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SEDIMENTOLOGY OF THE EOCENE TAGLU DELTA, BEAUFORT - MACKENZIE BASIN: EXAMPLE OF A RIVER-DOMINANT DELTA

James Dixon





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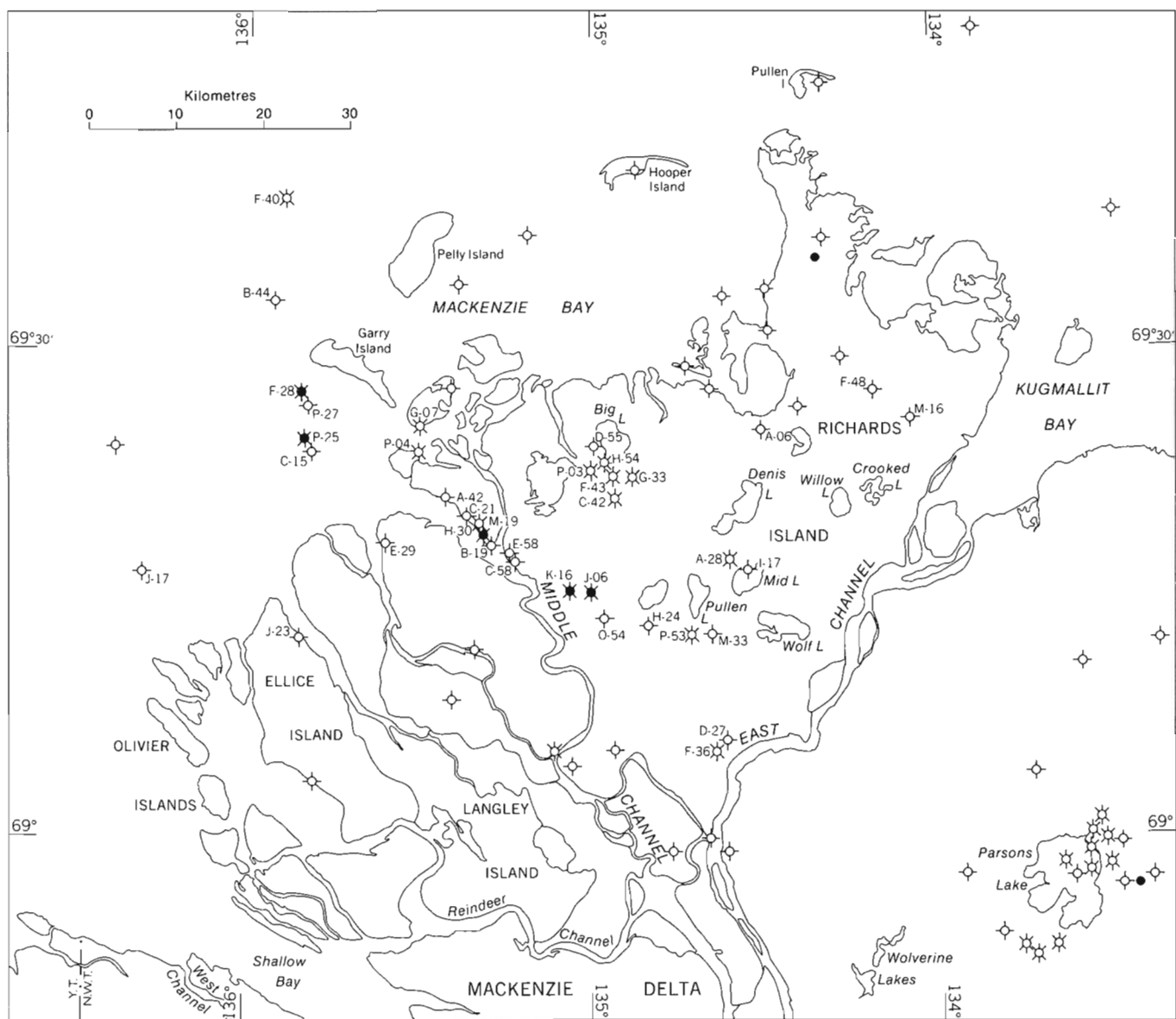
SEDIMENTOLOGY OF THE EOCENE TAGLU DELTA, BEAUFORT - MACKENZIE BASIN: EXAMPLE OF A RIVER-DOMINANT DELTA

Abstract

The Taglu Delta represents the final clastic delta wedge of the lower Tertiary Reindeer Formation before burial under a thick marine mudstone succession. Specific depositional subenvironments can be identified from core material and include delta front, distributary mouth bar, distributary channel, crevasse splay and interdistributary bay. Integration of core interpretations with geophysical log shapes and their extrapolation to uncored wells allows a three dimensional depositional framework to be established. Lobate distribution of sands and the prominence of channel sands points to a river-dominant delta. The character of the channel deposits suggests that some channels may have been braided. A relatively thick sequence of lower delta plain deposits also points to a moderate to strongly subsiding receiving basin and/or rapid delta compaction. Sands from the various subenvironments are predominantly quartz and chert. Other, less common, components include plagioclase, muscovite and clasts of limestone, volcanic rock, schist, coal and shale. Two main source areas seem likely for the Taglu Delta, one to the south and the other as far west as Alaska.

Résumé

Le delta de Taglu correspond à l'édification finale du prisme clastique deltaïque de la formation de Reindeer, d'âge tertiaire inférieur, avant l'enfouissement de celui-ci sous une épaisse succession marine à mudstones. À partir de carottes de sondage, on a pu identifier les sous-environnements sédimentaires spécifiques; ceux-ci comprennent le front du delta, des flèches littorales, des chenaux défluent, des alluvions déposées à travers les brèches des levées, et des indentations du front du delta. L'intégration de l'interprétation des carottes de sondage aux logs géophysiques et leur extrapolation à des puits non échantillonnés ont permis d'établir un schéma tridimensionnel applicable à la sédimentation. L'arrangement lobé des sables et l'importance des sables issus des chenaux indiquent qu'il s'agissait d'un delta à apports fluviaux dominants. Le caractère des dépôts formés dans les chenaux semble indiquer que certains de ces chenaux étaient anastomosés. Une succession relativement épaisse de dépôts formés dans la partie inférieure de la plaine deltaïque indique aussi une subsidence forte à modérée du bassin récepteur ou un tassement rapide des dépôts deltaïques. Les sables des divers sous-environnements sont surtout composés de quartz et de chert. Parmi les autres constituants moins communs, on trouve des plagioclases, de la muscovite, des clastes calcaires, des roches volcaniques, des schistes, du charbon et des argiles litées. Il semble que le delta ait reçu des matériaux de deux principales sources, l'une située au sud, l'autre située très à l'ouest, jusqu'en Alaska.



List of wells used in the study or cited in the text

BA Shell IOE Reindeer D-27
Chevron SOBC Upluk A-42
Chevron SOBC Upluk C-21
Gulf Mobil Kilagmiotak F-48
Gulf Mobil Kilagmiotak M-16
Gulf Imperial Shell Reindeer F-36
Gulf Mobil Toapolok O-54
Gulf Mobil Toapolok H-24
Gulf Mobil Ya Ya P-53
Gulf Mobil Ya Ya M-33

Gulf Mobil Ya Ya A-28
Gulf Mobil Ya Ya I-17
Imperial Adgo F-28
Imperial Adgo P-27
Imperial Adgo P-25
Imperial Adgo C-15
Imperial Delta 5 Ikattok J-17
Imperial Langley E-29
Imperial Mallik A-06
Imperial Netserk B-44

Imperial Netserk F-40
Imperial IOE Taglu West P-03
IOE Taglu C-42
IOE Taglu D-55
IOE Taglu F-43
IOE Taglu G-33
IOE Taglu H-54
Sun CCL BVX et al. Garry G-07
Sun SOBC BVX et al. Garry P-04
Shell Kumak C-58

Shell Kumak E-58
Shell Kumak J-06
Shell Niglintgak B-19
Shell Niglintgak H30
Shell Niglintgak M-19
SOBC North Ellice J-23

Oil producer●
Gas producer*

Oil and Gas producer*

Dry (abandoned)○

FIGURE 1. Location map.

SEDIMENTOLOGY OF THE EOCENE TAGLU DELTA, BEAUFORT - MACKENZIE BASIN: EXAMPLE OF A RIVER-DOMINANT DELTA

INTRODUCTION

Tertiary strata in the Beaufort-Mackenzie Basin have been the subject of several regional studies (Hawkings and Hatlelid, 1975; Young et al., 1976) but there are few detailed sedimentological analyses available. Bowerman and Coffman (1975) presented a general sedimentological account of the reservoir rocks in the Taglu gas field. These economically important strata are in the upper part of the Paleocene-Eocene Reindeer Formation (*sensu* Young et al., 1976). Shawa (1978) dealt with the same succession but expanded the study to include equivalent strata from other wells in the basin. He followed Bowerman and Coffman (1975) by concluding that these rocks originated in a deltaic setting. I re-examined the same rocks and although a general deltaic setting is re-affirmed I have arrived at different interpretations of the stratigraphy, specific depositional units and overall depositional model. The delta model proposed in this report will be useful in the exploration and production of petroleum, as it offers a means of predicting reservoir distribution and character.

The uppermost 200 to 250 m of the Reindeer Formation were analysed from thirty wells (Appendix I, Fig. 1) and core material was examined from Taglu C-42, G-33, D-55 and P-03; Kumak C-58, J-06 and K-16; Garry P-04 and G-07; Niglintgak B-19 and Upluk A-42. The cores from Taglu C-42 and G-33 and Garry G-07 were especially valuable and provided the basis for many of the detailed interpretations of the sedimentary environments. By integrating the core data, rock composition and grain size distribution with log shape (generally the gamma-ray log), a fairly reliable method of sedimentological analysis is available. Core and cutting samples are available for inspection at the Institute of Sedimentary and Petroleum Geology, Calgary.

Acknowledgments

Valuable comments and criticisms were made by G. Reinson and A.F. Embry. Photographic work was done by B. Rutley.

STRATIGRAPHY

Regional transgression during the Eocene buried the coarse clastic deltaic sediments of the Reindeer Formation under a thick mudstone succession, the "unnamed Eocene shale" of Young et al. (1976). The apparent rapid sea level rise during transgression prevented excessive erosion of the Reindeer Formation and the last delta cycle is preserved under the unnamed Eocene shale. The last delta cycle is referred to as the Taglu Delta, after the Taglu gas field (Fig. 2, interval above horizon 2).

Shawa (1978, 1979) proposed the term Taglu member for the upper part of the Reindeer Formation citing the Taglu G-33 well as the type location. The Taglu Delta of my report corresponds to the upper part of the Taglu member, as defined at the type well (Fig. 2, section A). Shawa's (op. cit.) choice of the Taglu member in some other wells differs markedly from my correlations. Bowerman and Coffman (1975), in their description of the Taglu gas field, divided the upper 400 m of the Reindeer Formation into three

depositional units labelled, in descending order, A, B and C. Units A and B are approximately equivalent to Shawa's (op. cit.) Taglu member and Unit A corresponds to the Taglu Delta of this report. Bowerman and Coffman (op. cit.) gave a generalized sedimentological interpretation of deltaic deposits and Shawa (op. cit.) presented a more extensive analysis.

By using the base of the unnamed Eocene shale as a regional marker, and also various local marker horizons, the Taglu Delta strata can be correlated throughout the Richards Island area (Fig. 2). Correlation problems occur on the peripheral areas of the Taglu Delta, such as at Mallik A-06, Kilagmiotak F-48 and M-16, Ikattok J-17 and Netserk F-40. While I believe that strata of the Taglu Delta are present in the Mallik A-06 and Netserk F-40 wells, the base of the delta cycle is not readily identified. At Kilagmiotak F-48 and M-16 an abnormally thin Eocene shale equivalent may be due to an interval erosional unconformity that eroded the top of the Reindeer Formation. The Reindeer Formation at Ikattok J-17 is encountered at shallow depths and a mid-Tertiary or younger erosional episode may have removed the equivalent of the Taglu Delta succession. However, it is tentatively suggested that Taglu Delta strata are present.

On the southeastern edge of the study area, at Reindeer D-27 and F-38, most of the Eocene shale has been eroded. The presence of *Wetzeliella hampdensis* and *Pesavis tagluensis* in the D-27 well (Staplin, 1976) indicates that a thin representative of the Eocene shale is present but it is difficult to identify the precise boundaries of the shale. Consequently, the Taglu Delta strata cannot be identified. The erosional event that truncated the Eocene shale cut progressively deeper towards the south, removing the upper part of the Reindeer Formation (Fig. 11).

DEPOSITIONAL ENVIRONMENTS AND LITHOFACIES

The Taglu Delta represents a single regressive depositional event, formed by a prograding delta, with marine deposits at the base grading upwards into lower delta plain deposits. Within this general framework specific depositional environments can be recognized, these include prodelta and shelf, delta front and distributary mouth bar, distributary channel and interdistributary areas.

Prodelta and shelf deposits

The continental shelf generally is remote from active delta construction but shelf deposits may be derived from deltas by one or more of the following: density currents, mass movement, longshore currents and wave activity. Prodelta areas are the submarine basal parts of active deltas. In areas with a narrow continental shelf the distinction between shelf and prodelta may not be possible. Mudstone is the dominant lithology with subordinate amounts of siltstone and sandstone. Calcareous beds (muddy limestones) may be present locally and these may be either nodular concretionary horizons or laterally persistent carbonate beds. Sandstone beds tend to be thin, composed of very fine to fine sand grains, but locally are coarse grained to pebbly. Thick sandstone units are present locally, such as at Taglu H-54

(Fig. 2, section A). Core 5 from Garry G-07 penetrated 17.7 m (58 ft) of prodelta mudstone. The mudstone is predominantly massive with zones containing plane and ripple laminated very fine sand and silt, some of which are deformed. Small burrow structures are present and there are a few zones of moderate bioturbation.

In general, shelf areas are further removed from the sediment source and tend to be richer in muddy deposits than the prodelta environment. In the Taglu Delta it is very difficult to distinguish between shelf and prodelta deposits. However, near the base of the Taglu regressive succession (Fig. 2) there is a tendency for sand-free intervals to be present and these may represent shelf-type facies.

Delta front and distributary mouth bar deposits

The delta front (sometimes referred to as the distal bar or delta platform) is "the seaward sloping margin of the advancing delta sequence" (Coleman, 1976, p. 29) and the distributary mouth bar is an area of shoaling where the distributary river enters the sea (or lake). Both environments are sites of active deposition.

In the Taglu Delta, delta front deposits can be separated from prodelta deposits using gamma ray or SP logs. There is a distinct, gradual shift to the left of the log trace, indicating an increase in sand content as the delta front deposits gradationally succeed prodelta mudstones. Accompanying the vertical increase in sand content is an upward increase in average sand grain size. Delta front deposits may be succeeded by distributary mouth bar sands, but the latter can develop only in association with an active distributary channel. In Figure 2 it can be seen that not all the delta front deposits are associated with distributary channels. In such cases it is possible that if the delta front deposits built up into the zone of wave influence a submarine bar, marginal to the distributary mouth, may have developed (see Kelling and George, 1971, Fig. 4, for similar deposits described from the Carboniferous of Wales). However, in the Taglu Delta there is no core data to confirm such an interpretation, but the lateral relationships of the various deposits (Fig. 2) strongly favour the presence of submarine bars capping some delta front deposits.

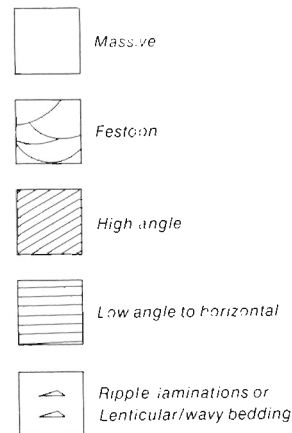
Delta front deposits in Taglu G-33 and C-42 consist of interbedded siltstone, fine to medium grained sandstone and mudstone (Figs. 3, 4, 5). Lenticular and wavy bedding are common in thin sandstone beds and in the thicker sandstone units crossbedding may be present. Load deformation is a common feature of lenticular and wavy bedded units. The mudstones may be massive, finely laminated, burrowed or bioturbated. In the modern Mississippi Delta (Coleman, 1976) delta front deposits are very similar to those described from the Taglu Delta. Elliot (in Reading, 1978, p. 128) attributed the sand-mud alternations of the delta front to repeated incursions of sediment-laden currents from the distributary mouth into an environment in which clay deposition is the norm.

Delta-front deposits are interpreted to be succeeded gradationally by distributary mouth bar deposits in the cores from Taglu C-42 (Figs. 4, 6) and G-33, between 2961.1-2973.3 m (9715-9755 ft) and 2572.5-2596.9 m (8440-8520 ft) respectively. These deposits consist of predominantly medium grained sandstone with local occurrences of coarse to pebble sized grains, interbedded with thin sandy-silty mudstone units. The sandstone beds vary from 1 to 3 m thick, may be massive, festoon crossbedded, planar crossbedded or horizontally bedded and have a basal erosion surface. Mudstone units vary from 15 to

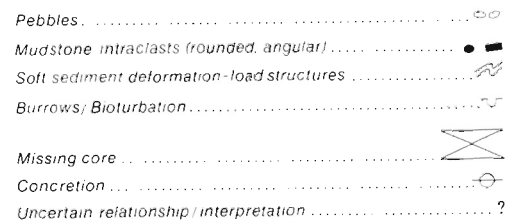
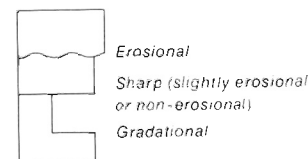
70 cm in thickness and commonly contain lenticular and wavy bedded fine sand and silt. Load deformation of these latter units is common. Such characteristics indicate deposition under high energy flow conditions forming medium to large scale bedforms in the sand-sized material, alternating with periods of lower energy flow, features consistent with a position at the distributary mouth. In the Mississippi Delta, detailed accounts of sedimentary structures in the distributary mouth bar are few, although Coleman (1976, p. 33) stated that small scale cross lamination and ripple lamination are very common. Horne and Fern (1978, p. 11 and 14) described multidirectional festoon crossbedding from the central part of distributary mouth bars.

In the Taglu G-33 well Shawa et al. (in Shawa, 1974) identified delta front deposits between 2587.8-2596.9 m (8490-8520 ft) and distributary mouth bar deposits between 2578.6-2587.8 m (8460-8490 ft). Above 2578.6 m (8460 ft) they identified two full and the lower third of another three fining upward sandstone units as channel deposits (i.e. distributary channels of this report). The two lower channels in G-33, as interpreted by Shawa et al. (op. cit.), are unusually thin when compared with other distributary channel deposits of the Taglu Delta (see Figs. 2, 4) and are here interpreted as chute deposits on a distributary mouth bar. The fining upward cycle above 2572.5 m (8440 ft) is interpreted as a true distributary channel deposit.

STRATIFICATION



CONTACT RELATIONS



GSC

FIGURE 3. Explanation of symbols for Figures 4, 8 and 10.

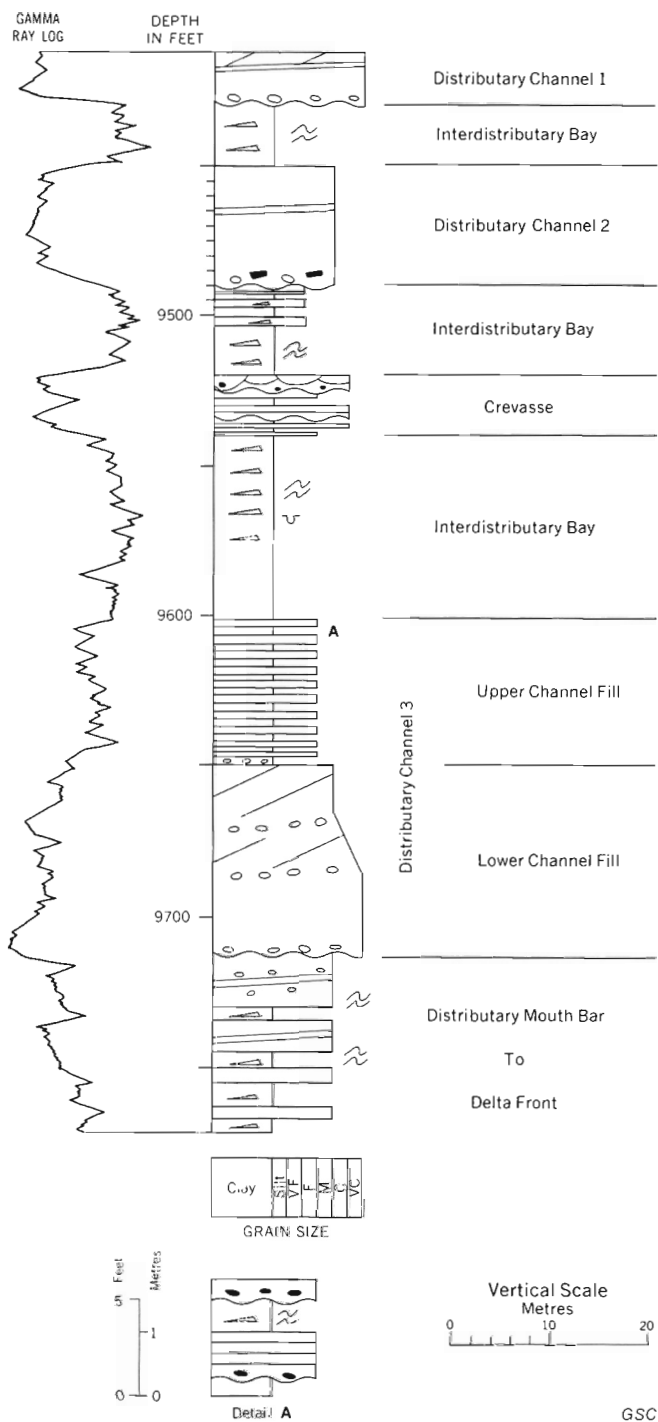


FIGURE 4. Graphic display of core and sedimentological interpretations; 2868.8-2978.5 m (9412-9772 ft); Taglu C-42.

The distribution between delta front and distributary mouth bar deposits can only be made when core material is available and, consequently, these two environments have been grouped for the purpose of correlation (Fig. 2). Also, it is quite common for distributary channels to erode down into delta front deposits, reducing the likelihood of preserving distributary mouth bar deposits.

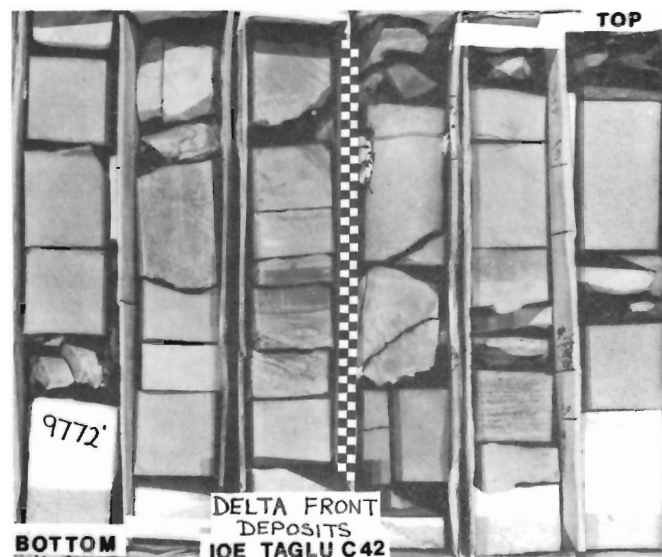


FIGURE 5. Delta front deposits, Taglu C-42. Bar scale 50 cm in 1 cm divisions.

Distributary channel deposits

Distributary channels are fluvial systems on the delta plain in which the bulk of the delta sediment is transported. In lower delta plain areas distributary channels tend to be straight or of low sinuosity, and deposition is mainly within the channel. This contrasts with deposition by lateral accretion of meandering river channels. In low sinuosity channels, the channel margins are built up by repeated flooding and deposition to form levees.

Distributary channel deposits have been recognized in core material from Taglu C-42 (Figs. 4, 6, 7), Taglu G-33, D-55 and P-03, Upluk A-42, Kumak C-58, K-16 and J-06. The channel deposits vary in thickness from 12.2 to 42.7 m; the latter value was obtained from an interpreted channel deposit in the Toapolok H-24 well (Fig. 2, section B). It is not known whether the H-24 example represents single or stacked channels. The thickest known single channel fill occurs in Taglu C-24 (Fig. 4, 2926.7-2961.1 m: 9602-9715 ft) where a 34.4 m channel deposit has been identified in core material. The Taglu C-42 example also illustrates another aspect of some channel deposits, that of a two-fold division, herein referred to as the lower and upper channel fill (Figs. 4, 6, 7).

Distributary channel deposits have an erosional base overlain by pebbly, coarse to very coarse grained sandstone grading upwards into finer grained, commonly pebble-free sandstone (Figs. 6, 7). Grain size may decrease upwards to fine sand but in some channel deposits a relatively uniform grain size is maintained, usually medium grained sand. Layers, lenses and isolated well rounded pebbles may occur throughout the lower channel fill. The most common feature of the lower channel fill is its massive appearance. Where present, sedimentary structures include subhorizontal bedding to very low angle crossbedding and some steeper dipping planar crossbedding. Festoon crossbedding has not been identified in any of the cored channel deposits. Internal scour surfaces may be present in the lower channel fill, such as in Taglu G-33 between 2485.0-2508.5 m (8153-8230 ft). In general, massive sands are more common in the basal parts of the lower channel fill and cross- or horizontal beds in the upper part (Figs. 4, 6).

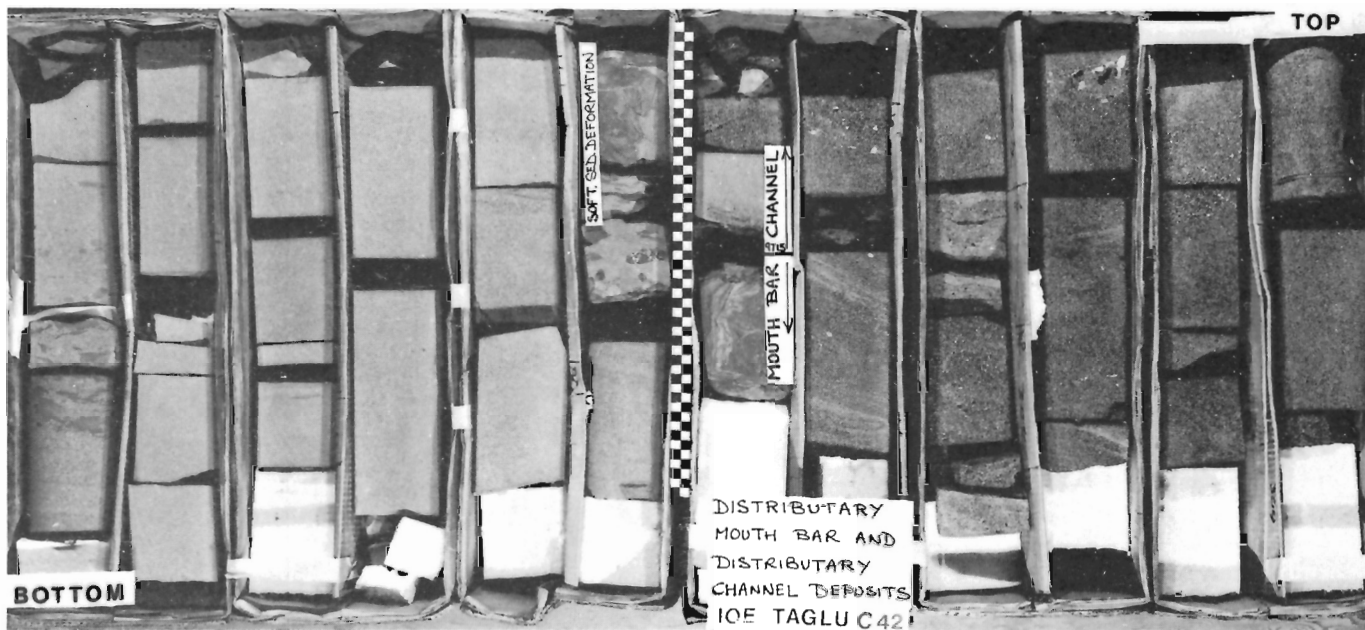


FIGURE 6. Distributary mouth bar and distributary channel deposits, Taglu C-42. Bar scale 50 cm in 1 cm divisions.

Upper channel fill deposits may consist of sandstone-mudstone cycles as in Taglu C-42 (Figs. 4, 7), Kumak K-16, and Niglintgak B-19 or fine grained, argillaceous sandstone as in Taglu G-33. In both cases, the unit is identified on the gamma-ray log by an abrupt shift to the right on the log trace immediately above the lower channel fill, and by a ragged log response throughout the thickness of the unit (Fig. 4). All the identified upper channel fill deposits are abruptly overlain by interdistributary mudstone and this change is seen as a further shift to the right on the gamma-ray log (Fig. 4).

The base of the upper channel fill sequence in the Taglu C-42 core (Figs. 4, 7) is marked by a pebble layer a few centimetres thick, gradationally overlain by mudstone. Succeeding strata consist of sandstone mudstone cycles (Figs. 4, 7) varying in thickness from 0.3 to 1.5 m. The basal fine to medium grained sandstone units rest sharply, and probably erosively, upon the underlying mudstone. Mud clasts are present at the base of some sandstone units. Very low angle to subhorizontal stratification is the most common sedimentary structure and only rarely are planar crossbeds or massive strata present. Penecontemporaneous deformation within the sandstones is very rare; one possible example is seen between 2943.8-2944.4 m (9658-60 ft) where clay-filled shear planes may be the result of such deformation. The mudstone units contain interlaminae of fine grained sand, with wavy and lenticular bedding in the latter. Thick, sand-free, massive mudstone units are also present. A thin zone of rippled sand with clay laminae occurs at the sandstone-mudstone contact. Burrows are rarely present.

In contrast, the upper channel fill deposits in the Taglu G-33 well consist of only fine grained sandstone, either massive or with low angle crossbedding. The base of the unit occurs at a 2 to 5 cm zone of finely laminated, fine grained sandstone, rich in coaly debris and abruptly overlying a massive, medium grained sandstone. There is no apparent cyclicity within the unit. Internal erosion surfaces are not readily recognized, although abrupt changes in dip directions of the cross strata may indicate the presence of minor truncation surfaces.

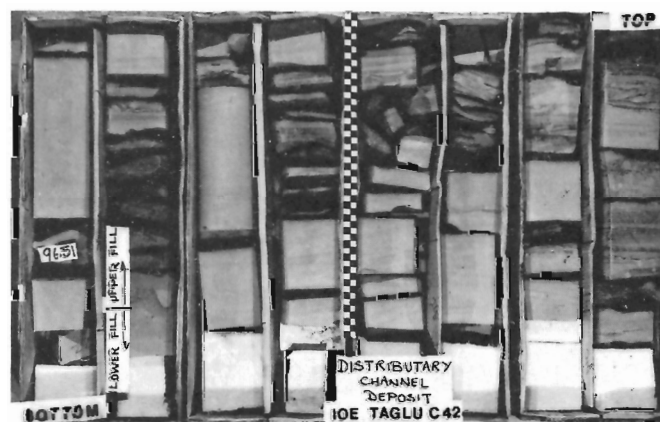


FIGURE 7. Upper channel fill deposits, Taglu C-42. Bar scale 50 cm in 1 cm divisions.

Most of the channel deposits recognized in the Taglu Delta (Fig. 2) have the twofold division; however, there are a number where interdistributary mudstone rests directly on lower channel fill (Channel 2, Fig. 4). The lower channel fill is interpreted as an in-channel deposit and the massive character of many of these units can be attributed to deposition under highly turbulent flow, such as that postulated by McCabe (1977) and Conaghan and Jones (1975). McCabe (op. cit.) suggested that massive beds may represent the trough deposits of large bedforms deposited under conditions of extreme turbulence. The presence of some stratification within or above massive beds (Fig. 4) indicates that fluctuating flow conditions allowed some stratification to develop sporadically.

The abrupt change in sediment character between lower and upper channel fill reflects differing hydraulic regimes. At Taglu C-42 the sand-mud cycles must have been deposited during rapidly waning flow conditions, the sand unit being deposited as low amplitude or plane bedforms during flood conditions and the mud deposited during slack water periods.

Wavy and lenticular bedded sand intercalated within the mud units point to minor current activity and reworking of sandy material. At Taglu G-33 equivalent deposits show no apparent cyclicity, have a more uniform grain size and are predominantly crossbedded. These characteristics are consistent with more uniform flow and deposition as larger bedforms such as megaripples or small sandbars. Compared to the lower channel fill, the upper channel fill deposits must have been laid down under lower flow conditions and/or shallower water.

The consistent vertical relationship between the lower and upper channel fills denotes a common depositional setting in which variable flow and/or bathymetric conditions produced the vertical succession. McCabe (1977) described similar twofold distributary channel successions from the Carboniferous of England, although the Carboniferous channels are considerably thicker than those in the Taglu Delta. A lower sandstone succession with giant crossbeds is overlain erosionally and/or gradationally by thinner units of trough and tabular crossbedded sandstone. McCabe (op. cit.) interpreted this succession as deposits of alternate bars in a low sinuosity channel. The lower strata were deposited within the deep channel and the upper strata were deposited on shoal areas of the alternate bars (McCabe, 1977, Fig. 11). These Carboniferous channels have maximum depths of over 40 m and up to at least 1.5 km wide. While McCabe (op. cit.) favoured an alternate bar origin for the deep channel deposits he did point out that braided rivers with deep channels could produce a similar succession.

In the Taglu Delta the basal distributary channel deposit (channel 3 in Taglu C-42, Figs. 2, 4) appears to be correlative throughout the Taglu gas field and must be at least 5 km wide. Lateral migration of a channel could produce a wide deposit, however, lower delta plain distributary channels in present day deltas tend not to migrate laterally but to maintain a relatively constant, slightly sinuous course, and channel position changes are by rapid switching due to avulsion. If this deposit resulted from a single distributary channel it is difficult to envisage a 5 km wide channel with such extensively developed alternate bars. McCabe's (op. cit.) suggestion of a braided river origin is more probable for some of the Taglu Delta channel deposits. A wide channelled zone with a few deep channels separated by shoal areas on which shallow braided distributaries flow, could account for the Taglu Delta deposits. The lower channel fill would represent deposits of the deep channels, and their wide extent may be explained by lateral migration or switching of the deep channels within the braided zone. The intervening shoal areas would have shallower, and possibly ephemeral streams, in which small-scale bedforms were deposited to form the upper channel fill. By the constant changing of positions of the deep and shallow channels within a braided zone the resulting deposits would have a vertical succession similar to that of some of the Taglu channel deposits.

Two known modern deltas have braided channels, the Ganges-Brahmaputra (Coleman, 1969) and the Copper (Galloway, 1976). Some of the characteristics of these modern deltas may be applicable to the Taglu Delta. Both the Ganges-Brahmaputra and Copper Deltas have wide, braided channel areas close to the distributary mouths, up to 15 km wide in the Ganges-Brahmaputra. The braided area consists of one or more deep channels, separated by shoal areas on which shallow braided distributary channels are separated by sand bars. During flood periods, the entire width of the braided zone may be full of water, as in the Ganges-Brahmaputra, and the braided nature becomes indistinguishable. Details of the channel deposits from the Ganges-Brahmaputra delta are lacking and no comparison with the Taglu deposits can be

made. Galloway (1976, p. 730) described the Copper River braided channel deposits as consisting of "repetitive sequences of crossbedded and planar bedded sand capped by interbedded muddy, ripple laminated units", a vertical succession broadly similar to some of the Taglu Delta channel deposits (see Taglu D-55 core, interval 3172.7-183.3 m: 10 409-444 ft). If the Taglu Delta distributary channels were braided the distributary mouth bars would have been very diffuse, occupying a wide zone, unlike the limited extent of the Mississippi-type of distributary mouth bar. This type of situation is found in the Ganges-Brahmaputra and Copper deltas, although in these examples wave activity modifies the distributary mouth bars.

Not all the distributary channels of the Taglu Delta are 5 km wide (Fig. 2) and the alternate bar model could still be applicable to some of the channel deposits. Also, it is possible that the twofold division of the channel deposits resulted from an active channel being abandoned. The lower fill would represent deposition in an active channel and the upper fill formed by small, perhaps ephemeral streams, occupying the abandoned channel. This process is well known in meandering river systems but apparently has not been identified in channels of the lower delta plain, and for the present a braided channel interpretation is preferred.

Interdistributary deposits

Distributary channel deposits are encased by a variety of facies of interdistributary origin. Interdistributary areas in the lower delta plain consist of open water, shallow bays or lagoons, which may or may not be connected to the sea, and are bordered by levées, marshes or splay deltas (Coleman, 1976, p. 36-43). Sedimentation in the bays is usually of fine-grained sediment, dominantly clay interlaminated with sand and silt. Significant amounts of sand may be introduced by crevasse splays from the distributary channels. Coleman and Gagliano (1964) likened the Mississippi crevasse deposits to microdeltas, exhibiting a coarsening upward succession similar to the much thicker Mississippi delta succession. Elliot (1974a, 1974b and in Reading, 1978) expanded our knowledge of crevasse deposition and showed that a wide range of vertical successions can be formed by crevassing. Elliot (in Reading, 1978) recognized two mechanisms of crevassing, namely:

- 1) crevasse splay which he defined as, "a sudden incursion of sediment-laden waters which deposits sediment over a limited area on the lower flanks of the levées and the bay floor, producing locally wide levée aprons". The resulting deposits may be either a sequence of sands deposited in small channels or turbidite-like;
- 2) formation of a microdelta (*sensu* Coleman and Gagliano, 1964) consisting of a minor mouth bar and crevasse channel complex.

In the Taglu Delta the first mechanism, crevasse splay, appears to have been dominant, consistent with the high energy conditions. Figures 8, 9 and 10 illustrate examples of crevasse deposits which, in detail, consist of a number of subenvironments. Channel-type deposits are very common in the crevasse splays and in Niglintgak B-19 (Fig. 9) a thick sequence of crevasse splay sediments appears to be composed of stacked channel deposits. Also shown (Fig. 4) are a number of other depositional environments of the interdistributary area. Beach deposits are generally thin units with fine subhorizontal bedding and abrupt, non-erosional upper and lower contacts. Marine bar deposits are characterized by an upward gradation from bay muds to planar crossbedded sands in turn abruptly overlain by bay muds. Sheet flood deposits may be represented by thin beds of massive or laminated sandstone with possible erosional bases and abrupt tops.

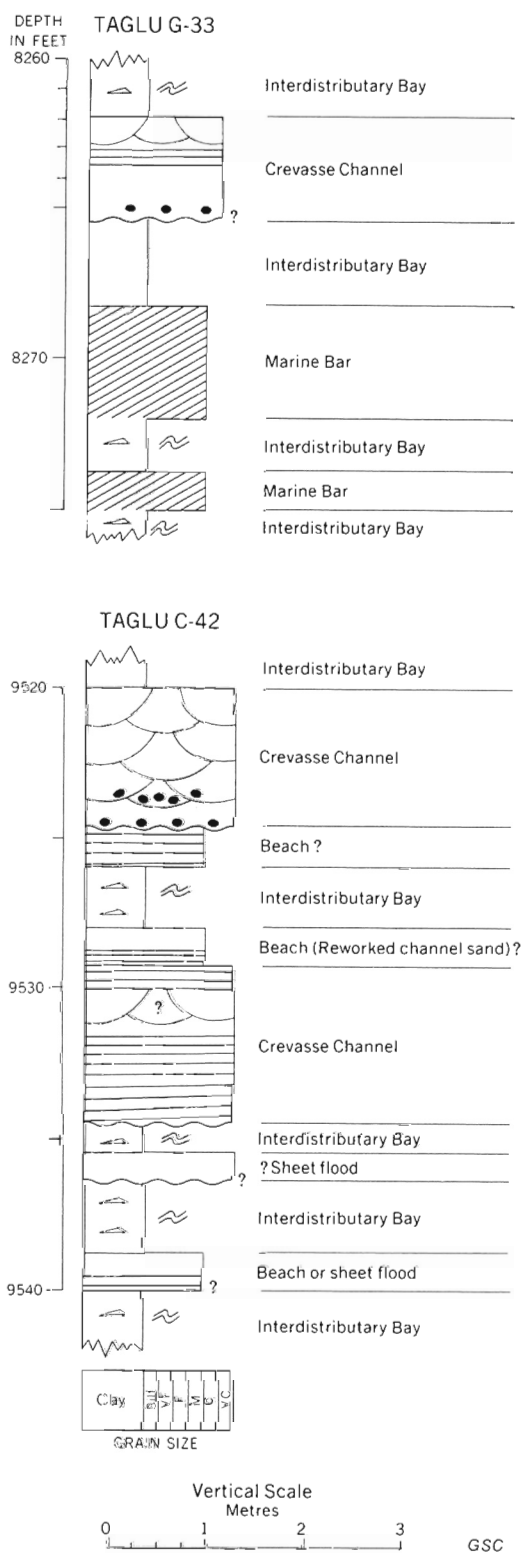


FIGURE 8. Graphic display of crevasse deposits, Taglu G-33 and C-42.

The above deposits are grouped as crevasse sediments and they form microdeltas and the levées of the distributary channels. Coleman (1969) noted that the levées of the braided Brahmaputra River are formed almost exclusively of overlapping crevasse splays and may extend laterally from a few tens of metres to over 1000 m. Leveé deposits typical of the Mississippi Delta (Coleman, 1976), consisting of

alternating mud and ripple laminated sand, have not been identified in the Taglu Delta and probably were never developed. This difference is probably due to the much higher energy conditions and coarser sediment load of crevasse splays in the Taglu Delta.

Sand deposition in interdistributary areas is mostly due to periodic incursions of sediment-laden currents, whereas the background sedimentation is of mud, commonly interlaminated with silt or very fine grained sand. Wavy and lenticular bedding, commonly with load deformation, is a ubiquitous sedimentary structure. Massive units of mudstone may also be present. Burrows are present, but not very common, and bioturbation is very rare.

A noticeable absence is coal, a swamp or marsh deposit which commonly caps crevasse deposits. It is probable that in the lower delta plain of the preserved Taglu Delta, high rates of sedimentation and the constant shifting of both crevasse and distributary channels prevented the establishment of coal swamps or marshes. Thus, in 25 m of core of the Niglintgak B-19 well, there are no coal beds in the crevasse splay sediments. Also, an open bay situation in the lower delta plain would favour oxidizing conditions, rather than the reducing conditions needed to preserve organic accumulations. However, within the sandstones there is abundant plant material and it is likely that this was derived from the more stabilized areas of the upper delta plain or from the fluvial flood plain, neither of which are preserved.

SANDSTONE PETROGRAPHY

Only the rocks from the Taglu wells are sufficiently well cemented to prepare standard thin sections. In other wells the sediments are unconsolidated to weakly cemented and some mixing of sediment has occurred in core boxes. However, in a general sense the sandstone compositions are very similar throughout the Taglu Delta. Thin sections from Taglu C-42 and G-33 were examined and an average of 560 point counts per slide were made on 46 of the C-42 samples. Table I summarizes the results.

According to Folk's (1968) sandstone classification, the Taglu sands are litharenites. However, the presence of clay matrix in some sands would favour the use of the term lithic wacke. Chert is very common and tends to attain higher percentages in the medium and coarse grained sandstones. A variety of chert types are present and include the following:

- 1) microcrystalline quartz (the most common chert type)
- 2) fibrous chalcedony
- 3) mixed fibrous and microcrystalline
- 4) interlaminated fibrous and microcrystalline
- 5) microcrystalline quartz replacing quartz grains
- 6) microcrystalline quartz with spherulites
- 7) brown, isotropic chert

Both single and polycrystalline quartz grains are present, although the former are more abundant. Other, less abundant, detrital components include plagioclase feldspar, sand-sized clay aggregates, minor amounts of detrital limestone (as microcrystalline calcite), muscovite, coaly debris (may be concentrated along bedding planes), shale clasts, rare quartz-mica schist, and volcanic rock. Heavy minerals are very rare, and although present were never encountered during the point counts. Muscovite grains commonly show compaction features, compression between two grains and a fan-like splaying of the grain ends into pore space. Volcanic rock fragments consist of small feldspar laths, commonly twinned, in a cryptocrystalline groundmass. Some volcanic fragments have weathered to kaolinite.

TABLE 1
Average composition for various sandstone bodies in Taglu C-42.

		Quartz	Chert	Feldspar	Organic fragments	Other grains	Clay	Carbonate cement	Porosity	Average grain size
Lower channel fill	1	26	28	<1	9	5	7	6	18	m
	2	30	25	<1	1	7	12	14	10	m
	3	24	45	<1	<1	4	7	4	14	m-vc
Upper channel fill	3	39	19	<1	<1	5	20	5	10	f
Interdistributary sands		34	30	<1	<1	6	16	2	10	f-m
Distributary mouth bar		34	23	<1	<1	3	13	10	15	f-m

Note: The anomalously high carbonate cement in channel two is due to a 4 m zone of carbonate cement within the channel sand. The clay portion is predominantly authigenic but it may include some allogenic clays not readily distinguishable from the authigenic ones (e.g. upper channel fill).

The most common cementing minerals are clays and dolomite. Some of the clays, especially in many of the finer grained sandstones from the interdistributary areas, may be primary in origin, but it is often very difficult to distinguish between authigenic and primary clays, especially if the latter have undergone some recrystallization. Shawa (1978) identified kaolinite, illite and chlorite as the major authigenic clays. The dolomite cements include both ferroan and non-ferroan varieties (Shawa, 1978, 1979). Calcite and siderite are present but are not as abundant as dolomite. Clay and carbonate cements are found in all sand body types although carbonate cements tend to be more common in the distributary mouth bar - delta front sands. Channel 2 in the Taglu C-42 well (Fig. 4) has an unusual dolomite cemented zone between 2885.9-2889.5 m (9468-9480 ft). In this zone, dolomite can attain 42 per cent by volume of the rock and appears to have replaced a considerable amount of the framework. A high velocity distinguishes this cemented zone and is readily recognized on the sonic log. The high velocity

layer can be traced to a channel sandstone in the Taglu P-03 well (2636.5-2638.7 m: 8650-8657 ft) and a common origin is postulated for the two zones. The localized nature of the cemented zone, its approximately horizontal attitude if the base of the channel deposit is used as a datum, and its lateral extent together point to early diagenesis, probably at an air-groundwater interface and perhaps similar in origin to that of caliche zones.

Quartz overgrowths although present are not common. The immature sandstone composition and abundance of clay minerals may have inhibited the development of quartz overgrowths. An additional factor that may have prevented quartz overgrowths developing is the overpressured nature of the Taglu sandstones (Hawkings and Hatlelid, 1975, Fig. 15). Overpressuring prevents compaction and hinders the redistribution of silica normally obtained by dissolution at grain to grain contacts.

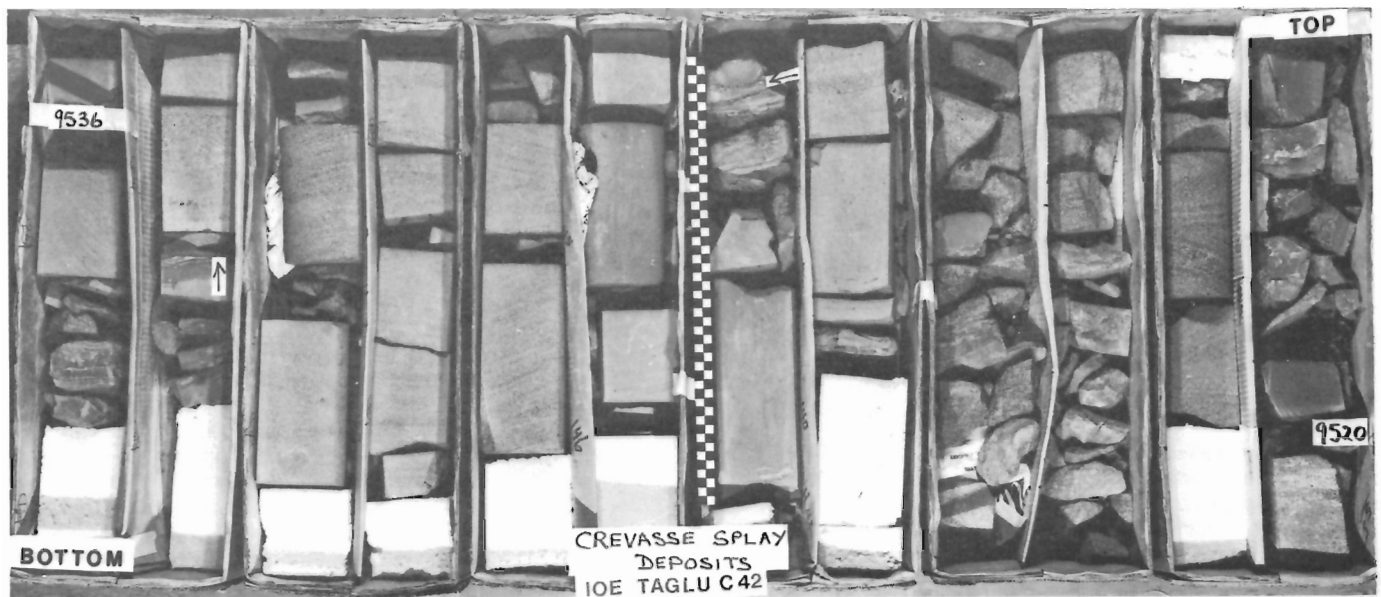


FIGURE 9. Crevasse deposits, Taglu C-42. Photographed interval corresponds to most of that illustrated in Figure 8. Bar scale 50 cm in 1 cm divisions.

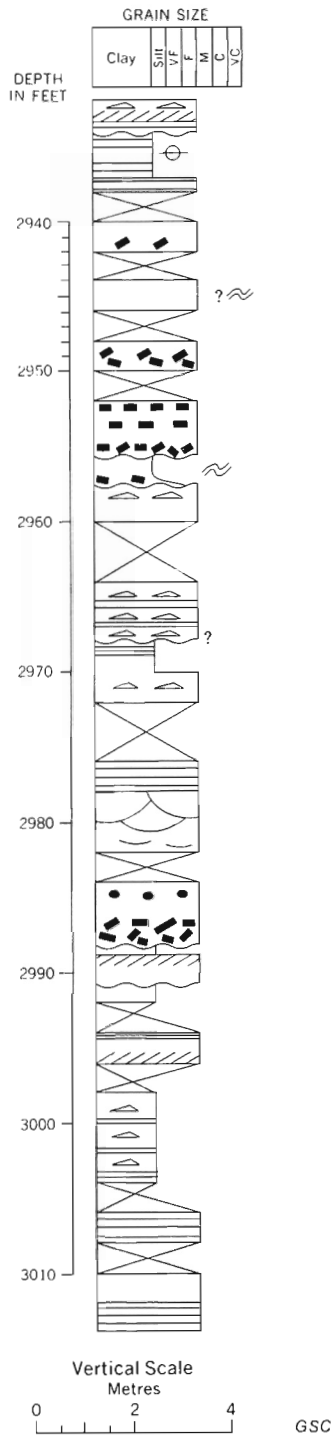


FIGURE 10. Graphic display of crevasse splay deposits, Niglintgak B-19.

The sandstone compositions point to a chert-rich provenance with some volcanic and metamorphic rocks. To the south, southwest and southeast of the Taglu Delta there is a clastic and chert-rich carbonate terrain but no known metamorphic rocks. The closest volcanic rocks are found in the White Uplift (Dyke, 1972), the Romanzof Uplift (Norris, 1972) and eastern Alaska (Brosgé and Dutro, 1973; Detterman, 1973) and metamorphic rocks are closer at hand, in the Neruokpuk Formation of the British Mountains (Brosgé et al., 1962; Norris, 1972), west of the Taglu Delta. The

latter formation is also rich in chert. Bowerman and Coffman (1975) postulated a general southerly origin for the whole of the Reindeer Formation basing their conclusion on isopach and facies trends. Isopach trends of the Taglu Delta (Fig. 11) also would indicate a southerly origin. However, the Taglu Delta is only partially preserved and the isopach trends could easily change. The abundance of large pebbles and coarse sands in the Taglu Delta requires high energy current flow and a steep river gradient. It is postulated that two source areas supplied the Taglu Delta, the terrain immediately south of the delta from which short, steep gradient rivers originated and a much larger catchment area to the west, probably extending into present day Alaska. The rivers from the latter area probably were less competent but still capable of transporting particles up to very small pebble size. It is interesting to note that Young (1975, Fig. 32) postulated a similar provenance for older Tertiary strata.

DEPOSITIONAL MODEL: DISCUSSION

The distinct vertical succession of depositional units, representing a change from prodelta to lower delta plain environments, the prominence of channel and crevasse splay deposits (Figs. 2, 4) and the apparent lobate shape (Fig. 11) of the Taglu Delta point to a river-dominant delta system (classification of Galloway, in Broussard, 1975). The lobate shape and laterally extensive delta front deposits indicate that there may have been wave modification. Fisher (1969) applied the term "lobate, high constructive delta" to this type of delta system. Although specific depositional environments within the Taglu Delta can be compared directly with those from the type river-dominant delta, the Mississippi Delta (Coleman and Wright, in Broussard 1975; Coleman, 1976), there are a number of major differences.

The abundance of coarse grains and pebbles in the Taglu Delta is in sharp contrast to the fine sand grains transported by the Mississippi Delta. This difference reflects, in part, the greater competency of the Taglu distributary rivers. Also, the Mississippi River system has a large drainage basin, most of which is in the plains area of continental United States and the delta is far removed from mountain source areas. On the other hand, the Taglu Delta had a much smaller drainage basin and was closer to the sediment source areas. The high energy characteristics of the Taglu channels is also reflected in the possible braided nature of some of the distributary channels, a characteristic not present in the Mississippi River.

Channel widths in the Taglu Delta may have attained 5 km, in contrast to the 1 km wide channels of the Mississippi. The sandstone successions in the Mississippi Delta tend to be relatively thin, up to a maximum of about 20 m whereas the Taglu Delta succession can be as thick as 180 m. This can be explained by an abundant sediment supply and a moderately to strongly subsiding receiving basin in the Taglu Delta.

Shawa (1978) also recognized the delta succession as river dominant but whereas I have distinguished only one delta cycle, he has two delta cycles in the same interval. For example, in Taglu C-42 Shawa's (op. cit., Fig. 31) two cycles are between about 2825.5-2926.1 m (9280-9600 ft) and 2926.1-3048 m (9600-10 000 ft). Each of his cycles represents a vertical change from prodelta shale-siltstone, through mouth bar sandstone and a capping of distributary channel sandstone. My interpretation is similar for the lower cycle but differs in the upper cycle. Instead of a repetition of a prograding delta lobe I have interpreted Shawa's (op. cit.) upper cycle as a lower delta plain environment and a continuation of the delta cycle begun in the underlying rocks.

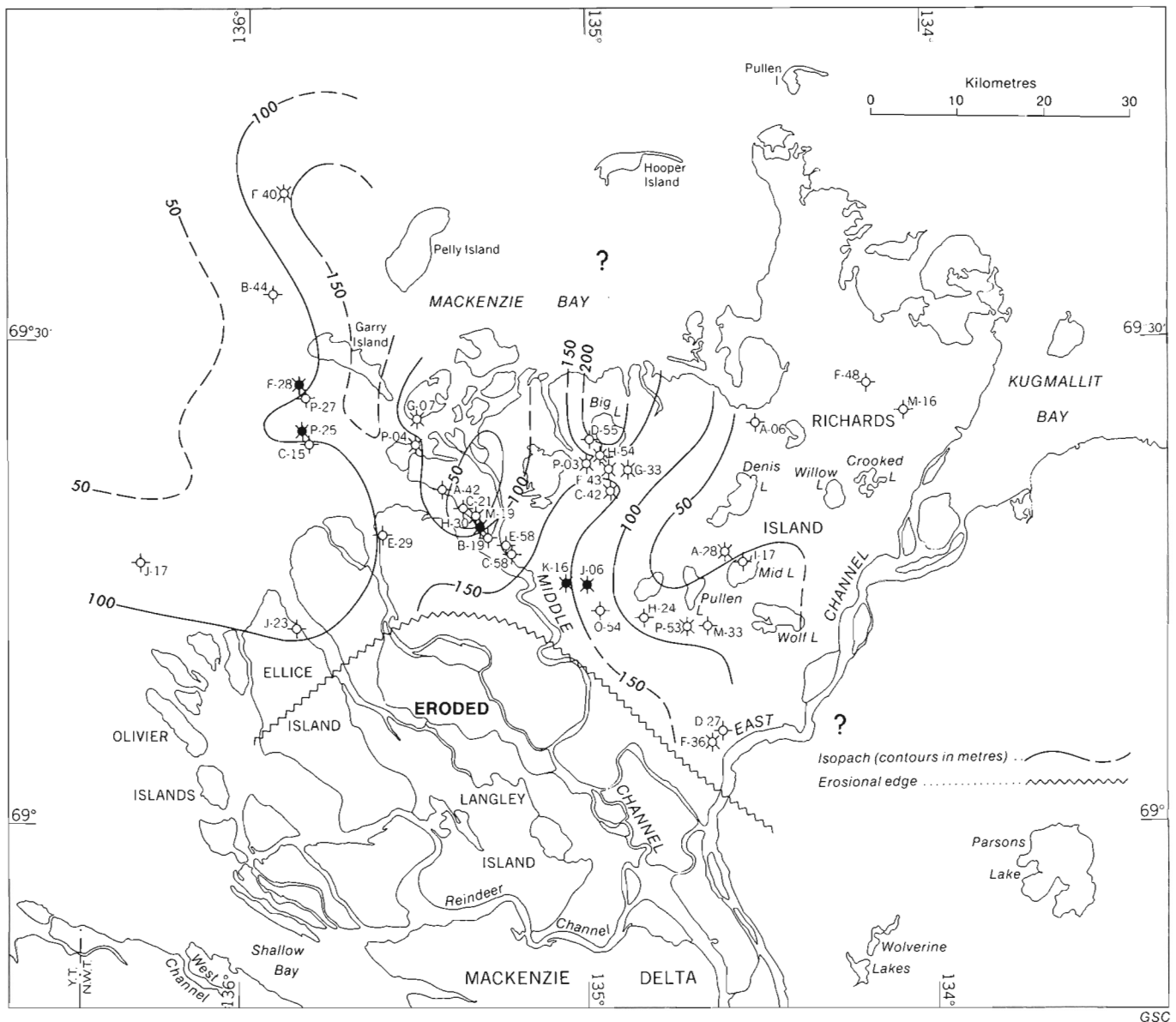


FIGURE 11. Gross sandstone thickness, Taglu Delta. Contours in metres.

This interpretation of the Taglu Delta may be of use to the petroleum industry in both exploration and in designing recovery programs when production begins in the Taglu and other gas fields. While only a brief study of the entire Reindeer Formation has been made by the author, it would appear that the Taglu Delta model may be applicable to other horizons within it. A major problem will be the correlation of delta cycles between wells. The Taglu Delta is readily correlated because of distinct marker horizons of regional significance, but such markers are not everywhere identifiable within the Reindeer Formation.

The interpretation of a high energy fluvial system supplying the Taglu Delta may have a favourable bearing on exploration in the Beaufort Sea area. It is highly probable that such a fluvio-deltaic system will generate turbidity flow into the offshore areas and result in the deposition of turbidite sands. Some evidence now exists to confirm this: Eocene sands in the Nektoralik K-59 well, (Jones et al., 1979), about 95 km north of the known extent of the Reindeer

Formation, have a log response character and a regional setting that could be interpreted as being typical of turbidites (Dixon and Snowdon, 1979).

The lateral and vertical distribution of sandstone facies within the Taglu Delta is such that most of the major sandstone bodies are interconnected (Fig. 2). Channel sandstones generally cut through crevasse splay sandstones, and the latter have an almost blanket-like distribution between channels. This favourable conduit system is well illustrated by the Taglu Gas field where the Taglu Delta sandstones are part of a single pressure system (Bowerman and Coffman, 1975, Fig. 13). In the wells drilled to date, most of the sandstones lie above the waterline and theoretically most, if not all, of the sandstones should be gas-bearing. (Bowerman and Coffman, 1975, Fig. 13). However, in Taglu H-54 the upper two channel sandstones (Fig. 2, section A) recovered water under high pressure and must have been isolated from the gas migration paths.

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APPENDIX I

List of wells and depth intervals used in study (sonic/gamma ray log depths unless otherwise stated).

Imp. Adgo	C-15:	3841 - 4470 ft:	1170.7 - 1362.5 m	
	F-28:	3365 - 3900 ft:	1025.7 - 1188.7 m	
	P-25:	2415 - 3135 ft:	736.1 - 955.6 m	
Sun et al. Garry	P-04:	5180 - 5883 ft:	1578.9 - 1793.1 m	Can Strat log depths were used as these correlated better with core lithology than did the Schlumberger Sonic/Gamma ray log.
	G-07:	7156 - 7740 ft:	2181.1 - 2359.2 m	
Imp. Ikattok	J-17:	700 - 1005 ft:	234.7 - 306.3 m	(tentative)
Shell Kumak	C-58:	3330 - 4030 ft:	1015.0 - 1228.3 m	
	E-58:	2700 - 3400 ft:	823.0 - 1036.3 m	
	K-16:	3984 - 4660 ft:	1214.3 - 1420.4 m	
	J-06:	3746 - 4450 ft:	1141.8 - 1356.4 m	
Imp. Langley	E-29:	1825 - 2230 ft:	556.3 - 679.7 m	
Imp. Mallik	A-06:	10230 - 10760 ft:	3118.1 - 3279.7 m	(tentative) The high dipmeter readings at this level (about 75°) mean that the true thickness is about 137 ft (41.8 m).
Imp. Netserk	B-44:	8920 - 9440 ft:	2718.8 - 2877.3 m	
	F-40:	?12370 - 12850 ft:	?3770.4 - 3916.7 m	(top may be slightly deeper)
Shell Niglintgak	B-19:	2920 - 3633 ft:	890.0 - 1107.3 m	
	H-30:	2502 - 2823 ft:	762.6 - 860.5 m	
	M-19:	2672 - 3040 ft:	814.4 - 926.6 m	
SOBC North Ellice	J-23:	1840 - 2465 ft:	560.8 - 751.3 m	
IOE Taglu	C-42:	9302 - 10050 ft:	2835.3 - 3063.2 m	
	D-55:	10378 - 11230 ft:	3163.2 - 3422.9 m	
	F-43:	8288 - 8932 ft:	2526.2 - 2722.5 m	
	G-33:	8143 - 8710 ft:	2482.0 - 2654.8 m	
	H-54:	8066 - 8664 ft:	2458.5 - 2640.8 m	
	P-03:	8450 - 9132 ft:	2575.6 - 2783.4 m	
Gulf Toapolok	H-24:	2478 - 3065 ft:	755.3 - 934.2 m	(CNL-Density log)
	O-54:	2812 - 3382 ft:	857.1 - 1030.8 m	
Chevron Upluk	A-42:	4070 - 4635 ft:	1240.5 - 1412.8 m	
	C-21:	1990 - 2600 ft:	606.6 - 792.5 m	(tentative)
Gulf Mobil Ya Ya	A-28:	5730 - 6720 ft:	1746.5 - 2048.3 m	(tentative)
	I-17:	5800 - 6704 ft:	1767.8 - 2043.4 m	(tentative)
	M-33:	4350 - 4970 ft:	1325.9 - 1514.9 m	(tentative)
	P-53:	4550 - 5176 ft:	1386.8 - 1577.6 m	(tentative)

Both BA Reindeer D-27 and Gulf et al. Reindeer F-36 are believed to contain equivalents of the Taglu Delta but due to the juxtaposition of the coarse clastic Upper Paleogene Unit "B" and/or Neogene Unit "A" (Young et al., 1976) to the Reindeer Formation and the erosion of the Eocene shale, it is difficult to identify the correct Taglu Delta mudstone-sandstone cycle.

APPENDIX II

Thicknesses used in Figure 10 (metres)

Imp. Adgo	C-15	92.7		SOBC North Ellice	J-23	86.9
	F-28	87.5		IOE Taglu	C-42	151.8
	P-25	105.8			D-55	201.2
Sun et al. Garry	P-04	137.2			F-43	137.8
	G-07	89.4			G-33	147.8
Imp. Ikattok	J-17	71.6			H-54	178.9
Shell Kumak	C-58	134.1			P-03	142.0
	E-58	179.8		Gulf Toapolok	H-24	93.6
	K-16	157.3			O-54	119.8
	J-06	132.9		Chevron Upluk	A-42	60.4
Imp. Langley	E-29	111.3			C-21	29.0
Imp. Mallik	A-06	22.9	(true thickness)	Gulf Mobil Ya Ya	A-28	28.4
Imp. Netserk	B-44	76.2			I-17	79.3
	F-40	146.0			M-33	70.1
Shell Niglintgak	B-19	134.1			P-53	61.0
	H-30	45.1				
	M-19	36.9				

