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Quaternary Development of Channels, Levees, and Lobes on Middle Laurentian Fan[1]

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ABSTRACT

Seismic reflection profiles from the middle Laurentian fan show that the western fan valley has an abrupt eastward (leftward) hook at its terminus. The right-hand levee of this valley has been built across an older depositional surface in which numerous south-trending channels developed before the abrupt bend formed. This older channeled surface probably represents a complex depositional lobe deposit. Eastward deflection of turbidity-current flow occurred after debris-flow or slide deposits partly obstructed the valley near its termination or after aggradation of the lobe deposits. This deflection produced an abrupt change in the valley trend. Through time, the eastward-growing part of the levee has migrated northward toward the axis of the channel; this northward migration confines turbidity-current flow against the levee of another valley immediately upfan.

This study documents progradation of muddy facies over sandy lobes thus providing conditions for an effective seal for any hydrocarbons accumulated in the lobe sands. Updip migration of hydrocarbons through valley-fill sands that are contiguous with the lobes could be blocked locally by thick debris-flow units or by fine-grained turbidite fill in abandoned channels.

INTRODUCTION

The Laurentian fan is the largest deep-sea fan on the Atlantic margin of Canada. Two main fan valleys on the upper fan that extend seaward from water depths of 3,500 m (11,500 ft) are fed by numerous coalescing small valleys and local submarine slide areas on the upper slope seaward of the Laurentian Channel (Fig. 1). Relief between channel floors and levee crests on the upper fan reaches 1,000 m (3,300 ft) locally (Uchupi and Austin, 1979) and is among the greatest of any modern turbidite channels (Normark, 1978). The high relief of the western valley on the upper fan terminates abruptly in water depths of about 4,700 m (15,400 ft) immediately west of our detailed study area (Fig. 2). Below the valley termination, local relief on the gently sloping mid-fan surface is minor, and the fan merges imperceptibly with the broad Sohm Abyssal Plain around lat 40°N.

The 1929 Grand Banks earthquake triggered a large slide on the continental slope north of the Laurentian fan, and the resulting turbidity current broke a series of submarine telephone cables (Heezen and Ewing, 1952; Uchupi and Austin, 1979). According to several studies, (Heezen and Drake, 1964; Emery et al, 1970; Heezen and Hollister, 1971, p. 297), the irregular upper fan and slope topography was generated by slumps or slides with individual slide blocks extending many tens of kilometers in width. Recent detailed seismic reflection profiling studies have shown that the continental slope off the Laurentian Channel, to water depths of 1,500 m (4,900 ft), is the result of extensive erosion influenced locally by several large slump scars (Piper and Normark, 1982a). The uppermost fan down to water depths of 3,500 m (11,500 ft), however, indicates extensive fan-valley-related sedimentation, in which a complex sequence of erosion and fill events can be recognized in seismic reflection data (Piper and Normark, 1982b). Within this area, several smaller channels coalesce to form two main fan valleys. Debris flows possibly related to the 1929 earthquake lie in two of the valleys (Piper and Normark, 1982a).

The lower part of the upper fan, from 3,500 to 4,500 m (11,500 to 14,800 ft) water depth, is traversed by two deep, asymmetric fan valleys. Detailed studies of piston cores by Stow (1981) have shown that valley floors are filled with sand and gravel, whereas overbank mud turbidites accumulate on the high levees.

The Laurentian fan has been little studied between the fan valley termination at around 4,700 m (15,400 ft) water depth, and the main part of the Sohm Abyssal Plain in 5,300 m (17,400 ft) of water, 400 km (250 mi) to the south. We refer to the area of transition from leveed valleys on the upper Laurentian fan to the smooth lower fan that merges with the flat Sohm Abyssal Plain as the middle fan. This transition includes a large depositional lobe that occupies approximately the middle 200 km (125 mi) of the more than 600 km (375 mi) long Laurentian Cone defined by Uchupi and Austin (1979, p. 1727). In this paper, we use "middle fan" as a geographic, not a morphogenetic term. The bathymetric compilation of Uchupi and Austin (1979, their Figures 2, 3) suggests that a large lobe is fed by the

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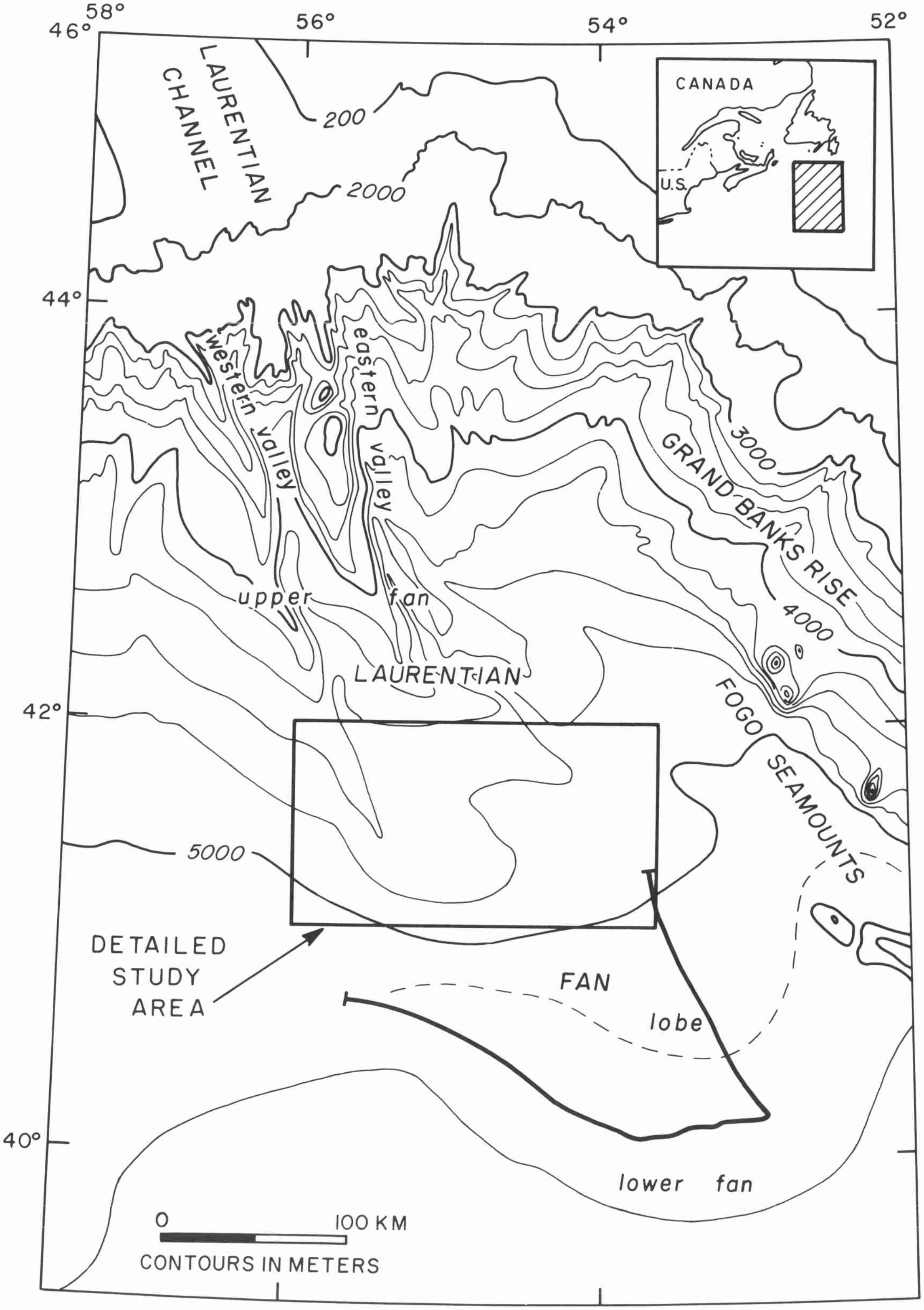

FIG. 1—Location map of Laurentian fan, showing reconnaissance seismic profile of lobe area (heavy line, lower part of map), and location of detailed survey area at terminus of western valley (Fig. 2). Bathymetry from Uchupi and Austin (1979). Contour interval 200 m (650 ft) for depths > 2,000 m (6,500 ft) except for the 5,100 m (16,700 ft) contour (dashed line) in the lobe area.

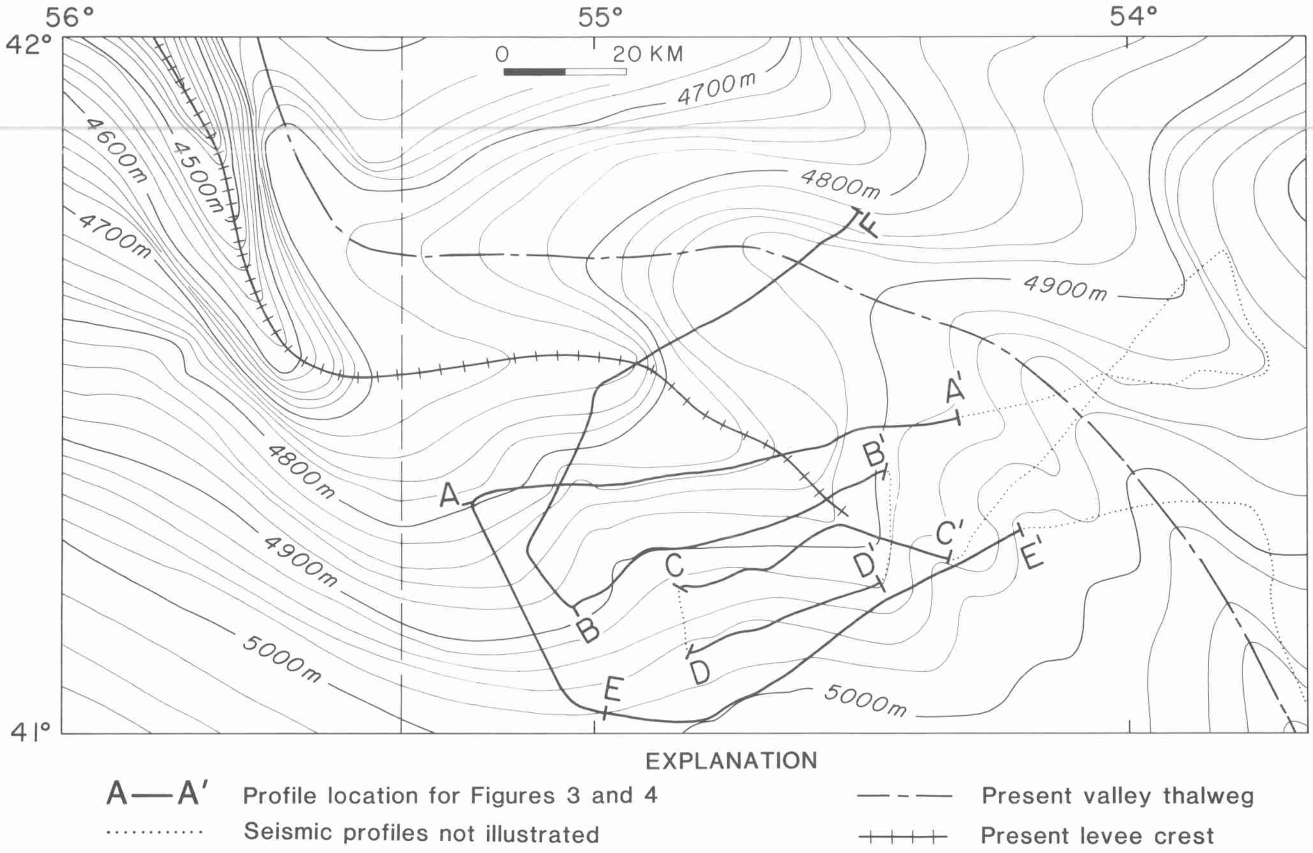

FIG. 2—Bathymetric and trackline map of the detailed study area. See Figure 1 for location. Bathymetric compilation adapted from D. A. V. Stow (1980, unpublished map). Profile locations for Figures 3 and 4 are indicated. Area to right of dashed vertical line near long. 55°20′W is area of map representation in Figures 5, 6, and 7.

western fan valley, whereas the eastern fan valley hooks eastward against the Fogo Seamounts at the base of the Grand Banks Rise. The few cores from this vast lobe area recovered thick sands, suggesting that the Laurentian fan has one of the largest sandy lobes in the world (Stow, 1981).

The sequence of turbidite sediments that constitutes the Laurentian fan lies above a prominent horizon, the L reflector, that can be traced throughout the area of rise and fan on seismic reflection profiles. Uchupi and Austin (1979) suggested that this reflector is of late Pliocene or early Pleistocene age. They mapped the sediment thickness above L as increasing from < less 300 m (1,000 ft) on the lower fan to > 1,500 m (4,900 ft) on the upper fan. Stow (1981), using other seismic reflection data, concluded independently that the base of the Pleistocene section on the upper fan lies at a depth of 1 to 1.5 km (0.5 to 1 mi) beneath the prominent levee areas, and about 600 m (2,000 ft) depth near the valley termination; this depth corresponds roughly to the depth of reflector L.

Seismic reflection profiles of the upper fan (Uchupi and Austin, 1979; Piper and Normark, 1982b) show that the initial progradational phase of sedimentation above horizon L indicates a single active fan valley. The upper half of the sequence on the upper fan, however, shows a more complex sedimentation pattern created by several major valley systems that, at present, lead to two main valleys (Fig. 1). The latest phase of sedimentation consists of a succession of erosion and fill episodes in these valleys, with continued slow aggradation of intervalley levees.

In this study, we use seismic reflection profiling to establish the character of the fan lobe formed downstream from the western valley as well as the nature of its transition with the leveed valley. The work was a joint study involving Dalhousie University, Bedford Institute of Oceanography, and the U.S. Geological Survey. Of special interest was the nature of an abrupt eastward bend of the western valley and its levee (Fig. 2), and the evidence for older distributary channels systems that might have fed earlier depositional lobes on the middle fan. We also attempt to correlate the Quaternary history of the middle fan with that inferred for the upper fan and continental slope and shelf.

DATA ACQUISITION AND INTERPRETATION

In July 1978, about 600 km (375 mi) of single-channel seismic reflection profiles were obtained over a 70 by 150 km (45 by 90 mi) area below the terminus of the western valley (Fig. 2), and an additional 400 km (250 mi) of data from a reconnaissance line that crosses the western half of

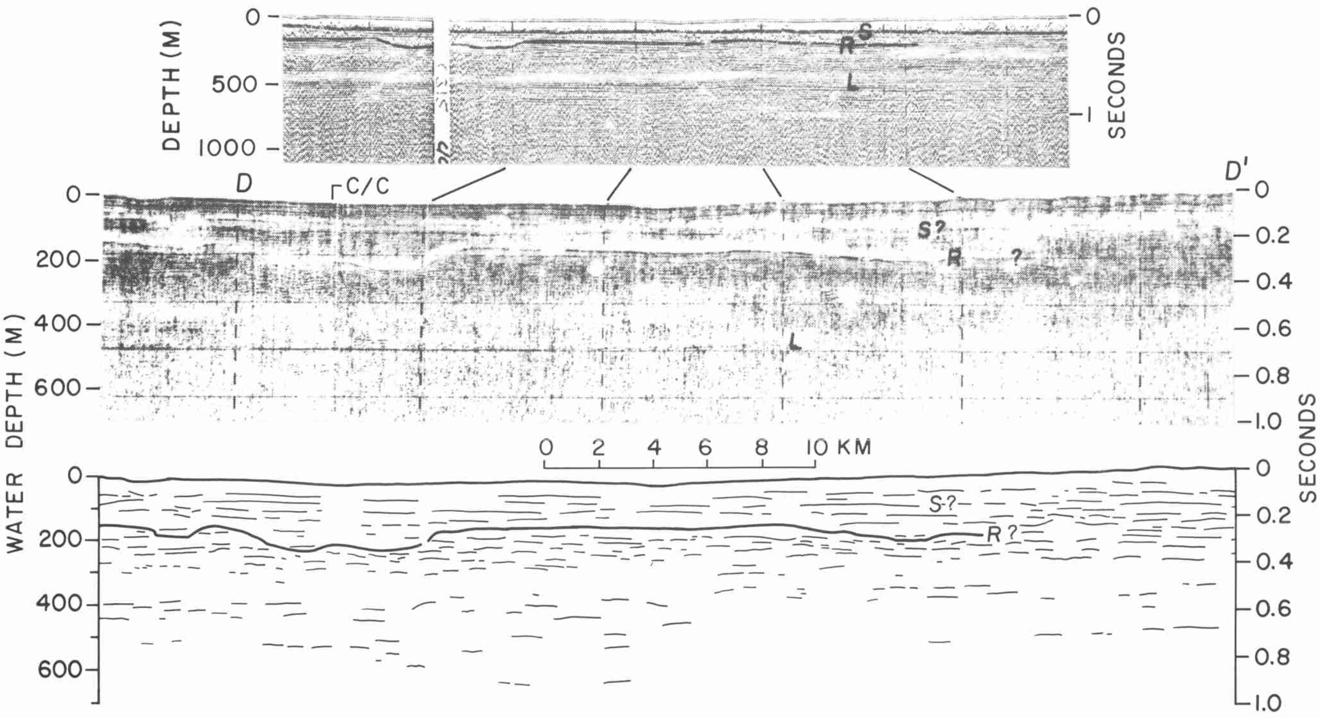

FIG. 3—Upper: original seismic reflection record showing reflectors L, R, and S. Right, vertical scale in seconds of round-trip traveltime. Left, vertical scale in meters, assuming sound velocity in water of 1480 m/sec (4,855 ft/sec). Profile is DD′ with some additional trackline data on left side that are from the track north of D (Fig. 2). The c/c indicates major change of course in profile. Middle: playback of central part of same record segment shown above. Scales are similar and reflectors L, R, and S are noted. Bottom: line drawing of playback record.

the fan lobe below the valley and then extends upfan to the detailed study area (Fig. 1). Position control for the ship was based on nonintegrated LORAN-C manually adjusted to satellite data; LORAN-C positions were obtained every 5 min. A sparker seismic reflection system provided by the U.S. Geological Survey was installed on the Canadian Survey Ship *Dawson*. The seismic system consisted of a 160-kJ-sparker sound source fired at a 4-sec repetition rate and a 60-m (200-ft), two-channel hydrophone array. The primary analog signal was recorded on magnetic tape for later playback. Shipboard records were filtered to 90 to 160 Hz (Fig. 3, upper). A second analog record was produced on shore by using a bandpass filter from 125 to 300 Hz that included the upper frequency-response limit of the hydrophone array (Fig. 3, middle). These records with higher frequencies have limited penetration but show excellent detail for reflecting horizons above the L reflector identified by Uchupi and Austin (1979).

The shipboard analog profiles show, in general, that the upper 1 to 2 km (0.6 to 1.2 mi) of sediment is regularly bedded. Few prominent reflectors can be traced through the entire survey area except for horizon L of Uchupi and Austin (1979) and a reflector, R, that lies roughly halfway between the sea floor and horizon L (Fig. 3, upper). Local relief features including small channels are difficult to map using the shipboard records. However, the playback records show much greater detail for the R horizon and the section above it (Fig. 3, middle and lower).

SEISMIC REFLECTION CHARACTER OF MIDDLE FAN

Marker Horizons

Three reflectors, L, R, and S from deepest to shallowest, have been traced through most of the detailed survey area (Fig. 4). Reflector L is easily identified on most of the original reflection profiles in the area (Fig. 3, upper) but only locally on the playback (Fig. 3, middle). An isopach map (Fig. 5C) of the interval between reflector L and the sea floor shows that the axis of maximum sediment thickness is an east-west trending band parallel to, but slightly south of, the present levee crest, and that the thinnest section underlies the present valley floor. This relation suggests that the sea floor in the study area had little local relief at the time reflector L was deposited, and this observation agrees with Uchupi and Austin's (1979) conclusion that reflector L marks the start of the present Laurentian fan depositional sequences.

Horizon R shows the most local relief of any major reflector in the playback records. It can be traced with confidence through 70% of the survey area and can be tentatively followed through the remainder of the area (Fig. 4). The most prominent features of reflector R are the

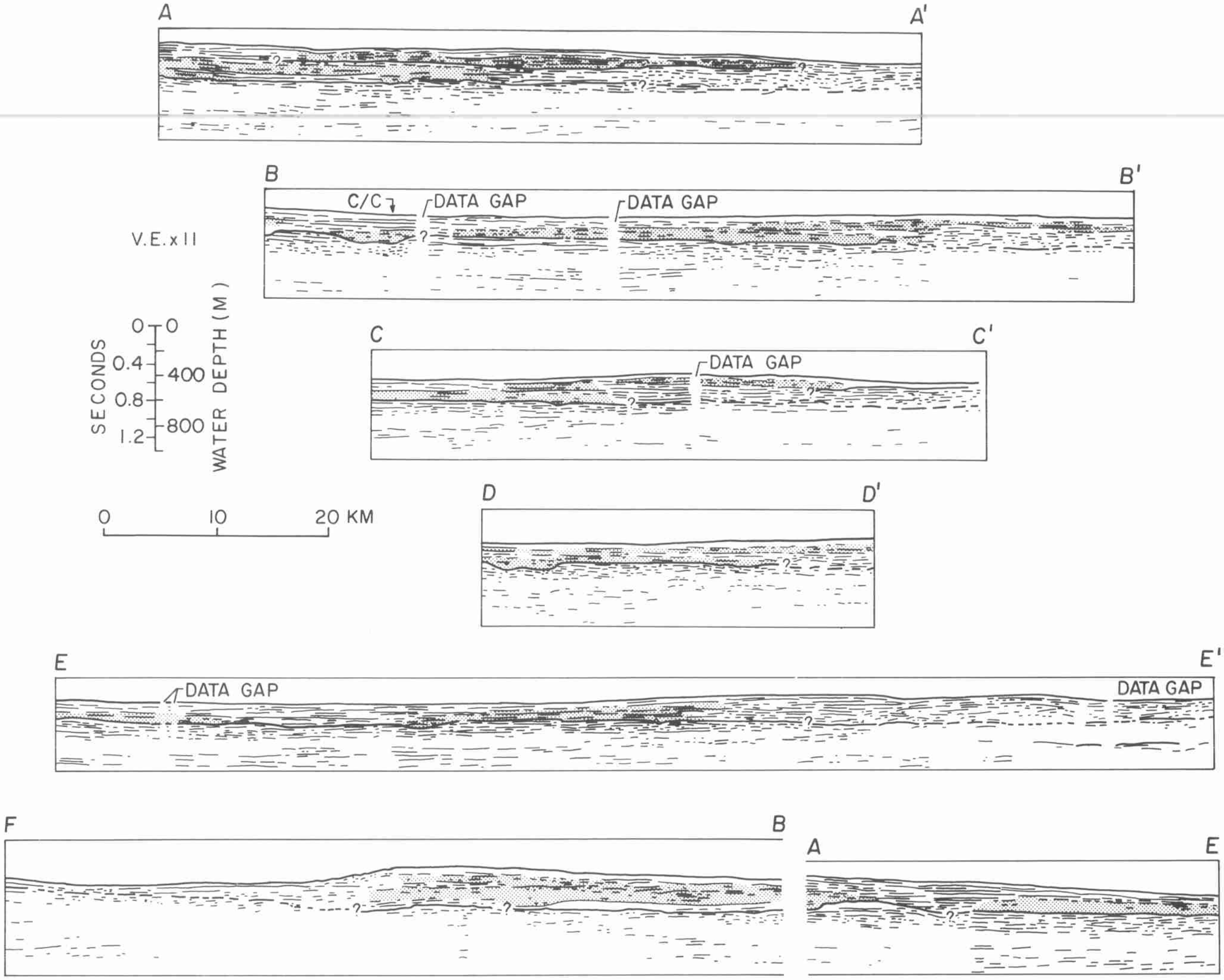

FIG. 4—Line drawings of playback seismic reflection records. Profile locations in Figure 2. Scales and c/c notation same as in Figure 3. Data gap in profile CC′ associated with course change. Break in profile FBAE indicates east-west offset of the line segments. Reflectors R (lower) and S are shown with heavier lines than other subbottom reflectors, and question marks or dashes indicate identification less certain. Shaded intervals indicate basal part of acoustically transparent horizons (compare playback with line drawing of playback in Figure 3) that overlie reflector R through much of the area. Reflector L is commonly not recorded in the higher resolution playback records but locally appears as the horizon of single, or in places multiple, reflectors near the bottom of each line drawing.

numerous channeled areas seen in most profiles. An isopach map of the interval between reflector R and the sea floor shows three filled channels (see arrows in Figure 5B) that meander from northwest to southeast in the area beneath the present levee. The modern valley floor corresponds to the thinnest section above R in the map area, and the channel relief developed on the R surface is only partly reflected in the present sea-floor topography (Fig. 6).

Reflector S, which lies about halfway between R and the sea floor (Fig. 4), can only be correlated with certainty in a few profiles on the south side of the present valley floor. On an isopach map of the interval from S to the sea floor (Fig. 5A), the thickest part of this interval underlies the modern east-west–trending levee.

The highly channeled reflector R is the most complex of the mapped surfaces. A paleobathymetric map (Fig. 6) shows three channels that narrow progressively and increase in relief from east to west. The location of the topographically highest area between the western and central channels suggests that these channels may have crossed (or breached) a broad, irregularly shaped topographic high. The upslope ends of these channel segments appear to converge in an area that underlies the present main valley floor near the pronounced bend in the levee (compare Figures 2 and 6). The eastward bend of the present levee thus postdates horizon R and characterizes main fan-valley deposition during the upper half of the Laurentian Cone sequence of Uchupi and Austin (1979).

The paleobathymetry of horizon L, the base of the fan sequence, shows only minor indications of channel-like relief with slight topographic irregularities on a gently southward-sloping surface (Fig. 7). The reflection profiles (Figs. 3 and 4) also do not show any clear channel relief on this surface.

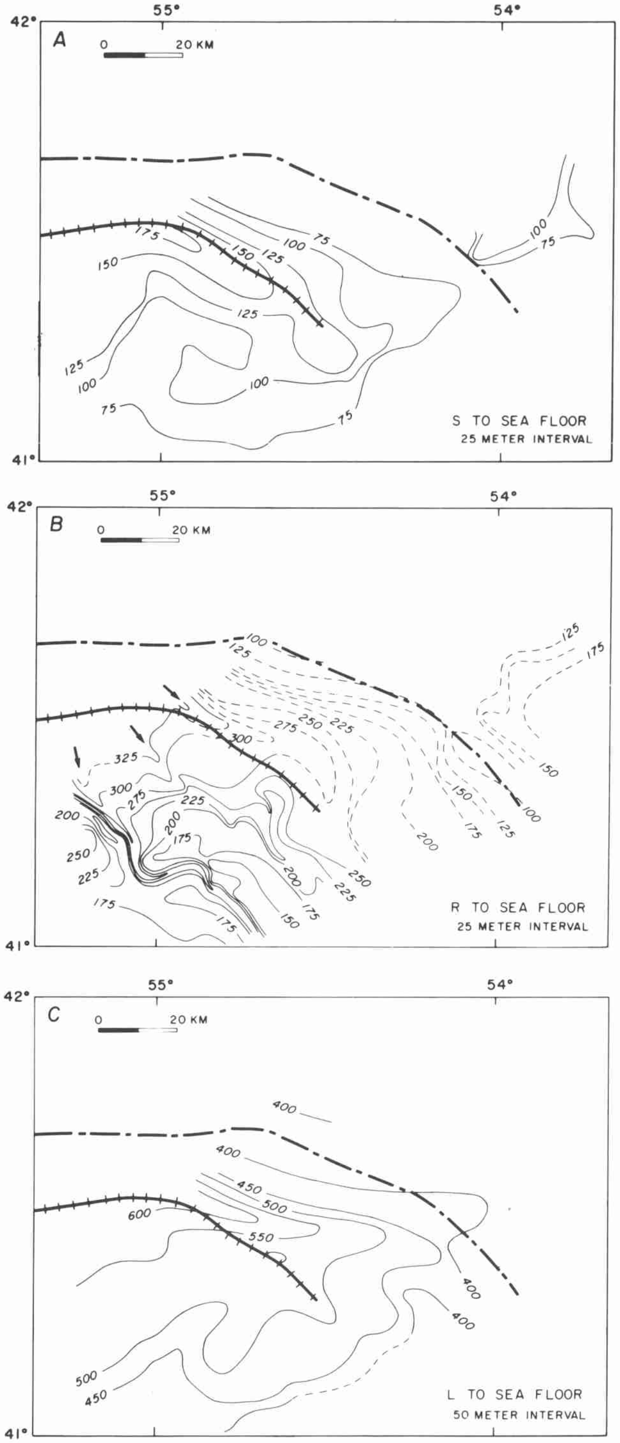

FIG. 5—Isopach maps of selected intervals between horizon L (Uchupi and Austin, 1979) and the sea floor. Contour intervals are in meters using a sound velocity of 1.6 km/sec (1.0 mi/sec) for section under present levee and 1.8 km/sec (1.1 mi/sec) for section underlying the main fan-valley floor. Sound-velocity values are interpreted from general results of sonobuoy oblique reflection data from Uchupi and Austin (1979). Patterns for modern valley axis and levee crest same as in Figure 2. (A) Interval S to sea floor. (B) Interval R to sea floor. Arrows indicate axes of filled channels. (C) Interval L to sea floor. Depth to L is taken from lower frequency shipboard profiles and cannot be resolved as clearly as R and S.

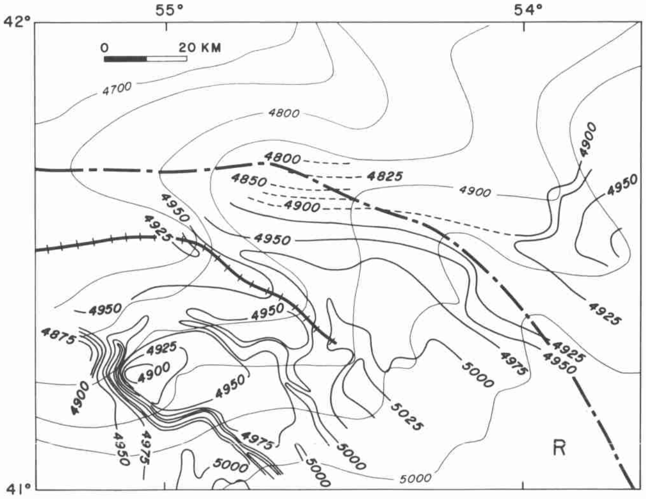

FIG. 6—Paleobathymetry of horizon R superimposed on the present bathymetry. Paleobathymetry (heavy contours) constructed assuming the sound velocities used in isopach maps of Figure 5 for the section between reflector R and the sea floor. Patterns for modern valley axis and levee crest same as in Figure 2.

Acoustic Character of Detailed Study Area

The sediments immediately above reflector L, although poorly resolved in the seismic reflection data, appear evenly stratified with generally conformable reflectors. Acoustically, this sediment sequence resembles the uppermost sequence on the western part of the distal lobe and shows little evidence of channeling or of proximity to a valley.

The sequence topped by the R surface is generally convex upward and consists of relatively highly reflective, short, discontinuous reflectors that are similar to the section underlying the modern valley floor (Figs. 3, 4). This character, along with the irregular topography between the channels (Fig. 6), suggests that the sediment beneath R is probably a lobe deposit with relatively coarse sediment. This channeled section is thus similar to channelized suprafan-lobe deposits found on smaller submarine fans (Normark, 1978).

The sediments immediately overlying the R surface are relatively acoustically transparent material with fewer and weaker reflectors than the section below the R surface (Fig. 3, middle). This material generally fills the channels and covers interchannel areas as well. Its acoustic character suggests that it may be a large debris flow that moved through the western valley. Alternatively, it may reflect an interval of deposition of finer grained material or hemipelagic sediment on the lobe. This relatively acoustically transparent material preserved the generally convex-upward form of the R surface in the lobe area.

The sediments overlying the acoustically transparent sequence above the R surface are generally well bedded in the reflection profiles. The S horizon occurs within this sequence, which closely resembles the levee sediments mapped on the upper fan (Piper and Normark, 1982b). The crest of the modern levee closely corresponds to the thickest section between S and the sea floor.

Acoustic Character of Lobe

Only one loop of seismic reflection profile is available on the lobe (Fig. 1). A prominent reflector between 250 and 500 m (800 and 1,600 ft) subbottom depth correlates with the L reflector. As suggested by our limited data, the isopach map of the section between reflector L and the sea floor shows a broad depositional lobe (Fig. 8). Much of the sequence above reflector L appears relatively evenly stratified; but in places, distinct shallow surface depressions, interpreted as channels, are visible. All of the channels are on the eastern and central parts of the lobe, downfan from the termination of the western valley. Only two of the channels have more than 30 m (100 ft) relief, and these two channels are between 5 and 10 km (3 and 6 mi) wide along the profiles; they may be highly oblique crossings of these features (Fig. 9). The observed channel crossings are consistent with the pattern of telephone cable breaks, which are thought to have resulted from turbidity currents flowing through channels (see Uchupi and Austin, 1979, Fig. 4), but no pattern for bifurcating or meandering channels can be recognized with existing data.

Between long. 53°45′ and 54°45′W on the southern crossing of the lobe, there are numerous buried channels in the interval between reflector L and the surface. The remainder of the track to the east and north shows relatively few buried channels southeast of the detailed survey. In general terms, this would indicate a shift in activity on the lobe from west to east during deposition on this sector of the fan that might correlate with development of the east-trending levee segment of the main valley.

HISTORICAL DEVELOPMENT OF CHANNEL SYSTEMS

The pronounced changes in the reflector morphology and in acoustic character from horizon L to the present suggest several stages in the fan development. Piper and Normark (1982b) suggest that at or shortly after horizon L time, there was one major valley with a large western levee on the upper fan (Fig. 10A). The buried channels above reflector L on the profile south of the detailed study area indicate a middle-fan depositional lobe presumably related to this valley. Correlation of this area with the upper fan studied by Piper and Normark (1982b) indicates that some time later, but still earlier than horizon R time, a second valley developed, probably by spillover on the upper fan, and prograded toward the study area (Fig. 10B). The prominent levee relief on the west side of this new valley then began to develop. The convex-upward surface of a coarse lobe deposit (section immediately beneath R) began to form at the end of this channel (Fig. 10B). The channels that developed on this lobe were then filled by acoustically transparent material that appears to cover much of the lobe surface. We do not know if this material is from a debris flow or if it is hemipelagic. The lobe and the acoustically transparent section above it formed a low topographic barrier at the termination of the western valley (feature 1 in Figure 10C), so that turbidity currents would generally be deflected to the east, and would build up a levee over this barrier. The thickness of sediment above the youngest correlatable reflector (S, Fig. 5A) shows that the levee crest migrated north as deposition continued. This migration, in turn, constricts turbidity-current flow against the outward slope of the levee of the eastern valley (Fig. 10D).

The finer details of relief seen in the present bathymetry are related, in part, to the relief developed on reflector R. Channeled areas developed on the R surface tend to be topographically high today (Fig. 6). If the lower parts of these channels are filled with coarser sediments, differen-

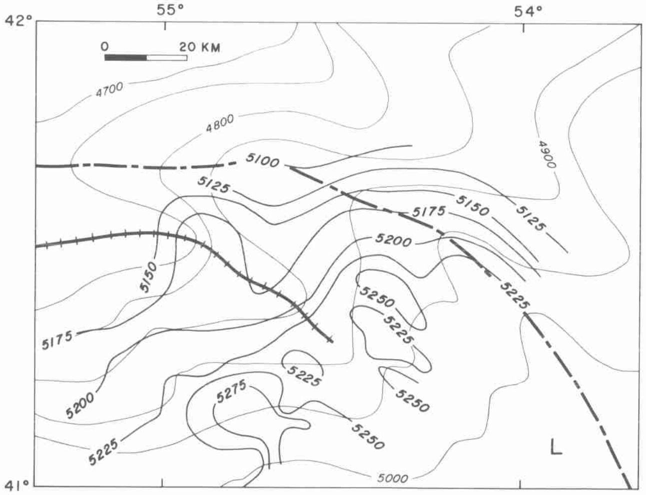

FIG. 7—Paleobathymetry of horizon L superimposed on present bathymetry. Format same as in Figure 6. Paleobathymetry constructed using sound velocities as described for Figures 5 and 6.

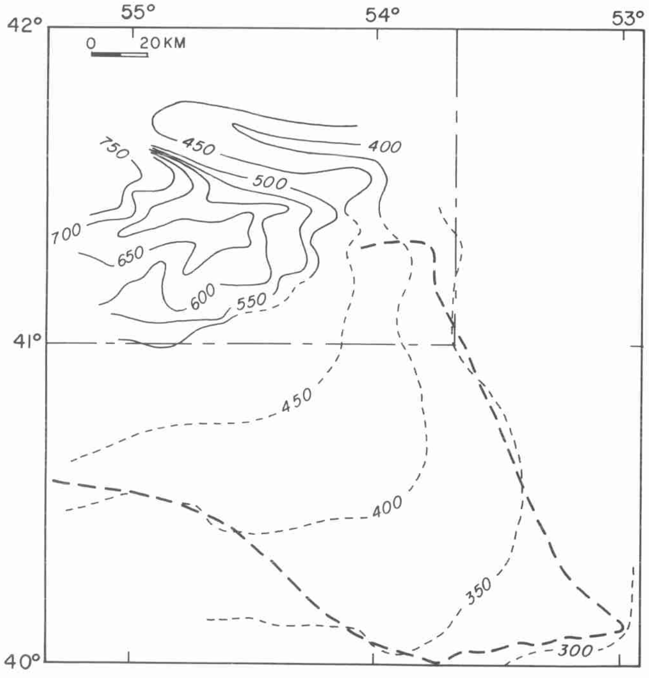

FIG. 8—Isopach map of the interval between reflector L and sea floor extended (light dashed lines) to area of depositional lobe. Units are in milliseconds of round-trip traveltime (approximately equal to meters; note Figure 5C for comparison).

tial compaction would tend to produce slightly inverted relief above R as overbank deposition continues. This relief has not been smoothed completely by subsequent levee deposition (Fig. 2).

Piper and Normark (1982b) speculated that the valley reorganization on the upper fan that led to the growth of the western valley was related to Pleistocene glacial erosion of the Laurentian Channel. The sediment source shifted from material carried by longshore drift to mass wasting of ice-rafted glacial debris on the upper slope. The deep shelf break of the Laurentian Channel prevented shelf-edge progradation during times of lowered sea level, while mass wasting, probably seismically induced, led to erosion and recession of the shelf break. This lengthened the turbidity-current channel thalweg, leading to valley incision (see also Normark and Piper, 1969). The debris flow above R was perhaps the result of a major submarine slide, but it is not possible to correlate it exactly with any specific event on the upper fan.

LAURENTIAN FAN GROWTH PATTERN

The Quaternary growth pattern of the Laurentian fan has produced a gross morphology that includes features common to submarine fans formed along passive continental margins. Foremost, the fan itself is large, about 600 km (375 mi) long between the base of the continental slope and the Sohm Abyssal Plain. Turbidity currents from the fan can spread across the abyssal plain for another 800 km (500 mi) (Fruth, 1965), so the entire system is among the world's largest sites of active turbidite deposition. The Laurentian fan has two major leveed valleys on the upper fan, and other shorter valleys can be identified, at least one of which is confluent with the present western valley (Piper and Normark, 1982b). Most large passive-margin fans have more than one leveed valley on the upper fan, for example, the Indus (F. Coumes, oral commun., 1981) and Bengal fans (Curray and Moore, 1971) which are fed from great river delta systems. The widths of the valley-levee complexes range from 50 to 80 km (30 to 50 mi) in proportion to the lengths of the turbidite systems (Normark, 1978, his Figure 6A). Also, like other passive margin fans, the Laurentian fan has rather nondescript small-channel relief in the area below the termination of the leveed valleys.

In addition to its general similarities to other passive-margin systems, the Laurentian fan has several unique features. The leveed channels are highly asymmetric, with the western (right-hand, looking downstream) levee apparently receiving most of the overbank sediments. The levee sediments are highly stratified on the basis of the character in seismic reflection profiles, similar to some northeast Pacific systems like the Delgada fan (Normark and Hess, 1980) but unlike the Bengal or Indus fans. The

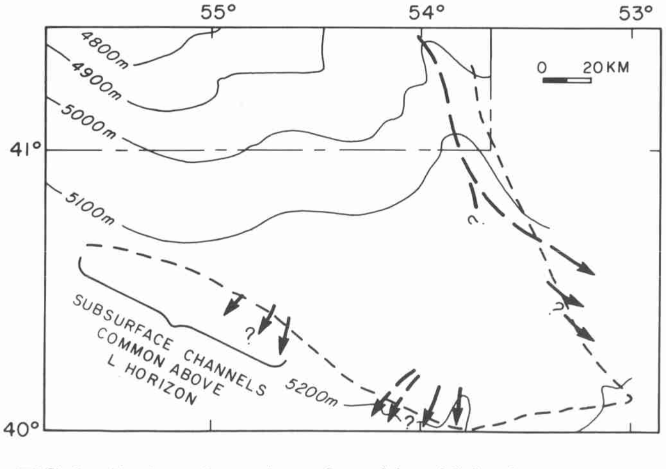

FIG. 9—Surface channels on depositional lobe shown as arrows where observed on seismic profiles (light dashed line). No distributary system can be determined with existing data.

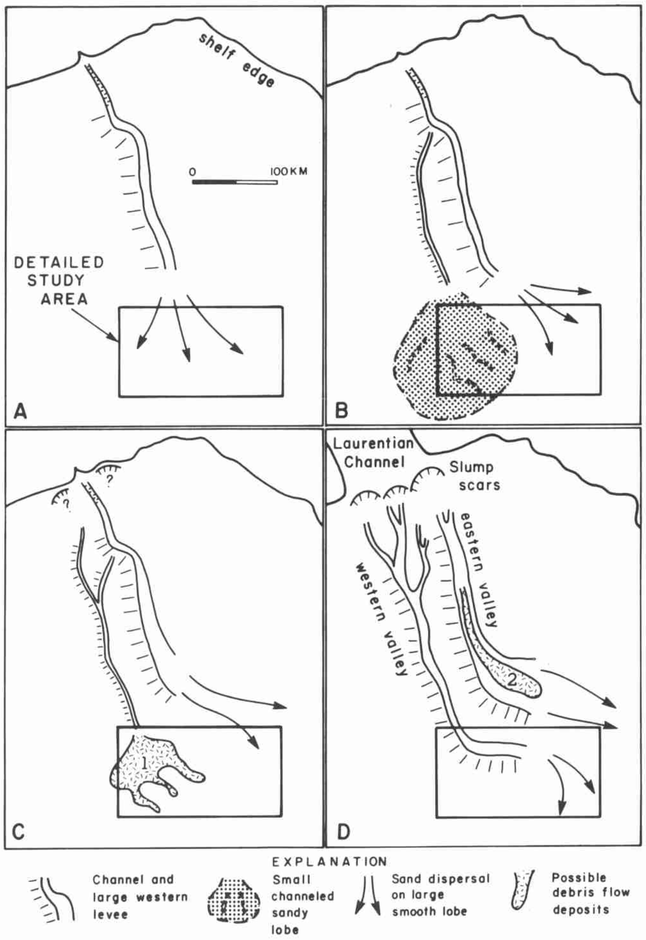

FIG. 10—Schematic illustration of stages in Laurentian fan growth from horizon L to present sea floor. (A) Immediate post-L time: the single major valley on upper fan has large western levee and feeds a broad, smooth depositional lobe. (B) Immediate pre-R time: a small, channeled sandy lobe is developing in study area below a second small fan valley, which formed from overflow through a breach in main valley levee on upper fan (Piper and Normark, 1982b). (C) Immediate post-R time: debris flow (1) or hemipelagic sediment covers upper part of lobe. Aggradation of lobe area produced low topographic barrier to turbidity currents in main valley. (D) Subsequent turbidity current deposition in detailed study area is deflected eastward against right-hand levee of eastern valley. Debris flow deposits (2) lead to bifurcation of eastern valley.

eastern valley of the Laurentian fan has levee-crest-to-valley-floor relief that locally exceeds 1 km, the greatest of any submarine fan yet described. The steepest depositional slopes on the Laurentian fan are on the prominent right-hand levees, being 1:100 along the downfan trend of the levee crest and 1:40 on the bedding slope away from the channel; both values are significantly steeper than the slope of the channel axis, 1:140. Further, the straight part of the right-hand levee of the western valley terminates with slopes approaching 1:30. As described earlier, both major valleys end with eastward hooks in their right-hand levees.

The major differences in growth pattern between the Laurentian fan and the other passive-margin fans probably reflect: (1) differences in the sediment supply, (2) effects of mass wasting and channel erosion on the upper slope off the Laurentian Channel, and (3) effects of bottom-water circulation on sediment dispersal (or redistribution after deposition) where contour-following currents move or deflect sediment perpendicular to downslope-trending turbidite channels. Most of the larger submarine fans receive a relatively restricted range of sediment grain sizes supplied from the extensive deltas formed on the shelves above the fans. The Laurentian fan, however, receives sediment from a glaciated margin underlain by extensive deposits of glacial till (Stanley et al, 1972), and the sediment ranges in size from clay to gravel. In addition, mass wasting, including large slides, of the upper slope sediments has provided large amounts of debris for the fan. Subsequent headward erosion of slope-channel thalwegs into slide scar areas has resulted in deepening of the entire valley system (Normark and Piper, 1969). The sliding can result from either the instability of underconsolidated material on the slope or the seismic shaking along a still active segment of an extension of an oceanic fracture zone along the Grand Banks Rise and outer Laurentian Channel (King and MacLean, 1976; Stewart, 1979).

The wide range of grain size of material moving through the Laurentian fan valleys will act to maintain extreme levee-crest-to-valley-floor relief, because the overbank deposition of clay and silt will cause aggradation of the levees while gravel and other coarse materials will erode the channel floor (Stow, 1981). The prominent stratification in the levee sections is also a result of the wide range of grain size and sliding. The infrequent, but very large, turbidity currents (Piper and Normark, in press) are capable of producing overbank deposition of a larger amount of coarse sediment than is generally available in fans fed from deltaic sources.

Although the asymmetry of the levees on the Laurentian fan might in part be a reflection of the Coriolis effect on turbidity-current flow at high latitude in the Northern Hemisphere (Menard, 1955), more probably it results from the pronounced westward flow of the Western Boundary Undercurrent along the Canadian margin (Heezen and Hollister, 1971). The effect of thermohaline contour currents farther southwest off the continental slope of the United States has been strong enough to prevent typical submarine fan morphology from developing below most of the submarine canyons (Emery and Uchupi, 1972).

The steep backside slopes of the levee sequence are similar to those of some deep-sea fans off California. The abrupt termination of the levee is a striking feature and suggests that a relatively large proportion of the turbidity currents fill or overflow the valley; therefore, when the current expands laterally at the end of the valley, rapid deposition results in progradation over the full levee height. If a large proportion of the turbidity currents are less than bank-full flow, the levee progradation will occur preferentially at the base of the levee and the overall levee relief will decrease more gradually. If this argument is correct, the east-west–trending part of the levee that forms the abrupt hook in the channel is probably formed only by deposition of the suspended load; most of the washload of the turbidity current must continue south as it is stripped from the top of the flow remaining in the channel (Piper and Normark, in press). In time, the high, muddy levee will advance southward, eventually burying the short segment that forms the hook.

The growth pattern suggested by our study of part of the middle Laurentian fan gives some insight into the formation of stratigraphic traps on large, deep-water submarine fans. The principal area of sand accumulation on the fan is the very large sandy lobe, which extends laterally for several hundred kilometers and is several hundred meters thick. Cores (including one short DSDP hole) on the lobe recover sand almost exclusively, although the stratified acoustic character suggests muddy interbeds occur. Proximally, the sand lobe passes into sandy channel facies (Stow, 1981), but because of the shifting channel patterns on the upper fan (Piper and Normark, 1982b), updip migration of hydrocarbons would be largely prevented by shaly channel fills in abandoned or cutoff channels. At the northern edge of the sandy lobe, thick fine-grained levee sediments are rapidly prograding over the lobe. Cores suggest these sediments are predominantly muds, with thin interbedded silts. This suggests that large sandy lobes on deep-water fans could become excellent reservoirs for hydrocarbons where the lobes are buried deeply enough to be contiguous with adequate source beds.

CONCLUSIONS

The Laurentian fan is a large Quaternary deposit that displays growth characteristics intermediate between passive-margin fans fed by major river deltas and intermediate-size fans developed along active transform margins of the northeast Pacific Ocean. Multiple, wide, leveed-valley complexes dominate the upper fan as in delta-fed systems, but the sediment distribution and internal structure in the complexes reflect the more heterogeneous nature of the sediment supplied and the effects of headward erosion into the upper slope sediments. The erosional retreat of the shelf-slope edge is the result of both glacial cutting of the Laurentian Channel and local mass wasting, probably resulting from earthquakes. Development of the levees and depositional lobe in the middle fan area may be directly affected by larger submarine slide episodes. In the case of the western valley of the Laurentian fan, lobe aggradation and/or partial blocking of the valley at its termination has resulted in an eastward deflection of turbidity-current flow. This deflection has resulted in a sharp eastward hook in the valley and its levee.

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