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Processes and depositional environments of Neogene deltaic-lacustrine sediments, Pannonian basin, southeast Hungary: core investigation summary

by

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CONTENTS

INTRODUCTION

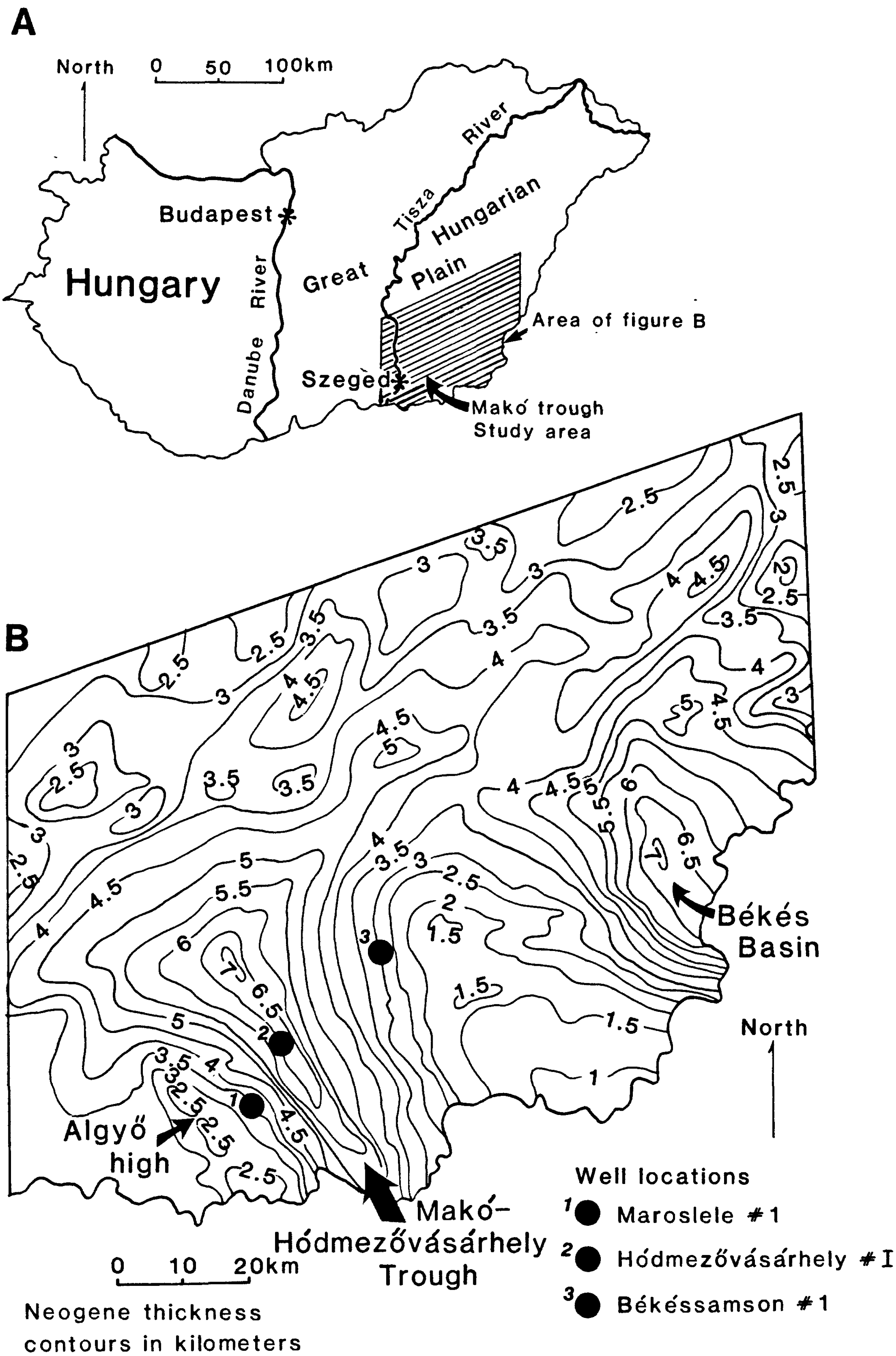
This report presents the results of geologic investigations conducted in the Pannonian Basin in Hungary during 1981. The purpose of this study is to define and interpret the depositional environments and sedimentological history recorded in cores of Neogene strata underlying the southern part of the Great Hungarian Plain.

The area of investigation is in southeastern Hungary northeast of the city of Szeged. The study area lies within the Makó-Hódmezővásárhely trough which is located directly east of the Algyő structural high and oil field (figure 1). The Makó-Hódmezővásárhely trough is a NNW-SSE trending depression containing over 6000 m of Neogene and Quaternary sediments (Kőrössy, 1981) (figure 1). Cores from three wells drilled on both flanks and within the center of the trough are the basis of determining the geology, facies and depositional history of the basin fill. The three wells and total depths drilled are: 1) Maroslele #1 (Ml), 3190 m; 2) Hódmezővásárhely #I (Hód), 5842 m; and 3) Békéssámson #1 (Bés), 2886 m (figure 1).

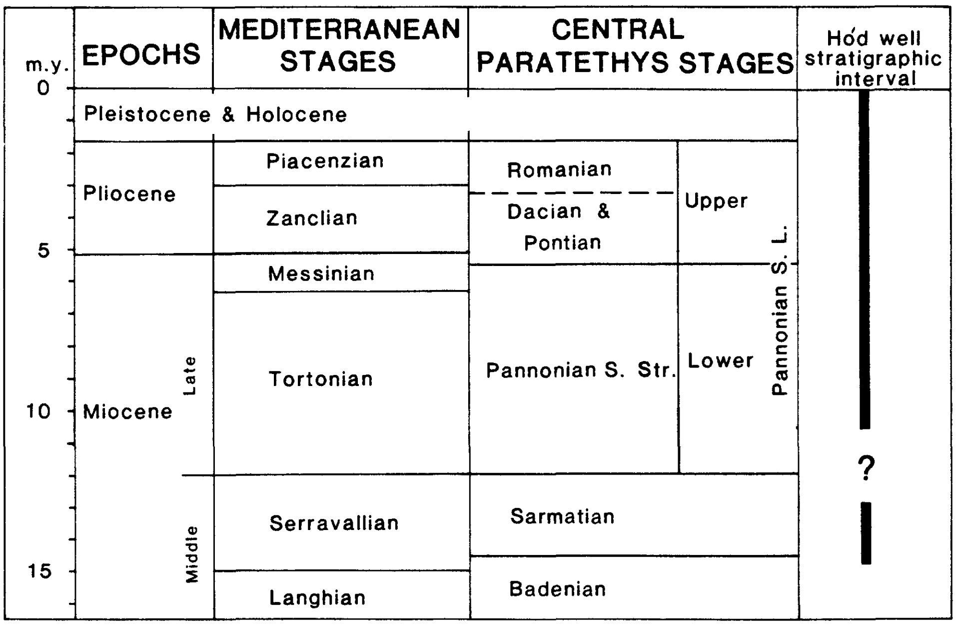
The basement rocks underlying the Neogene sediments consist mainly of Paleozoic metamorphic rocks and locally Triassic dolomite (Bérczi and Kókai, 1976, Magyar and Révész, 1976, Kőrössy, 1981). The Neogene sediments filling the basin are lacustrine marls and turbidites, and deltaic to fluvial marls and clastics. A geophysical profile of the Makó-Hódmezővásárhely trough, including the Hód #I well section, shows at least 3 distinctive seismic units one of which contains inclined southeastward prograding strata (Varga and Pogácsás, 1981). The age determinations are based on reported paleontological data included within the well logs and from published data (figure 2).

STUDY METHODS

Investigation involved an initial review of the well histories including descriptions of well cuttings, sediment samples, sediment analyses, core descriptions and all geophysical logs (SP, gamma ray, gamma-gamma and resistivity) obtained for each well. The data on rock densities, porosities, permeabilities and $CaCO_3$ percent are obtained from the unpublished well reports. The second part of the study involved a detailed study of the well cores including descriptions and analyses of major depositional processes and interpretation of the depositional environments contained within the three wells. The core sections for each well were initially viewed within the core storage laboratory of the Hungarian Hydrocarbon Institute at Szeged. Cores were then selected of either representative sections or essentially continuous lithological similar stratigraphic intervals or cores that contained either abundant sand or sedimentary structures that apparently record distinctive sedimentalogical processes. The selected cores were then studied in detail in Budapest. The core descriptions for each well are



1. A--Map of Hungary with location of study area. B--Isopachs of Neogene and younger sediments overlying Paleozoic basement within and adjacent to the Makó-Hódmezővásárhely trough. Isopachs compiled from Bérczi and others (1981).



2. Age relationships of the Pannonian Basin strata (after Nagymarosy, 1981a) and stratigraphic intervals reported for the Hód well. The Sarmatian Stage was not identified in the Hód #I well possibly due to lack of fossils which probably reflects the anoxic brackish depositional environment. Organisms could not live within this environment and apparently were not transported into the deep lake basin during this time interval.

included in the following sections of this report.

The three wells were drilled between 1966 and 1969. Approximately 5 m of coring was attempted for every 100 m of strata drilled. The recovered core is approximately 12 cm in diameter. The amount of sediment recovered during the coring procedure is apparently related to both the amount of cementation and sediment texture. Poor to no recovery of sediment occurred in poorly cemented sandy sections while cemented sections of sandstone and marl or only marl yielded up to 100 percent recovery. Within the deepest well, Hód #I, continuous core sections of 28 and 39 m length were also obtained within the deep part of the well. A total of 369 m of coring was attempted yielding 274.9 m of core recovered (74.4% recovery) within the Hód #I well. Within the Maroslele well, 152.6 m of coring was attempted yielding 114.1 m of core recovered (74.1% recovery). In the Békéssámson well, 93.6 m of coring was attempted yielding 48.6 m of core recovered (51.9% recovery).

Limitations to our core study include: 1) poor core recovery in some poorly cemented sandy sections; 2) core selection biased toward cores containing sand, gravel or obvious sedimentary structures other than parallel laminated fine-grained marls; 3) extensive marl sections only briefly described; 4) availability of core material; and 5) limited core material and core recovery available for depths above 2000 m.

The stratigraphic depths and thickness of of the facies are based on seismic interpretations as determined by Bob Mattick (personel communications, 1984) (with the exception of the basal facies-deep basin facies contact where the top of the basal facies is determined from the stratigraphic highest conglomerate in the cores). Identification of the facies boundaries based on seismic interpretation allows the development of a systematic sedimentation model of a prograding delta system integrating both the seismic data and the depositional environments determined from the preserved sedimentary structures.

FACIES DESCRIPTION

Within the Neogene strata in the deepest well drilled, Hód #I, 5 major facies and two subfacies are recognized. However, within the wells on the flanks of the basin a maximum of 3 facies are identified. Within the Hód #I the facies, depths and stratigraphic thickness are in ascending order:

1) Basal facies, 5842 to 5450 m (392 m)

2) Deep basin facies, 5450 to 4285 m (1165 m)

3) Prodelta facies, 4285 to 3250 m (1035 m)

4) Delta front facies, 3250 to 2517 m (733 m)

5) Delta plain facies 2517 m to surface.

Only the upper three facies, the prodelta, delta front, and delta plain, are recognized in the Maroslele #1 well and the delta front and delta plain facies are identified in the Békéssámson #1 well on the flanks of the basin. The facies in all three wells are summarized and discussed below.

BASAL FACIES

Summary: (Hód #I, cores 39-45)

1) Thickness--392+m, the total thickness unknown; basement not reached.
2) Texture--argillaceous to silty marl, coarse sand and conglomerate.
3) Sedimentary structures include: graded sandstone and conglomerate with Bouma Tab and Tbc sequences; soft sediment deformation features including flame structures, slumped beds and load structures; parallel sandstone laminations interbedded with marl and small scale cross-strata.
4) Possible progradational sequence; strata exhibit an overall coarsening upward texture.
5) Strata consist of horizontal to inclined (7 to 11 degree dip) beds of sandstone and conglomerate (both clast and matrix supported) interbedded with marl.
6) NO BIOTURBATION--sparce fossils in cores may all be reworked and transported into the basin.
7) Water depth unknown.

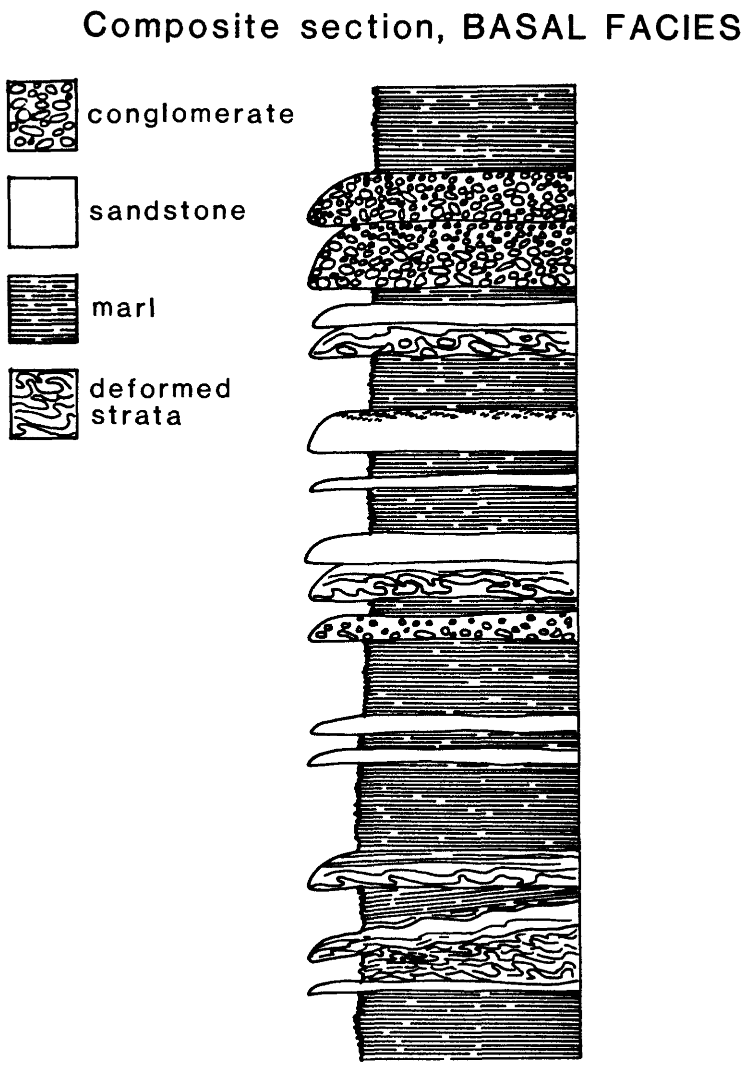
DEPOSITIONAL ENVIRONMENT

This facies was deposited in a reducing euxinic environment characterized by the precipitation of $CaCO_3$, deposition of mud from suspension, and periodic deposition of coarse-grained turbidites. The turbidites most likely flowed along the axis of the basin or may have been locally derived from the flanks of the basin. The periodic occurrence of interbedded marl and sandstone beds dipping at angles of up to 11 degrees suggest either: 1) and irregular lake bottom with local relief, 2) the strata are filling (prograding) into previously cut turbidite "channels", or 3) the strata were deformed during transport and deposition. A composite section shows the major depositional features (figure 3).

DEEP BASIN FACIES

Summary: (Hod #I, cores 28-38)

1) Thickness--1165 m.
2) Texture--argillaceous to silty marl.
3) The sedimentary structures include horizontal, parallel laminae to structureless calcareous to silty marl.
4) The lake depth, as determined from the thickness of



3. Composite section of the depositional elements of the basal facies. Turbidites, interbedded with marl, form the dominant bedding structures.

strata overlying the Deep Basin Facies to the top of the basement high to the west at the Marosele #1 well, would be 1100 m. No sandstone-conglomerate turbidites derived from flanks of the topographic highs are identified in this stratigraphic interval. Therefore, this would suggest the lake level was above the bedrock highs. This water depth does not take into account subsidence of the basin or compaction of the sediment.

5) NO BIOTURBATION.

DEPOSITIONAL ENVIRONMENT

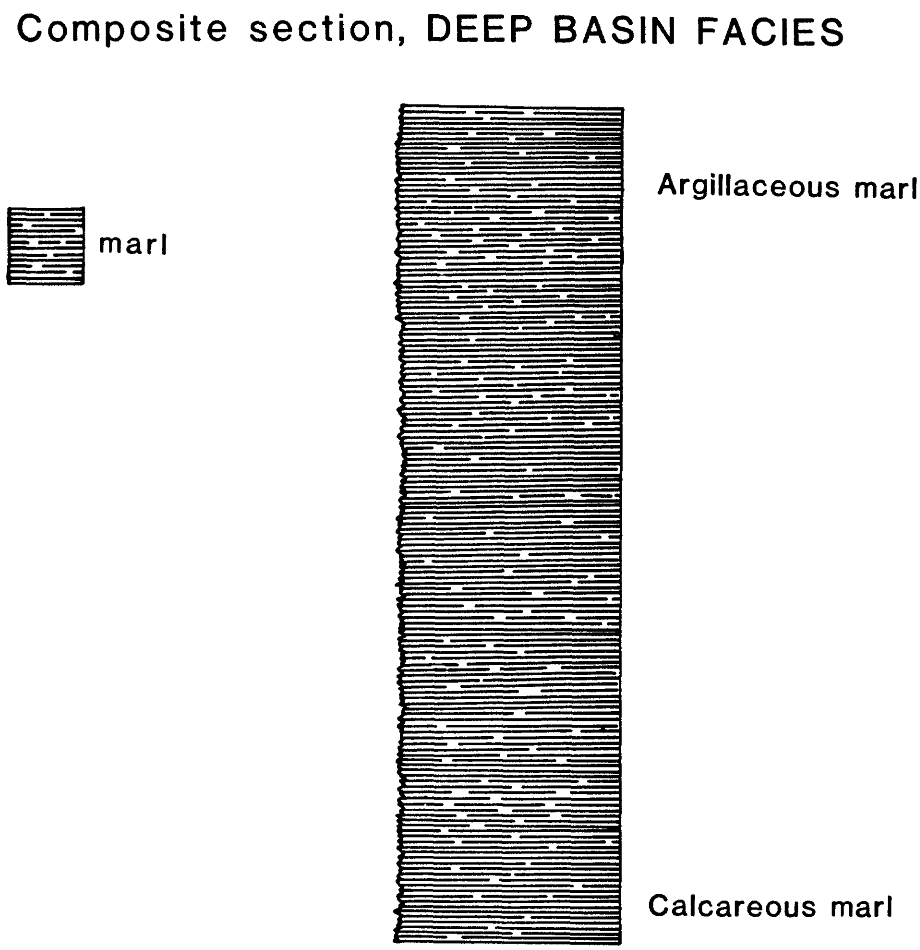
Deposition of mud from suspension and precipitation of $CaCO_3$ occurred with the deep part of the lake basin containing a reducing euxinic environment. The sediments were deposited below the oxygen minimum zone as indicated by the lack of biogenic structures. A decreasing $CaCO_3$ percent from 67% (calcareous marl) at the base of this facies to 33% (argillaceous marl) toward the top of this facies records increasing clastic sediment input into the basin from the advancing delta system (figure 4).

PRODELTA FACIES

Summary: This facies can be divided into two subfacies, subfacies A, 685 m thick, overlain by subfacies B, 350 m thick.

SUBFACIES A, parallel-bedded strata, (Hód #I, cores 20-27)

1) Thickness--685 m.
2) Texture--silty marl to medium-grained sand.
3) Sedimentary structures include: thick parallel graded sandstone beds with Bouma Tbc and Tce sequences; abundant amalgamated sandstone beds; dish structures; load structures; and solitary thin sandstone beds as parallel laminae or as small-scale cross-strata interbedded with marl. Marl rip-up clasts are very rare in the graded beds in contrast to abundant marl rip-up clasts in the overlying subfacies B.
4) An increasing thickness of argillaceous marl laminae separates the individual sandstone beds toward the base of this facies.
5) The vertical succession of sedimentary structures from the lower to the upper part of this facies suggests a depositional environment ranging from distal to proximal parts of the basin (in relation to the advancing delta front). The sandstone beds change vertically from thin laminae in marl to small-scale cross-strata to amalgamated beds. Likewise, a decrease in sand bed thickness, grain size, and increasing thickness of marl intervals characterizes the distal basin deposits.
6) NO BIOTURBATION
7) Water depth--greater than 700 m based on the thickness



4. Composite section of the depositional elements of the deep basin facies. Laminated to massive calcareous to clay marl forms the depositional elements of this facies.

of the Delta Front Facies.

DEPOSITIONAL ENVIRONMENT

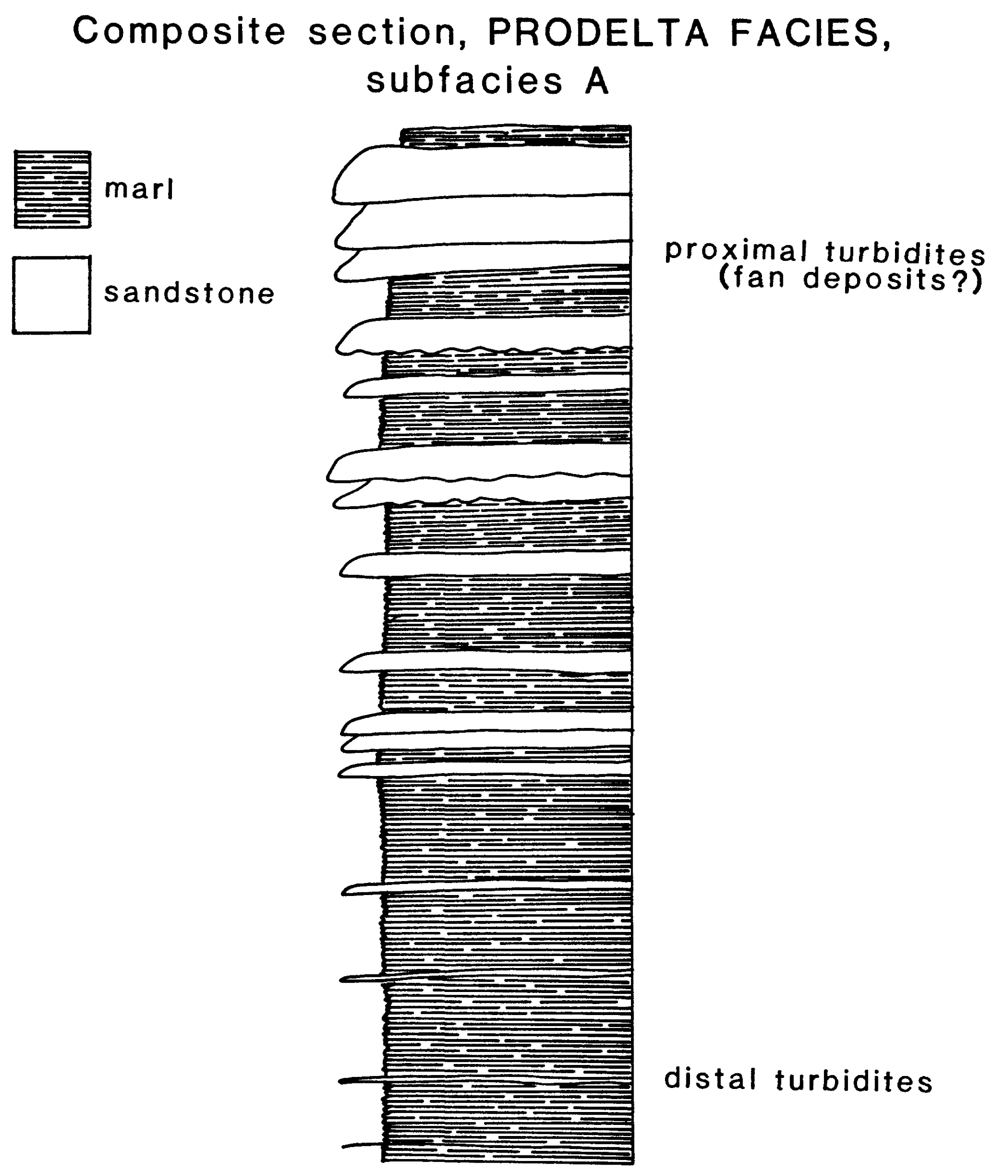
The depositional environment represents a deep basin where the deposition of sand occurred as turbidity flow along with marl deposition. The change from proximal to distal turbidites indicates decreasing sediment transport in the outer basin regions. The thick amalgamated sandstone beds near the top to this facies may represent deposition in a lacustrine fan or sediment deposited adjacent to or in a channel system in front of the prograding delta front (figure 5). The sediments were deposited below the oxygen minimum zone in a reducing euxinic environment.

SUBFACIES B, (deformed strata, cores 14-19, Hód #I, and 27-29, Ml #1)

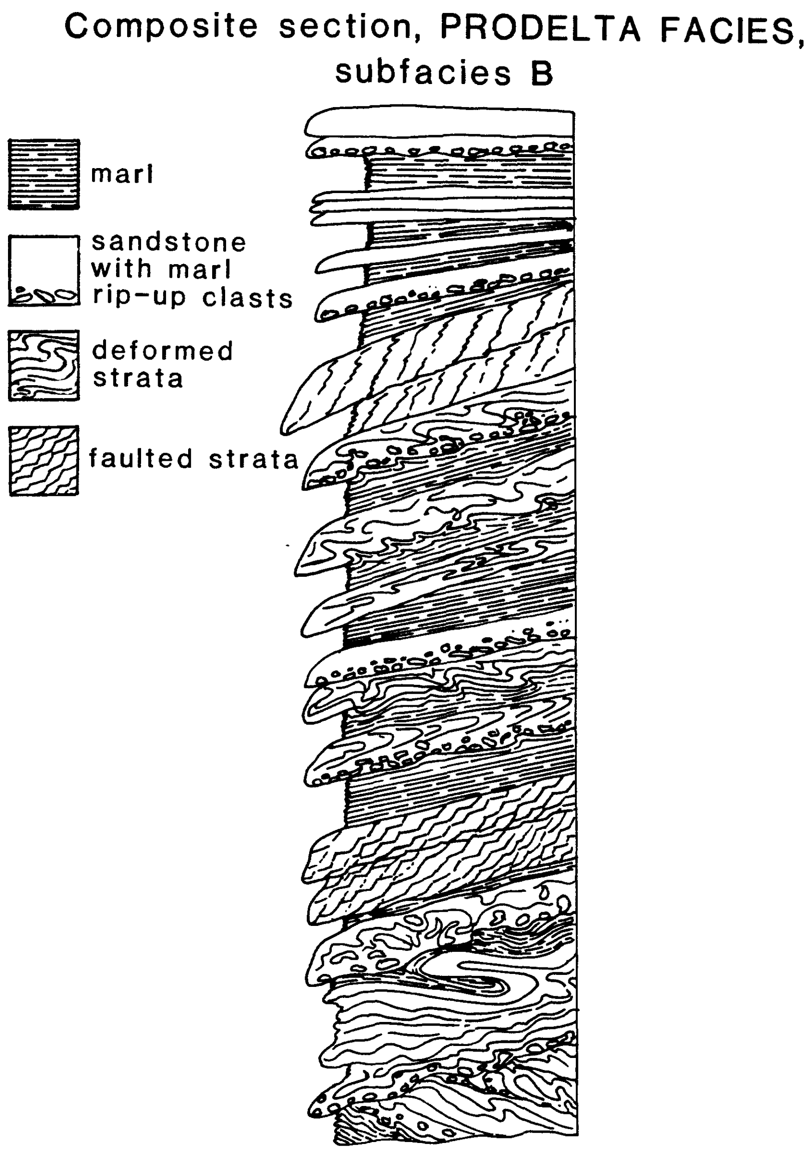
1) Thickness--350 m.
2) Texture--argillaceous marl and fine- to medium-grained sand to conglomerate (marl rip-up clasts in graded beds). This facies contains abundant sandstone.
3) Sedimentary structures include: abundant graded beds with Bouma Ta, Tab, and Tabc sequence with Tab the most abundant bedding type; the graded beds containing load casts, flame structures, abundant marl rip-up clasts, and dish structures. Some sandstone beds are amalgamated.
4) Sandstone and marl occurs as interbedded parallel strata. The most distinguishing feature of this facies is the inclined strata dipping from 4 to 25 degrees. The inclined strata usually contain abundant soft sediment deformation features including penecontemporaneous faulting, disrupted bedding (slumps), and completely overturned strata. The deformed strata in places are truncated and overlain by undeformed beds. The upper part of this facies contains horizontal, parallel graded beds of sandstone.
5) NO BIOTURBATION
6) Water depth--greater than 700 m based on the thickness of the Delta Front Facies.

DEPOSITIONAL ENVIRONMENT

The inclined and deformed beds represent deformation (large- to small-scale slumping) to complete overturning of the strata producing hummocky broken terrane basin-ward of the prograding delta. Sedimentation in this environment was dominated by turbidity currents, grain flow, mud flow and slumping, as well as by deposition from suspension of fine-grained sediments and precipitation of $CaCO_3$ (figure 6). Deposition occurred below the oxygen minimun zone as indicated by the lack of biogenic structures in the cores in a reducing euxinic environment.



5. Composite section of subfacies A of the prodelta facies. Sandstone, interbedded with marl, exhibits an increasing bed thickness within the vertical sequence. The turbidite sandstones represent deposition within a prograding lacustrine fan system.



6. Composite section of subfacies B of the prodelta facies. Slumped and deformed strata interbedded with marl represent deposition from repeated debris flows derived from the delta front slope.

DELTA FRONT FACIES

Summary (cores 8-13, Hód #I, 20-26, Ml #1, and 15-25, Bés #1)

1) Thickness--733 m, which would also indicate the water depth.
2) Texture--ranges from medium- to fine-grained sand, silt, and clay as well as conglomerate clasts (marl rip-ups).
3) Sedimentary structures include abundant graded beds (Bouma Ta, Tab, or Tabc sequence), containing load casts, flame structures, and marl rip-up clasts. Small-scale cross-strata and parallel sandstone laminations interbedded with marl are also common.
4) Sandstone and marl also occur as repeated thin (0.04-0.5 cm thick) parallel graded beds. Most strata are generally inclined dipping from 5 to 7 degrees and usually deformed. The inclined strata usually contain soft sediment deformation features including penecontemporaneous faulting and disrupted slumped bedding with dips up to 20 degrees.
5) Bioturbation is abundant down to depths of 3060 m (Hód #I) and 3093 m (Ml #1), no biogenic structures are observed at deeper depths.

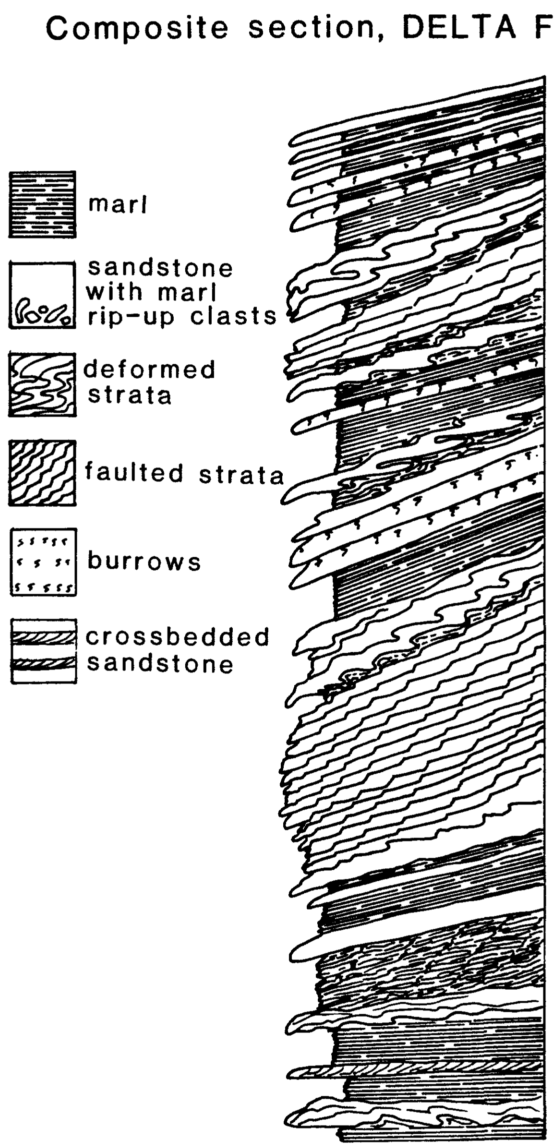
DEPOSITIONAL ENVIRONMENT

This facies was deposited on the front of a prograding deltaic system on slopes of approximately 5 degrees. Sedimentation in this environment is dominated by down-slope flow of turbidity currents and grain flows and by slumping of the slope deposits. Fine-grained silt was deposited from suspension or by current flow down the delta front. The precipitation of $CaCO_3$ also resulted in marl deposition on the delta front slope. Penecontemporaneous faulting is the most common deformation feature indicating down-slope creep of sediment (figure 7). An oxygen minimum zone possibly starts at approximate depths of 3060 (Hód #I) and 3093 m (Ml #1) as this is the greatest depth at which bioturbated sediment was observed.

DELTA PLAIN FACIES

Summary: (cores 2-4, Hód #I, 3-16, Ml #1, and 6-8, Bés #1)

1) Thickness--2517 m.
2) Texture--medium-grained sand, silt and clay.
3) Sedimentary structures include horizontal parallel-bedded silt to argillaceous marl to horizontal parallel thin graded beds of sandstone, siltstone and marl, with repeated small-scale cross-bed sets. Repeated graded cyclic strata are common.
4) Locally lignite and possible algal mat structures are observed in interbedded siltstone and mudstone. Oxidized mudstone (redbeds) and abundant plant fragments may be locally common.



7. Composite section of the depositional elements of the delta front facies. Deformed strata with abundant penecontemporaneous faulting and laminated marls interbedded with sandstone form the most common structures of this facies.

5) Most strata are bioturbated.

DEPOSITIONAL ENVIRONMENT

The depositional environments of this facies vary from shallow lake, fluvial and marsh to possibly terrestrial (figure 8).

DISCUSSION

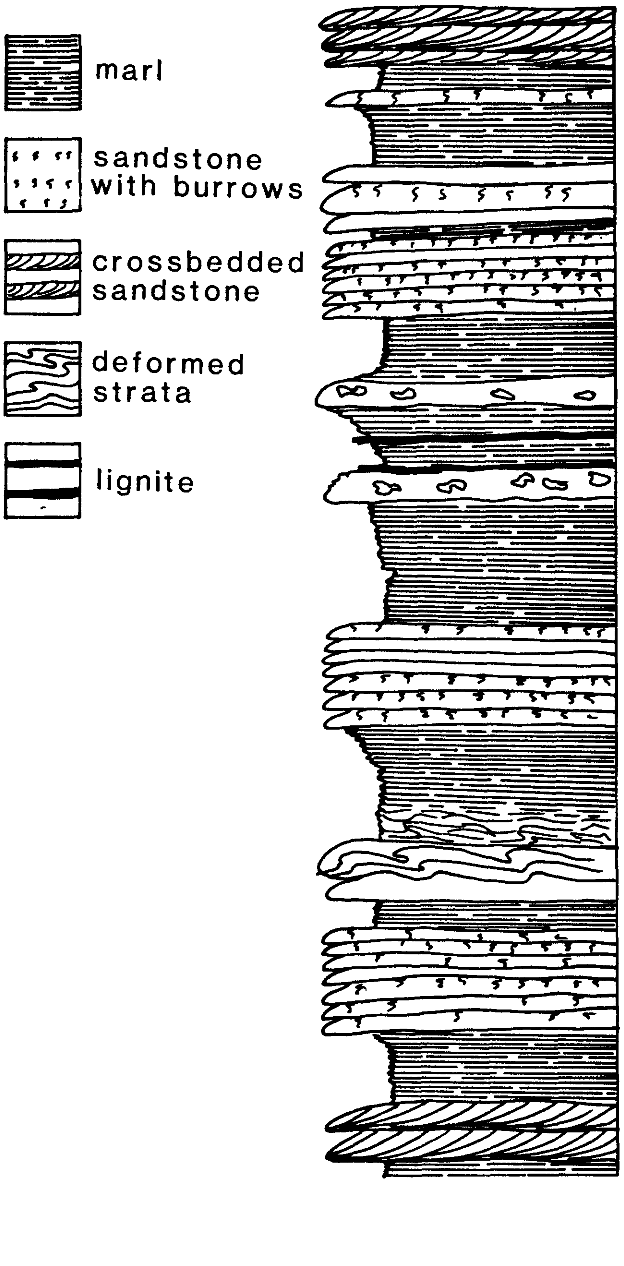
The three wells studied are located in a part of the Pannonian Basin known as the Makó-Hódmezővásárhely trench (Mucsi and Révész, 1975; Varsanyi, 1975), the Hódmezővásáhely-Makó graben (Meskó and Kis, 1981), or the Makó trough (Bérczi and Kókai, 1976; Nagymarosy, 1981a; Kőrössy, 1981) (figure 1). The trough containing Neogene and younger sediment is approximately 30 km wide in an east-west direction at the latitude of the Hód #I well. To the south of the Hód #I well the basin narrows and the basement rises from 6500 m to 5000 m within a distance of 20 km. North of the Hód #I well the basin widens and deepens to 7000 m where it intersects a northeast-southwest trending trough. Paleozoic basement on the adjacent basin flanks rises to within 1500 to 2500 m of the present land surface.

The Makó-Hódmezővásárhely trough originated in the middle Miocene by regional east-west extensional tectonism (Horváth and Royden, 1981, Burchfiel and Royden, 1982). A series on NW-SE trending synsedimentary normal faults, which were active during deposition within the Makó-Hódmezővásárhely trough (Kőrössy, 1981), bound the basin graben. Rapid subsidence occurred during the initial development of the basin, and was followed by slower rates of subsidence until the present time (Nagymarosy, 1981b). High rates of subsidence during the Pliocene are also suggested (Bérczi and others, 1981, Csillag, 1983).

Marine sedimentation within the Pannonian Basin ended during the middle Miocene (late Badenian stage, Nagymarosy, 1981a) when connection of the Pannonian Basin with the Mediterranean Adria Basin was severed (Hámor, 1983). A brackish to freshwater lake system then evolved. A large lake, over 500 km long in an east-west direction, covered much of the Pannonian Basin based on the present distribution of Pannonian (s.l.) age sediments. The Makó-Hódmezővásárhely trough records in vertical section continuous brackish marine to lacustrine to deltaic-fluvital sedimentation and basin filling from middle Miocene through the Quaternary (figure 2).

Based on core investigations some of the features of the lake system within the Makó-Hódmezővásárhely trough can be identified. A minimium water depth can be determined from the thickness of the inclined delta front strata based on seismic reflection profiles and by the thickness of the Delta Front facies. A lake depth of at least 700 to 750 m is indicated within the Makó-Hódmesővásárhely trough.

Composite section, DELTA PLAIN FACIES



8. Composite section of the depositional elements of the delta plain facies. Parallel bedded bioturbated sandstone interbedded with marl forms the major structures. Lignite and oxidized clay beds suggest marsh to terrestrial influence within the strata. The deformed strata may represent material slumping into distributary channels.

The lake system was permanently stratified (meromictic system). Black organic-rich sediments, pyrite, and the complete lack of biogenic structures dominate the 3 lower facies identified in the Hód #I well (2592 m sediment thickness). A reducing, brackish euxinic environment characterizes the lower part of the depositional system. The Makó-Hódmezővásárhely trough, however, may represent part of a larger silled basin at least in the early history of the Pannonian Basin based on the varying sediment thickness of Neogene sediment (figure 1b). The sills probably aided in the restriction of circulation resulting in permanently anoxic brackish water (a monimolimnion system). A density stratification within the lake system may have also resulted from temperature contrast or salt content.

Bioturbated sediments are found to depths of 3060 m (Hód #I) and 3093 m (Ml #1) on the delta front. The Neogene sediments below these depths were apparently deposited in an oxygen minimum zone. The presence of bioturbated sediments stratigraphically above unbioturbated anoxic sediments suggests that the lake waters were stratified. Based on the thickness of the delta front (700 m) and last occurrence of bioturbated sediments in the Hód #I well a basal oxygen-poor layer, approximately 200 m thick was overlain by a zone of mixing, approximately 500 m thick. Sufficient oxygen existed to support benthic organisms in the upper part of the lake. Underflow of river derived waters down the delta front may have supplied oxygen to the deeper lake levels (down to 500 m depth). Seasonal overturning, storms, geostrophic currents and fluvial flow may have also aided in mixing the water and supplied oxygen to at least the upper part of the lake based on the depth of bioturbated sediments.

BASIN FILL PROCESSES

BASAL FACIES

The initial Neogene sediments deposited within the Makó-Hódmezővásárhely trough consisted of marl interbedded with sand and gravel. Turbidity currents deposited the coarse-grained sediments. The Basal Facies is composed of over 390 m of sediment. The $CaCO_3$ content of the sediment increases toward the top of this facies indicating reduced fine-grained sediment input into the basin. The reduced fine clastic input into the basin may be due to increasing water depth as the lake filled and the shoreline shifted away from this basin. The water depth is unknown. The topographic highs on the flanks of the basin were probably covered with water at least by the end of deposition of this stage as gravels were no longer transported into the basin. The reducing environment (apparent lack of mixing of waters within the system and no biogenic structures) would, however, suggest an early development of a stratified deep water brackish environment early in the history of basin fill. This early stage of brackish water may also represent a silled anoxic marine basin overlain by normal marine salinity water as a few planktonic foraminifera, *Globigerina*, have been found only in this facies in the Hód #I well. The foraminifera, however, may only represent transport and redeposition of foraminifera from older strata as foraminifera (similar to Nodosaria) are observed in carbonate pebbles at a depth of 2806.50-2807.3 m in the Bés-1 well (core no. 17). During the Late Badenian stage marine salinities decreased and resulted in the extinction of marine life within the Pannonian Basin (Hámor, 1983; Nagymarosy, 1981a; and Bérczi and others, 1981).

DEEP BASIN FACIES

The Deep Basin Facies, 1165 m thick, represents a considerable time span during which chemical precipitation of $CaCO_3$ as well as fine-grained sediments deposited mainly from suspension formed thinly laminated marls. An apparent reduction in the $CaCO_3$ content from 63-67% (calcareous marl) between depths of 5370 m and 5070 m to 10-33% (argillaceous marl) near the top of this facies (4450-3800 m depth) apparently reflects a gradual increase in the clastic sediment input into the basin. The increase in the clastic component is most likely due to delta progradation from the northwest. An increasing abundance of silt laminae occur in the upper part of this facies. Thin sand laminae in core 35 and small-scale cross-strata in core 28 may also indicate that currents existed on the lake floor capable of transporting sand-size sediment, but waning turbidity flow most likely produced these cross-bedded sands.

Overlying the thick marl section of the Deep Basin Facies three depositionally related facies, the delta front, prodelta and the delta plain, record a coarsening upward texture resulting from increased clastic input from deltaic-fluvital progradation into the lake. A river-dominated sand-rich delta system suggests high delta construction rates within a low wave energy environment.

DELTA FRONT FACIES

The inclined strata of the Delta Front Facies, 733 m thick, record three major sedimentary processes that resulted in the transport and deposition of sediment: 1) repeated thin laminae of combinations of marl, sand, and silt represent precipitation of $CaCO_3$ as well as sediment deposition both from suspension and down-slope transport of the coarse sediment fraction. Interbedded with the cyclic marl laminae are small-scale cross-strata indicating down-slope sediment transport by currents (underflow of river water down the delta slope). 2) Graded sandstone beds, up to 14 cm thick, contain Bouma Ta, Tab, or Tabc intervals and marl rip-up clasts indicating erosion, transport and deposition by turbidity flow as well as grain flow down the delta front. The graded sandstone beds occur as solitary strata interbedded with marl or as amalgamated beds. 3) Deformational structures such as convolute laminae, strata dipping at angles up to 20 degrees, and abundant penecontemporaneous faulting of inclined stata, indicate down-slope slumping and movement of sediment. Abundant bioturbation is also common in the upper 2/3 of this facies.

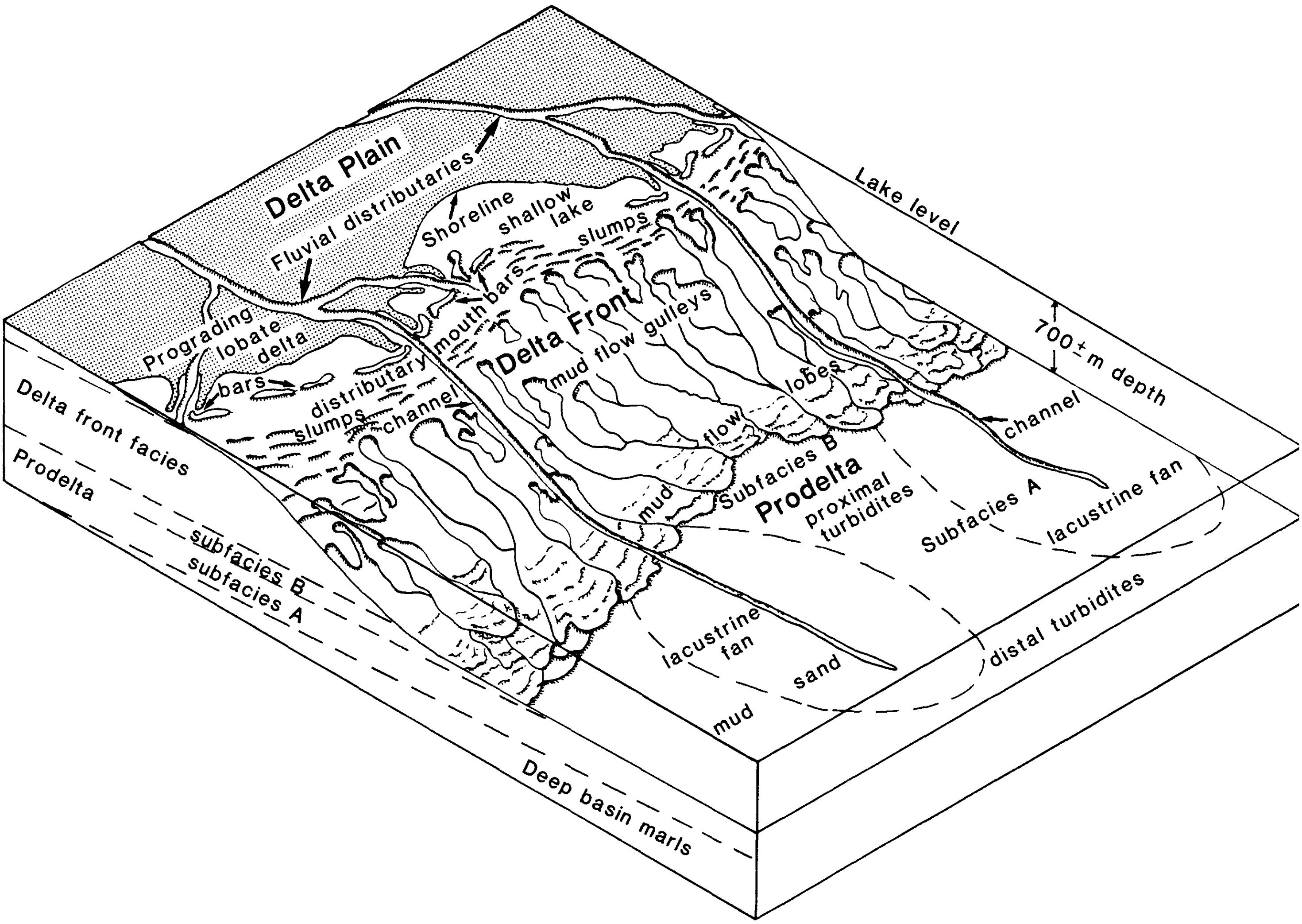
Two major processes, sand transport within channels and slumping of strata apparently dominated the delta front and resulted in sediment transport to the prodelta region. Sand-rich rivers constructing deltas usually contain channels connected directly to the river down the delta front as reported by Houbolt and Jonker (1968) in Lake Geneva, Sturm and Matter (1978) in Lake Brienz, Syvitski and Farrow (1983) in bayhead deltas in British Columbia, and Kastaschuk and McCann (1983) in fjordhead deltas in British Columbia. By analogy with these examples, a channel system originating from the river mouth down the delta front to the prodelta region is suggested for the delta system in the Makó-Hódmezővásárhely trough (figure 9).

Modern delta front channels may contain levees, and in the upper parts of the channel may also contain actively migrating ripples or sandwaves to 50 cm high (Houbolt and Jonker, 1968, Syvitski and Farrow, 1983). Small-scale bedforms may also move down the delta slope by undercurrents. Small-scale cross-strata are observed in delta front cores in the Hód #I well, cores 9, 10, and 11, and in the Ml #1 well, core 25. These cross-strata may represent sediment transport and deposition by currents moving down the delta slope.

Amalgamated graded sandstone beds containing marl rip-up clasts also suggest erosion of the delta front sediments and may represent channels cut into the slope substrate (core 25, Ml #1).

Deformation processes, indicating down-slope movement of sediment, are recorded in most of the cores of the delta front. Small-scale displacements along penecontemporaneous faults probably represent down-slope movement (creep) possibly caused by sediment loading on the upper part of the delta. The deformed strata in places are overlain by parallel-bedded undeformed strata (cores 20, 22, Ml #1) indicating perodic movement of sediment followed by sediment deposition without deformation. Slumping and soft sediment deformation produced high angle dips of up to 20 degrees in the delta front facies (core 20, Ml #1). Most of the strata, however, dip between 4 and 11 degrees.

Modern deltas, both lacustrine and marine, exhibit abundant down-slope movement of sediment as mudflows that generally are restricted to gulleys or retrogressive slides (Coleman and Prior, 1982). Rotational slumps with slump blocks and pull-apart features containing irregular surface relief are common on the upper parts of modern deltas (Pharo and Carmack, 1979, Coleman and Prior, 1982, Pickrill and Irwin, 1983). Compressional hummocks identified by irregular surface relief are found at the base of the delta slope and on the prodelta. The irregular hummocky morphology characterizes the depositional lobes of the subaqueous debris flows. The mudflows may coelese and individual flows may range up to 20 m in relief above the basin floor (Coleman and Prior, 1982). The internal features of the slump deposits range from discontinuous contorted parallel bedding (Pickrell and Irwin, 1983) and may contain strata dipping at angles up to 15 degrees (Coleman and Prior, 1982). Extensive small-scale pressure ridges may also form in front of the debris



9. Major depositional processes within a high constructional fluvial-dominated delta system. A prograding lobate delta system probably contained a channel system connecting the fluvial distributaries to the prodelta lacustrine fan. Progradation of the fluvial delta system results in the vertical assemblage of facies and sedimentary structures observed within the cores within the Makó-Hódmezővásárhely trough.

flow lobes (Coleman and Prior, 1982).

PRODELTA FACIES

Within the Prodelta Facies evidence of episodic slumping and down-slope movement of sediment from the delta front to the prodelta region is recorded in the deformed and inclined strata in subfacies B of the prodelta facies. Approximately 350 m of inclined and deformed strata interbedded with horizontal graded sandstone beds containing marl rip-up clasts represent the subaqueous slumped deposits. All cores from this facies in the Hód #I well, cores 14 to 19, contain either inclined or deformed strata. Associated with the deformed strata are horizontal parallel graded sandstone beds with Bouma Ta, Tab, and Tabc intervals (cores 14 and 18, Hód #I, cores 27, 28, 29, Ml #1) indicating turbidity current deposition. The sandy turbidites may have originated from sand funnelling down the debris chutes and covering the mud flows, or they may represent deposition from more than one delta front channel.

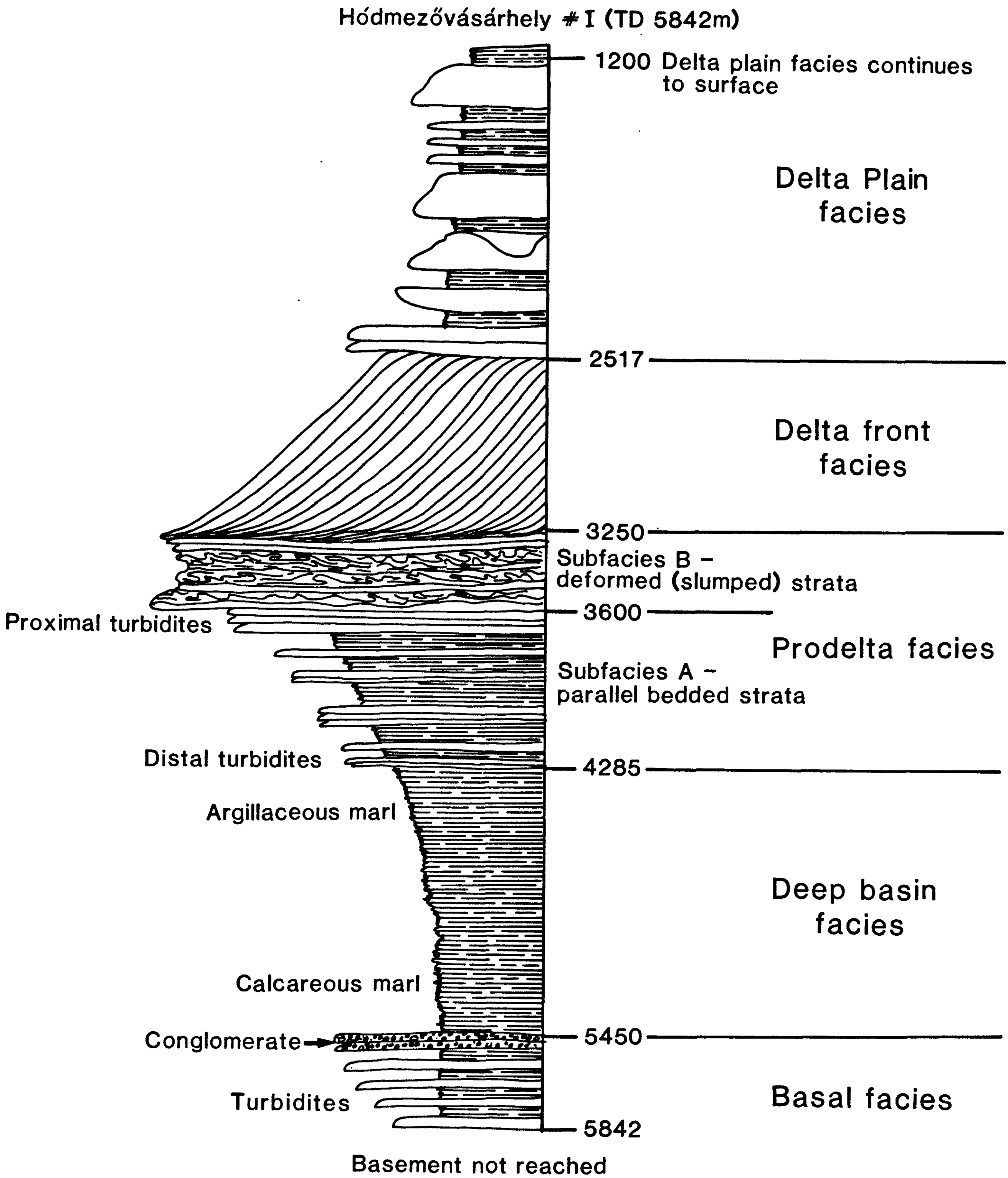
Underlying the inclined and deformed strata of subfacies B are the horizontal strata of subfacies A, which is 685 m thick. Vertically in subfacies A the sedimentary structures change from solitary small-scale cross-strata interbedded with marl to graded sandstone (Bouma Tbc intervals) interbedded with marl to thick amalgamated graded sandstone beds (Bouma Tabc intervals). The horizontal parallel graded beds represent turbidity current deposition probably within a subaqueous fan system. The sublacustrine channel system transported sand down the delta front through or over the slump deposits (prodelta subfacies B) at the base of the slope and deposited sand essentially as graded turbidites in a fan system. The channel-fan system within the Makó-Hódmezővásárhely trough is apparently very similar to the modern channel-fan system identified in Lake Geneva (Houbolt and Jonker, 1968). The fan deposits in Lake Geneva also consist of horizontal bedded graded sand.

DELTA PLAIN FACIES

The uppermost facies, the Delta Plain Facies, is over 2500 m thick. Most of the cores within the 3 wells record cyclic bioturbated beds grading from sandstone to argillaceous marl. Oxidized mudstone, abundant plant remains, lignite beds and slumped strata are also common. The depositional environments range from shallow lake to fluvial to terrestrial.

The fluvial channel sandstones apparently were not cored or the sandstones were not recovered in these 3 wells studied. However, on the west flank of the basin the fluvial channels have been identified and discussed by Révész (1982).

The vertical sequence of facies and textures observed in the Hód #I well shows an overall increasing clastic sediment input into the lacustrine basin above the basal facies due to deltaic progradation (figure 10). Correlation of the facies across the Makó-Hódmezővásárhely trough shows that the delta front facies is



10. Schematic illustration of the stratigraphic section and facies recorded in the Hód #I well.

present in all 3 wells. Only a thin prodelta facies (subfacies B) is identified in the Ml #1 well (figure 11).

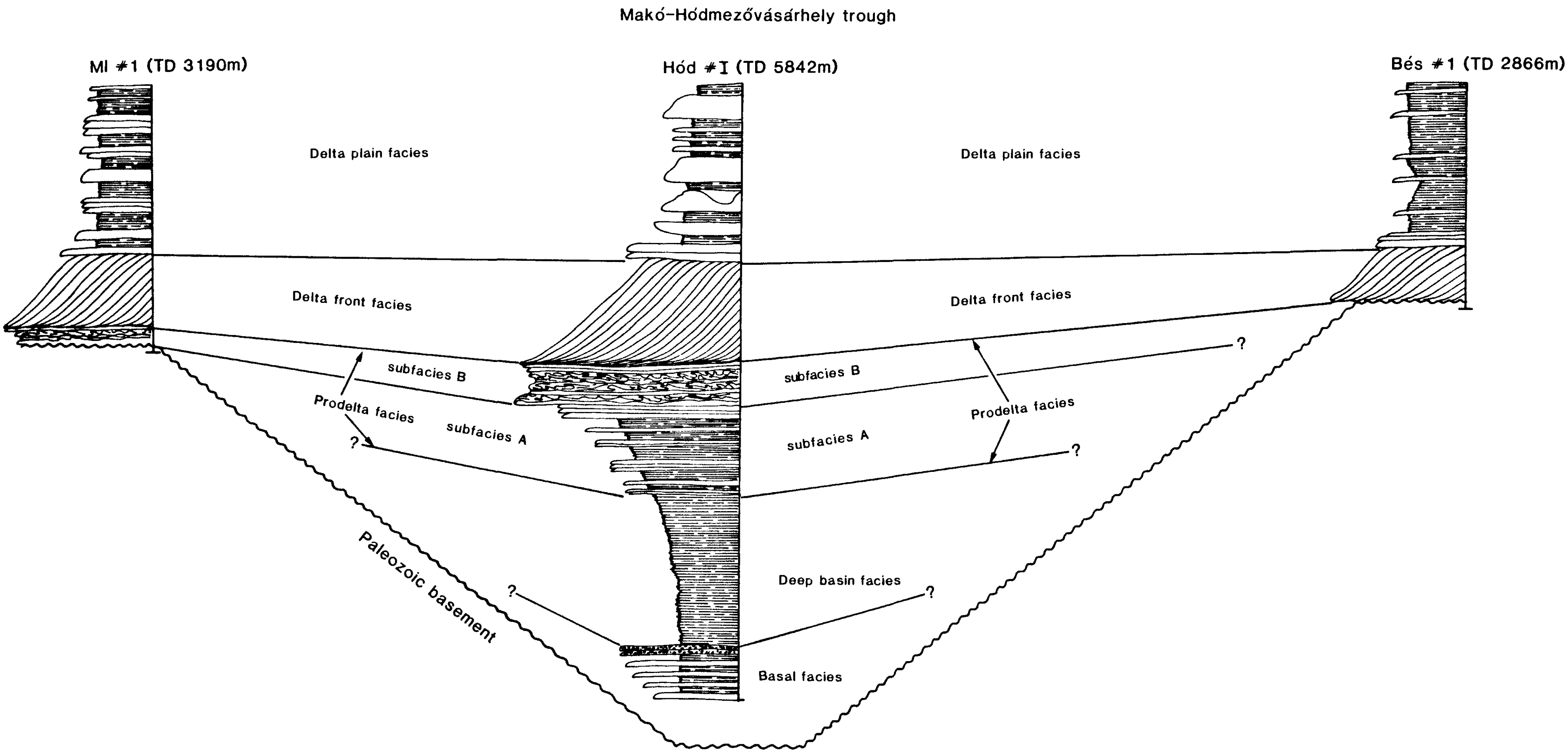
POSSIBLE PETROLEUM TRAPS

Petroleum accumulations, including the Maros-Szőreg oil field located on the west flank of the Makó-Hódmezővásárhely trough, are found mainly in fluvial channel sandstones on top of the delta front facies (Révész, 1982). In the Maros-Szőreg oil field a compaction anticline forms the main trapping mechanism. Similar traps have been identified elsewhere in the Pannonian Basin (Bérczi and others, 1981). Besides fluvial channel sandstones, distributary channel sandstones as well as possible distributary mouth bar deposits represent the the depositional environments of the sandstones now containing petroleum in the adjacent Maris-Szőreg oil field. Sandstones deposited in similar depositional environments and depositional setting and containing hydrocarbons have been identified in China in fluvial-lacustrine sediments (Yu, 1981, Shice and Hengjian, 1981), in Cretaceous delta plain distributary channel deposits in California (Cherven, 1983) and from a variety of deltaic deposits and prodelta turbidites (Berg, 1982). Fouch and Dean (1982) also report that most of the petroleum accumulations in lacustrine sediments are found in clastic sediments around the margins of the ancient lake deposits.

Within the Makó-Hódomezővásárhely trough the petroleum source beds are the organic-rich marls (deep basin and prodelta facies) which contain an efficient collection system consisting of turbidite sands interbedded with marl. Hydrocarbons migrated along the turbidite sands and up the delta front facies to the distributary channel-bar-fluvial channels where petroleum accumulated within compaction anticlines.

Other stratigraphic traps for petroleum accumulation within the Makó-Hódmezővásárhely trough can be expected. In particular, potential reservoirs and traps may exist as stratigraphic traps within the turbidite sands (fan deposits) of subfacies A of the prodelta facies. The amalgamated turbidite sandstones, interpreted as fan deposits (prodelta subfacies A) in the Hód #I well, will apparently pinch out on the flanks of the trough on the basement highs. Differential compaction has resulted in strata dipping into the trough. Petroleum may accumulate updip within these inclined sandstones where they pinchout forming possible stratigraphic traps. Similar hydrocarbon traps are reported in the lateral margins of delta-fan deposits in California (Cherven, 1983). A delta fan environment would also be inferred for the petroleum-rich thin blanket sands in front of delta front strata in China investigated by Shice and Hengjian (1981).

Fan deposits may also produce traps due to differential compaction of sediments forming stratigraphic traps. If sufficient sands thickness exists in the Makó-Hódmezővásárhely



11. Lateral facies relationships within the three wells drilled within and on the flanks of the Makó-Hódmezővásárhely trough. The delta front facies is identified within the 3 wells; only the prodelta facies is identified in the Ml #1 and the Hód #I wells.

trough fans differential compaction may have also produced stratigraphic traps provided closure was obtained. A similar trapping mechanism is identified in Neogene strata in the San Joaquin Basin in California (MacPherson, 1977) and in the North Sea in Eocene strata (Heritier and others, 1979).

Sand interbedded with marl may have also been selectively transported and deposited along the west side of the Makó-Hódmezővásárhely trough due to Coriolis force. Counterclockwise current flow and sediment transport due to Coriolis force has been previously noted within lake systems (Sturm and Matter, 1978, Pharo and Carmack, 1979, and Pickrill and Irwin, 1983) and would have also been expected within the ancient lake system in the Makó-Hódmezővásárhely trough. These sands where they pinchout with marl may also form stratigraphic petroleum traps.

CONCLUSIONS

Over 6000 m of Neogene and younger fluvial-deltaic-lacustrine sediments fill the Makó-Hódmezővársárhely trough in southeast Hungary. Five major facies are identified in the basin and include in ascending order: 1) a BASAL facies of marl interbedded with turbidite deposited sandstones and conglomerate; 2) a DEEP BASIN facies of laminated to structureless calcareous to silty marl; 3) a PRODELTA facies containing a lower unit of parallel-bedded sandstone interbedded with marl overlain by a sequence of deformed strata (slumped deposits); 4) a DELTA FRONT facies of inclined (5 to 20 degree dip) and deformed beds of sandstone and marl; and 5) a DELTA PLAIN facies of horizontal beds of sandstone, siltstone, lignite and marl. The sedimentation records deltaic progradation into a deep lake of about 700 m depth.

Besides the present petroleum accumulation in the delta front facies in the adjacent Maros-Szőreg oil field, stratigraphic traps may exist in the lacustrine fan deposits in the prodelta facies.

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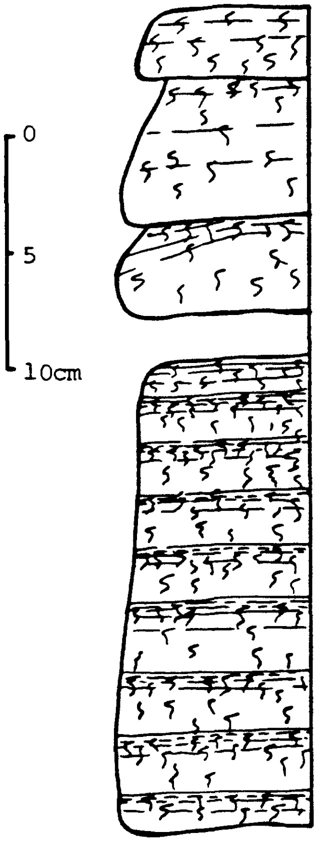
APPENDIX--CORE DESCRIPTIONS

Core number	Cored interval(core recovered)	
1	2049-2055(4.2)	DELTA PLAIN FACIES
2	2290-2296(4.75)	DELTA PLAIN FACIES
3	2385-2390(3.0)	DELTA PLAIN FACIES
4	2500-2505(2.5)	DELTA PLAIN FACIES
5	2582-2588(0.0)	DELTA PLAIN FACIES
6	2601-2606(0.0)	DELTA PLAIN FACIES
7	2700-2705(5.0)	DELTA FRONT FACIES
8	2759-2764(2.7)	DELTA FRONT FACIES
9	2885-2890(2.5)	DELTA FRONT FACIES
10	2953-2956(1.95)	DELTA FRONT FACIES
11	3051-3060(6.3)	DELTA FRONT FACIES
12	3098-3107(5.05)	DELTA FRONT FACIES
13	3179-3184(5.0)	DELTA FRONT FACIES
14	3270-3279(9.0)	PRODELTA FACIES
15	3328-3337(9.0)	PRODELTA FACIES
16	3433-3442(9.0)	PRODELTA FACIES
17	3476-3485(9.0)	PRODELTA FACIES
18	3527-3535(8.0)	PRODELTA FACIES
19	3582-3590(8.0)	PRODELTA FACIES
20	3686-3693(7.0)	PRODELTA FACIES
21	3809-3818(2.05)	PRODELTA FACIES
22	3930-3933(1.3)	PRODELTA FACIES
23	4002-4010(0.0)	PRODELTA FACIES
24	4017-4026(9.0)	PRODELTA FACIES
25	4117-4125(8.5)	PRODELTA FACIES
26	4195-4204(8.5)	PRODELTA FACIES
27	4263.8-4371(7.2)	PRODELTA FACIES
28	4538-4546(7.2)	DEEP BASIN FACIES
29	4701-4702(0.0)	DEEP BASIN FACIES
30	4702-4704(1.2)	DEEP BASIN FACIES
31	4885-4888(0.0)	DEEP BASIN FACIES
32	4888-4894(0.8)	DEEP BASIN FACIES
33	4983-4988(0.7)	DEEP BASIN FACIES
34	5070-5074(3.4)	DEEP BASIN FACIES
35	5167-5183(13.5)	DEEP BASIN FACIES
36	5250-5267(8.4)	DEEP BASIN FACIES
37	5310-5328(10.6)	DEEP BASIN FACIES
38	5405-5418(4.0)	DEEP BASIN FACIES
39	5450-5468(18.0)	BASAL FACIES
40	5468-5486(18.0)	BASAL FACIES
41	5486-5489(2.75)	BASAL FACIES
42	5572-5577(1.4)	BASAL FACIES
43	5650-5677(27.0)	BASAL FACIES
44	5727-5738(10.3)	BASAL FACIES
45	5806-5823(8.8)	BASAL FACIES

Total depth well is 5842.5 m.
Total core length attempted is 369.2 m of which 274.85 m core recovered (74.4%).

DELTA PLAIN FACIES

Core 2(2290.0-2296.0[4.20])

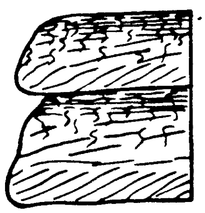


Core Description

Sandstone, organic-rich, light grey, micaceous to silty containing parallel and horizontal low-angle laminae, strata intensely bioturbated. $CaCO_3$ ranges from 14.9-21.6% and sandstone density is 1.9-1.92 gm/cm^3 between depths of 2050 and 2300 m.

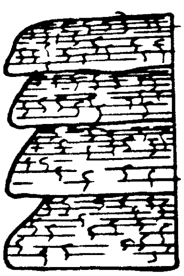
Cyclic thin parallel beds of graded sandstone, siltstone and argillaceous marl. Strata are intensely bioturbated.

Core 3(2385.0-2390.0[3.0])



Sandstone, organic-rich, bioturbated, silty, containing small-scale cross-strata changing vertically to parallel laminae; top bed graded from sandstone at base to argillaceous marl at the top. Burrows oriented vertically.

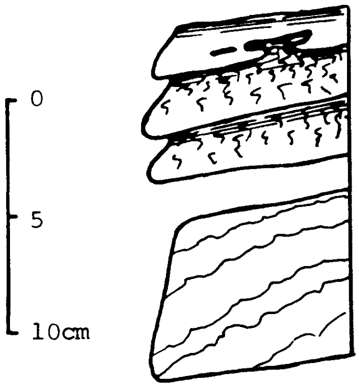
Core 4(2500.0-2505.0[2.5])



Cyclic parallel beds grading from sandstone at base to siltstone to argillaceous marl at top within each bed, argillaceous marl dominates. Bioturbation abundant. $CaCO_3$ content is 21.2 %, density is 2.39 gm/cm^3.

DELTA FRONT FACIES

Core 8(2759.0-2764.0[2.7])

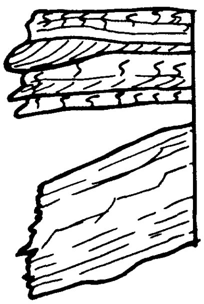


Core description

Sandstone, siltstone and argillaceous marl as graded beds All strata dip at 5 to 7 degrees. Individual beds may contain thinly laminated organic-rich sediment. Bioturbation is abundant. Upper-most bed is disrupted with flame structure. $CaCO_3$ content of marl is 22.1%; $CaCO_3$ content of sandstone is 22.7%. Sandstone density is 2.32 gm/cm^3.

Sandstone with distorted (slumped) laminae of organic-rich sediment dipping at approximately 6 degrees.

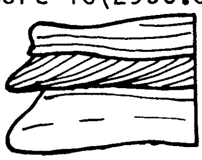
Core 9(2885.0-2890.0[2.8])



Horizontal to inclined parallel beds of alternating sandstone and silt-argillaceous marl. Sandstone contains small-scale cross-strata. Bioturbation is abundant.

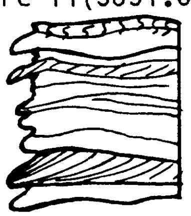
Interbedded inclined parallel laminae of disrupted (micro-faulted) silty marl and sandstone (rare).

Core 10(2953.0-2956.0[1.95])

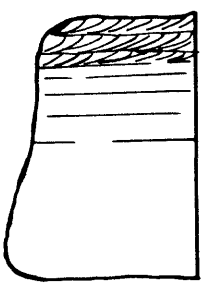


Sandstone, parallel thin laminae with one small-scale crossbed. The sandstone is organic-rich and micaceous.

Core 11(3051.0-3060.0[6.3]



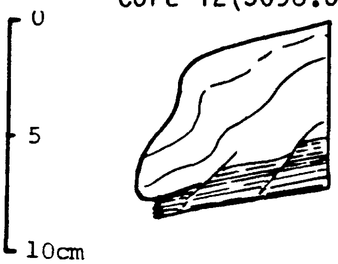
Interbedded inclined thin parallel laminations of organic-rich sandstone and silty marl. Sediment contains unidirectional, small-scale cross-strata. Bioturbation is locally restricted to individual beds.



Sandstone, with horizontal, planar laminations changing to small-scale cross-strata at the top of the bed.

DELTA FRONT FACIES

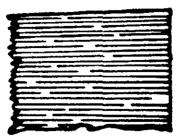
Core 12(3098.0-3107.0[5.05])



Core description

Sandstone, graded, with abundant soft sediment deformation features and faults. The strata dip at 10 to 15 degrees. The sandstone rests on argillaceous marl.

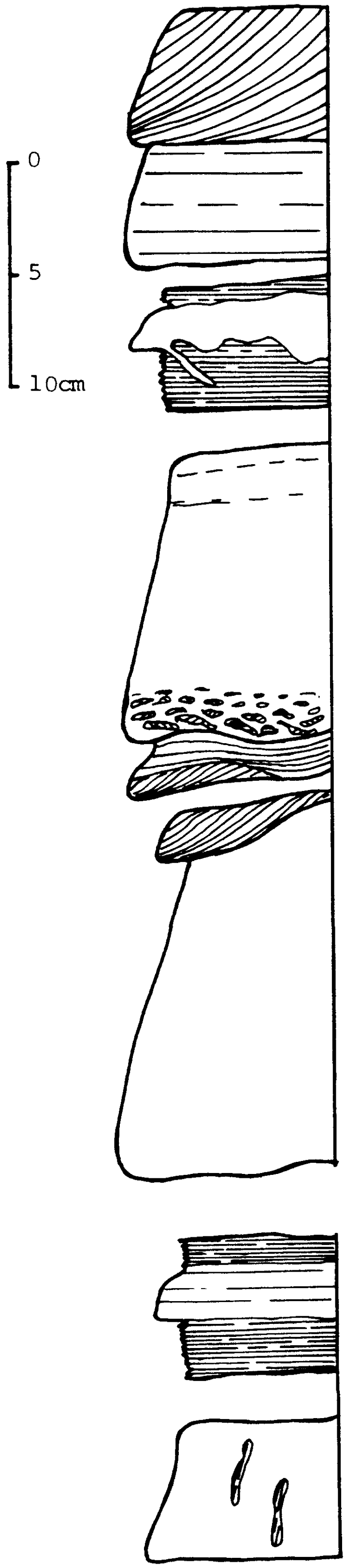
Core 13(3179.0-3184.0[5.00])



Marl, silty to argillaceous and is thinly laminated.

PRODELTA FACIES, subfacies B

Core 14(3270.0-3297.0[9.0])



Core description

Sandstone, horizontal planar laminations changing to one cross-stratified bed at top of core (strata dip at 32 degrees).

Interbedded sandstone and argillaceous marl. The sandstone bed is deformed containing load casts. The marl is thinly laminated.

Sandstone, the basal bed contains part of a small-scale crossbed which is overlain by parallel silt laminae. The uppermost bed is normally graded with abundant marl rip-up clasts at the base and horizontal thin laminae at the top. $CaCO_3$ content of marl interbeds is 24.8%; $CaCO_3$ content of sandstone is 17.2%. The sandstone density is 2.35 gm/cm^3 between depths of 3128 and 3435 m.

Sandstone, normally graded, with small-scale cross-strata at top of the bed, plant remains (leaf) at the base of the bed.

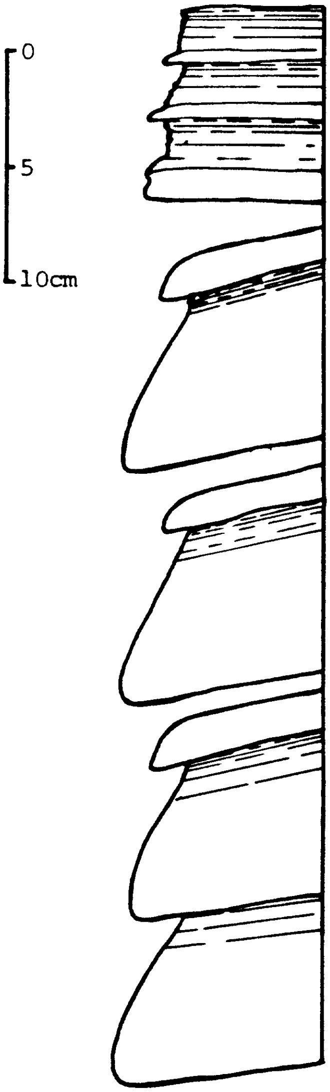
Interbedded parallel layers of argillaceous marl and sandstone, all strata contain thin parallel laminae.

Sandstone, structureless(?) with two large vertically-oriented marl rip-up clasts suggesting soft sediment deformation of the bed.

HÓDMEZŐVÁSÁRHELY #I

PRODELTA FACIES, subfacies B

Core 15(3328.0-3337.0[9.0])



Core description

Interbedded sandstone, siltstone and argillaceous marl as parallel laminated normally graded beds.

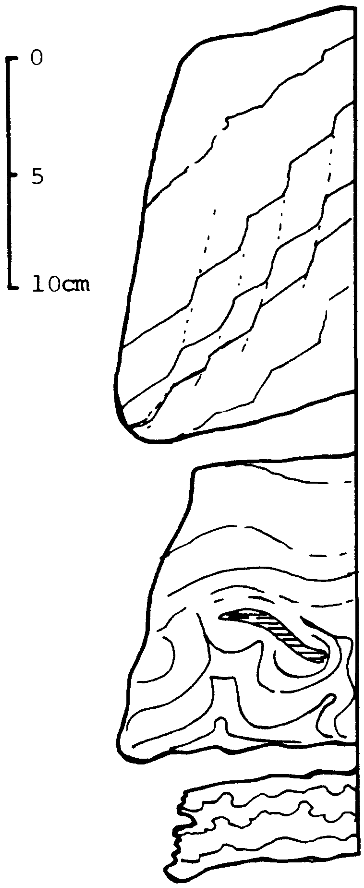
Sandstone, normally graded, changing from medium-grained sandstone at base of bed to parallel thinly laminated silty marl at the top of the bed. All strata dip at 10 degrees.

Sandstone, normally graded to organic-rich silty marl. Strata dip at 7 degrees.

Interbedded normally graded sandstone changing to organic-rich micaceous marl at top of beds. Strata dip at 7 degrees.

PRODELTA FACIES, subfacies B

Core 16(3433.0-3442.0[9.0])



Core description

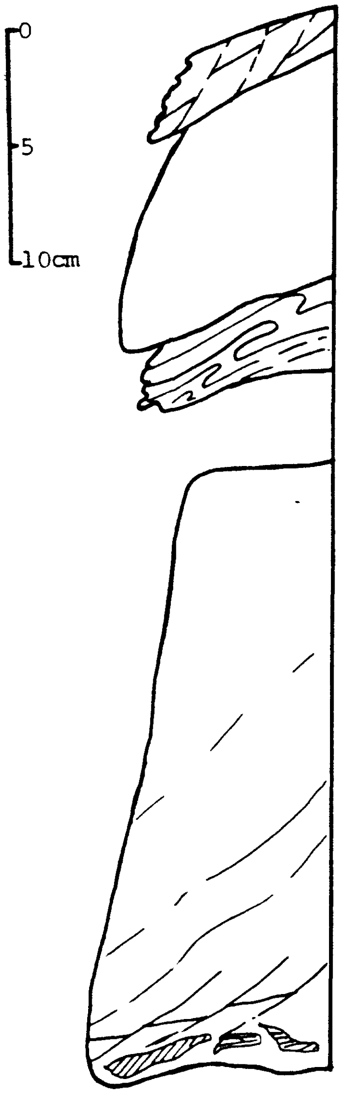
Sandstone with abundant soft sediment deformation as penecontemporaneous faults. Sandstone possibly graded. Faulted laminae contain organic-rich sediment. Strata dip at approximately 10 degrees.

Sandstone, disrupted, soft sediment deformation (flame structures), contains one large marl rip-up clast.

Interbedded sandstone and thin, organic-rich laminae, all strata are disrupted (soft sediment deformation).

PRODELTA FACIES, subfacies B

Core 17(3476.0-3485.0[9.0])



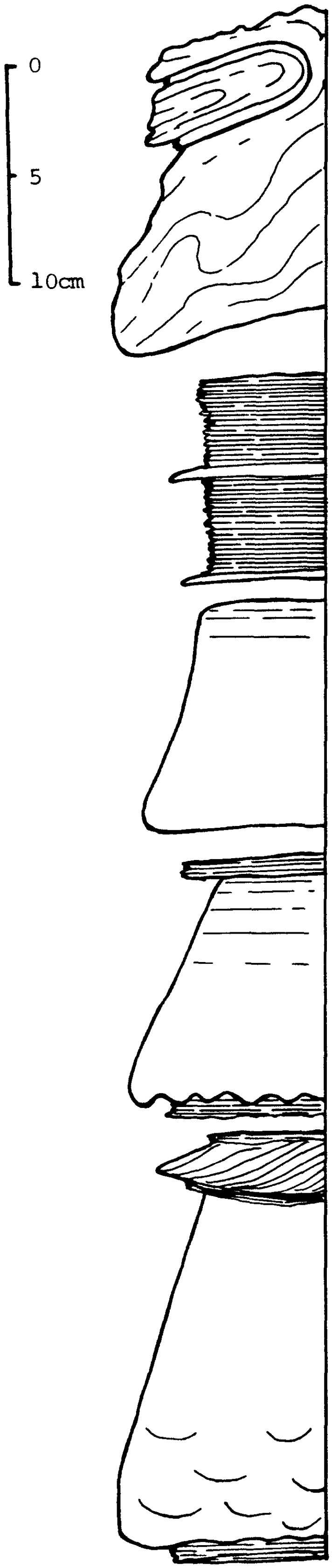
Core description

Sandstone, normally graded, containing disrupted siltstone laminae (soft sediment deformation) in the basal strata and numerous penecontemporaneous faults in the uppermost strata. The sandstone bed between the deformed strata is graded. Strata dip at approximately 6 degrees. $CaCO_3$ content of sandstone is 23.2% and density is 2.38 gm/cm^3 between depths of 3435 and 3800 m.

Sandstone, organic-rich, miceous, normally graded, with soft sediment deformation. Marl rip-up clasts to 5 cm length occur at the base of the bed.

PRODELTA FACIES, subfacies B

Core 18(3527.0-3535.0[8.0])



Core description

Sandstone, with soft sediment deformation. The upper-most strata are completely overturned, the lower laminae are distorted resulting from slumping. Plant fragments are abundant.

Interbedded parallel silty marl laminae and thin-bedded sandstone laminae.

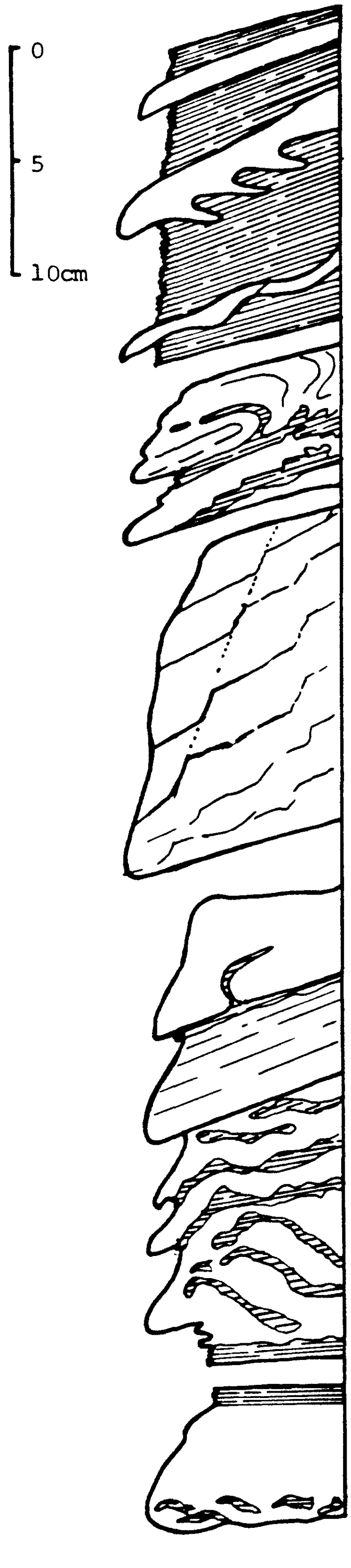
Sandstone, normaly graded.

Sandstone, normally graded to silty marl. Sandstone contains load structures on marl at the base of the bed.

Sandstone, normally graded with load structures on marl at the base of the bed. Possible dish structures occur near the base of the graded strata. Small-scale cross-strata occurs at the top of the bed.

PRODELTA FACIES, subfacies B

Core 19(3582.0-3590.0[7.0])



Core description

Interbedded sandstone and argillaceous marl. Sandstone contains soft sediment deformation features. All strata dip at approximately 15 degrees. The laminae contain abundant plant fragments.

Interbedded and disrupted sandstone and marl, with flame structures.

Sandstone, soft sediment deformation (penecontemporaneous faulting), strata dip at approximately 8 degrees.

Sandstone, deformed, containing flame structure.

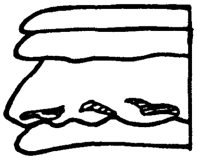
Sandstone, organic-rich, grading from medium-grained sand stone to argillaceous marl.

Sandstone, normally graded with marl rip-up clasts, soft sediment deformation abundant, possible small-scale cross-strata near top of bed. The sandstone bed rests on marl.

Sandstone, normally graded with abundant clay marl rip-up clasts.

PRODELTA FACIES, subfacies A

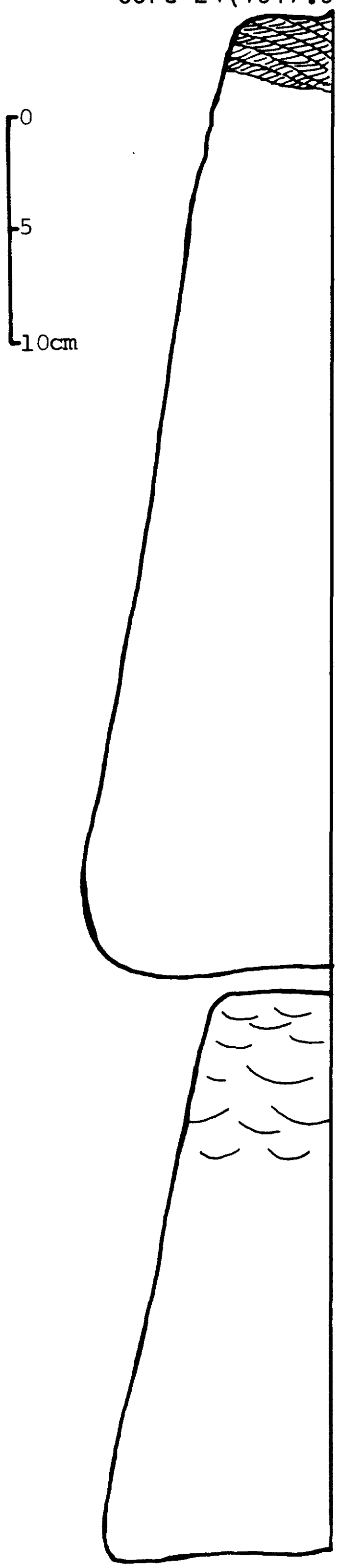
Core 20(3686.0-3693.0[7.0])



Core description

Sandstone, planar parallel normally graded beds, with one bed containing marl rip-up clasts

Core 24(4017.0-4026.0[9.0])

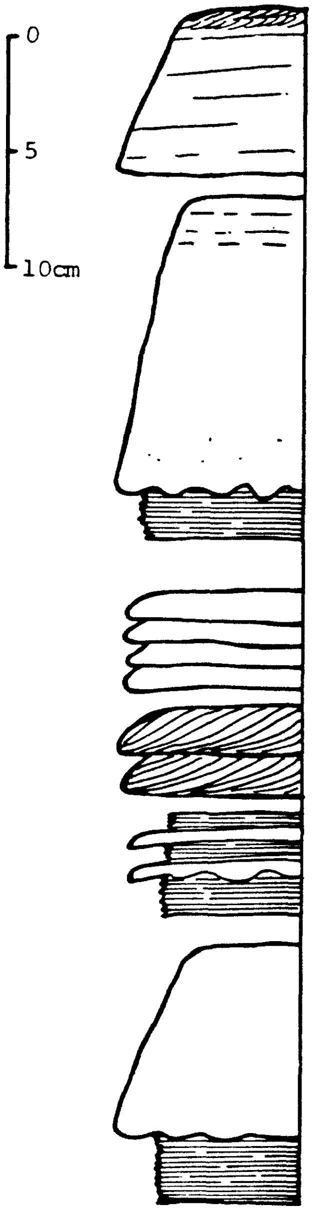


Sandstone, well-cemented, normally graded with small-scale climbing cross-strata at top of bed. Sandstone micaceous. $CaCO_3$ content of sandstone is 24.1%, density is 2.43 gm/cm^3, with a porosity of 7%, permeability of 110.47 md. $CaCO_3$ content of marl varies from 10 to 33.4% between depths of 3800 and 4450 m.

Sandstone, fine-grained, possibly graded with small-scale cross-strata and possible dish structures near the top of the bed.

PRODELTA FACIES, subfacies A

Core 25 (4117.0-4125.0[8.5])



Core description

Sandstone, normally graded with planar, parallel laminae; small-scale cross-strata occur at the top of the bed.

Sandstone, graded with planar, parallel laminae and abundant organic-rich fragments on the upper part of the bed. Load structures occur at the base of the bed.

Repeated parallel beds of normally graded sandstone.

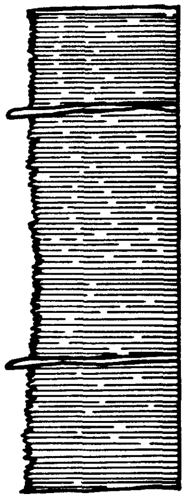
Sandstone, with unidirectional small-scale cross-strata

Interbedded parallel sandstone beds and thin marl laminations. Some of the sandstone beds contain load structures.

Sandstone, normally graded with possible horizontal parallel laminae at the of the bed. The sandstone bed rests on marl.

PRODELTA FACIES, subfacies A

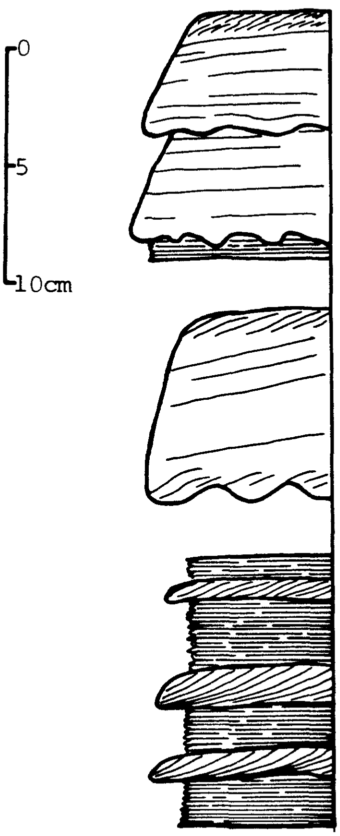
Core 26(4195.0-4204.0[8.5])



Core description

Argillaceous marl, as horizontal planar laminae containing two thin (2 mm thick) sandstone laminae.

Core 27(4263.0-4271.0[7.2])



Core description

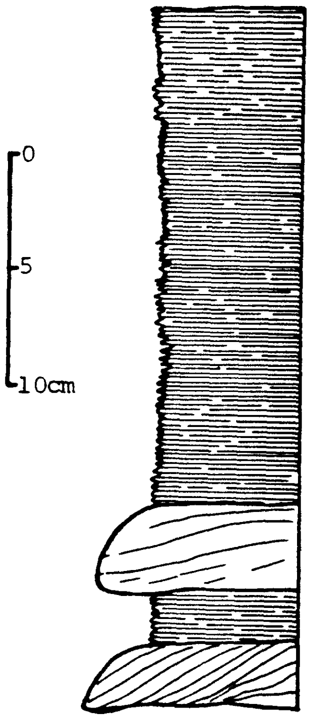
Sandstone, normally graded with horizontal parallel beds and load structures where sandstone rests on marl. Small-scale cross-strata occur at the top of the bed.

Sandstone, normally graded with load structures at the base of the bed and small-scale cross-strata at the top of the bed, possible low-angle dipping parallel laminae.

Interbedded sandstone and marl with unidirectional small-scale cross-strata.

DEEP BASIN FACIES

Core 28(4538.0-4546.0[7.2])



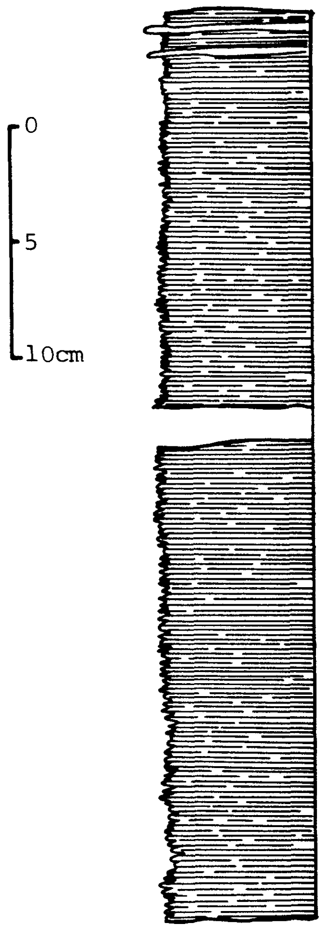
Core description

Interbedded horizontal laminae of marl with two sandstone beds. One sandstone bed is normally graded, the other sandstone bed contains small-scale cross-strata. The $CaCO_3$ content of argillaceous marl ranges from 40.8 to 50.3%. Porosity of silt and sandstone laminae averages 9.3%, permeability is less than 0.1 md between depths of 4450.0 and 4700 m.

DEEP BASIN FACIES

Between depths of 4800 to 5070 m the $CaCO_3$ content of the argillaceous marl ranges from 28 to 31 %, the $CaCO_3$ of the calcareous marl is 63.2%. The density of the marl is 2.70 gm/cm^3.

Core 35(5167.0-5183.0[13.5])



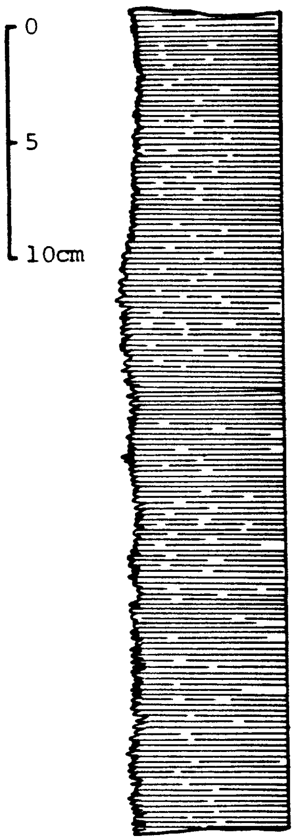
Core description

Marl, horizontal parallel laminae of argillaceous marl. Two thin (less than 0.5 mm thick) sandstone laminae occur near the top of the core. The $CaCO_3$ of the sandstone is 19 %, the argillaceous marl is 38 %, and marl ranges between 50-66 %. The density of the marl is 2.70 gm/cm^3.

Marl, horizontal, parallel laminae.

DEEP BASIN FACIES

Core 36(5250.0-5267.0[8.4])



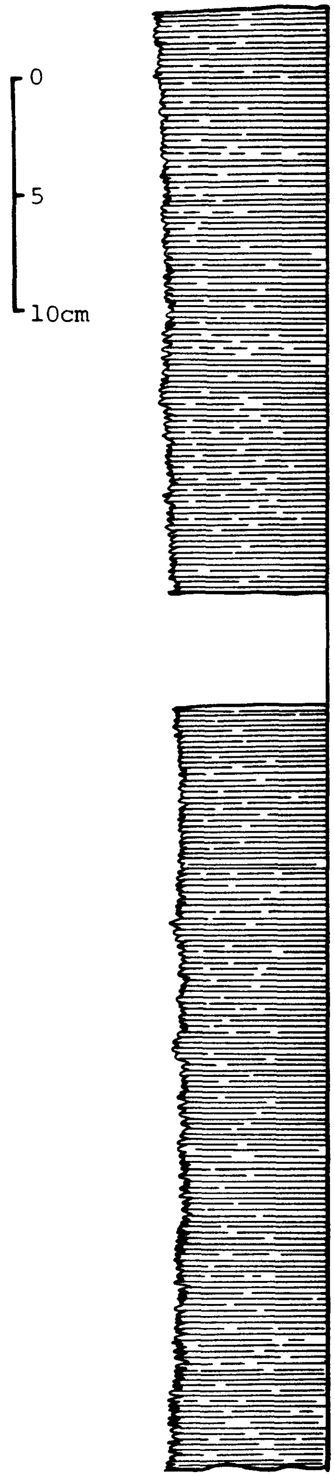
Core description

Marl, horizontal parallel laminae, slightly micaceous.

DEEP BASIN FACIES

Core 38(5405.0-5418.0[4.0])

Core description

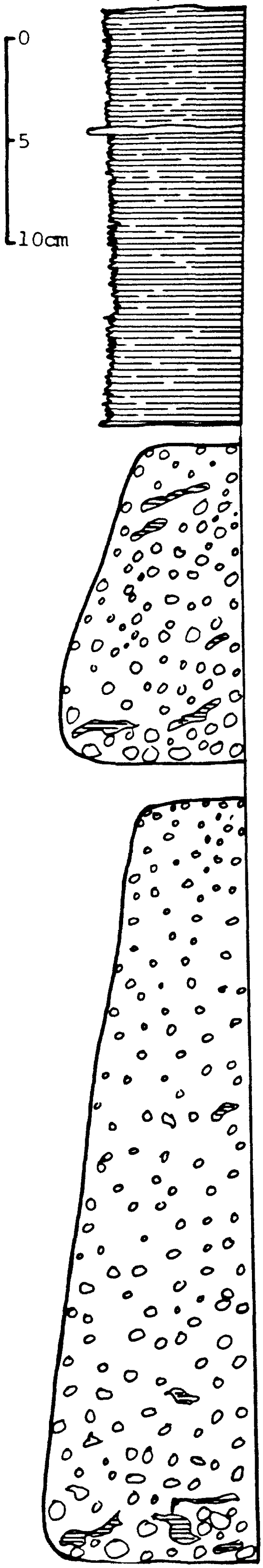


Marl, horizontal parallel laminae.

Marl, horizontal parallel laminae of argillaceous marl.

BASAL FACIES

Core 39(5450.0-5468.0[18.0])



Core description

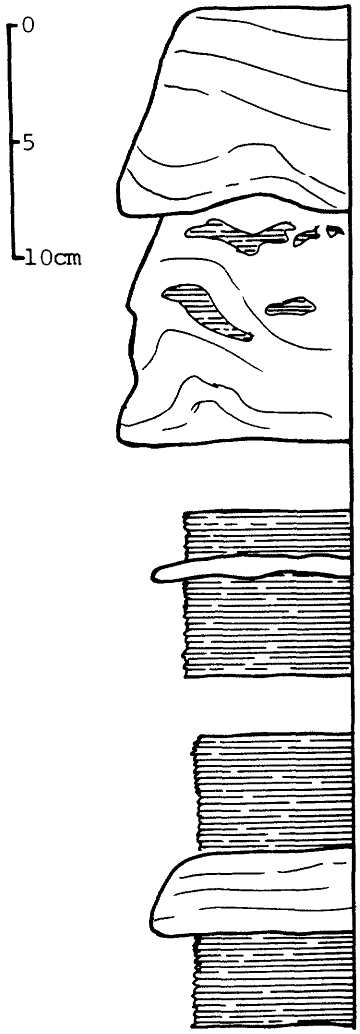
Marl, horizontal parallel laminae with one sandstone lamina (0.5 mm thick).

Conglomerate, with well-rounded quartz pebbles and marl rip-up clasts.

Conglomerate, normally graded, with well-rounded quartz pebbles, marl rip-up clasts occur at the base of the bed.

BASAL FACIES

Core 40(5468.0-5486.0[18.0])



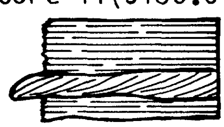
Core description

Sandstone, normally graded, abundant soft sediment deformation of strata, large marl rip-up clasts and quartz pebbles to 0.5 mm diameter in lower bed. Low-angle parallel laminations grading to marl occur in the upper part of the bed.

Interbedded, horizontal parallel laminations of marl and sandstone. Sandstone contains parallel planar laminations.

Interbedded, horizontal parallel laminations of marl and sandstone.

Core 41(5486.0-5489.0[2.75])

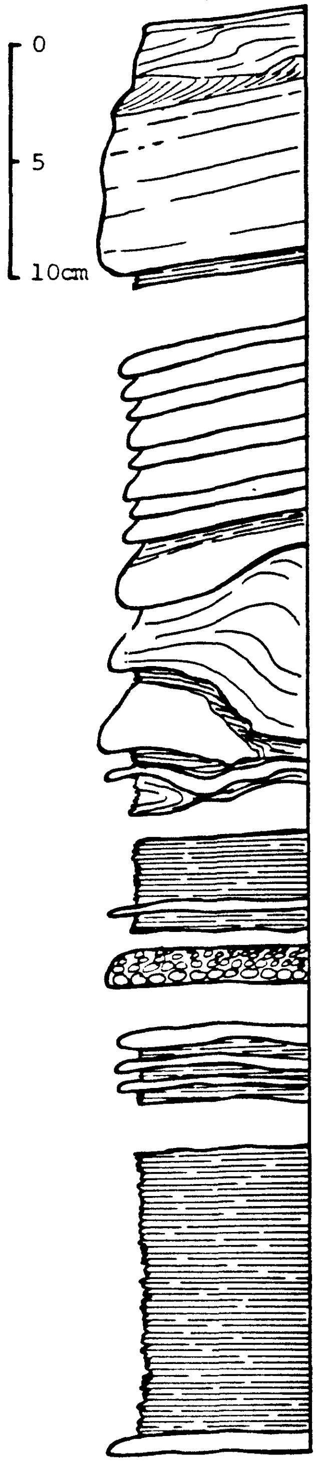


Core description

Interbedded horizontal parallel silty marl and sandstone. Sandstone bed contains a small-scale cross-strata.

BASAL FACIES

Core 43(5650.0-5677.0[27.0])



Core description

Sandstone, coarse-grained and normally graded with parallel laminae dipping 7-8 degrees changing to small-scale cross-strata at the top of the bed. A distorted sandstone bed occurs above the cross-stratified bed.

Repeated normally graded beds of sandstone. The strata dip at 11 degrees.

Sandstone, normally graded from coarse-grained sandstone to marl, strata disrupted (soft sediment deformation).

Interbedded marl and sandstone. Sandstone bed contains parallel laminae.
Conglomerate, normally graded, well-rounded quartz pebbles imbricated with load casts at base of the bed.

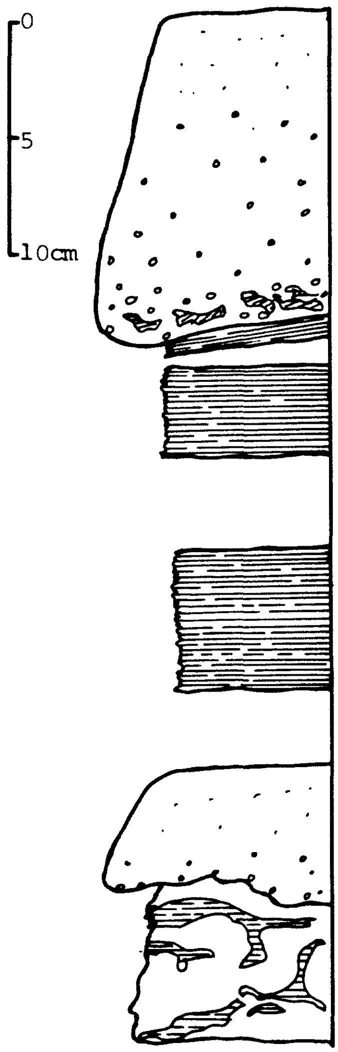
Interbedded marl and sandstone as parallel laminations.

Marl, micaceous, horizontal parallel laminations with one normally raded sandstone bed at the base of the core.

BASAL FACIES

Core 43 continued

Core description



Conglomerate, normally graded from fine pebbles and marl rip-up clasts to coarse-grained sandstone at the top of the core The strata dip at 7 degrees.

Marl, horizontal parallel laminae.

Marl, horizontal parallel laminae.

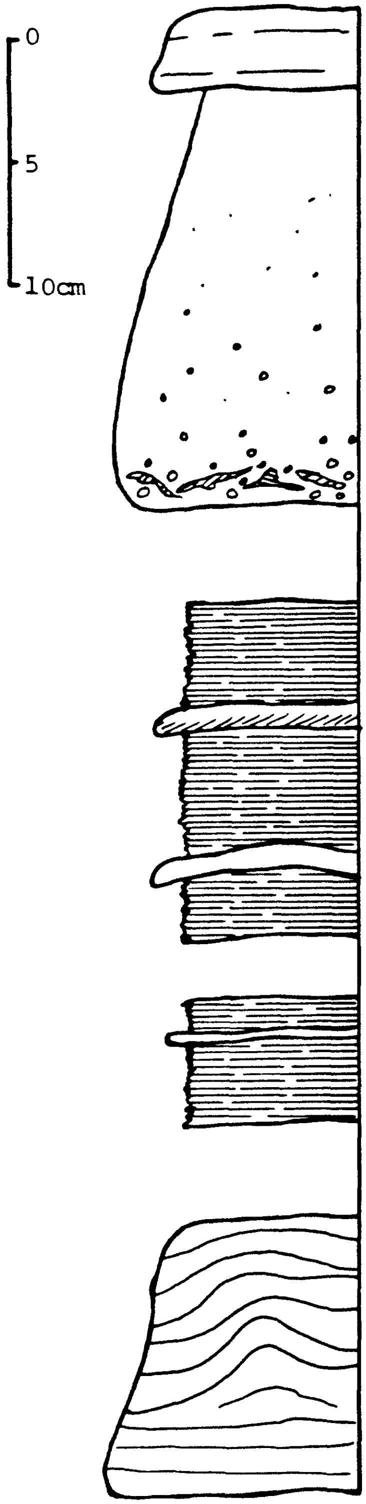
Sandstone, normally graded granules to coarse-grained sandstone.

Coarse-grained sandstone containing soft sediment deformation consisting of marl injections.

BASAL FACIES

Core 44(5727.0-5738.0[10.3])

Core description



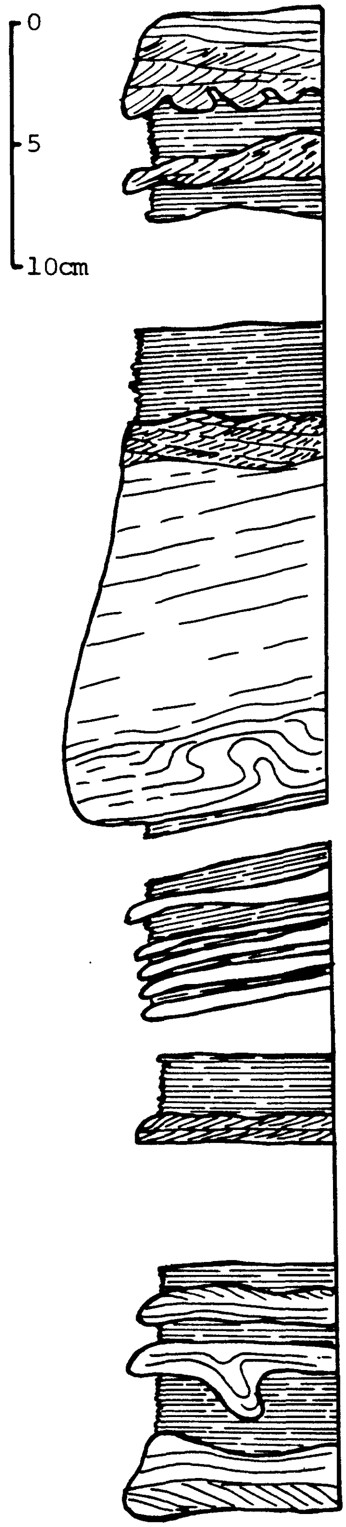
Sandstone, normally graded from granules and marl rip-up clasts at the base of the core to coarse-grained sandstone at the top of the core.

Interbedded marl and sandstone as horizontal parallel laminae. The sandstone beds occur as parallel laminae and possibly contain small-scale cross-strata.

Sandstone, possibly graded, disrupted (soft sediment deformation).

BASAL FACIES

Core 45(5806.0-5823.0[8.8])



Core description

Interbedded sandstone and marl. Sandstone occurs as small-scale climbing cross-strata with load structures at the base of the upper bed.

Sandstone, normally graded containing distorted laminae near the base of the bed changing to subhorizontal parallel laminae (dip at 10 degrees), to small-scale climbing cross-strata at the top of the bed. Marl overlies and underlies the graded sandstone bed.

Interbedded horizontal parallel laminae of sandstone and marl. Strata dip at 11 degrees.

Interbedded horizontal parallel laminae of sandstone and marl. The sandstone contains unidirectional small-scale cross-strata.

Interbedded sandstone and marl. The sandstone contains load casts, parallel laminations and small-scale cross-strata.

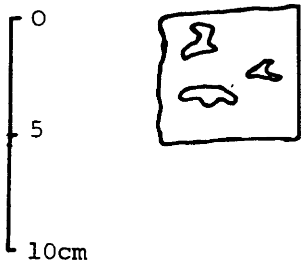
Core number	Cored interval(core recovered)	
1	801-807(4.0)	DELTA PLAIN FACIES
2	1001-1006(1.0)	
3	1201-1205.6(1.4)	
4	1400-1405(2.0)	
5	1604-1609(1.6)	
6	1802-1808(2.2)	
7	1902-1904(1.75)	
8	1955-1959.5(0.93)	
9	2010-2012.5(0.1)	
10	2012.5-2013.5(0.3)	
11	2046-2051.5(1.1)	
12	2094-2096.5(1.3)	
13	2148-2153(2.0)	
14	2194-2201(5.55)	
15	2270-2273(3.03)	
16	2320-2230.5(9.3)	
17	2410-2415(4.9)	
18	2501-2517(16.0)	
19	2553-2556(3.0)	DELTA FRONT FACIES
20	2609-2614(3.9)	
21	2649-2656(6.9)	
22	2703-2709(6.0)	
23	2764-2767(2.0)	
24	2786-2788(1.1)	
25	2872-2879(7.0)	
26	2976.5-2981.5(5.0)	
27	3003-3006.5(3.1)	PRODELTA FACIES
28	3049-3054(3.0)	
29	3093-3099(5.4)	
30	3130-3134(3.5)	
31	3165-3168(1.0)	

Total depth well 3190 m.
Total core length attempted is 152.6 m of which 114.1 m core recovered (74.1%).

DELTA PLAIN FACIES

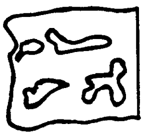
Core 3(1201.0-1205.6[1.43])

Core description



Mudstone, oxidized, mottled.

Core 6(1802.0-1808.0[2.2])



Mudstone, oxidized, mottled with a thin lignite bed at the top of the core.

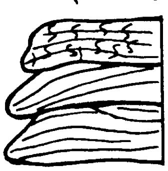
Core 8(1955.0-1959.5[0.93])

Mudstone, oxidized, mottled with abundant plant fragments.

Core 11(2010.0-2012.5[0.1])

Sandstone containing planar to low angle laminae.

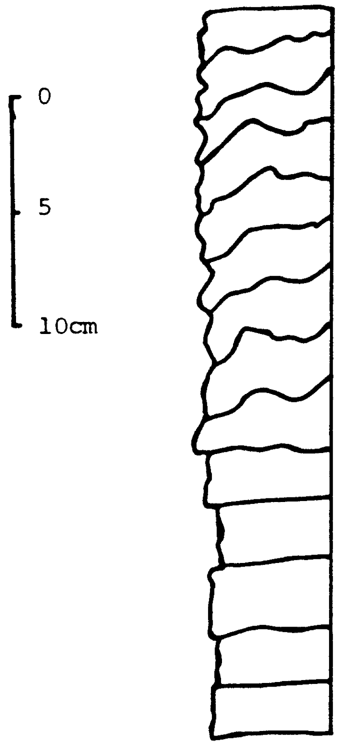
Core 12(2094.0-2096.5[1.3])



Sandstone and organic-rich siltstone occur as low angle cross-strata, overlain by parallel silt laminae. The top of the core is bioturbated.

DELTA PLAIN FACIES

Core 14(2194.0-2201.0[5.5])

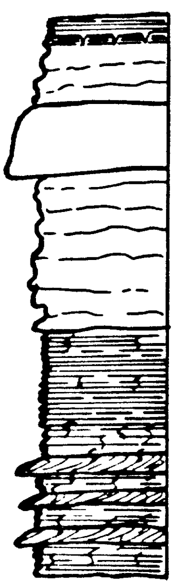


Core description

Interbedded organic-rich siltstone and mudstone containing intensely disrupted (slumped) strata.

Mudstone, with three oxidized (redbeds) in silty organic-rich strata. Mica is abundant.

Core 15(2270.0-2273.0[3.03])



Siltstone, oxidized, organic-rich, micaceous, occurring as parallel laminae. An algal mat structure is present.

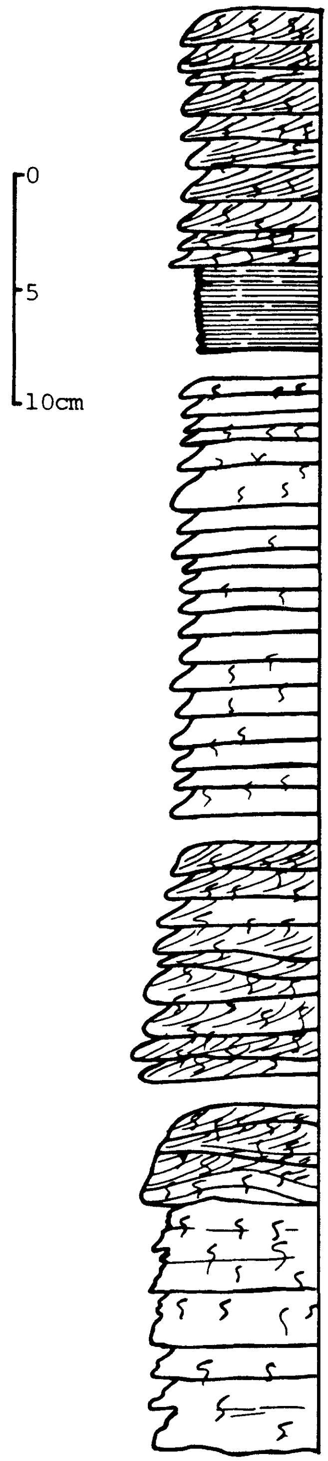
Sandstone.

Siltstone, brown and organic-rich.

Interbedded laminations of sandstone, siltstone, and marl. Small-scale unidirectional cross-strata increase toward the base of core. Bioturbation is abundant.

DELTA PLAIN FACIES

Core 16(2320.0-2330.5[9.3])



Core description

Sandstone as small-scale cross-strata to parallel beds of sandy silt. The strata are bioturbated.

Marl containing parallel laminations.

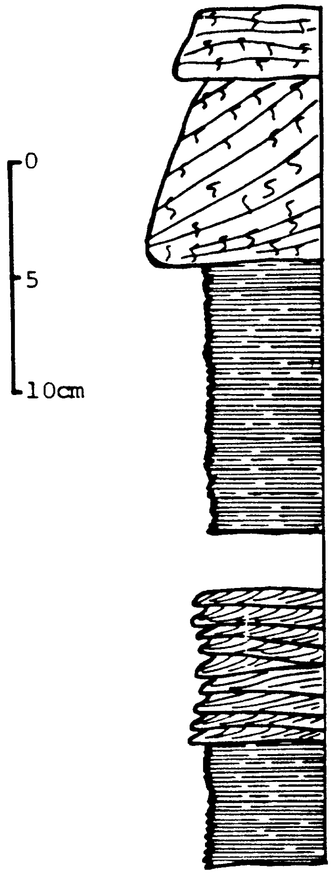
Sandstone and siltstone as repeated parallel horizontal beds up to 1.5 cm thick. Burrows are scattered and rare.

Sandstone, organic-rich containing unidirectional, small-scale crossbeds alternating with siltstone laminae. Bioturbation is abundant.

Sandstone, top of core contains organic-rich, small-scale cross-strata and parallel siltstone laminae. Lower part of core contains repeated normally graded sandstone beds. All the strata are bioturbated.

DELTA PLAIN FACIES

Core 18(2501.0-2517.0[16.0])



Core description

Sandstone containing a 7 cm thick crossbed with parallel strata on top of the crossbed. Bioturbation is abundant.

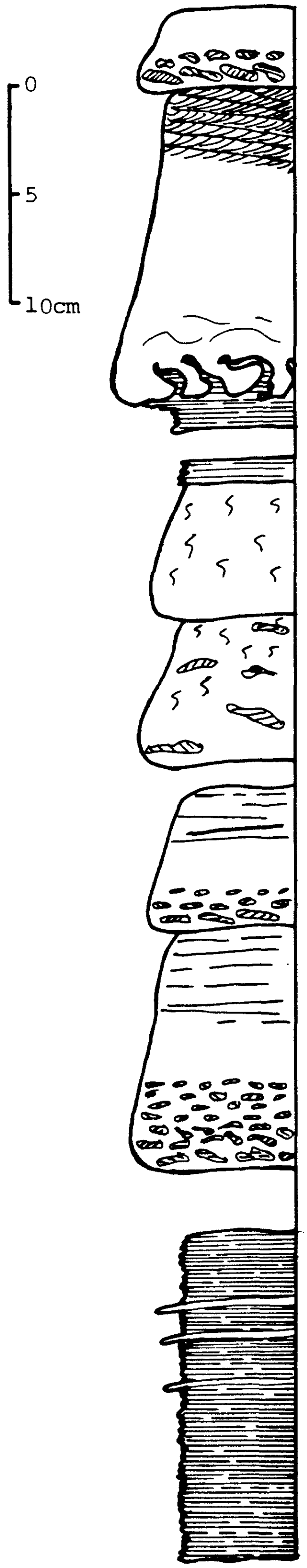
Marl as horizontal planar laminae containing thin sand laminae. Bioturbation is abundant.

Sandstone, organic-rich, micaceous, containing small-scale climbing cross-strata.

Marl, poorly laminated with possible normal grading of the laminations.

DELTA FRONT FACIES

Core 20(2609.0-2614.0[3.9])



Core description

Sandstone, normally graded with imbricated marl rip-up clasts at the base of the bed.

Sandstone, normally graded, organic-rich containing flame structures at the base of the bed and climbing small-scale cross-strata at the top of the bed.

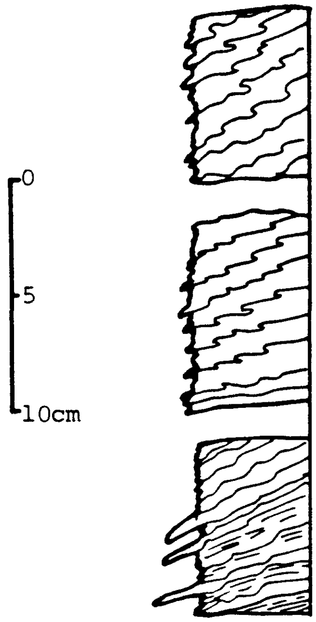
Sandstone, with parallel organic-rich laminae at the top of the upper bed and marl rip-up clasts at the base of the lower bed. Bioturbation is abundant.

Sandstone, normally graded containing abundant marl rip-up clasts at base of the bed and organic-rich horizontal parallel laminae at the top of the bed.

Sandstone, normally graded containing abundant marl rip-up clasts at the base of the bed changing to horizontal laminations at the top of the bed.

Marl, with a few very thin sand laminae. All of the core is bioturbated with sand- and mud-filled burrows.

Core 20 continued



Core description

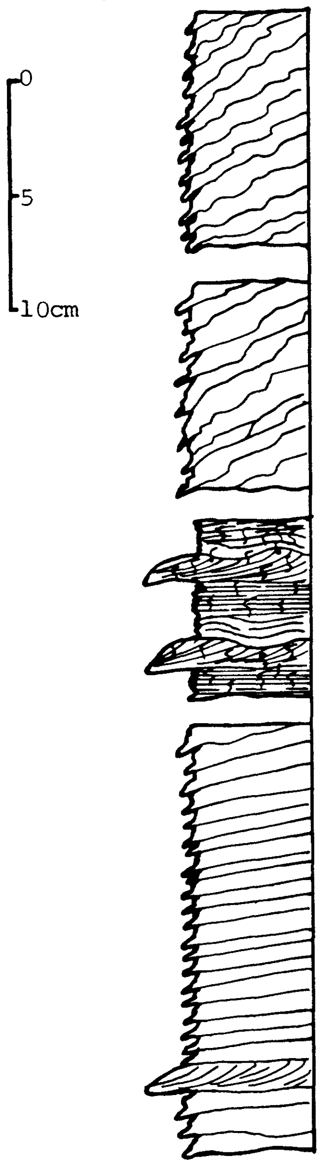
Sandstone, organic-rich containing disrupted silty beds (slumped, soft sediment deformation).

Interbedded sandstone, siltstone and argillaceous marl as normally graded beds to 1.0 cm thick. All strata deformed (slumped) and dip 20 degrees at the top of the core and 4 degrees at the base of the core.

Interbedded sandstone and marl, strata are disrupted (slumped). Strata dip at 7 degrees.

DELTA FRONT FACIES

Core 25(2872.0-2879.0[7.0])



Core description

Interbedded, slumped (soft sediment deformation) normally graded sandstone, siltstone and marl. Small-scale cross-strata are abundant. Bioturbated is also common with horizontal burrows to 1.0 cm diameter.

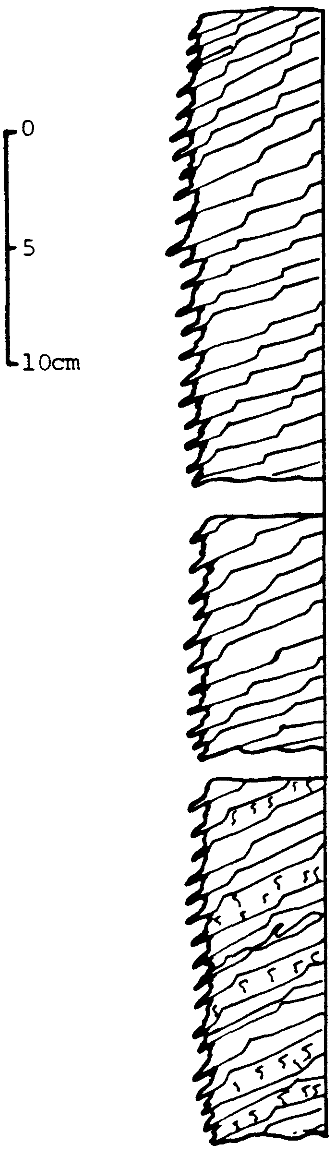
Interbedded, normally graded sandstone, siltstone and marl. All strata are disrupted (slumped).

Interbedded sandstone and marl. Sandstone occurs as small-scale unidirectional cross-strata interbedded with parallel silt-marl laminae. Bioturbation is abundant.

Interbedded, normally graded, sandstone, siltstone and marl. Over 47 laminae occur in 18.2 cm of core. One small-scale crossbed containing marl rip-ups at base of the bed occurs near the base of the core.

DELTA FRONT FACIES

Core 26(2976.5-2981.5[5.0])



Core description

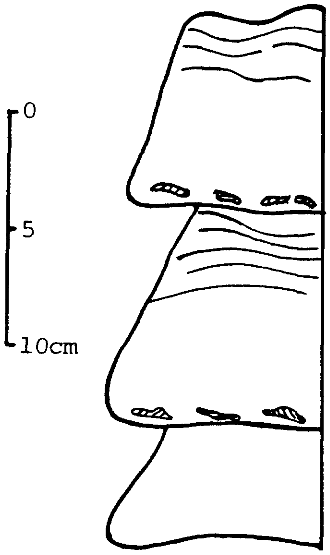
Interbedded sandstone, siltstone and marl, normally graded, and organic-rich. Strata all disrupted (soft sediment deformation) with penecontemporaneous faulting. Strata dip at approximately 7 degrees.

Interbedded sandstone, siltstone and marl, as normally graded laminations. Sandstone laminae are up to 1.0 cm thick. All strata are deformed (soft sediment deformation).

Interbedded sandstone, siltstone and marl, as normally graded beds. Sandstone beds are up to 1.5 cm thick. The strata are disrupted (soft sediment deformation). Bioturbation is abundant with sand-filled burrows.

PRODELTA FACIES

Core 27(3003.0-3006.5[3.1])



Core description

Sandstone, repeated normally graded beds, micaceous, organic-rich, with marl rip-up clasts and parallel laminations.

Core 28 (3049.0-3054.0[3.0])

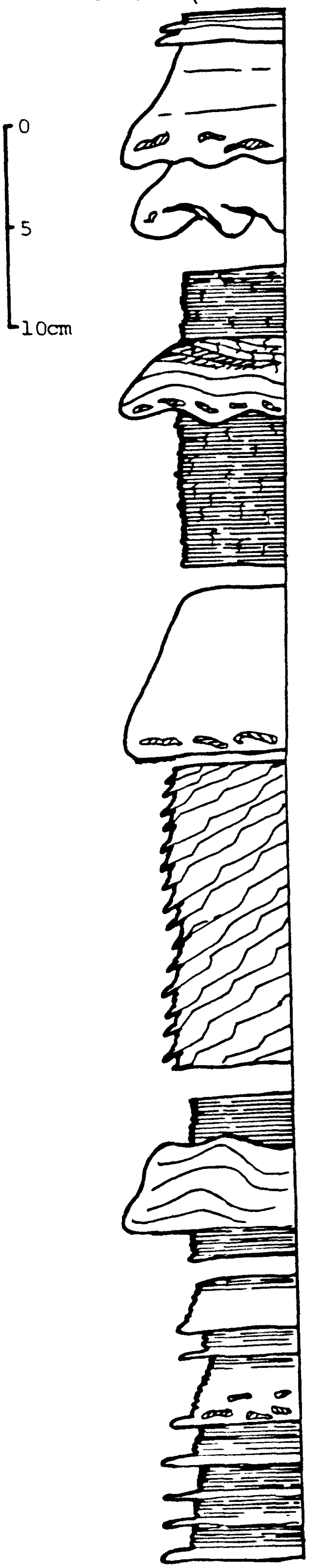
Sandstone, possibly normally graded with flame structure at base of bed where sandstone rests on marl.

Sandstone, organic-rich, micaceous with small-scale cross-strata and horizontal planar laminations.

Sandstone, normally graded, organic-rich, micaceous, containing load structures at base of core.

PRODELTA FACIES

Core 29(3093.0-3099.0[5.4])



Core description

Sandstone, normally graded with the basal bed containing flame structures. The upper bed contains marl rip-up clasts to 5.7 cm which grade to silty marl.

Interbedded sandstone (normally graded bed) and marl laminations. The sandstone bed contains marl rip-up clasts, parallel laminations and small-scale, climbing cross-strata. Bioturbation is abundant.

Sandstone, normally graded, organic-rich with marl rip-up clasts.

Interbedded and normally graded sandstone, siltstone and argillaceous marl. All strata are slumped (soft sediment deformation).

Interbedded and normally graded sandstone and clay marl. The sandstone is organic-rich and disrupted (soft sediment deformation).

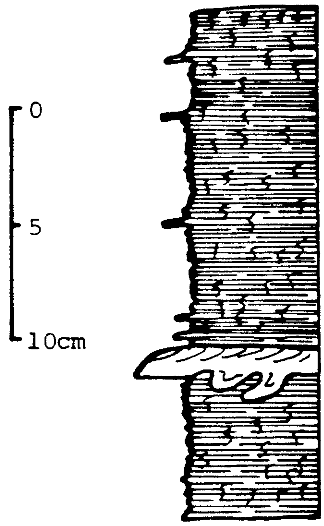
Interbedded sandstone, siltstone and clay marl. One sandstone bed contains marl rip-up clasts.

Core number	Cored interval(core recovered)	
1	940-945(2.2)	
2	1240-1245(2.0)	
3	1350-1355(1.0)	
4	1420-1425(5.0)	DELTA PLAIN FACIES
5	1550-1555(3.4)	
6	1700-1705(3.8)	
7	1800-1805(4.0)	
8	1900-1905(5.0)	
9	2000-2005(4.5)	
10	2298-2303(0.53)	
11	2400-2405(0.2)	
12	2609-2614(3.5)	
13	2728-2731.5(1.8)	
14	2752-2753.5(1.25)	DELTA FRONT FACIES
15	2753.5-2756.5(2.6)	
16	2780-2782(1.4)	
17	2806.5-2810.5(1.8)	PRODELTA FACIES ?
18	2810-2814.5(2.7)	
19	2823-2824(0.3)	
20	2856.5-2859.5(1.6)	BEDROCK
21	2882.5-2886(0.0)	
22	2886-2880.6(0.0)	

Total depth well 2886.6 m.
Total core length attempted is 93.6 m of which 48.6 , core recovered (51.9%).

DELTA PLAIN FACIES

Core 6(1700-1705.0[3.8])



Core description

Silty marl with very thin sandstone laminae and abundant bioturbation.

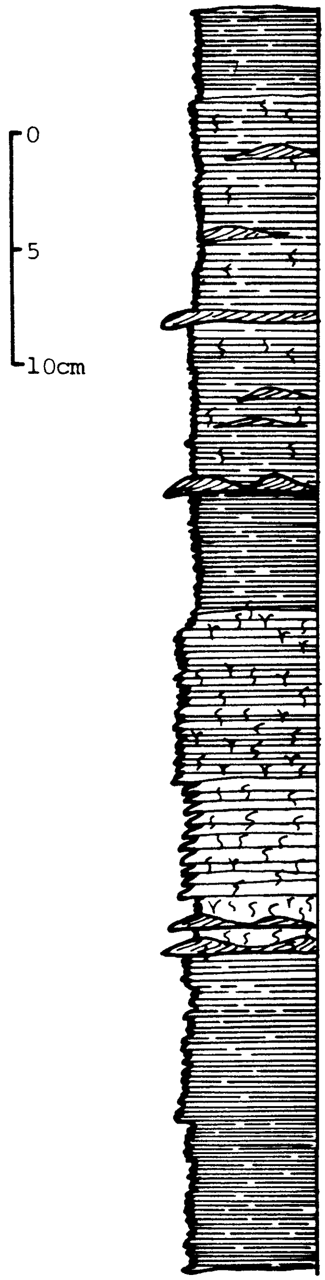
Sandstone with small-scale cross-strata and load structures.

Organic-rich, bioturbated marl containing repeated very thin laminae of fine-grained sandstone or siltstone.

DELTA PLAIN FACIES

Core 8(1900.0-1905.0[5.0])

Core description



Marl, silty with scattered and isolated small-scale cross-strata (flaser bedding) and thin laminae of sandstone. Bioturbation is abundant.

Sandstone-marl interbeds containing 46 graded laminae of sandstone to marl in 7 cm of core.

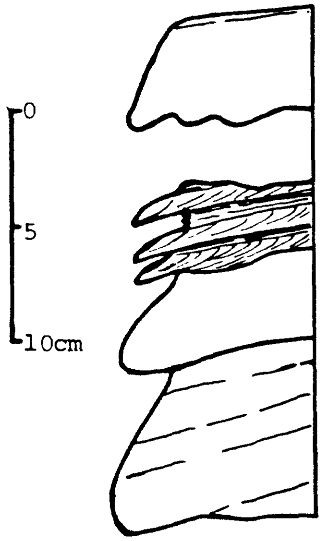
Sandstone-marl interbeds with the sandstone beds to 0.6 cm thick. The strata are bioturbated.

Sandstone-marl interbeds containing small-scale cross-strata.

Marl, silty.

DELTA FRONT FACIES

Core 12(2609.0-2614.0[3.5])

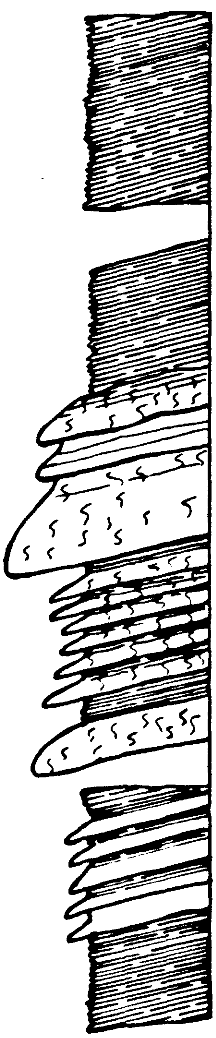


Core description

Sandstone, micaceous, apparently structureless with abundant plant fragments and possible load structure at base of the core.

Sandstone, graded, with small-scale cross-strata at the top of the core. The strata dip at approximately 7 degrees.

Core 15(2753.5-2756.5[2.6])



Marl, massive, micaceous with silt laminae.

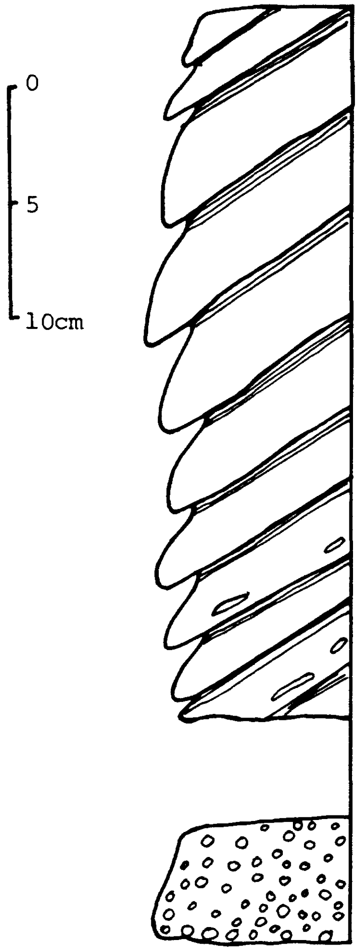
Marl, micaceous with silt laminae.

Sandstone, normally graded and interbedded with marl. Alternating beds of sandstone graded to marl. All strata dip at 12 degrees. Bioturbation is abundant.

Sandstone interbedded with silty marl. Sandstone normally graded to marl.

PRODELTA FACIES(?)

Core 17(2806.5-2810.5[1.8])



Core description

Sandstone, fine-grained, micaceous with strata dipping at 33 degrees. Strata are normally graded and also contain marl rip-up clasts in the basal beds. Strata are also fractured and sheared.

Conglomerate, mainly as fragments, clasts are less than 1 cm, well-rounded and composed of limestone and metamorphic rocks.