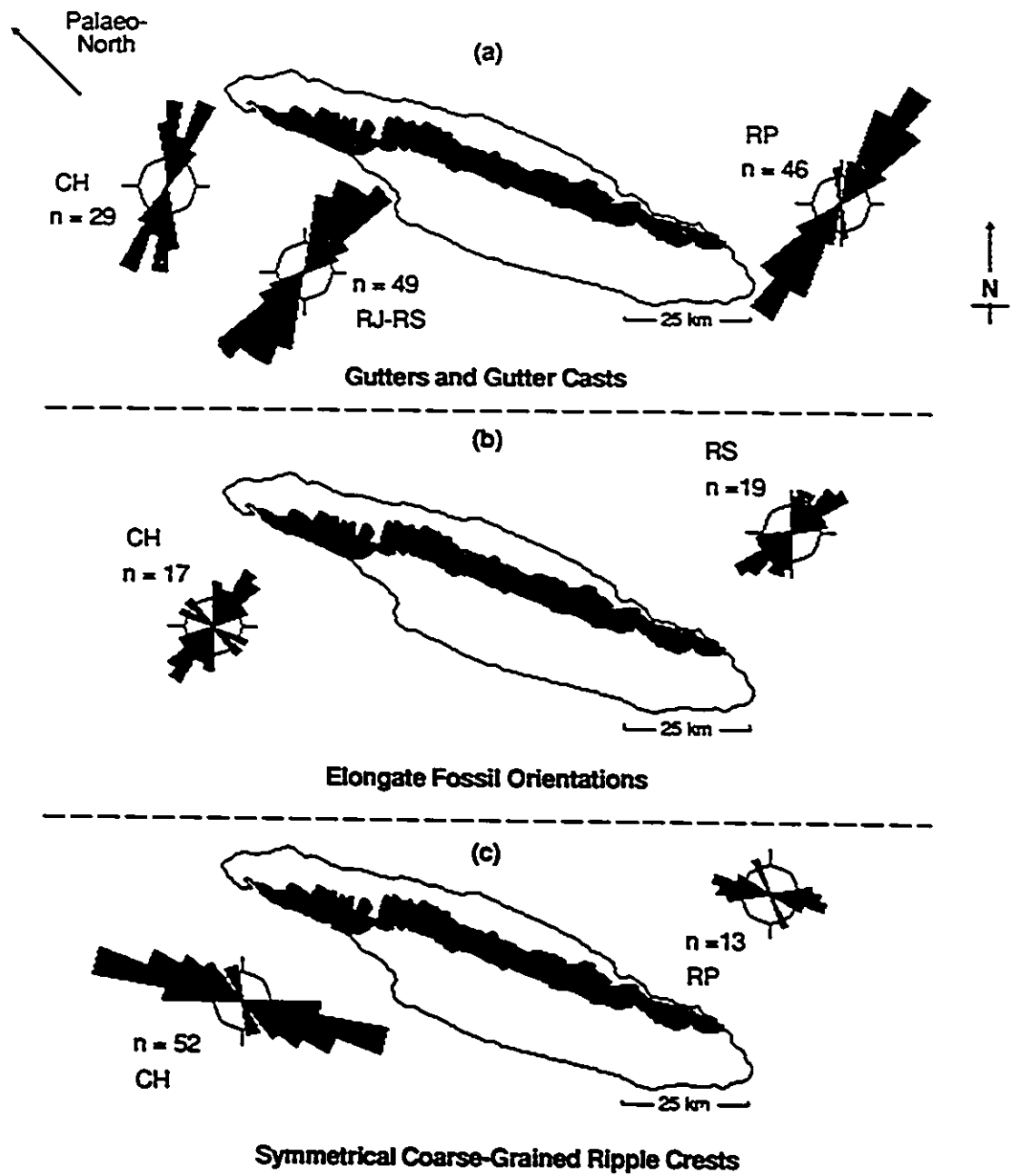


Figure 31: Palaeocurrent rose plots for: (a) Gutters and gutter casts; (b) Elongate fossil orientations; and (c) Symmetrical coarse-grained ripple crests, showing distribution and lateral variations. CH=Cap Henri-R. aux Cailloux section, RJ=R. Jupiter section, RS=R. aux Saumons section, and RP=R. Prinsta-Reef Point section (n=number of measurements).

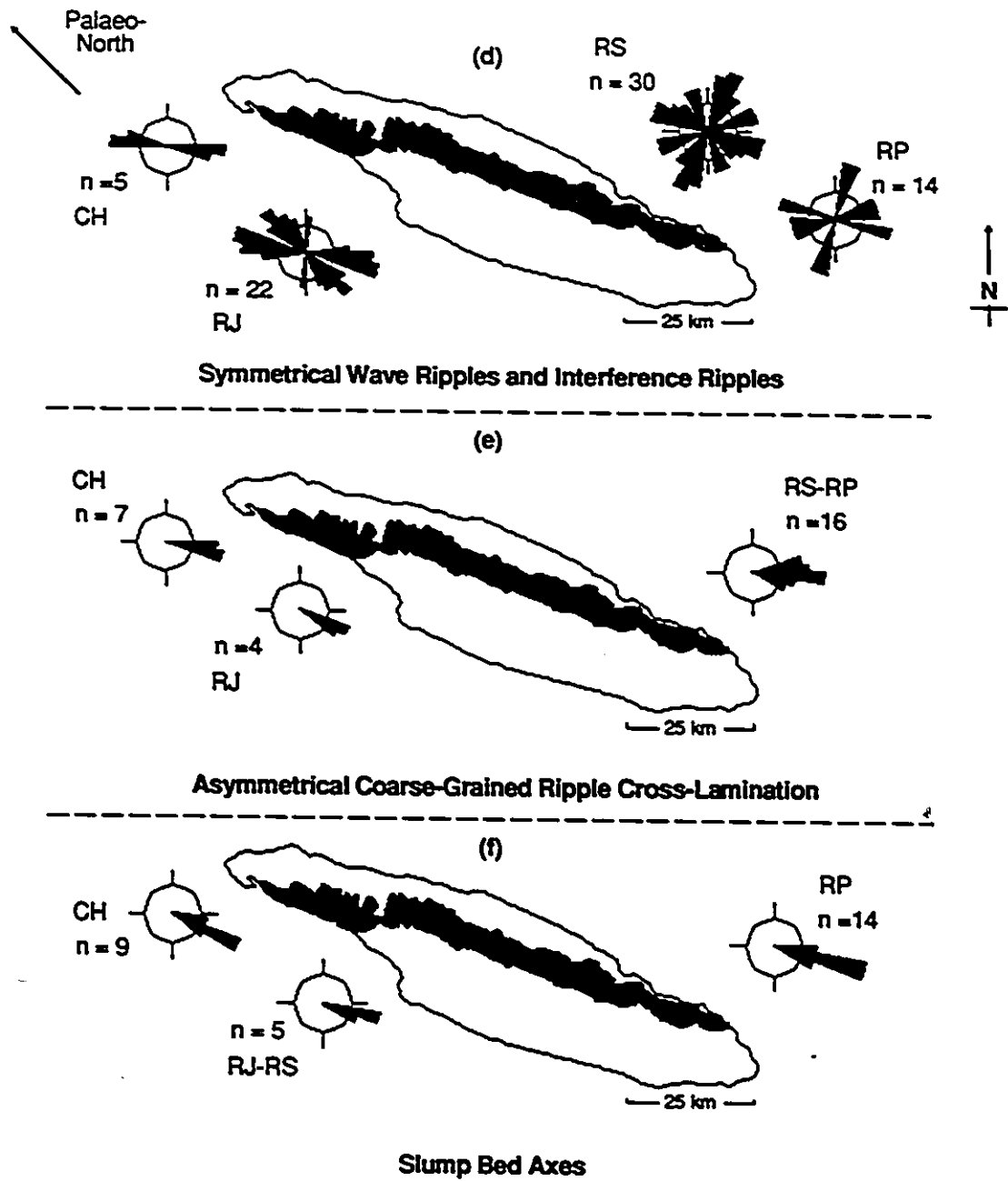


Figure 32: Palaeocurrent rose plots for: (d) Symmetrical and interference ripple crests; (e) Asymmetrical coarse-grained ripple cross-lamination; and (f) Slump bed axes, showing distribution and lateral variations. Section location abbreviations are as in Fig.31 (n=number of measurements).

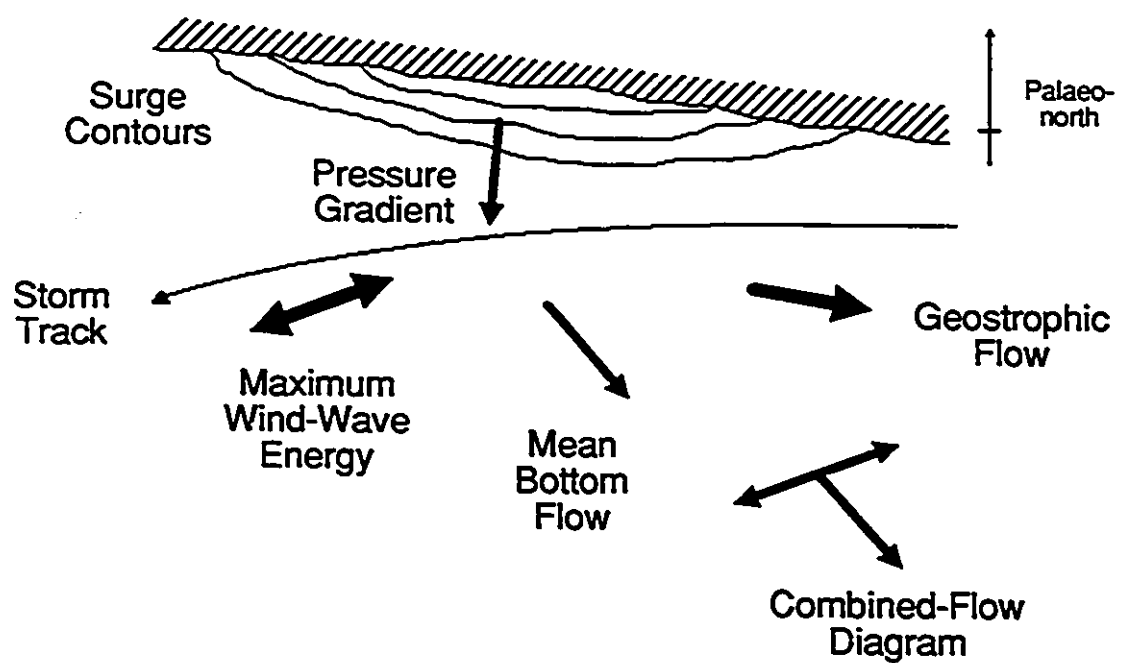


Figure 33: Storm flow dynamics inferred for the Anticosti ramp during deposition of the Becscie Formation, showing storm track and induced water movements based on palaeogeographical reconstructions and palaeocurrent data (modified from Swift and Nummedal 1987).

bottom and geostrophic currents would have been generated and directed southeastwards and eastwards respectively (Fig. 33). The information is summarized in a palaeogeographic reconstruction of the Anticosti Basin for the earliest Silurian (Becscie time) (Fig. 34). The ramp is subdivided into inner, middle, and outer parts. It deepened into the Iapetus Ocean to the southeast and shallowed towards a proposed shoreline to the northwest. The orientation of the shoreline is based on the palaeocurrent information and sedimentary structure orientation: gutters subparallel to shoreline (Aigner 1985) and CGR crests subparallel to shoreline (Leckie 1988). The shoreline orientation can vary by up to 15° rotation in either sense. Superimposed on this reconstruction is the inferred storm track path illustrated in Fig. 33.

Storm Nature

Inferring palaeolatitudes of 15 to 20° S (Ziegler *et al.* 1977, Scotese *et al.* 1985) from Early Silurian palaeocontinental reconstructions, the Anticosti Basin was situated in a zone that would have been strongly influenced by cyclonic storms. This classification is based on modern latitudinal distribution of cyclones and mid-latitude winter storms. Assuming that their distribution was similar in the Early Silurian (Becscie time) then the dominant storm type producing tempestite beds on the Anticosti Platform would have been cyclonic. Circulation models for the Early Silurian (Ziegler *et al.* 1977) show storm tracks rotating counterclockwise in the southern hemisphere. Cyclones would have initiated near the equator and travelled westwards and polewards. Cyclones crossing the Anticosti Basin would likely have been generated on the west coasts of Kazakhistania or Baltica, depending on the size of the Iapetus Ocean, and crossed the basin from east to west (Fig. 2). Palaeocurrent data measured in the Becscie Formation supports this path (Figs 33 & 34).

Barron (1989), however, contends that simple latitudinal distinctions for storm types are not adequate to consider genetic links for storm-related deposits. He maintains

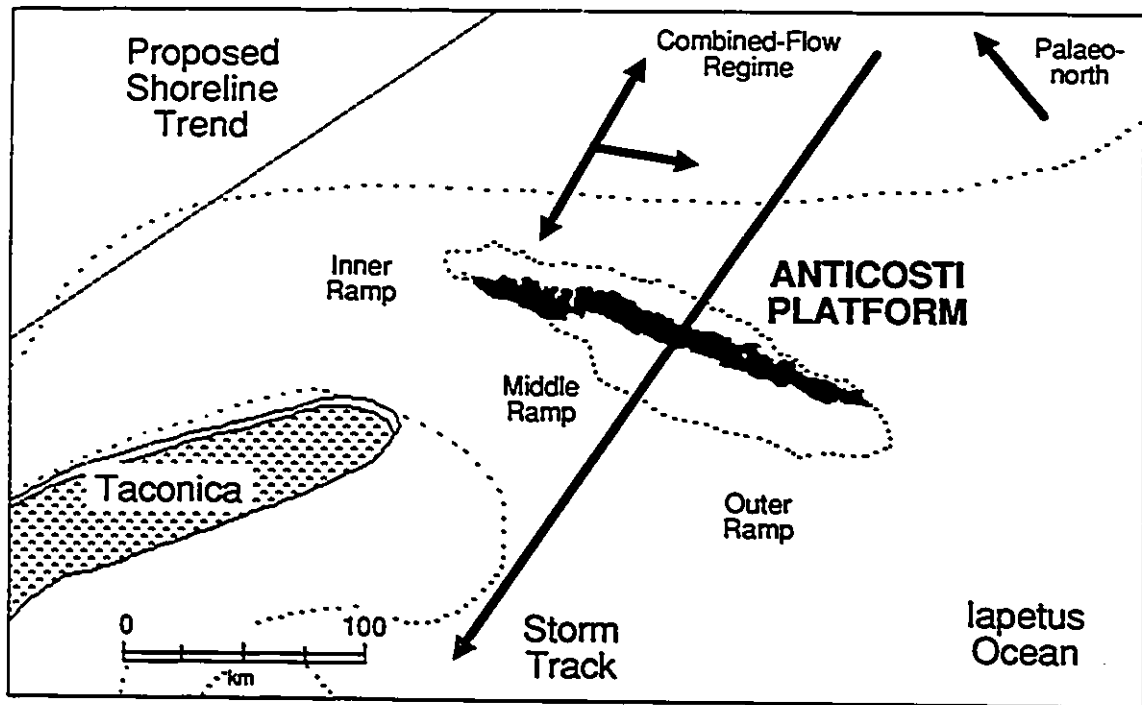


Figure 34: Palaeogeographical reconstruction of the Anticosti Basin during deposition of the Becscie Formation, showing storm track and induced combined-flow regime superimposed on ramp subdivisions. The proposed shoreline is located to the northwest, based on proximity and lithofacies trends and its orientation is based on palaeocurrent measurements. The ramp deepens southwestwards towards the partially open Iapetus Ocean.

that climate and geography produce substantial variability in the generation rates and distribution of severe storms. Although the Anticosti Basin lies in what might presently be considered a cyclone-dominated zone, Early Silurian palaeogeography could have produced different storm-type distributions.

Basin Parameters

The extent of surface outcrop of the Anticosti sequence indicates a minimum shelf length of 150 to 200 kilometres. This may be increased to between 400 and 500 kilometres with the addition of offshore studies (Haworth and Sanford 1976). The shelf width, however, is more difficult to establish. On Anticosti Island, eastern and western exposures are between 30 and 70 kilometres apart perpendicular to inferred depositional strike (Fig. 34), producing a probable minimum width of about 50 kilometres. Offshore seismic surveys extend this up to 85 kilometres (Petryk 1981a). Assuming a 1 to 2° palaeoslope, eastern and western exposures differ by about 20 to 40 metres in water depth, with eastern exposures being the deeper, and corresponding to the observed lithofacies distributions. Assuming a maximum water depth of 120 metres for the deepest lithofacies (LF 1) and a minimum of 10 metres for the shallowest lithofacies (LF 5), the palaeo-shoreline may be located as close as 35 kilometres at maximum lowstand and as distant as 400 kilometres at maximum highstand. Actual values are probably more conservative, ranging from 50 to 200 kilometres.

Conclusions

Several limestone rock types are present in the Lower Silurian (Rhuddanian, A₁-A₄) Becscie Formation exposed on Anticosti Island. These rock types can be classified into five distinct lithofacies and separated into four stratigraphic members. The lithofacies suggest that the Becscie Formation was deposited on the inner to outer parts of a storm-dominated, muddy carbonate- to shale-dominated ramp. Palaeocurrents and sedimentary structures demonstrate that the resultant tempestites were deposited within a combined-flow regime, probably as the result of cyclonic storms. The tempestites exhibit proximality trends which prove useful in defining member boundaries, palaeobathymetric fluctuations and basin geometry.

The lateral proximality trends, lithofacies changes, and palaeocurrent data imply that the Anticosti Basin deepened into the partially-opened Iapetus Ocean to the southeast and shallowed towards a proposed northeast-southwest trending shoreline to the northwest. The vertical proximality fluctuations and lithofacies changes enable the recognition of palaeobathymetric and climatic fluctuations. The Becscie sequence exhibits a third-order eustatic deepening-shallowing-deepening cycle, with the first deepening episode producing a lime-mud dominated ramp and the second a shale-dominated ramp. Superimposed on this cycle are up to five second-order relative sea-level fluctuations and problematic third-order fluctuations which may reflect palaeobathymetric or climatic changes.

The resolution of fluctuations observed with tempestite proximality trends is an order of magnitude higher than those identified by either lithofacies or palaeontologic methods. With further investigation into the factors controlling tempestite proximality, these trends may become powerful tools in the analysis of storm-dominated basins.

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Appendices

Appendix I - Measured Section Locations

The measured stratigraphic sections were combined into four composite sections by region (Appendix Fig. 1). New sections were initiated at stratigraphic breaks or when a large lateral displacement was made.

Cap Henri-R. aux Cailloux Composite Section

This composite section includes sections located along the southwest coast of Anticosti Island from Pointe Laframboise to R. St. Anne (Appendix Fig. 2):

PL-1 Pointe Laframboise 1

CH-1 Cap Henri 1

CH-2 Cap Henri 2

CH-3 Cap Henri 3

CH-4 Cap Henri 4

FO-1 Falaise Ouest 1

CA-1 Cap a l'Aigle 1

CA-2 Cap a l'Aigle 2

CA-3 Cap a l'Aigle 3

CO-1 Cap a l'Ours 1

PR-1 Petite Riviere 1

PR-2 Petite Riviere 2

BS-1 Baie des Sarcelles 1

RG-1 R. aux Graines 1

RG-2 R. aux graines 2

RB-1 R. Becscie 1

RB-2 R. Becscie 2

RB-3 R. Becscie 3

RB-4 R. Becscie 4

RDB-1 Ruisseau de la Balcine 1
RDB-2 Ruisseau de la Baleine 2
RDB-3 Ruisseau de la Baleine 3
RDB-4 Ruisseau de la Baleine 4
CSM-1 Cap St. Marie 1
CSM-2 Cap St. Marie
RC-1 R. aux Cailloux 1
RC-2 R. aux Cailloux 2

Rivière Jupiter Composite Section

This composite section includes sections measured to the north and to the south of the bridge at Jupiter 24 lodge along the Jupiter River, along the Jupiter River road, to the east and west of the bridge, and a core drilled near Jupiter 24 (Appendix Fig. 3b).

RJN-1 R. Jupiter North 1
RJN-2 R. Jupiter North 2
RJN-3 R. Jupiter North 3
RJN-4 R. Jupiter North 4
RJS-1 R. Jupiter South 1
RJS-2 R. Jupiter South 2
RJS-3 R. Jupiter South 3
RJS-4 R. Jupiter South 4
RJS-5 R. Jupiter South 5
RJS-6 R. Jupiter South 6
RJS-7 R. Jupiter South 7
RJR-1 R. Jupiter Road 1
RJR-1 R. Jupiter Road 1
RJR-2 R. Jupiter Road 2

RJR-3 R. Jupiter Road 3

RJR-4 R. Jupiter Road 4

NACPA-1 New Associated Consolidated Paper Anticosti #1

(Core - 85' to 325', total thickness of Becscie core = 73.15 metres)

R. aux Saumons Composite section

This composite section contains sections measured along the R. aux saumons, to the east of the bridge Fig. 3a).

RS-1 R. aux Saumons 1

RS-2 R. aux Saumons 2

RS-3 R. aux Saumons 3

RS-3a R. aux Saumons 3a

RS-3b R. aux Saumons 3b

RS-3c R. aux Saumons 3c

RS-4a R. aux Saumons 4a

RS-4b R. aux Saumons 4b

RS-5 R. aux Saumons 5

RS-6 R. aux Saumons 6

RS-7 R. aux Saumons 7

RS-8a R. aux Saumons 8a

RS-8b R. aux Saumons 8b

RS-9 R. aux Saumons 9

RS-10a R. aux Saumons 10a

RS-10b R. aux Saumons 10b

RS-11a R. aux Saumons 11a

RS-11b R. aux Saumons 11b

RS-12a R. aux Saumons 12a

RS-12b R. aux Saumons 12b

RS-13a R aux Saumons 13a

RS-13b R aux Saumons 13b

R. Prinsta-Reef Point Composite Section

This composite section includes sections measured along the Prinsta River, Fox River, in Fox Bay and along Reef Point on the east coast of Anticosti Island (Appendix Fig. 4).

RPR-1 R. Prinsta 1

RPR-2 R. Prinsta 2

RPR-3 R. Prinsta 3

RPR-4 R. Prinsta 4

RPR-5 R. Prinsta 5

RPR-6 R. Prinsta 6

RPR-7 R. Prinsta 7

RPR-8 R. Prinsta 8

RPR-9 R. Prinsta 9

RPR-10 R. Prinsta 10

RPR-11 R. Prinsta 11

RPR-12a R. Prinsta 12a

RPR-12b R. Prinsta 12b

RPR-13 R. Prinsta 13

FR-1a Fox River 1a

FR-1b Fox River 1b

FR-2 Fox River 2

FB-1 Fox Bay 1

FB-2 Fox Bay 2

RP-1 Reef Point 1

RP-2 Reef Point 2

RP-3 Reef Point 3

RP-4 Reef Point 4

RP-5 Reef Point 5

RP-6 Reef Point 6

Appendix II - Proximity Trend Software Listing

STORMER.GFA

Software designed to plot proximity parameters of
tempestite-dominated sequences

Software written in GFA BASIC on an Atari 1040ST by

Terry Sami
Dept. of Geology
University of Ottawa
Ottawa, Ontario, K1N 6N5

Software may be freely used and distributed
provided this copyright notice is included

Code may be improved or modified, just let me know
so that I can get improvements and update

```
DIM pal2(15)
newfile:
DIM dat_array(5,1000)
,
' Read Data File
,
SOUND 1,15,5,6,10
SOUND 1,0
ALERT 3,"Put data disk into drive A",1,"OK",a%
GOSUB reader
,
DIM mean_freq(2000)
DIM intra_mean_freq(2000)
DIM sealev1(2,3000)
DIM sealev2(2,2000)
DIM sealev3(2,2000)
CLS
,
' Choose analysis
,
restart:
n9=1
n2a=1
i5=4000
dat_num=1
```

```

cyclcr=0
overflow1=0
sl1=0
sl2=0
sl3=0
CLS
PRINT "(L)ithologies-full scale"
PRINT "(I)ntraclast Frequency"
PRINT "(I1)Mean intraclast Frequency 1"
PRINT "(I2)Mean intraclast Frequency 2"
PRINT "(C) Intraclast Percentage"
PRINT "(A)malgamation"
PRINT "(G) amalgamation frequency"
PRINT "(B)ed thickness"
PRINT "(F)requency"
PRINT "(Q1) Mean frequency 1"
PRINT "(Q2) Mean frequency 2"
PRINT "(M)aximum thickness of storm units"
PRINT "(X) Mean thickness of storm units"
PRINT "(P)ercentage storm units"
PRINT "(E)xit"
PRINT
INPUT "What type of analysis is required? ",analyses$
CLS
.
. Begin analysis
.
starter:
i5=i5+4000
cyclcr=cyclcr+1
SELECT analyses$
CASE "L","l"
GOSUB lithology
GOSUB full_scale_bar
GOTO skipper
CASE "I1","i1"
GOSUB intraclast_freq_mean
GOTO tryagain
CASE "I2","i2"
GOSUB intraclast_mean_freq
CASE "I","i"
GOSUB intraclast_freq
CASE "C","c"
GOSUB intraclast_percent
CASE "A","a"
GOSUB amalgamate
CASE "G","g"
GOSUB amalgamate_freq
CASE "B","b"
GOSUB bed_thickness
CASE "F","f"
GOSUB frequency
CASE "Q1","q1"

```

```

GOSUB frequency_mean
GOTO tryagain
CASE "Q2","q2"
GOSUB mean_frequency
CASE "M","m"
GOSUB max_thickness
CASE "X","x"
GOSUB mean_thickness
CASE "P","p"
GOSUB percentage
CASE "E","e"
GOTO done
ENDSELECT
GOSUB scale_bar
.
' Save plot as a picture file
.

skipper:
SOUND 1,15,5,6,10
SOUND 1,0
ALERT 3,"Insert File Save Disk!",1,"OK|CANCEL",a%
IF a%=2
CLS
GOTO tryagain
ENDIF
GOSUB save_degas_screen
.
' returns to beginning for rest of section
.

tryagain:
CLS
SOUND 1,15,6,6,50
SOUND 1,0
INPUT "Does the section continue (y) or (n) ",end$
IF end$="y" OR end$="Y"
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"You cannot continue since data|has run out!",1,"OK",as%
GOTO tryagain
ENDIF
CLS
GOTO starter
ENDIF
IF end$="n" OR end$="N"
GOTO ender
ENDIF
GOTO tryagain
.

```



```

' Restart
,
ender:
CLS
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 3,"Data file is exhausted. To reuse data RESTART. To call up new data file NEWFILE.",3,"RESTART|NEW-FILE|QUIT",ans%
ENDIF
,
' Plot combined proximity curve
,
SELECT ans%
CASE 1
GOTO restart
CASE 2
ERASE intra_mean_freq()
ERASE mean_freq()
ERASE dat_array()
ALERT 3,"Do you wish to plot a|Proximity Curve for this|Data file?",2,"YES|NO",slans%
SELECT slans%
CASE 1
GOSUB sea_level_plot
DEFAULT
ENDSELECT
ERASE sealev1()
ERASE sealev2()
ERASE sealev3()
GOTO newfile
CASE 3
GOTO done
ENDSELECT
done:
END
,
PROCEDURE reader
,
,
' Reads data from a file on disk
,
,
,
dat_num=0
FILESELECT "a:\*.dat", "\*.dat", fname$
OPEN "I", #1, fname$
DO UNTIL EOF(#1)
dat_num=dat_num+1

```

```

FOR y=1 TO 5
INPUT #1,dat_array(y,dat_num)
NEXT y
LOOP
cnt=dat_num
CLOSE #1
RETURN
.
.
.
PROCEDURE save_degas_screen
.
' saves screen as a picture file
.
' Reserve an area of memory for the alternate palette
.
GOSUB save_palette
HIDEM
.
SGET screen1$
.
rez=XBIOS(4)
IF rez<=2
CLS
ALERT 1,"Must be High Resolution|for Degas Elite File",1,"OK",b
CLS
SPUT screen1$
GOTO not_degas
ENDIF
.
default$="A:\*.PI3"
FILESELECT default$,"",infile$
CLS
SPUT screen1$
OPEN "c",#1,infile$
.
' First WORD to 2 for Hi Rez
.
OUT #1,0
OUT #1,2
.
' save color palette
.
FOR ctr%=0 TO 15
hi=INT(pal2(ctr%)/256)
lo=pal2(ctr%)-256*hi
OUT #1,hi
OUT #1,lo
NEXT ctr%
.
' save screen info
.
BPUT #1,XBIOS(3),32000

```

```

,
CLOSE
,
not_degas:
,
,
,
finito:
,
RETURN
,
,
,
PROCEDURE save_palette
,
' SAVE "original color palette"
,
LOCAL i
,
,
,
FOR ctr%=0 TO 15
pal2(ctr%)=XBIOS(7,W:ctr%,W:-1)
NEXT ctr%
RETURN
,
,
,
PROCEDURE scale_bar
,
REM draws scale bar and metre values
,
LINE 95,0,95,399
LINE 90,0,90,399
FOR i=9 TO 399 STEP 10
LINE 90,i,95,i
NEXT i
DEFFILL 1,1
FOR i2=10 TO 390 STEP 20
FILL 91,i2+1
NEXT i2
RETURN
,
,
,
PROCEDURE intraclast_freq
,
' Plots frequency of intraclastic tempestites per 5 metres
,
number2=0
IF cyclr>1
metre2=i5+250
GOTO graph2

```

```

ENDIF
metre2=i5+500
graph2:
limit2=metre2-250
IF limit2>=i5+4000
GOTO end2
ENDIF
toolow2:
tally2=dat_num
IF dat_array(1,dat_num)<{(metre2-500)
dat_num=dat_num+1
GOTO toolow2
ENDIF
again2:
IF dat_array(1,dat_num)<=metre2
IF dat_array(5,dat_num)=1
number2=number2+1
ENDIF
IF dat_num=cnt
GOTO draw2
ENDIF
dat_num=dat_num+1
GOTO again2
ENDIF
dat_num=dat_num-1
draw2:
base2%=(399-((metre2-250)-i5)/10)
length2=110+(15*number2)
LINE length2,base2%,110,base2%
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end2
ENDIF
metre2=metre2+50
number2=0
dat_num=tally2
GOTO graph2
end2:
RETURN
,
,
,
PROCEDURE intraclast_freq_mean
,
' Calculates first part of combined frequency-mean thickness of intraclastic tempe-
tites per 5 metres
,

```

```

number2a=0
IF cycler>1
metre2a=i5+250
GOTO graph2a
ENDIF
metre2a=i5+500
graph2a:
limit2a=metre2a-250
IF limit2a>=i5+4000
GOTO end2a
ENDIF
toolow2a:
tally2a=dat_num
IF dat_array(1,dat_num)<(metre2a-500)
dat_num=dat_num+1
GOTO toolow2a
ENDIF
again2a:
IF dat_array(1,dat_num)<=metre2a
IF dat_array(5,dat_num)=1
number2a=number2a+1
ENDIF
IF dat_num=cnt
GOTO draw2a
ENDIF
dat_num=dat_num+1
GOTO again2a
ENDIF
dat_num=dat_num-1
draw2a:
base2a%=(399-((metre2a-250)-i5)/10)
length2a=390-(15*number2a)
intra_mean_freq(n2a)=number2a
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end2a
ENDIF
metre2a=metre2a+10
n2a=n2a+1
number2a=0
dat_num=tally2a
GOTO graph2a
end2a:
RETURN
.
.
.

```

```

PROCEDURE intraclast_mean_freq
,
' Calculates second part of combined frequency-mean thickness of intraclastic tempe-
tites per 5 metres and plots
,

number2b=0
total2b=0
IF cycler>1
metre2b=i5+250
GOTO graph2b
ENDIF
metre2b=i5+500
graph2b:
limit2b=metre2b-250
IF limit2b>=i5+4000
GOTO end2b
ENDIF
toolow2b:
tally2b=dat_num
IF dat_array(1,dat_num)<(metre2b-500)
dat_num=dat_num+1
GOTO toolow2b
ENDIF
again2b:
IF dat_array(1,dat_num)<=metre2b
total2b=total2b+dat_array(2,dat_num)
number2b=number2b+1
IF dat_num=cnt
GOTO draw2b
ENDIF
dat_num=dat_num+1
GOTO again2b
ENDIF
dat_num=dat_num-1
draw2b:
IF number2b=0
mean2b%=0
GOTO zero2b
ENDIF
mean2b%=total2b/number2b
zero2b:
base2b%=(399-((metre2b-250)-i5)/10)
length2b=110+(intra_mean_freq(n2a)*mean2b%*2)
sealev1(1,sl1)=base2b%
sealev1(2,sl1)=length2b-110
sl1=sl1+1
LINE length2b,base2b%,110,base2b%
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10

```

```

SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end2b
ENDIF
metre2b=metre2b+10
n2a=n2a+1
total2b=0
mean2b%=0
number2b=0
dat_num=tally2b
GOTO graph2b
end2b:
RETURN
.
.
.
PROCEDURE intraclast_percent
.
. Plots percentage of intraclastic tempestites per metre
.

total2c=0
IF cyclcr>1
metre2c=i5+50
GOTO graph2c
ENDIF
metre2c=i5+100
graph2c:
limit2c=metre2c-50
IF limit2c>=i5+4000
GOTO end2c
ENDIF
toolow2c:
tally2c=dat_num
IF dat_array(1,dat_num)<metre2c-100
IF dat_array(5,dat_num)=1
IF dat_array(1,dat_num)+dat_array(2,dat_num)>metre2c-100
fullthick2c=dat_array(1,dat_num)+dat_array(2,dat_num)
baser2c=metre2c-100
total2c=fullthick2c-baser2c
dat_num=dat_num+1
GOTO again2c
ENDIF
ENDIF
dat_num=dat_num+1
GOTO toolow2c
ENDIF
again2c:
IF dat_array(1,dat_num)<metre2c
IF dat_array(5,dat_num)=1
total2c=total2c+dat_array(2,dat_num)
IF dat_array(1,dat_num)+dat_array(2,dat_num)>metre2c
truethick2c=metre2c-dat_array(1,dat_num)
overflow2c=dat_array(2,dat_num)-truethick2c

```

```

total2c=total2c-overflow2c
GOTO percentage2c
ENDIF
ENDIF
IF dat_num=cnt
GOTO percentage2c
ENDIF
dat_num=dat_num+1
GOTO again2c
ENDIF
dat_num=dat_num-1
percentage2c:
base2c%=(399-((metre2c-50)-i5)/10)
length2c=110+(4*total2c)
LINE length2c,base2c%,110,base2c%
metre2c=metre2c+10
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end2c
ENDIF
dat_num=tally2c
total2c=0
GOTO graph2c
end2c:
RETURN
,
,
,
PROCEDURE amalgamate
,
' Plots occurrence of amalgamated surfaces
,
graph3:
IF dat_array(1,dat_num)>=i5+4000
GOTO end3
ENDIF
IF dat_array(4,dat_num)=1
SELECT dat_array(3,dat_num)
CASE 0,1,2
length3=300
CASE 3,4
length3=335
CASE 5,6,7
length3=370
ENDSELECT
base3%=(399-(dat_array(1,dat_num)-i5)/10)
LINE length3,base3%,110,base3%

```



```

ENDIF
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end3
ENDIF
dat_num=dat_num+1
GOTO graph3
end3:
RETURN
.
.
.
PROCEDURE amalgamate_freq
.
' Plots frequency of amalgamated tempestites per metre
.

number3a=0
IF cyclar>1
metre3a=i5+250
GOTO graph3a
ENDIF
metre3a=i5+500
graph3a:
limit3a=metre3a-250
IF limit3a>=i5+4000
GOTO end3a
ENDIF
toolow3a:
tally3a=dat_num
IF dat_array(1,dat_num)<(metre3a-500)
dat_num=dat_num+1
GOTO toolow3a
ENDIF
again3a:
IF dat_array(1,dat_num)<=metre3a
IF dat_array(4,dat_num)=1
number3a=number3a+1
ENDIF
IF dat_num=cnt
GOTO draw3a
ENDIF
dat_num=dat_num+1
GOTO again3a
ENDIF
dat_num=dat_num-1
draw3a:
base3a%=(399-((metre3a-250)-i5)/10)

```

```

length3a=110+(25*number3a)
LINE length3a,base3a%,110,base3a%
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end3a
ENDIF
metre3a=metre3a+50
number3a=0
dat_num=tally3a
GOTO graph3a
end3a:
RETURN
,
,
,
PROCEDURE bed_thickness
,
' Plots actual bed thickness stratigraphically, at base of each bed
,
graph4:
IF dat_array(1,dat_num)>=i5+4000
GOTO end4
ENDIF
base4%=(399-(dat_array(1,dat_num)-i5)/10)
length4=110+(dat_array(2,dat_num)*5)
LINE length4,base4%,110,base4%
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end4
ENDIF
dat_num=dat_num+1
GOTO graph4
end4:
RETURN
,
,
,
PROCEDURE frequency
,
' Plots frequency of tempestites per metre
,

```

```

number5=0
IF cyler>1
metre5=i5+50
GOTO graph5
ENDIF
metre5=i5+100
graph5:
limit5=metre5-50
IF limit5>=i5+4000
GOTO end5
ENDIF
toolow5:
tally5=dat_num
IF dat_array(1,dat_num)<(metre5-100)
dat_num=dat_num+1
GOTO toolow5
ENDIF
again5:
IF dat_array(1,dat_num)<=metre5
number5=number5+1
IF dat_num=cnt
GOTO draw5
ENDIF
dat_num=dat_num+1
GOTO again5
ENDIF
dat_num=dat_num-1
draw5:
base5%=(399-((metre5-50)-i5)/10)
length5=110+(15*number5)
LINE length5,base5%,110,base5%
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end5
ENDIF
metre5=metre5+10
number5=0
dat_num=tally5
GOTO graph5
end5:
RETURN
.
.
.
PROCEDURE frequency_mean
.

```

* Calculates first part of combined frequency-mean thickness of tempestites per metre

```

,
number9=0
IF cyler>1
metre9=i5+50
GOTO graph9
ENDIF
metre9=i5+100
graph9:
limit9=metre9-50
IF limit9>=i5+4000
GOTO end9
ENDIF
toolow9:
tally9=dat_num
IF dat_array(1,dat_num)<(metre9-100)
dat_num=dat_num+1
GOTO toolow9
ENDIF
again9:
IF dat_array(1,dat_num)<=metre9
number9=number9+1
IF dat_num=cnt
GOTO draw9
ENDIF
dat_num=dat_num+1
GOTO again9
ENDIF
dat_num=dat_num-1
draw9:
base9%=(399-((metre9-50)-i5)/10)
length9=110+(15*number9)
mean_freq(n9)=number9
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end9
ENDIF
metre9=metre9+10
n9=n9+1
number9=0
dat_num=tally9
GOTO graph9
end9:
RETURN
,
,
,
PROCEDURE mean_frequency

```

.
 ' calculates second part of combined frequency-mean thickness of tempestites per metre and plots
 .

```

number10=0
total10=0
IF cyc1er>1
  metre10=i5+50
  GOTO graph10
ENDIF
metre10=i5+100
graph10:
limit10=metre10-50
IF limit10>=i5+4000
  GOTO end10
ENDIF
toolow10:
tally10=dat_num
IF dat_array(1,dat_num)<=(metre10-100)
  dat_num=dat_num+1
  GOTO toolow10
ENDIF
again10:
IF dat_array(1,dat_num)<=metre10
  total10=total10+dat_array(2,dat_num)
  number10=number10+1
  IF dat_num=cnt
    GOTO draw10
  ENDIF
  dat_num=dat_num+1
  GOTO again10
ENDIF
dat_num=dat_num-1
draw10:
IF number10=0
  mean10%=0
  GOTO zero10
ENDIF
mean10%=total10/number10
zero10:
base10%=(399-((metre10-50)-i5)/10)
length10=110+(mean_freq(n9)*mean10%*2)
sealev2(1,sl2)=base10%
sealev2(2,sl2)=length10-110
sl2=sl2+1
LINE length10,base10%,110,base10%
IF dat_num=cnt
  SOUND 1,15,5,6,10
  SOUND 1,0,0,0,5
  SOUND 1,15,5,6,10
  SOUND 1,0,0,0,5
  SOUND 1,15,5,6,10
  SOUND 1,0,0,0,5

```

```

ALERT 1,"Ran out of data",1,"OK",a%
GOTO end10
ENDIF
metre10=metre10+10
n9=n9+1
total10=0
mean10%=0
number10=0
dat_num=tally10
GOTO graph10
end10:
RETURN
.
.
.
PROCEDURE max_thickness
.
. Plots maximum thickness of tempestites per metre
.

number6=0
IF cycler>1
metre6=i5+50
GOTO graph6
ENDIF
metre6=i5+100
graph6:
DIM max%(100)
limit6=metre6-50
IF limit6>=i5+4000
GOTO end6
ENDIF
toolow6:
tally6=dat_num
IF dat_array(1,dat_num)<(metre6-100)
dat_num=dat_num+1
GOTO toolow6
ENDIF
again6:
IF dat_array(1,dat_num)<=metre6
number6=number6+1
max%(number6)=dat_array(2,dat_num)
IF dat_num=cnt
GOTO draw6
ENDIF
dat_num=dat_num+1
GOTO again6
ENDIF
dat_num=dat_num-1
draw6:
SSORT max%(-)
max_num6=max%(0)
base6%=(399-(limit6-i5)/10)
length6=110+(2*max_num6)

```

```

LINE length6,base6%,110,base6%
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end6
ENDIF
metre6=metre6+10
max_num6=0
number6=0
dat_num=tally6
ERASE max%()
GOTO graph6
end6:
ERASE max%()
RETURN
.
.
.
PROCEDURE mean_thickness
.
. Plots mean thickness of tempestites per metre
.

number7=0
total7=0
IF cyler>1
metre7=i5+50
GOTO graph7
ENDIF
metre7=i5+100
graph7:
limit7=metre7-50
IF limit7>=i5+4000
GOTO end7
ENDIF
toolow7:
tally7=dat_num
IF dat_array(1,dat_num)<(metre7-100)
dat_num=dat_num+1
GOTO toolow7
ENDIF
again7:
IF dat_array(1,dat_num)<=metre7
total7=total7+dat_array(2,dat_num)
number7=number7+1
IF dat_num=cnt
GOTO draw7
ENDIF
dat_num=dat_num+1

```

```

GOTO again7
ENDIF
dat_num=dat_num-1
draw7:
IF number7=0
mean7%=0
GOTO zero7
ENDIF
mean7%=total7/number7
zero7:
base7%=(399-((metre7-50)-i5)/10)
length7=110+(5*mean7%)
LINE length7,base7%,110,base7%
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end7
ENDIF
metre7=metre7+10
total7=0
mean7%=0
number7=0
dat_num=tally7
GOTO graph7
end7:
RETURN
.
.
.
PROCEDURE percentage
.
' Plots percentage tempestite per metre of section
.
total8=0
IF cycler>1
metre8=i5+50
GOTO graph8
ENDIF
metre8=i5+100
graph8:
limit8=metre8-50
IF limit8>=i5+4000
GOTO end8
ENDIF
toolow8:
tally8=dat_num
IF dat_array(1,dat_num)<metre8-100
IF dat_array(1,dat_num)+dat_array(2,dat_num)>metre8-100

```



```

fullthick8=dat_array(1,dat_num)+dat_array(2,dat_num)
baser8=metre8-100
total8=fullthick8-baser8
dat_num=dat_num+1
GOTO again8
ENDIF
dat_num=dat_num+1
GOTO toolow8
ENDIF
again8:
IF dat_array(1,dat_num)<metre8
total8=total8+dat_array(2,dat_num)
IF dat_array(1,dat_num)+dat_array(2,dat_num)>metre8
truethick8=metre8-dat_array(1,dat_num)
overflow8=dat_array(2,dat_num)-truethick8
total8=total8-overflow8
GOTO percentage8
ENDIF
IF dat_num=cnt
GOTO percentage8
ENDIF
dat_num=dat_num+1
GOTO again8
ENDIF
dat_num=dat_num-1
percentage8:
base8%=(399-((metre8-50)-i5)/10)
length8=110+(4*total8)
sealev3(1,sl3)=base8%
sealev3(2,sl3)=length8-110
sl3=sl3+1
LINE length8,base8%,110,base8%
metre8=metre8+10
IF dat_num=cnt
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
SOUND 1,15,5,6,10
SOUND 1,0,0,0,5
ALERT 1,"Ran out of data",1,"OK",a%
GOTO end8
ENDIF
dat_num=tally8
total8=0
GOTO graph8
end8:
RETURN
.
.
.
PROCEDURE sea_level_plot
.
```

```

' Plots combined proximity curves
.
x=0
y=0
c=0
redo:
CLS
FOR sl=0+x TO 374+y
length100%=(110+((sealev2(2,sl+20)*sealev3(2,sl+20))/275)+(sealev1(2,sl)/2)
base100%=sealev2(1,sl+20)
LINE 110,base100%,length100%,base100%
NEXT sl
GOSUB scale_bar
ALERT 3,"Insert File Save Disk!",1,"OK|CANCEL",a%
IF a%=2
CLS
GOTO tiggy
ENDIF
GOSUB save_degas_screen
tiggy:
ALERT 3,"Does the curve continue?",1,"YES|NO",got%
IF got%=1
IF c=0
x=x+375
y=y+400
c=c+1
GOTO redo
ENDIF
c=c+1
x=x+400
y=y+400
GOTO redo
ENDIF
RETURN

```

WRITER.GFA

Program designed to insert field data on tempestite units
into data file readable by STORMER.GFA

```
.  
.   
.   
.   
* Writes inputted data to a specified file on disk  
.   
.   
DIM dat_array(5,2000)  
restart:  
CLS  
DEFTXT 1,0,0,32  
TEXT 20,30,"Data Input"  
LOCATE 1,5  
dat_num=0  
same_data:  
SOUND 1,15,5,5,10  
SOUND 1,0  
INPUT "Base Level (cm)? ";dat_array(1,dat_num)  
INPUT "Thickness (cm)? ";dat_array(2,dat_num)  
INPUT "Facies (0-7)? ";dat_array(3,dat_num)  
INPUT "Amalgamation-base (n=0/y=1)? ";dat_array(4,dat_num)  
INPUT "Intraclasts (n=0/y=1/r=99)? ";dat_array(5,dat_num)  
PRINT  
IF dat_array(5,dat_num)=99  
SOUND 1,15,5,5,40  
SOUND 1,0  
dat_num=dat_num+1  
GOTO same_data  
ENDIF  
counter=dat_num+1  
INPUT "Is data correct [(y)es, (n)o, (e)nd]? ",yne$  
SELECT yne$  
CASE "e"  
GOTO nam_file  
CASE "n"  
GOTO same_data  
DEFAULT  
check=dat_num-1  
IF dat_num>0  
IF dat_array(1,dat_num)<=dat_array(1,check)  
SOUND 1,15,5,5,10  
SOUND 1,0,0,0,5
```

```

SOUND 1,15,5,5,10
SOUND 1,0,0,0,5
ALERT 1,"Base level value is lower than|previous base level",1,"OK",chk%
PRINT
GOTO same_data
ENDIF
IF dat_array(1,dat_num)<dat_array(1,check)+dat_array(2,check)
SOUND 1,15,5,5,10
SOUND 1,0,0,0,5
SOUND 1,15,5,5,10
SOUND 1,0,0,0,5
ALERT 1,"Base level is below top of|previous unit",1,"OK",chk2%
PRINT
GOTO same_data
ENDIF
ENDIF
PRINT "This is the data element #";counter
PRINT
dat_num=dat_num+1
GOTO same_data
ENDSELECT
nam_file:
FILESELECT "A:","\*.DAT",name$
IF name$=""
ALERT 2,"Do you REALLY wish to lose|the data?",2,"YES|NO",b%
SELECT b%
CASE 1
GOTO cancel
CASE 2
GOTO nam_file
ENDSELECT
ELSE IF RIGHT$(name$)="\"
PRINT AT(10,24),"Please choose a name for file!"
GOTO nam_file
ENDIF
OPEN "O",#1,name$
FOR t=0 TO dat_num
FOR x=1 TO 5
PRINT #1,dat_array(x,t)
NEXT x
NEXT t
CLOSE #1
cancel:
ALERT 2,"Do you wish to open a new file",2,"NO|YES",a%
SELECT a%
CASE 2
GOTO restart
DEFAULT
ENDSELECT
END

```

Plates

Plate I

Fairweather Rock Types

- a. Unlaminated mudstone (light grey) interbedded with laminated packstone and Calcisiltite (dark grey)(section RS-4b). The mudstone contains few fossils and shows some burrows. The upper contacts of the mudstone are sharp and locally shows some scours. Scale bar is 5 cm.
- b. Photomicrograph of unlaminated mudstone showing dense micrite with dispersed microspar and isolated sponge spicules (section RS-4a). Scale bar is 1 mm.
- c. Unlaminated packstone (light grey) interbedded with laminated calcisiltite and packstone (dark grey)(section CH-4). The packstone contains large, par-autochthonous brachiopods showing geopetal cement fill, in a micrite matrix. Scale bar is 5 cm.
- d. Photomicrograph of unlaminated packstone showing articulated and disarticulated brachiopods, ostracodes, and gastropods in a dense mud matrix (section RS-3c). Scale bar is 1 mm.
- e. Argillaceous, unlaminated mudstone and packstone overlying an argillaceous, laminated packstone (section RJR-3). Unlaminated unit shows abundant clay, fossil material and burrows. Scale bar is 2 cm.
- f. Photomicrograph of argillaceous packstone showing abundant fossil material in a clay and micrite matrix (section RJR-3). Scale bar is 1 mm.

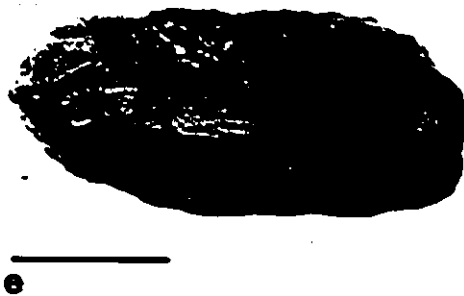
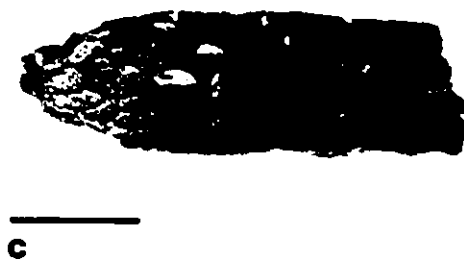
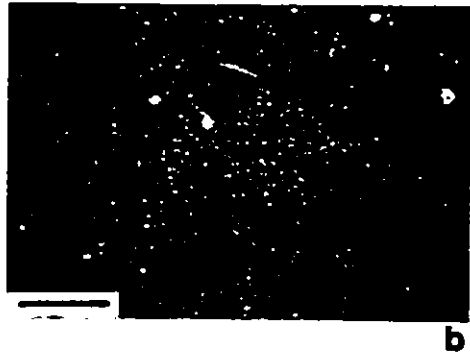
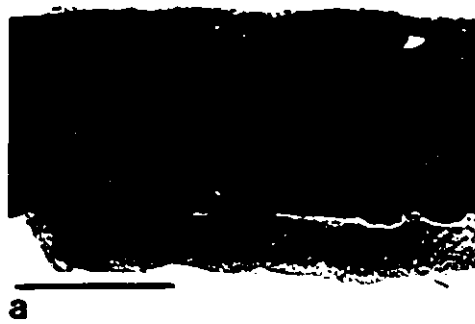


Plate II

Fine-Grained Tempestites

- a. Laminated mudstone (burrowed) overlying unlaminated mudstone (section CH-1).
The contact is sharp and the laminated unit shows well-defined grading and lamination cut by *Chondrites* burrows. Scale bar is 2 cm.
- b. Photomicrograph of laminated mudstone showing faint parallel lamination defined by quartz silt, fossil material, micrite and microspar (section RJS-1). Scale bar is 1 mm.
- c. Laminated packstone (top) grading up from laminated calcisiltite (base)(section RJS-2). The packstone shows well-defined lamination defined by the parallel orientation and the relative abundance of fossils. Scale bar is 3 cm.
- d. Photomicrograph of laminated packstone grading up into mudstone with a decrease in fossil content. Oriented fossils and quartz silt aid in defining the lamination (section RJS-2). Scale bar is 1 mm.
- e. Photomicrograph of laminated calcisiltite showing the alternation of crinoid/peloid-rich laminae (top and bottom, dark) with quartz silt/ostracode-rich laminae (middle, bright)(section RB-4). Scale bar is 1 mm.
- f. Laminated calcisiltite showing well-developed horizontal lamination (top, bottom) which truncates and is truncated by shallow-dipping lamination (centre), (possible HCS)(section RS-3a). Scale bar is 2 cm.

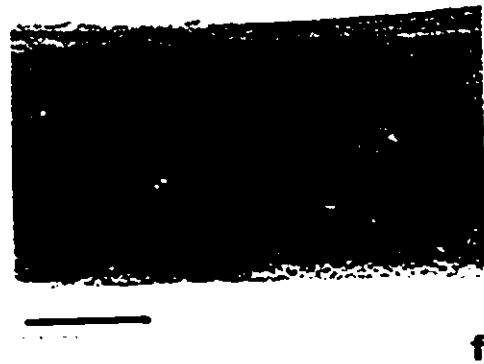
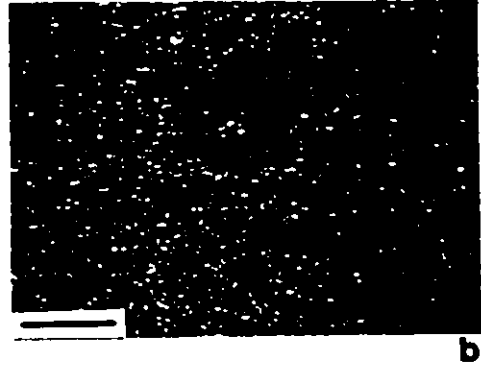


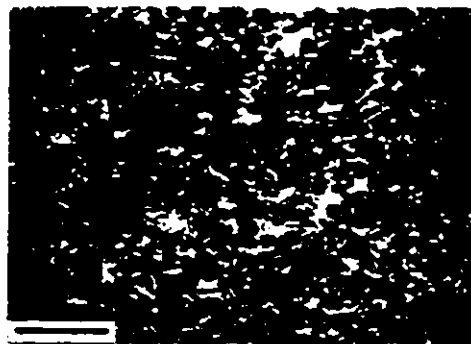
Plate III

Coarse-Grained Tempestites

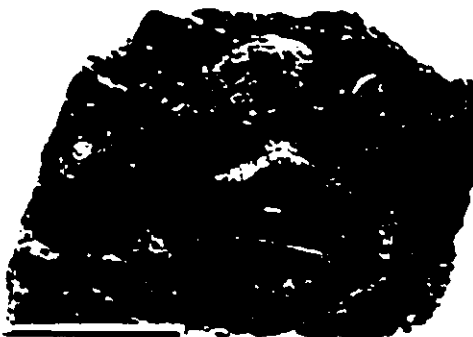
- a. Medium to fine-grained grainstone overlying laminated calcisiltite with a sharp, erosional base (section RS-1). Grading is poorly developed within the abundant, disarticulated fossil material. Lamination is poorly-defined. Scale bar is 3 cm.
- b. Photomicrograph of medium- to fine-grained grainstone showing abundant fossil material in calcite spar (section RB-1). Scale bar is 1 mm.
- c. Coarse bioclastic rudstone showing abundance of large disarticulated fossils in a calcite cement (section RJS-2). Scale bar is 3 cm.
- d. Photomicrograph of bioclastic rudstone showing large, well-preserved bryozoan, brachiopod and crinoid debris in an abundant calcite spar (section RJS-1). Scale bar is 1 mm.
- e. Photomicrograph of intraclastic rudstone showing mudstone and packstone intraclasts in a coarse- to fine-grained grainstone matrix (section RJN-2). Scale bar is 1 mm.
- f. Coarse intraclastic rudstone showing a diversity of elongate intraclast types, including laminated packstone and calcisiltite, and irregular (possibly bored), dense mudstone intraclasts in a coarse- to fine-grained grainstone matrix (section RPR-12b). The orientation of some intraclasts suggests an imbricate texture. Scale bar is 4 cm.



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Plate IV

Lithofacies 1, 2, and 3

- a. Section of lithofacies 1 exposed along the R. Jupiter road (section RJR-3). The sequence is dominated by shale with few nodular limestone beds. Scale bar is 1,5 metres in length.
- b. Detailed view of nodularly-bedded limestones within lithofacies 1 on the Prinsta River (section RPR-13). The nodular limestones are overlain by a heavily burrowed calcisiltite tempestite (beneath pencil). Pencil is 15 cm in length.
- c. Cliff section of lithofacies 2 at Cap Henri (section CH-1) showing laterally continuous bedding. The strata consist mainly of mudstones with thin interbedded shales. Scale bar is 1,5 metres in length.
- d. Close-up of lithofacies 2 (same locality as in c) showing irregularly bedded fairweather mudstones and regularly-bedded, laminated mudstones and packstones. Tape measure is 90 cm long.
- e. Riverside section of the lower part of lithofacies 3 along the Jupiter River (section RJS-7), south of the bridge. The thick tempestite beds are interbedded with nodular mudstones and shales. Hammer is 34 cm long.
- f. The upper part of lithofacies 3 exposed along the shoreline near R. Cailloux (section RC-2) showing a tabulate coral-stromatoporoid-rich horizon within shale and nodular limestone units. Scale bar is separated into 10 cm intervals (total length of 32 cm).



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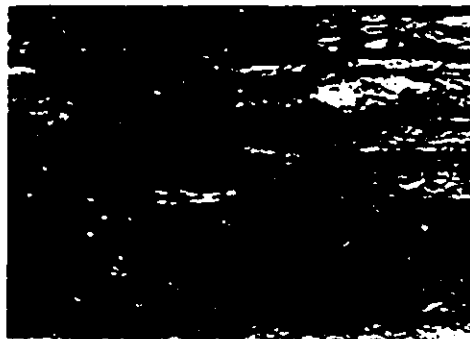


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Plate V

Lithofacies 4 and 5 and Formation Boundaries

- a. Shoreline cliff exposure of lithofacies 4 near Cap Henri (section PL-1). The tempestites are interbedded with thick, nodularly-bedded mudstones. The lens cap is located on a packstone-filled depression between two hummocks of a HCS tempestite which is gradational upwards from an intraclastic base. Lens cap is 55 mm in diameter.
- b. Close-up view of lithofacies 4 (section RDB-1) showing the lateral thinning and pinching-out of tempestite units. Hammer is 34 cm long.
- c. Shoreline cliff exposure of lithofacies 5 near R. Becscie (section RB-4) showing thick amalgamated tempestites and the absence of mudstones. Scale bar is divided into 10 cm intervals.
- d. Thick, amalgamated tempestite of lithofacies 5 from Cap a l'Ours (section CO-1). White grains are bryozoans. Lens cover is 55 mm in diameter.
- e. Contact between the Becscie and Gun River formations at R. Jupiter (section RJS-7). The contact is located near the top of the hammer at the first occurrence of dense mudstones. A small excavated trench is located in shales of Member 4 of the Becscie Formation. Hammer is 34 cm in length.
- f. The contact between the Ellis Bay and Becscie formations near Cap Henri (section FO-1). Strata of the transition zone at the base of the Becscie Formation are shown abutting against and draping over a bioherm of member 7 of the Ellis Bay Formation. The thick ball and pillow unit at center of the view is 65 cm above the contact, and is approximately 15 to 25 cm thick.



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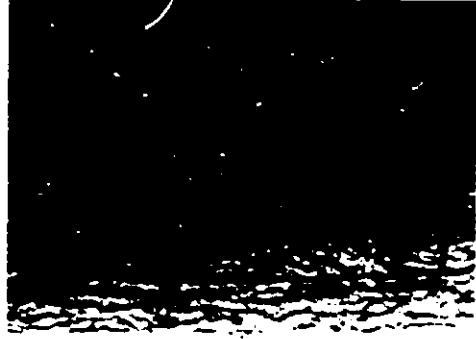
Plate VI

Graded Tempestites, Amalgamation, and Scouring

- a. Graded tempestite unit showing an abrupt transition from a coarse intraclastic rudstone base to a well-laminated calcisiltite, with an interference-rippled top (section RS-8). Lens cover is 55 cm in diameter.
- b. Graded tempestite bed showing a gradual transition from intraclastic rudstone to calcisiltite (section RP-6). Pencil is 15 cm long.
- c. Tempestite showing a gradual transition from bioclastic rudstone to calcisiltite (section CO-1). Lens cap is 55 cm in diameter.
- d. Graded tempestite with a sharp transition from a bio/intraclastic rudstone base to a laminated packstone/mudstone top (section CSM-1). Lens cover is 55 mm in diameter.
- e. Three distinct amalgamated tempestite units (section RG-2). The basal unit contains well-developed HCS. The coarse-grained bio/intraclastic rudstone of the middle unit possesses a channel morphology. The upper unit is a HCS calcisiltite with a hummocky surface. Hammer is 34 cm in length.
- f. Irregular scoured surface developed in a faintly laminated mudstone and overlain by a graded, laminated medium-grained grainstone/calcisiltite tempestite (section RPR-8). Discoloration of the scoured surface suggests the formation of a hard- or firmground. Irregularities in the surface are infilled by mudstone intraclasts (possibly derived from the underlying mudstone) and the overlying grainstone and calcisiltite. Sample is 15 cm in length.



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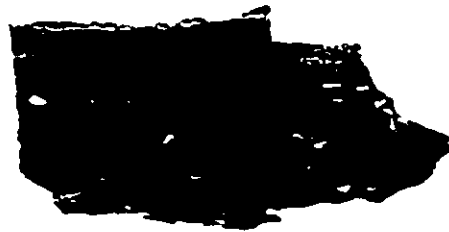
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Plate VII

Hummocky Cross-Stratification and Bedding

- a. Thin HCS tempestite unit, showing well-developed laminations, interbedded with nodular mudstones (section RP-3). Field book is 19 cm long.
- b. Wave-rippled, hummocky cross-stratified unit within an amalgamated sequence (section RDB-1). Lens cap is 55 mm in diameter.
- c. Thick amalgamated HCS sequence with a hummocky surface (section RG-2). Hammer is 34 cm long.
- d. Isolated lens of microhummocky cross-laminated highly burrowed mudstone (section RDB-1). Lenses are spaced at 2 to 3 metre intervals along the same horizon. Hammer is 34 cm long.
- e. Hummocky bedform with HCS and interference-rippled top exposed on wave cut platform (section RP-6). Pencil is 15 cm long.
- f. Mudstone- and packstone-filled depression on a hummocky tempestite surface (section RS-10a). Most likely a scour-produced feature which was subsequently infilled by fairweather sediments. Hammer is 34 cm long.



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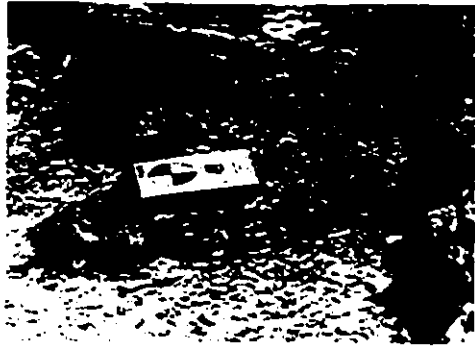
Plate VIII

Gutters and Gutter Casts

- a. Gutter scoured into a coarse-grainstone tempestite and showing a coarse cobble lag (wave-cut platform off section RB-3). The lag is covered by mudstone which has been eroded away at this location but is still preserved in other gutters. Hammer is 34 cm long.
- b. Exhumed gutter cast formed of coarse grainstone (section RP-5). Gutter scoured into a mudstone which has been locally eroded. Field book is 19 cm long.
- c. Exhumed, guttered calcisiltite tempestite surface (section RS-9). Calcisiltite fill is preserved in cliff section. Hammer is 34 cm long.
- d. Partially exhumed mudstone-filled gutter scoured into mudstone substrate (section RS-7). Lens cap is 55 cm in diameter.
- e. Partially-exhumed guttered surface which shows evidence of delayed-fill (section RS-7). Hammer is 34 cm in length.
- f. Close-up of (e) showing borings in laminated calcisiltite. Many borings were subsequently filled by intraclasts and coarse bioclasts. Lens cap is 55 cm in diameter.



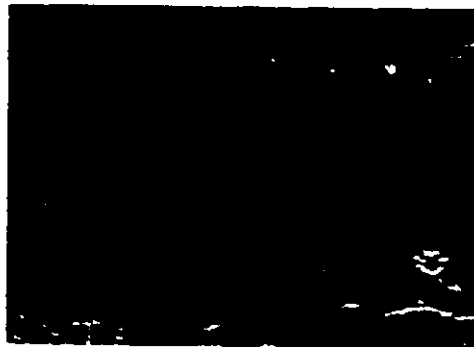
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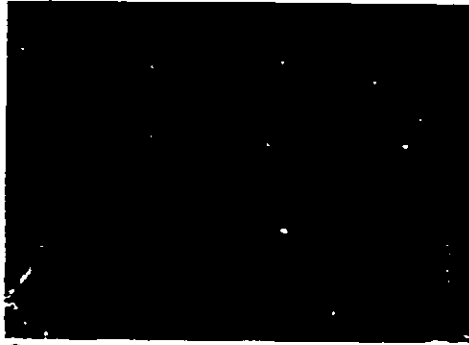


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Plate IX

Interference, Symmetrical and Coarse-Grained Ripples

- a. Calcisiltite tempestite bed showing well-formed hexagonal interference ripples (section RP-5). Hammer is 34 cm long.
- b. Symmetrical wave ripples developed on a calcisiltite tempestite bed (section RS-4a). Ripples are slightly sinuous and commonly bifurcate. Hammer is 34 cm long.
- c. Interference-rippled tempestite overlain by a hummocky-bedded tempestite which shows gradational interference and symmetrical wave ripples (section RS-11a). Hammer is 34 cm long.
- d. Hummocky surface showing transition from symmetrical to interference ripples (section RS-7). hammer is 34 cm long.
- e. Wave-cut platform (near section CH-1) showing sinuous, symmetrical coarse-grained ripples. Hammer is 34 cm long.
- f. Asymmetrical coarse-grained ripple showing internal cross-lamination and asymmetrical form (section RP-6). Pencil is 15 cm long.



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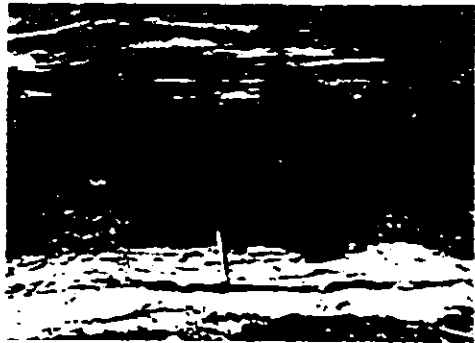
Plate X

Other Sedimentary Structures

- a. Calcisiltite unit with ball and pillow structure, showing upturned lamination, enclosed in nodular mudstone layer (section RDB-1). Hammer is 34 cm long.
- b. Laterally extensive ball and pillow horizon (section RDB-1). Hammer is 34 cm long.
- c. Slab of intraclastic rudstone showing highly irregular mudstone intraclasts associated with irregular, scoured surfaces (section FB-1). Pencil is 15 cm long.
- d. Imbricated intraclasts in an upwar ls-grading intraclastic rudstone tempestite, overlying dense mudstone with a sharp, scoured contact (section RS-8). Lens cap is 55 cm in diameter.
- e. Edge of scoured channel showing truncated laminated calcisiltite tempestite and mudstone fill (section RP-6). Pencil is 15 cm long.
- f. Channel edge showing undercut calcisiltite tempestite side wall and subsequent mud fill (section RP-6). Pencil is 15 cm long.



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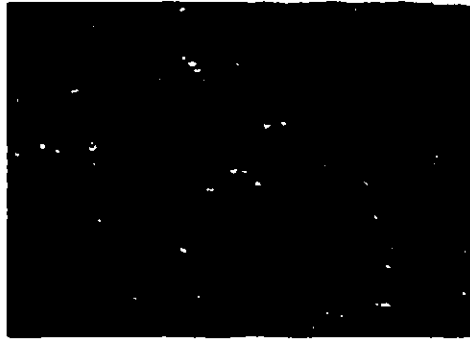


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Plate XI

Oriented and *In Situ* Fossils and Bioturbation

- a. Orthocone nautiloids oriented parallel to palaeocurrent direction in medium-grained grainstone (section RS-4a). Hammer is 34 cm long.
- b. Crinoid stems oriented parallel to palaeocurrent direction in medium-grained grainstone (section RS-3a). Lens cap is 55 mm in diameter.
- c. *In situ* hemispherical tabulate corals and stromatoporoids interbedded with nodular limestones and shales of lithofacies 3 (section RC-2). Hammer is 34 cm long.
- d. *In situ* colony of small, hemispherical tabulate coral heads located on the top of a tempestite bed and covered by unlaminated mudstone (section RS-9). Lens cap is 55 mm in diameter.
- e. Highly-burrowed unlaminated mudstone (section RJS-4). Lens cap is 55 cm in diameter.
- f. Calcisiltite tempestite showing irregular, burrowed surface (section RPR-13). Hammer is 34 cm long.



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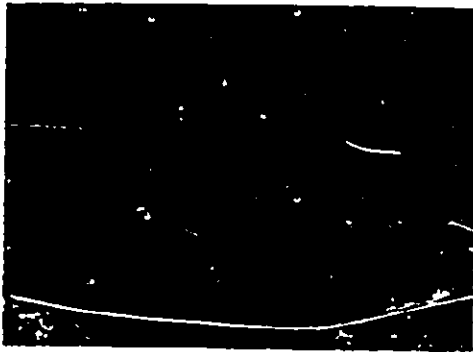
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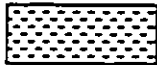
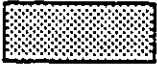
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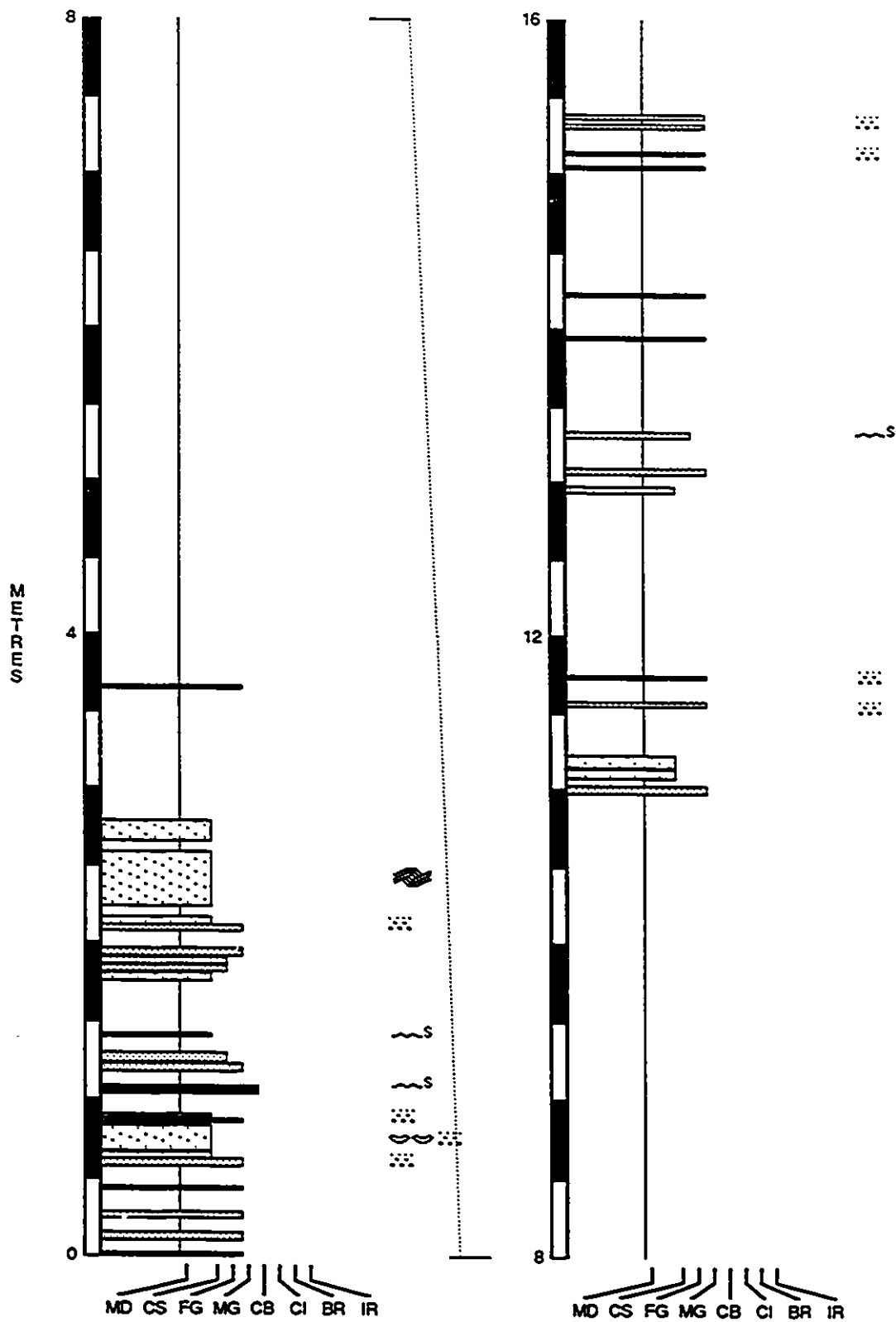


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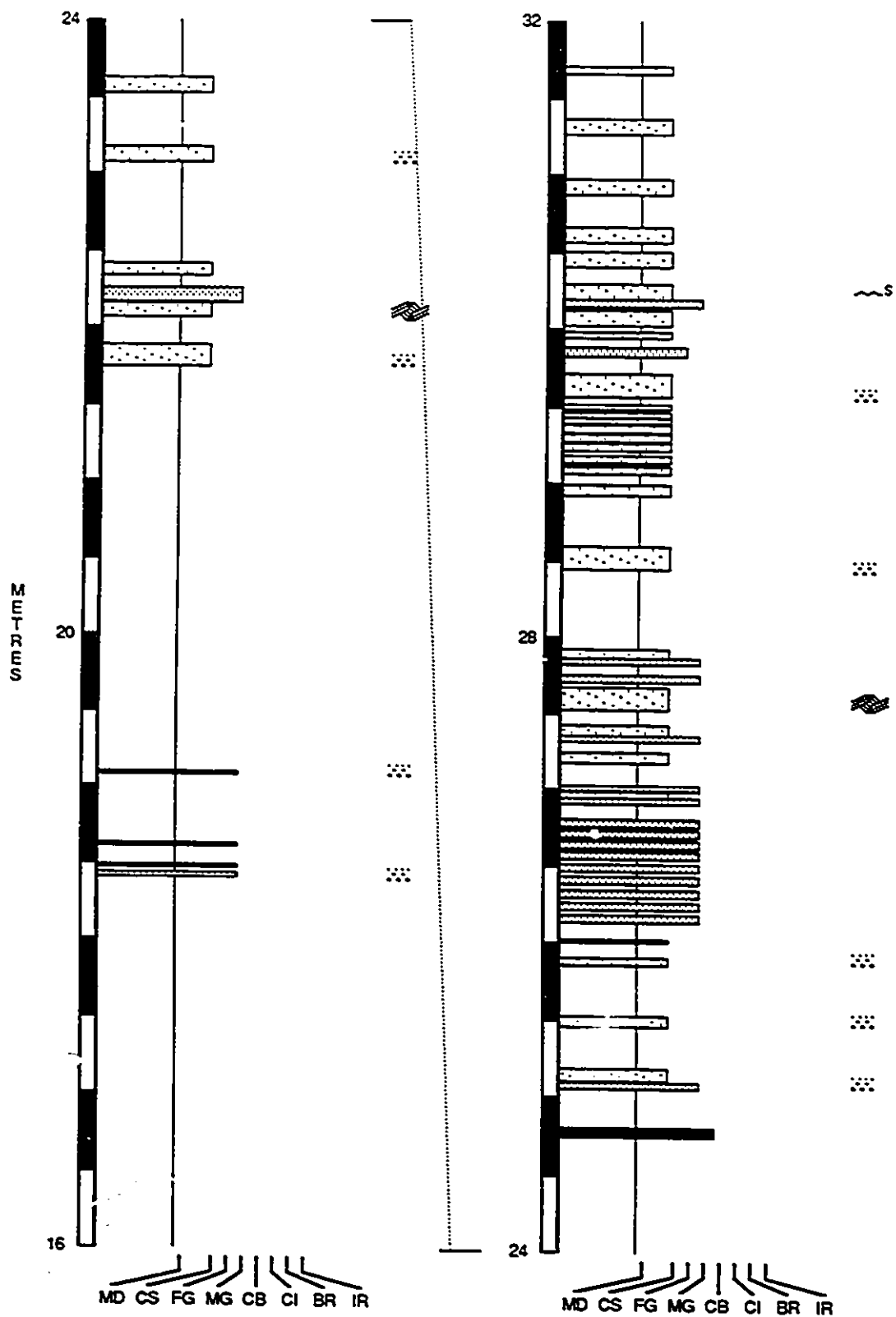
Insert A - Detailed composite stratigraphic sections

Legend

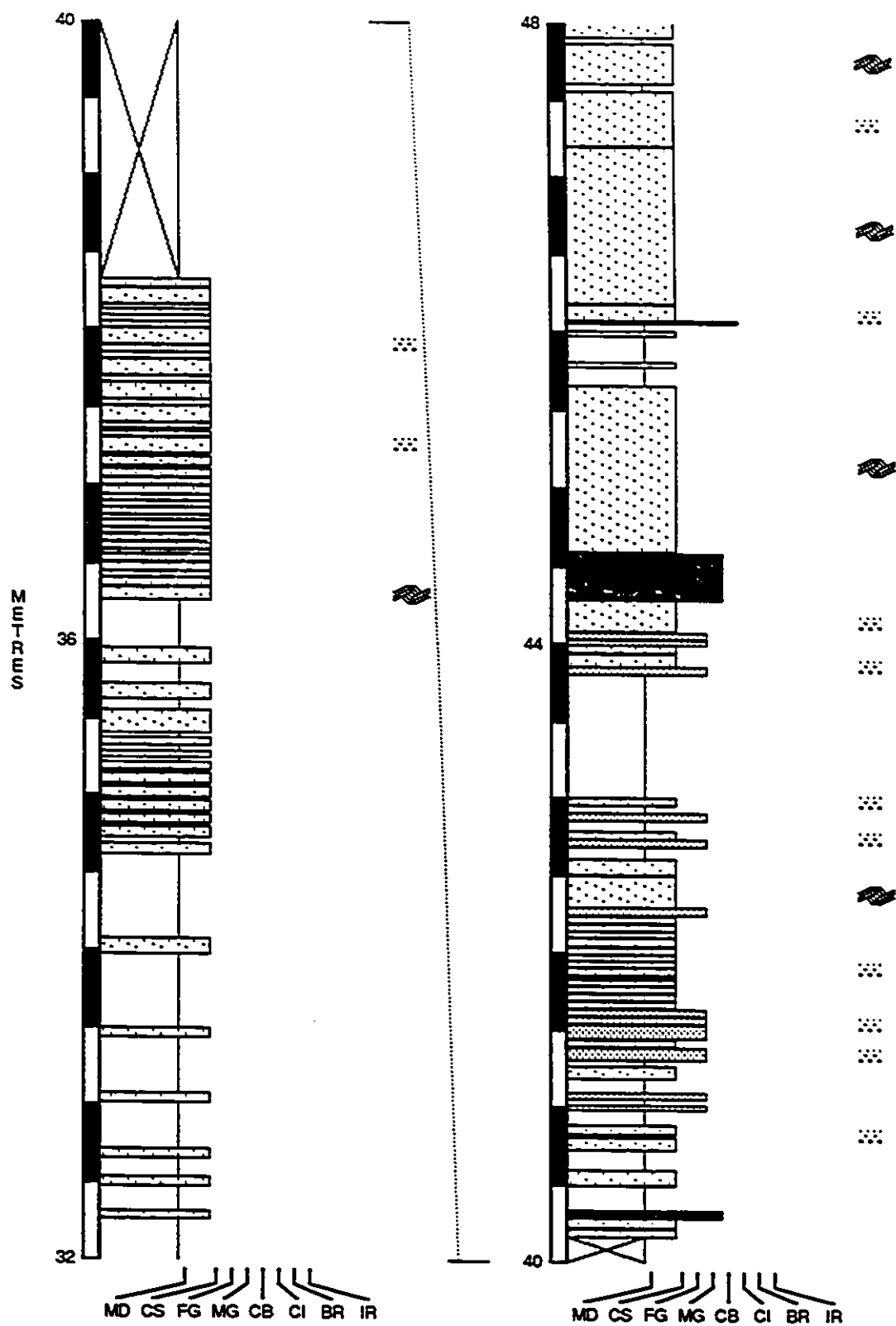
	Shale, with minor mudstone
	Irregular to nodular, shaley mudstone
	Dense to nodular mudstone with shale seams
	Laminated calcisiltite
	Medium to fine-grained grainstone
	Coarse to medium-grained grainstone
	Coarse intrabioclastic rudstone
	Amalgamated bedding contact
	Hummocky cross-stratification
	Normally-graded bedding
	Scours and/or channels
	Ball and pillow structures
	Gutters and gutter casts
	Interference ripples
	Symmetrical ripples and sand waves
	Slump beds
MD	Mudstone, shaley mudstone, and shale
CS	Laminated calcisiltite
FG	Fine-grained grainstone
MG	Medium-grained grainstone
CB	Coarse-grained bioclastic grainstone
CI	Coarse-grained intraclastic grainstone
BR	Bioclastic rudstone
IR	Intraclastic rudstone



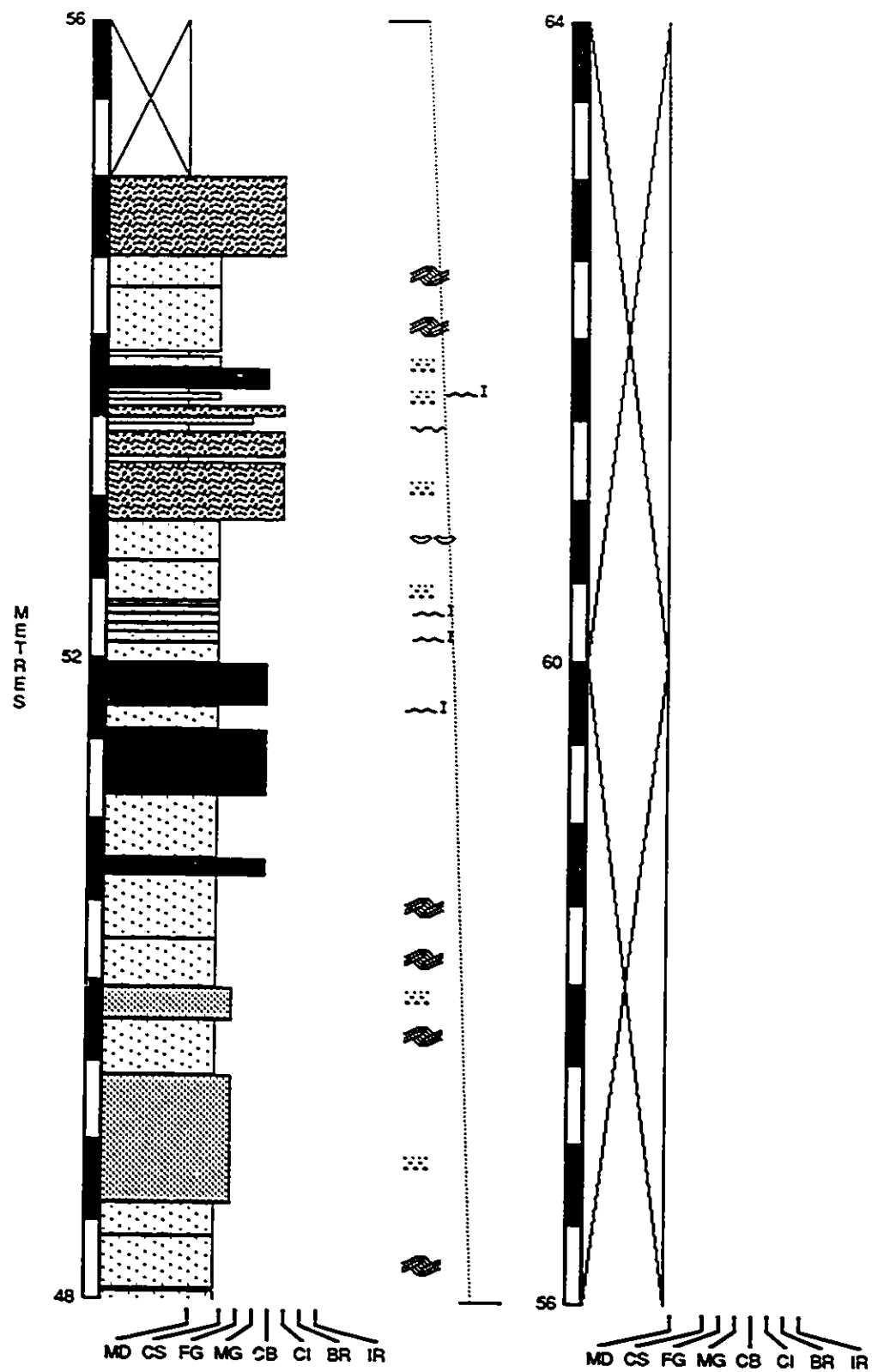
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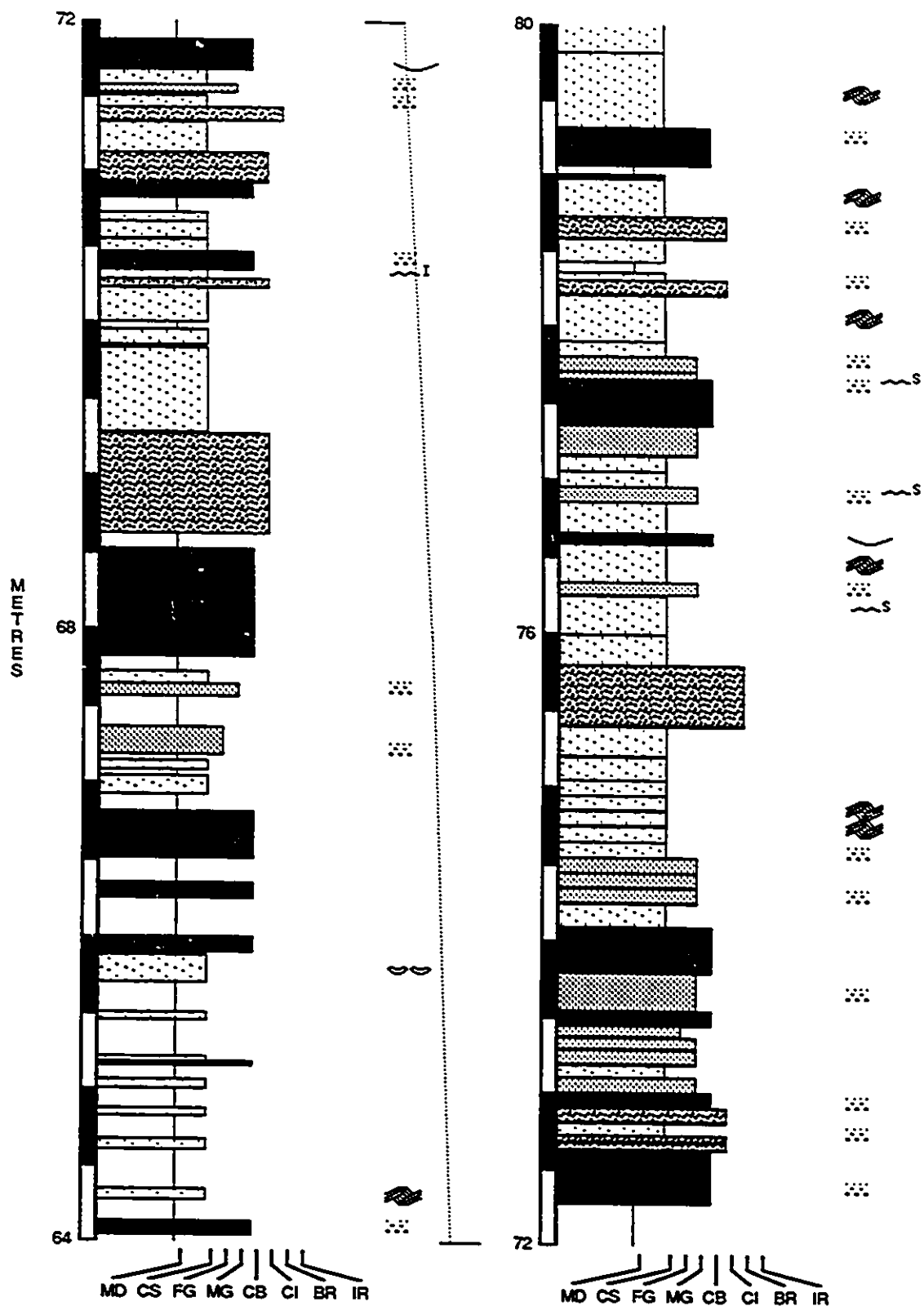
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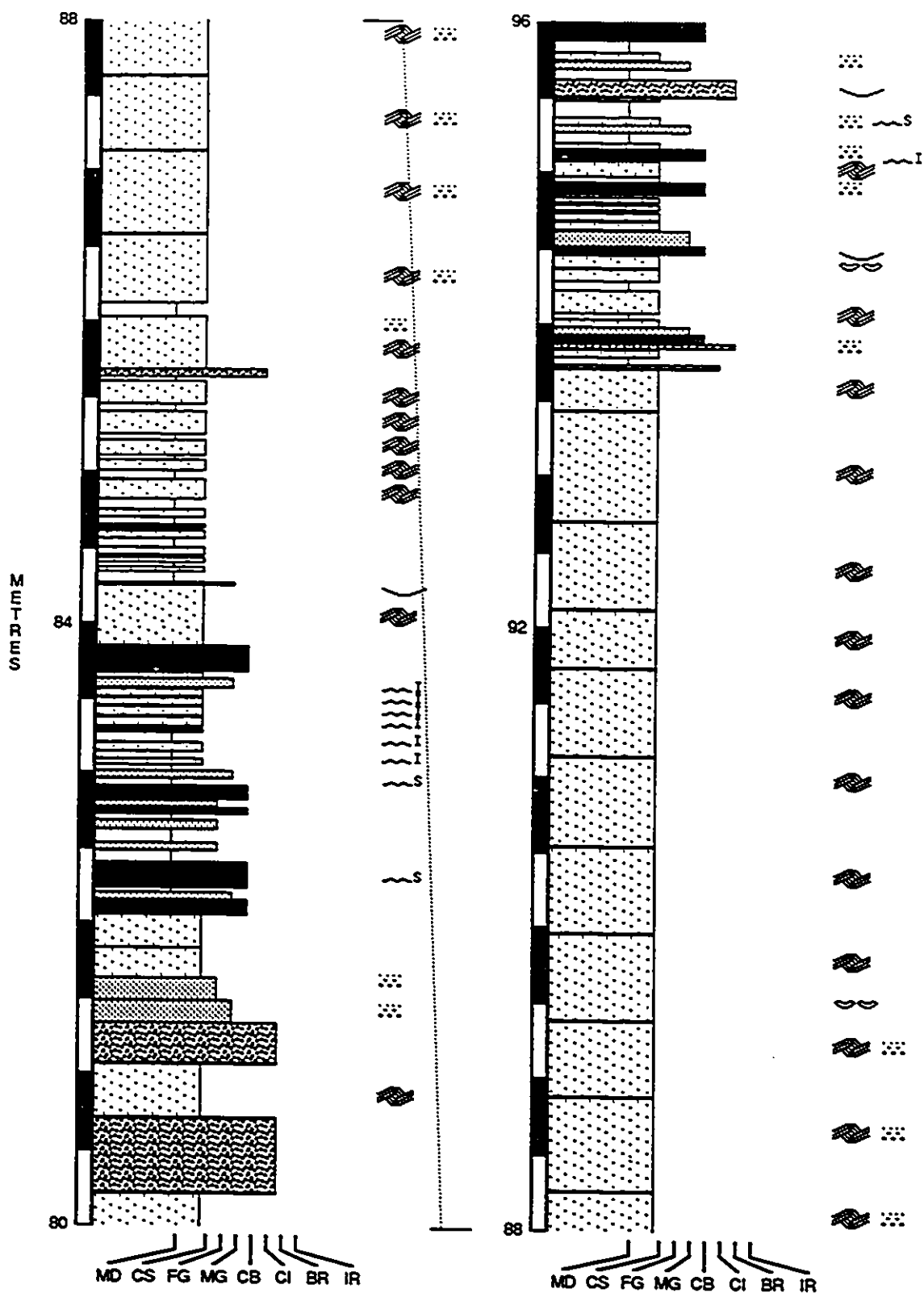


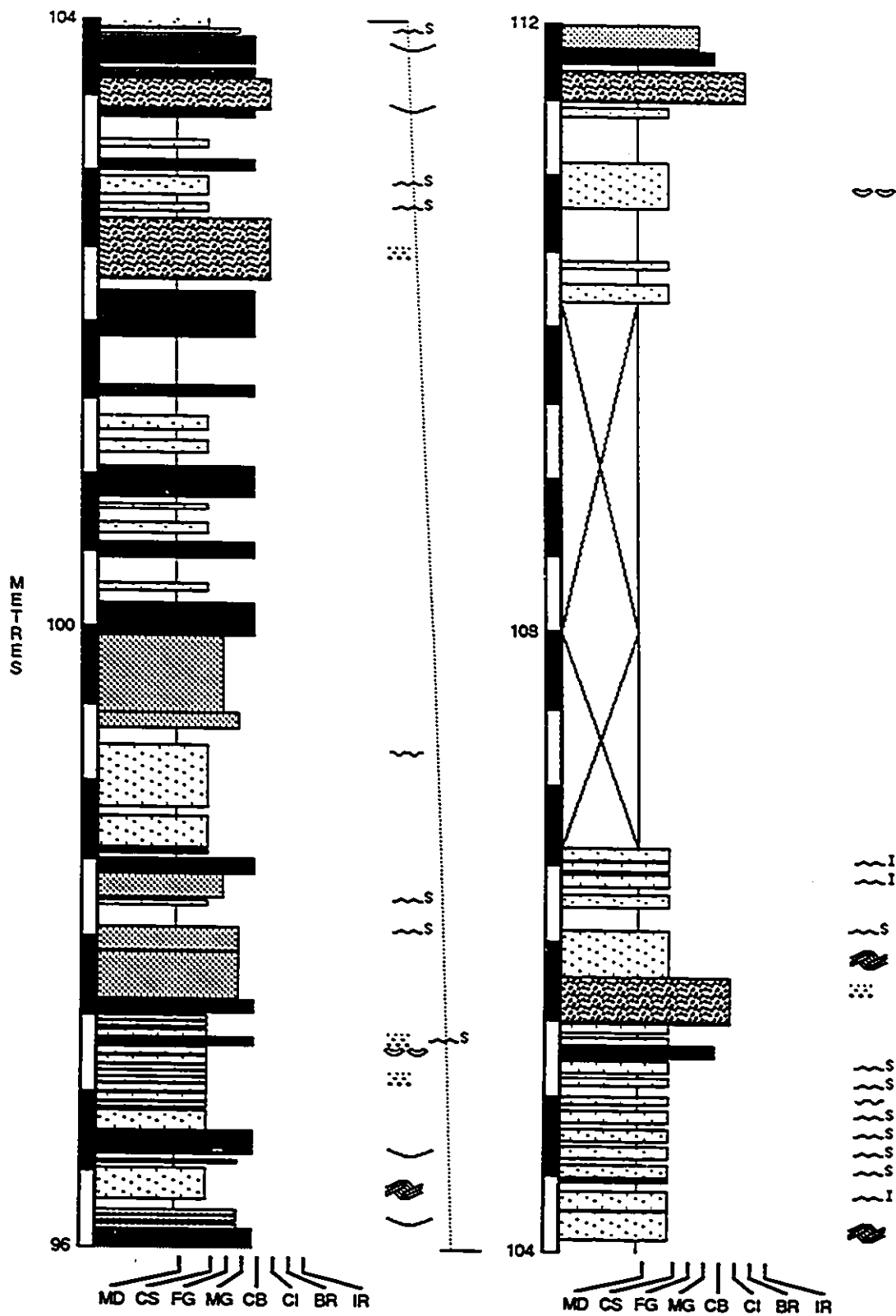
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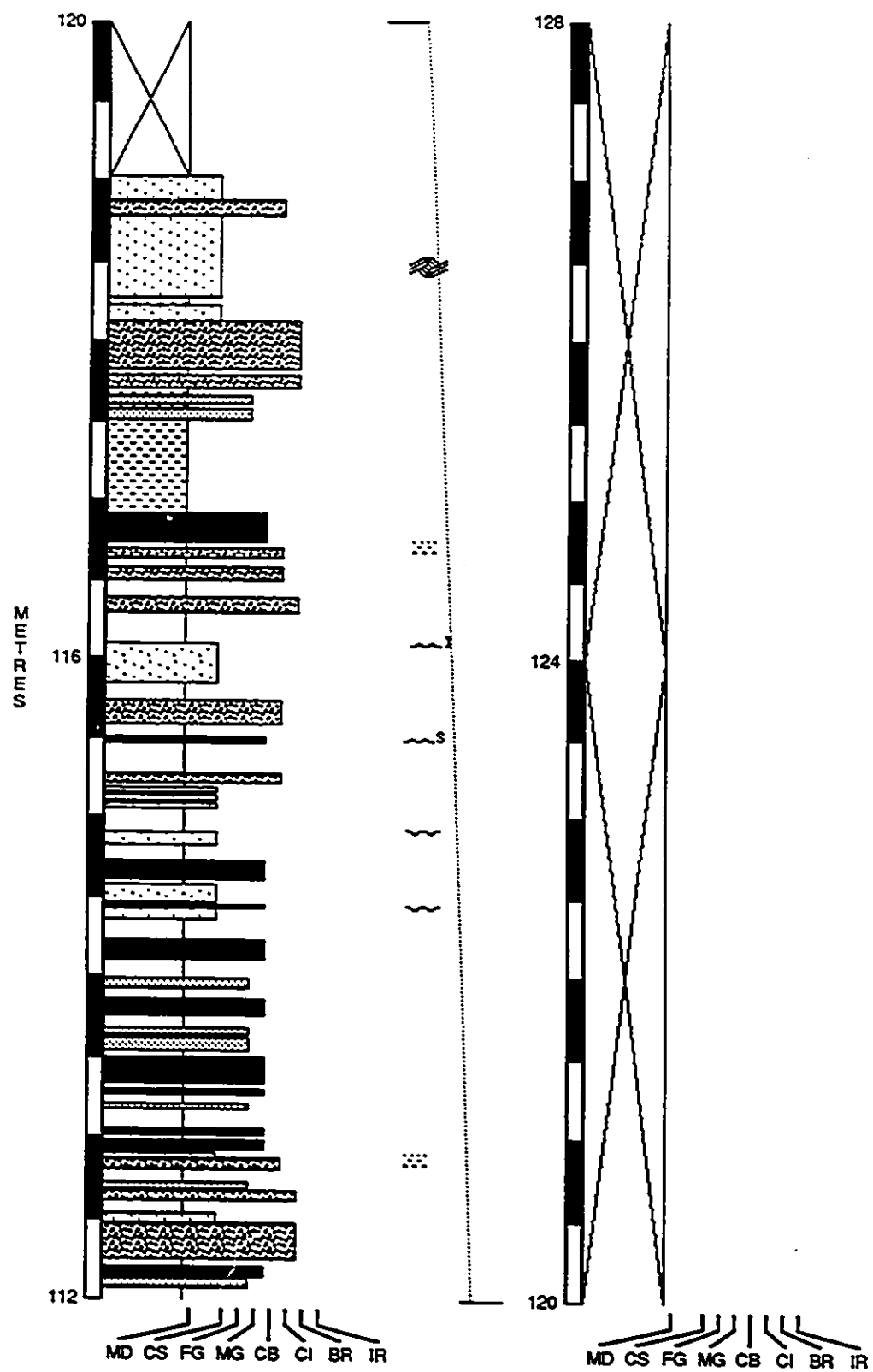
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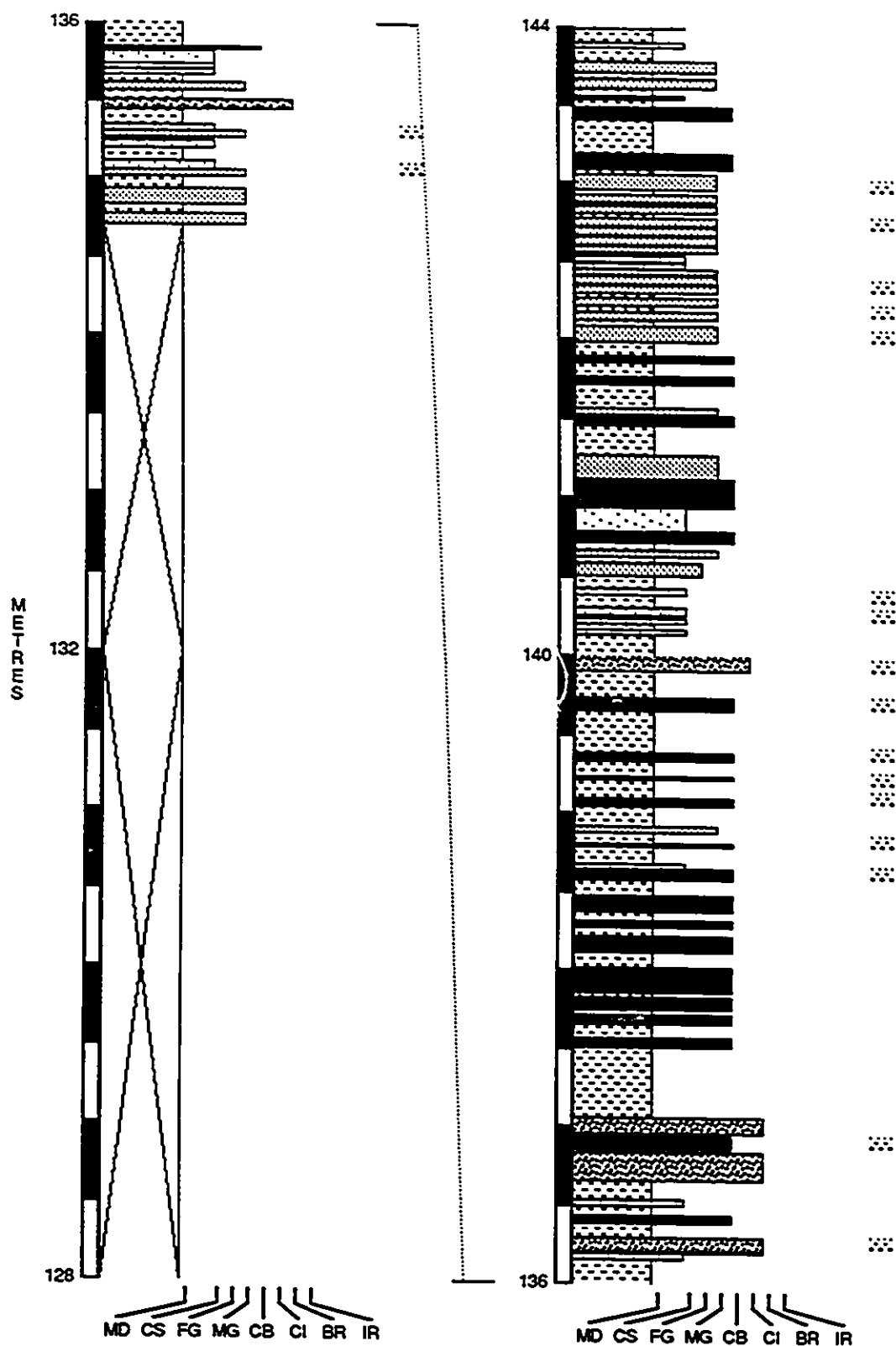




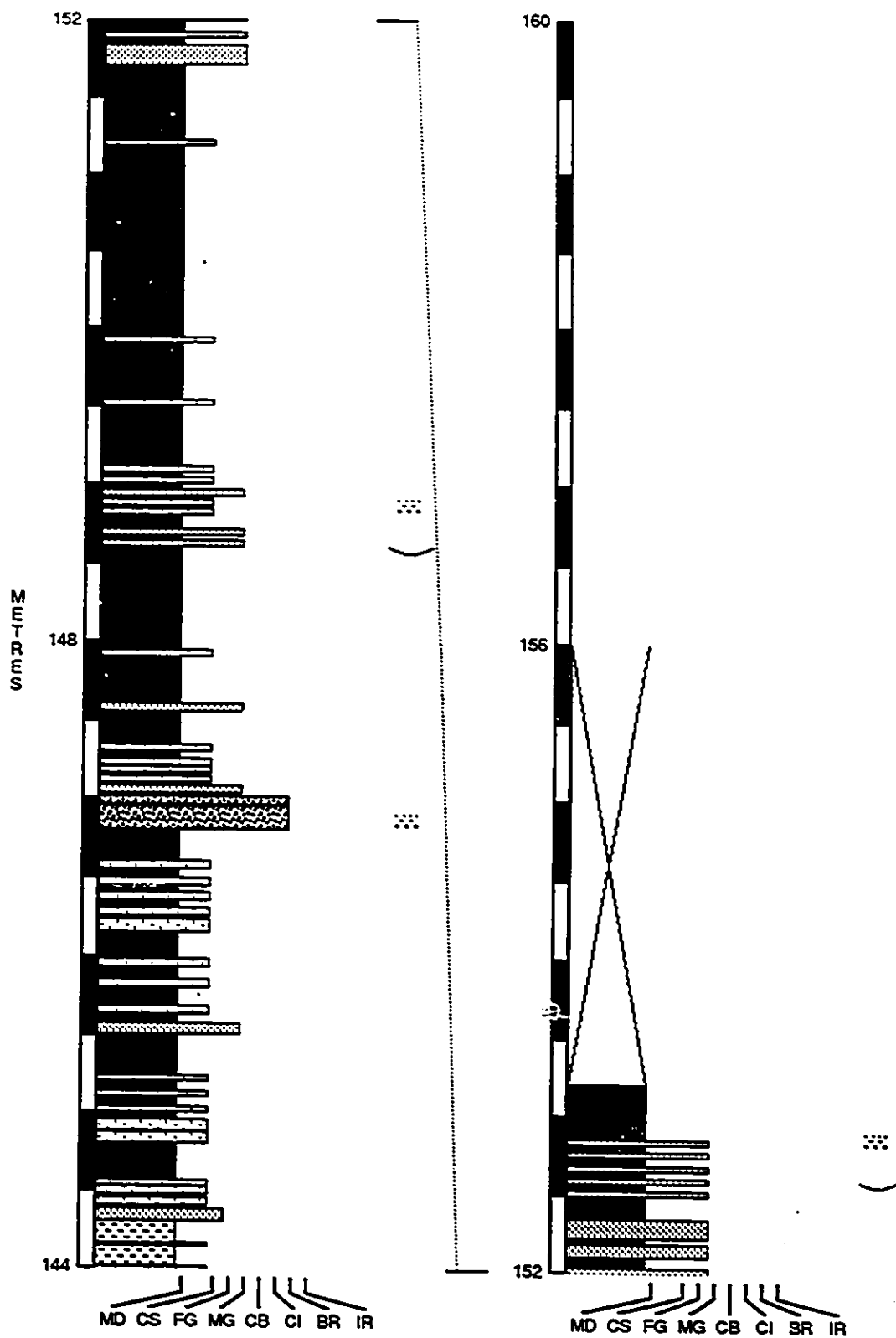
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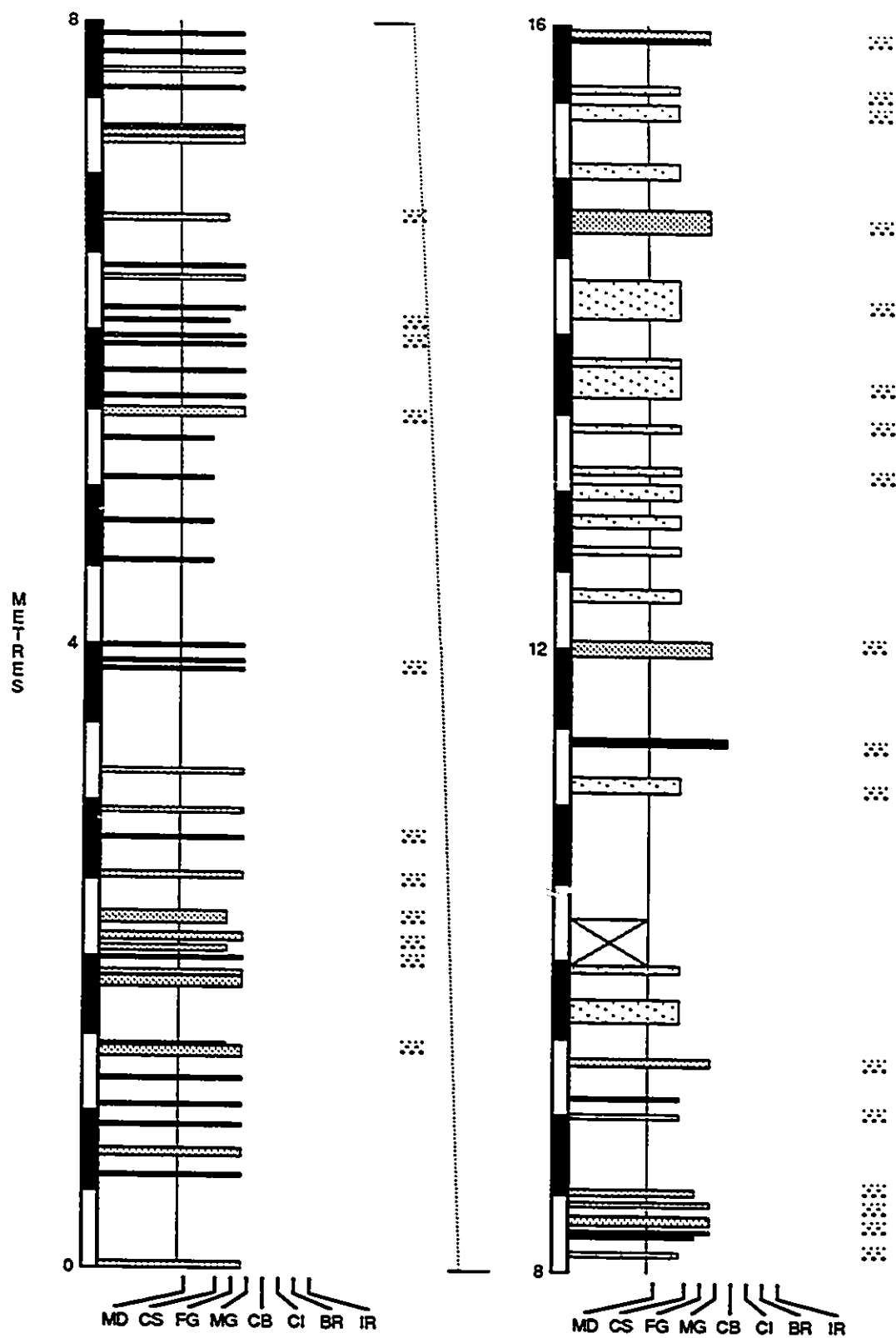
Cap Henri to R. aux Cailloux composite section



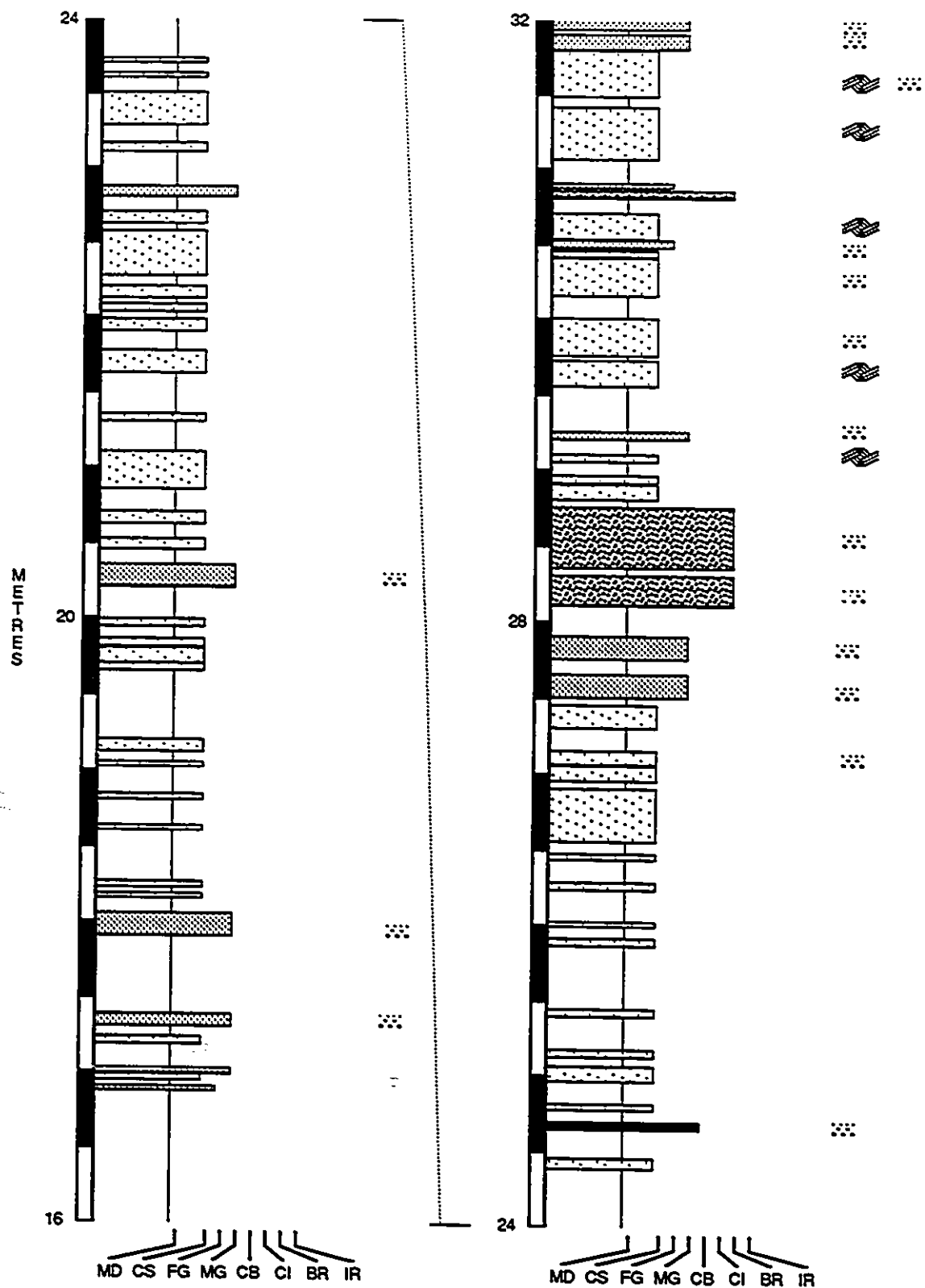
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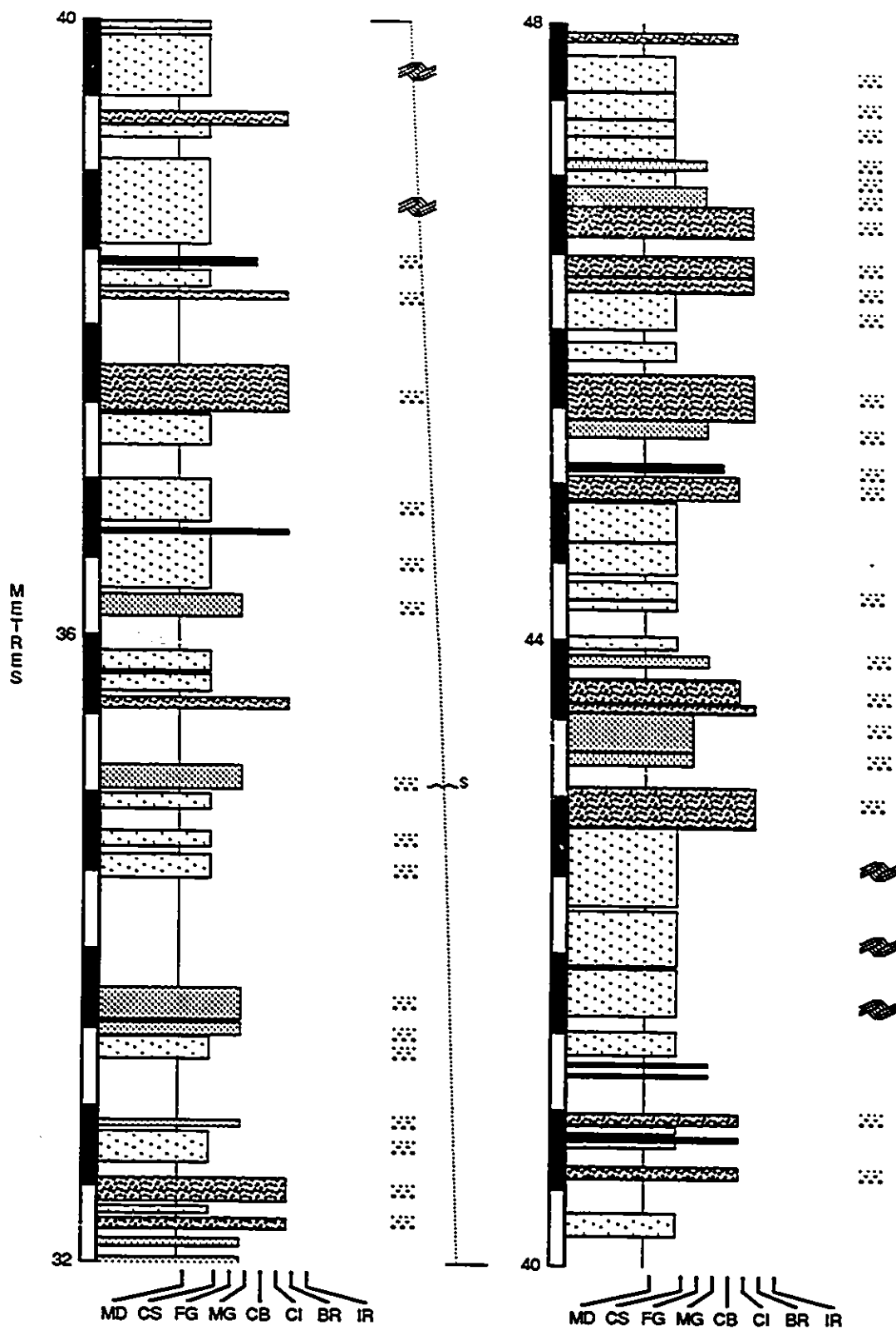
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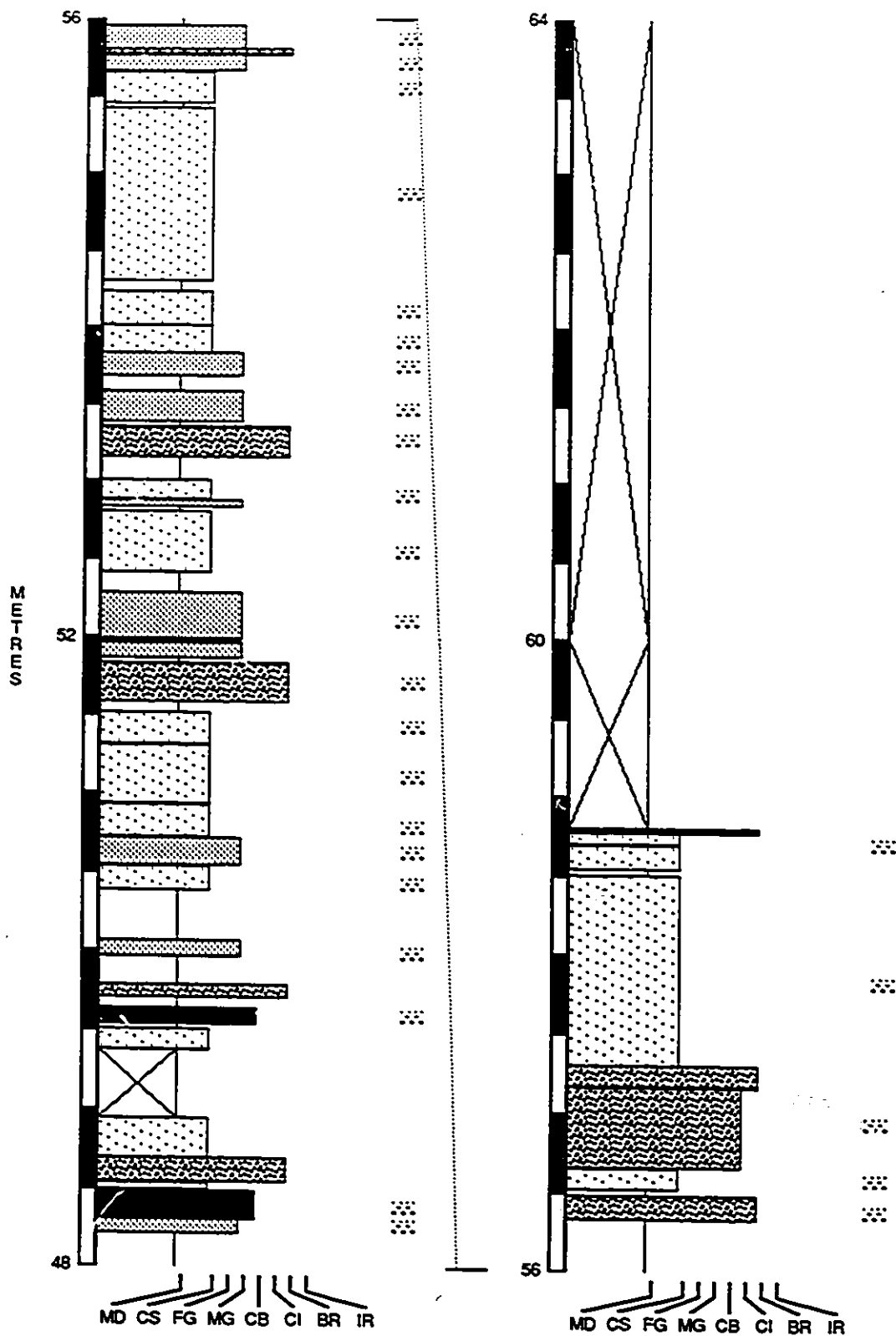
R. Jupiter composite section



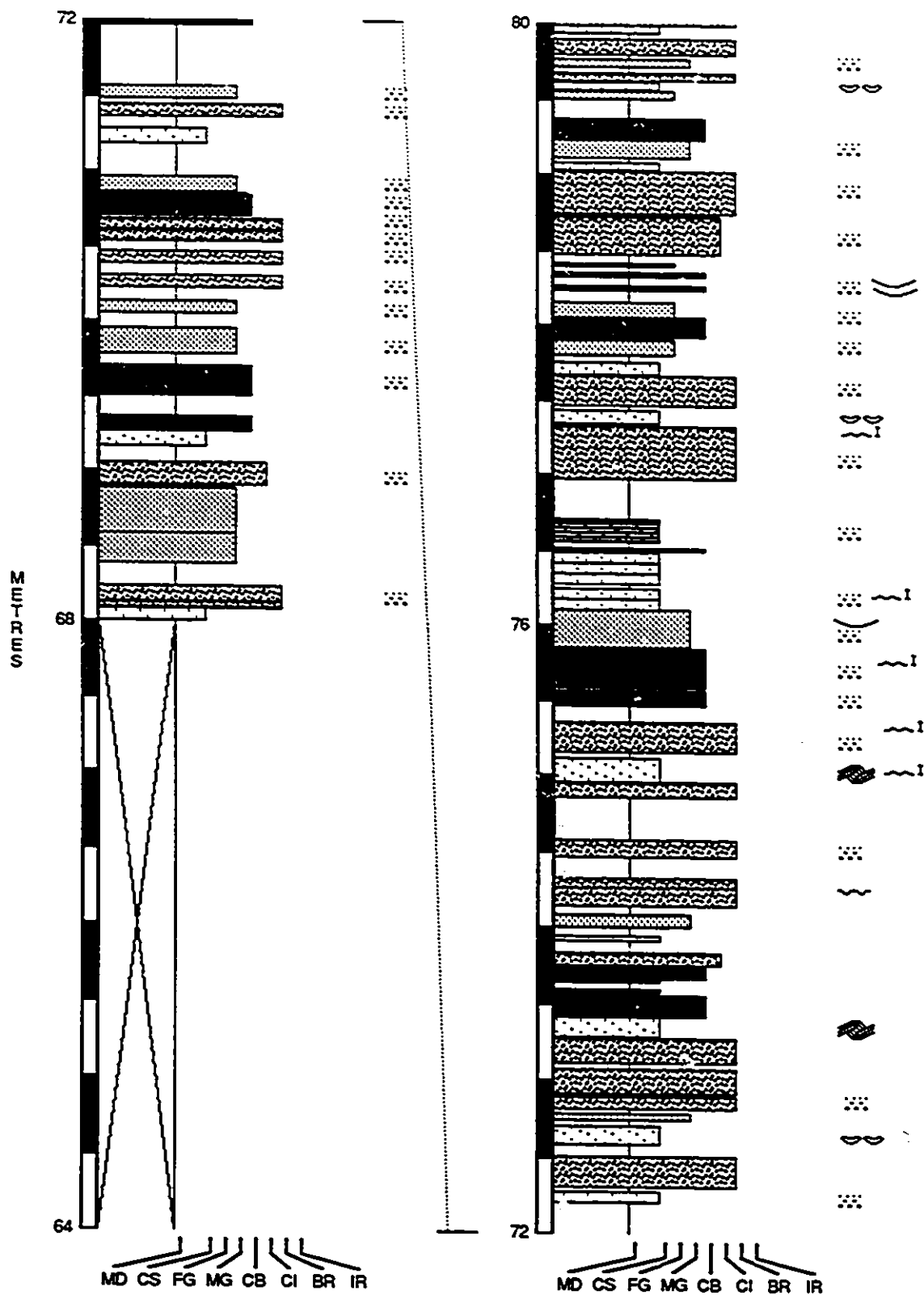
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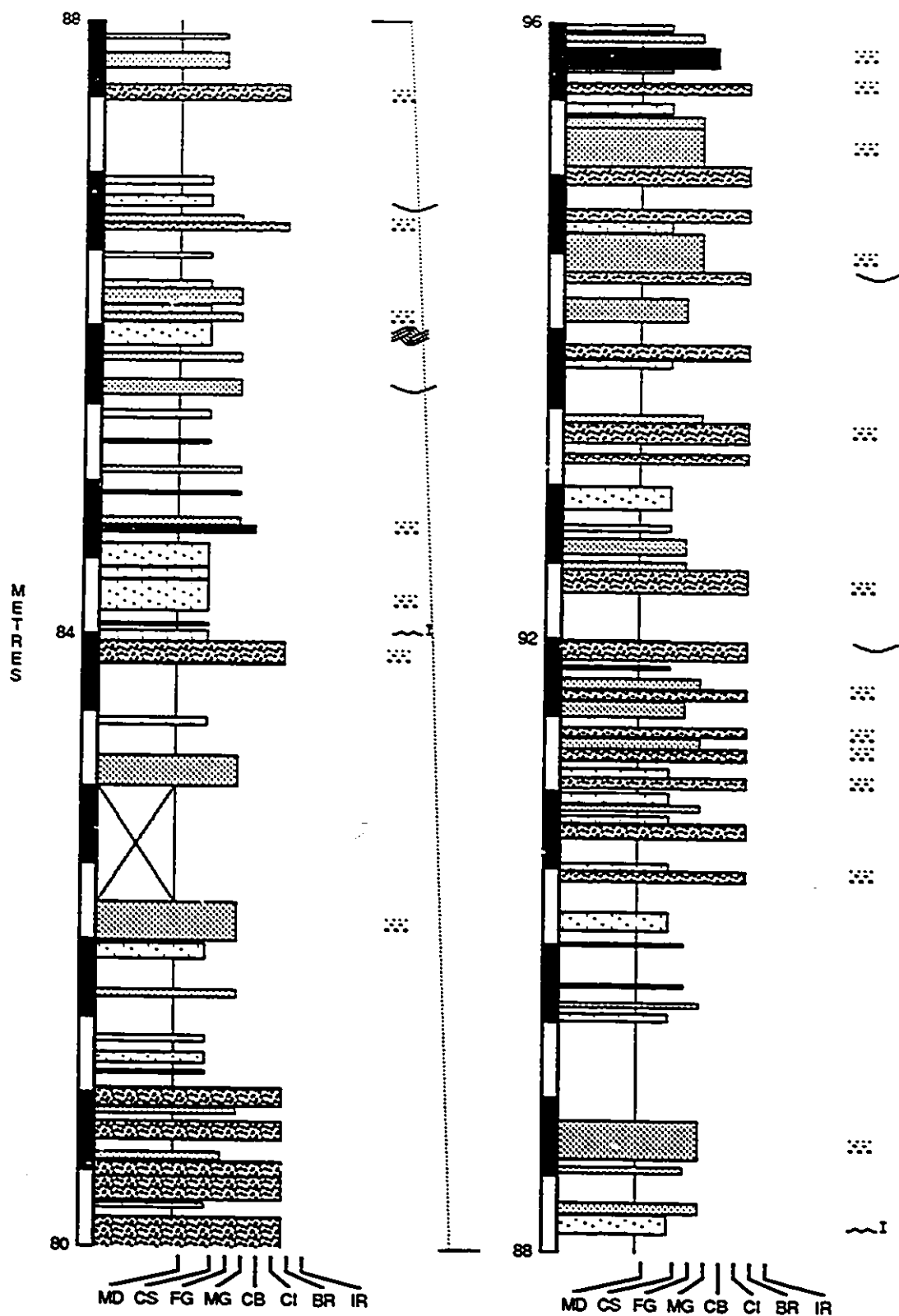
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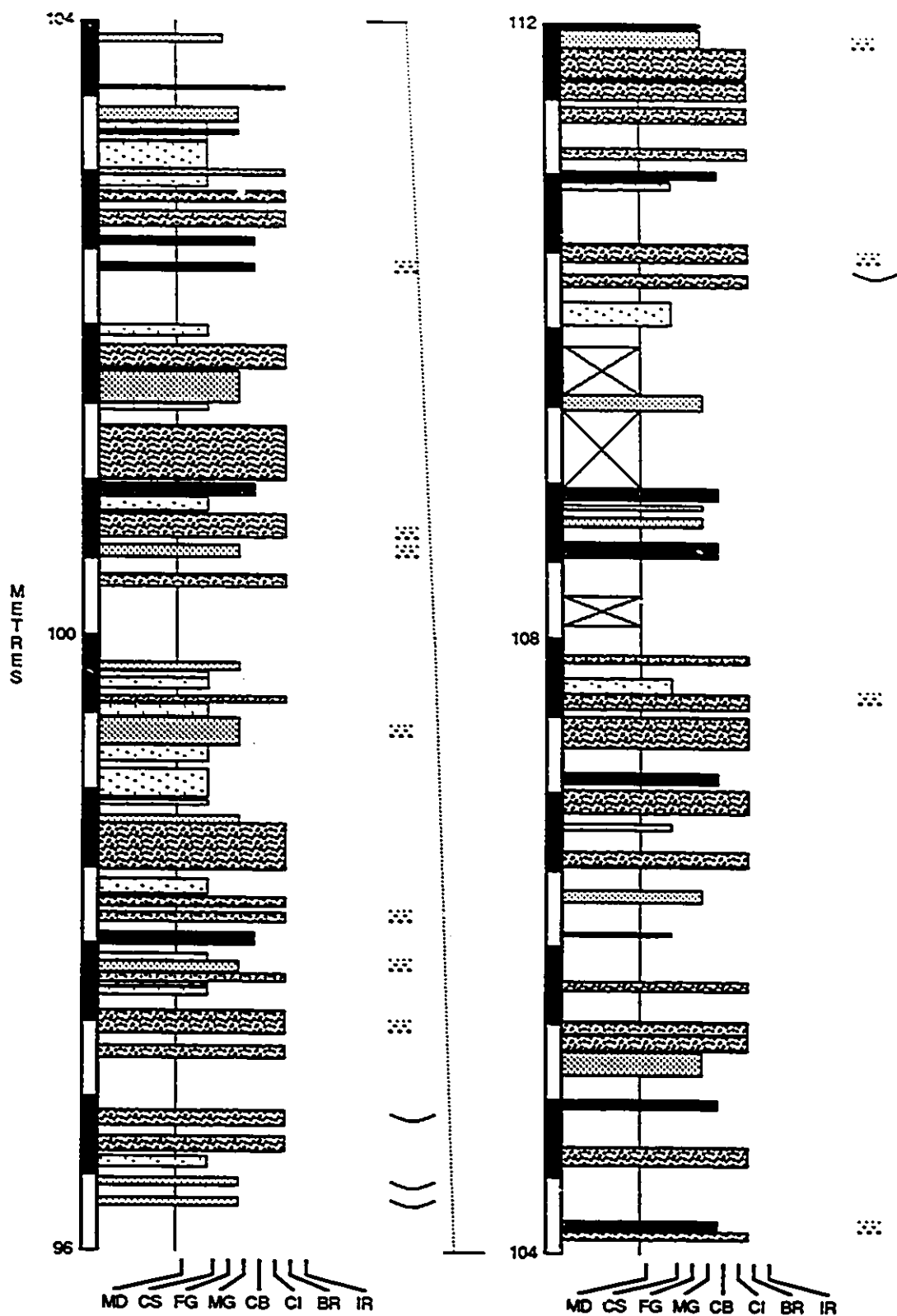
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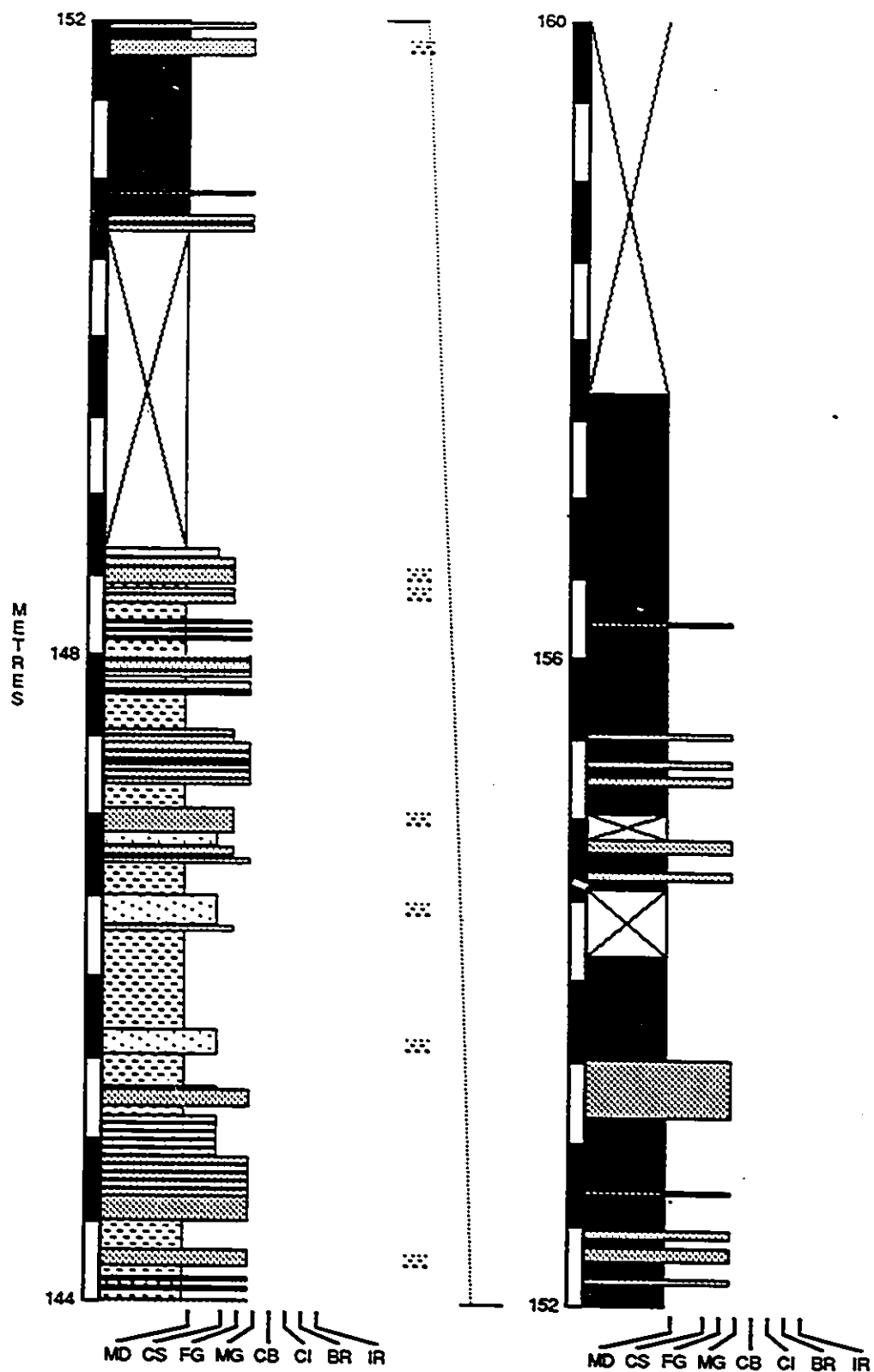
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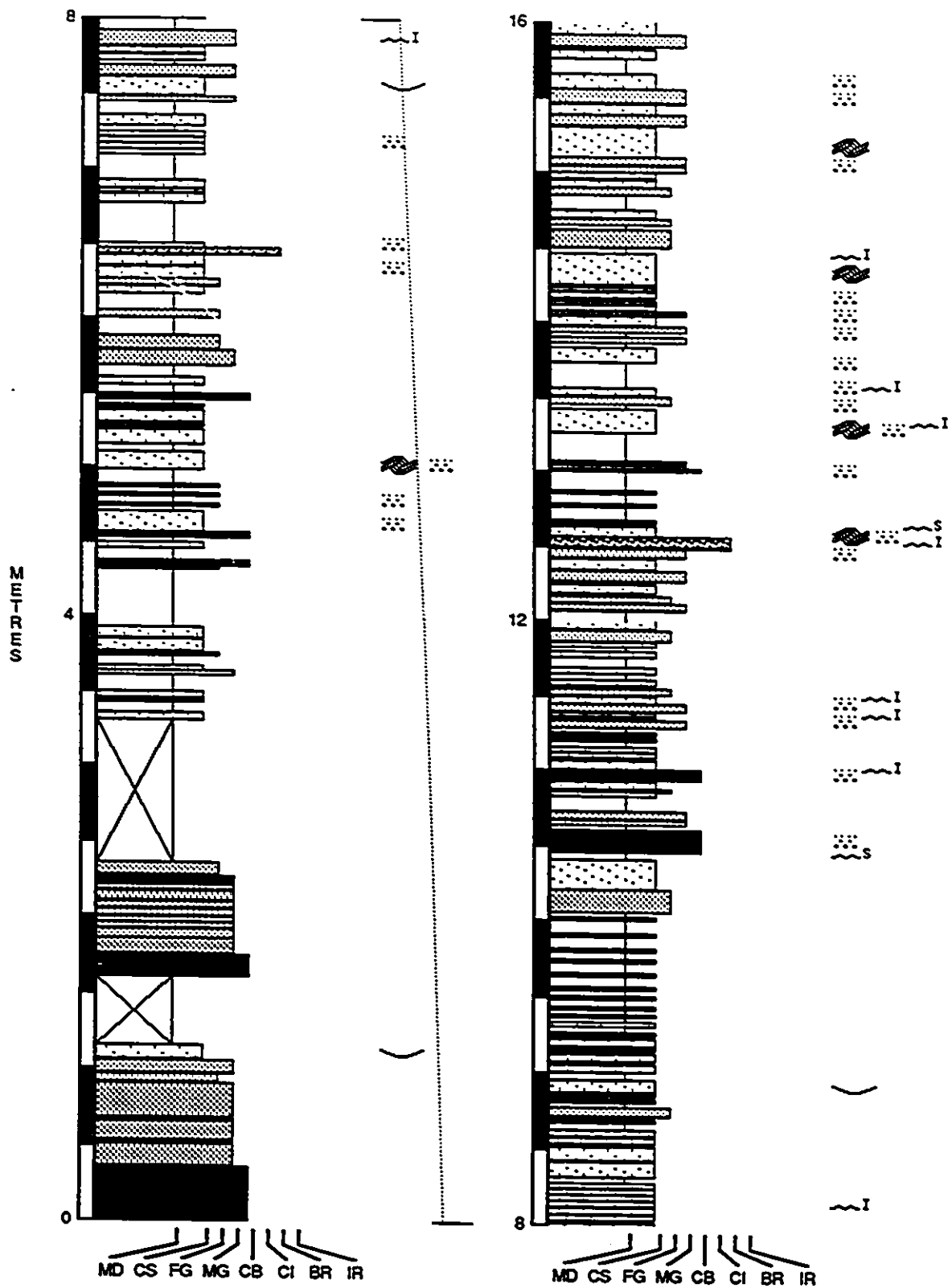
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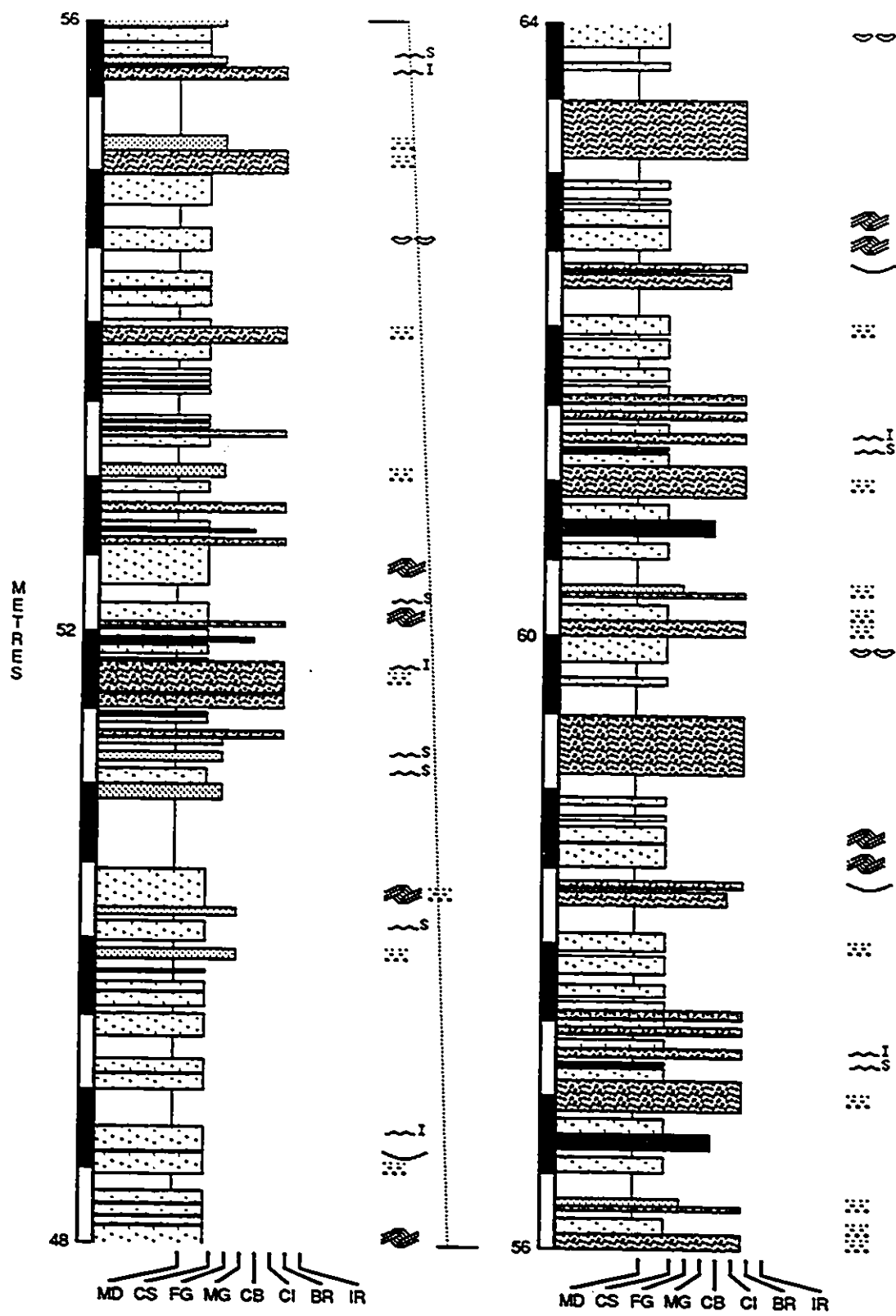
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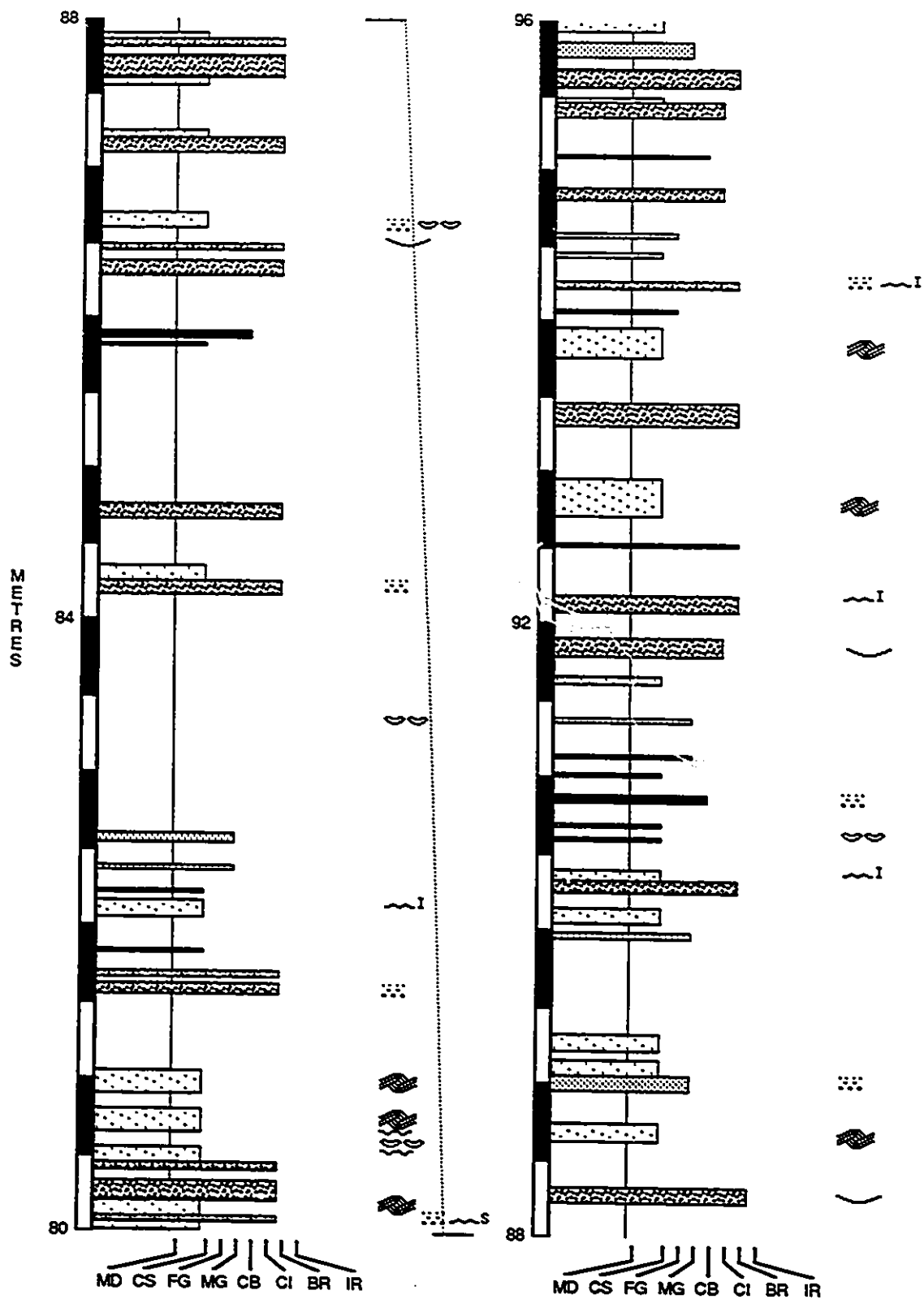
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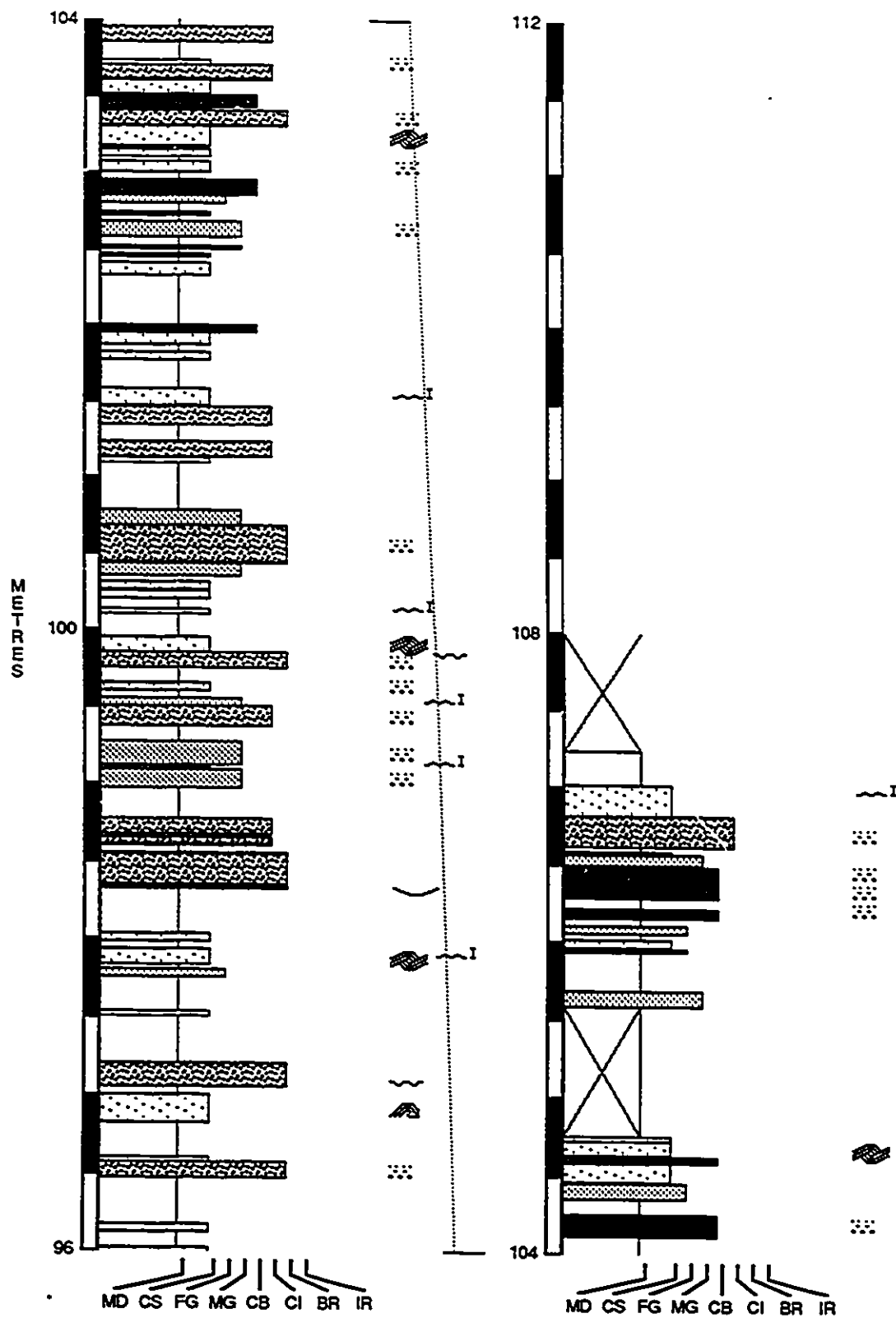
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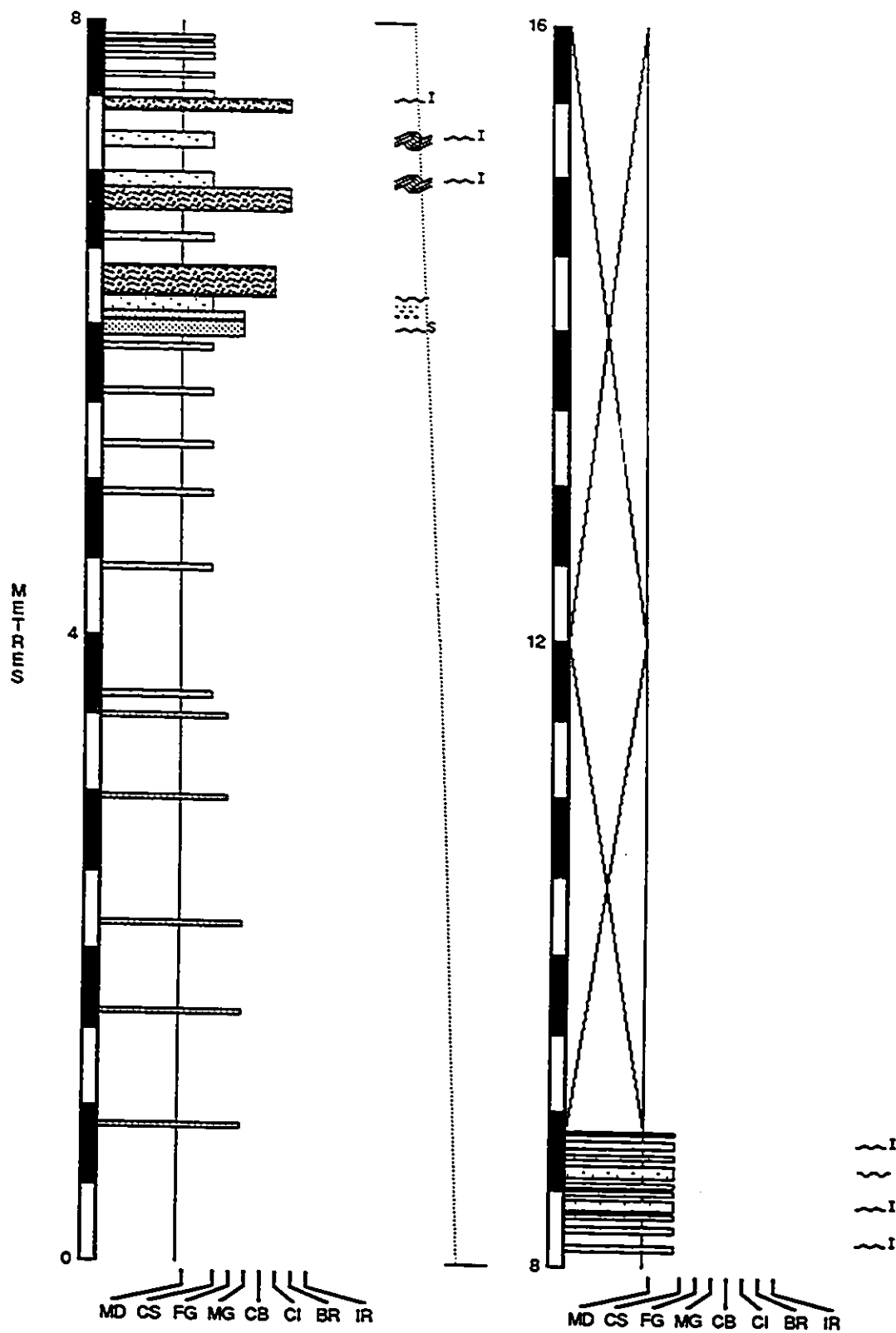
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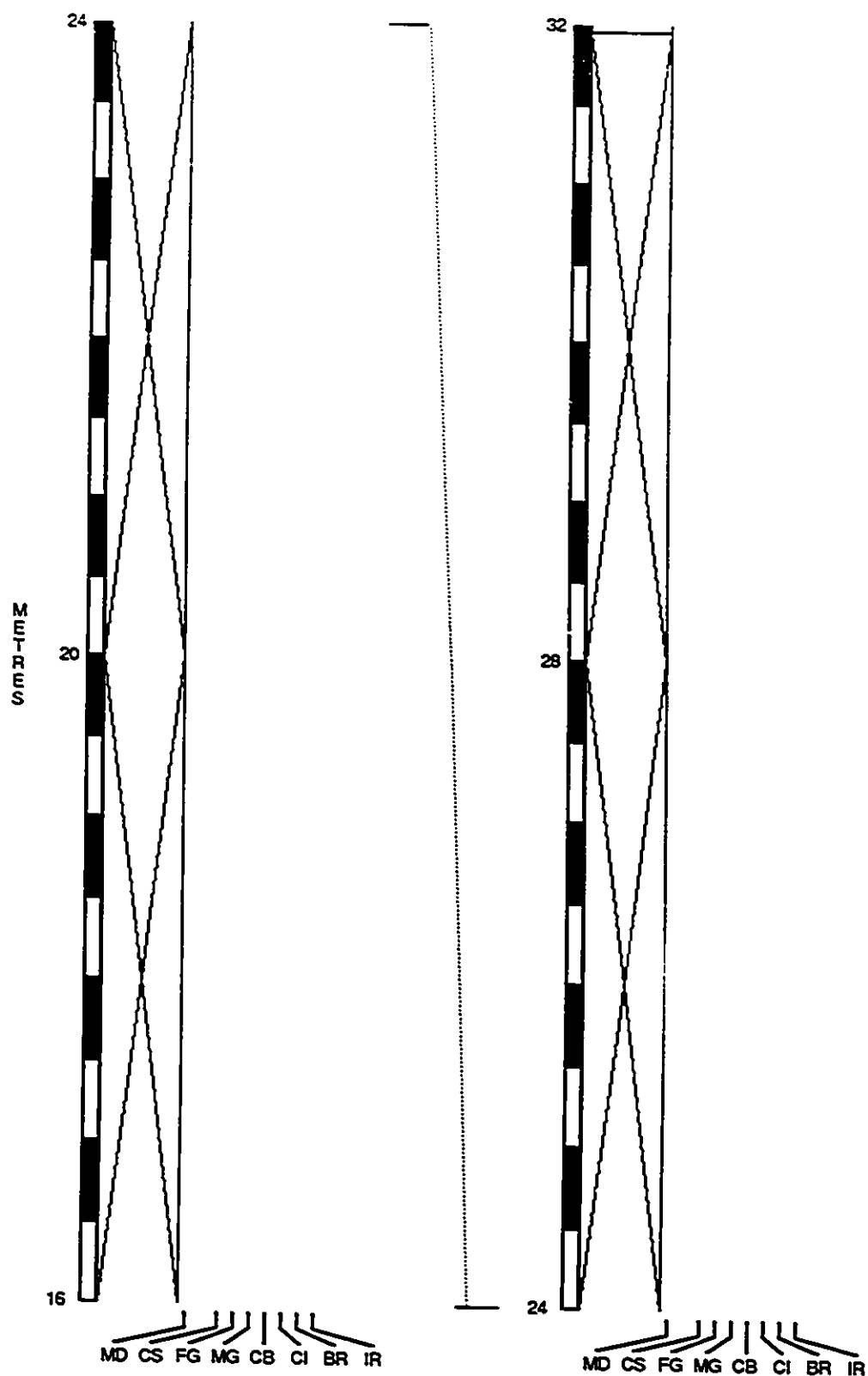
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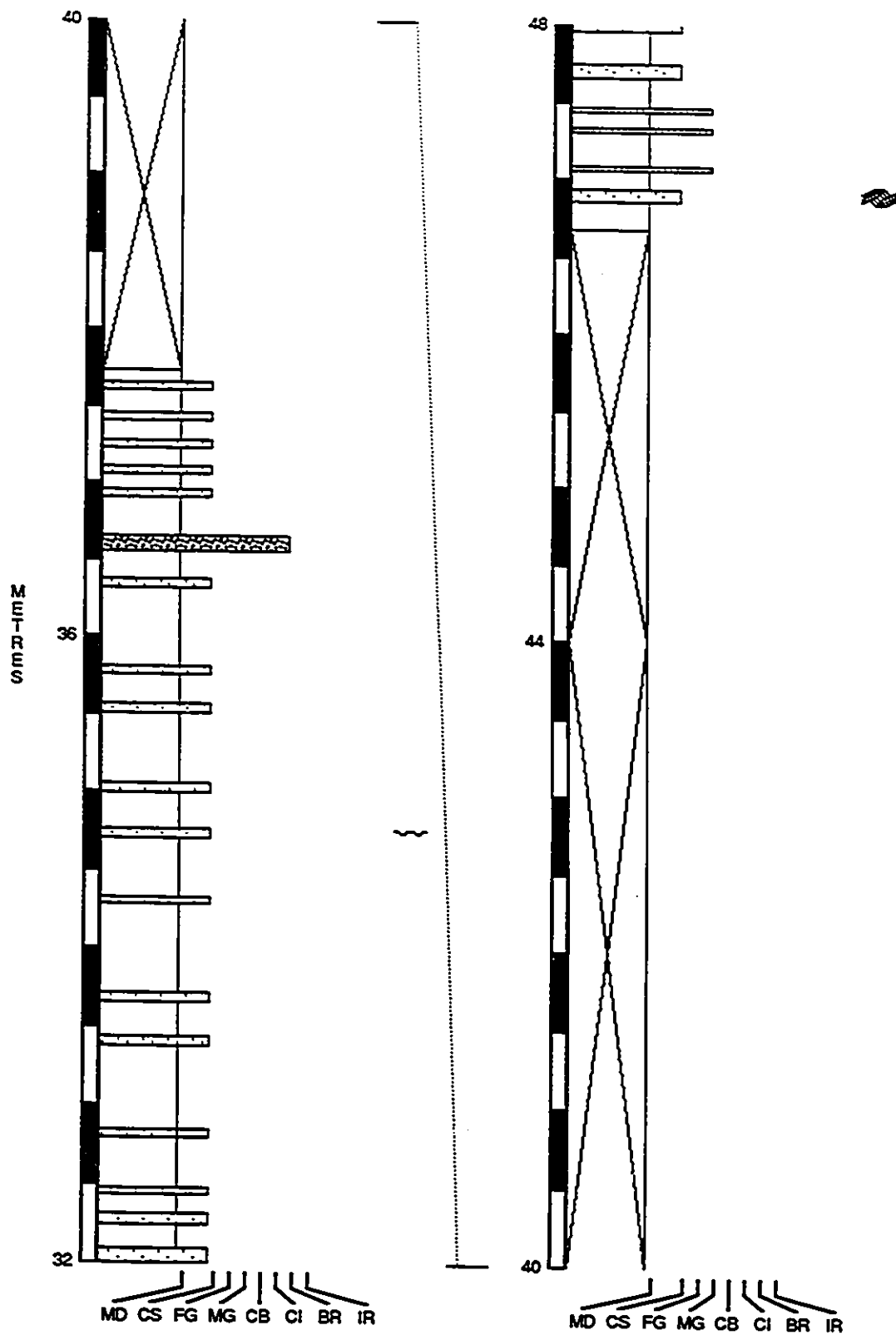
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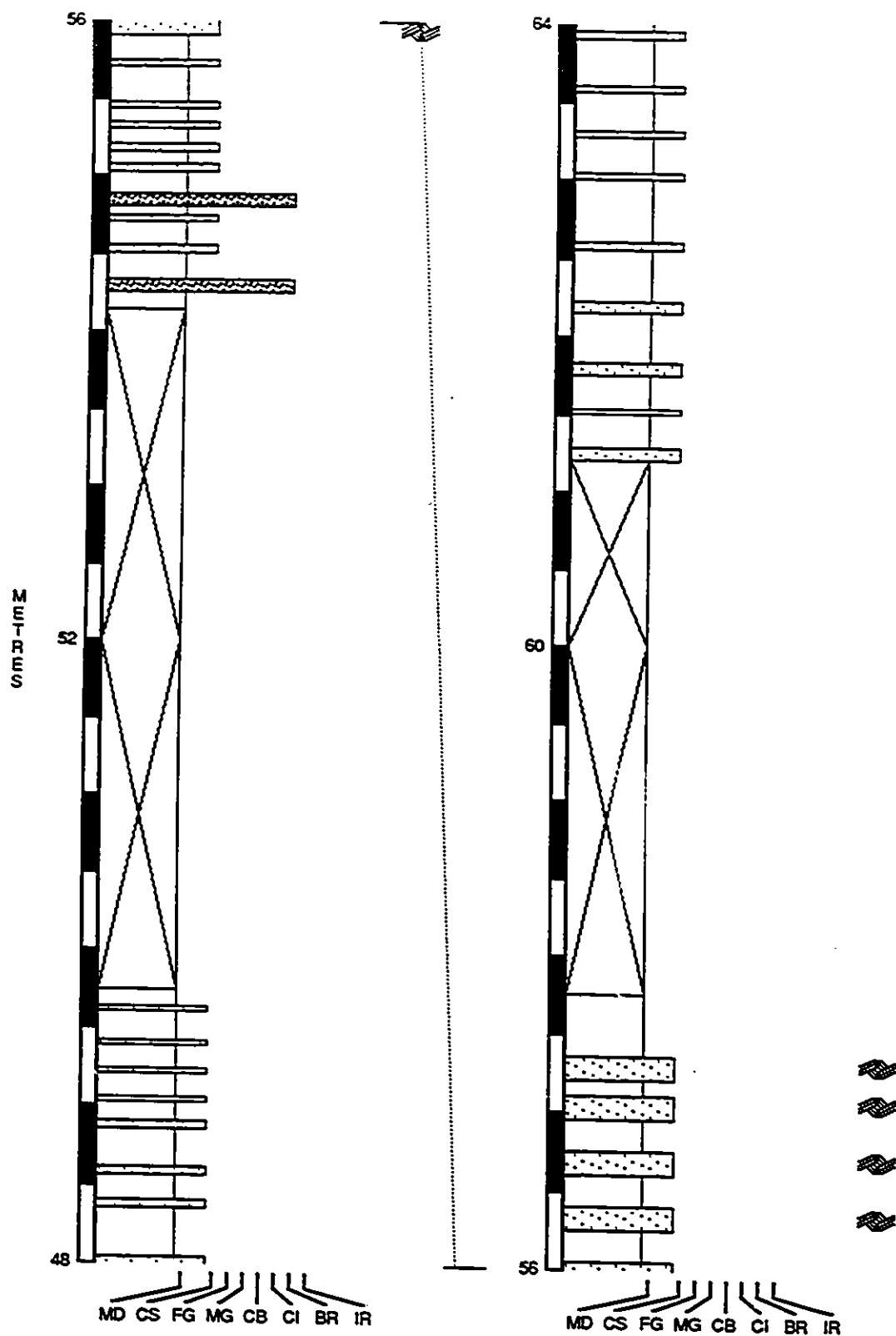
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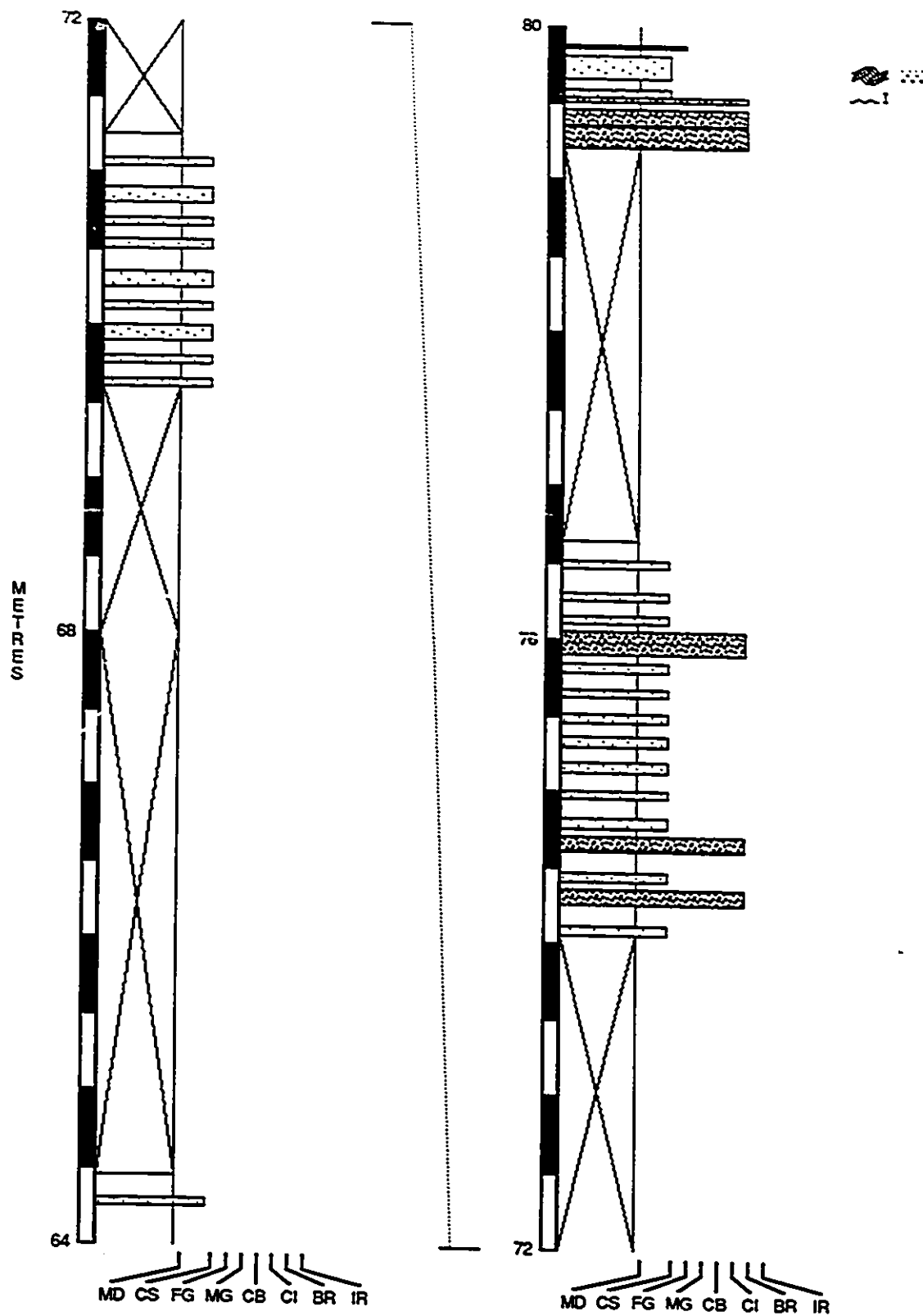
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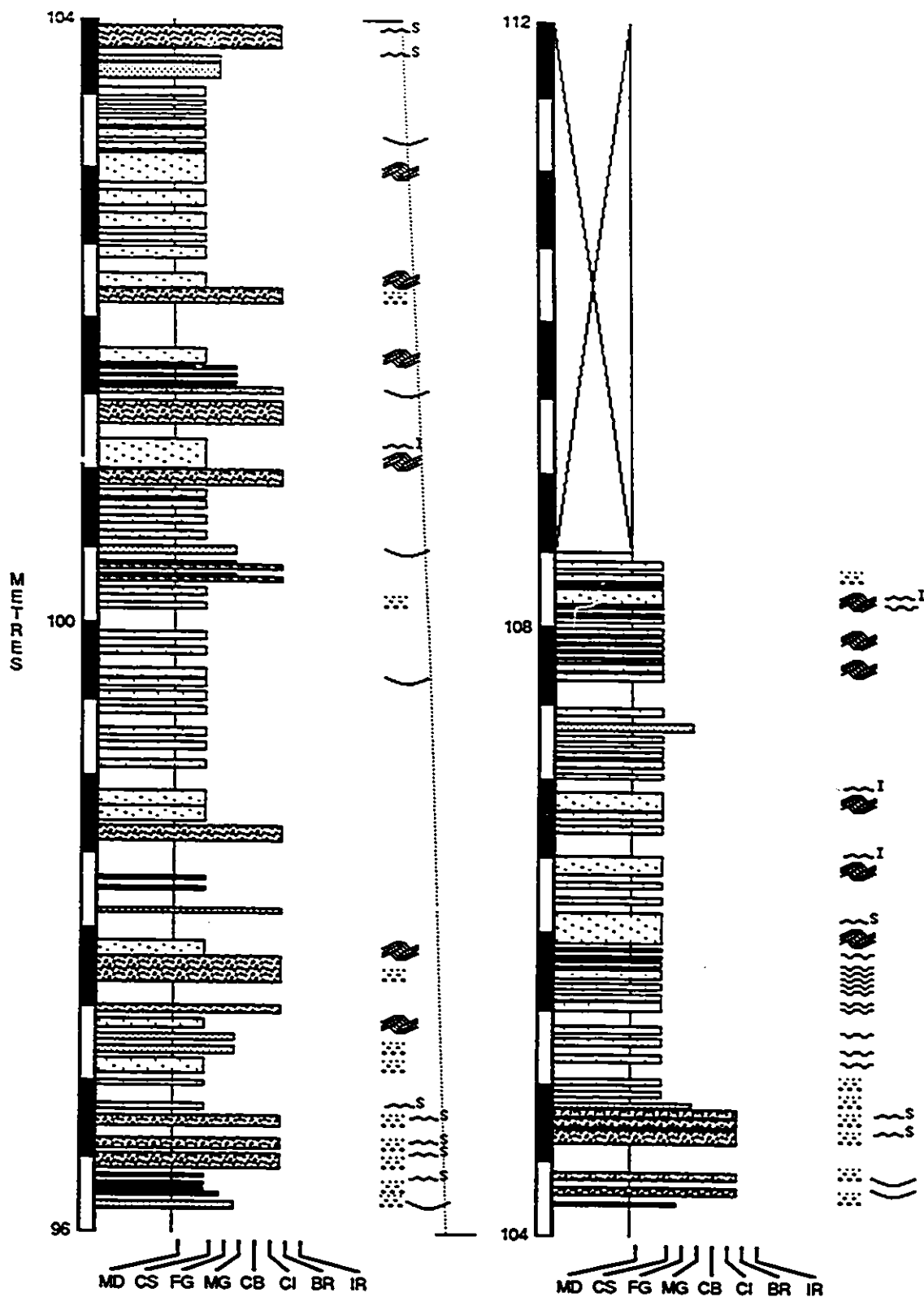
R. Prinista to Reef Point composite section



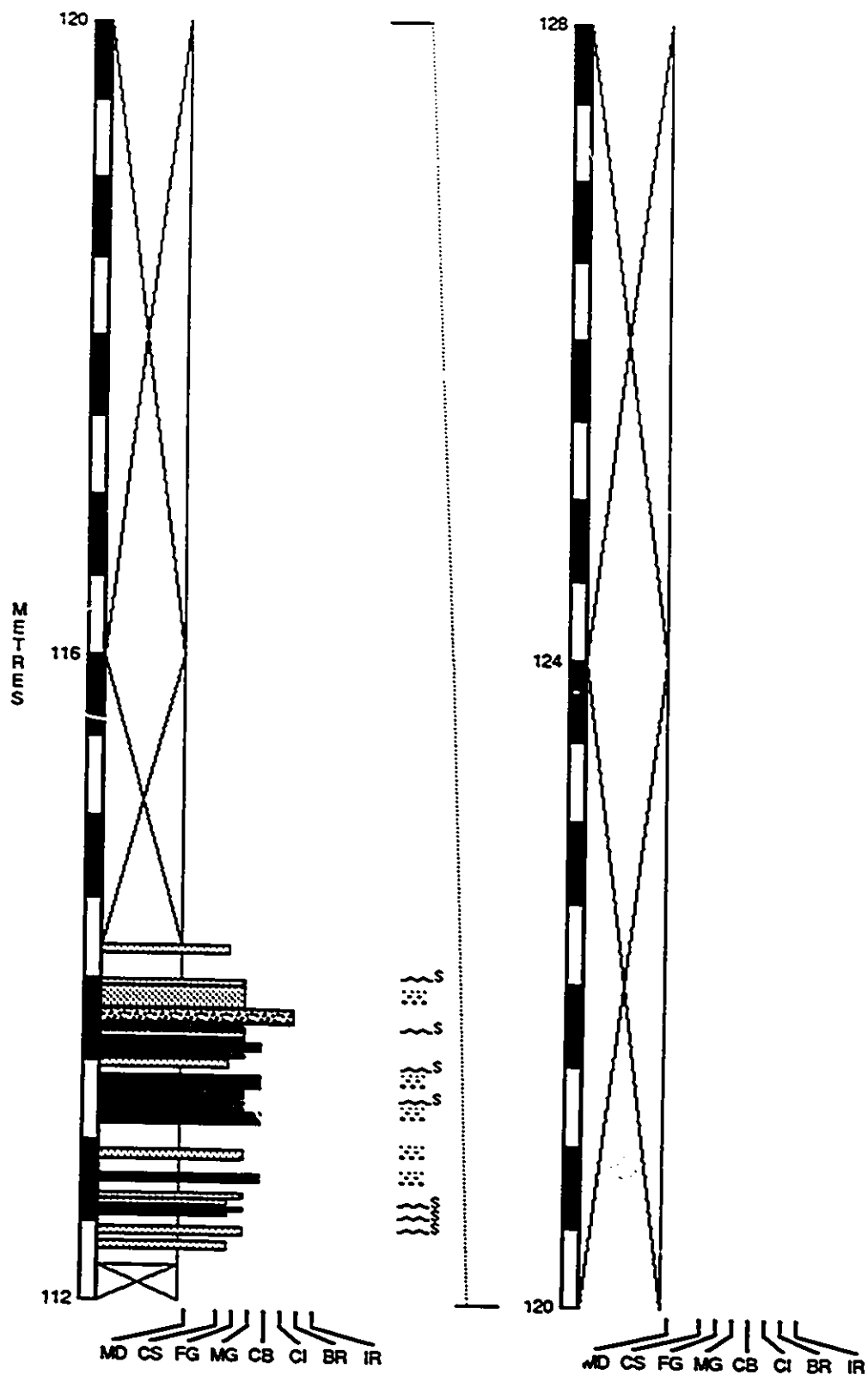
R. Prinsta to Reef Point composite section



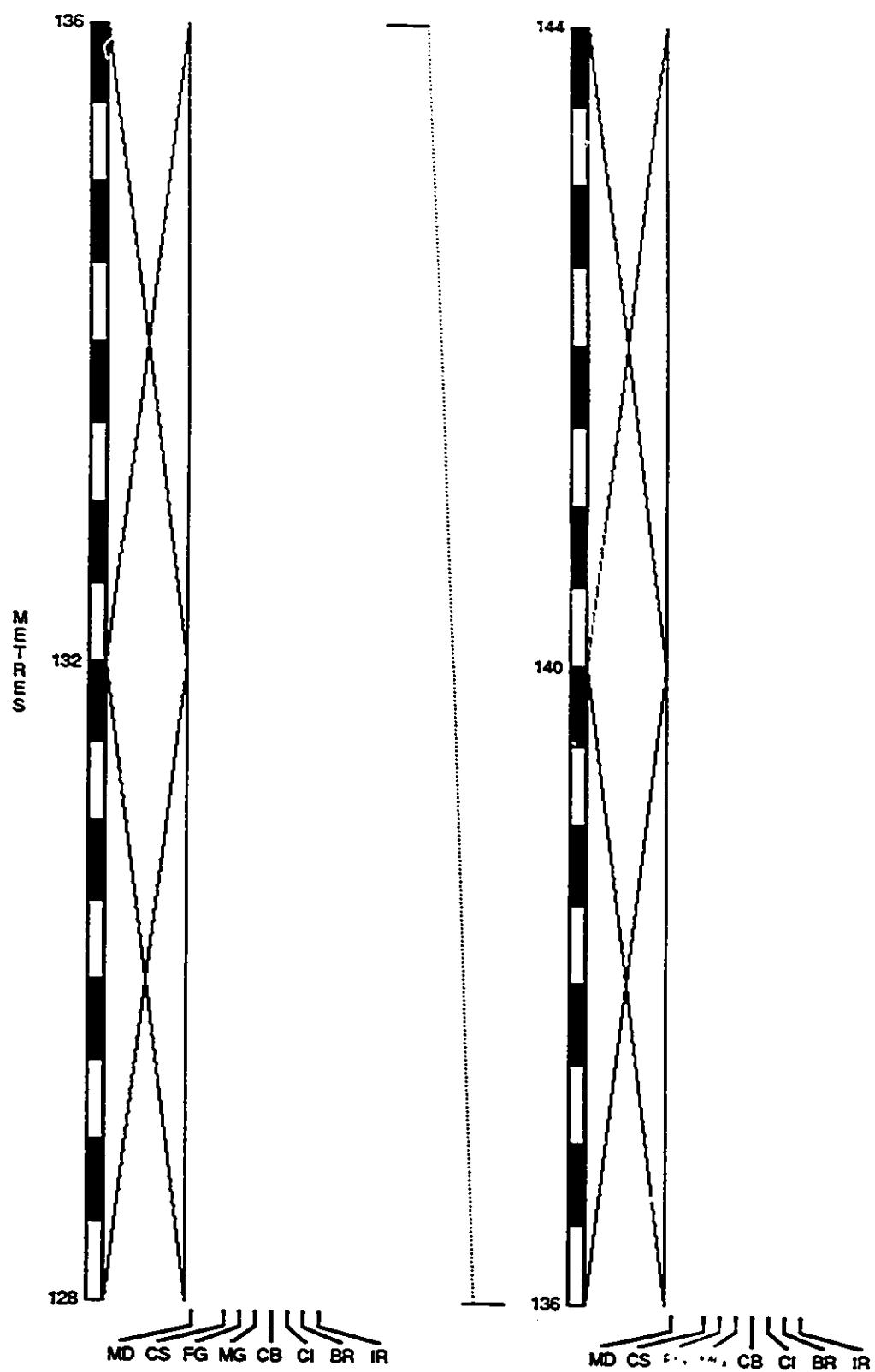
R. Prinista to Reef Point composite section



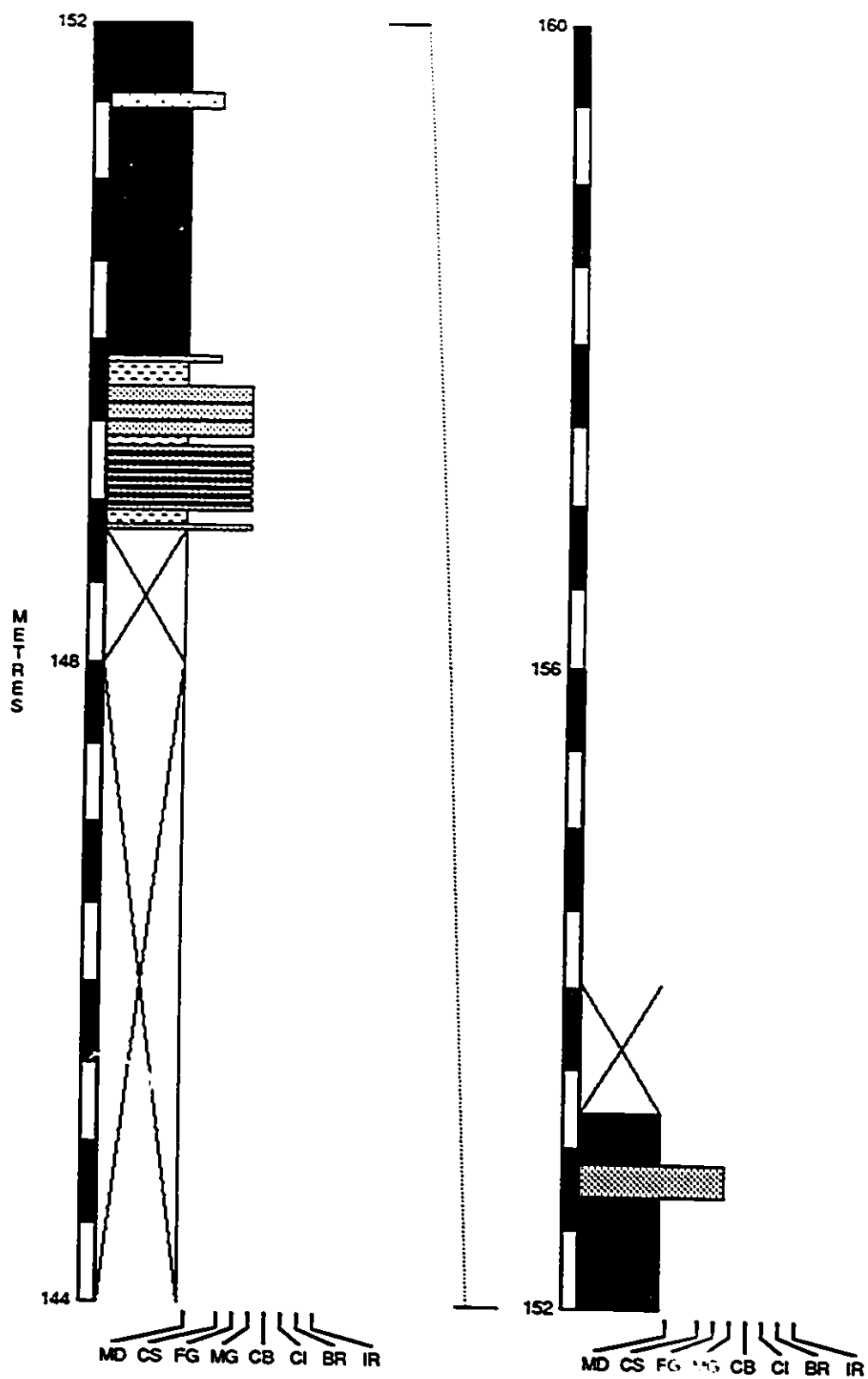
R. Prinsta to Reef Point composite section



R. Prinsta to Reef Point composite section



R. Prinsta to Reef Point composite section



R. Prinista to Reef Point composite section