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The Laurentian Fan: Sohm Abyssal Plain

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Abstract

The 0.5- to 2-km thick Quaternary Laurentian Fan is built over Tertiary and Mesozoic sediments that rest on oceanic crust. Two 400-km long fan valleys, with asymmetric levees up to 700-m high, lead to an equally long, sandy, lobate basin plain (northern Sohm Abyssal Plain). The muddy distal Sohm Abyssal Plain is a further 400-km long. The sediment supplied to the fan is glacial in origin, and in part results from seismically triggered slumping on the upper continental slope. Sandy turbidity currents, such as the 1929 Grand Banks earthquake event, probably erode the fan-valley floors; but thick muddy turbidity currents build up the high levees.

Introduction

The Laurentian Fan is located off the eastern continental shelf of Canada, in the bight between the rifted continental margin of Nova Scotia and the (inactive) transform margin of the southwest Grand Banks (Fig. 1). This margin developed during the Early Jurassic opening of the central Atlantic Ocean. The bathymetrically defined modern fan comprises up to 2 km of Quaternary sediment. It rests on a thick Jurassic to Tertiary continental margin sequence [1], principally of older deltaic and fan sediments derived from the ancestral St. Lawrence River [2].

The Laurentian Fan lies seaward of the Laurentian Channel, a 700-km long, 80-km wide, glacial trough that crosses the continental shelf and has been excavated some 300 m below the regional depth of the shelf. The shelf break at the southern end of the Laurentian Channel lies at about 400 m water depth; consequently it would not have been emergent even during maximum glacio-eustatic lowerings of sea level. However, the Laurentian Channel was probably the main discharge route for much of the ice in southern Quebec and the Atlantic Provinces of Canada [3], either as grounded ice, an ice shelf, or icebergs. Rapid melting would have occurred where the Laurentian Channel fed into the open ocean, not far from the Gulf Stream [4], over the continental slope above the Laurentian Fan.

The southern end of the Laurentian Channel and adjacent continental slope is an area of moderate seismic activity and was the site of the magnitude 7.2 Grand Banks earthquake that occurred in 1929 [5]. This seismicity has provided a triggering mechanism for the resedimentation of at least some of the glacial till and glaciomarine sediments [6].

The Laurentian Fan leads southwards to the Sohm Abyssal Plain (SAP). This abyssal plain receives sediment not only from the Laurentian Fan but also from the Northwest Atlantic Mid-Ocean Channel (NAMOC), and from an unnamed channel leading from the slope off Northeast Channel at the entrance to the Gulf of Maine [7] (Fig. 1). Most of the Wisconsinan sediment on the distal SAP has been transported across the Laurentian Fan [8,9].

Sediment accumulation on the SAP is confined between the Bermuda Rise in the west and the flanks of the midocean ridge to the east (Fig. 1). The Bermuda Rise also diverts sediment from the Georges Bank and Nova Scotian continental margins eastwards to the SAP. The SAP is divided into a northern and southern half by the Corner Seamounts and the southeastern part of the New England Seamount Chain (Fig. 2). Abyssal hills and seamounts rise above the southern SAP. The J-anomaly Ridge and the Fogo Seamount Chain divert turbidity currents at the southeastern edge of the Laurentian Fan (Fig. 3).

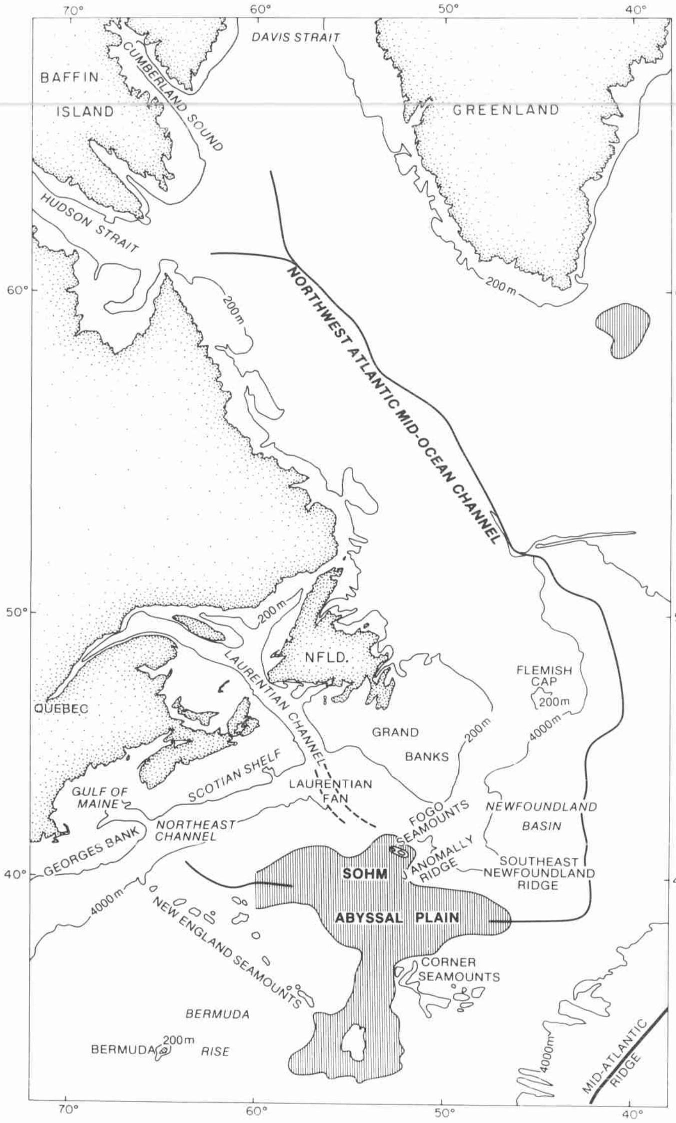

Figure 1. Map of northwestern Atlantic Ocean showing regional setting of Laurentian Fan and Sohm Abyssal Plain.

Morphologic Divisions, Size and Shape

Bathymetric profiles with an average line spacing of 20 km are available for the Laurentian Fan [1,10], but data are more sparse and less well navigated on the SAP. GLORIA coverage has been obtained for the entire fan above the 4500-m isobath [11] but is as yet unpublished.

We recognize the following morphologic subdivisions of the Laurentian Fan from north to south (Fig. 3)

Continental Slope: an area of irregular relief resulting from substantial erosion of Late Quaternary sediments, extending from the shelf break at 400 m to the 2000-m isobath [6].

Slope-valley Transition: the area between the 2000- and 3000-m isobaths. This is an area of complex erosional valleys with some intervalley accumulation of Late Quaternary

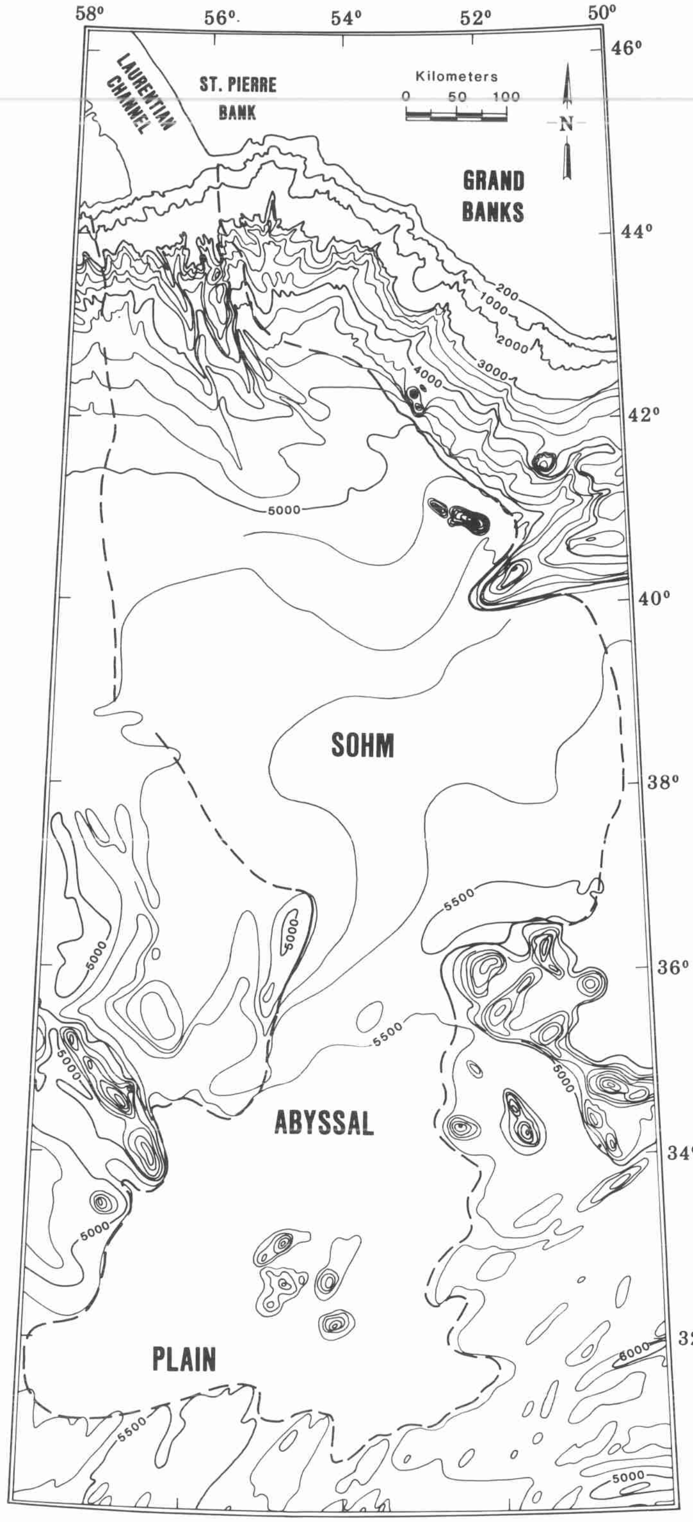

Figure 2. Bathymetric map of Laurentian Fan and Sohm Abyssal Plain. Laurentian Fan and continental margin contoured at 200-m interval, based on Uchupi and Austin [1] with modifications from Bedford Institute of Oceanography (B.I.O.) ship tracks. Southern SAP and adjacent areas contoured at 500-m interval, based on GEBCO chart [21] with modifications from B.I.O. ship tracks. (Track density for compilation is approximately as shown on GEBCO chart [21]).

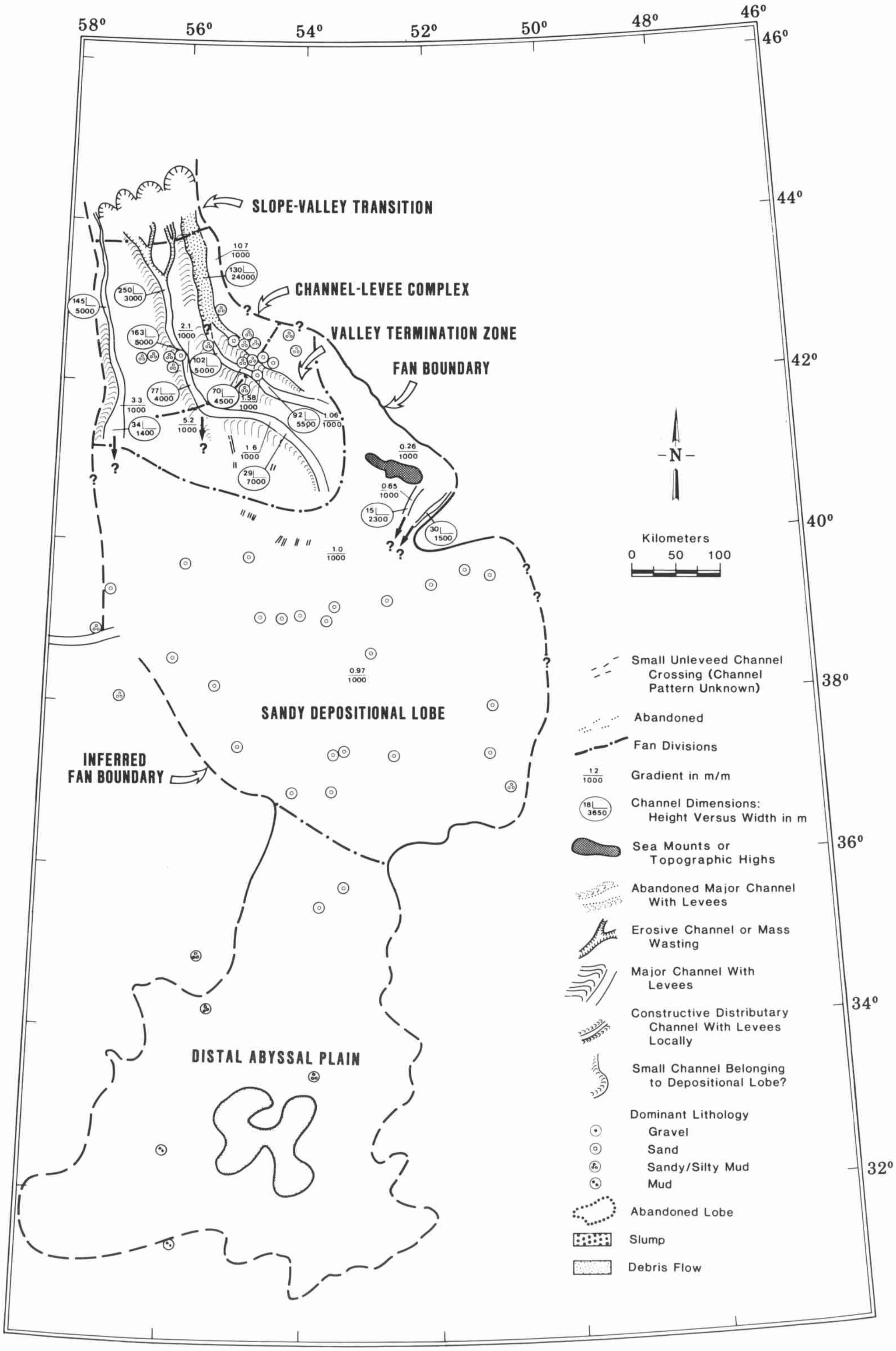

Figure 3. Morphometric map of Laurentian Fan and Sohm Abyssal Plain.

sediment and some large slide blocks [2].

Channel-levee Complex: the area extending from the slope-valley transition zone to the 4600-m isobath. This area is tranversed by two major fan valleys (eastern and western valleys) with erosional western walls and highly asymmetric levee systems (Fig. 2). The higher west levees are up to 1000-m above the valley floor. Both seismic profiles [12] and cores [4] show that the levees accumulated overbank sediment during the Late Quaternary. Their asymmetry is probably the result of the southwestward flow of the Western Boundary Undercurrent in this area [13].

Valley Termination Zone: the area from 4600 to 5000 m. Relief of both the fan valleys and levees becomes progressively more subdued [13], and the eastern valley bifurcates.

Sandy Depositional Lobe: from 5000 to 5500 m. Channels are very shallow or absent in this area. There is a pronounced overall lobate morphology to around 5200 m, but to the south the gradient decreases to less than 1:1000, and morphology appears influenced by the NAMOC and the channel leading from the Gulf of Maine.

Distal Abyssal Plain: this is the virtually flat (?ponded) area southwest of the Corner Seamounts at 36°N, in water depths of more than 5500 m.

Stratigraphy

About 25 piston cores have been collected from the Laurentian Fan [4], 25 from the sandy depositional lobe on the northern SAP [7,14] and 15 from the distal abyssal plain [7,8,15,16]. Biostratigraphic studies allow the distinction of Holocene from Wisconsinan (Late Pleistocene) sediment [4,8]; in most cores, Holocene sediments are about 1 m thick, giving an average sedimentation rate of about 0.1 m/10^3 yr. Most cores do not completely penetrate the Wisconsinan sequence. On the Laurentian Fan, Holocene sediments are interpreted as mostly muddy contourites [4]. Holocene turbidites are found on the SAP: turbidity currents apparently flowed through the fan valleys and sediment thus by-passed the fan (Fig. 4).

Wisconsinan mud-accumulation rates on the Laurentian Fan are estimated at 0.1 to 0.3 m/10^3 yr, with one turbidity current every 100 to 300 years depositing on the levees [4]. Rates of accumulation on the distal SAP are probably higher [8]. Sand-accumulation rates are not known.

A distinctive acoustic reflector can be mapped beneath much of the Laurentian Fan [1,12,13] and has been tentatively assigned to around the Pliocene–Quaternary boundary, based on a change in depositional style and correlation with stratigraphy in wells on the shelf edge and upper slope. Where there has been no subsequent erosion, this acoustic reflector is found about 1.5 to 2.0 secs subbottom at the 3000-m isobath and about 0.7 secs deep at the 4500-m isobath, giving Quaternary sediment accumulation rates of the order of 0.5 to 1 m/10^3 yr (Fig. 5). Acoustic stratigraphy of the channel-levee complex [12] suggests that the Laurentian Fan was a simple progradational system with a single fan valley in the Early Quaternary, but the fan has experienced widespread erosion with the development of two major valleys in the Late Quaternary [12]. There are no suitable data to extend this acoustic stratigraphy to the SAP.

Distribution and Source of Sediment

The acoustic character of the surficial sediments on the fan is mapped from widely spaced 3.5-kHz [1,6,17] and high-frequency, filtered, sparker profiles [12,13]. Acoustically transparent facies occur on levees in both the valley-levee complex and the valley termination zone, and in the distal SAP. Highly reflective sediments occupy the valley floors and the sandy depositional lobe. Valley terraces show intermediate acoustic penetration. Within 100 km of the epicenter of the 1929 earthquake, surface stratified sediments are very discontinuous, indicating widespread surface slumping [6], and valley walls are mantled by material giving many surface hyperbolic reflections [12]. Large slide blocks of dimensions of hundreds of meters are rare [12]. A large debris flow in the eastern valley is distinguished by characteristic surface morphology [6] and extends across the valley termination zone [17]. There is also an acoustically transparent debris flow on the west side of the westernmost levee [17].

Pleistocene cores from the Laurentian Fan and SAP yield a distinctive red-brown mud (5 YR 4/4 to 10R 4/2) interbedded with silt, sand, and gravel. Silts and muds occur on levees and interchannel areas of the fan and on the distal abyssal plain. Sands and gravels are found in the fan valleys. Sand is the dominant sediment on the sandy depositional lobe of the northern SAP; thin sands also reach the distal abyssal plain and the levees. The gravels are composed of clasts largely derived from the Gulf of St. Lawrence, and the mineralogy of sands and clays confirms that this is the dominant source [4]. Holocene sediment contains relatively more montmorillonite transported by the Western Boundary Undercurrent [4].

The principal Late Quaternary sediment source is the slumping of glaciomarine sediment and till [6,18] from the upper slope. Much of this slumping is probably seismically triggered; a zone of recent seismicity extends east-west across the Laurentian Channel and the upper continental slope off St. Pierre Bank (Fig. 4). Turbidites are much more frequent during glacial periods [4,8], suggesting that slumping may in part have been the result of very rapid sediment supply, or even direct flow of cold turbid water from beneath an ice shelf [4]. This slumped material moved across a highly eroded continental slope cut by irregular gullies that coalesce into distinct valleys around the 3000-m isobath.

The 1929 magnitude 7.2 Grand Banks earthquake had an epicenter [19] on the continental slope above the Laurentian Fan (Fig. 4). Surficial sliding occurred within a zone of about

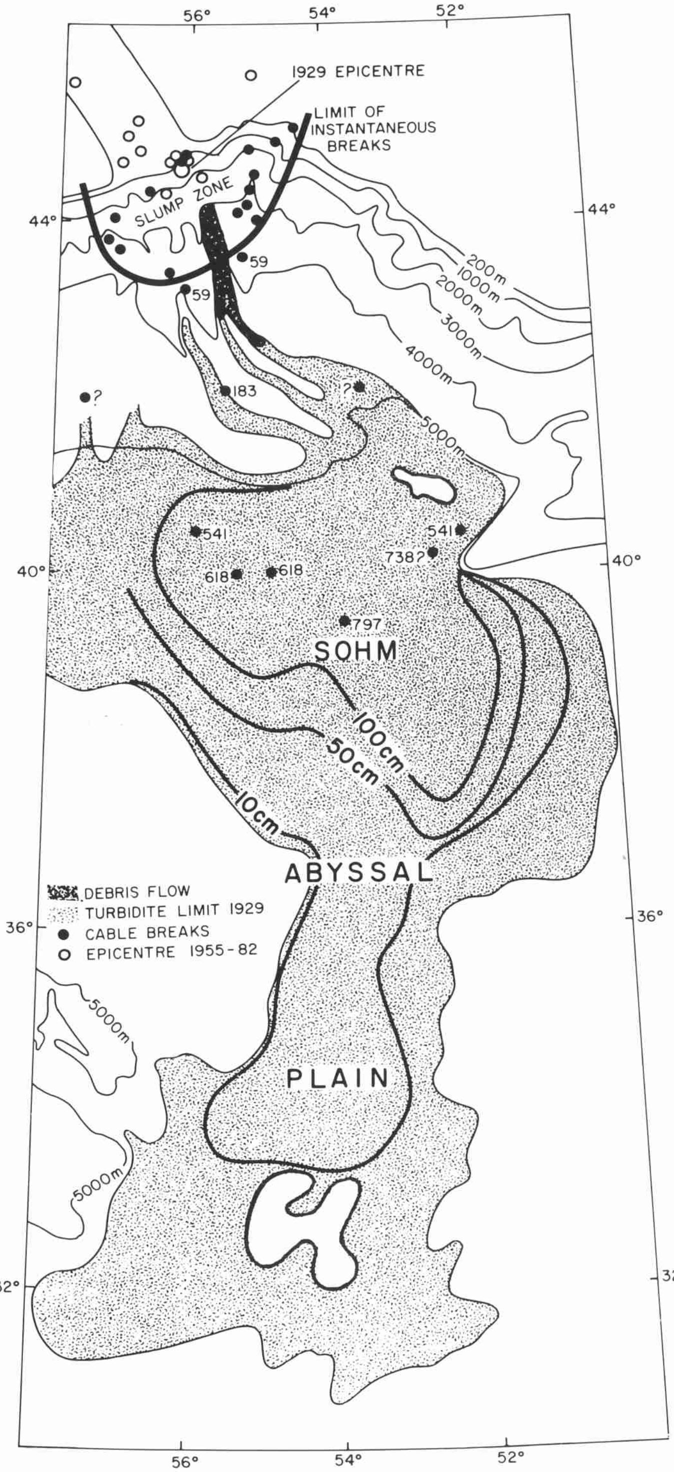

Figure 4. Map showing geologic effects of 1929 Grand Banks earthquake. Epicenter of 1929 earthquake from Basham and Adams [19]. Location and time (minutes after main shock) of cable breaks from Doxsee [5]. Limit of 1929 turbidite on Laurentian Fan interpreted from data of Stow [4]; on SAP from data of Fruth [14]. Isopachs of 1929 turbidite from Fruth [14]. Extent of debris flow based on 12-kHz soundings, and is probably underestimated (Jacobi, personal communication [17]).

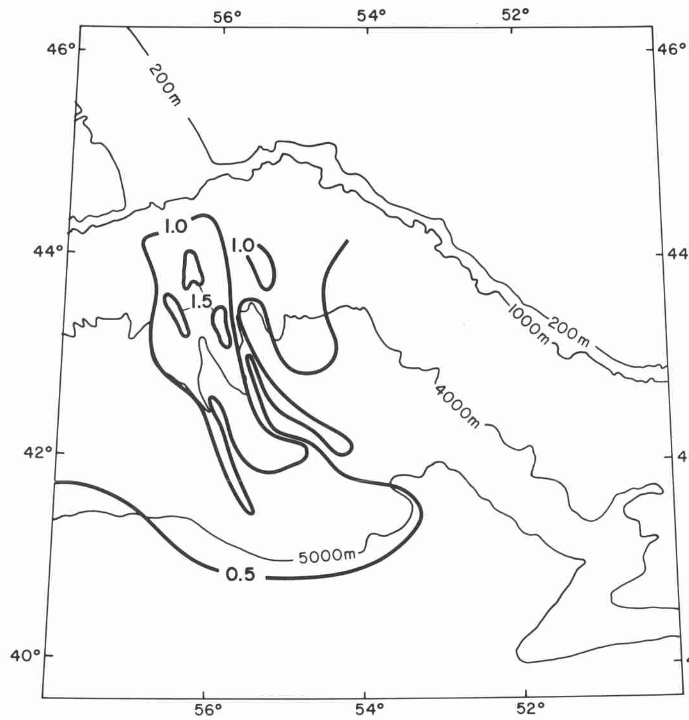

Figure 5. Isopach map of (?) Quaternary sediment on Laurentian Fan (in km) (after Uchupi and Austin [1] with minor modifications from [12].

a 100-km radius around the epicenter, and a large debris flow moved down the Eastern Valley [6]. Cable breaks [5] indicate that turbidity currents flowed down both the eastern and western valleys at velocities of between 73 and 41 km/hr. The currents appear to have been slowed by ponding behind the southern Fogo Seamounts. Cores from levees from the valley termination zone do not contain turbidities on the surface [4], but thick, sorted, and graded gravels occur in the valleys in this zone [7]. According to Fruth, over a meter of sand was deposited on the sandy depositional lobe [14], whereas only a few centimeters of silty mud may be present in places on the distal abyssal plain [14].

Many Wisconsinan turbidity currents were of quite different character from the 1929 event. They were hundreds of meters thick, overtopped the levees, were probably principally of mud, had low suspended sediment concentrations, and velocities of only 0.10 to 0.15 m/s [20].

Conclusions

The Laurentian Fan resembles other large passive-margin fans by having large and long fan valleys. It has a short line source of slumped glacial material at the end of the Laurentian Channel, the major Pleistocene glacial ice outlet in southeastern Canada. Some of the slumping is seismically triggered. Irregular slope gullies coalesce to form two active fan valleys. Pronounced levee asymmetry is related to the Western Boundary Undercurrent interacting with thick, low-density, muddy turbidity currents. The glacial source supplied large proportions of sand and gravel, which have been resedimented to form a vast sandy lobe ($\approx 10^5$ km^2) with a gradient of about 1:1000, and also abundant mud, which has built up most of the thick channel-levee complex. Sandy turbidity currents are probably responsible for the pronounced Late Quaternary erosion of the Laurentian Fan.

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