Reports

DEEP WATER SANDS AND SILTS ON THE NOVA SCOTIAN CONTINENTAL MARGIN

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INTRODUCTION

The Nova Scotian slope and rise (from 200 to 5000 m in depth, Fig. 1) have been the sites of thick sediment accumulation since the opening of the North Atlantic in the Jurassic (Jansa and Wade 1975). This margin has been described by Emery and Uchupi (1972) as a series of overlapping Pleistocene fans. The largest is the Laurentian Fan which extends some 100 km further seawards than the adjacent continental rise.

During Pleistocene glacial maxima sea level was lowered by amounts up to 120 m. This exposed much of the shelf to sub-aerial erosion (King 1969, Prest and Grant 1969), and increased considerably the volume of sediment delivered to the deep ocean margin. A floating ice shelf probably developed in the Laurentian Channel (King 1976) and may have extended beyond the shelf break during certain glacial maxima, dumping sediment directly onto the upper slope above the Laurentian Fan.

The Scotian slope and rise are crossed by numerous, small, V-shaped canyons, originating on the upper slope or at the shelf break and mostly dying out on the lower rise. The slope above the Several previous workers have studied the late Quaternary stratigraphy and sedimentation in this area from scattered piston cores (Stanley *et al* 1972, Piper 1975). The upper, olive gray mud facies (50 to 100 cm thick) is probably the result of hemipelagic settling during the Holocene. The dominant Wisconsin facies is a red mud with frequent silt laminae and occasional thicker sand beds - the origin of which is still a matter of controversy. One model (Piper 1975) considers it to be of turbidite origin, slumping of unstable sediments on the upper slope, particularly above the Laurentian Fan, initiated large, muddy turbidity currents such as the one following the 1929 Grand Banks earthquake. Rip-current generated turbidity currents (Piper 1970) were probably more common off the beaches that developed south of Sable Island and Banquereau Banks during periods of glacially lowered sea level.

Another model (Heezen *et al* 1966, Hollister 1967, Bouma and Hollister 1973) proposes that the main sedimentation process on the slope and rise has been that of contour-current deposition. Large turbidity currents feeding the Laurentian Fan put much fine-grained material into suspension; this is caught in the powerful Western Boundary Under-

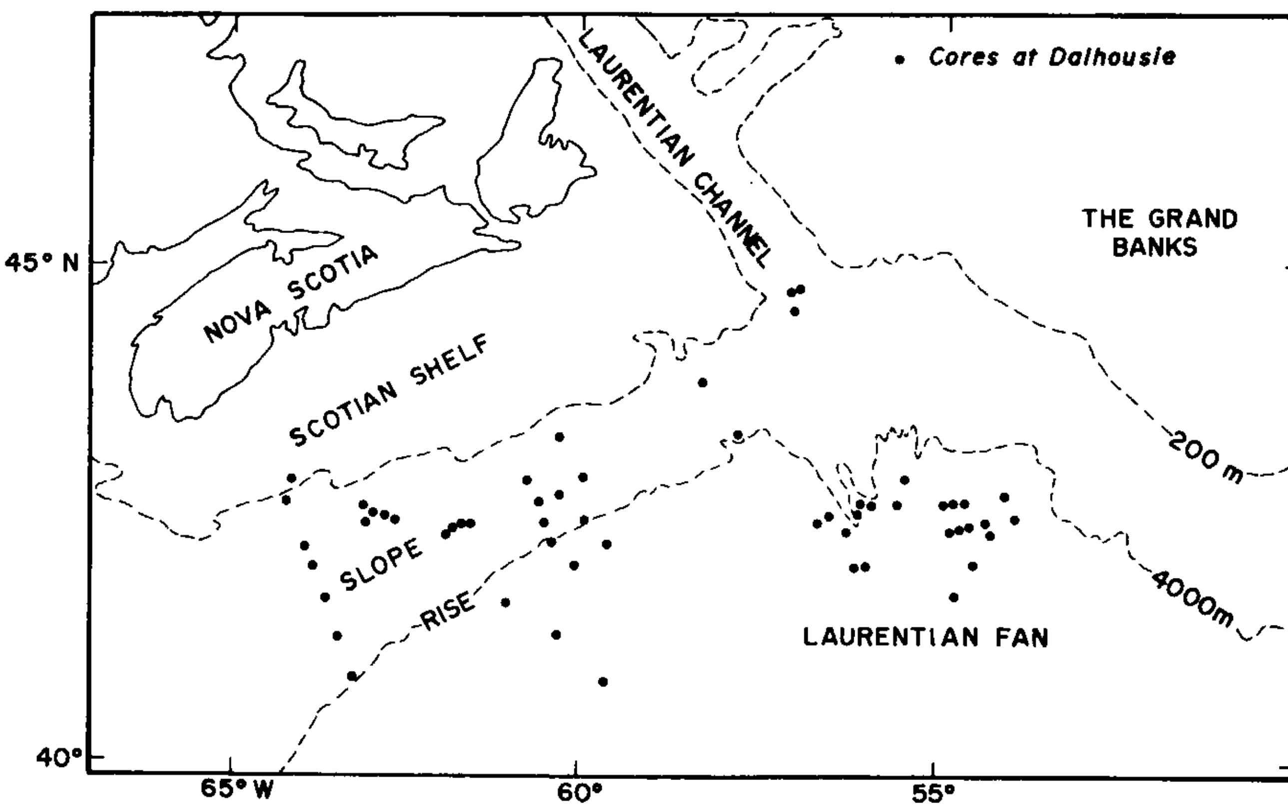


FIG. 1 Map showing area of present study and location of cores.

current and deposited as laminated silts, mud and sand on the slope and rise.

A large number of cores has been examined for the present paper, and many hundreds of silt and sand layers studied. Several of these cores have been selected for detailed structural and textural analysis by standard sedimentological methods (Carver 1971) in an attempt to comment upon the processes involved in their deposition.

RESULTS

Layer Thickness and Distribution

On the Laurentian Fan the main channels are invariably floored by thick, graded sands and gravels, sometimes exceeding 2 m in thickness. Thin sands (1 to 10 cm thick) are found close to the channels, but the dominant facies of the inter-channel areas is a silt-laminated, red mud. The silt laminae decrease in abundance and thickness away from the channels (Fig. 2b).

On the slope and rise the cores are more widely spaced than on the fan so that a distribution pattern of coarse layers is less easily recognized. However, two trends are suggested by the data: (a) an increase in the number of laminae with depth, to a maximum concentration at about 4000 m (Fig. 2a); (b) a decrease in the number of laminae away from the channel axes.

Sedimentary Structures in Sand and Silt layers

The thick sands and gravels of the channel floors are megascopically graded, and often show well-developed Bouma sequences. In the massive A-division clasts are up to 40 mm long; the sequence then grades into coarse and fine sand. A cross-laminated C-division followed by fine, laminated D-division sand may be present. In one case there is a very fine turbidite mud (E-division) at the top of the core.

Size grading in the thin sand beds is almost ubiquitous. They commonly have sharp bases with load structures, and gradational tops, and are overlain by silt-laminated sequences or bioturbated, olive-gray muds. Bouma sequence structures may be developed, and both cross lamination and horizontal lamination may be accentuated by concentrations of heavy minerals, lutite or forams. Two or more pulses of deposition are sometimes suggested (Fig. 3b).

Individual thin silt laminae are similar to the sand beds in internal structures (Fig. 3a). In some cases grouped silt laminae may be recognized, showing an upward decrease in thickness, abundance and distinctness of the laminae over a distance of 5 to 25 cm (Fig. 4).

Grain size properties

Most of the sands contain less than 10 to 15 % clay-sized material, and the finer silts, less than

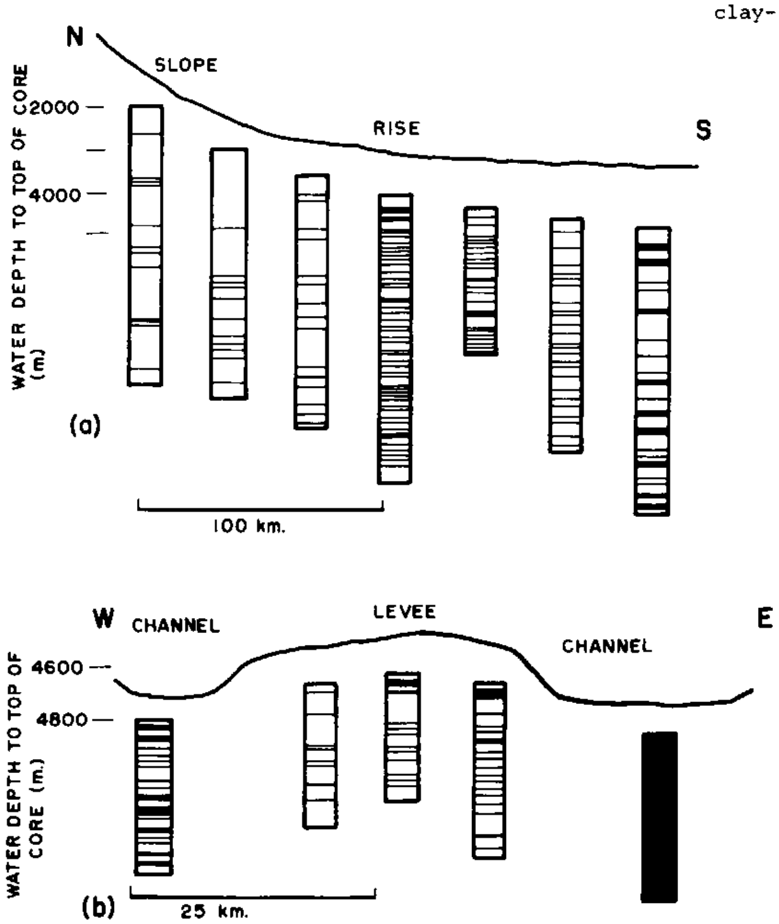


FIG. 2 Distribution of coarse layers in selected deep sea cores.
(a) north-south transect across the Scotian Slope and Rise
(b) east-west transect across channel-levee topography on the Laurentian Fan. Thin lines represent prominent silt and sand laminae; heavier lines and shaded areas represent sand beds more then 5 cm thick.

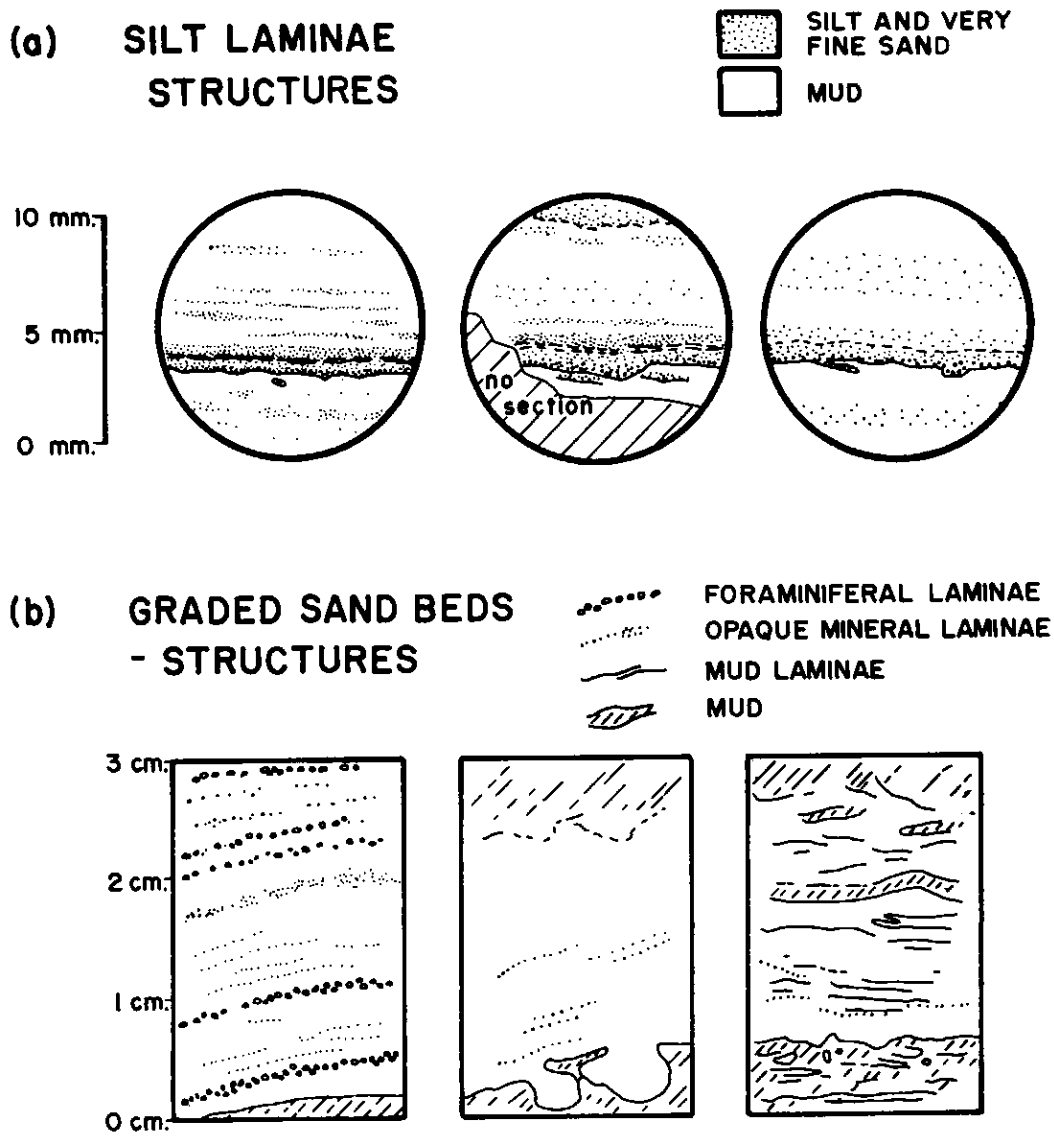


FIG. 3 Drawings from thin sections showing internal structures of coarse layers: (a) in silt laminae, (b) in thin sand beds.

20% clay. There is no noticeable difference between the slope and rise and the Laurentian Fan in this respect; the apparent sandier nature of the slope and rise sands indicates a larger proportion of thin sand beds in this area as opposed to the abundant silt laminae of the Laurentian Fan (Fig. 5).

Wherever two or more samples have been taken from a single bed, grading is evident - in thick sands, thin sands, individual laminae and groups of laminae. Possible lateral grading in a thin, correlateable silt lamina across 30 km of levee is also seen (Figs. 5 and 9).

The dominant mean size in the Laurentian Fan samples is in the coarse-medium silt range, and that of the slope and rise samples is in the very fine sand range. The sorting is moderately good, except for the thickest sand beds and the thinnest silt laminae, and all the samples are positively skewed (Fig. 6).

The values of mean size have been plotted against those of standard deviation (Fig. 7a). A sinusoidal relationship is apparent for all samples (Folk and Ward 1957). These results are similar to those obtained by Horn *et al* (1971) for sands from the Hatteras and Sohm abyssal plains. According to their interpretation, the sands were deposited from both high velocity currents (coarser, well-sorted), and the slower moving tails of turbidity currents (finer, poorly-sorted). There are no samples equivalent to their "Phase 1" sands (which "represent dumping of polymodal) detritus from swift flows without segregation of size grades"), although some of the samples in the present study were from very thick sand units.

Fig. 7b is a plot of mean size against skewness. The trend indicated is similar to than shown by recent analyses of Black Sea turbidites (Jipa 1972). Hubert (1964) also provides evidence of similar relationships between mean size and standard deviation or skewness in deep sea sands from the

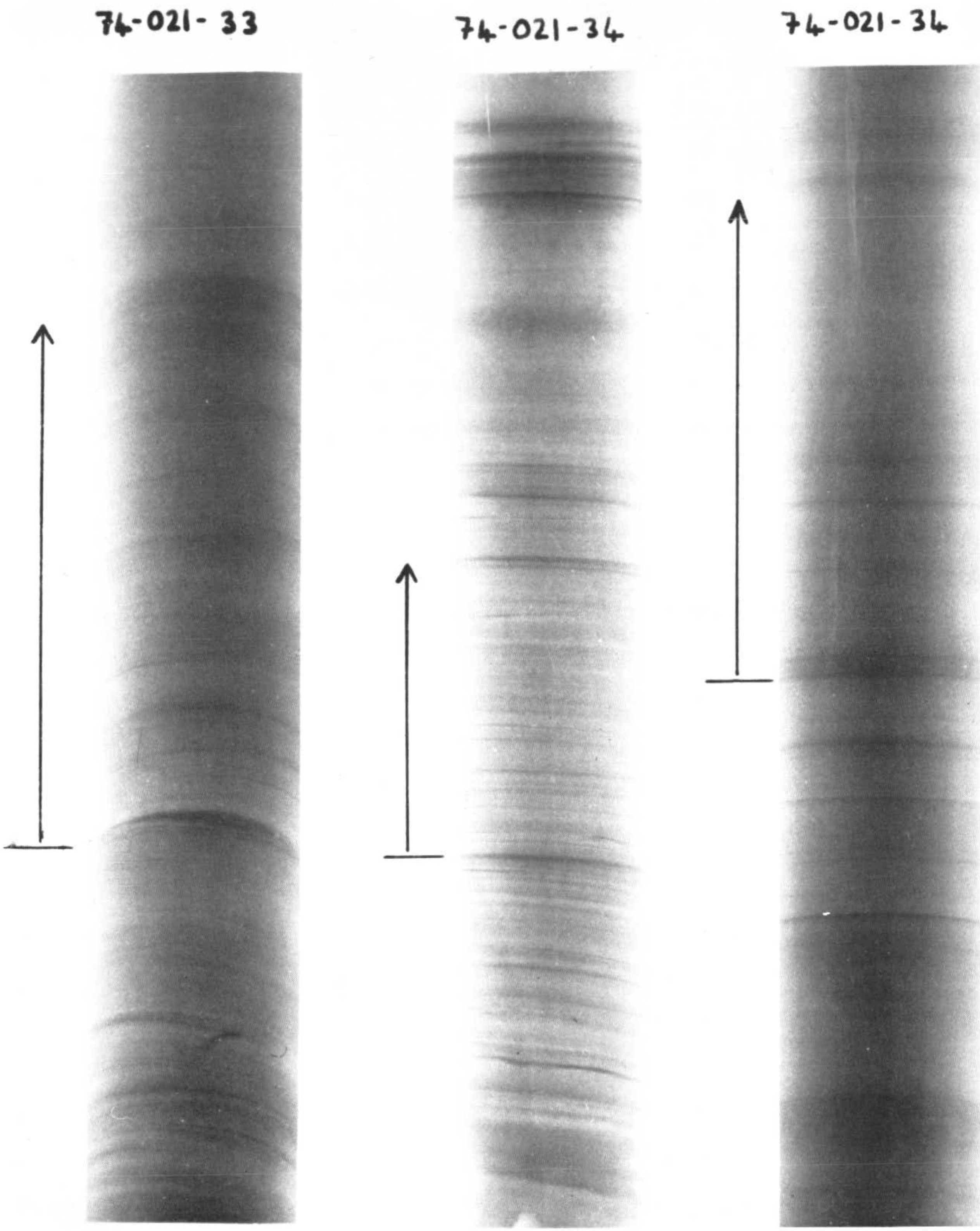


FIG. 4 Possible grading of grouped silt laminae in Laurentian Fan Cores.

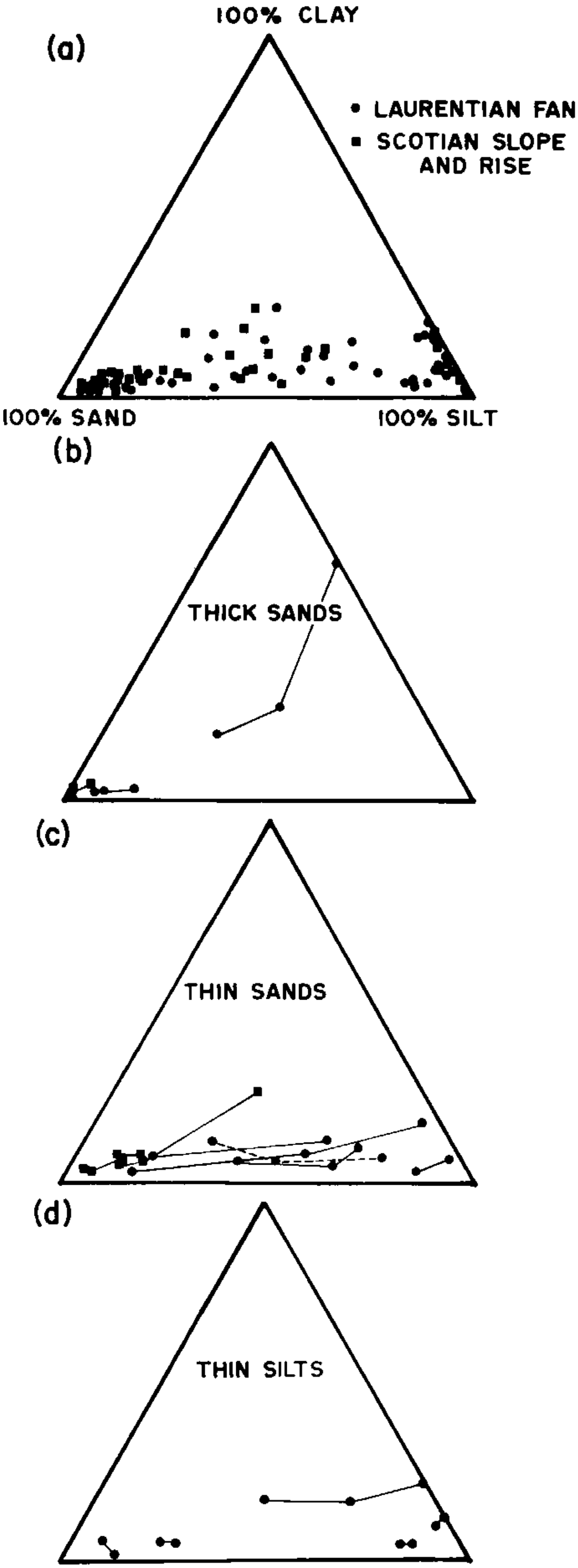


FIG. 5 Sand-Silt-Clay ternary diagrams. The lines joining points in B and C represent grading within single beds. D shows grading in individual silt laminae and lateral grading in a correlateable silt laminae in three different cores across 30 km of levee.

western North Atlantic. However, he argues that as these trends are known to be characteristic of deposition by bottom currents in continental, littoral and shallow marine environments, the deep sea sands analysed are not the products of turbidity-current deposition.

The mean size of samples is also seen to increase systematically with layer thickness in both areas, although the thin sands on the rise tend to be coarser than their equivalents on the fan (Fig. 8a). This may be an indication of proximality. Furthermore, the mean size tends to decrease with increasing water depth up to about 4200 m, and then to begin increasing again (Fig. 8b). This trend reflects the concentration of thin silt laminae on the lower rise.

Cumulative frequency plots of thin sands show well-sorted, Gaussian distributions, with very small coarse tails and moderately large fine tails. They also show clear grading through individual beds. The silt laminae show similar curves, with a slightly larger fine tail. Sequential grading is indicated in groups of laminae as well as lateral grading across a levee. The thick sand beds are seen to be clearly graded (Fig. 9).

DISCUSSION

Thick Sands and Gravels

The extreme thickness and coarseness of these beds, the Bouma sequence of structures and their location in channel axes leave little doubt that these deposits are the result of highly competent turbidity currents crossing the Laurentian Fan. Limited foraminiferal evidence suggests that those on the fan are Holocene in age and perhaps result from the 1929 Grand Banks earthquake and subsequent turbidity current. The one thick, channel sand so far recovered from the Scotian rise is covered by a complete Holocene to Wisconsin hemipelagic facies, indicating that the sand was from a glacial period.

It is thought that the large, fine tails of these turbidity currents over-top the channel levees and contribute to interchannel fine-grained sedimentation.

Thin Sand Beds

The regional setting and morphology of the Laurentian Fan indicate that, as with other deep sea fans, turbidity currents have played a very important part in its formation. The thin sands

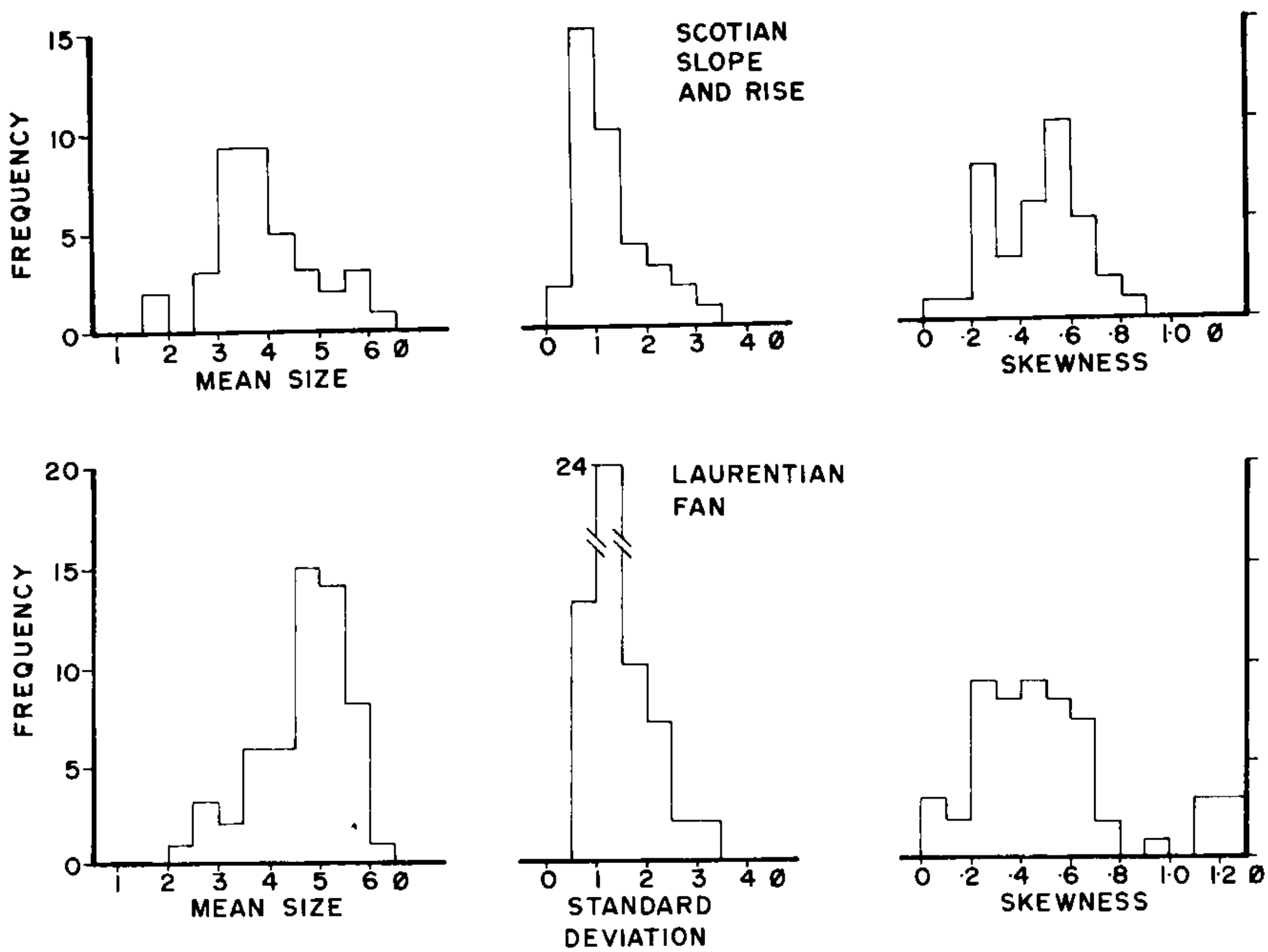


FIG. 6 Frequency histograms of three statistical parameters in Scotian Margin deep sea sands and silts.

tend to be close to channel axes, to have sharp, erosional bases with load structures and to display partial Bouma sequences and grading. In addition, the quartz surface textures of sand grains and heavy mineral provinces suggest transport perpendicular to the shelf break. A turbidity current origin best explains these features.

The Scotian slope-and-rise sands compare very closely with those of the Laurentian Fan, and a similar origin seems likely. No clear distinction between slump-generated and rip-current generated turbidity currents has yet been found.

Thin Silt Laminae

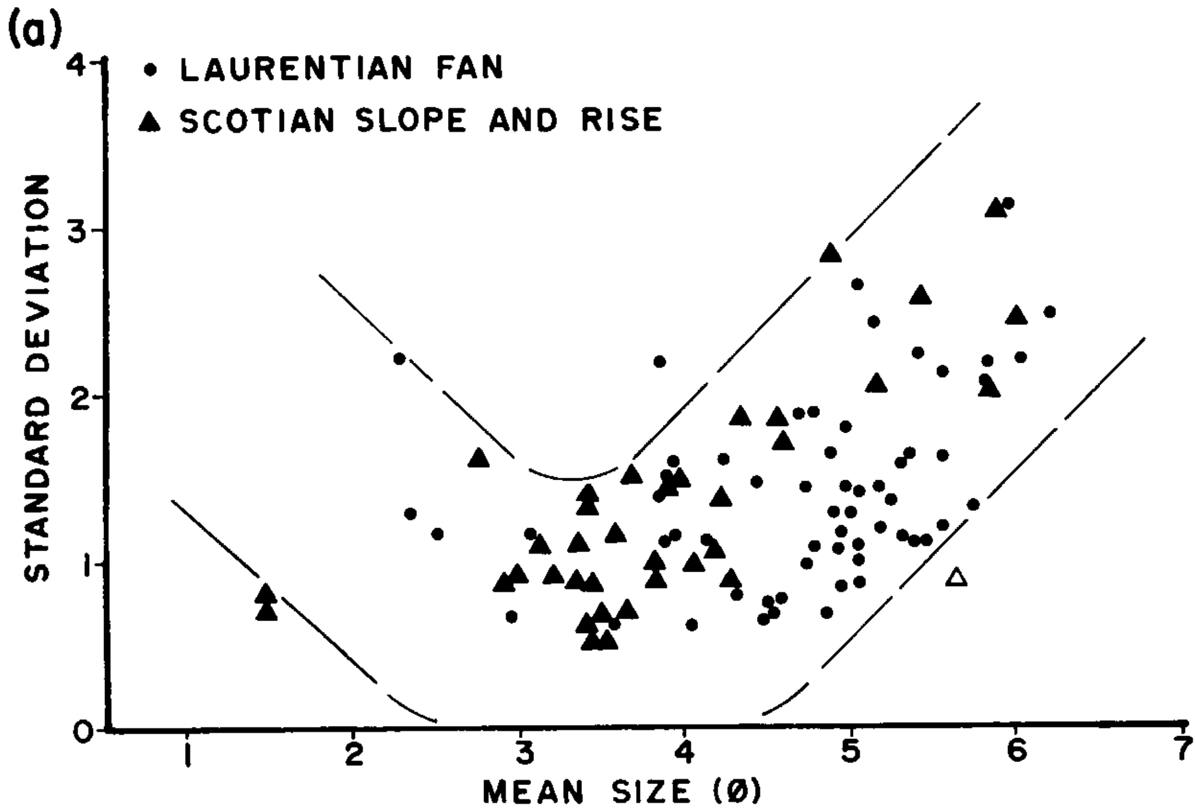
The depositional process producing silt-laminated muds is still an important problem in sedimentology. No satisfactory criteria have been established for distinguishing between fine-grained turbidites and contourites (Piper 1973, Piper and Brisco 1975, Bouma and Hollister 1973, Bouma 1972, Hesse 1975) although the facies is very widespread in the deep sea.

There are three possible explanations for the origin of the laminated muds of the Scotian margin: (1) overbank spilling from fine tails of large turbidity currents; (2) overbank spilling and short transport by contour currents; and (3) entrainment of material in contour currents from winnowing or from suspension and considerable laterial transport. (1) and (2) are considered to be turbidites, and (3) to be a contourite.

The following features suggest a turbidity origin for the silt laminae analysed:

(a) their close relationship to the channels;
(b) the grading of individual laminae, their erosional bases and load structures, and their non-lenticularity;
(c) the grading of grouped laminae;
(d) the thick unbioturbated sequences indicating rapid deposition;
(e) the positive skewness of all samples analysed.

Features which more closely favour a bottom current origin are:
(a) the concentration of laminae on the rise between 4000 and 4300 m;
(b) individual laminae with sharp bases and tops.



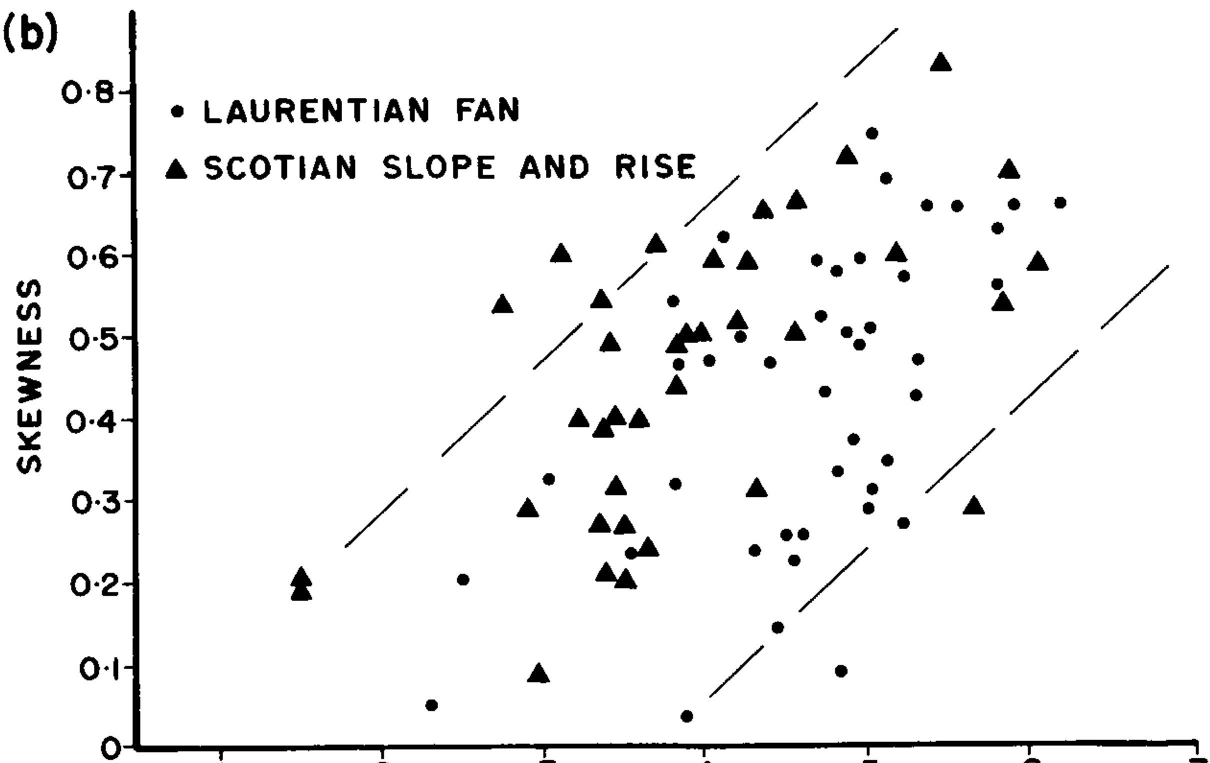


FIG. 7 Plots of Standard Deviation (a) and Skewness (b) against mean size.

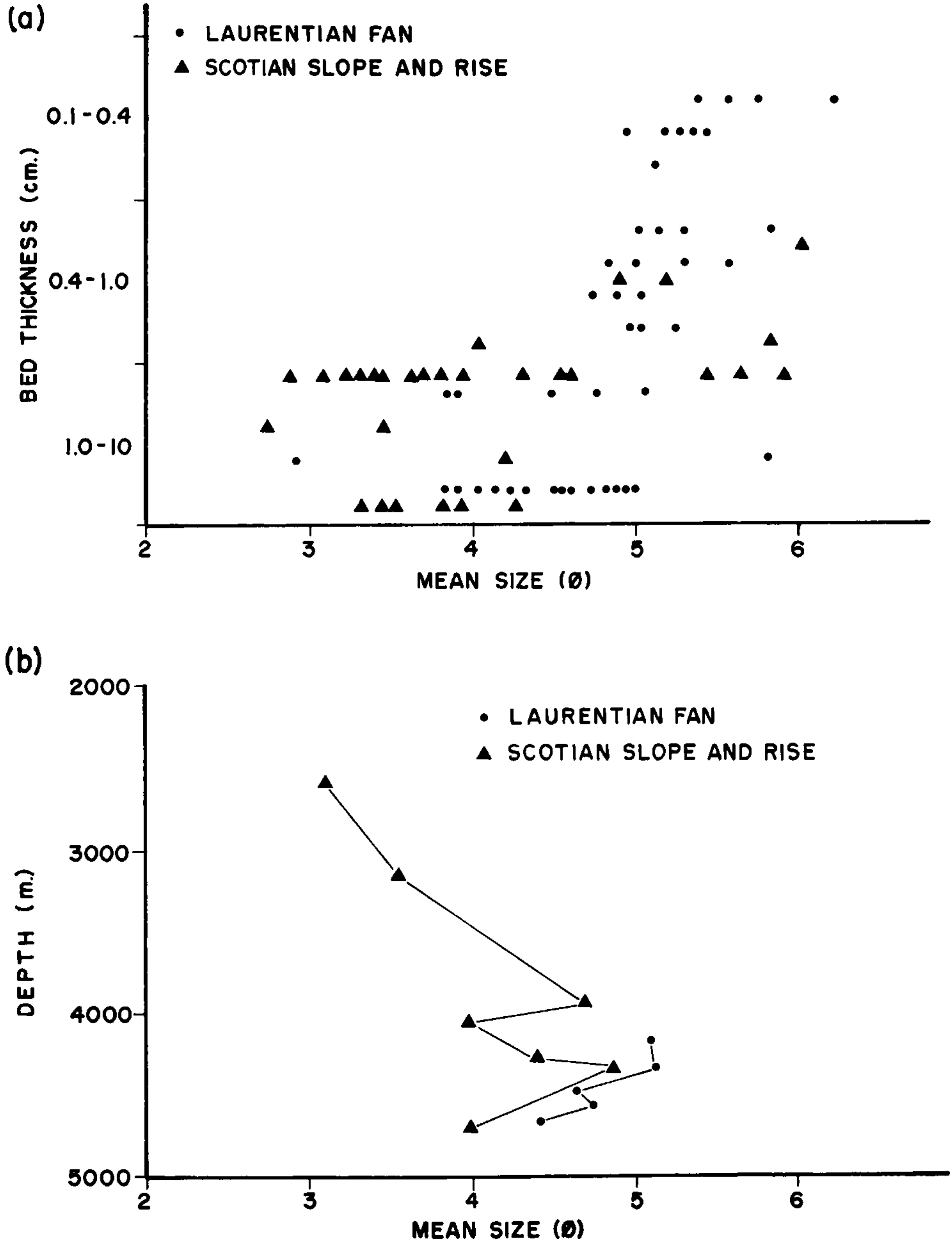


FIG. 8 Plots of Bed thickness (a) and Depth (b) against mean size.

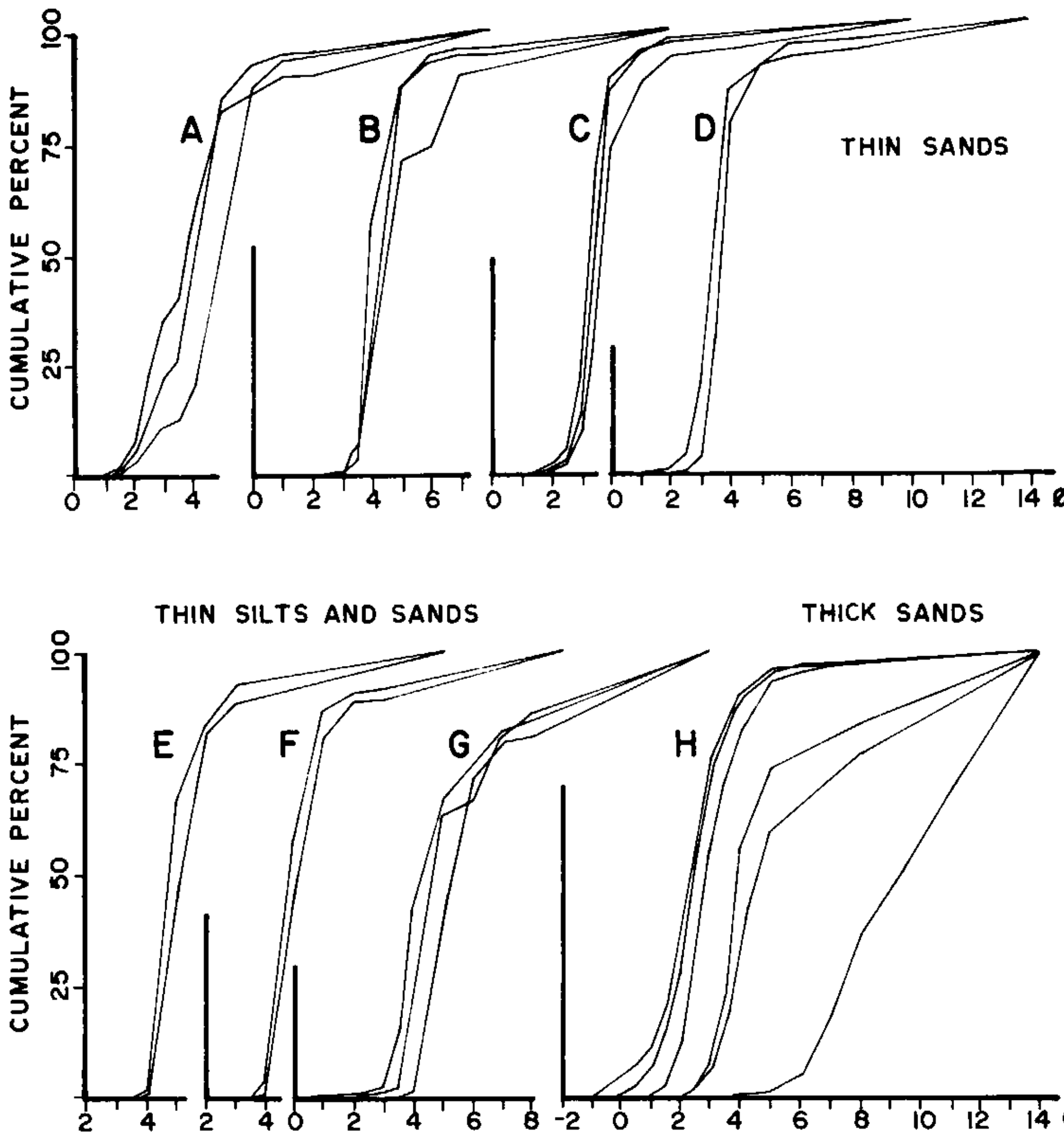


FIG. 9 Cumulative Frequency Curves from grain size analyses of selected Scotian Margian deep sea sands and silts. A to D show grading from top to bottom in 5 - 10 cm thick sand beds. E and F show vertical grading in grouped silt laminae. G shows lateral grading across 30 km of levee. H shows grading from 0 to 30 cm in one thick channel sand and from 30 to 120 cm in a second.

CONCLUSION

Careful study has been made of numerous sand and silt layers in deep sea cores recovered from the Nova Scotian continental slope and rise. Results suggest that the thin sand beds as well as the thick channel gravels have been deposited by turbidity currents. The depositional process producing the dominant silt-laminated mud facies is not yet clearly understood, although a turbidite origin seems probable at least on the Laurentian Fan. Further work is in progress on these finer grained sediments.

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