DEPOSITIONAL ANALYSIS OF A SECTION OF THE LOWER MEGUMA (LOWER PALEOZOIC), SHIP HARBOUR, NOVA SCOTIA

by

John D. Dwyer

Submitted as a requirement of a

Bachelor of Science with Honours

Dalhousie University

March 1978

DEPARTMENT OF GEOLOGY
DALHOUSIE UNIVERSITY
HALIFAX, NOVA SCOTIA
CANADA
B3H 4J1

DALHOUSIE UNIVERSITY, DEPARTMENT OF GEOLOGY

B.Sc. HONOURS THESIS

Author: John D. Dwyer

Title: Depositional Analysis of a Section of the Lower Meguma (Lower Paleozoic) Ship Harbour, Nova Scotia

Signature of author

Date: June 15, 1978

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ABSTRACT

A section of the lower Meguma (Lower Paleozoic) near Ship Harbour, Nova Scotia, was examined in detail in terms of bed thickness, sedimentary structures and grain size.

Interpretation of depositional processes and environment was attempted in view of models of sediment gravity flow and deep sea fan deposition.

The deposition of beds is the product of sediment gravity flows in the mid fan area of a deep sea fan. The thick sands showing delayed and complex grading and thin lutite layers may be the product of a combination of fludizied flow and grain flow transitional with immature turbidity current deposition. Sediment flows appear to have been confined in channels and on open areas. A reverse trend in this environment indicates retrograde development of the fan.

The variation in bed thickness is believed to reflect the changing distribution of sediment gravity flows in channelled and unchannelled areas of the fan. Trends in sand thicknesses similar to those found in other deposits were observed. Power spectrum analysis was used to determine if there were cyclic variations in sand thickness. Evidence of periodic tendencies of several scales was found, up to a vertical thickness of 25 m. These cycles are attributed to channel switching and depositional lobe movement.

ACHKNOWLEDGEMENTS

The work of this thesis was carried out under the supervision of Dr. P. E. Schenk, whose advice and enthusiasm are greatly appreciated.

Dr. J. Thiebeaux provided advice on time series analysis and clarified mathematical theory. Dr. D. Huntley helped greatly with the intricacies of power spectra.

My thanks also to Dianne Crouse for her excellent typing job.

SECTION I - INTRODUCTION

1. Geology of the Meguma Group

The Lower Paleozoic Meguma Group of southern Nova Scotia is composed of the lower Goldenville Formation, conformably overlain by the Halifax Formation (Stevenson 1959). It is a thick unit of interbedded meta-sandstone and slate, having most of the diagnostic features of flysch as described by Dzulynski and Walton (1965) (Campbell and Schenk 1967). The Meguma is considered to have been deposited in a deep marine eugeocline separate from the major Appalachian or Acadian Geosyncline (Schenk 1970, Harris 1971) (see Figure 1).

The Goldenville (Woodman 1904a) has a maximum thickness in excess of the measured thickness of 5590 m (18,350 ft.) (Faribault 1914), since the base is not exposed. It is a monotonous succession of meta-sandstones with thinner interbedded slates, the latter becoming more dominant up into the overlying formation. This, the Halifax (Ani 1900), is as much as 4400 m (14,500 ft.) thick (Phinney 1961). The entire Meguma represents a thickness of over 10 km and shows a transition from sandy to shaly flysch.

Lack of fossils makes age determination and stratigraphic correlation difficult. The graptolite *Dictyonema flabelliforme* (Eichwald) is found in parts of the Halifax Formation (Crosby 1962) indicating early Ordovician age, but only one poorly preserved example of a graptolite has been found in a sandier part of the Meguma

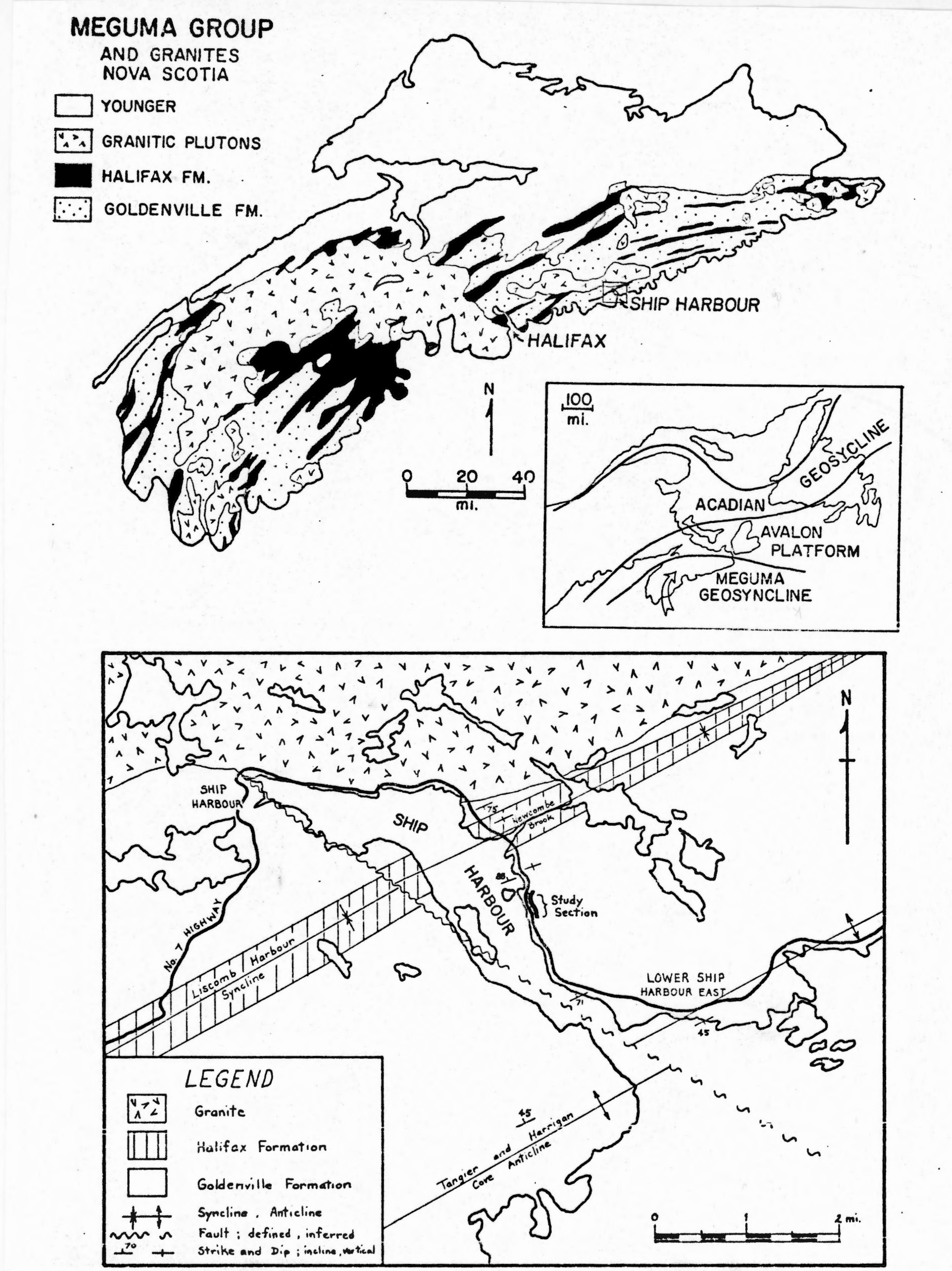


Figure 1. Geological map of the Meguma and inset showing its geological setting in the Late Precambrian-Early Ordovician from Schenk (1970). Local geological map showing location of the study section by Fairbault (1897).

(Schenk 1970). Trace fossils in the Goldenville are occasional feeding trails and common sand volcanoes attributed to burrowing, although the latter may not, in fact, be biogenic in origin (Harris 1971).

The major folds are a series of large, open, low-plunging synclines and anticlines trending generally NE-SW. The unit is intruded by several large granitic masses.

2. Previous Work

A number of authors have suggested environments for the deposition of the Meguma.

Woodman (1904b) suggested a moderately shallow, occasionally turbulent sea. Fluctuating conditions were used to explain the interbedded sands and shales by Malcom (1929). He suggested sediment supply changed due to wet and dry climatic conditions controlling runoff, changes in direction or velocity of shore currents, or variation in subsidence rate. Douglas *et al.* (1938) indicated seasonal variations and compared graded layers in the Halifax to yearly varves. This is the first examination of part of the Meguma for evidence of periodic tendancies in sedimentation. Use of a peridogram showed a weak indication of a 3 "year" (i.e. layer) cycle and no longer periodicites. Seasonal variation was also suggested by Crosby (1962).

Phinney (1961) concluded, from examination of part of the Goldenville, that sand and shale beds were turbidites. This was suggested by Taylor (1967) who attributed deposition of the Goldenville to northwest trending turbidity currents in deep water, ceasing as water depth decreased and the Halifax was deposited. A similar distribution pattern was found by Campbell (1966). A regional study by Schenk (1970), using various properties and analyzed by moving average and trend surface maps, indicates turbidity current distribution from a source to the south-southeast in a sharp right curving direction to the north east. Deposition may have been modified by bottom currents.

Harris and Schenk (1975) suggest an at least partly coeval association of the Halifax and Goldenville Formations. The formations may represent "distal" and "proximal" facies respectively, sometimes in close spatial association, in a deep sea fan environment.

The work of Schenk and his students (Schenk and Campbell 1967, Harris and Schenk, 1968, Harris 1971, Harris 1975) has indicated that the Goldenville is the result of deep water sedimentation by high energy "proximal" gravity controlled processes. Described as "fluxoturbidites" (Harris and Schenk 1968) these are typically thick, poorly graded sand beds showing features of rapid fluidized emplacement and down slope slumping (Harris, 1971) in some cases. Cyclic trends in sedimentation observed are described as "megarythms" extending vertically on a smaller scale (25 m) and a larger scale (200 to 700 m) in Harris and Schenk (1975).

3. Purpose of Study

The present study is a continuation of the investigation of the Meguma Group by Schenk (1970). It is an attempt to determine the nature of sedimentary processes responsible for the deposition of part of the Goldenville Formation and to see if the results are consistent with the present deep sea fan model. Examination for periodic tendancies in sedimentation is also undertaken, as cyclic trends appear to have been observed and have been described in other similar formations.

Bed by bed mapping of a single long section and subsequent observation and analysis of these data are presented here in two basic parts: 1) a qualitative description of the sedimentary features and trends present, and the interpretation in terms of models of sediment gravity flow and deep sea fan facies, and 2) a quantitative analysis to determine the presence of any cyclic tendancies in sedimentation with an interpretation of the results.

4. Thesis Area and Methods

The section of the lower Meguma (Goldenville Formation) is exposed by road cut near Newcombe Brook, on the No. 7 Highway between the communities of Ship Harbour and Lower Ship Harbour East, about

72 km (45 mi.) by road northeast of Halifax (see Figure 1). The road cut runs northwest along the eastern side of Ship Harbour.

The strata strike east-northeast (067 to 071 degrees true) and dip almost exactly vertical, with the up direction to the north. The section is on the north side of a large anticline and the top of the section is estimated to be 800 m stratigraphically below the contact of the Goldenville with the overlying Halifax Formation,as exposed in the Liscomb Harbour Syncline.

The section represents a vertical stratigraphic thickness of 350 m. Lateral exposure of bedding is limited by the height of the outcrop, which ranges from over 10 m to less than 1 m.

Regional metamorphism is low in the area and the section is beyond the contact aureole of the granitic pluton to the north so that grain size and sedimentary structures are preserved. The freshness of the outcrops presents some problem in the recognition of sedimentary structures, which are best displayed by differential weathering. The slate layers have well developed cleavage which also masks sedimentary structures.

The section was mapped by graphic logging using modified Bouma logs (Bouma 1962) at a scale of 20:1. Reduced copies of the original logs are shown in Appendix III.

Thickness of bedding units were logged by taping to the nearest 5 cm, so that all measurements are plus or minus 2.5 cm. This was deemed appropriate for several reasons: 1) it is the limit of accuracy for measurement and graphic representation at the scale of logging; 2) for ease of calculation to minimize error, a major factor in such a long section; 3) bed thickness often varies by this order of magnitude due to undulating contacts; and 4) no rythmic units (Dzulynski and Walton 1965) were found to be significantly thinner than 5 cm (the average being over a degree of magnitude greater).

Great importance is placed on the recognition of the nature of contacts. A "rythmic unit" represents a turbidite event, and in the Meguma may or may not contain a sand layer and a shale layer above. The term bed unit or bed is used here to define a layer bounded above and below by contacts that represent periods of non-deposition between turbidite events. Non-depositional contacts display parting or incipient parting or can be seen to be sharper than sudden depositional changes.

Grain sizes are field estimations, using a grain-size card in the case of sands. Sand grain boundaries are hard to discern due to recrystallization, so that size estimations are only approximate, but comparable throughout the section. In slates grain size was estimated by scratching with a fingernail to test for the presence of silt size particles. Recrystallization may have affected any pure clay layers as well.

Sedimentary structures, though not as apparent as in weathered outcrop, nearby, were reasonably discernable even in the slates showing slaty cleavage. A short part of the section where alteration nearly obliterates structures and grain size is noted in the section logs. The presence and distribution of sedimentary structures was noted throughout. Orientation of structures was not measured carefully.

Paleocurrent indicators exposed on bedding plane surfaces were rotated by the "pencil, elastic band and notebook" method (Potter and Pettijohn 1963) and recorded where recognizable. Paleocurrent indicators seen in section are subject to tectonic strain (Harris 1971) and the angle of sectioning, in their interpretation. Therefore these require careful measurement and are considered to be of limited use in this study. Paleocurrent analysis would however be useful in a more detailed depositional environment/facies interpretation where more paleocurrent indicators are exposed.

SECTION II - SEDIMENTOLOGICAL MODELS

1. Sediment gravity flow theory

As an introduction to the examination and interpretation of the study section, a brief summary of turbidity and related currents is in order. Walker (1973) deals fully with the history of turbidite theory evolution. The application of more recent work in hydraulics has added much in terms of depositional theory to the classical model of Bouma (1962). The present "state of the art" is summarized in Middleton and Hampton (1973).

Sediment gravity flows, including turbidity currents, are accepted as being surge-like movements of sediment and water mixtures that move downslope due to their density difference from the surrounding water. The operation of sediment gravity flow and deposition is based on four "end member" mechanisms: 1) turbidity currents, 2) fluidized flow, 3) grain flow, and 4) debris flow.

Turbidity currents utilize turbulence as the suspending agent, and decreasing flow regime produces the classic Bouma sequence of traction deposits. Autosuspension occurs in flows where the slope is such that the downslope component contributes more energy than is lost by friction and the flow is self-perpetuating. This can occur on quite low slopes.

Fluidized flow entails the excess pore pressure of liquified sediment to support grains and allow cohesionless flow. Deposition is caused by the loss of the interstial water which causes "freezing" from the bottom up.

Grain flow depends on the dispersive pressure from the interaction of grains driven by gravity in a cohesionless sediment. This process requires greater slopes than those mentioned previously. Deposition is a sudden mass freezing as the effect of gravity becomes less than the yield strength of the sediment.

Debris flow is essentially mass movement of cohesive sediment along zones of shearing, and requires high angle slopes.

Middleton and Hampton (1973) suggest most sediment gravity flows result as a combination of these processes. Structures resulting from "end member" flows (excluding debris flow) are shown in A, B, and C of Figure 2.

The distribution of sediment concentration and grain sizes is recognized to vary spatially in a sediment flow and through time as a flow evolves. A flow has a thick, possibly erosive head where sediment is concentrated. This is followed by an even body and a diminishing tail of more dilute finer material. Loss of energy in a flow due to friction or reduction of slope, causes the amount and grain size of sediment carried to decrease through time.

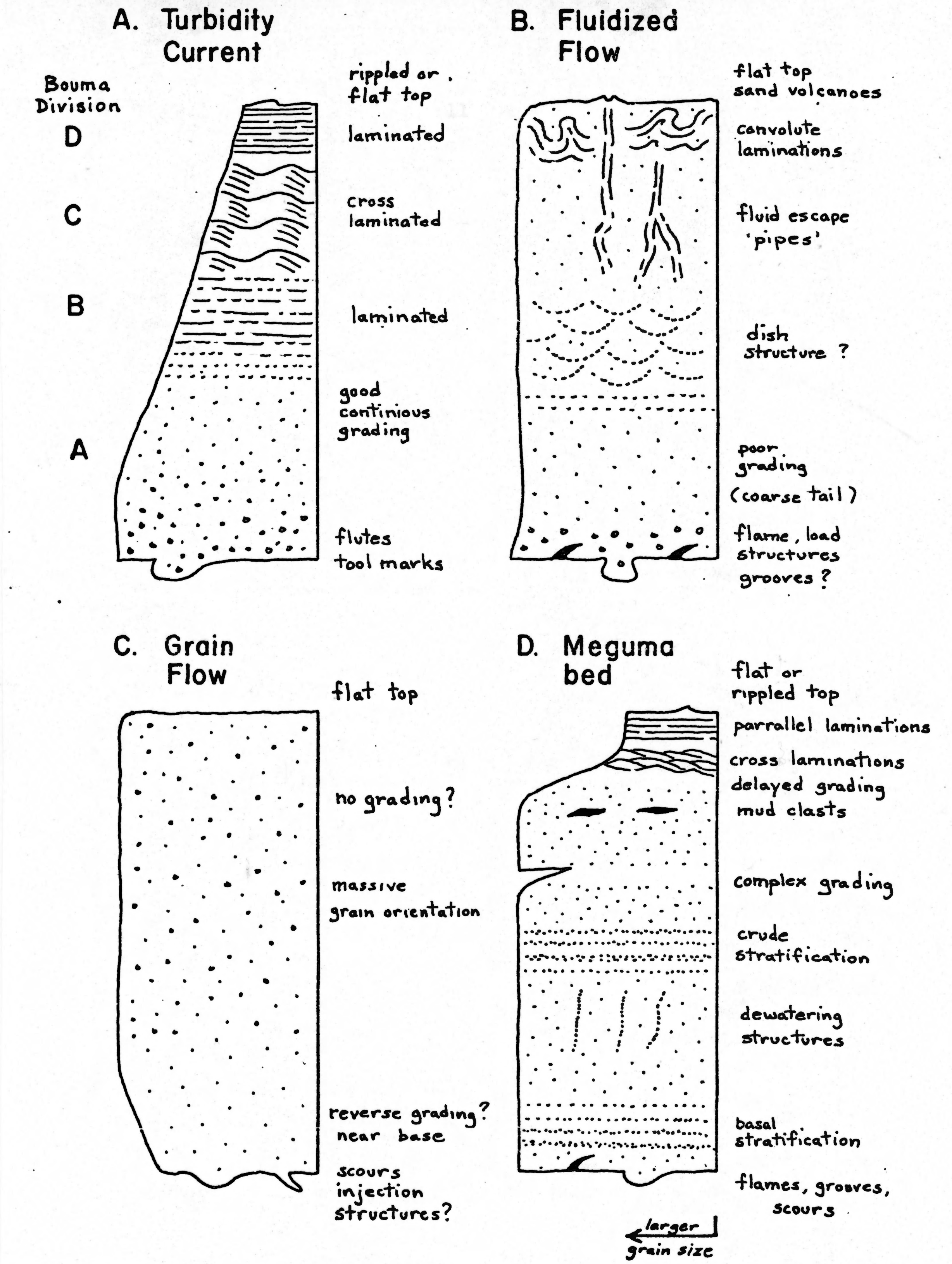


Figure 2. A, B, and C: Sequences of structures in hypothetical single-mechanism deposits from Middleton and Hampton (1973). D: Composite bed of the Meguma in the study section. (Actual beds are generally more structureless).

In classical turbidites the reduction in flow regime,as the parts of a current pass, results in the Bouma division sequence. Flowing away from its source a turbidity current undergoes reducing flow regime, producing downslope distribution of the Bouma sequence. Turbidites beginning with A Bouma division are considered "proximal" and those beginning with successive divisions are more "distal" (Walker 1967).

Fluidized and grain flows "run out of steam" more quickly and dump their sediment load rapidly. Hence bed thickness will decrease rapidly as deposition progresses away from its source. The concept of proximal and distal applies to a sediment flow moving downslope and also spreading laterally away from its main path (axis of deposition).

Hence bed thickness and sedimentary structures are indicators of the "proximity" of a deposit to the source of the flow (downslope proximity) or to the axis of deposition of a laterally spreading flow (lateral proximity). Changes in both types of proximity will be slower for a pure turbidity current, rapid for a fluidized flow, and sudden for a grain flow. Lateral proximity changes will depend on the degree of confinement of the flow (see below).

2. Deep Sea Fan Facies Model

Work on Recent sedimentation on continental rise and slopes has led to the recognition that deep sea fans are a major deposit resulting from sediment gravity flows. Basic deep sea fan morphology, deposits, and sedimentary processes are summarized in Nelson and Kulm (1973), Normark (1974), and Kelling and Stanley (1976). The generalized deep sea fan model is presented in Figure 3.

Study of ancient deposits combined with the fan model has resulted in a facies model of sediment gravity flows in a deep sea fan environment (Walker and Mutti 1973, Mutti 1974, Nelson and Nilsen 1974; Ricci Lucchi 1975, Mutti 1977). Downslope and lateral proximal to distal evolution of sediment flows is controlled by fan morphology and results in certain facies being characteristic of particular areas of the fan.

The fan model can be summarized, for purposes here, as follows: (Facies designations are those of Walker and Mutti (1973) and Ricci Lucchi (1975).)

Slope and Canyon: On the slope into the basin and in the feeding canyon deposits are the result of slumping and mass movement of sediment where sediment flows are initiated. Coarse deposits and slumps sit in pelagic deposits and lag deposits may be found in the channel.

Inner Fan: The Inner Fan consists of the main leveed channel bounded by the mainly pelagic deposits beyond the levees. In the channel thick coarse and finer deposits due to fluidized and grain flow or high concentration turbidity currents are found. Facies A and B predominate here. Overflowing of the channel results in levees

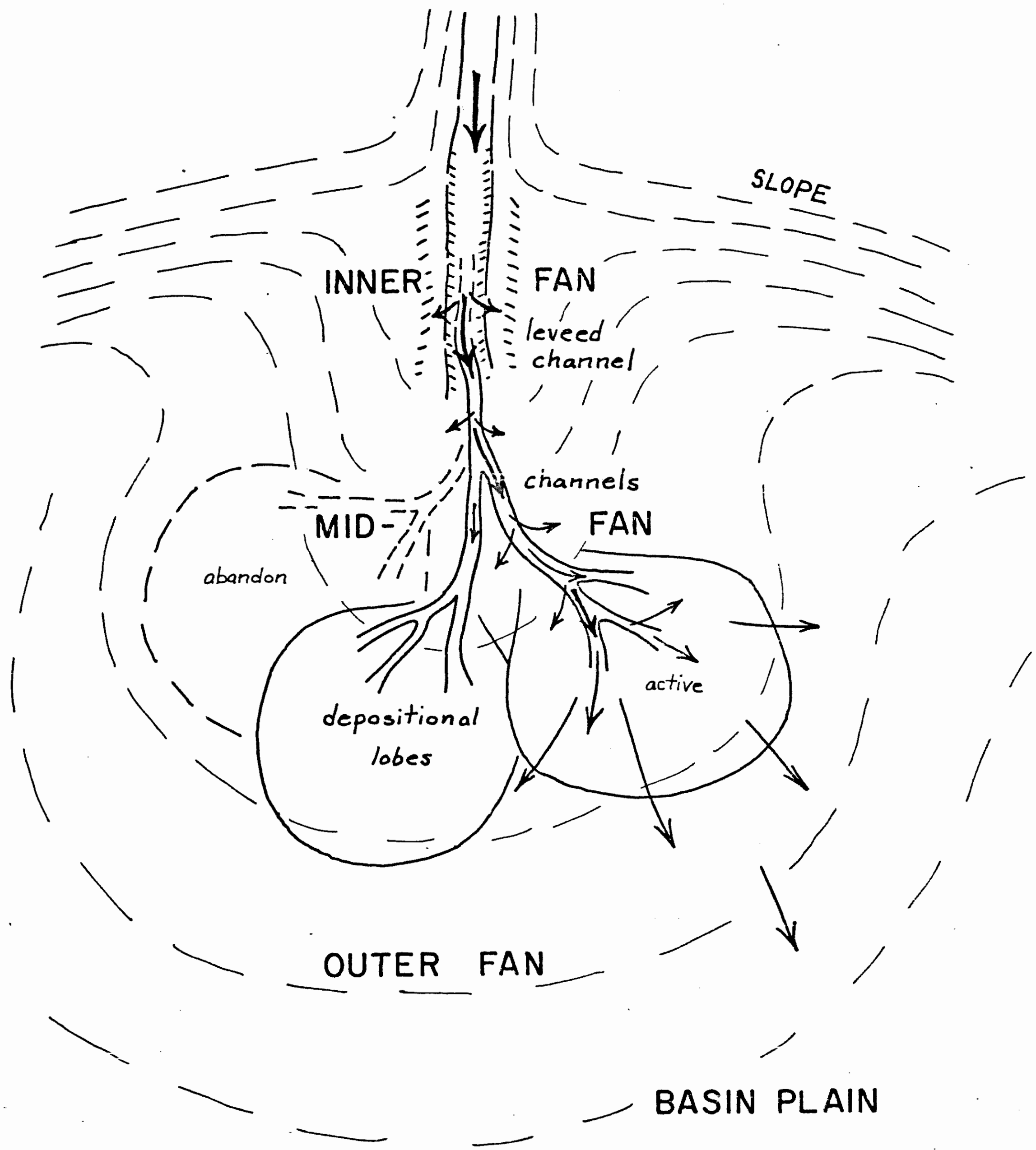


Figure 3. The deep sea fan model, after Walker and Mutti (1973).

consisting of sands on the channel side grading to muds away from the channel (Mutti 1977). Limited overflow of fluidized and grain flows would result in a rapid decrease in "lateral proximity". Hence facies E deposits would pinch out to be replaced by muds.

Middle Fan: The middle fan has smaller branching or braided channels that pass into depositional lobes. The depositional lobes (of the Suprafan of Normark 1974) mark a break in slope.

Thick sands of A, B and C facies are deposited in the distributary channels. Greater overbank deposition occurs from the less confining channels in the form of D and E facies deposits. Here the decrease in "lateral proximity" away from the channels is less rapid.

The area of depositional lobes receives turbidite deposition of facies C to D and facies B. Sediment flows are unconfined and lateral spreading is extensive, so that proximal-distal evolution of a flow is gradual in a radiating pattern.

Outer Fan: The flatter outer portion of the fan extends to the basin plain and received deposition of thin broad distal flows of facies D and pelagic sedimentation.

Certain trends in sedimentation are characteristic of the facies in the Middle Fan. Fining- or thinning-up trends (progressively finer grained or thinner beds; apparent decrease in proximity) indicate episodes of channel filling. Coarsening- or thickening-up trends (apparent increase in proximity) are the result of the progradation of depositional lobes (Walker and Mutti 1973, Mutti 1974, Ricci Lucchi 1975).

Development of the fan results in the shifting of channels and depositional lobes. It is suggested that lateral shifting of channels in the upper Middle Fan is characterized by rather rapid changes in the apparent proximity of deposits at a given fixed geographic location. In the lower Middle Fan progradation, retrogradation, and lateral shifting of depositional lobes is recorded as gradual changes in proximity of deposits at one spot.

SECTION III - SEDIMENTOLOGY

1. Lithology

The exposed section is 347 m long and consists of alternating thicker meta-sandstone layers and thinner slate layers.

The sandstone is of a greenish grey colour and predominantly of a fine grain size (1/8 - 1/4 mm), with minor amounts of medium sand (1/16 - 1/8 mm). No sand coarser than medium grade was observed, although grain size estimation in the rock is somewhat subjective. No gravel, conglomerate or granules are present, and the source sediment for the sediment flows appears to have been well sorted fine sands and finer material.

The slate is dark grey to reddish in colour. Grain size is mostly silty clay with some silt grade material, collectively referred to as lutite. No lutite layers of less than silty clay grade (being gritty to a scratching thumbnail) were observed. This is believed to be due to metamorphic recrystallization, rather than being the original grain size distribution. The lutite layers show a good deal of slaty cleavage nearly parallel with the bedding plane.

2. Bedding Characteristics

a) Bed unit lithology

The vast majority of the sand and slate layers occur as couplets, where the sand layer is sharp bottomed and grades up into silt or silty clay near the top. These bed units show contacts above and below with parting or incipient parting that are believed to represent a period of non-deposition between sediment gravity flow events.

In several cases a thin layer of fine lutite (up to 1 cm thick) was noted above the parting, adhering to the base of the overlying sand layer. This lutite does not show slaty cleavage and may represent the structureless pelagic sediment overlying laminated or microlaminated current worked fine material of the sediment flow.

A bed unit is defined as a layer that appears to be bounded by non-depositional contacts and usually consists of a sand layer grading to a shale layer. The section consists of 446 bed units with an average thickness of 78 cm, but ranging from 5 to 740 cm thick.

Only 2.5% of the beds consist of lutite only and these are generally thin. Most of the lutite occurs as the upper half of the thinner (less than 25 cm) beds. Rare thick beds of predominantly lutite do occur (up to 260 cm thick) but usually contain some sand, often display "unusual" grading and have several sand layers in the bed.

Most beds however contain little lutite and the sand/shale ratio of the section is 6:1 (i.e. 86% of the thickness of the section is sand). Beds having little or no lutite are common and tend to be thicker beds, so there is a good correlation of bed thickness to sand/shale ratio.

Amalgamated beds are those that appear to be made up of sand layers separated by an erosional contact with no indication of grading present in the lower layer. Because there is no indication of the original thickness of the lower layer the amalgamated unit is treated as a single unit. Amalgamated beds make up 4.5% of the beds in the section and are both thick and thin. Only a few beds have a large thickness due to amalgamation and in many cases the lower portion is less than 20 cm. Amalgamated beds occur more frequently near the top of the section. They may be similar to or gradational with complex grading (see below).

The predominant bed type are medium thick to very thick sands with thin shale layers on top as shown in Plate 2. The second main type is thinner sand shale couplets with lower sand shale ratios (about 1) as shown in Plate 3.

b) Bed shape

Bedding is even and parallel with flat to wavy bedding planes within the maximum 10 m lateral exposure of beds. Nine small channels were observed, averaging 11 cm in depth but as deep as 30 cm. They vary in nature from large flute-like bulges in the base of a sand layer to a pinched out sand bed with no lateral equivalent (as shown in Plate 4). Very rare beds of even thickness but with varying sand

Plate 1. The study section of the lower Meguma near Newcombe Brook. View looking stratigraphically up towards the north. Section is 350 m long.

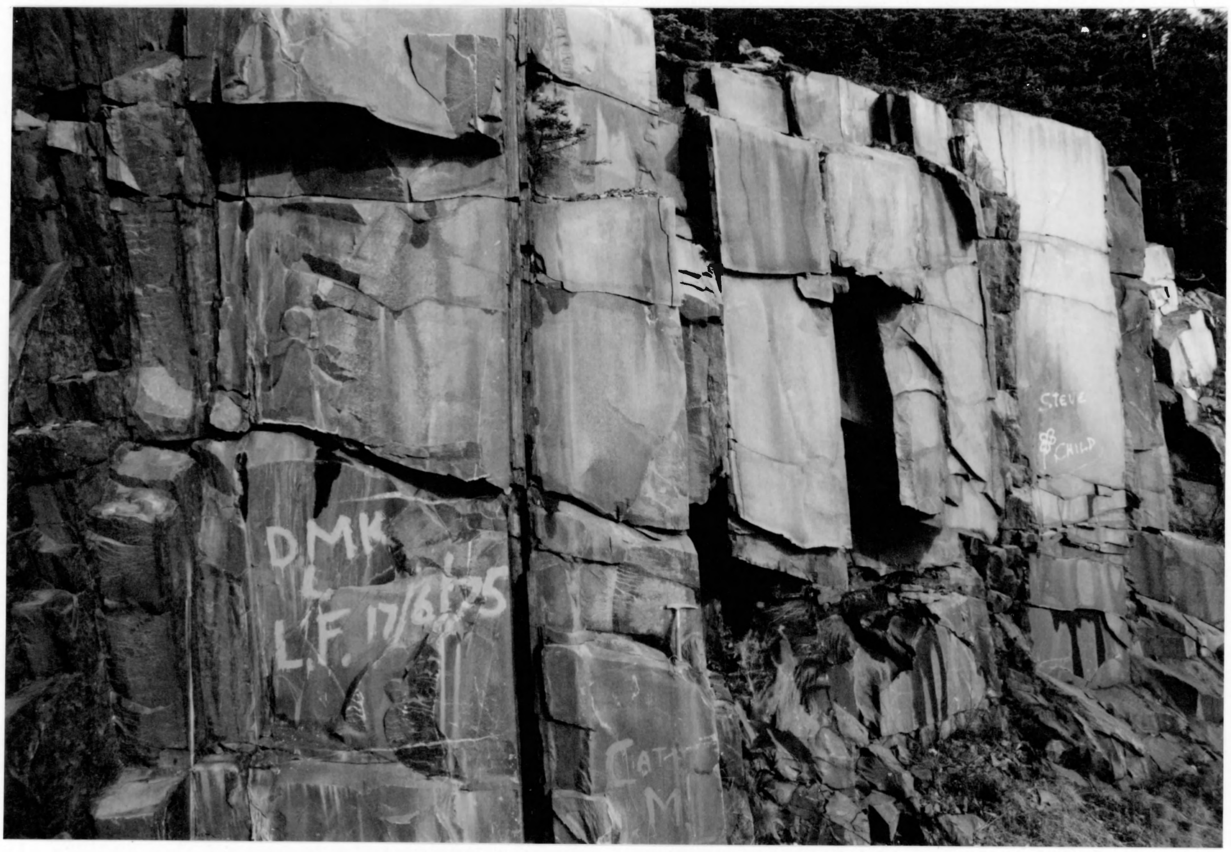


Plate 2. Medium thick beds of massive ungraded sands grading abruptly to lutite at the tops. Up is to the left. Hammer lower middle is 30 cm long.

Plate 3. Thin beds composed of graded sand-lutite couplets above a thicker sandy bed (bed 143) possibly overbank deposits. Up is to the left.

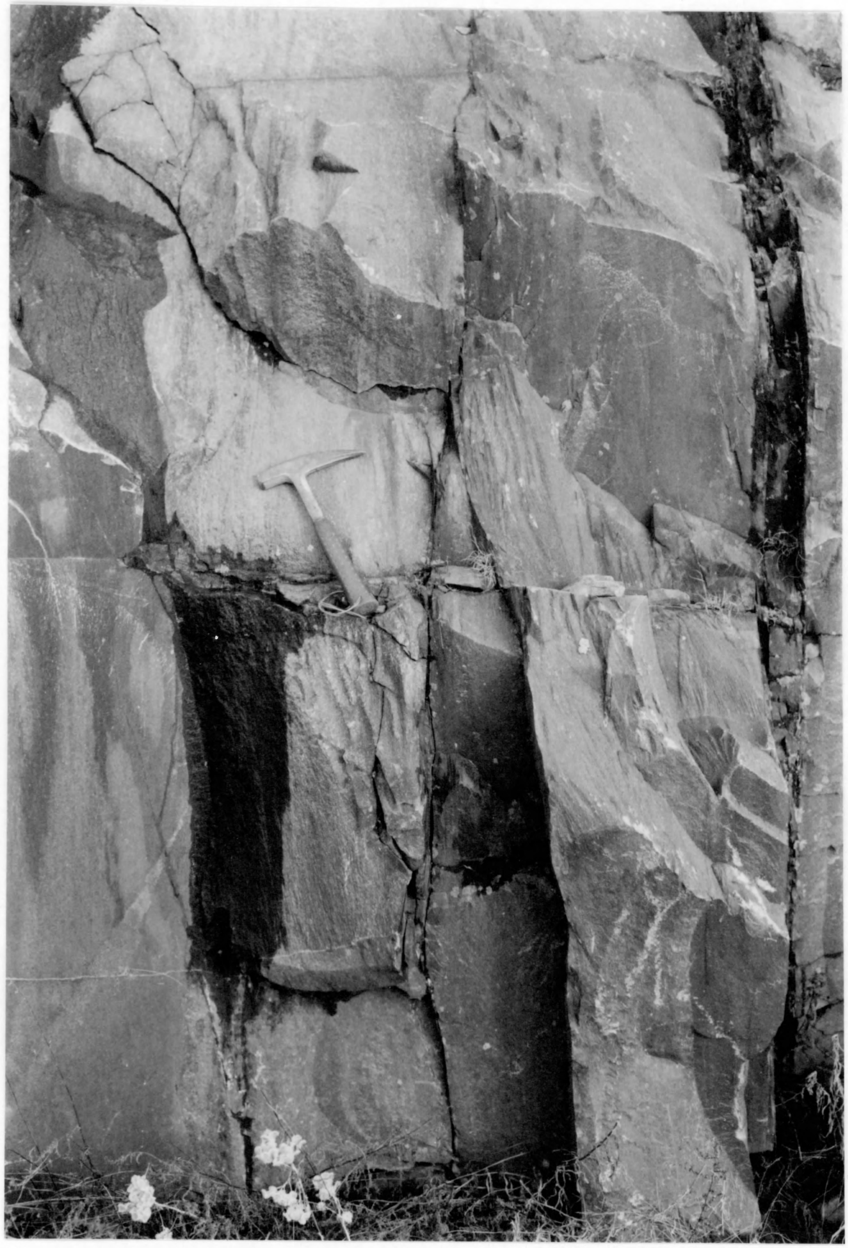


Plate 4. A pinched out channel-like sand bed, between beds 94 and 95. Up is to the left.

Plate 5. A lutite bed containing two lenticular sand layers. Sole marks are present on the base of the lower sand layer above the hammer. Note the rather unchannel-like shape of the upper sand layer and the greater thickness of the bed at the sand layers. Up is to the left.

layer thickness are present. Plate 5 shows a largely lutite bed that has two lenticular sand bodies present in it. Because of sole marks on the base of one of the sand layers this case appears to be due to initial deposition, rather than slumping or "pull apart" structures. This suggests local sand flow in a fine grained sediment flow, and other channels may represent localized paths of erosion in a flow.

(c) Graded Bedding

Almost all bed units show grading from a lower sand layer to an upper lutite layer. The predominant type of grading present is delayed to interrupted (Dzulynski and Walton 1965) which occurs in 70% of the beds. The sand layer is massive and ungraded, and at the top grades suddenly through silt to silty clay (delayed grading). If there is no intervening silt between the sand and silty clay it is termed interrupted, although the two types are graditional. Simple continuous grading (Dzulynski and Walton 1965) occurs in 7% of the beds. But this type is gradational with delayed grading as there is almost always some delay in grading. About 3% of the beds are not graded (not considering lower portions of amalgamated beds). Reverse grading is found in less than 1% of the beds.

What is termed complex grading is found in 20% of the beds. This includes several types which are summarized in Figure 4:

1) Recurrent or multiple grading (Dzylynski and Walton 1965) is one or more repetitions of normal to delayed grading and constitutes 30% of the complex graded beds.

2) Complex interrupted grading is one or more fairly sharp bounded, substantial lutite layers in the sand layer and is found in 29% of the complex beds.

3) Graditional with complex interrupted grading is fluctuated grading. It is several thin closely spaced lutite layers found in the sand layer. This type makes up 36% of the complex beds.

4) Irregular grading is defined as one or more coarser layers within a fine bed so that the bottom of the bed is not the coarsest sediment. About 6% of the complex beds show irregular grading.

Complex grading can occur throughout a bed, as it does 70% of the time, concentrated at the top (in 20% of complex beds), or near the bottom only (10%).

Both thick and thin beds show complex grading. Thick beds with low sand shale ratios almost always show complex, often irregular grading. Complex graded beds tend to occur in groups.

The occurrence of mudclast inclusions (see below) is definitely associated with complex graded beds. An example of recurrent grading, with associated mud clasts, is seen in plate 8.

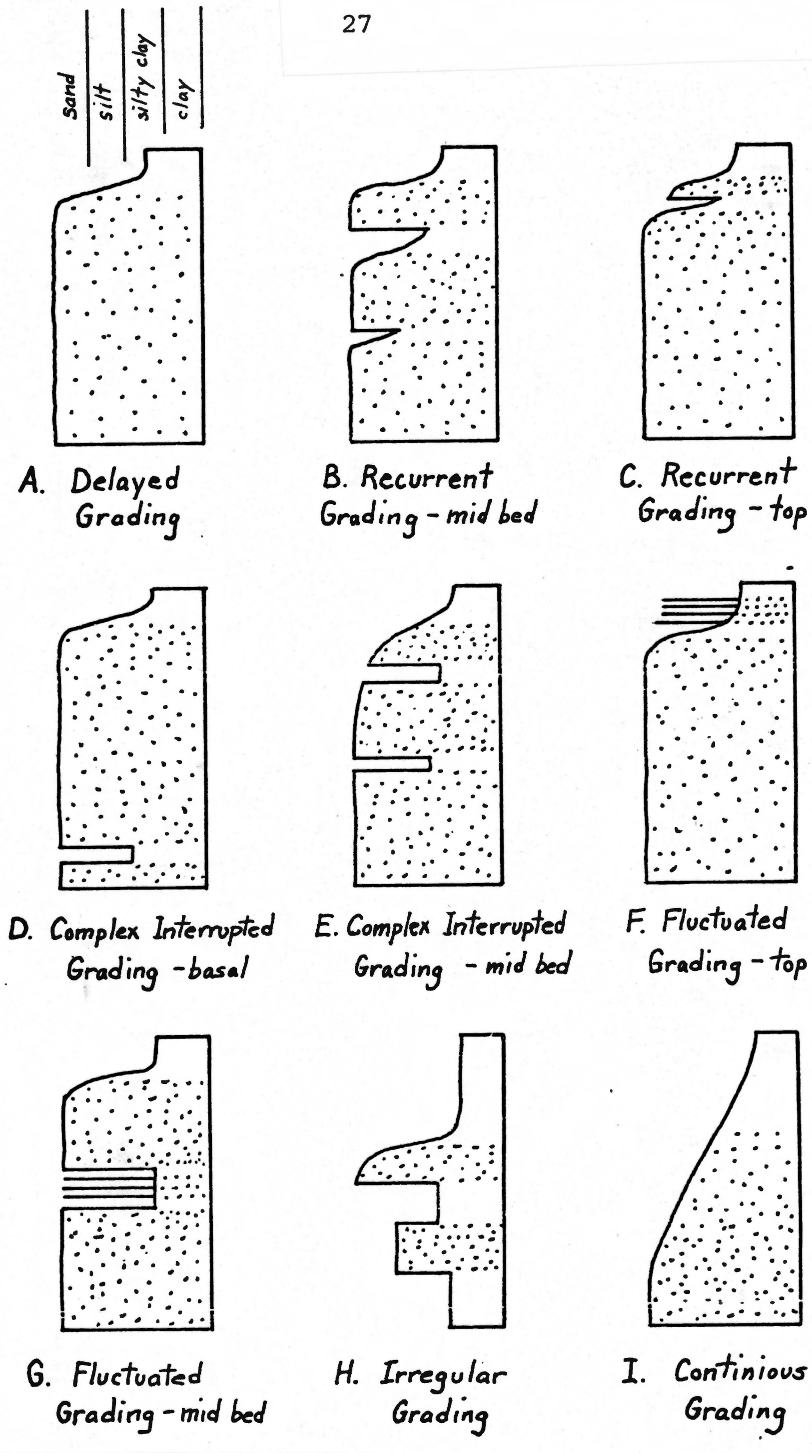


Figure 4. Various types of grading representative of the spectrum of different graded beds present in the study section, and applicable terminology. B to H are collectively termed complex grading.

(d) Interpretation of Grading

i) Delayed Grading

Delayed grading, produced by the bulk of the sediment being deposited in a mixture without sorting, is considered an indication of "immature" flows (Dzulynski and Walton 1965). Such bedding suggests "freezing" from suspension in the manner expected from fluidized and grain flow (Middleton and Hampton 1973). The process of turbulent autosuspension may also result in delayed grading (Dzulynski and Walton 1965). The most plausible explanation is that the ungraded sand layer is deposited from the part of the sediment flow where turbulent, grain and/or fluidized flow exist, after which decreasing turbulence deposits the graded part of the bed. The suddenness and degree of delay depends on the relative importance of the processes.

There is a tendency for thicker beds to have interrupted or sudden delayed grading and thin lutite layers. Thinner beds show less delayed, more continuous grading and thicker lutite beds. This may be due to a downslope transition in a sediment flow from turbulent, fluidized, grain flow to more "classical" turbidity current flow. In "proximal" areas sediment is deposited suddenly from suspension in a thick bed. As the flow advances less sediment is suspended by fluidized or grain flow so that the ungraded portion is thinner in the deposit. The waning of turbulence then results in better developed grading and the further travelling lutite is deposited in a thicker layer. This concept is represented in Figure 5.

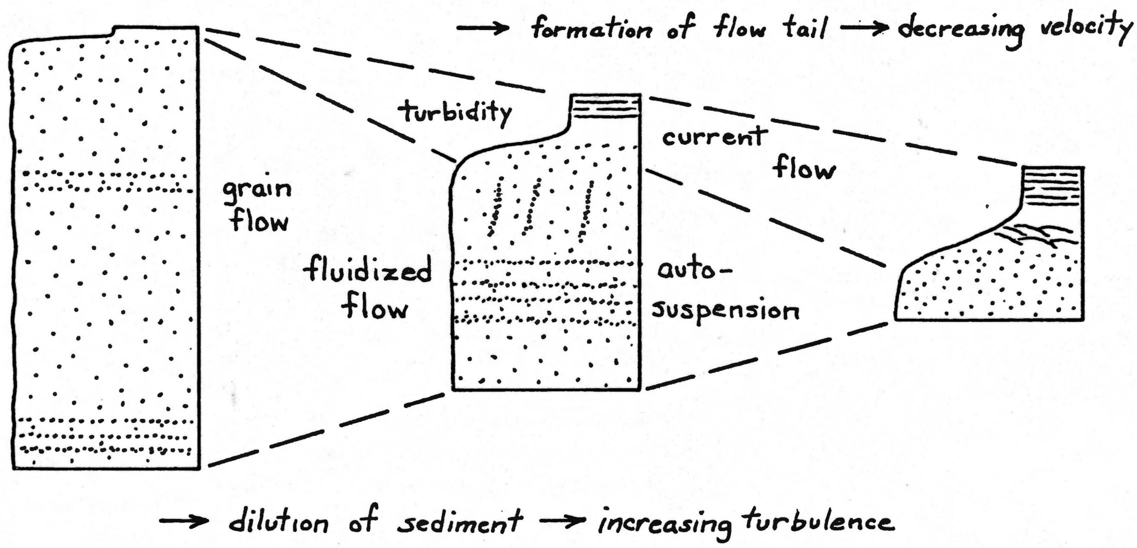


Figure 5. Hypothetical transition of sediment gravity flow from proximal fluidized grain flow to less proximal fluidized turbidity current flow. This would occur as a flow moved downslope or spread laterally.

ii) Complex Grading

Dzulynski and Walton (1965) consider "multiple" grading as an indication of proximal "coarse sandy flysch". There are several theories for the formation of complex graded beds:

1) the coalescence of two or more sediment gravity flows initiated at the same or nearly the same time;

2) the breaking up of a single sediment flow by concentration of sediment in the head and acceleration away from the body, perhaps more than once;

3) the passing sediment flow triggering slumping, perhaps by channel undercutting, and minor secondary flows being initiated;

4) the division of the bulk of the sediment flow into two or more distributary channels which then coalesce in the open area.

Two or more major parts to a recurrent graded bed would suggest 1) or 4) from above, when well developed flows follow one another in quick succession with a period of non-deposition between. Abrupt lutite layers (with or without thin sand layers) in the main part or near the base of the bed, may be due to separation of a high density fluidized or grain flow head as in 2). This initial immature "pulse" would not have developed a graded tail. Complex grading near the top of a bed suggests minor flows following the main sediment flow, in the case of 3).

The association of mud clast rip ups with complex graded beds is compatible with several of these theories. If the initial pulse of the flow were a faster and erosive accelerated head, mud clasts would be found in the lower portion of the complex bed. This is the case in half the occurrences of mud clasts in complex graded beds. Bank undercutting and slumping would conceivably more often result in mud clasts occurring in the second pulse of the flow. The rest of the mud clast occurrences in complex graded beds are in the upper portions and occasionally they are found in both. Resurgence of a sediment flow could also tend to rip up the cohesive but unconsolidated mud deposited by the initial part of the flow.

3. Sedimentary Structures

a) Bedding Plane Structures

Bedding planes are predominantly flat to slightly wavy with an amplitude of up to 5 cm, but normally 2 or 3 cm.

i) Ripples: Upper bedding planes occasionally show ripples rarely exceeding 2 cm in height and having sharp crests. When seen in section running NW-SE the ripples often have an apparent direction to the southeast (all directions true). Three examples of exposed bedding planes with ripples gave two directions nearly due east and one southeast. Steepening of ripples on the southern side as seen in section, may in part be due to deformation during folding by differential movement of the overlying bed towards the anticlinal axis to the south. Exposed bedding surfaces show ripples to be traverse and linear, with the current direction not always evident.

ii) Flame Structures: Equally as common as ripples are flame structures. These are over-steepened thin wisps of lutite extending into the overlying sand of the next bed. They are generally solitary or widely spaced and may represent the beginnings of erosion by the overriding flow or injection of unconsolidated lutite into the overlying sand due to loading. Flames generally have a SE apparent direction as viewed in the plane of the section. This would indicate that their true direction is similar to this or that the flames were also deformed. (See below for paleocurrent discussion.)

iii) Load Structures: Load structures of sand bulging into underlying lutite are rare and tend to be more bulbous than flutes.

iv) Sole Marks: Sole marks are generally scarce, partly due to the fact that good exposure of bedding planes is limited to the upper part of the section. Numerous bedding planes exposed were devoid of sole marks and many sole marks observed were not well defined.

The main types of sole marks are current grooves; long continuous to discontinuous, straight, widely spaced, small troughs. They may be the marks of clay clasts carried in non turbulent flows, although no good association of grooves and clasts was observed. Grooves show the line of flow but not the direction.

Flute marks are individual, bulbous and shallow (Dzulynski and Walton 1965) and there are bulbous undulations in the bedding plane that appear flute-like but do not give an indication of current direction. Flutes are generally interpreted as being scours caused by turbulent flow.

b) Paleocurrents

Five good readings and two general directions were obtained from exposed ripples and sole marks that gave a good indication of flow line or direction. The approximate mean is just slightly south of due east (true), although directions range from NNE to SSW. Ripples show E to SE direction when exposed, and this is consistent with the apparent direction of ripples and flames seen in section. It is interesting to note that the rather anomalous direction of SSW was obtained from flute marks on the base of the odd channel-like sand lense in the bed shown in plate 5. Paleocurrent directions observed are not unlike those of Campbell (1966) and Harris (1973) in the nearby area, but seem a bit more southerly. A summary of paleocurrent data is shown in Figure 6.

c) Internal Structures

Internal sedimentary structures are much better exposed and are fairly common upon close examination of many apparently featureless beds.

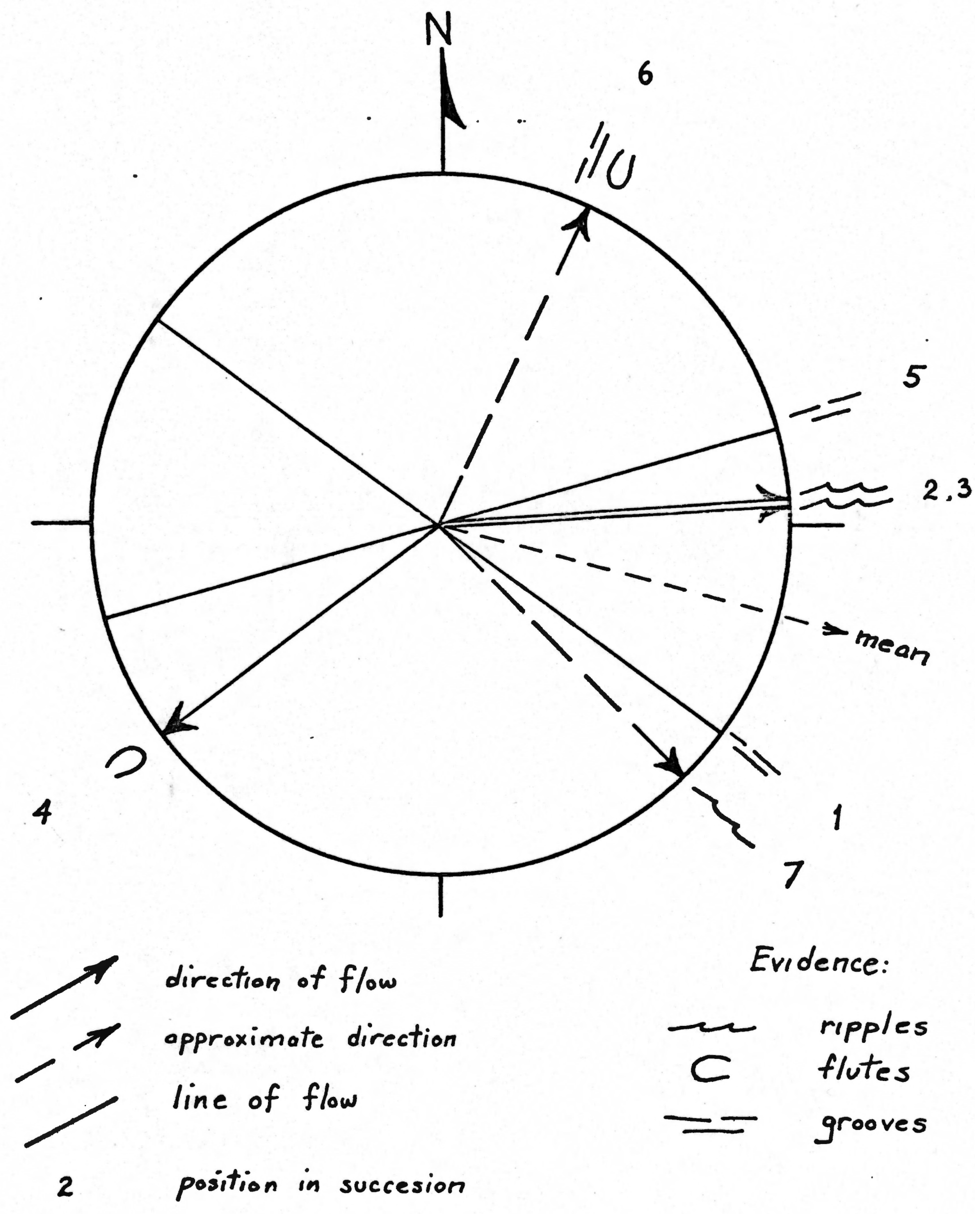


Figure 6. Graphic summary of paleocurrent showing type of structure and directions indicated.

i) Parallel Laminations: Parallel laminations are the most common structure. They are confined mainly to lutite layers, though in some cases are gradational into coarser laminations found in sand layers. The laminations vary from well defined 5 mm thick bands to indistinct thin layers less than 1 mm thick. Lighter and darker colour differences often define laminations with little apparent difference in grain size. The colour differences may reflect lighter silt and darker clay layers, however.

Thicker lutite layers tend to show better developed parallel laminations. Parallel laminations are often found throughout thicker beds with a low sand shale ratio. Thin lutite layers of thick sandy beds are less likely to show good laminations.

Parallel laminated lutite fits the description of the Bouma D division (Walker 1965) representing low energy regime laminar flow. They would be associated with the tails of turbidity type deposition.

ii) Cross-laminations are common and occur in two types. Those that consist of sediment with little difference in grain size are defined by colour difference mainly, while other cross-laminations consists of alternate coarse silt and fine lutite. Cross-laminations consist of low-angled, inclined laminations or lenses a few mm's thick, and are rather laterally inconsistent in their form. They are not often in the form of prograding or climbing ripples. The alternating coarse and fine cross laminations are usually better defined.

The upper part of sand layers and the lutite layer are usually where cross laminations occur, although coarse-fine cross laminations in the main body of the sand layers also occur. If the latter are substantial and continuous enough they constitute fluctuated grading, although thin parallel layers of lutite are the main form.

The cross laminations present may correspond to the Bouma C division, caused by current traction. The alternating coarse and fine cross laminations indicates fluctuations in the current and this may account for the lack of well formed prograding ripple laminations.

iii) Convolute laminations: contorted laminations in the upper fine part of beds are very rare and occur in only a couple of cases. They fit the description of convolute laminations (Dzulynski and Walton 1965) and are generally interpreted as deformation of semi-liquified sediment by depositional loading or pressure differences.

iv) Crude stratification: Coarse, distinct to indistinct parallel laminations are found laterally continuous in the sand layers of many beds. This stratification seems to be due to colour and textural differences, possibly with some small difference in grain size and are diffuse rather than sharply defined. They are often 1 cm or more apart, not always regularly spaced and rarely pass upwards into other structures, usually occurring in an isolated band in the massive part of a sand layer. Occasionally they are transitional into parallel laminations where found at the top of a sand layer, or more rarely occur in coarser lutite alone. In these cases the difference between parallel laminations and crude stratification is transitional and dependent on the definition of the margins of the laminations. Crude laminations are very rarely non-parallel so as to be termed crude cross-stratification.

v) Basal stratification: Basically similar to crude stratification is basal stratification that differs only in its preference of occurrence at or just above the base of a bed, or more rarely near the base of upper sand layers in recurrent graded beds. Basal stratification occurs at the base of the sand layer or more often up to 5 cm above the base, and upwards for a thickness of 10 to 20 cm (up to a maximum of 80 cm in thick beds) often fading out. Rarely basal stratification is associated with interrupted complex grading near the base of the bed. An example of well defined basal stratification is shown in Plate 7. A discussion of the origins of stratification follows in d).

vi) Dewatering Structures: Fine, often slightly curving, near vertical lineations occasionally occur in thick sand layers. They are apparent as partings or often as fine linear concretions and are interpreted as water escape structures. Curvature is often slightly S-shaped and tilting towards the anticlinal axis to the south. Dewatering structures are generally 10 to 20 cm long, discontinue at either end and occur parallel but widely spaced. There appears to be no preference for position in the sand layer. They are not as abundant in a layer or as well defined and thick as similar structures shown in Harris (1971).

These structures suggest loss of interstital water after sudden deposition as in the case of fluidized flow.

vii) Mud Clasts

Thin lenticular inclusions of fine lutite are commonly found individually or clustered in a layer in the sand layer of 15% of the beds in the section. These mud clasts (see plates 8 and 9) are generally several centimeters long and up to 1 cm thick. Clasts occurring in groups tend to be smaller and the largest observed measured 29 by 3 cm. Mud clasts seen in plan view showed a rectangular shape and they commonly have the long axis horizontal in section. Rarely the clasts appear to be imbricated but this is almost always towards the anticlinal axis and is believed to be tectonic deformation. They tend to be found near the top of sand layers and may have a tendency to rise in the flow due to their flake-like shape.

Mud clasts are strongly associated with complex graded bedding, as mentioned previously. Forty percent of all complex graded beds have mud clasts, while they occur in only 10% of the rest of the beds. They occur equally in the upper and lower portions of complex graded beds.

Mud inclusions are generally interpreted to be rip-ups from the mud deposited by the previous sediment flow or possibly due to channel bank undercutting and collapse.

Lutite clasts may be associated with fluidized flow deposits (Middleton and Hampton 1973). It is suggested that the soft clasts are more likely to be preserved if there is less turbulence and internal movement in the flow. Fluidized flow would be a good mechanism as grains are kept apart by pore water pressures.

viii) Concretions: Lenticular to layer-like concretions of easily weathered calcareous material are quite common. These are generally up to 10 cm thick and a few tens of centimeters long, but may extend across small outcrops. Concretions may be centered about mud clasts and often delineate dewatering structures.

d) Interpretation of Stratification

Cross stratification and parallel laminations correspond to C and D divisions of the Bouma sequence quite well. These structures would therefore indicate reduced flow regime and deposition in traction by a turbidity current. Gradation from cross to parallel laminations is observed, though it is not the rule.

Crude stratification may be equivalent to the Bouma B division, representing high flow regime laminar flow. Good transition from crude stratification, through cross laminations to parallel laminations

(Bouma B, C, D sequence) is almost never present. The presence of crude stratification within a sand layer may represent periods of laminar flow in an otherwise turbulent flow. Basal stratification may also be due to traction, possibly antidune migration, as rare cross-stratification was observed in thick sand layers.

Ungraded sands show structures that suggest deposition other than from traction flows, so basal and crude stratification are unlikely to be formed by traction. Diffuse stratification is often associated with "dish" structures in fluidized flow deposits (Middleton and Hampton 1973) and characteristic of A and B facies (Ricci Lucchi 1975). It is suggested they represent semi-discrete "pulses" of deposition from fluidized flow by "freezing up" of sand. This can be envisioned as the result of minor separation of portions of a high concentration flow, especially just in front of the head, resulting in the basal stratification. As this separation of portions of flow increases sand may undergo traction between pulses. The forward portion may develop a fine grained tail and a lutite layer would result, as complex grading. Certainly the stratification demonstrates that conditions fluctuate during the passage of a flow.

Alternately stratification may be the result of "shearing" of semi-cohesive sediment in a flow. This is analogous to shearing zones in a debris flow (Middleton and Hampton 1973).

Plate 6. From left to right. A sandy bed showing delayed grading and a thin lutite layer; an ungraded, relatively thick lutite bed showing some parallel laminations; and a thick massive ungraded sand bed. Coin is 2.5 cm in diameter. Up is to the left.

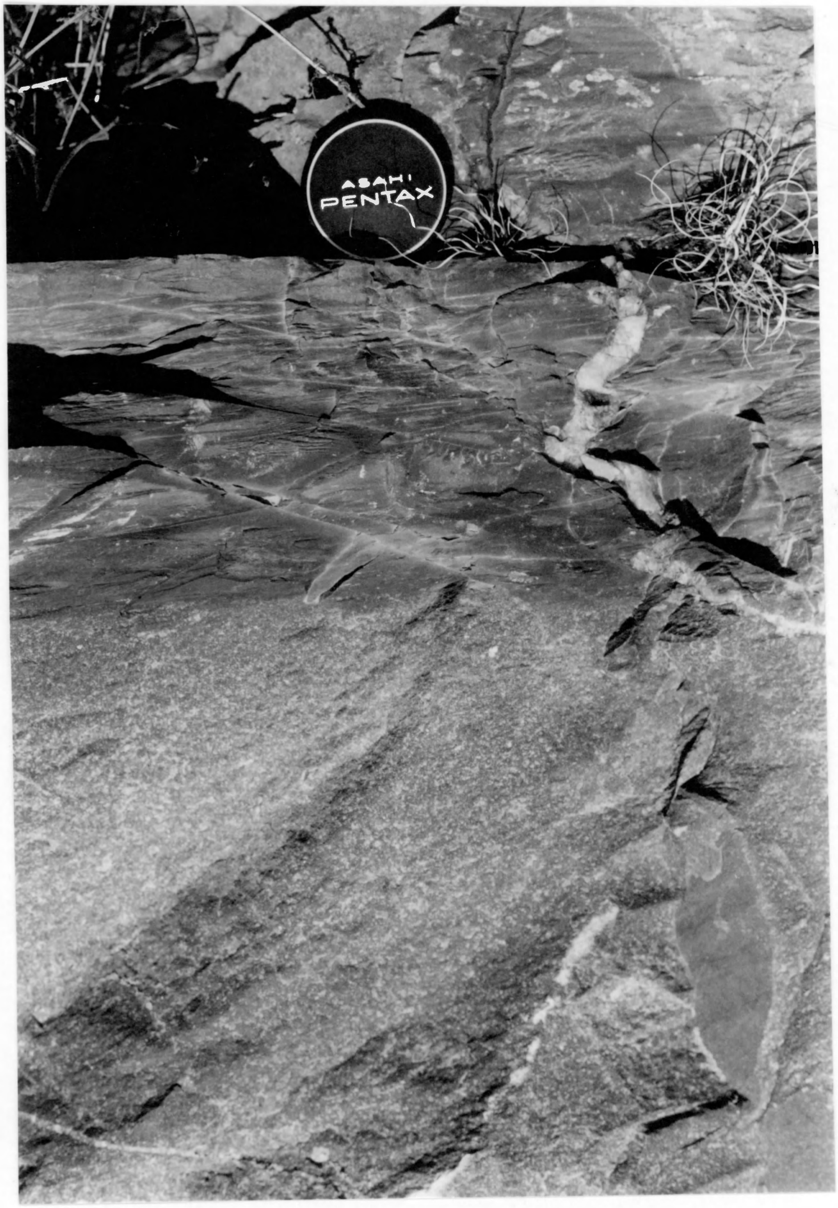


Plate 7. Top of a bed showing sudden delayed grading from fine sand to silty clay. Irregular cross-laminations are present in the lutite. Irregular light bands are quartz veins. Lens cap is 5 cm in diameter.

Plate 8. Top of a bed showing recurrent grading. Fine sand with crude stratification grades suddenly to lutite with parallel laminations, above which is a sand layer with small mud clasts, and a thin lutite layer at the top.

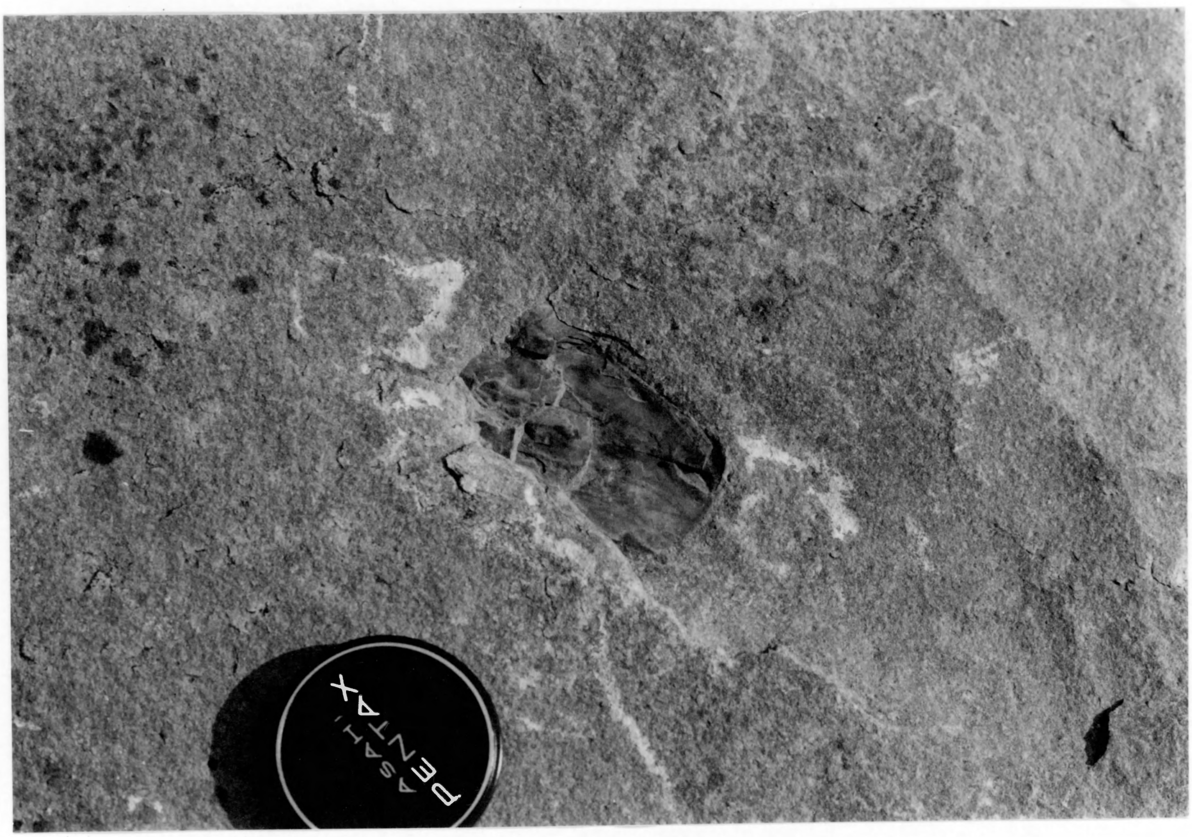


Plate 9. Mud clast seen in plain view.

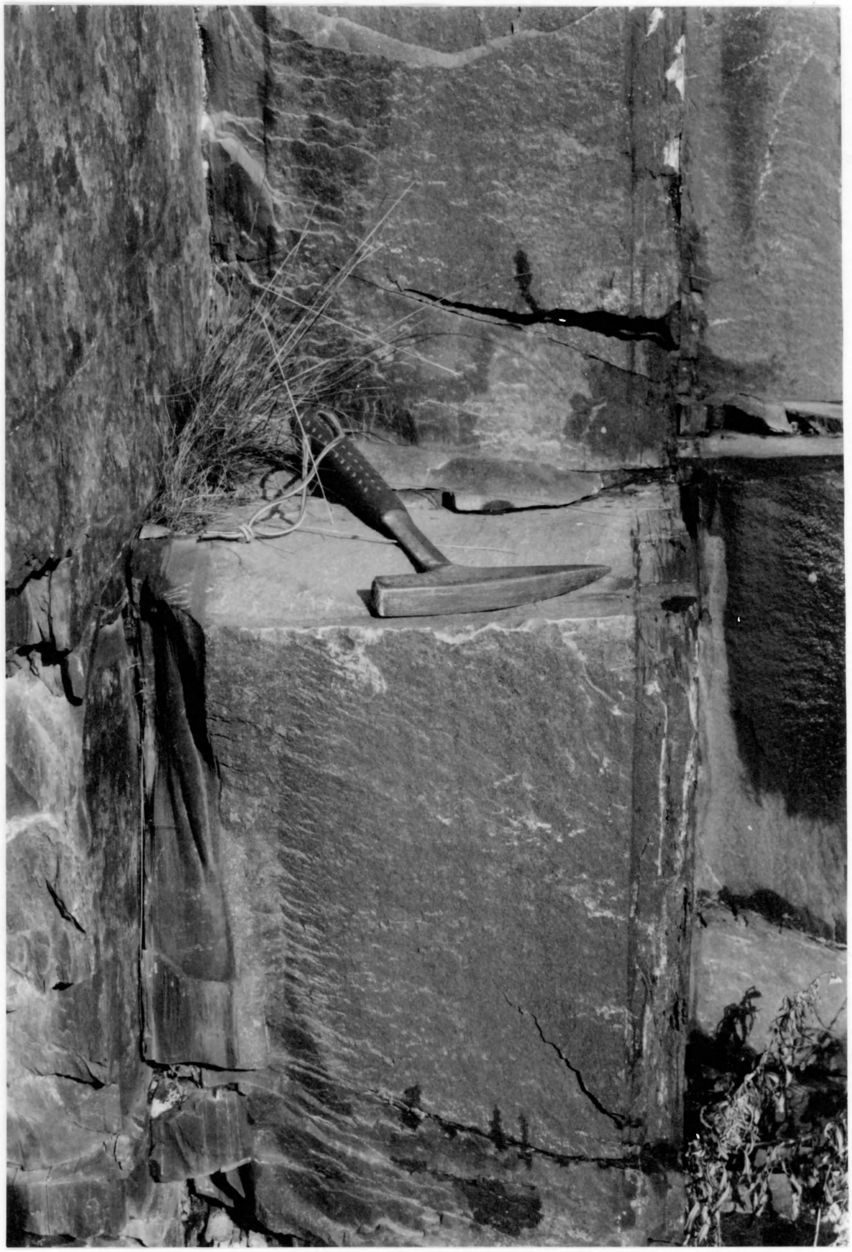


Plate 10. Bed showing basal stratification, in this case with a fine lutite layer. Hammer head is 18 cm long. Up is to the left.

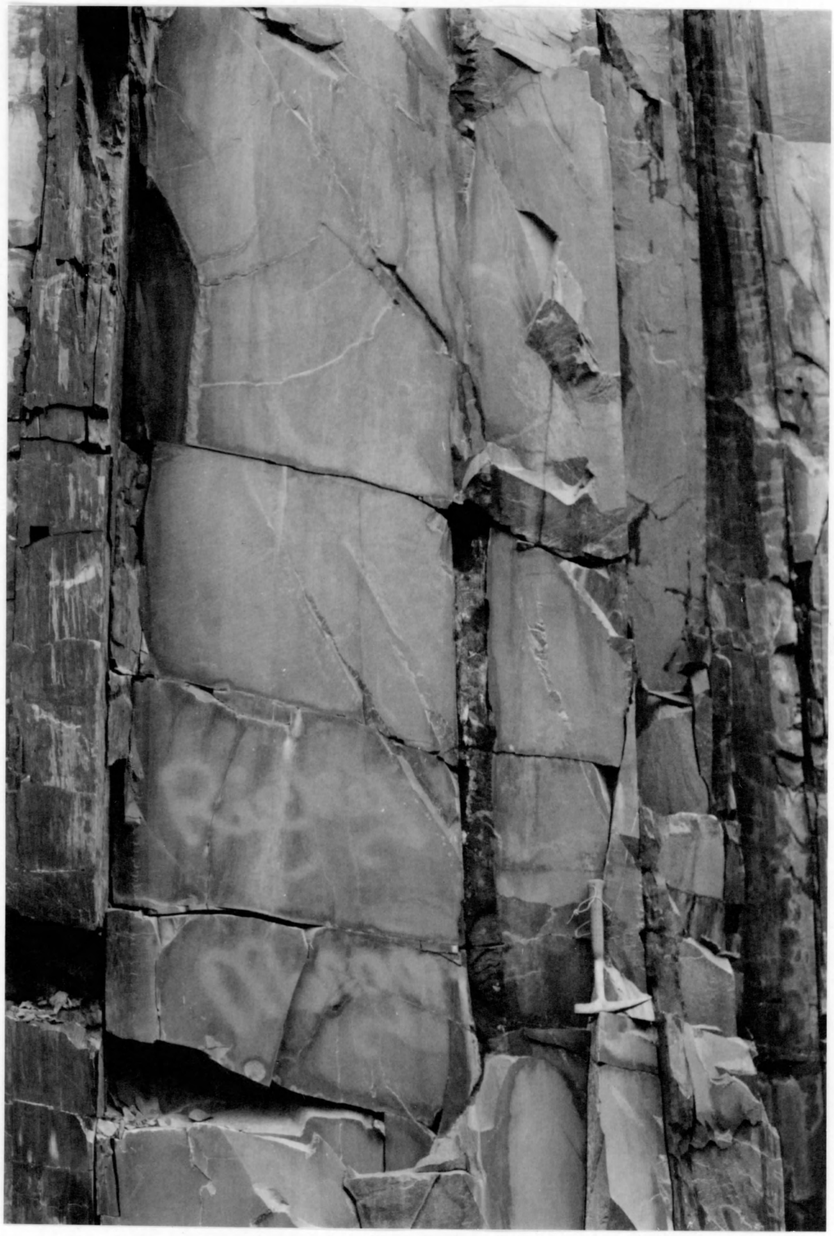


Plate 11. A large concretion in a sand layer. Up is to the left. Hammer is 30 cm long.

SECTION IV - DEPOSITIONAL PROCESSES AND ENVIRONMENT

1) Sediment gravity flow processes

The vast majority of the beds in the section can be described as thick, fine grained sand layers, usually massive and featureless except for occasional stratification. They show sudden delayed grading and thin, often parallel or cross laminated lutite layers. Evidence of fluctuations in the sediment gravity flows vary from large-scaled, resulting in recurrent grading, to small-scaled coarse and fine laminations. A composite bed typical of the section is shown in Figure 2D. The sedimentary structures present indicate that more than one process was instrumental in the deposition of many beds.

a) Turbidity currents

Few of the beds fit the full classical Bouma sequence, although this is not unusual in many turbidites. Many beds can be described as "immature" turbidites of the Bouma A/E variety. Examples of A to D division transitions are common, irregular ACD transitions occur, while ABCD, ABC and BCD sequences are very rare. Turbidity current processes resulting in grading and cross to parallel laminations predominate in the upper part of the beds, and are more common in thinner beds. Autosuspension may play a role in producing delayed grading.

b) Fluidized, Grain, and Debris Flow

Many aspects of the sedimentary structures observed suggest one or a combination of fluidized flow and grain flow processes as described by Middleton and Hampton (1973). The absence of grading, diffuse stratification, water escape structures in sand layers and a general lack of structures in the sands indicates that these processes predominate in the lower parts of many beds.

Fluidized flow is enhanced by large thicknesses of sediment and finer grain sizes so that pore water is lost less quickly (Middleton and Hampton 1973). The section does display thick, fine grained sands. It should be noted that "dish structures", well developed fluid escape pipes and sand volcanoes are not present in the section, although the latter two are common in nearby parts of the formation (Harris 1971).

Reverse grading, often attributed to grain flow, is rare. Debris flow, although characterized by coarse material, in the case of sands alone would be essentially featureless and massive.

c) Variations and Combinations of Processes

It is held by Middleton and Hampton (1973) that rarely does one "end member" process alone account for the transportation and deposition of sediment. The study section is probably a good example of the result of the combination of processes.

Evidence suggests that grain -fluidized flow dominates in the lower portion of beds and turbidity current flow in the upper portion, the latter being more important in thinner beds. Transition from one process to another is expected in different portions of a sediment flow, and through time as a flow evolves (Middleton and Hampton 1973).

The head of a model sediment flow has the highest concentration of sediment and is where fluidized-grain flow would operate. The body of the flow would have greater turbulence and turbidity current deposition would result, with grading into the waining tail. Initially the flow may have had a rapid transition from dense head to dilute tail, so sudden delayed grading and their lutite layers would result. As the flow develops greater turbulence and a more gradational body better grading and more lutite would be deposited.

Fluidized and grain flow tend to be short lived processes that dump their sediment as pore water is lost or the slope become insufficient. Dilution of these flows is a means of allowing them to continue. The hypothetical development of a flow is presented, and is summarized in Figure 5.

The flow would be initiated by down slope mass movement starting perhaps as debris flow or grain flow. Mixing of the top of the flow with the water above forms the initial tail. The protruding snout of the head forces water under the flow allowing it to, in effect, slide over a cohesiveless liquified base, possibly forming laminations in the base of the deposit. Incorporation of water allows fluidized flow to carry the current further than grain flow alone. Increased dilution would allow turbulent flow and auto-suspension would cause the delayed grading to persist much farther down slope. As the flow evolved, the body and tail would develop and turbidity current deposition dominate. Rather distal flows could still show some autosuspension in the head but would be well graded and have thick lutite layers from the tail.

2) Facies Interpretation

Application of the facies of Walker and Mutti (1973) and Ricci Lucchi (1975) is useful in determining the depositional environment of the study section.

The majority of thicker sandy beds appear to fit the description of facies B and the immature variety of C. Facies B is thick sands, amalgamated occasionally, with very high sand shale ratios, coarse grained laminae (crude stratification) and fluid escape structures (subdivided by Walker and Mutti into B1, having "dish" structures, and B2, without these). The deposition of this facies is attributed to fluidized flow, grain flow, high density turbulent flow or a combination.

Immature C facies consists of turbidite deposits of "proximal" Bouma sequences of ACE, AC or AE divisions. Although not very well developed in the section, these could be applied to many beds. The "typical" bed of the section is perhaps transitional between these two facies.

Thinner beds with better grading and sand/shale ratios closer to one roughly fit facies D. This facies is transitional from facies C and represents more "mature" turbidity currents. Thinner beds with high sand/shale ratios, delayed grading, occasional amalgamation and AE Bouma suggest facies E. These are due to high density low volume flows bypassed by main flows, as overbank deposits.

It should be noted that these facies are generalized and gradational among one another. Assignment of a particular bed to a single facies is often impossible, often for lack of criteria.

What can be determined is that the probable environment of deposition is the middle fan area of a deep sea fan. Facies characteristic of channelled mid fan, interchannel areas, and depositional lobes appear to be present in the study section. Up slope large channel deposits in pelagic shales would be present, and down slope thicker lutite layers and turbidity current deposition would be predominant.

The types of flows apparent suggest the action of sediment flows escaping the confines of channels and hitting the break in slope at the convex bulge of the depositional lobes (suprafan in Nelson and Kulm 1973). Here the sudden decrease in slope would cause fluidized-grain flows to dump the bulk of their loads, and perhaps stop autosuspension (see Figure 3).

Switching of channels and the migration of channels and unconfined flows would result in characteristic changes in bed thickness and character.

3) Depositional Trends

a) Description

To examine trends in sedimentation and facies changes a plot of sand layer thickness versus bed number was examined (Appendix I). The use of sand layer thickness is discussed further in section V.3 on the Application of Time Series, and it is considered an index of downslope and lateral proximity of the deposit.

Variation in sand layer thickness is observed to occur on three different scales.

The plot of sand thickness is very spiky. There is a strong tendency for thick beds to alternate with thin beds. Groups of thick beds always have alternating thin beds, but groups of thin beds alone may occur.

Sand thickness in medium thick beds tends to be less spiky and gradual changes are observed, trending for 5 or 6 beds.

Larger trends are present, though less regular. They often involve trends in a series of sand thicknesses peaks. Examples of these trends are shown in Figure 7.

These trends in sand thickness for a few beds or a few 10's of beds are similar to the classical thickening and thinning up sequences as well as the symetrical and complex trends of Ricci-Lucchi (1975). The types observed are summarized in Figure 8. The recognition of trends, especially longer ones, is somewhat subjective.

There is an overall trend in the section in terms of thick and thin bed association. In the first 150 or so beds (Appendix 2) great sand thicknesses (2.25 m or more) occur in groups, and there are groups of quite thin sands. Peaks in sand thickness become generally more isolated and fewer grouped thin beds are found. The last 100 beds shows a marked decrease in the magnitude of peaks.

b) Interpretation

The observed thickening up and thinning trends are similar to those described by Ricci Lucchi (1975) and Walker and Mutti (1973) among others. These are attributed to lobe progradation and channel filling respectively. Sestini (1970, Figure 7) explains thinning up sequences in terms of successive sediment flows in an open area. This could be caused by deposition of a series of flows in one spot, each one forced to spread over the resulting "bulge" and therefore

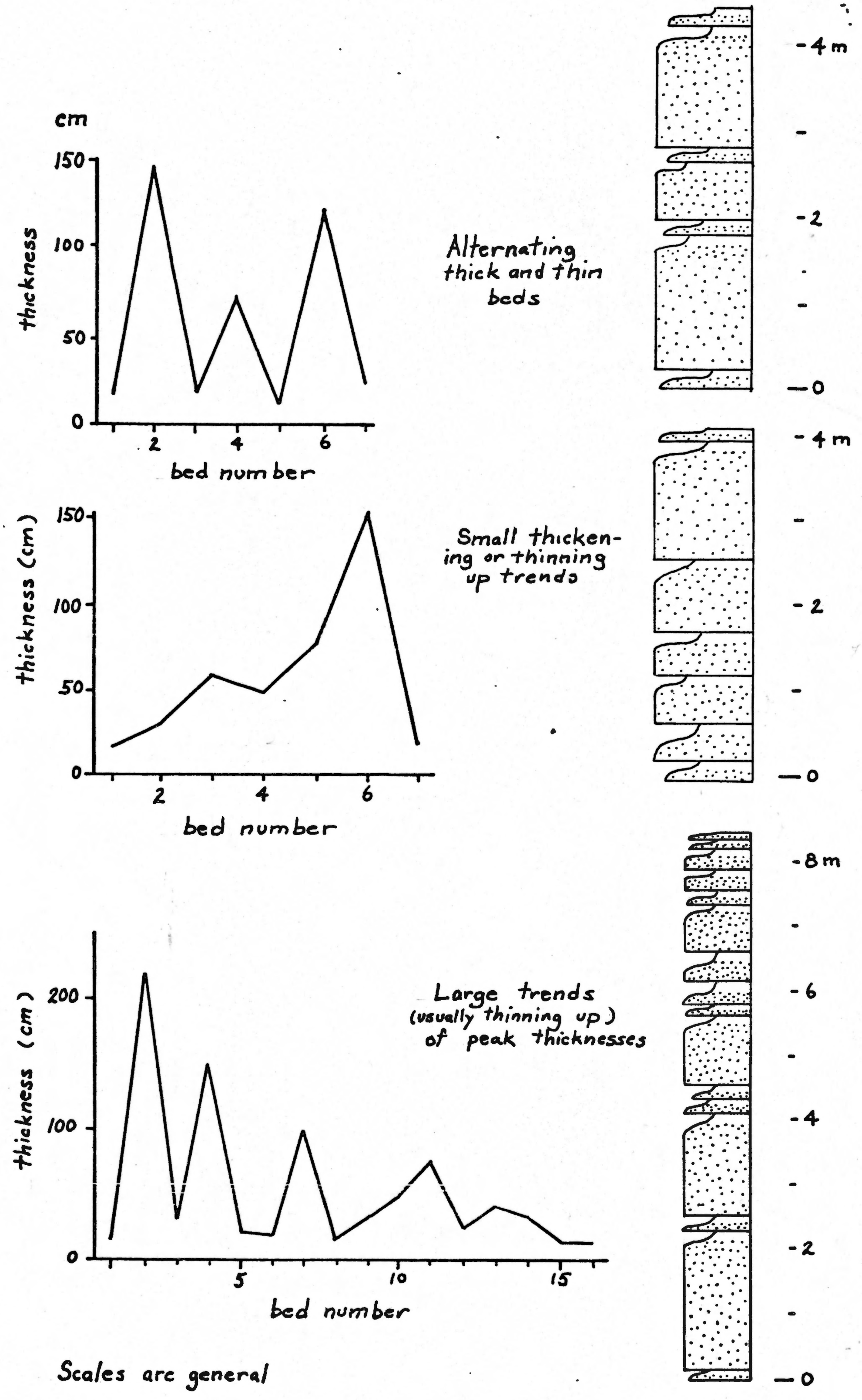


Figure 7. Idealized examples of the scales of variations and trends in sand layer thicknesses in the section.

thinner. Successive flows may "pile up" behind the last resulting in thickening up or thinning up trends, depending on the point of observation. Lateral deflection will also produce trends. See Figure 8.

Groups of flows may form trends as well due to similar processes on a larger scale than successive single flows. These result in composite or multiple (complex) trends (Ricci Lucchi 1975). Thinning-up sequences seem the easiest to "produce" in a fan that is not actively prograding.

4) Facies Trends

The overall trend in the section of the reduction of grouping and magnitude of sand thickness peaks show possible fan evolution. It is believed that the degree of confinement of sediment flows controls the degree of change in lateral proximity (bed thickness) with shifting of the path of the flows, as discussed previously.

Groups of thick beds may represent confined upper mid fan channels where flows are forced one atop the next. Groups of thin beds result as channels are abandoned and the area receives over-bank deposition. This trends to an area of more moderate changes and trends in sand thickness. Where flows are less confined they can shift laterally and spread so that thickness differs less with proximity to the axis of the flow. This suggests shallow channels

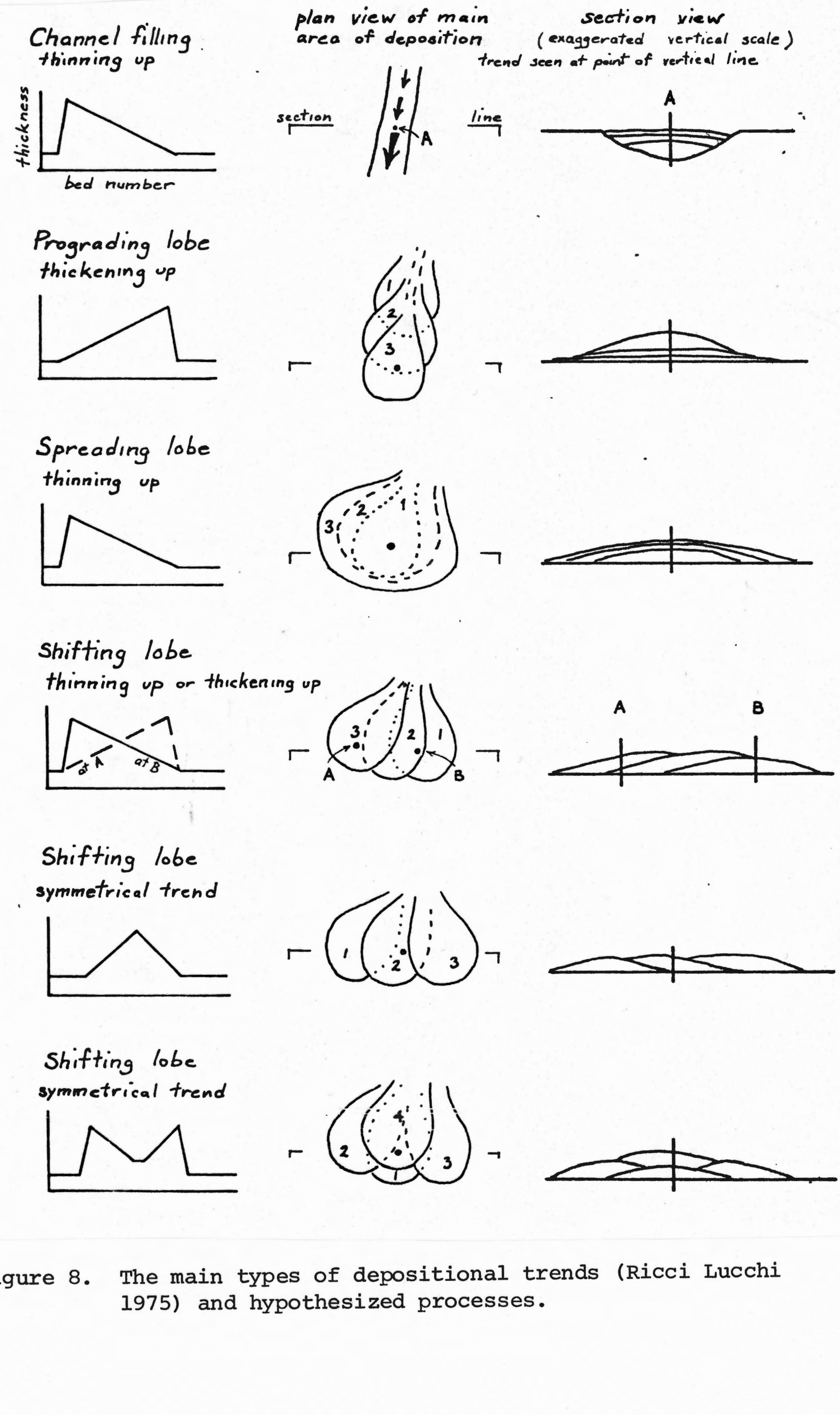


Figure 8. The main types of depositional trends (Ricci Lucchi 1975) and hypothesized processes.

and channel to lobe transition. The end of the section shows a reduction of large influxes which may be the outer mid fan where large fluidized-grain flows do not reach.

This gives an overall, somewhat subjective, picture of retrograde development of a deep sea fan within the mid fan area. Visual examination of beds for changes in facies suggesting an increasing distal nature (other than sand thickness) does little to prove or disprove this hypothesis and further, more quantitive work would be necessary. It is interesting to speculate that this retrograde trend may be part of the overall fining-up trend of Goldenville to Halifax Formation. The section is just stratigraphically below what is mapped as Halifax Formation in the Liscomb Harbour Syncline, which could represent the distal outer fan environment.

SECTION V - QUANTITIVE ANALYSIS

1) Analysis of Cycles

The occurrence of cyclic processes of sedimentation are widespread. The observation and definition of such cycles is important in understanding the nature of the processes. The understanding of the deposition of turbidity currents resulted from the observation of the "rhythms" of their internal structure (Bouma 1962).

The model of the deep sea fan suggests that deposition by turbidity and related sediment gravity flows in such an environment should be of a cyclic nature on a larger scale. The recognization of different facies associations of turbidites (Walker and Mutti 1973) and observation of their organization indicates changes in the depositional processes. There have been numerous descriptions in the literature of "megarythms" of various scales (see Walker 1970 for further references) consisting of repeated coarsening or thickening-up and fining or thinning up sequences. But there has been little work done to statistically describe such cycles.

Cycles in other successions, such as the deltaic cyclothems, can often be analyzed by such basically simple methods as transition matrices and Markov Chains (Davis 1973, Chapt. five). These depend on the recognition and assignment of units to a particular facies and an examination of tendencies in the transition from one facies to another.

In turbidite successions, while general facies are present, they are not usually distinct. There tends to be a continuous spectrum of types. Changes in facies are better observed by examining the variation in sedimentary properties, such as grain size, bed thickness, sand/shale ratios, and internal structures.

Many analyses of turbidite successions have been done. Walker (1970) has published a good review of some of the methods suited to this. There are two basic approaches to the problem. There is a general method of facies recognition in which units are grouped by their sedimentary properties, often by such sophisticated means as factor analysis. These facies have environment connotations and general changes can be observed. The second is basically time series analysis, in which one (or more) of the sedimentary properties is observed as it varies through the succession (time). From this changes in environment can be inferred.

Mutti (1977) has assigned facies designations to groups of beds and shown good continuous variation in the sequence through these facies in a cyclic way.

Walker (1967) developed an ABC index of proximity based on the basally occurring Bouma division in each bed. Variation in this index showed changes in depositional processes. Walker and

Sutton (1967) used this method to show cyclic progradation in basin filling. Such analysis is ideal for "classic" turbidites that show good Bouma divisions, but where this is not the case other parameters of proximity must be employed.

Other authors (Ricci Lucchi 1975, Sestini 1970) have used plots of bed or sand layer thicknesses, often smoothed by a moving average technique, to observe thickening up and thinning up cycles. In most cases it is noted that sand thickness is considered one of the main indices of proximity (for example Mutti 1977, Figure 9; Ricci Lucchi 1975) and good correlation can be seen with this and Walker's ABC index (Walker 1970, Figure 6; Walker 1967, Figure 2) in one particular formation.

Most analyses of depositional "cycles" has been subjective, depending on visual inspection of condensed vertical sequences. Little actual quantitive work on apparent cycles has been attempted. Perhaps this is because in the successions studied they have been fairly obvious and more powerful sophisticated techniques have not been necessary.

The use of Fourier analysis, including power spectra, has been used with seismic and x-ray diffraction data (Davis 1973). More important to this discussion, it has been applied to varved sequences to determine the presence of cycles or periodicites. Anderson and

Koopmans (1963) for example, used amplitude and power spectrum analysis to determine the nature of variations in varved sediments. Anderson and Dean (1967) used Fourier (amplitude) analysis on a silt-claystone turbidite sequence to show that there were no cyclic variations in the thickness of layers.

A quantitive method such as Power spectrum analysis will show if cycles are present in the succession, or if the variation is merely random. By describing the magnitude and frequency of any cycles present it can also provide insight into the processes involved.

Because the variations in sedimentation of the study section are of various scales and are expected to be cyclic in nature it has been chosen to use time series analysis (power spectra in particular) to determine if variations observed are in fact periodic and the result of cyclic processes.

2. Time Series and Power Spectra

A more complete discussion of Power Spectra theory is found in Appendix II .

A time series is a series of values through time that vary through time due to some process. In the case of a turbidite succession, variations in the bed or sand thickness up through section are in effect a time series. Processes controlling these values can be due to cyclic processes (the signal) and random processes (noise).

Power spectrum analysis is used to determine the frequency or period of cycles in the series. This is done by matching portions of the series with itself to see how often it statistically resembles itself. By the use of sine and cosine functions this is transformed into an expression showing at what periods or frequencies the series tends to repeat. The plot of the power spectrum shows peaks where periodic tendencies are present. If several cyclic processes are superimposed their frequencies and relative strengths can be observed.

3) Application of Time Series

a) Signal and Noise

It has been stated that the sand layer thickness of a sediment flow deposit is an index of the distance it has travelled down slope and the distance it has spread laterally. The latter shows greater change over a short distance.

A vertical section is a view of successive sediment flows through time from a single geographic location. As the main path of successive sediment flows varies in distance from this spot the thickness of each deposit varies. Changes in this lateral proximity is believed to be the major control of variation, thickness seen in the section, and is considered the signal. Because the distribution of flows may be controlled by different scale processes there may be several components of different frequencies present in the signal.

Other factors can cause variation in sand thickness:

1) changes in the down slope proximity are gradual and could be considered an overall trend or drift.

2) the initial volume of sediment flow will probably vary in a random way. It has been suggested that factors such as climate or tectonics (repeated uplift of the source area) may produce periodic variation in the sediment supply (Sestini 1970). Any record of this would be masked or of too large a scale to be present in the study section.

3) the mechanics of the sediment gravity flow have a bearing on the resulting thickness; that is a dilute flow will result in a thinner deposit over a greater area. Changes in the nature of sediment flows due to fan evolution (Kelling and Stanley 1976) is again likely to be on a scale too large to be observed.

4) erosion of underlying deposits results in removal of the complete "record" and the amalgamation of beds. Amalgamated units were treated as a single entity in the series and so some overly large sand layer thicknesses resulted. However few beds received a major addition in thickness due to amalgamation.

5) the resolution of the signal is reduced for the more distal sediment flows. It is believed that beyond the main area of deposition of a current in a channel or lobe that thickness does not

decrease so readily with reduced proximity. That is, interchannel and interlobe deposits tend to be more even bedded and laterally continuous so they are a less accurate measure of proximity.

6) sediment flows may originate from different sources (Walker 1970) and confuse the signal. This results in different thickness from a similar volume flow having its main deposition in the same area but having travelled a greater of less distance from its source.

Power spectral analysis of bed unit thickness should determine cycles in the variation of the proximity of deposition of successive sediment flows (the signal). Presumably other factors causing variation in thickness (noise) would be random and would not be of a magnitude to mask the main input.

In the case of this sequence the sand layer thickness was chosen as the best index of proximity for several reasons:

1) it removes the random input of the non-turbidite shale, the original thicknesses of which are unknown.

2) other proximity indicators such as sedimentary structures are not widespread enough. Sand/shale ratios are too limited, being generally high, and too few beds can be adequately described by the Bouma sequence to use a method such as Walker's ABC index.

3) from the suggested nature of the predominant sediment gravity flow type in the sequence, the thickness of the sand layer, being lenticular in shape, would be a good indicator of proximity to the axis of deposition.

4) Sand layer thicknesses have been used before with success in observing trends, and correlate well with other parameters.

b) Power Spectrum Computer Program

A BMD package program BMDO2T was used to calculate the power spectrum. The program calculates autocovariance and power spectra for a signal series as well as cross covariance and power cross spectra for comparison of several series. A more complete description as well as options and procedures can be found in Dixon (1964).

One drawback of the program is that no confidence limits are provided to determine the significance of the power spectrum. These can easily be estimated by hand for this program. (My thanks to Dr. David Huntley for help in this aspect, particularly).

Anderson and Koopmans (1963) hold that confidence limits applied to a high noise series (such as a varve or turbidite succession) may result in real peaks being labelled insignificant. A random process will tend to show many frequencies, like "white noise" containing all frequencies. This will then result in a high background level to any peaks present, making them appear less significant. This complicates deciding whether or not a peak represents a cyclic tendency or is insignificant and due to random processes.

The number of lags (the amount the series is compared with itself) should be less than a quarter of the length of the series. Low lag values prevent bias and increase confidence limits but reduce resolution by smoothing the spectrum. A balance must be found therefore by trying different maximum lags and comparing the results. Stable peaks in the spectrum can be observed also by doing this and thereby reducing the reliance on confidence limits in determining significant peaks (Huntley 1978, personal communication).

The arthmetic operations used in the program and in calculating confidence intervals, as well as explanations of terms, can be found in Appendix II.

4) The Power Spectrum

a) The Calculated Spectrum

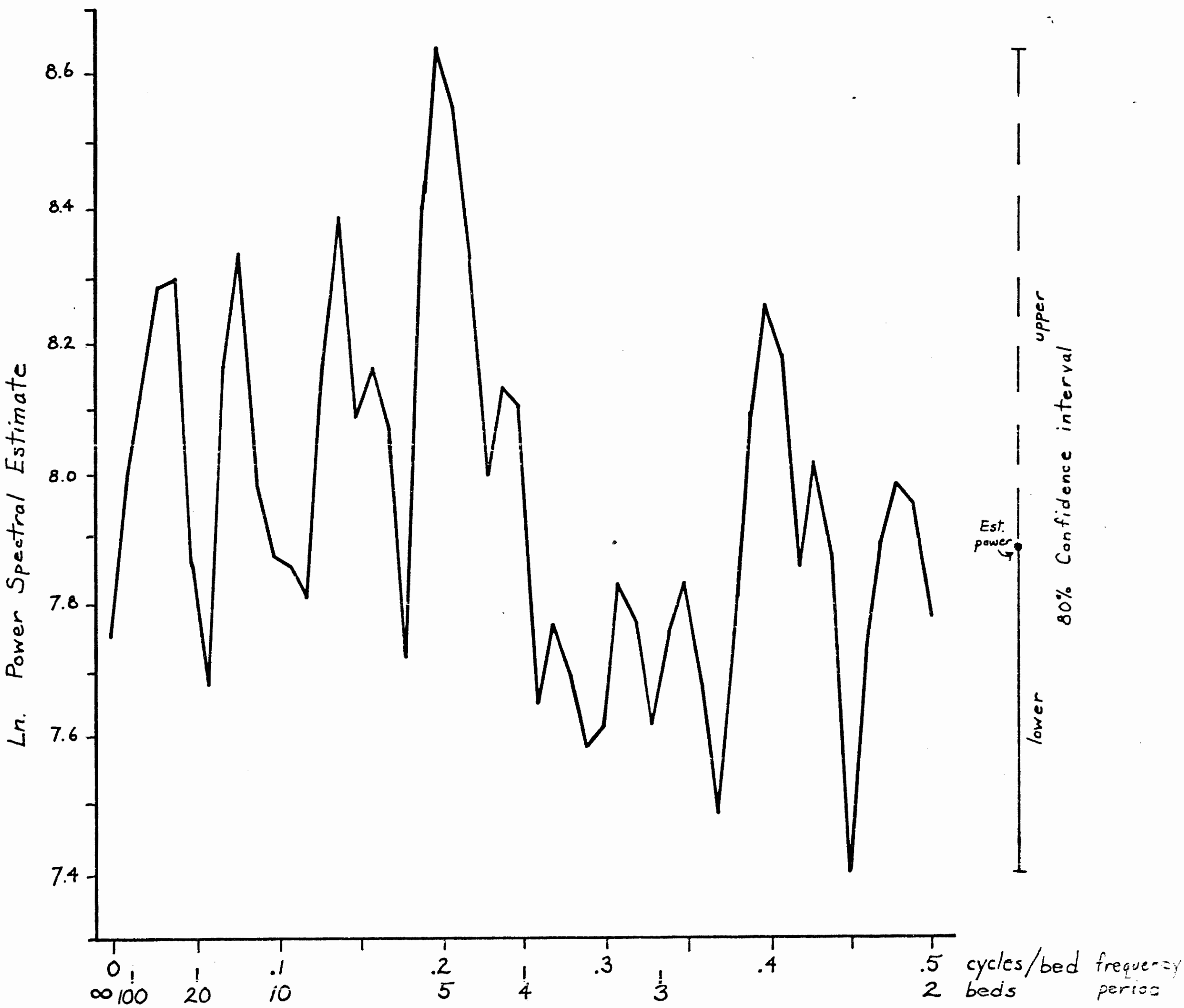
The calculated power spectra using maximum lags of 50 and 100 bed units are shown in Figures 9 and 10 respectively.

Examination of the spectra show relatively high power for the entire frequency range, and as a result confidence intervals are large in relation to the peak heights. This indicates a high noise input to the signal, since "white noise" contains all frequencies and will provide a high background level to the spectrum.

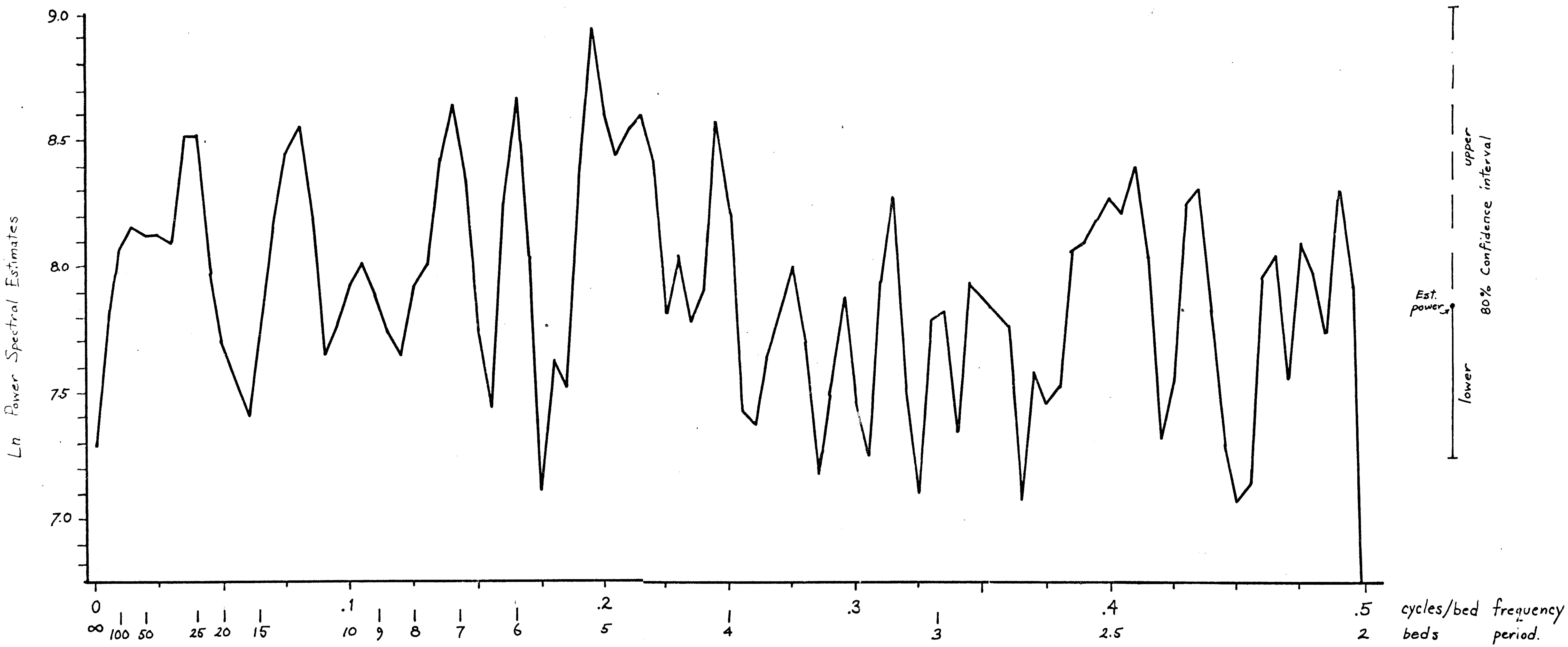
Several peaks are present in both spectra and have lower confidence intervals above the troughs. The fact that the upper confidence interval of the troughs is above some of the peaks is

Figure 9. Power spectrum of sand layer thickness using a maximum lag of 50 bed units. Natural log of the power plotted against frequency and period.

Note that the scales are different in Figures 9 and 10.



Ln. Power Spectral Estimate
8.6
8.4
8.2
8.0
7.8
7.6
7.4
0
.1
.2
.3
.4
.5
cycles/bed
frequency
∞
100
20
10
5
4
3
2
beds
period
Est. power
upper
lower
80% Confidence interval



Ln Power Spectral Estimates
9.0
8.5
8.0
7.5
7.0
0
.1
.2
.3
.4
.5
cycles/bed frequency
∞ 100 50 25 20 15 10 9 8 7 6 5 4 3 2.5 2
beds period.
Est. power
upper
lower
80% Confidence interval

Figure 10. Power spectrum of sand layer thickness using a maximum lag of 100 bed units.

generally not considered important (Huntley 1978, personal communication). In the lower resolution 50 lag spectrum only two peaks are above the confidence interval of the noise background. In the greater biased 100 lag spectrum the corresponding stable peaks are mostly above this limit. One particular peak centered at approximately a 5 bed period has a definite 50% confidence of being statistically significant, since the lower limits of peak and the upper limits of the adjoining trough do not overlap.

Because the signal has a large noise component, confidence limits should not necessarily be taken too seriously (Anderson and Koopmans 1963). They are used here only to show that certain peaks are stronger and more significant, rather than to label others as insignificant.

The strongest peak is centered at a frequency equivalent to a period of 5 beds. The peak is broad below this and there are peaks above it at periods of roughly 6 and 7 beds. Periodicities of such close wavelengths would in fact be related and show as separate peaks because of the resolution at this scale.

A peak is present at a period around 2.5 beds, best observed in the less detailed 50 lag spectrum.

At lower frequencies loss of resolution smooths the spectrum and less confusion results from peak clustering. A peak is present centered at a period of 12.5 beds and another broader peak ranges from a 25 to 33 bed period, with a tendency to longer periods evident in the 100 lag spectrum. In the 50 lag plot this is reaching the limits of resolution as cycles with a period longer than the lag cannot be detected.

b) Interpretation

The high frequency variation of sand thickness, with a period around 2.5 beds, is due to the observed tendency of thicker beds to be separated by much thinner ones. This is the result of successive sediment flows to be deflected by the "bulge" of the previous deposit. In confined channels following flows cannot wander too far, and must return to the initial path within two or three deposits. The relative weakness of this peak indicates that this is not the main factor controlling flow distribution.

The strong periodicity of 5 to 7 beds may be the result of lateral migration of deposition by sediment flows that are semi confined as they leave channels and move onto the depositional lobes. Here flows can migrate back and forth, but return as they are directed into the general area by a channel. This may be the most important process present in the section.

The longer period tendencies of 12.5 and 22 to 33 beds may be related to the switching of sediment flows across the main part of the fan as one system of distribution becomes plugged. Different scales are a result of switching at different points in the hierarchy of distributary channels. See Figure 11.

While these processes are somewhat hypothetical they do represent the scale of the distribution patterns evident from the analysis, and are compatible with the fan model and the environment interpreted. The main conclusion from the analysis should be that processes of sediment distribution show fairly good cyclic tendencies of several scales, as would be expected in a deep sea fan. The method is limited of course by the length of the section and in this case the largest "megarythm" well quantified was in the order of 22 to 33 beds, or 20 to 25 meters (average bed thickness being 78 cm). The section could be analysized for larger cyclic tendencies but only at the risk of biasing the examination towards the ends of the series and hence less confidence in the findings.

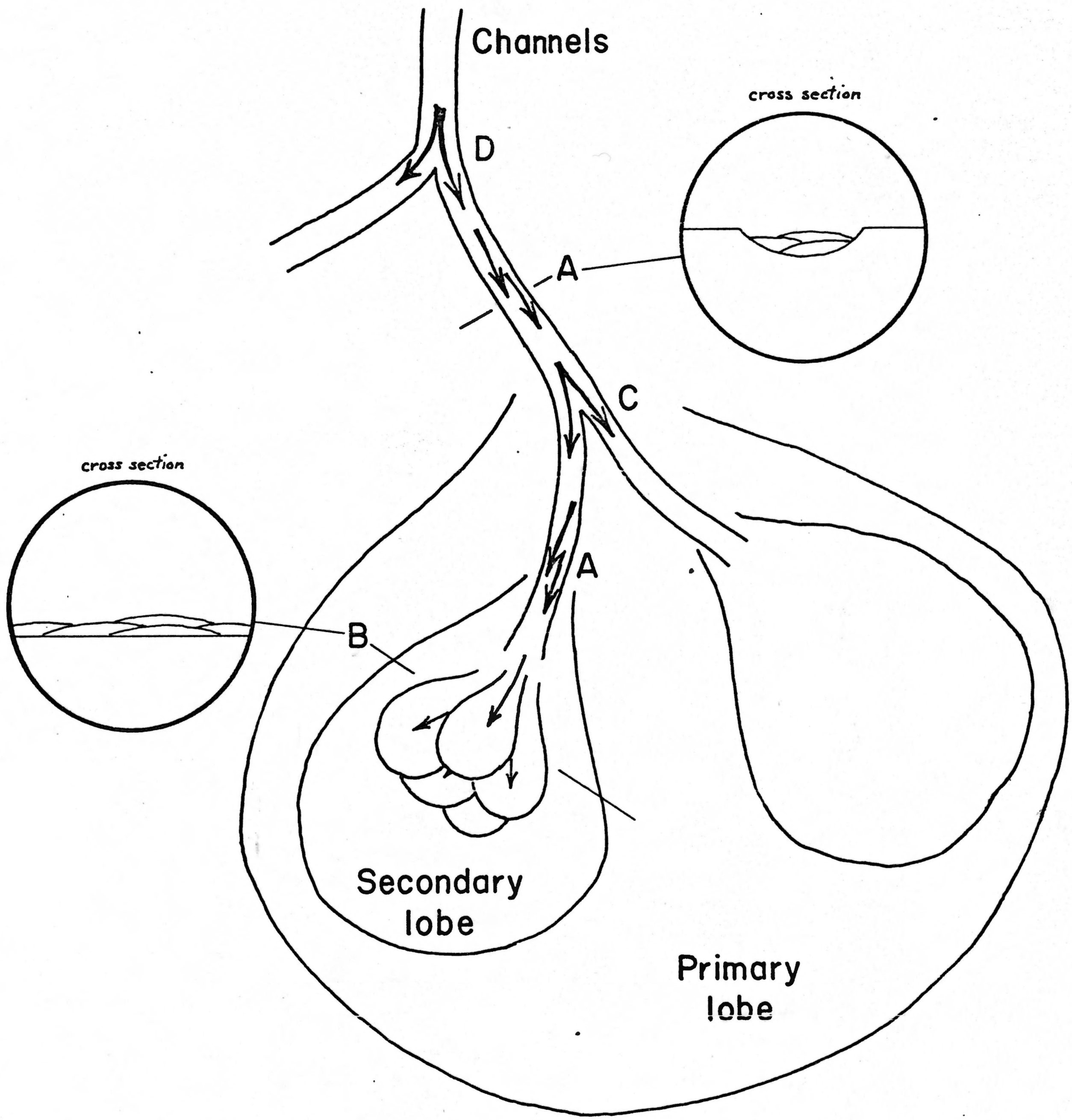


Figure 11. Hypothetical representation of the different scaled controls of sediment flow distribution - the "distribution hierarcy"

A: the path of flows return to the same spot every second or third event

B: flows can migrate laterally and return after several events (5 to 7)

C: build up of the secondary lobe; switching of the secondary channel after 12 or so flows

D: build up of the primary lobe causes switching of the channels after about 25 flows

SECTION VI - CONCLUSIONS

Study of the section has lead to some conclusions on the nature of the sedimentation that are compatible with the existing deep sea fan model:

1) The deposition of individual beds, in many cases, is the product of a combination of sediment gravity flow processes. The main types of processes evident are combined fluidized and grain flow transitional with immature trubidity current deposition.

2) The nature of the processes indicated and the thickness trends observed suggests a mid fan environment where sediment flows deposit sediment in channelled and open areas. There is some evidence to suggest a retrograde development of the fan environment up through the section. It is suspected that this represents part of the overall transition from sandy Goldenville to shaley Halifax Formation in the vicinity.

The section proved ideal for the application of time series analysis to test for the presence of cycles in deposition hidden from less quantitive analysis.

3) There is an indication of cyclic tendencies in thickness variation on several different scales. The true nature of these periodicities is problematic, but are best attributed to the different controls of distribution of sediment gravity flows on a deep sea fan.

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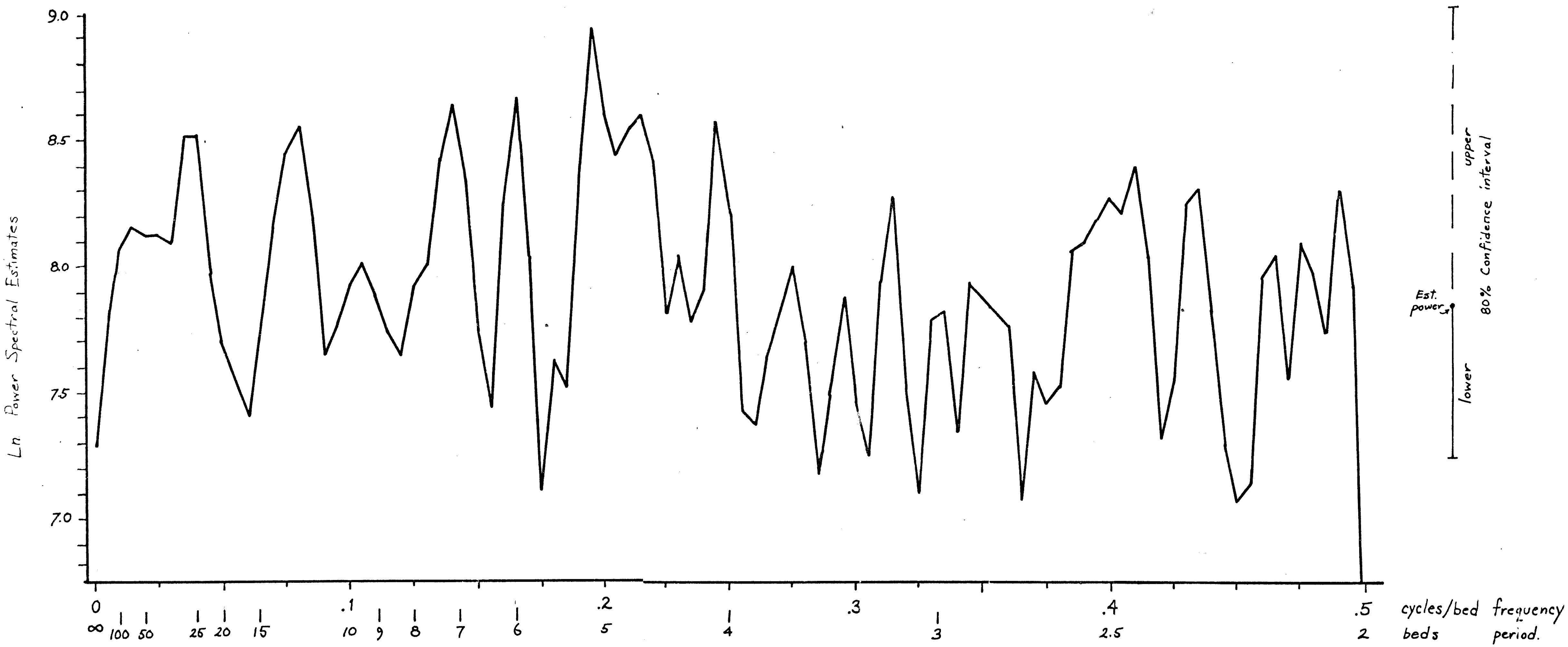
APPENDIX I

Plot of sand layer thickness against bed number.



9.0
8.5
8.0
7.5
7.0
Ln Power Spectral Estimates
0
.1
.2
.3
.4
.5
∞
100
50
25
20
15
10
9
8
7
6
5
4
3
2.5
2
cycles/bed
frequency
beds
period.
Est. power
upper
lower
80% Confidence interval

APPENDIX II

Power Spectrum Analysis

A basic, rather non mathematical discussion of the theory leading to Power Spectra is attempted here. Davis (1973, Chapter Five) deals with Fourier series and power spectra in simple understandable terms. A summary of the theory is presented in Anderson and Koopmans (1963) and much more complete dealings with theory and applications are found in Jenkins and Watts (1968) as well as Blackman and Tukey (1958) and Bloomfield (1976).

a) The Time Series

A time series is a function X of a variable t, which usually represents time. A discrete time series can be represented as:

$$X(t) = X_1, X_2, X_3 \dots X_N$$

and is made up of values of X at certain time intervals. A turbidite sequence can be considered a time series in that it is a series of values (i.e. bed thicknesses, sand layer thicknesses, or sand/shale ratios) that vary as a function of position in the sequence, which is equivalent to time. The actual time between events in the sequence is not known but this is not relevant. Because each turbidite bed can be identified and assigned certain values it becomes a point in the time (event) series and the series viewed as a record of the changes in depositional processes through time at the point in space that the vertical sequence occupies.

A time series can be considered to be made up of random and non random parts, the "signal" or component that is controlled by a process (such as an oscillator producing a wave form) and a random input (noise). The signal may be made up of more than one frequency or harmonic constituent.

b) The Autocovariance

If a series is cyclic or repetitive in nature it will statistically resemble itself along different portions of the series. This resemblance is reduced by the noise present, and by any overall trend in the series. A series is made up of three main parts:

1) one or more periodic or cyclic components

2) a random noise component

3) a linear trend or drift.

The linear trend tends to gradually reduce the resemblance of parts of the series with previous parts, so this is removed to make the series "stationary". This is often done by a least squares fitting method, so the series is considered as fluctuations about a fitted straight line.

To determine the cyclic nature of a series it is then compared to itself with all points corresponding, at lag = 0, then progressively displaced at lags = 1, 2, 3 ... Davis (1973) compares this process to two identical chains being laid side by side, the two compared, one chain moved along by a link, the two compared again, the chain moved by another link, and so on. The autocovariance is the sum of the variance of the series at a given lag. At certain lag intervals, corresponding to the period of the cyclic components, the series will compare better with itself.

It can be seen that at high lag values less of the series is being compared with itself and bias towards the ends of the series results. If low lag values are used long cycles with periods greater than the maximum lag will not be recognized. Therefore in actual analysis the maximum lag value must be chosen with care. The length of the series is also proportional to the length of the cycles that can be seen in it and must be a good deal longer. The more times a cycle is repeated in the series the better it will be defined.

c) Fourier Series and Power Spectrum

A cyclic series that is made up of several periodic components can be broken down into these harmonic constituents by Fourier analysis. A Fourier series of Sine and Cosine turns can be used to describe a periodic function or wave form. A complicated wave form can be described by the addition of successive harmonic waves to a fundamental frequency (the equivalent period of which is the maximum lag). In practice a least squares estimation of coefficients of these harmonics is used.

The sum of these estimated coefficients for a harmonic is then the "power" or variance of the series accounted for by that frequency component when a Fourier transform of the autocovariance is performed. When the power (variance) is plotted against frequency or period of the function, generally after being smoothed, it is the power spectrum. It shows the relative contribution to the variability of the series made by a given harmonic term, in effect the relative strengths of the various periodicities present in the series.

In summary, a time series, or series of values through time (or space) are considered as a signal or wave form. From this is determined the component frequencies and ~~their~~ relative intensities, of this signal. This is analogous to using a prism (Fourier transform) to break white light (the series) down into its component colours (frequencies or wavelengths) (Davis 1973).

d) Confidence Intervals

The BMD package uses a rectangular lag window, which means that the autocovariance for each lag up to the maximum lag value are considered equally. The attempt to approximate the fundamental frequency by the Fourier transform of this rectangular window results in a broad frequency response of the spectrum (a series of successive diminishing harmonics of a sine wave are necessary to fit a square wave). The addition of this response to the spectrum reduces the confidence of the power estimate. Other shaped windows can be used to increase confidence (see Jenkins and Watts 1968 Chapter 6) and are recommended strongly.

The type of window used defines the degrees of freedom, from which confidence limits are calculated. For the rectangular window the degrees of freedom are

$$d.f = \frac{n}{m}$$

where n = number of points in the series; m = maximum lag.

Confidence intervals for various degrees of freedom are plotted in Jenkins and Watts; Figure 3.10 pg. 83 can be used (Huntley 1978 personal communication). The interval is proportional to the value of the point on the spectrum. When the spectrum is plotted on a lag scale this is a constant interval.

d) Operations performed by BMD program

BMD02T (Dixon 1964)

on the discrete time series $X(t) = X_1, X_2, X_3 \ldots X_n$ where:

$R^{(p)}$ = autocovariance at lag P

$A^{(p)}$ = autocovariance after detrending at lag P

$P^{(h)}$ = power spectral estimate at frequency $\frac{h\pi}{m\Delta t}$

$SP^{(h)}$ = smooth power spectral estimate at frequency $\frac{h\pi}{m\Delta t}$

n = number of points in series

p = lag

m = maximum lag

Δt = constant time interval

1. The autocovariance

$$R^{(p)} = \frac{1}{n-p} \sum_{q=1}^{n-p} X_q X_q + p \qquad p = 0,\ 1,\ 2\ \ldots\ m$$

$$R^{(p)} = R\ (p\Delta t)$$

2. The series is detrended, using a least squares fit method.

$$A^{(p)} = R^{(p)} - \beta - \propto i$$

where $i = 0,\ 1,\ 2\ \ldots\ n-1$

$$\propto = \sum_{i=0}^{n} x\ (2i-n+1)/(((n-1)n(n+1))/6)$$

$$\beta = \bar{x} - \propto(n-1)/2$$

$\bar{x}$ = the mean

3. The raw estimate of the power spectrum:

$$p^{(h)} = \frac{2\Delta t}{\pi} \sum_{p=0}^{m} p\ R^{(p)} \quad \text{Cos}\ \frac{hp\pi}{m}$$

$h = 0, 1, 2 \ldots m$

$$p = \begin{cases} 1 & o<p<m \\ 1/2 & p=o,\ m \end{cases}$$ the rectangular lag window

$$p^{(h)} = p\left(\frac{h\pi}{m\Delta t}\right)$$

4. The raw estimates of the power spectrum are smoothed by a triangular filter

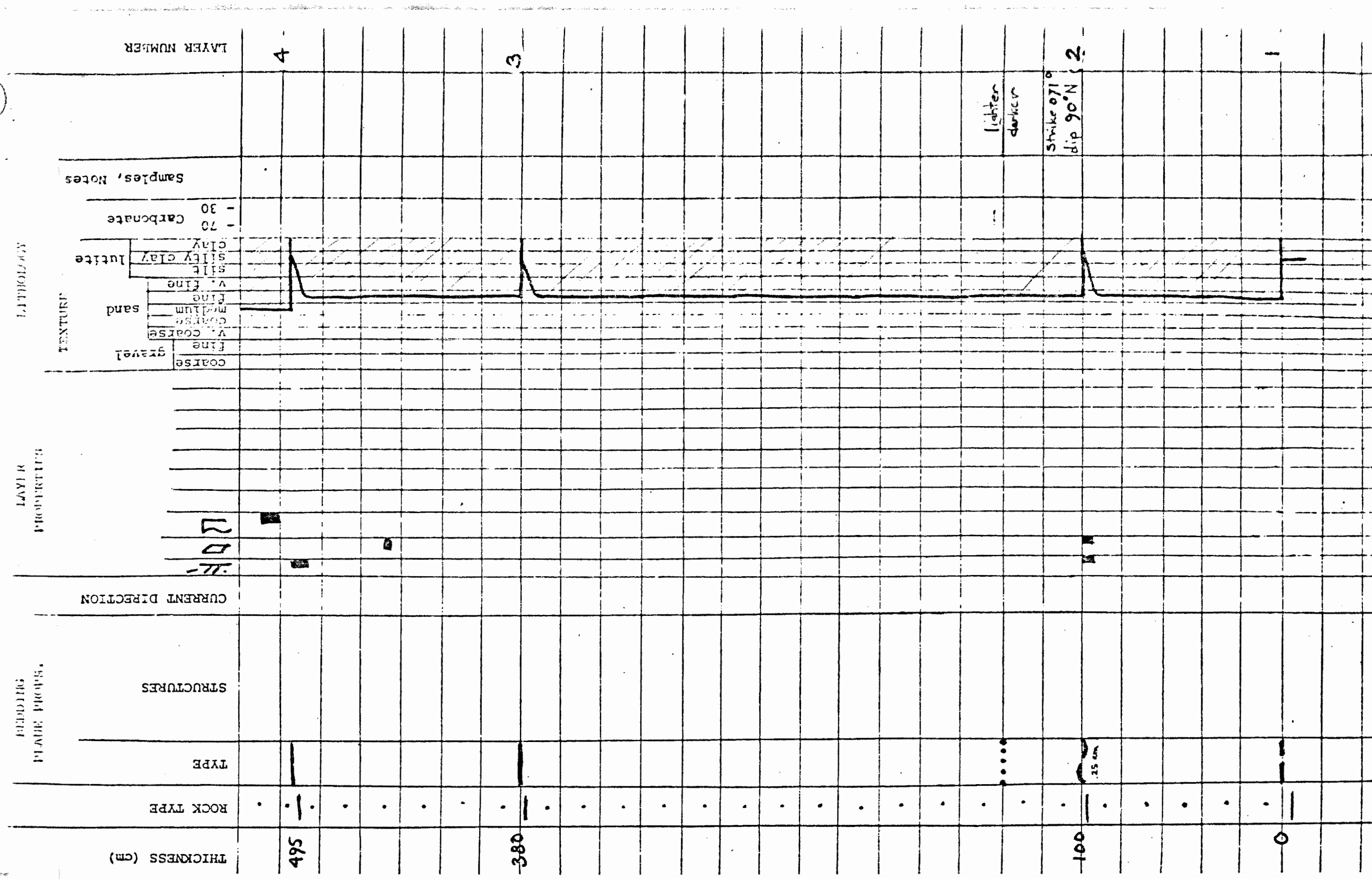
$$Sp^{(o)} = .54p^{(o)} + .46p^{(1)}$$

$$Sp^{(h)} = .23p^{(h-1)} + .54p^{(h)} = .23p^{(h+1)}$$

$o < h < m$

$$Sp^{(m)} = .54p^{(m)} + .46p^{(m-1)}$$

APPENDIX III - Bouma logs of Section



LEGEND:

Rock type

- sand
- lutite

Bedding plane type

- sharp flat contact (parting)
- distinct flat contact
- transitional contact
- wavy contact (amplitude in cm)

Bedding plane structures

- ripples
- flame structures
- load structures
- grooves
- flute marks
- channel (depth in cm)

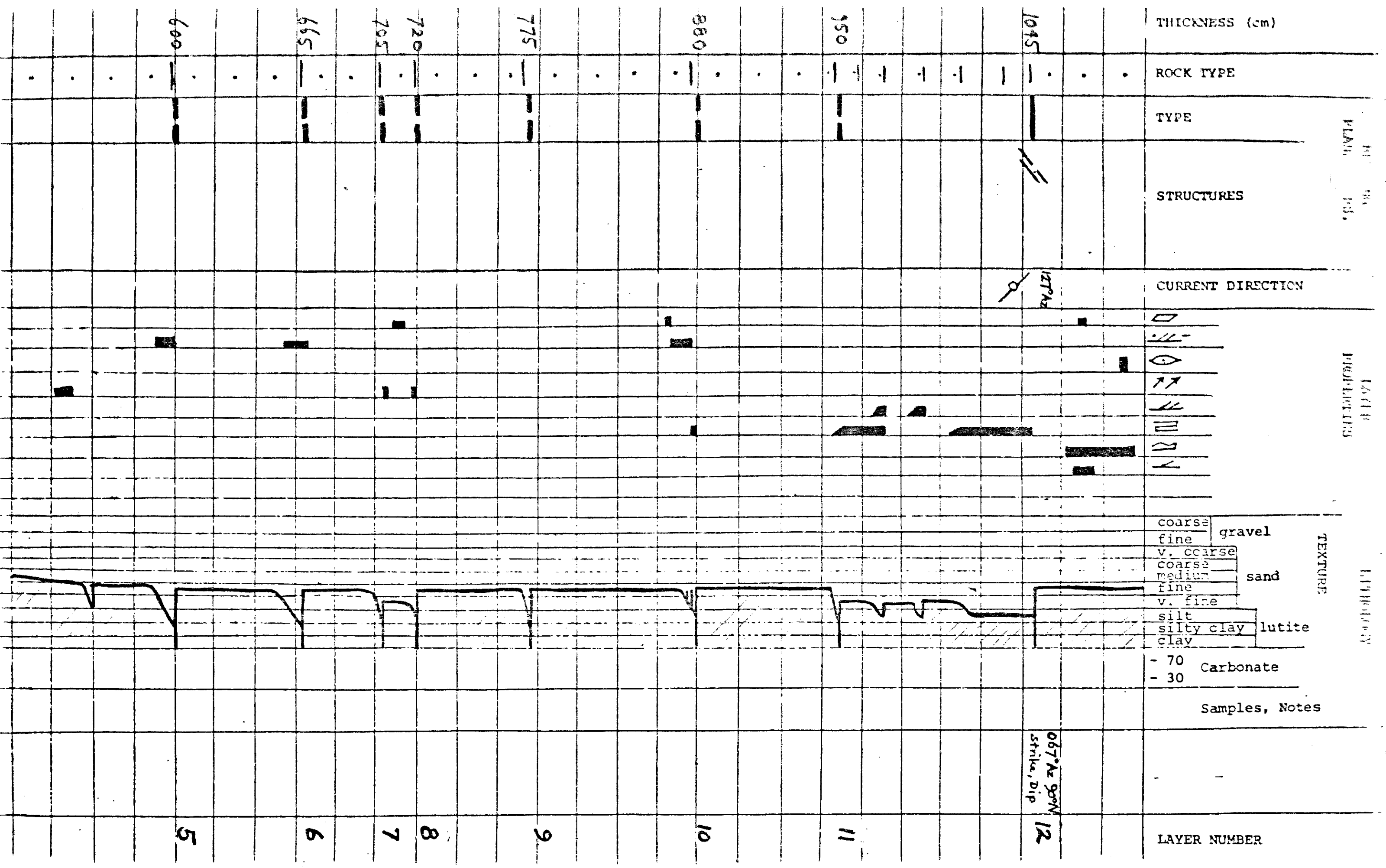
Paleocurrent

- direction
- line of flow
- 127°Az — direction in degrees azimuth (true)

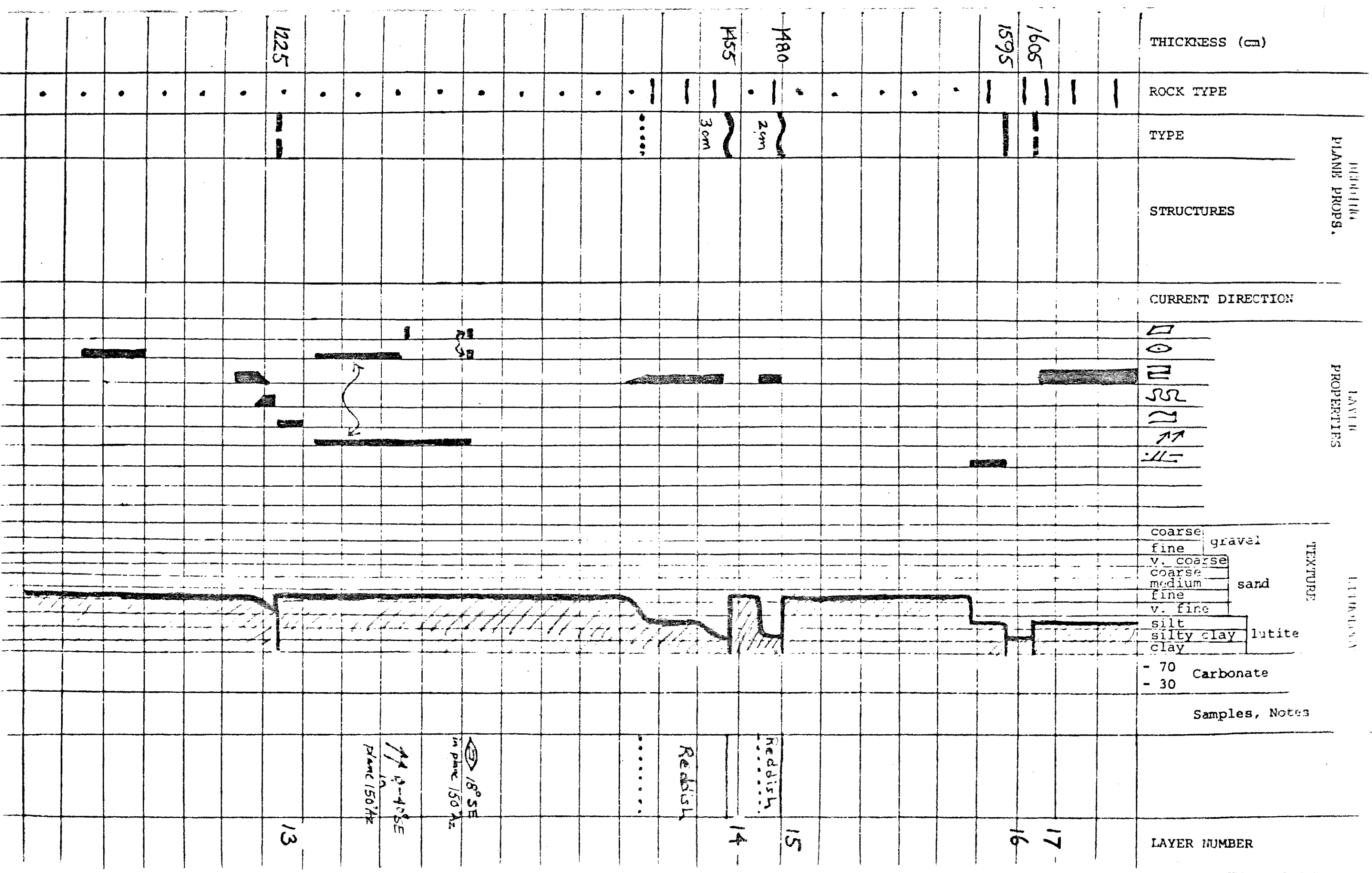
Sedimentary Structures

- parallel laminations
- cross laminations (one grain size)
- cross laminations (alternating grain size)
- convolute lamination
- crude stratification
- basal stratification
- basal cross-stratification
- dewatering structures
- mud clasts
- concretions
- concretion (layer-like)

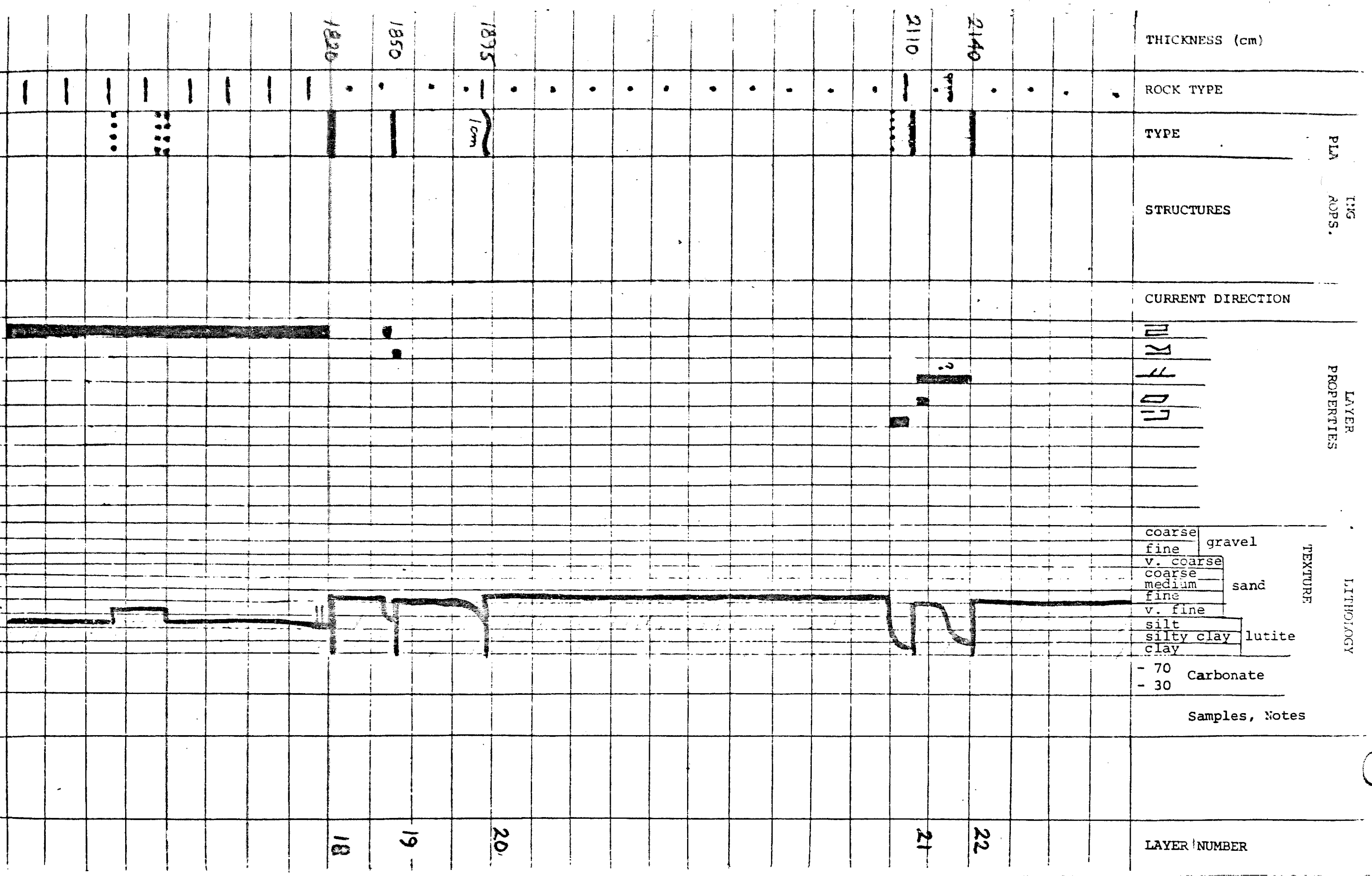
Height of the bar indicates the vertical distribution of the structure, the width of the bar the lateral abundance or degree of definition.


THICKNESS (cm)
600
665
705
720
775
880
950
1045
ROCK TYPE
TYPE
BEDDING PLANE PROPS.
STRUCTURES
CURRENT DIRECTION
127°Az
LAYER PROPERTIES
TEXTURE
LITHOLOGY
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
- 70
- 30
Carbonate
Samples, Notes
067°Az 90°N strike, Dip
LAYER NUMBER
5
6
7
8
9
10
11
12

2

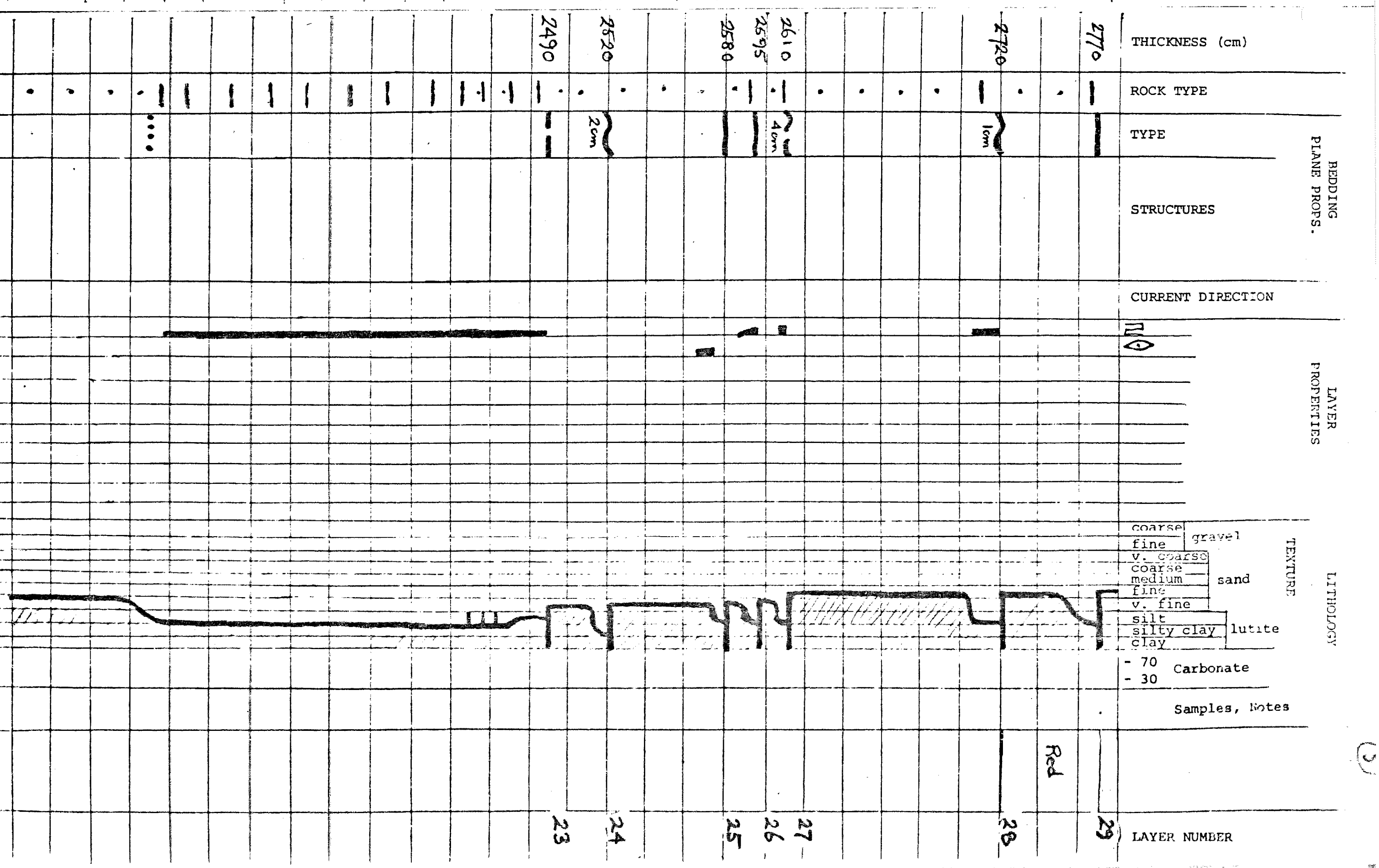

THICKNESS (cm)
1225
1455
1480
1595
1605
ROCK TYPE
TYPE
3cm
2cm
BEDDING PLANE PROPS.
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
TEXTURE
LITHOLOGY
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
- 70
- 30
Carbonate
Samples, Notes
in plane 150°Az
18°SE in plane 150°Az
Redish
Reddish
LAYER NUMBER
13
14
15
16
17

3



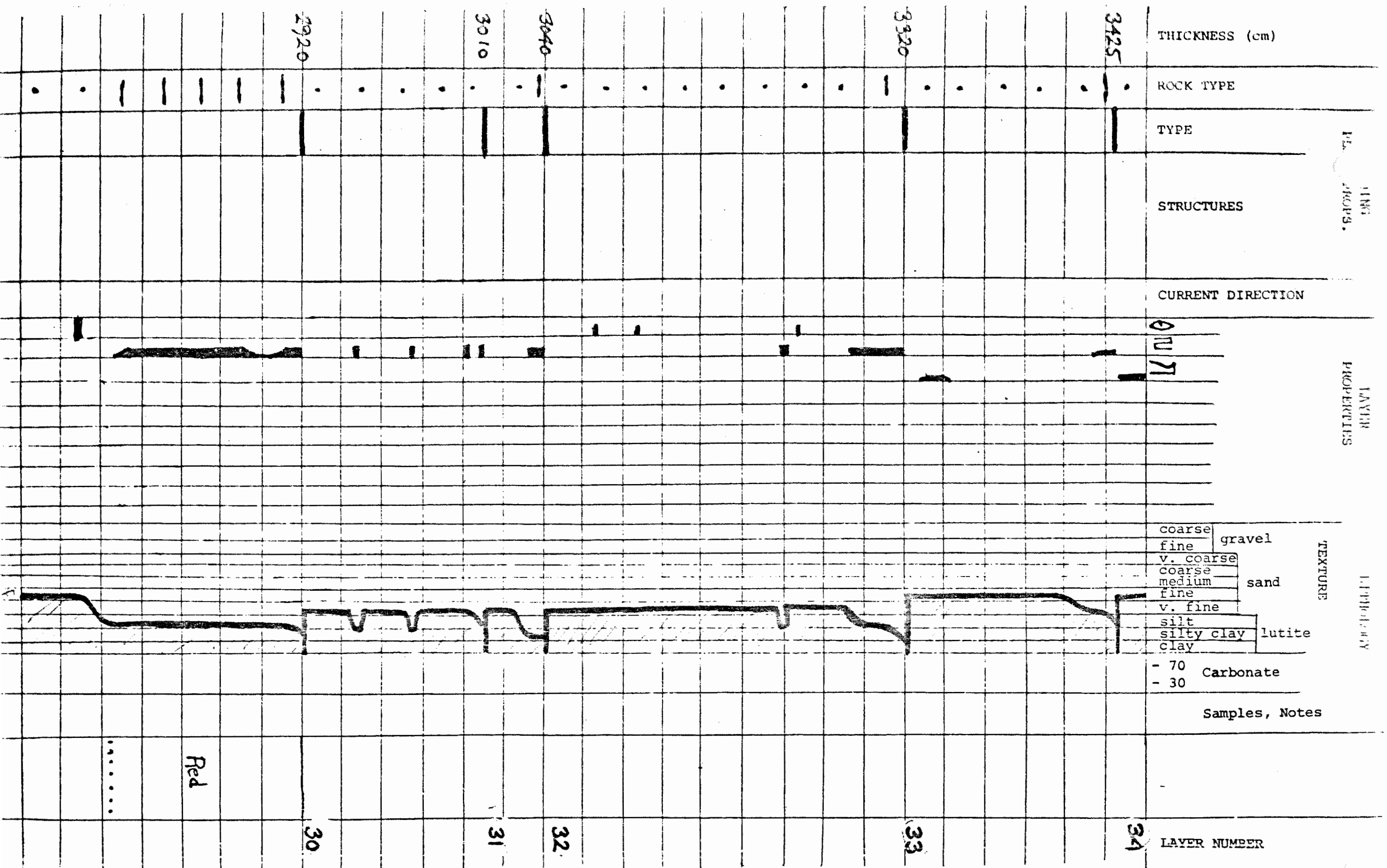
THICKNESS (cm)
1820
1850
1875
2110
2140
ROCK TYPE
TYPE
1cm
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
LAYER NUMBER
18
19
20
21
22

4

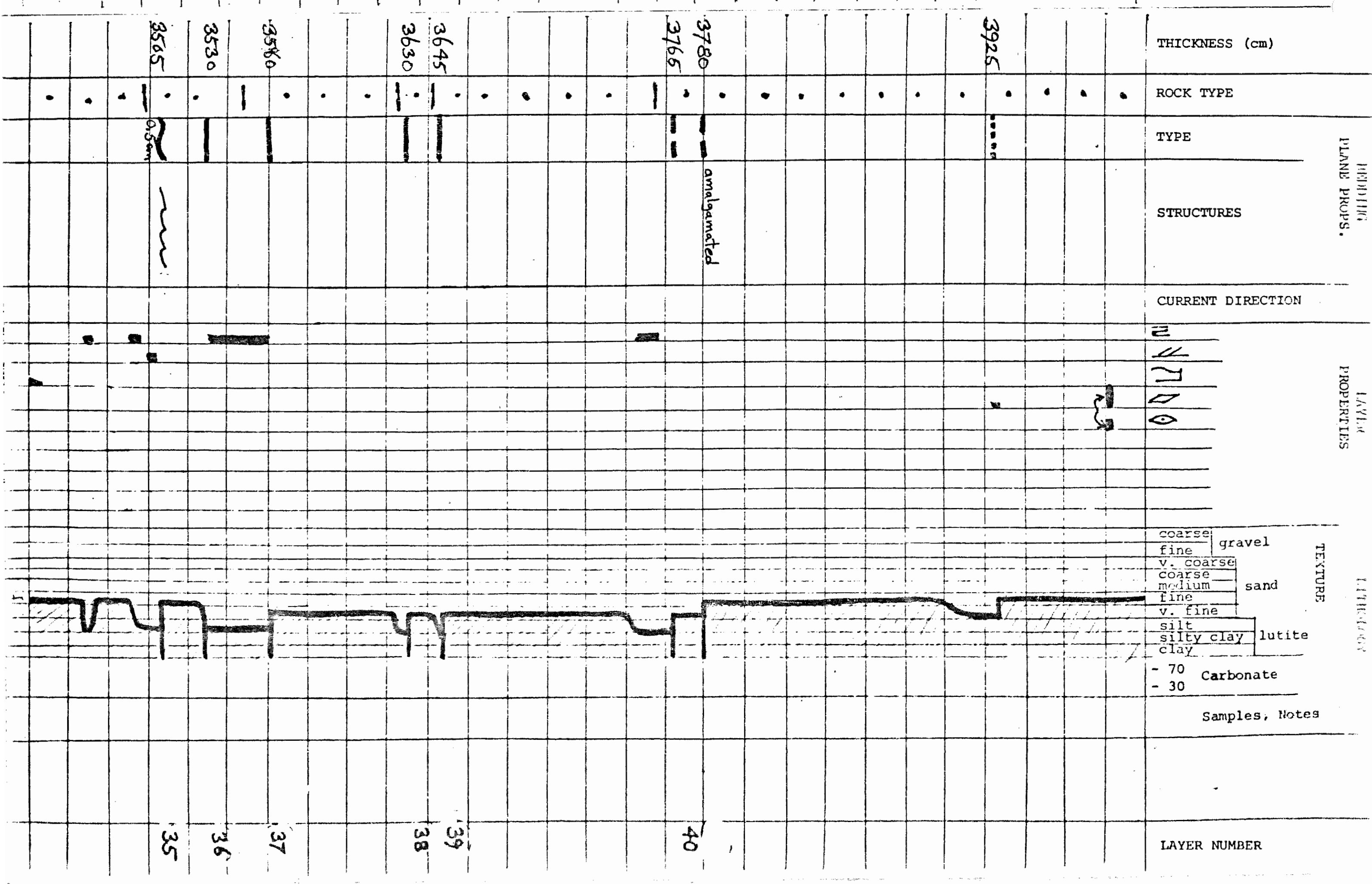


THICKNESS (cm)
2490
2520
2580
2595
2610
2720
2770
ROCK TYPE
TYPE
2cm
4cm
1cm
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
Red
LAYER NUMBER
23
24
25
26
27
28
29

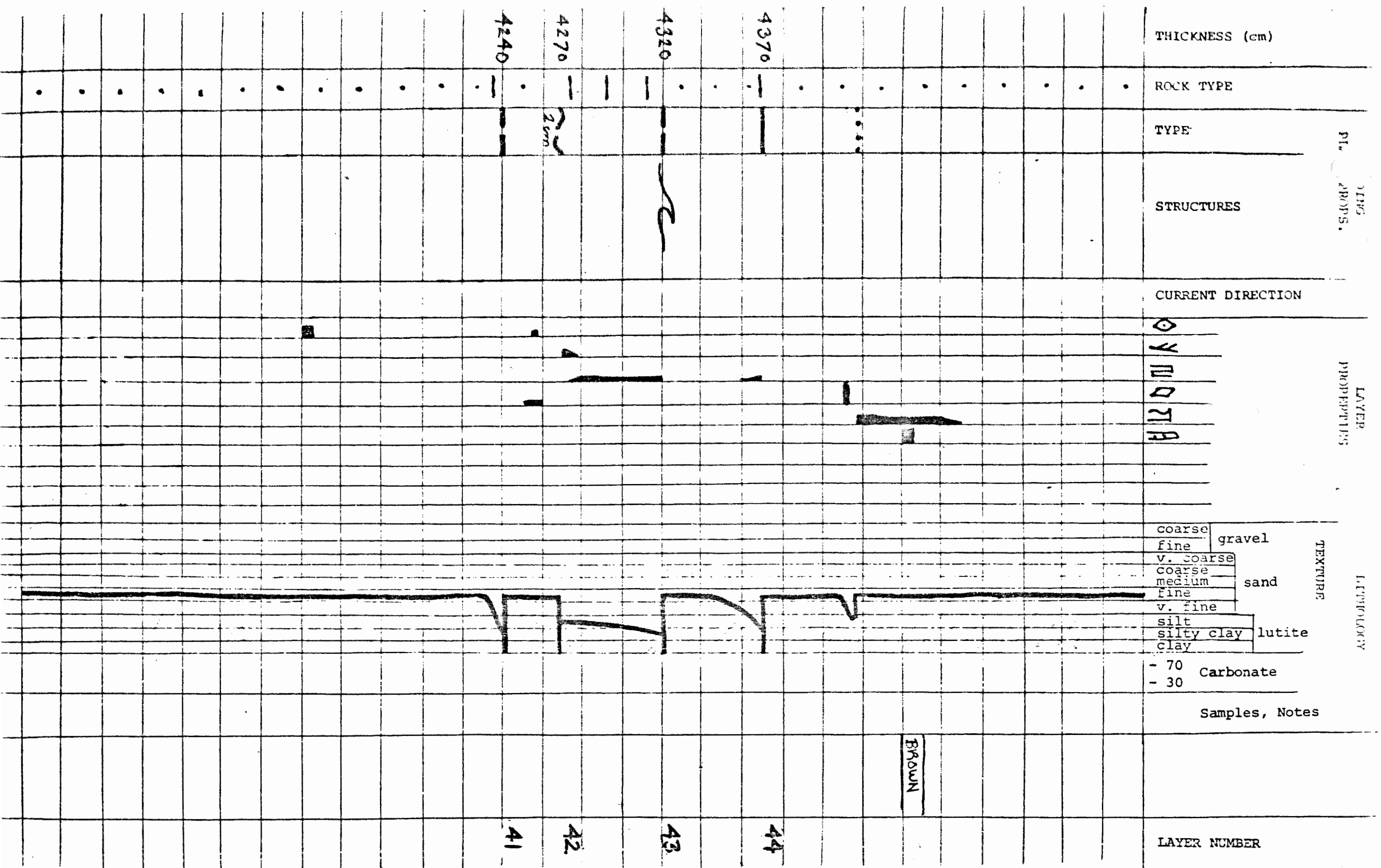
5


2920
3010
3040
3320
3425
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
sand
fine
v. fine
silt
silty clay
lutite
clay
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
Red
30
31
32
33
34
LAYER NUMBER

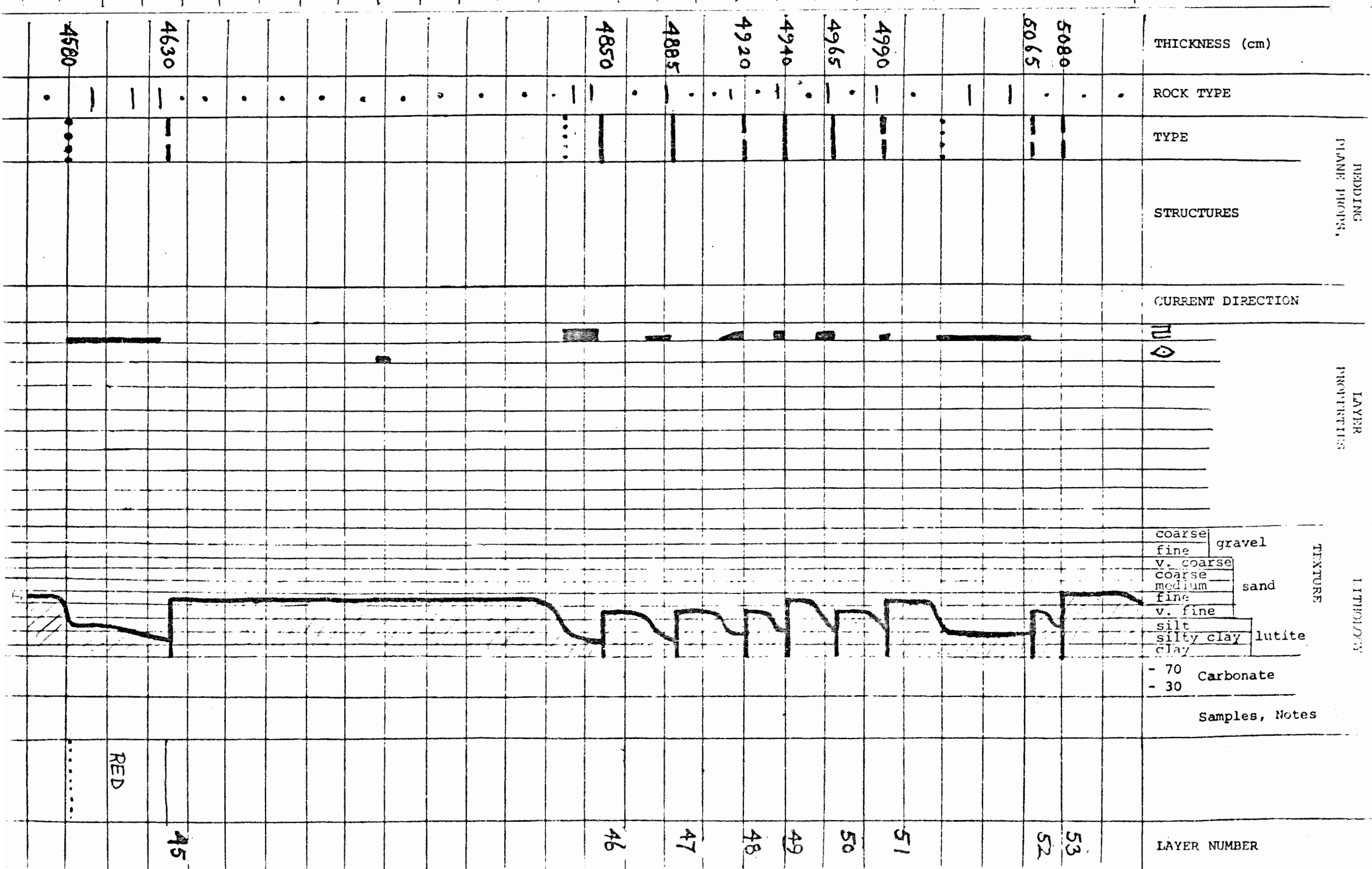
6


3565
3530
3580
3630
3645
3765
3780
3925
THICKNESS (cm)
ROCK TYPE
0.5cm
TYPE
amalgamated
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
sand
fine
v. fine
silt
silty clay
lutite
clay
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
35
36
37
38
39
40
LAYER NUMBER

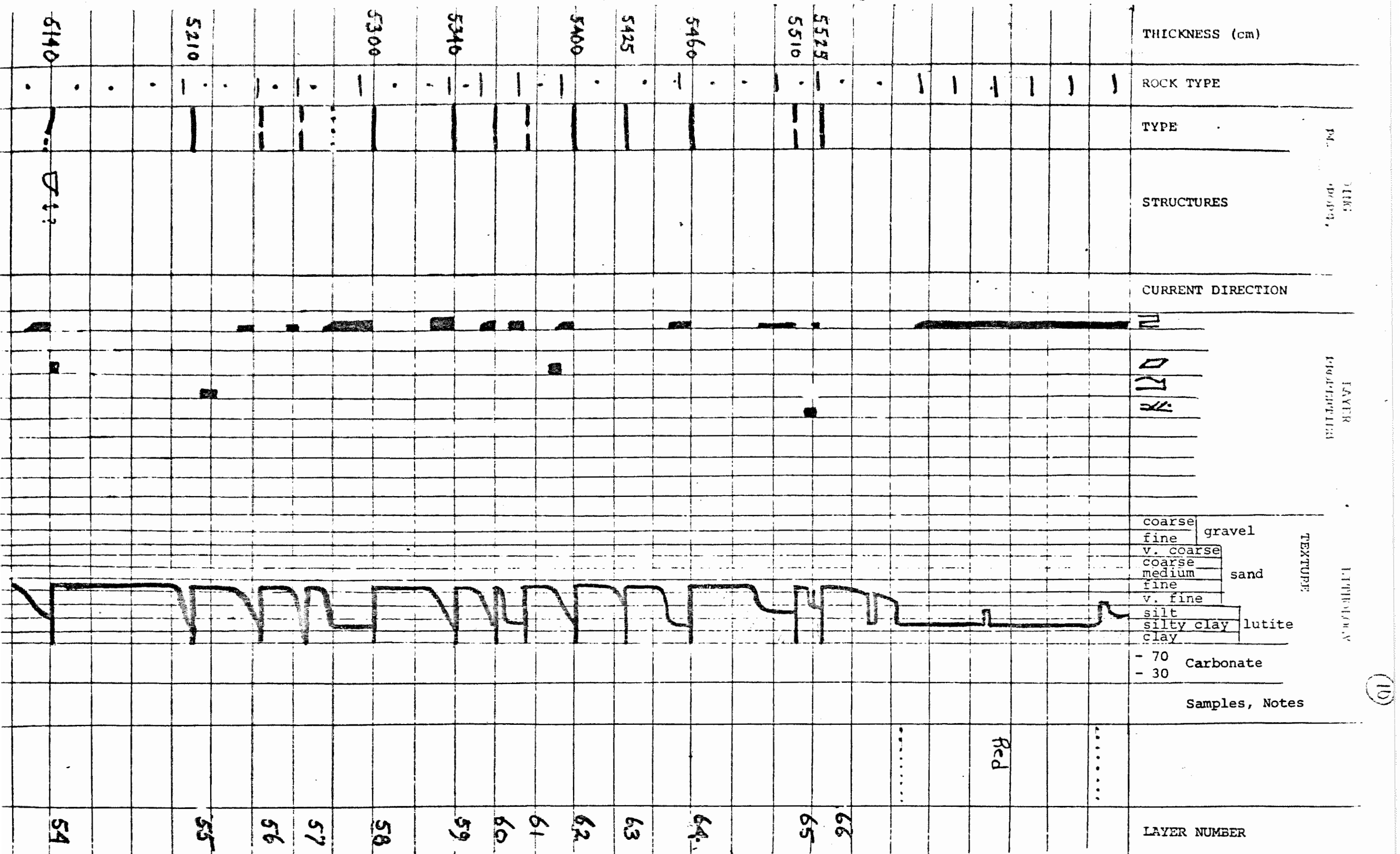
7

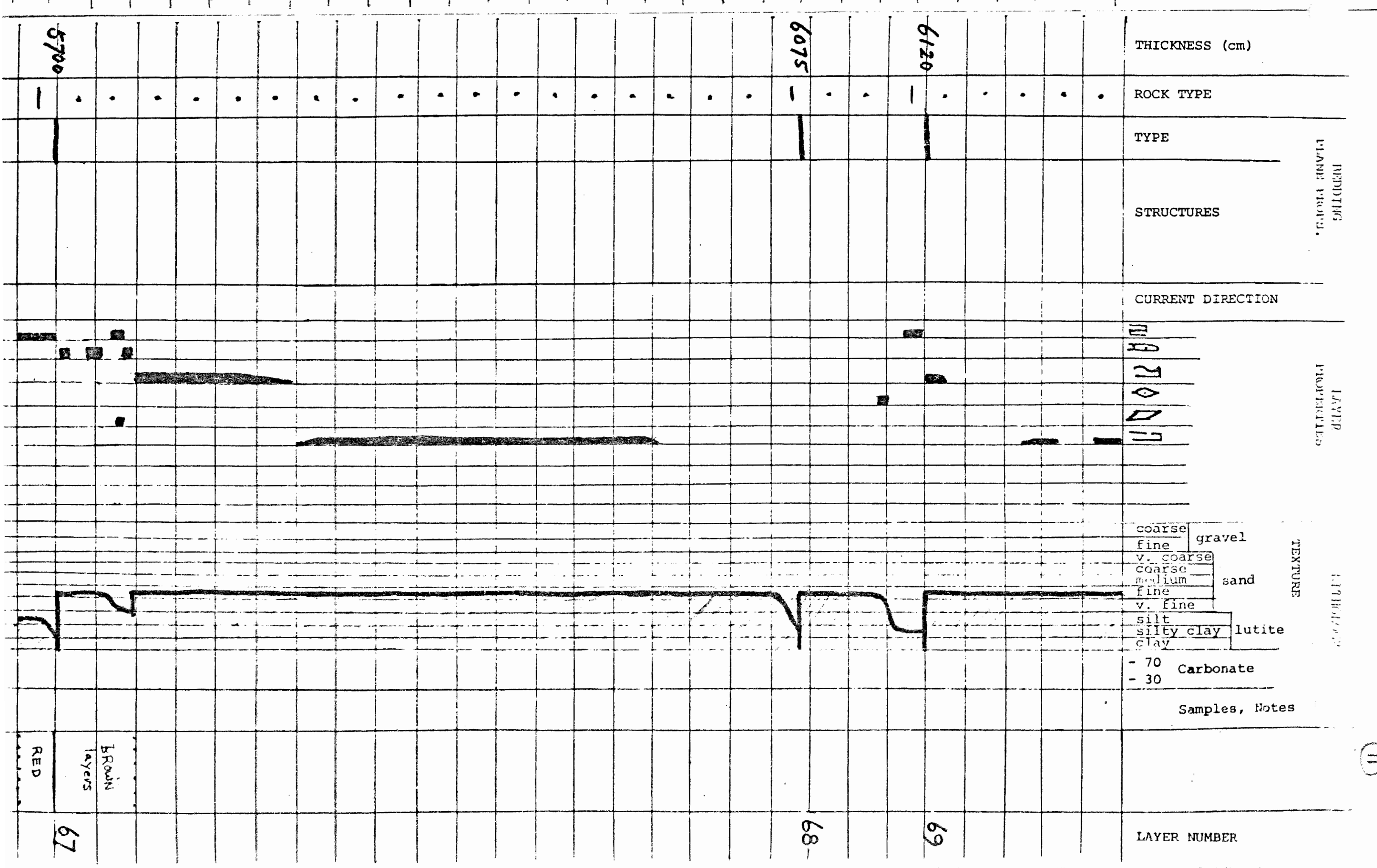

THICKNESS (cm)
4240
4270
4320
4370
ROCK TYPE
TYPE
2cm
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
BROWN
LAYER NUMBER
41
42
43
44

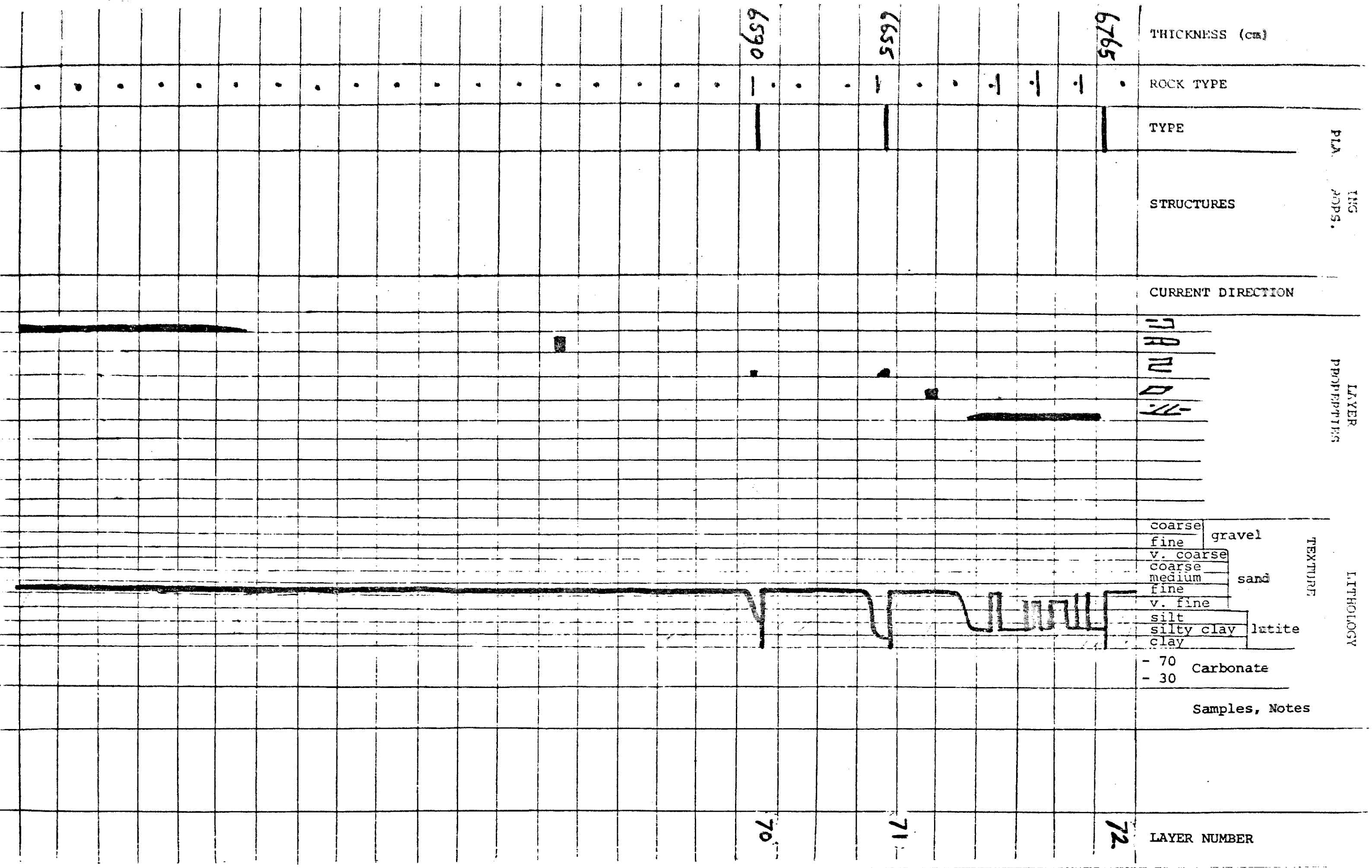
(8)


THICKNESS (cm)
4580
4630
4850
4885
4920
4940
4965
4990
5065
5080
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
RED
LAYER NUMBER
45
46
47
48
49
50
51
52
53

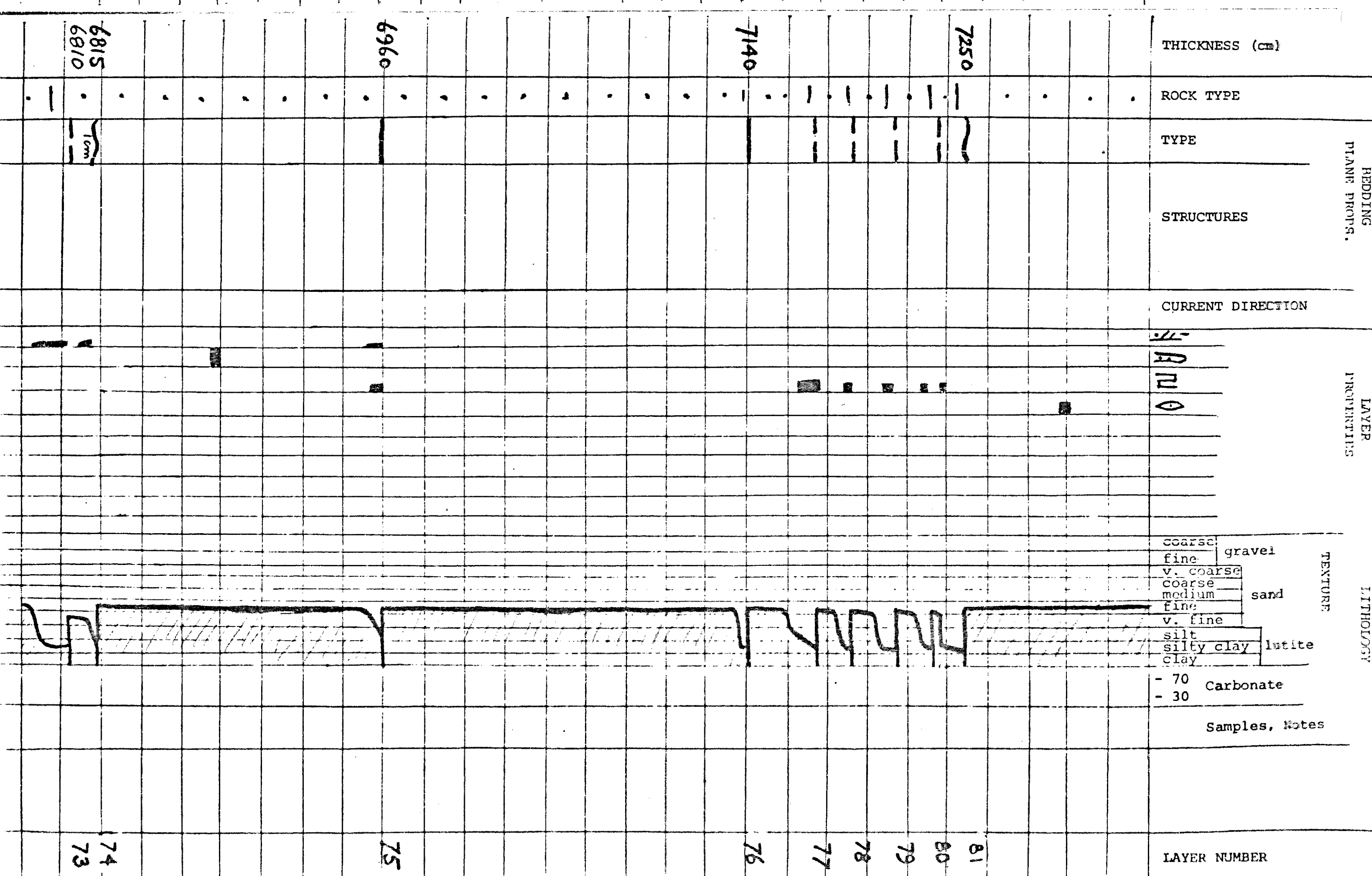
(9)


5140
5210
5300
5340
5400
5425
5460
5510
5525
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
Red
54
55
56
57
58
59
60
61
62
63
64
65
66
LAYER NUMBER
(10)

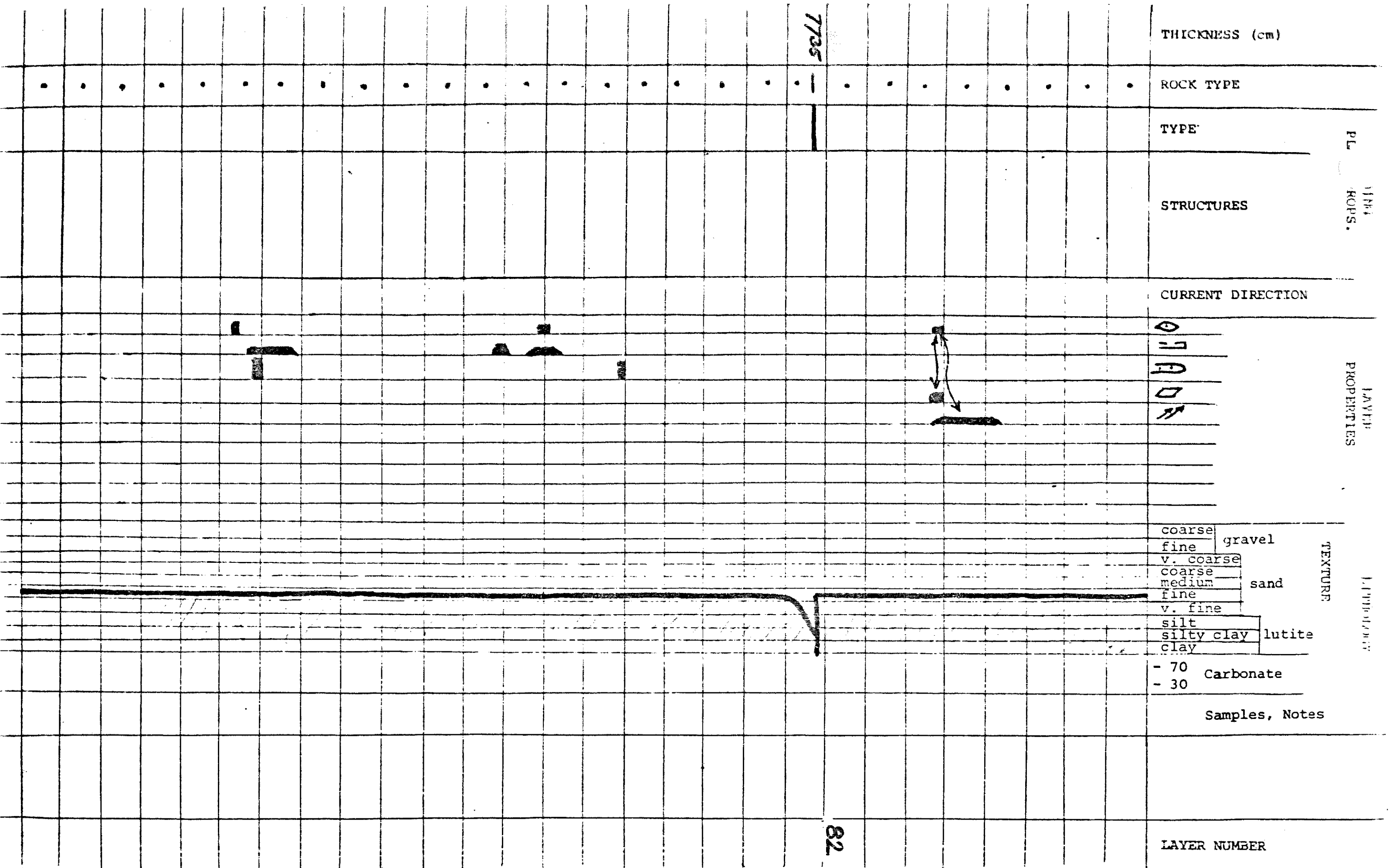

5700
6075
6120
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
RED
BROWN layers
67
68
69
LAYER NUMBER
(11)


6590
6655
6765
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
70
71
72
LAYER NUMBER

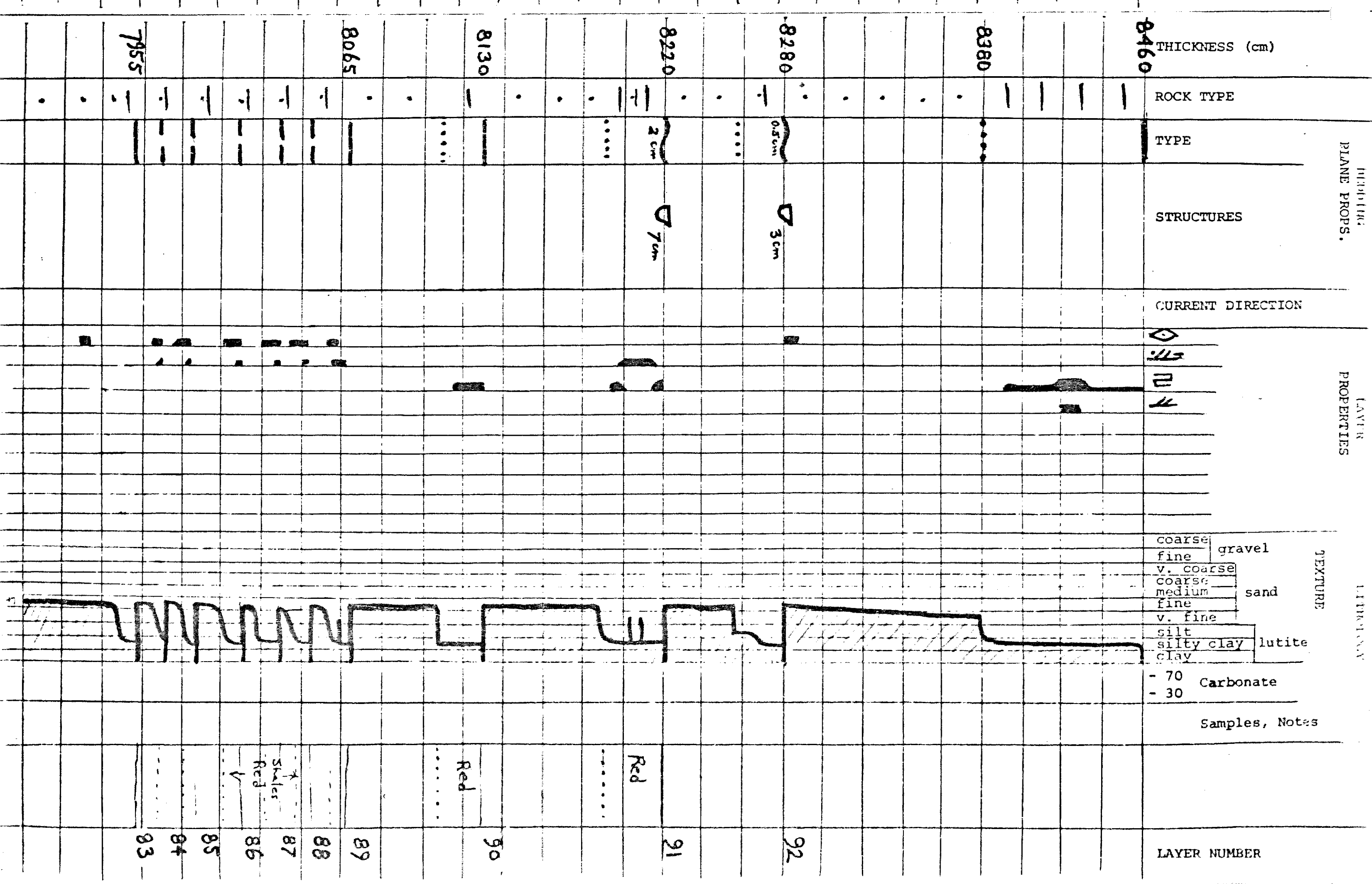
(12)


6815
6810
6960
7140
7250
THICKNESS (cm)
ROCK TYPE
1cm
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
73
74
75
76
77
78
79
80
81
LAYER NUMBER

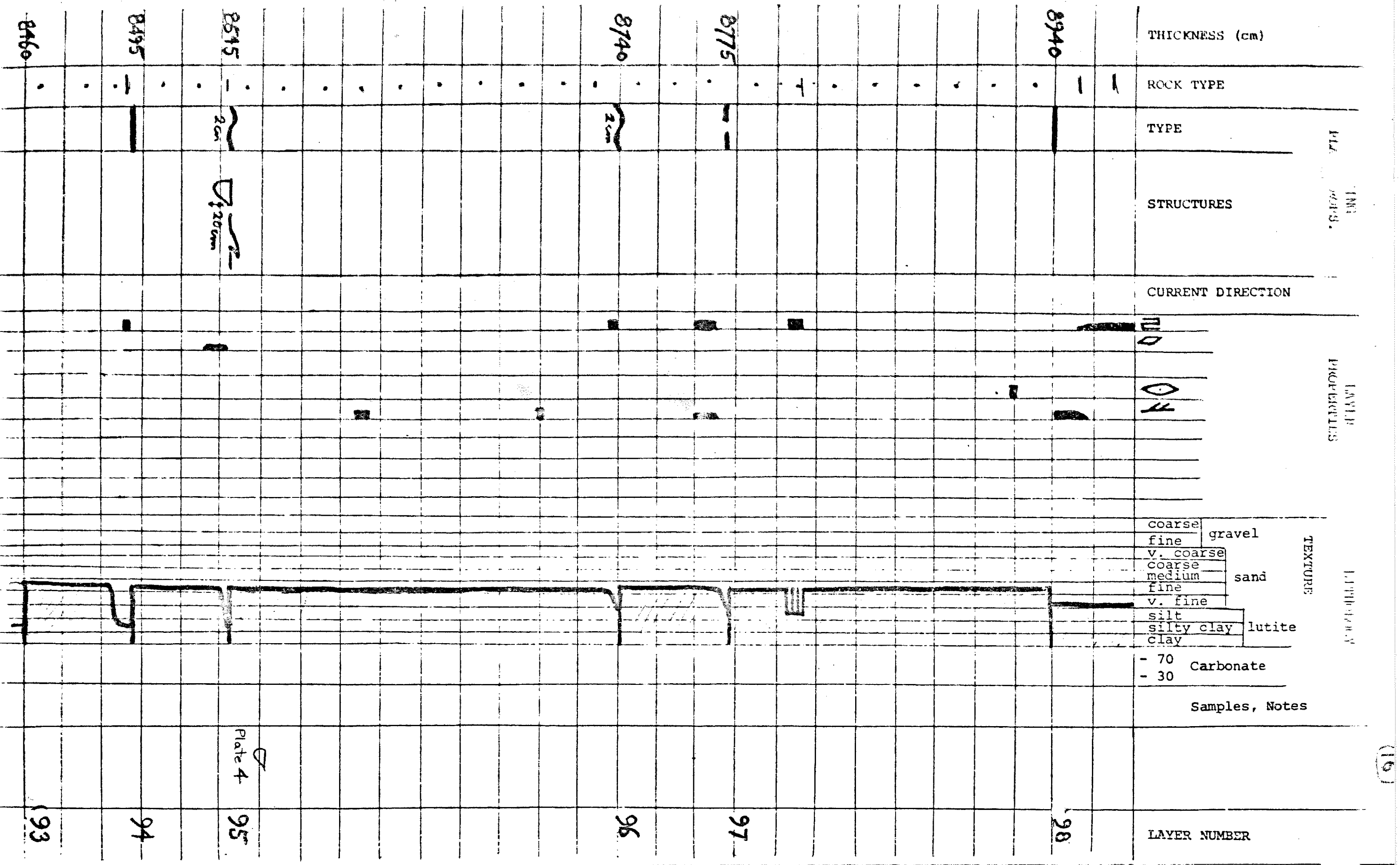
(13)



7735
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
- 70
- 30
Carbonate
Samples, Notes
82
LAYER NUMBER

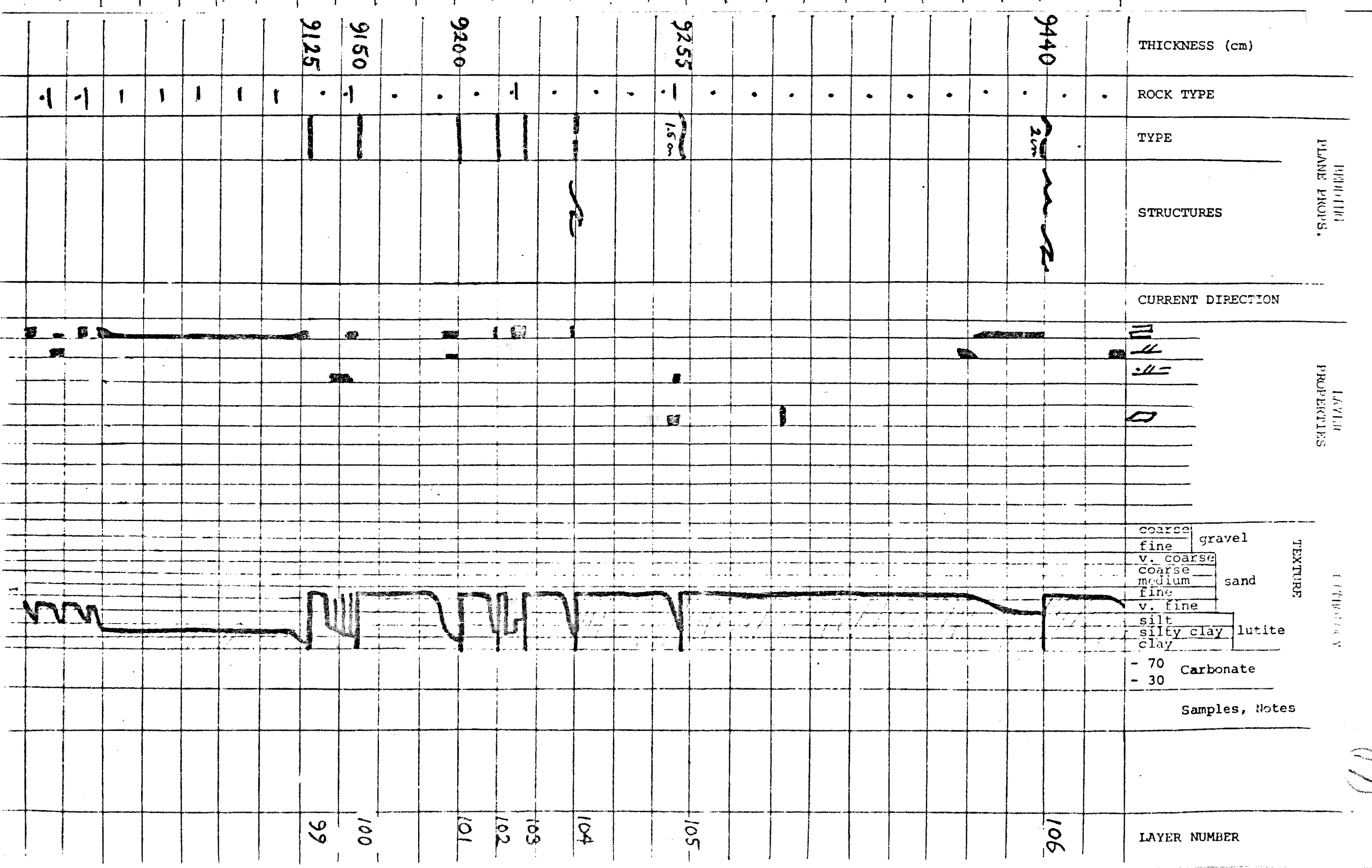


7955
8065
8130
8220
8280
8380
8460
THICKNESS (cm)
ROCK TYPE
2 cm
0.5 cm
TYPE
7 cm
3 cm
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
- 70
- 30
Carbonate
Samples, Notes
Shales
Red
Red
Red
83
84
85
86
87
88
89
90
91
92
LAYER NUMBER



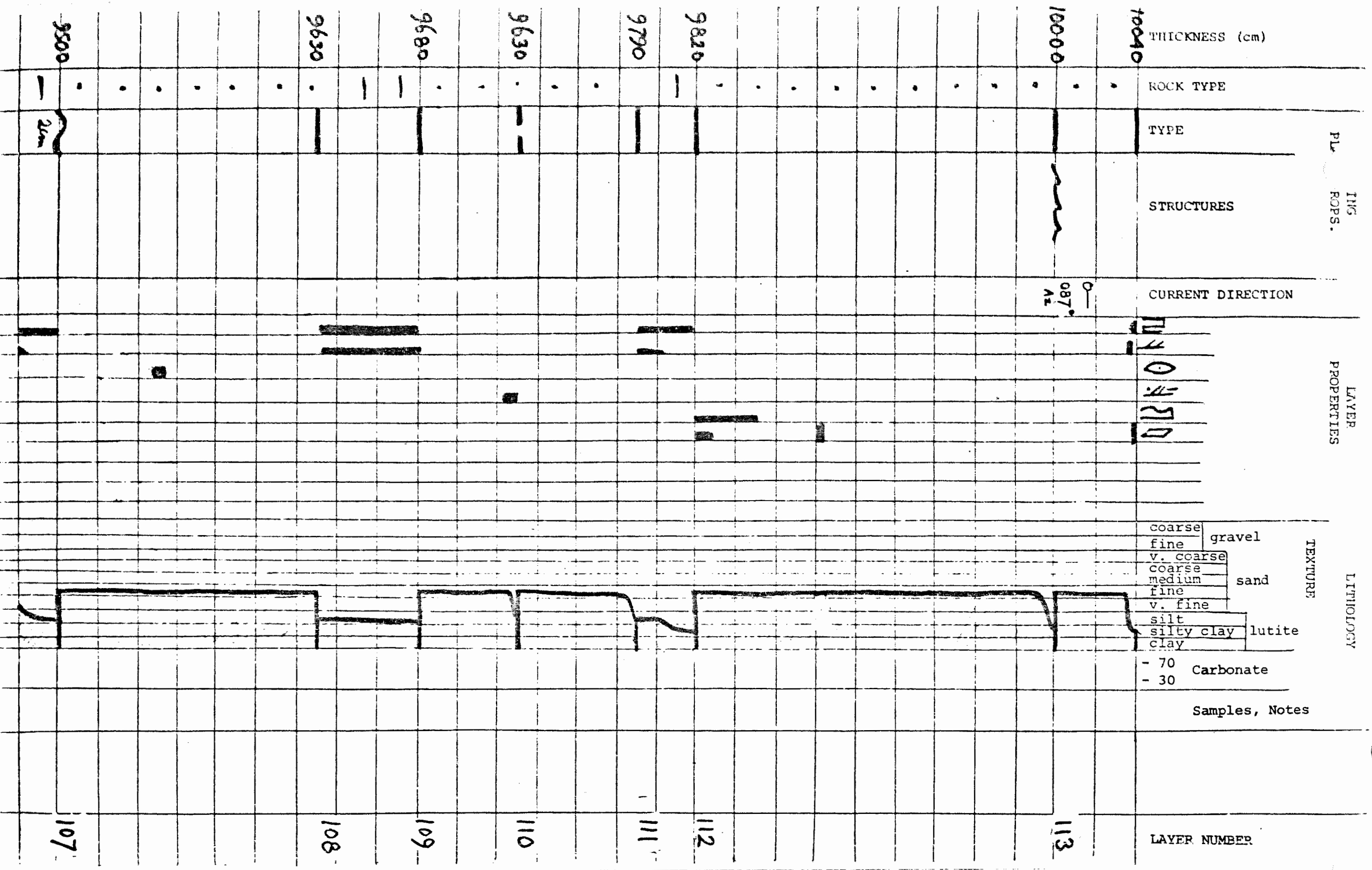
8460
8495
8545
8740
8775
8940
THICKNESS (cm)
ROCK TYPE
TYPE
2cm
STRUCTURES
20cm
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
lutite
clay
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
Plate 4
93
94
95
96
97
98
LAYER NUMBER

(16)

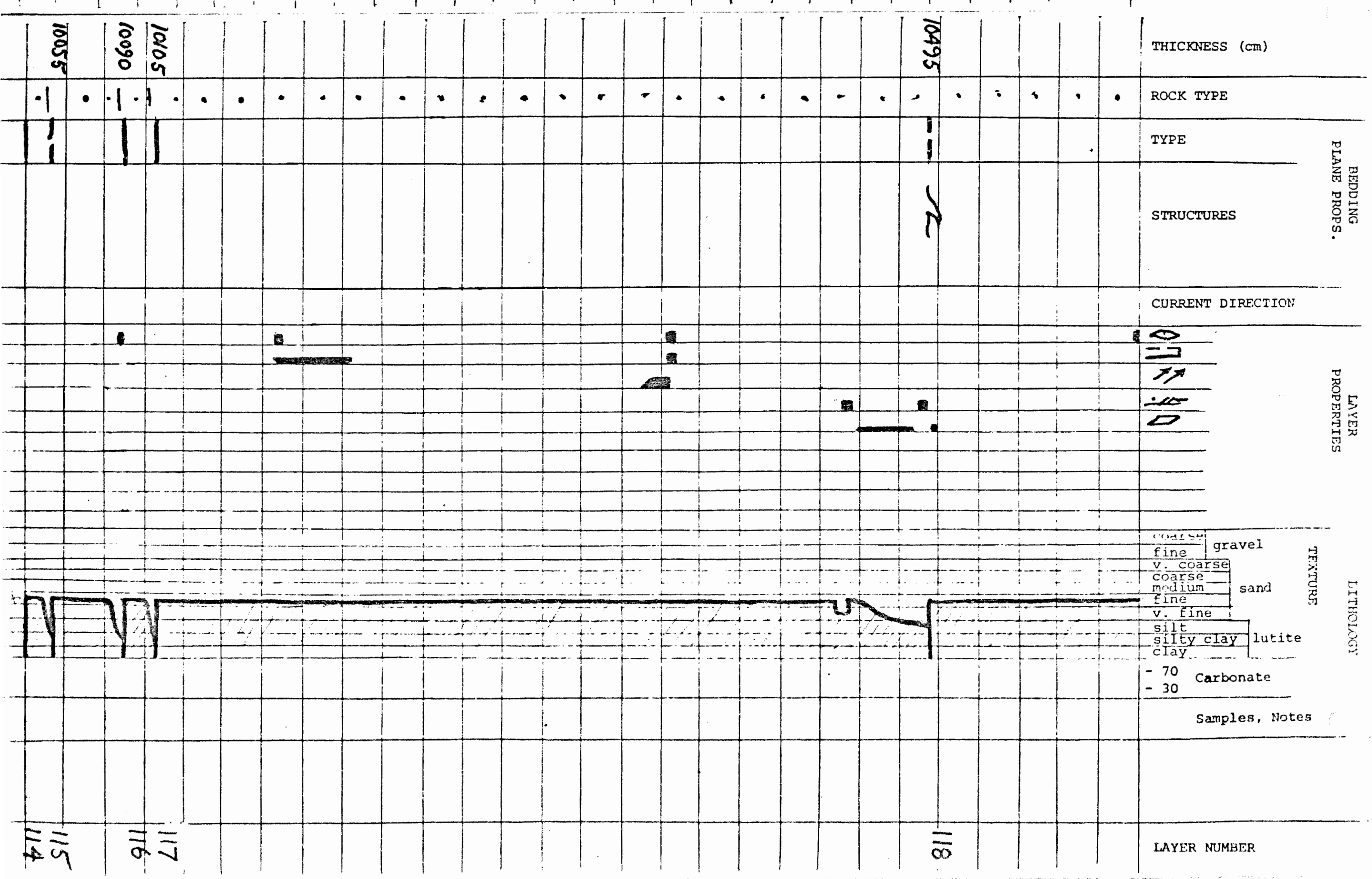


9125
9150
9200
9255
9440
THICKNESS (cm)
ROCK TYPE
1.5cm
2cm
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
lutite
clay
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
99
100
101
102
103
104
105
106
LAYER NUMBER

(17)


9500
9630
9680
9630
9790
9820
10000
10040
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
087° Az
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
107
108
109
110
111
112
113
LAYER NUMBER

(18)


10055
10090
10105
10495
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
114
115
116
117
118
LAYER NUMBER

(19)

THICKNESS (cm)

ROCK TYPE

TYPE

STRUCTURES

PL. 'ING ROPS.

CURRENT DIRECTION

LAYER PROPERTIES

coarse	gravel	TEXTURE	LITHOLOGY
fine			
v. coarse	sand		
coarse			
medium			
fine			
v. fine			
silt	lutite		
silty clay			
clay			

- 70 Carbonate
- 30

Samples, Notes

20

LAYER NUMBER

THICKNESS (cm) 11235 11325 1145 11505

ROCK TYPE

TYPE 2cm

STRUCTURES

BEDDING PLANE PROPS.

CURRENT DIRECTION

LAYER PROPERTIES

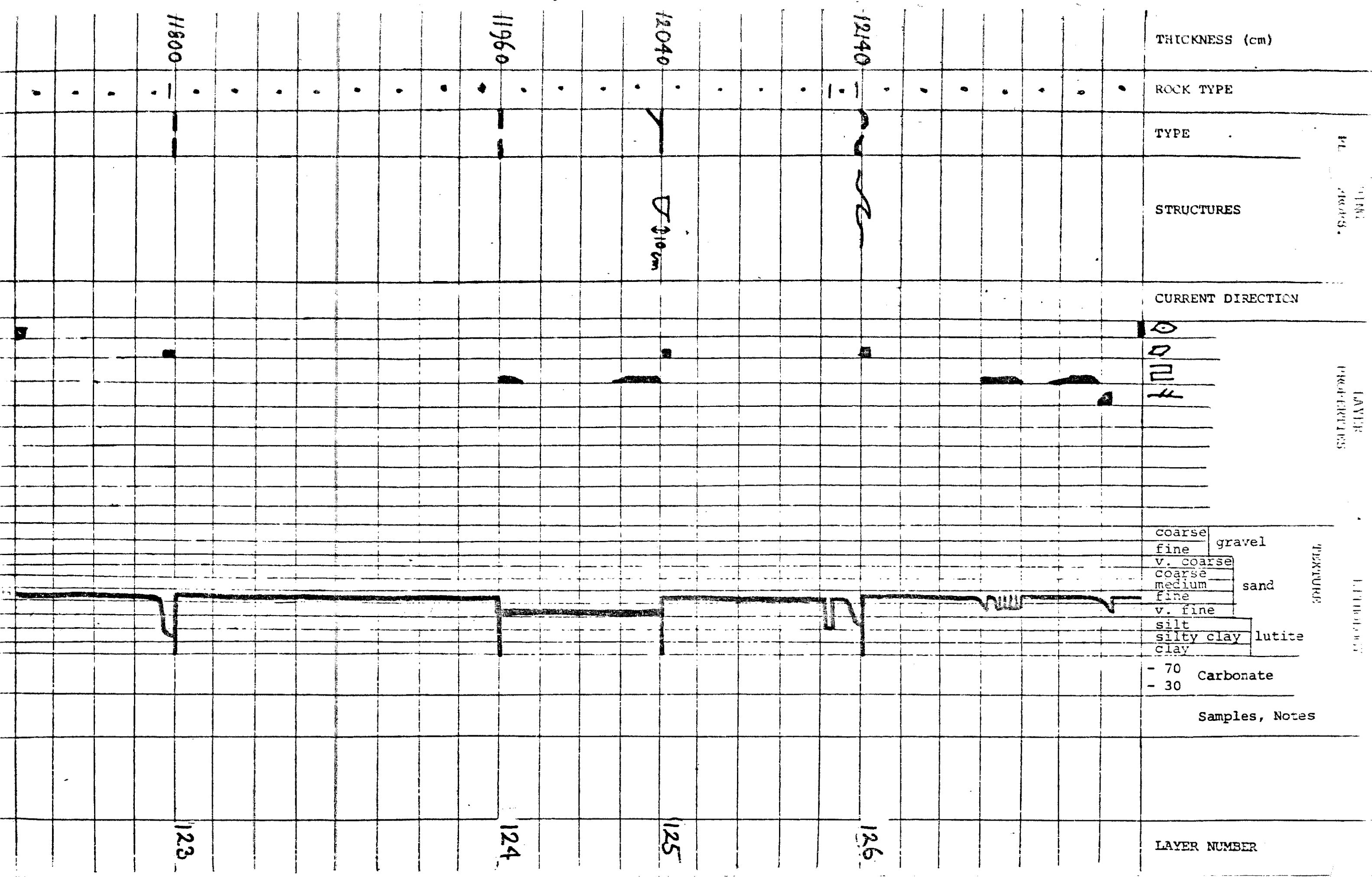
coarse	gravel	TEXTURE	LITHOLOGY
fine			
v. coarse	sand		
coarse			
medium			
fine			
v. fine			
silt	lutite		
silty clay			
clay			

- 70 Carbonate
- 30

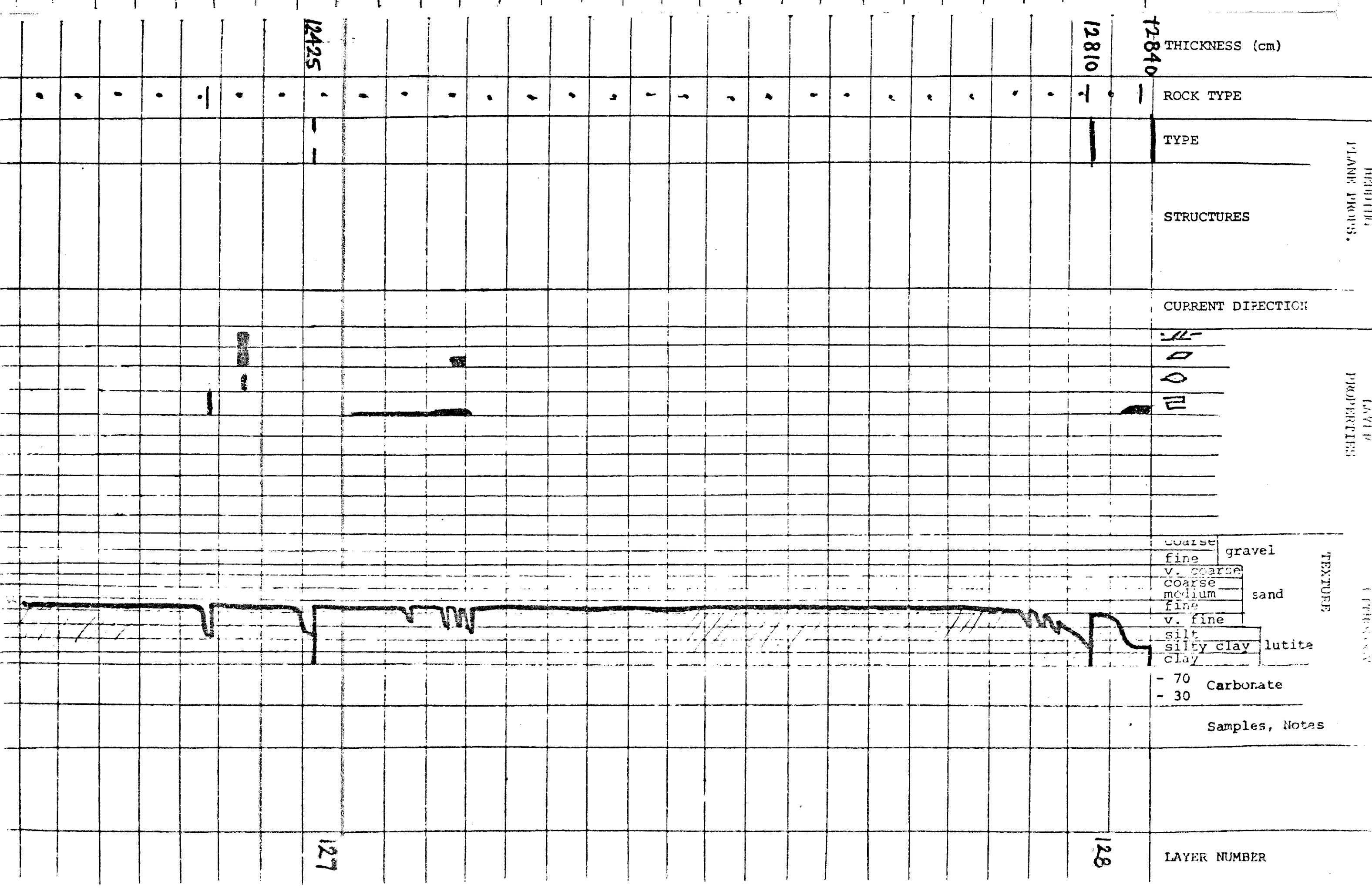
Samples, Notes

21

LAYER NUMBER 119 120 121 122


11800
11960
12040
12140
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
10cm
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
- 70
- 30
Carbonate
Samples, Notes
123
124
125
126
LAYER NUMBER

(22)


12425
12810
12840
THICKNESS (cm)
ROCK TYPE
TYPE
BEDDING PLANE PROPS.
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
- 70
- 30
Carbonate
Samples, Notes
127
128
LAYER NUMBER

(23)

12890 12965 13000

THICKNESS (cm)

ROCK TYPE

15cm

TYPE

STRUCTURES

BEDDING PLANE PROPS.

CURRENT DIRECTION

LAYER PROPERTIES

coarse / fine — gravel
v. coarse / coarse / medium / fine / v. fine — sand
silt / silty clay / clay — lutite

TEXTURE

LITHOLOGY

- 70
- 30
Carbonate

Samples, Notes

(24)

129 130 131 132

LAYER NUMBER

13420 13440 13460 13640 13670 13890

THICKNESS (cm)

ROCK TYPE

20cm

TYPE

STRUCTURES

BEDDING PLANE PROPS.

CURRENT DIRECTION

LAYER PROPERTIES

coarse / fine — gravel
v. coarse / coarse / medium / fine / v. fine — sand
silt / silty clay / clay — lutite

TEXTURE

LITHOLOGY

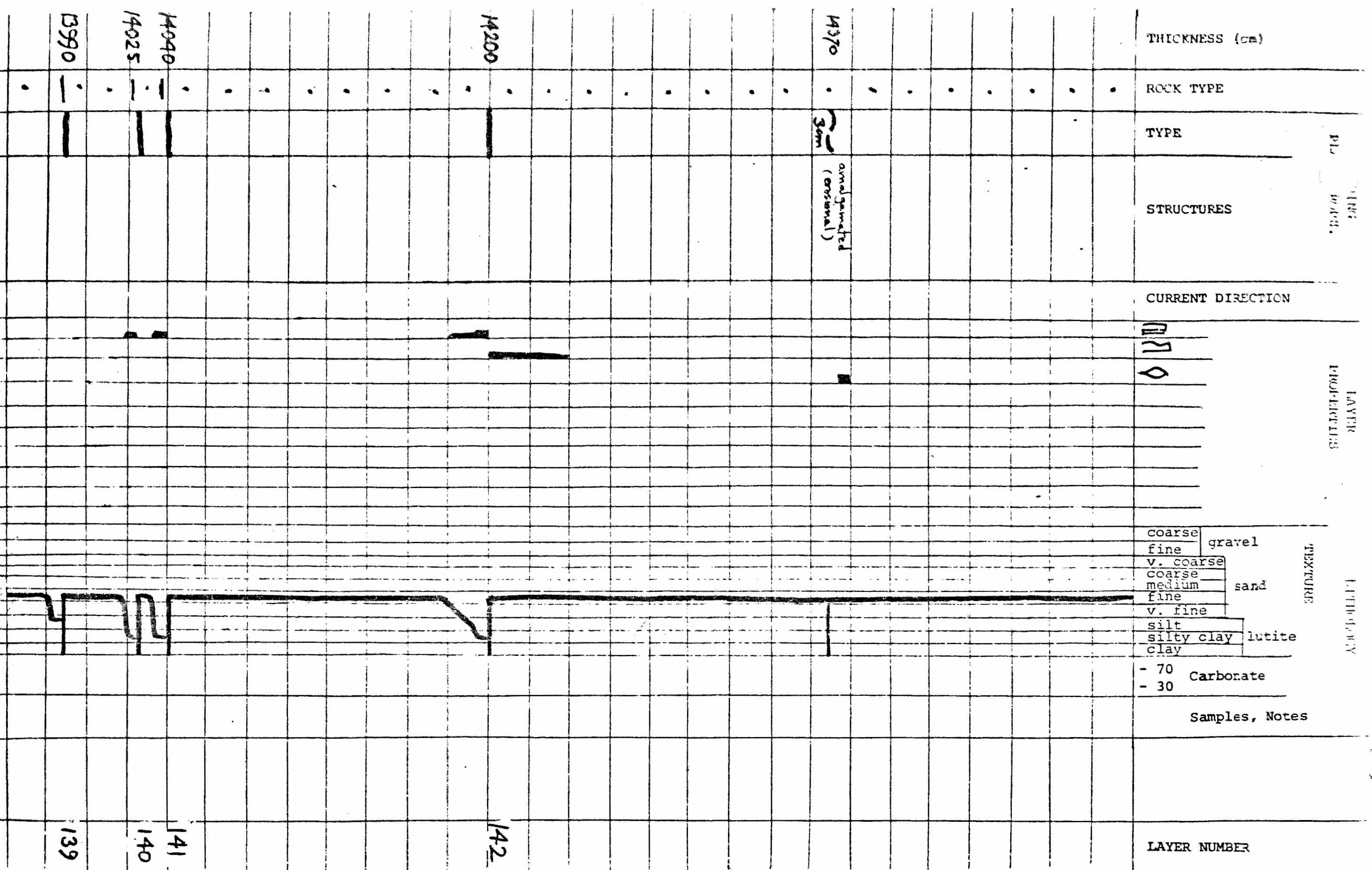
- 70
- 30
Carbonate

Samples, Notes

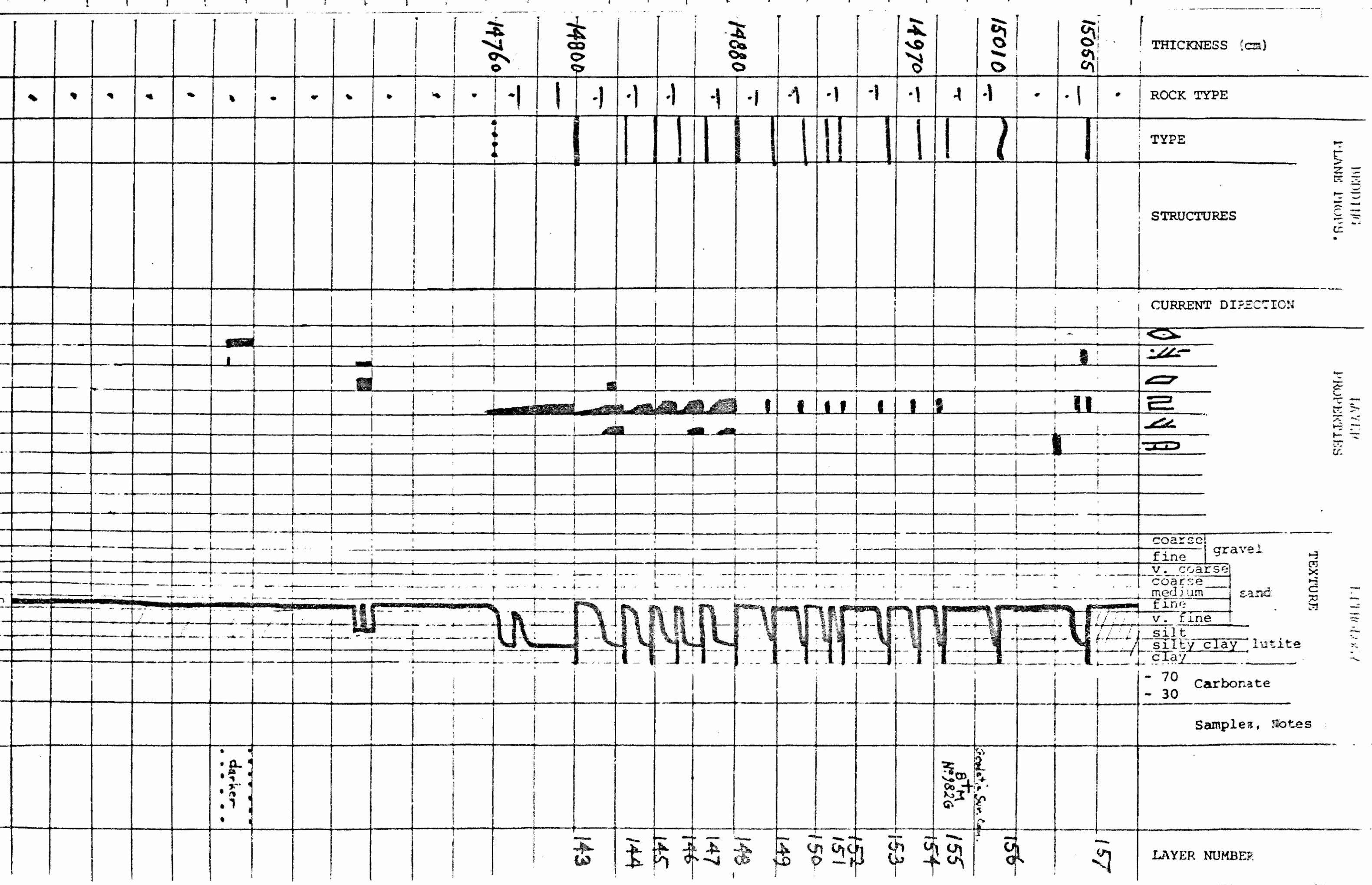
(25)

133 134 135 136 137 138

LAYER NUMBER


THICKNESS (cm)
13990
14025
14040
14200
14370
ROCK TYPE
TYPE
3cm
STRUCTURES
amalgamated (erosional)
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
lutite
clay
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
139
140
141
142
LAYER NUMBER

(26)


THICKNESS (cm)
14760
14800
14880
14970
15010
15055
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
lutite
clay
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
darker
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
LAYER NUMBER

(27)

THICKNESS (cm)	15245	15390	15480	15490	15500	15530
LAYER NUMBER	158	159	160	161	162	163

THICKNESS (cm)

ROCK TYPE

BEDDING PLANE PROPS.: TYPE; STRUCTURES

CURRENT DIRECTION

LAYER PROPERTIES

LITHOLOGY — TEXTURE: gravel (coarse, fine); sand (v. coarse, coarse, medium, fine, v. fine); lutite (silt, silty clay, clay)

Carbonate: - 70, - 30

Samples, Notes

LAYER NUMBER

(28)

THICKNESS (cm)	15570	15630	15645	15675	15720	15805
LAYER NUMBER	164, 165	166	167	168	169	170

1.5 cm

THICKNESS (cm)

ROCK TYPE

BEDDING PLANE PROPS.: TYPE; STRUCTURES

CURRENT DIRECTION

LAYER PROPERTIES

LITHOLOGY — TEXTURE: gravel (coarse, fine); sand (v. coarse, coarse, medium, fine, v. fine); lutite (silt, silty clay, clay)

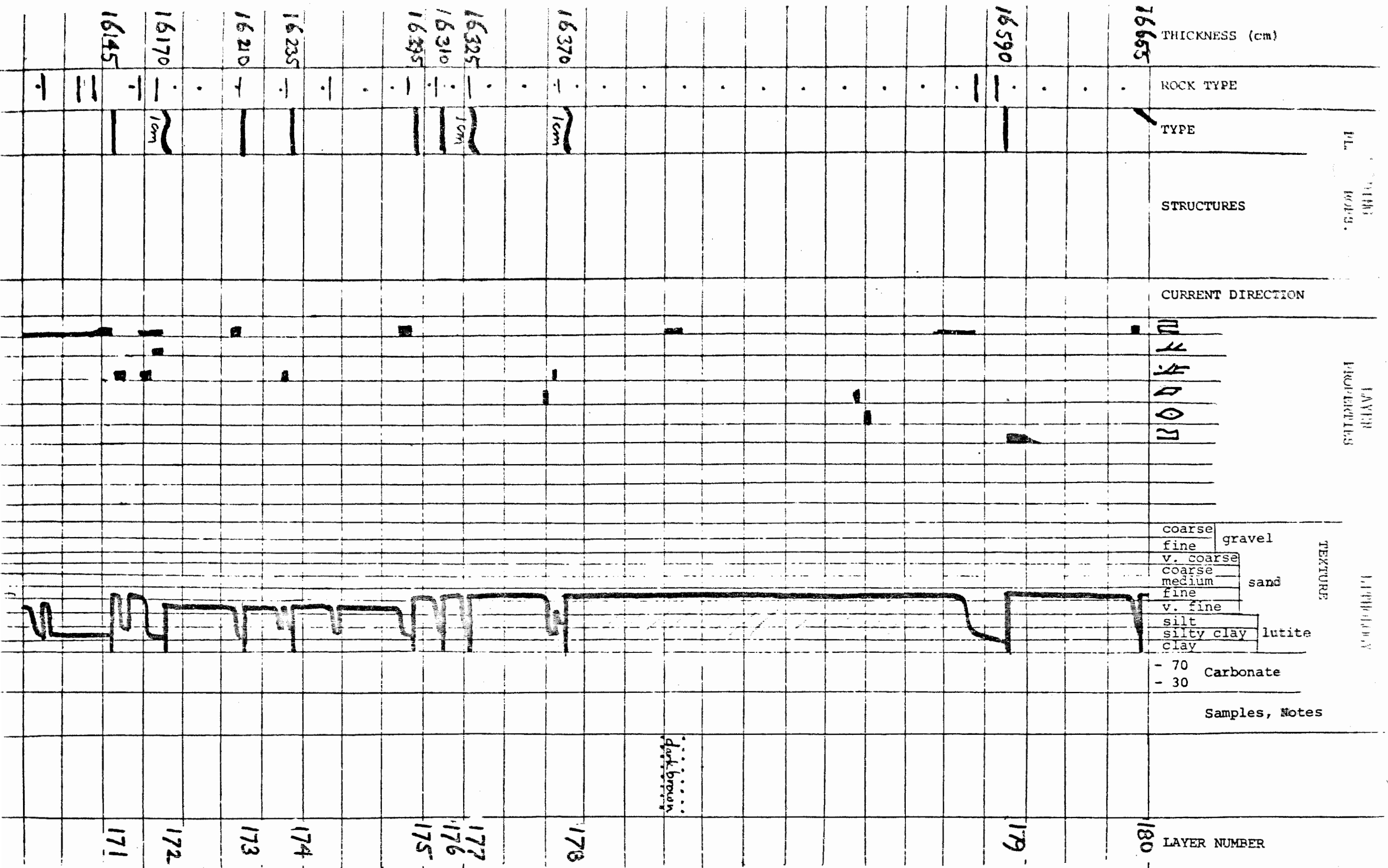
Carbonate: - 70, - 30

Samples, Notes

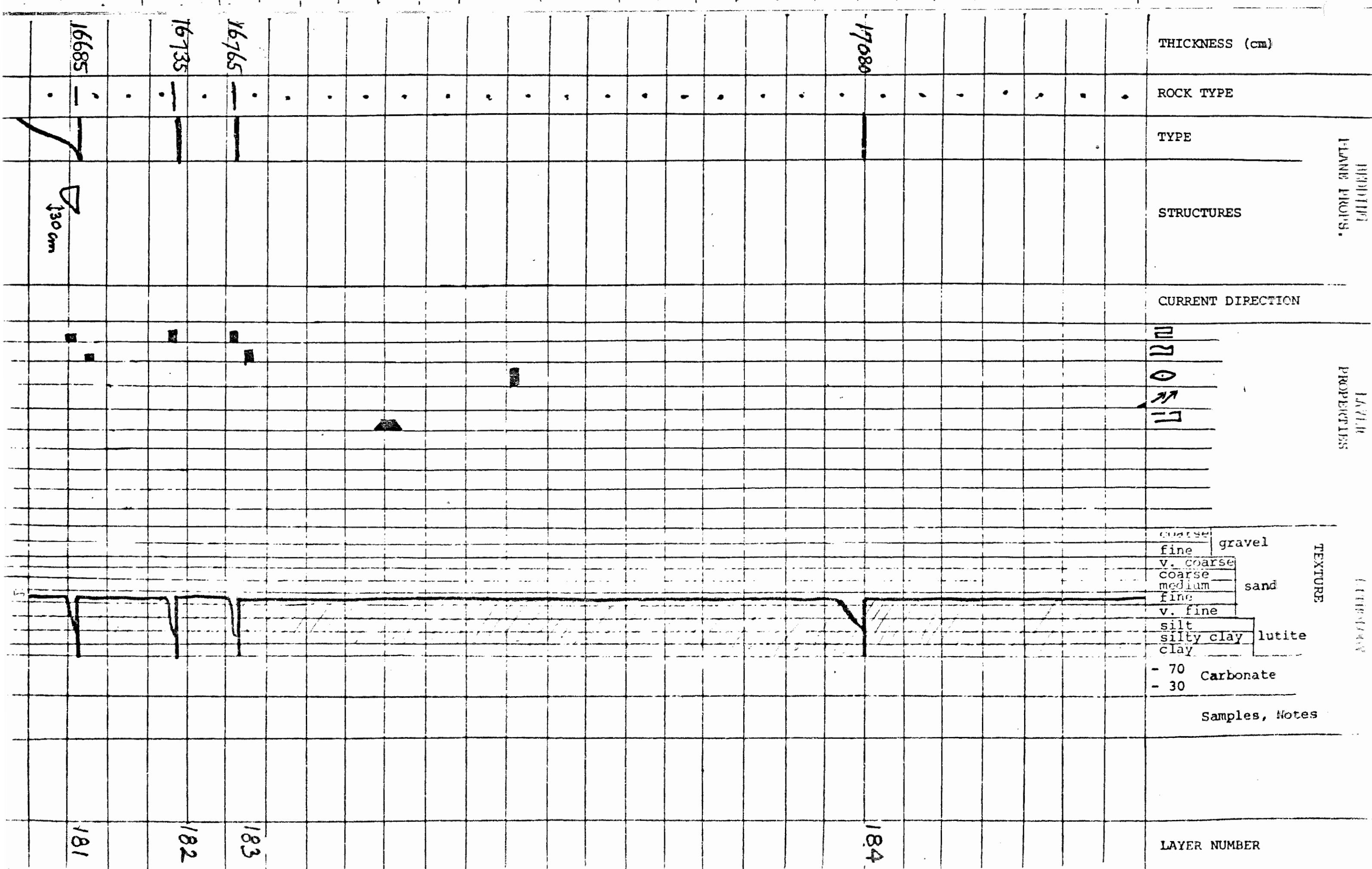
dark brown

LAYER NUMBER

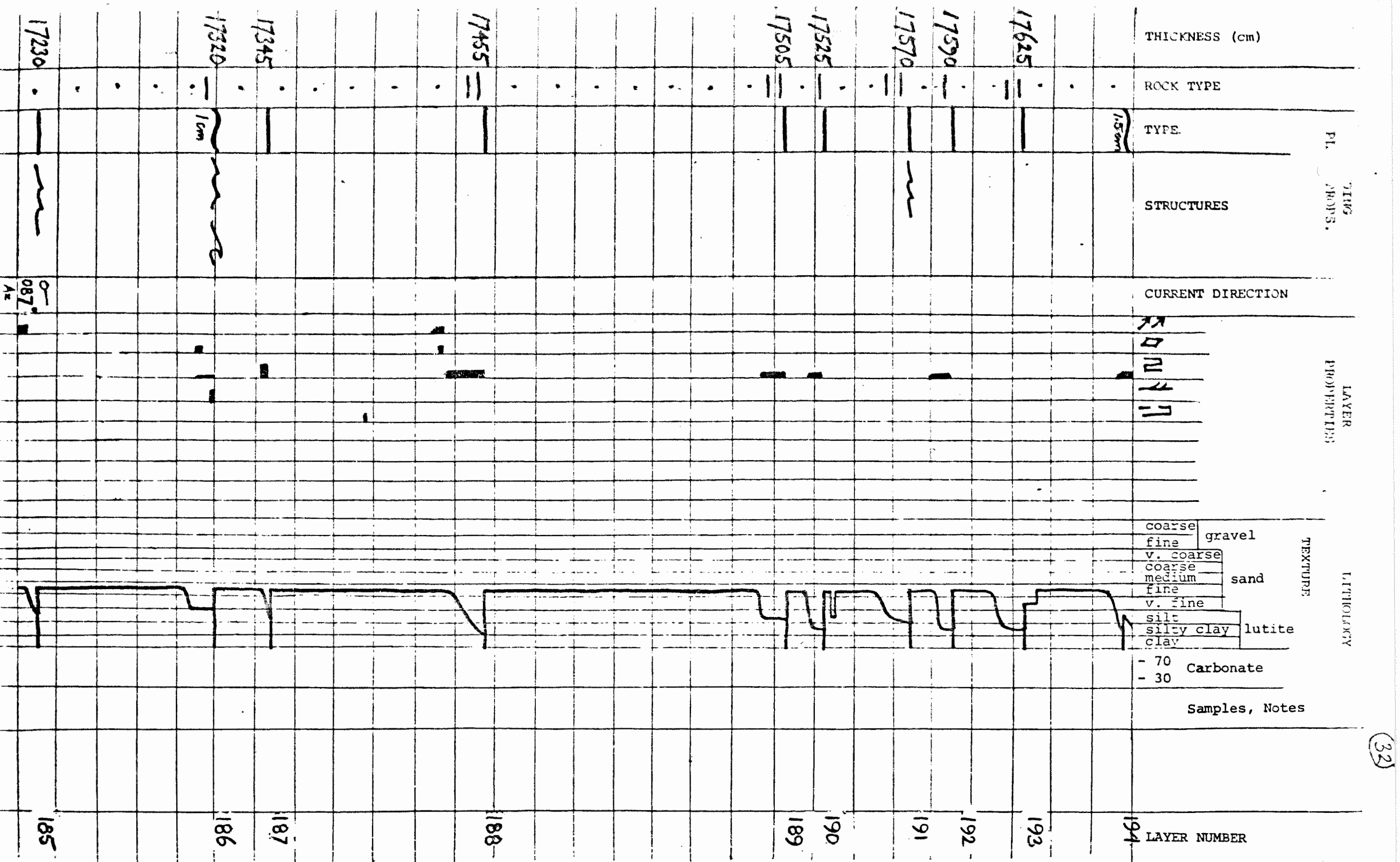
(29)

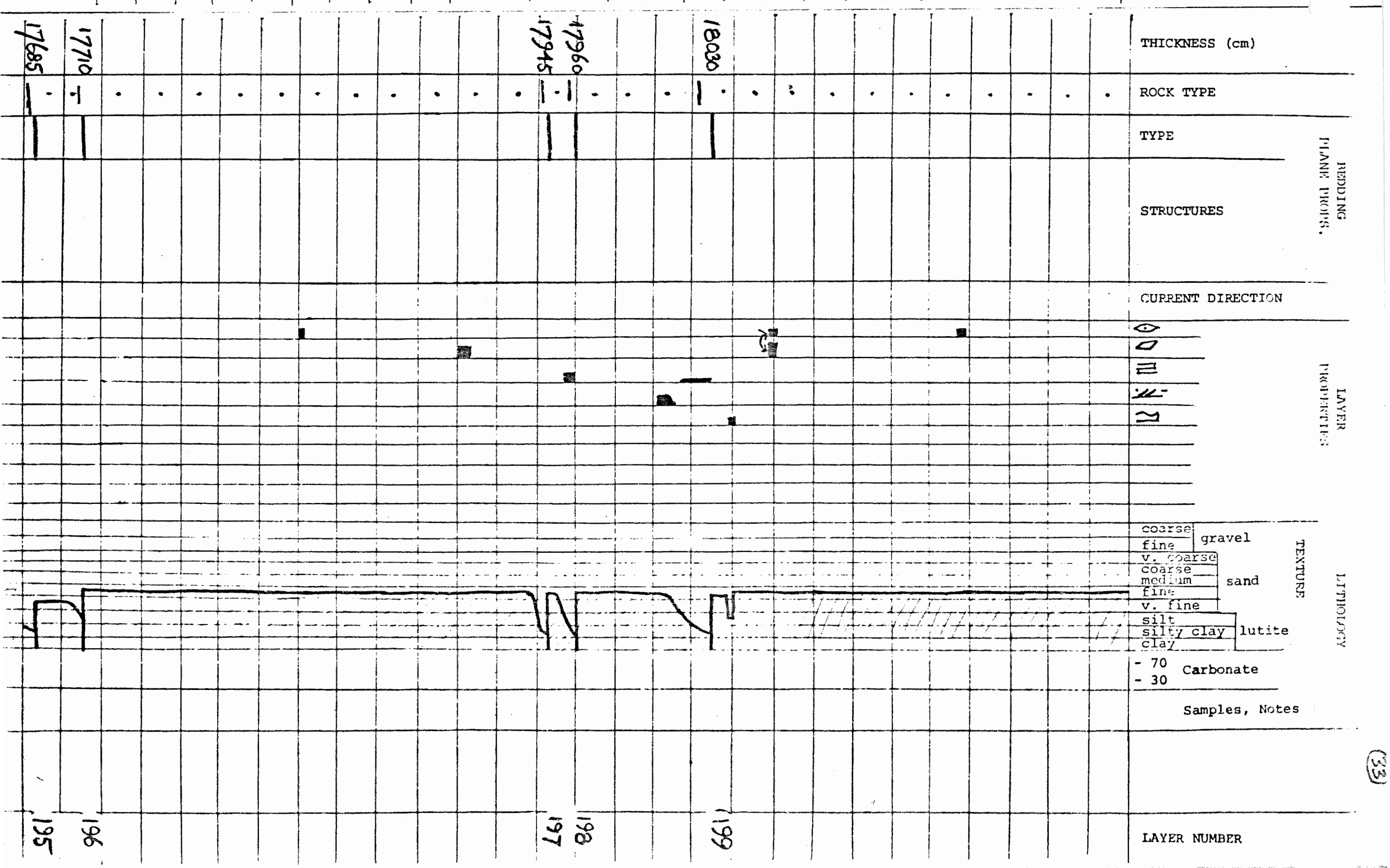

THICKNESS (cm)
16145
16170
16210
16235
16295
16310
16325
16370
16590
16665
ROCK TYPE
TYPE
1cm
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
dark brown
LAYER NUMBER
171
172
173
174
175
176
177
178
179
180

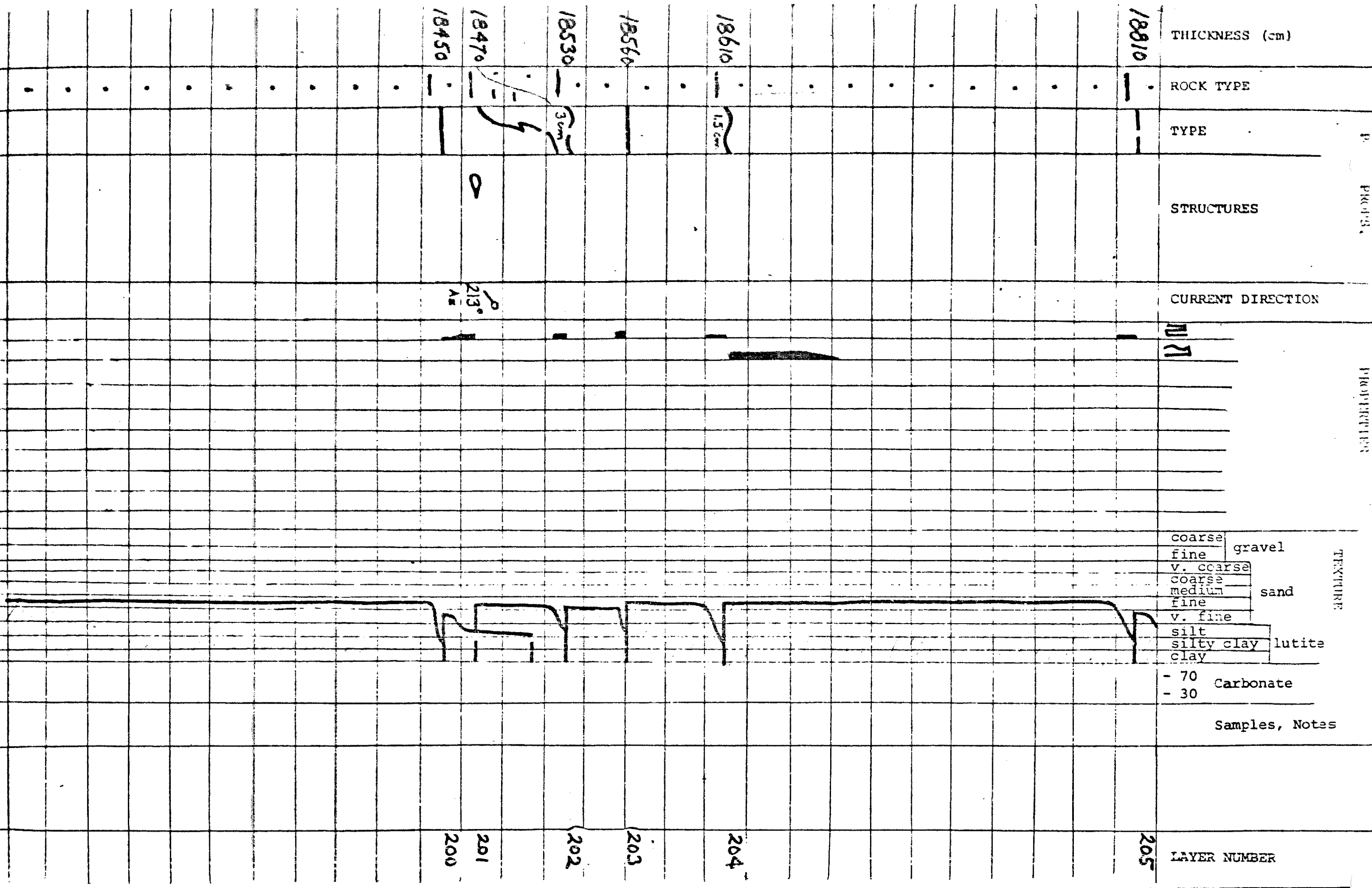
(30)


THICKNESS (cm)
16685
16735
16765
17080
ROCK TYPE
TYPE
STRUCTURES
30cm
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
LAYER NUMBER
181
182
183
184

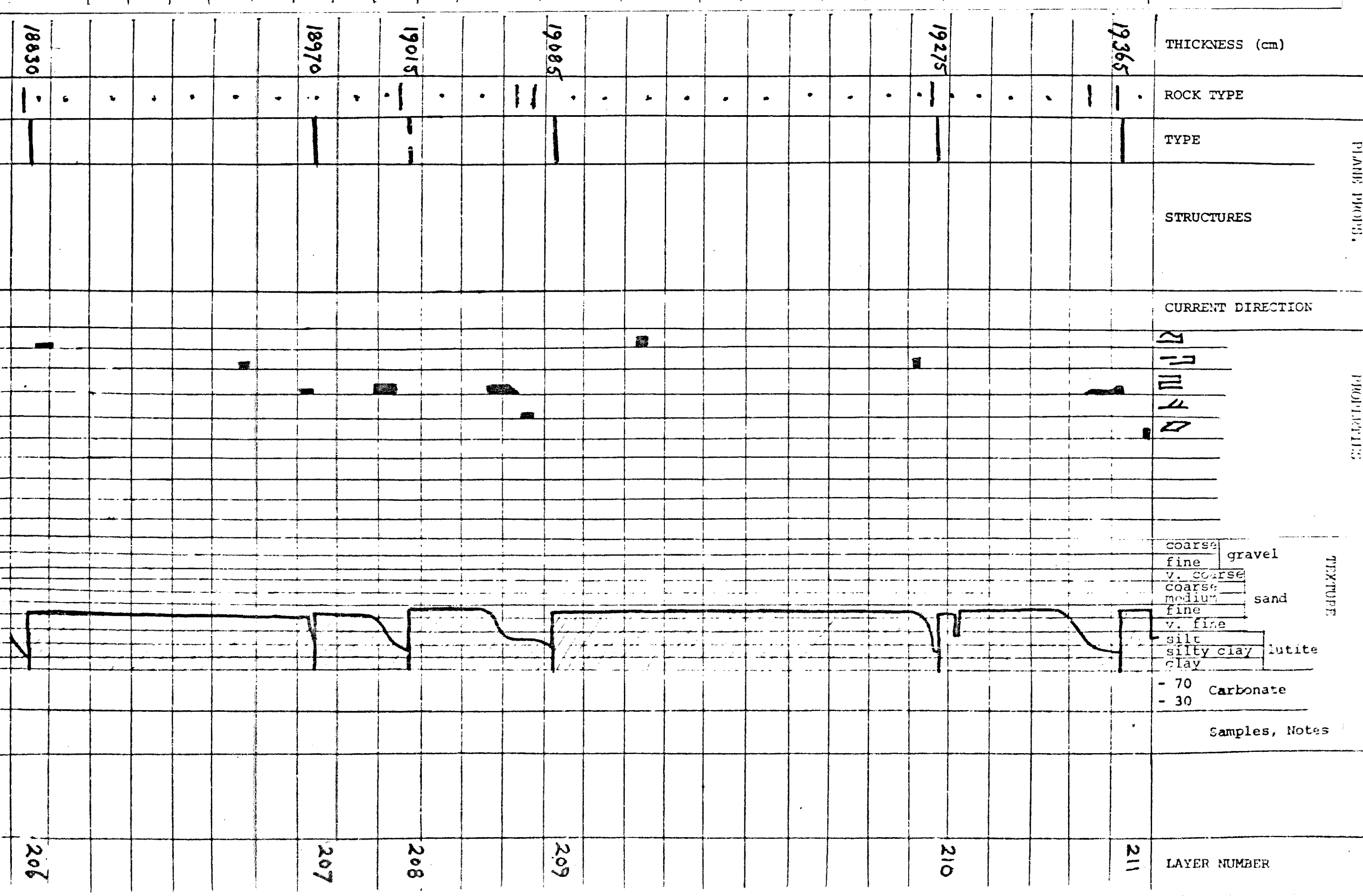
(31)


17230
17320
17345
17455
17505
17525
17570
17590
17625
THICKNESS (cm)
ROCK TYPE
1cm
1.5cm
TYPE
STRUCTURES
PL.
CURRENT DIRECTION
087° Az
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
185
186
187
188
189
190
191
192
193
194
LAYER NUMBER
(32)

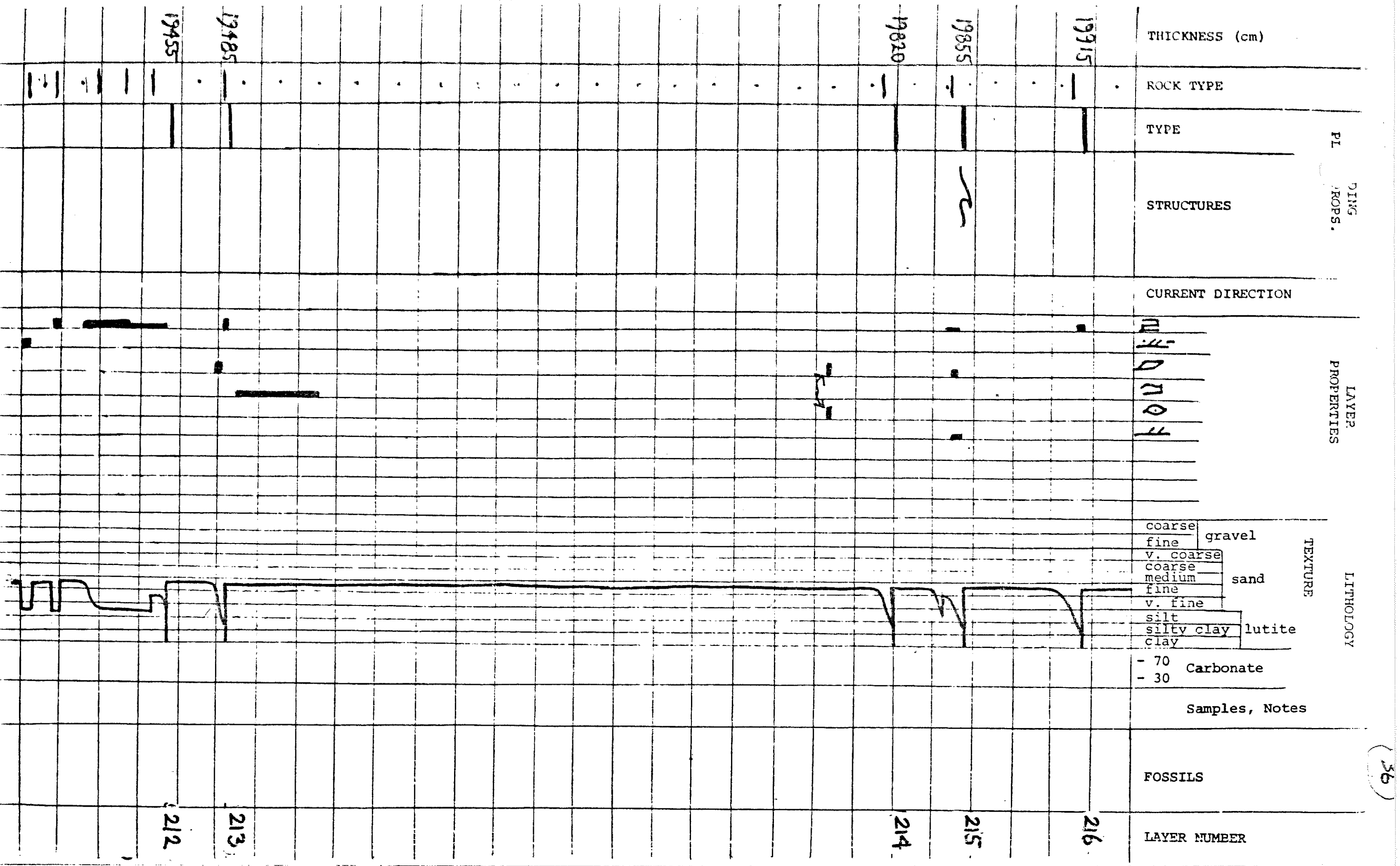

17685
17710
17945
17960
18030
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
195
196
197
198
199
LAYER NUMBER
(33)


18450
18470
18530
18560
18610
18810
THICKNESS (cm)
ROCK TYPE
3cm
1.5 cm
TYPE
STRUCTURES
213°
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
- 70
- 30
Carbonate
Samples, Notes
200
201
202
203
204
205
LAYER NUMBER

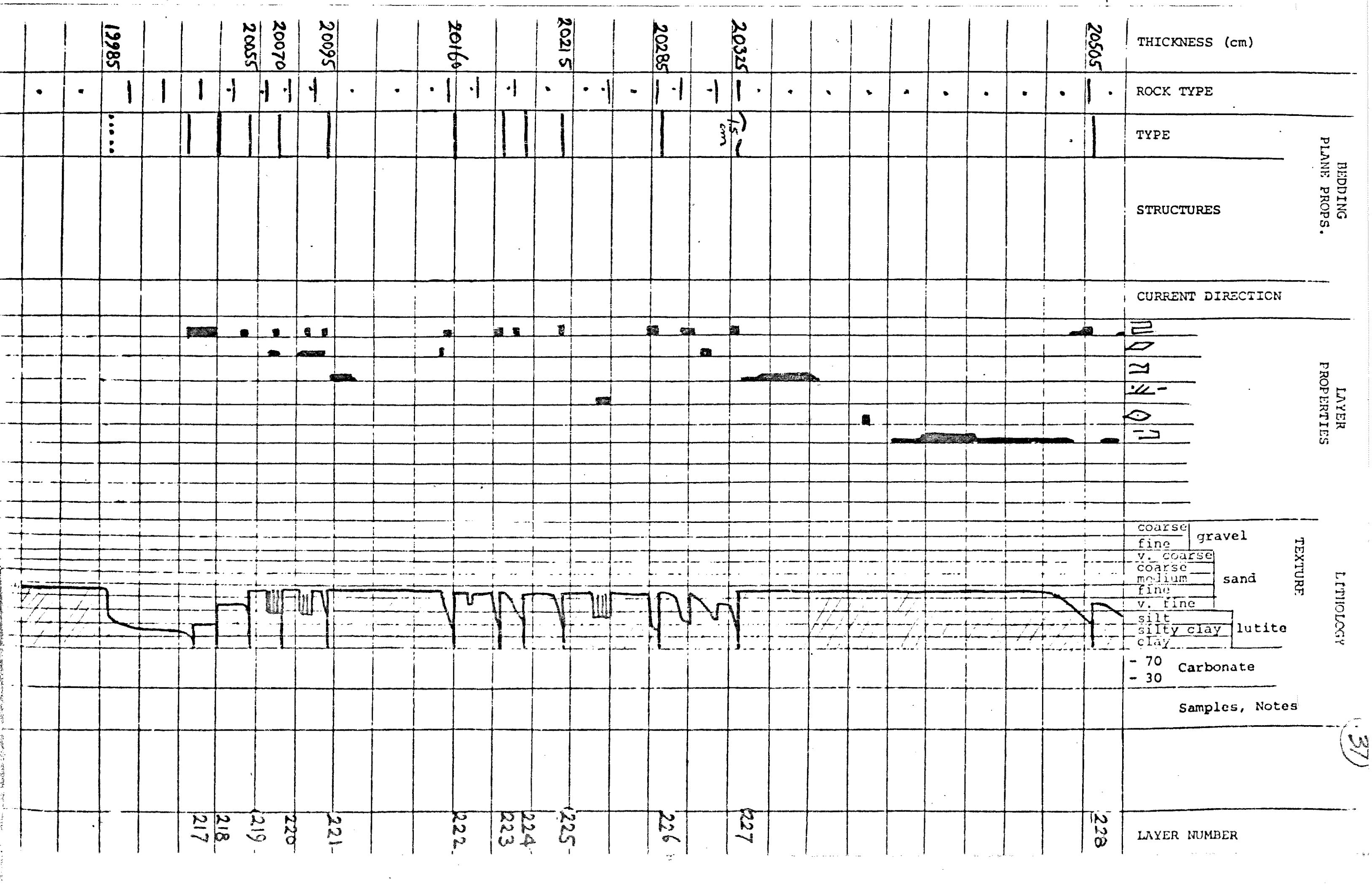
(34)


18830
18970
19015
19085
19275
19365
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
- 70
- 30
Carbonate
Samples, Notes
206
207
208
209
210
211
LAYER NUMBER

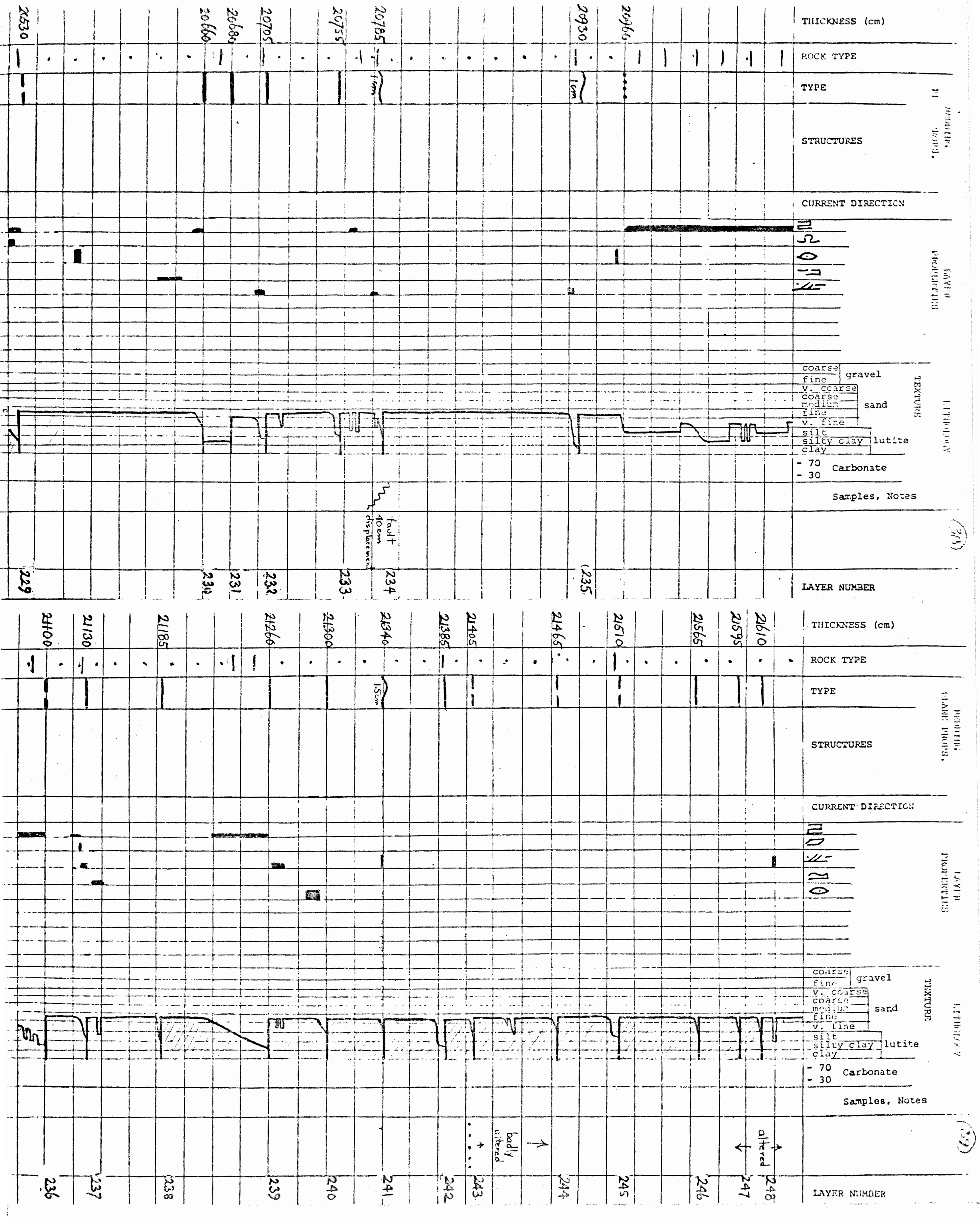
(35)



(36)
THICKNESS (cm)
19455
19485
19820
19855
19915
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
FOSSILS
LAYER NUMBER
212
213
214
215
216



(37)
THICKNESS (cm)
19985
20055
20070
20095
20160
20215
20285
20325
20505
ROCK TYPE
TYPE
15 cm
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
LAYER NUMBER
217
218
219
220
221
222
223
224
225
226
227
228


THICKNESS (cm)
ROCK TYPE
BEDDING PL. PROPS.
TYPE
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
LITHOLOGY
TEXTURE
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
- 70
- 30
Carbonate
Samples, Notes
LAYER NUMBER
20630
20660
20680
20705
20755
20785
20930
20965
1cm
1cm
fault
40cm
displacement
229
230
231
232
233
234
235
21100
21130
21185
21260
21300
21340
21385
21405
21465
21510
21565
21595
21610
1.5cm
badly
altered
altered
236
237
238
239
240
241
242
243
244
245
246
247
248

THICKNESS (cm)
21780 21815 22140 22170

ROCK TYPE

BEDDING PL. PROPS.
TYPE
3 cm 3cm

STRUCTURES
amalgamated
amalgamated 10cm

CURRENT DIRECTION

LAYER PROPERTIES

LITHOLOGY
TEXTURE
coarse / fine — gravel
v. coarse / coarse / medium / fine / v. fine — sand
silt / silty clay / clay — lutite

- 70
- 30
Carbonate

Samples, Notes

40

LAYER NUMBER
249. 250. 251 252.

THICKNESS (cm)
22405 22430 22550 22560 22580 22630 22625 22670 22740

ROCK TYPE

BEDDING PLANE PROPS.
TYPE

STRUCTURES
amalgamated
1cm

CURRENT DIRECTION

LAYER PROPERTIES

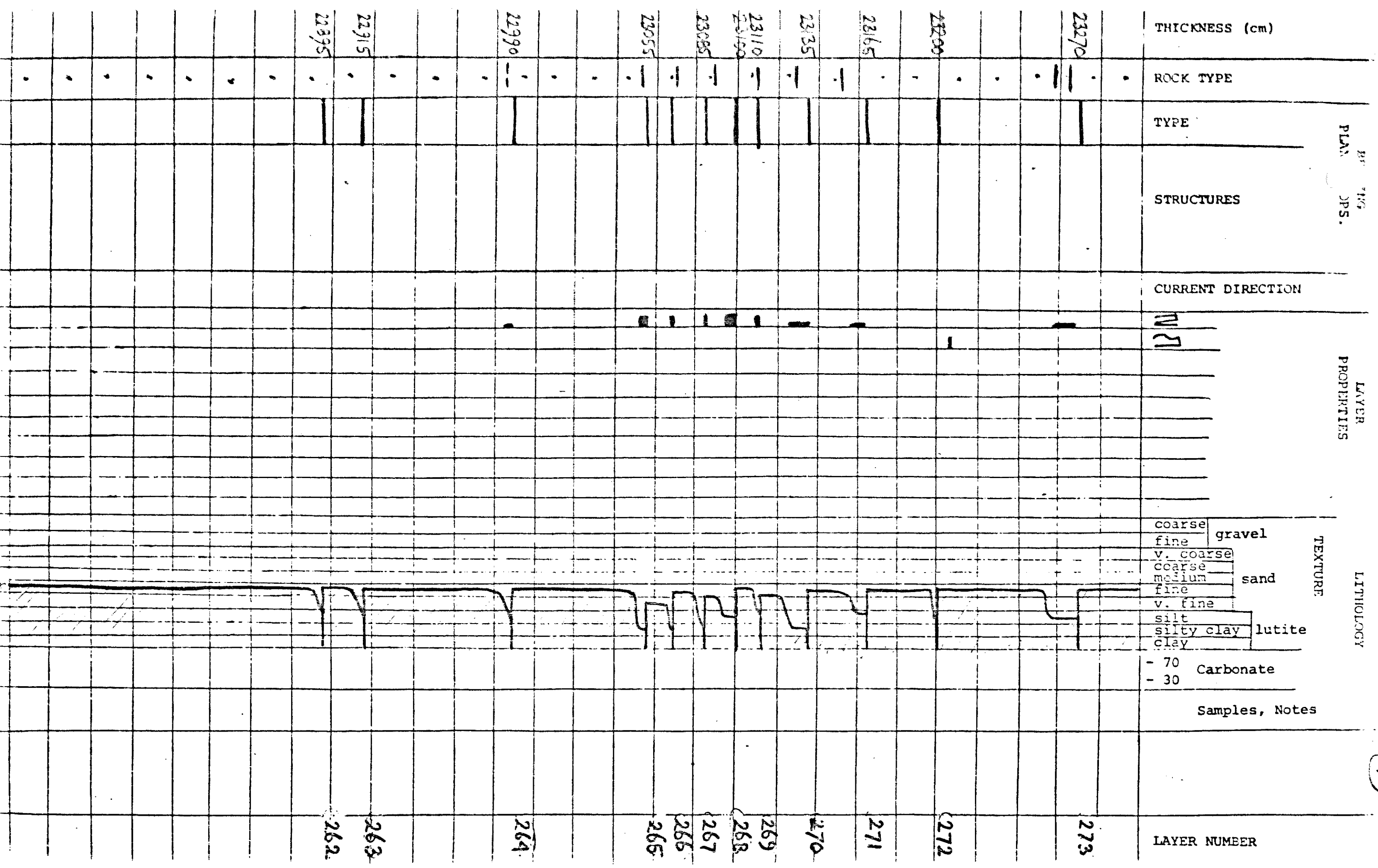
LITHOLOGY
TEXTURE
coarse / fine — gravel
v. coarse / coarse / medium / fine / v. fine — sand
silt / silty clay / clay — lutite

- 70
- 30
Carbonate

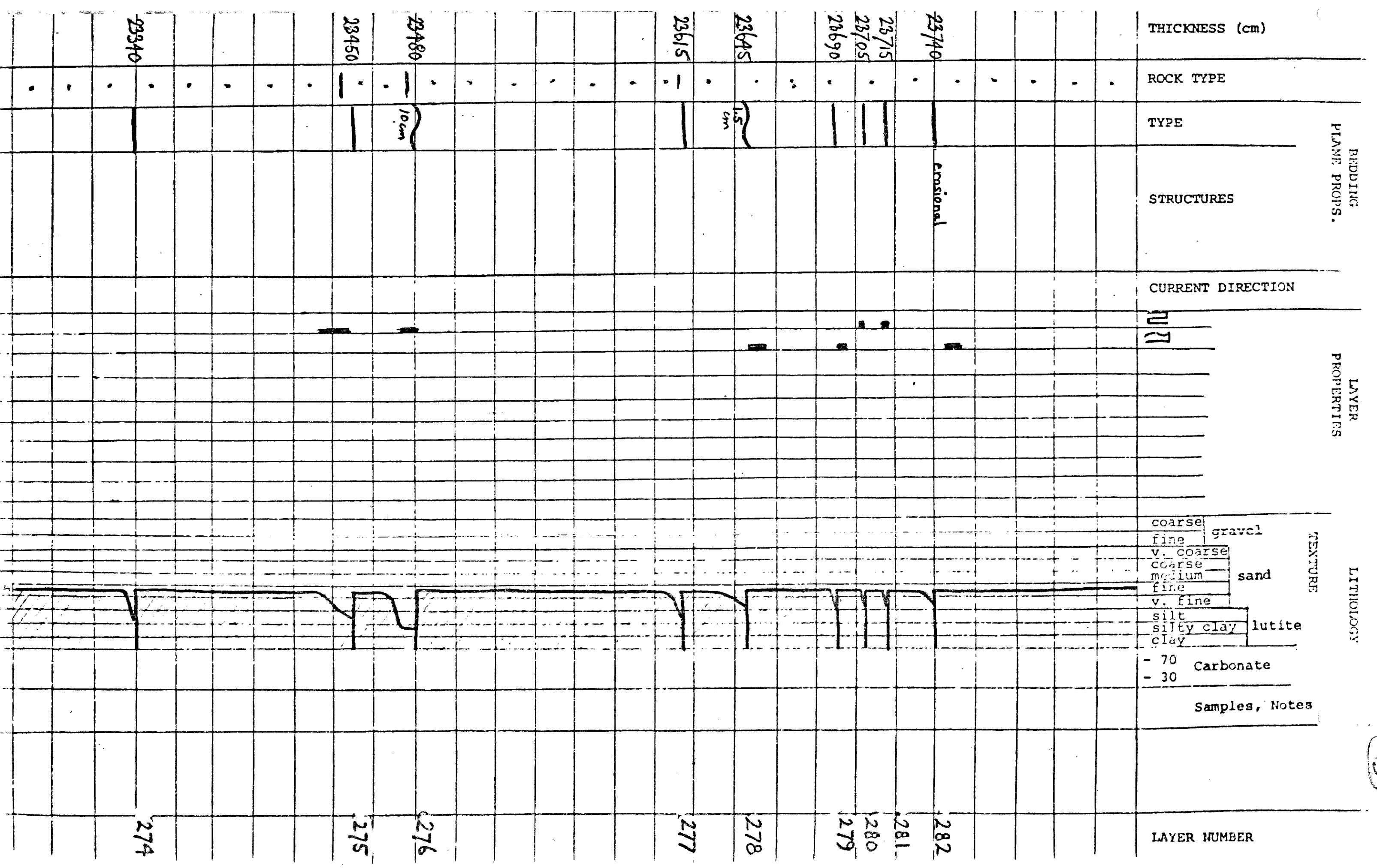
Samples, Notes

41

LAYER NUMBER
253 254 255 256 257 258 259 260 261


THICKNESS (cm)
22895
22915
22990
23055
23085
23100
23110
23135
23165
23200
23270
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
LAYER NUMBER
262
263
264
265
266
267
268
269
270
271
272
273

42


THICKNESS (cm)
23440
23450
23480
23615
23645
23690
23705
23715
23740
ROCK TYPE
TYPE
10 cm
1.5 cm
STRUCTURES
erosional
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
LAYER NUMBER
274
275
276
277
278
279
280
281
282

43

THICKNESS (cm)

ROCK TYPE

BEDDING PLANE PROPS.: TYPE; STRUCTURES

CURRENT DIRECTION

LAYER PROPERTIES

LITHOLOGY

TEXTURE: coarse / fine — gravel; v. coarse / coarse / medium / fine / v. fine — sand; silt / silty clay / clay — lutite

- 70
- 30 Carbonate

Samples, Notes

44

LAYER NUMBER: 282

THICKNESS (cm): 24430, 24540, 24660, 24730, 24860, 24870, 24890

ROCK TYPE

BEDDING PLANE PROPS.: TYPE; STRUCTURES: amalgamated

CURRENT DIRECTION: 074° Az

LAYER PROPERTIES

LITHOLOGY

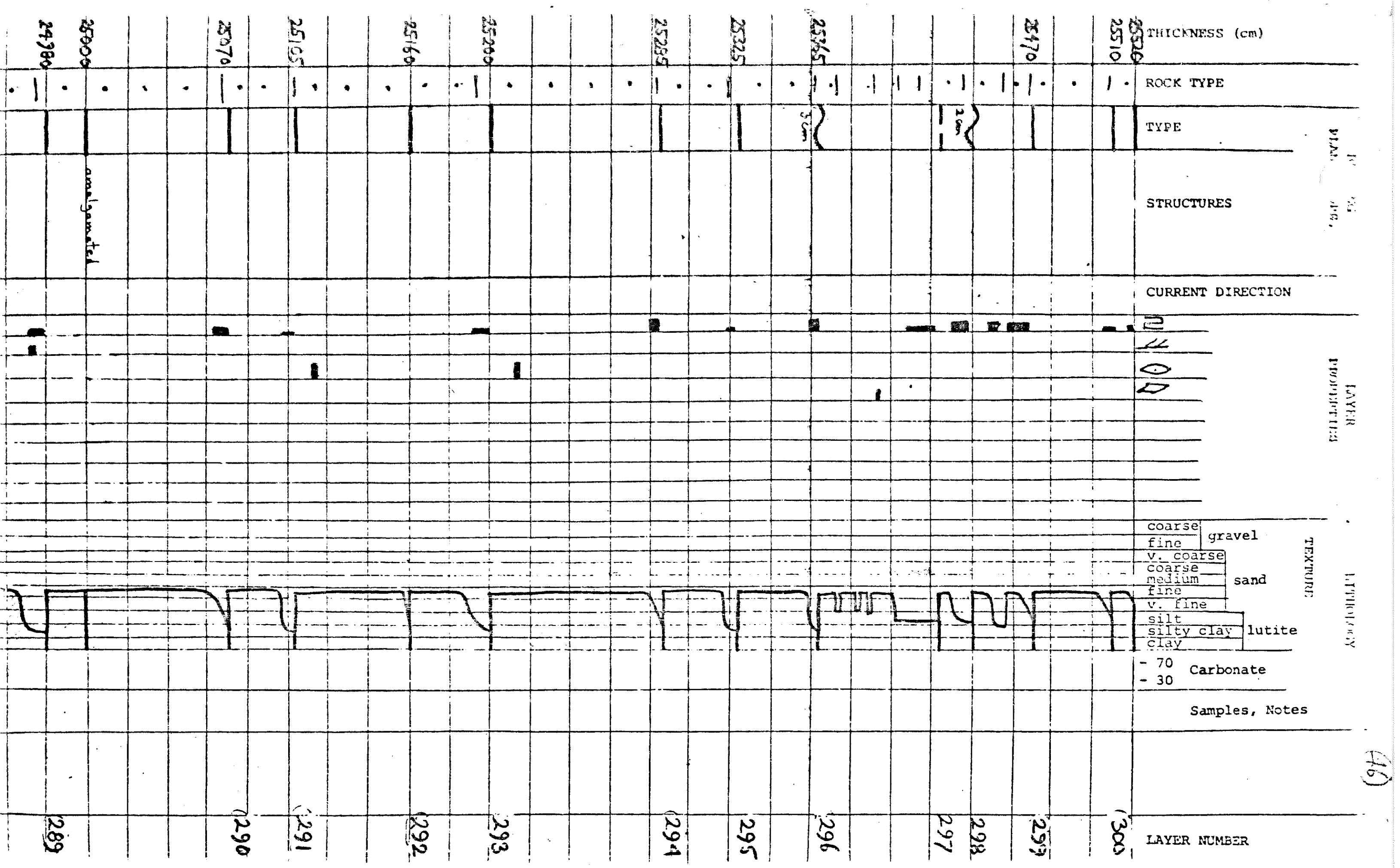
TEXTURE: coarse / fine — gravel; v. coarse / coarse / medium / fine / v. fine — sand; silt / silty clay / clay — lutite

- 70
- 30 Carbonate

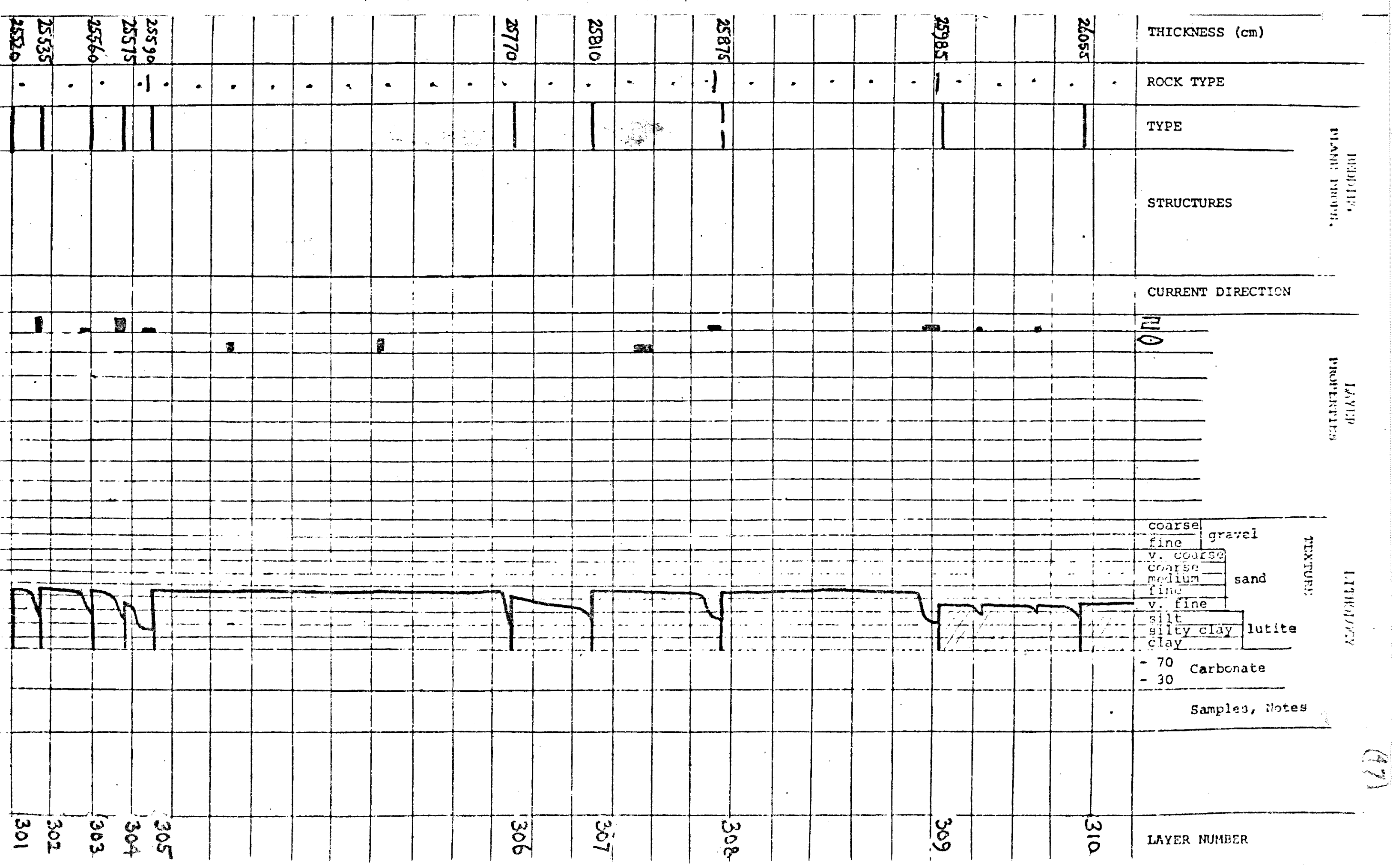
Samples, Notes

45

LAYER NUMBER: 283, 284, 285, 286, 287, 288



24980
25000
25070
25165
25160
25200
25285
25325
25365
25470
25510
25520
THICKNESS (cm)
ROCK TYPE
TYPE
3cm
2cm
BEDDING PLANE PROP.
amalgamated
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
(46)
289
290
291
292
293
294
295
296
297
298
299
300
LAYER NUMBER



25520
25535
25560
25575
25590
25770
25810
25875
25985
26055
THICKNESS (cm)
ROCK TYPE
TYPE
BEDDING PLANE PROP.
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
(47)
301
302
303
304
305
306
307
308
309
310
LAYER NUMBER

26120

311

THICKNESS (cm)

ROCK TYPE

TYPE

STRUCTURES

BEDDING PLANE PROPS.

CURRENT DIRECTION

LAYER PROPERTIES

coarse	gravel	TEXTURE	LITHOLOGY
fine			
v. coarse	sand		
coarse			
medium			
fine			
v. fine			
silt	lutite		
silty clay			
clay			
- 70	Carbonate		
- 30			

Samples, Notes

LAYER NUMBER

48

26695 26725 26810 26885 26885 26895 26915

amalgamated

5cm erosional

amalgamated

312 313 314 315 316 317 318

THICKNESS (cm)

ROCK TYPE

TYPE

STRUCTURES

BEDDING PLANE PROPS.

CURRENT DIRECTION

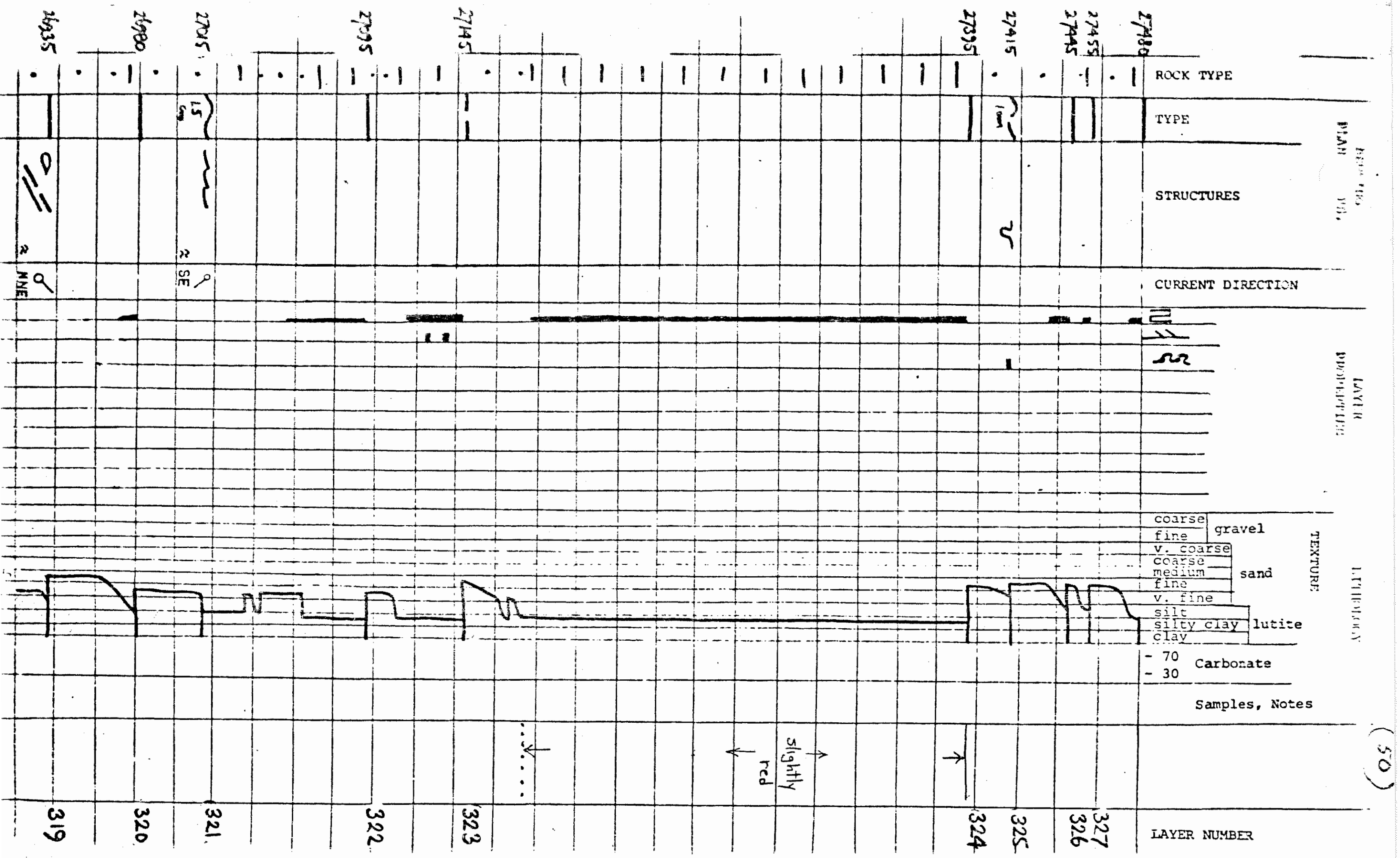
LAYER PROPERTIES

coarse	gravel	TEXTURE	LITHOLOGY
fine			
v. coarse	sand		
coarse			
medium			
fine			
v. fine			
silt	lutite		
silty clay			
clay			
- 70	Carbonate		
- 30			

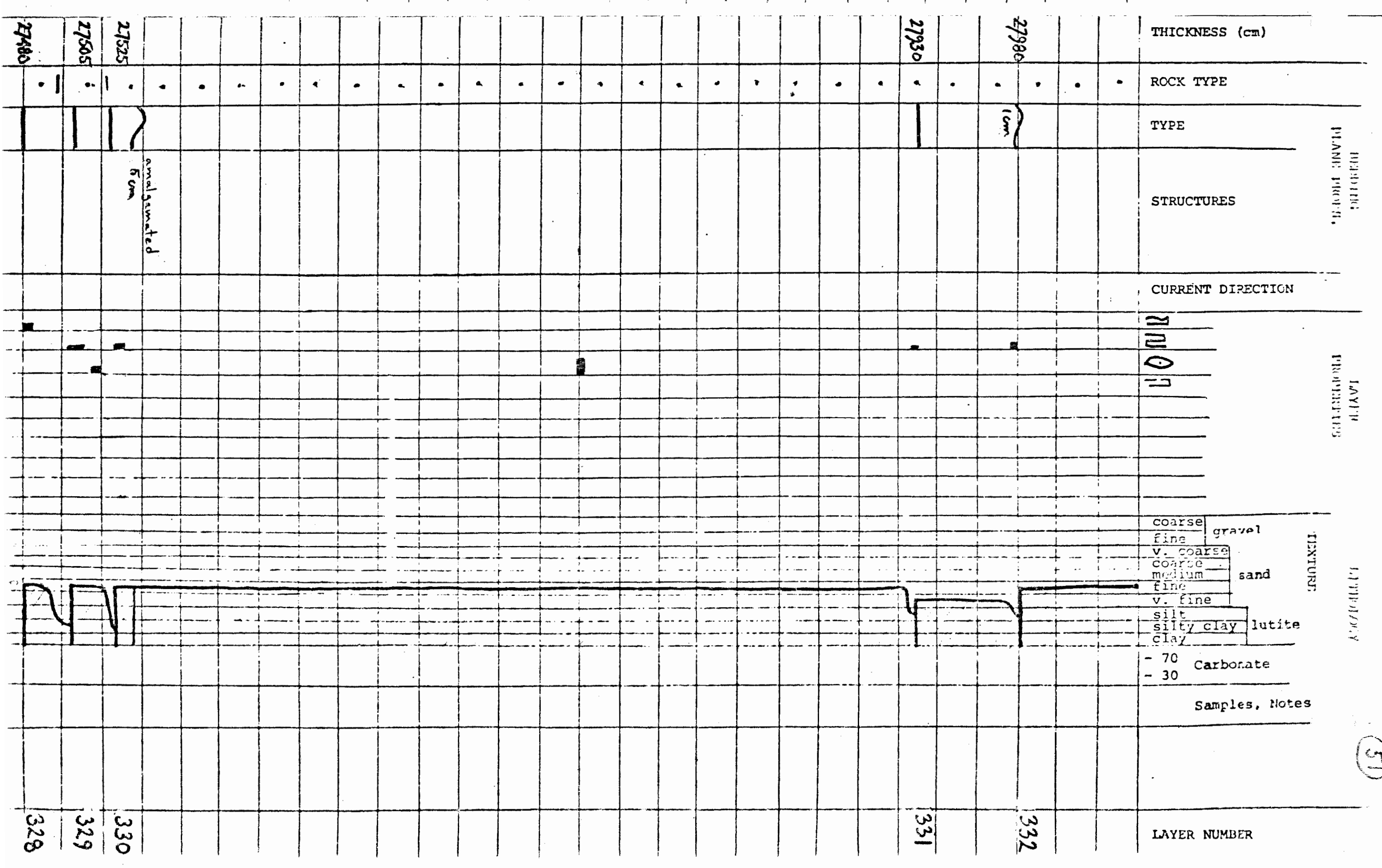
Samples, Notes

LAYER NUMBER

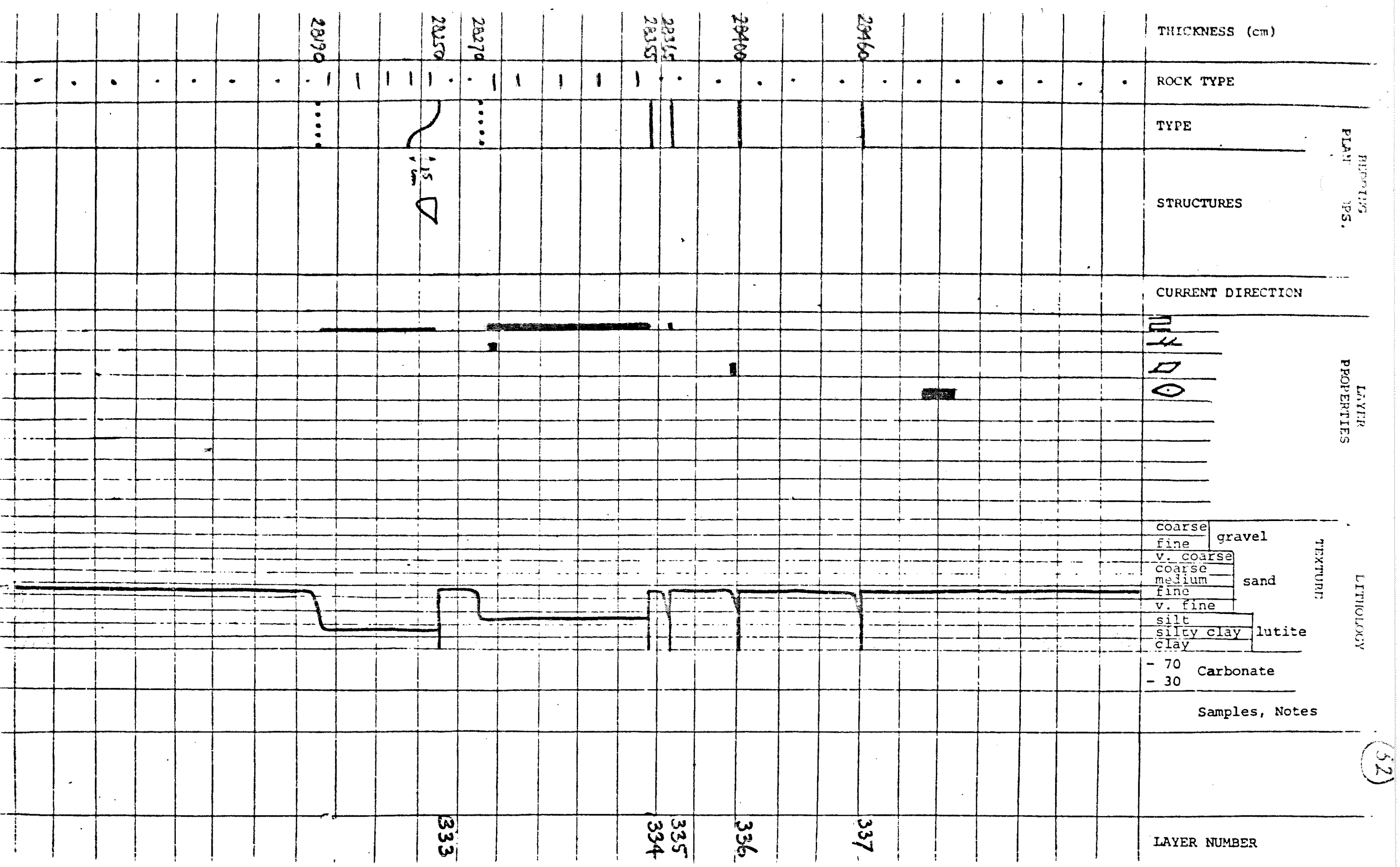
49



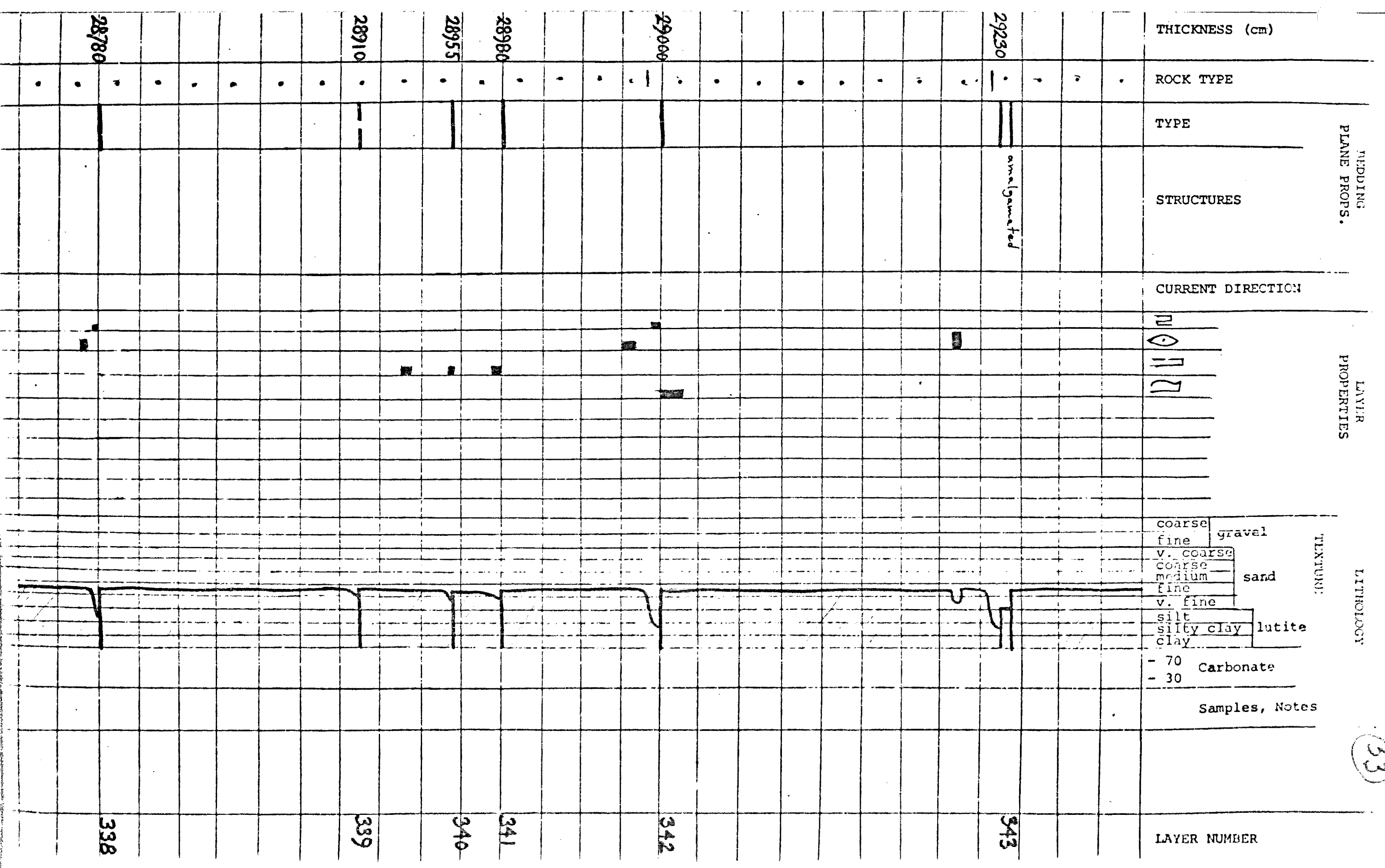
26935
26980
27015
27095
27145
27395
27415
27445
27455
27480
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
LS
1cm
NNE
SE
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
slightly red
50
319
320
321
322
323
324
325
326
327
LAYER NUMBER



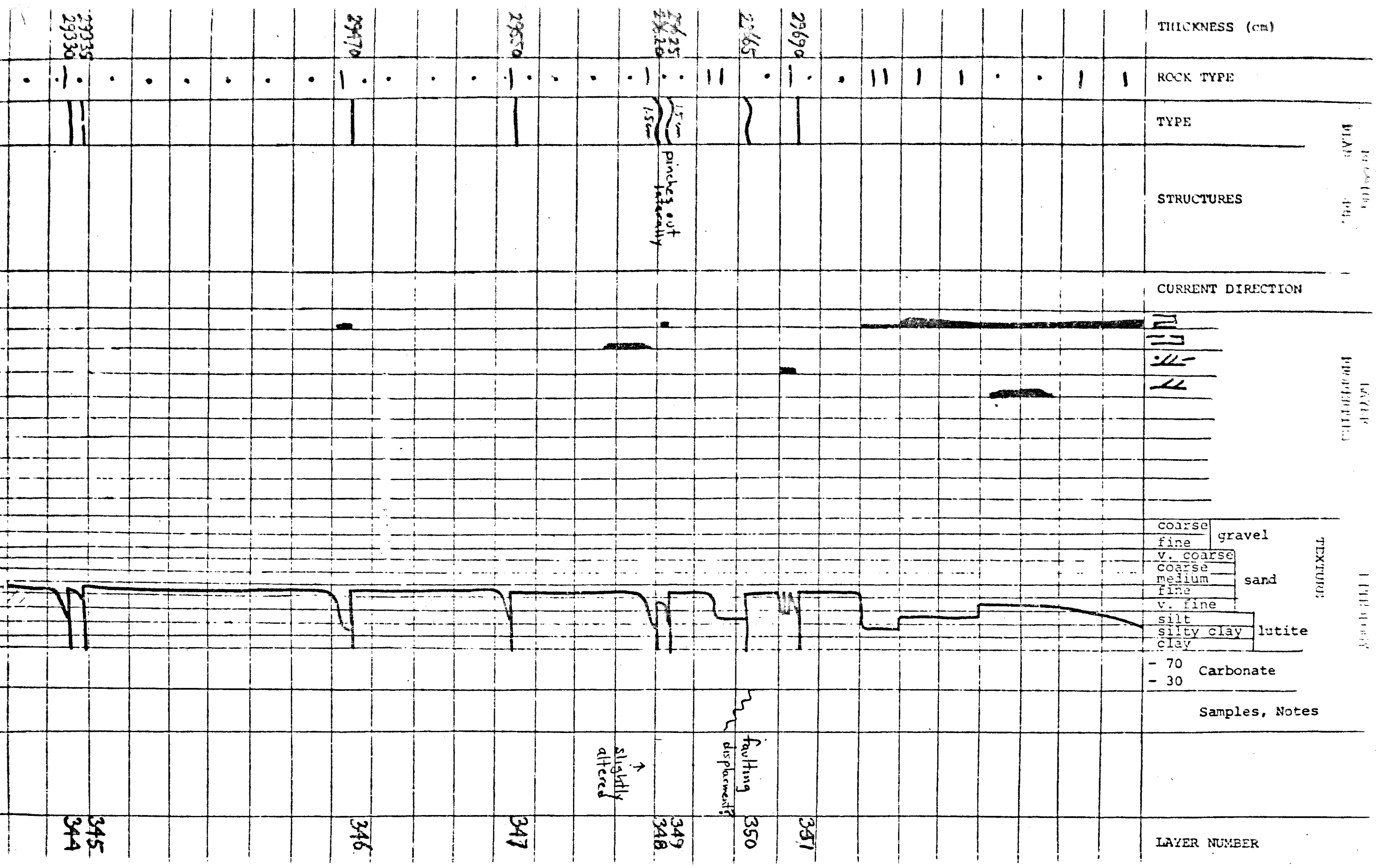
27480
27505
27525
27930
27980
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
1cm
amalgamated 5cm
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
51
328
329
330
331
332
LAYER NUMBER



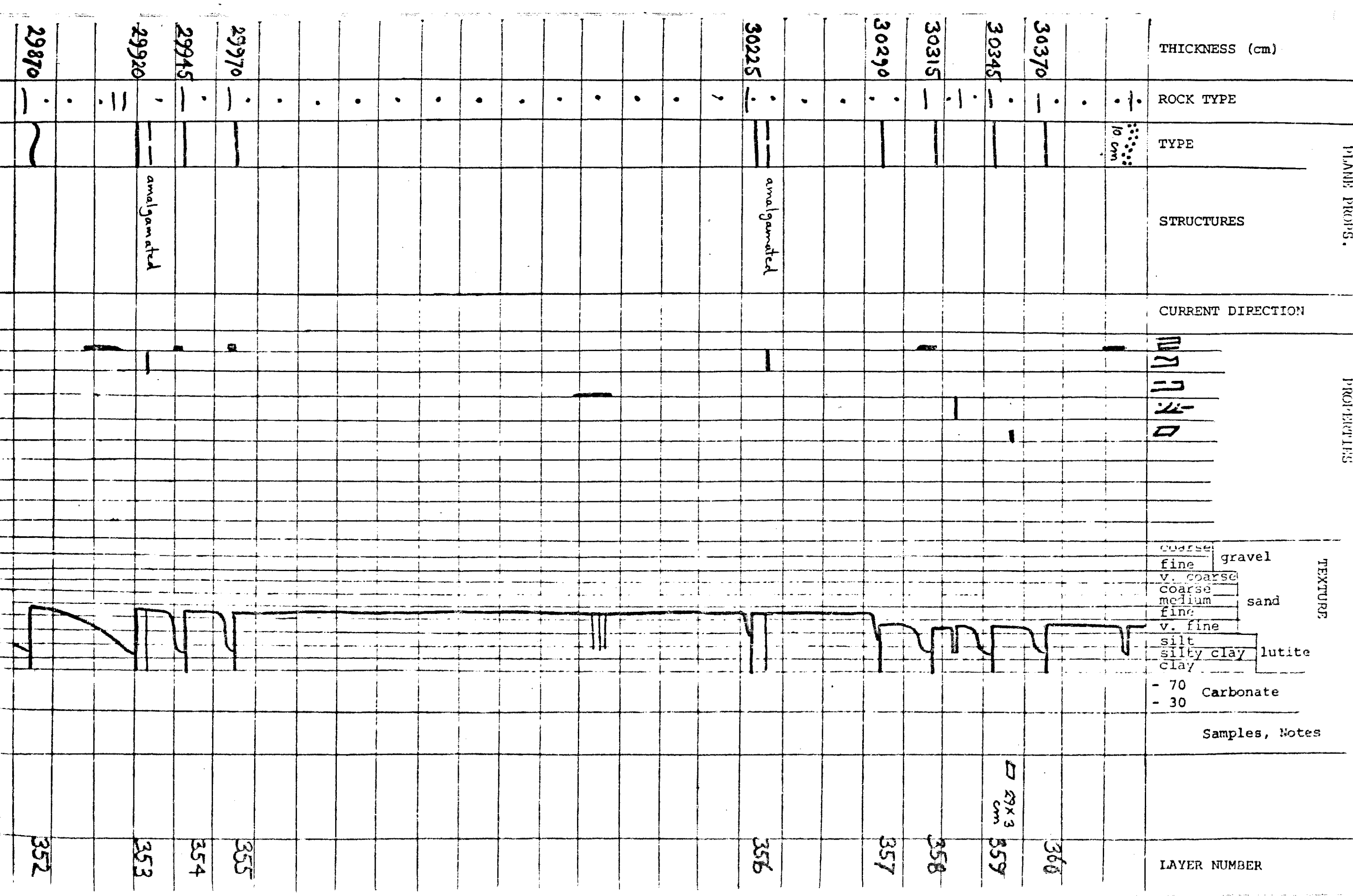
THICKNESS (cm)
2890
2850
2870
2815
2835
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
52
333
334
335
336
337
LAYER NUMBER



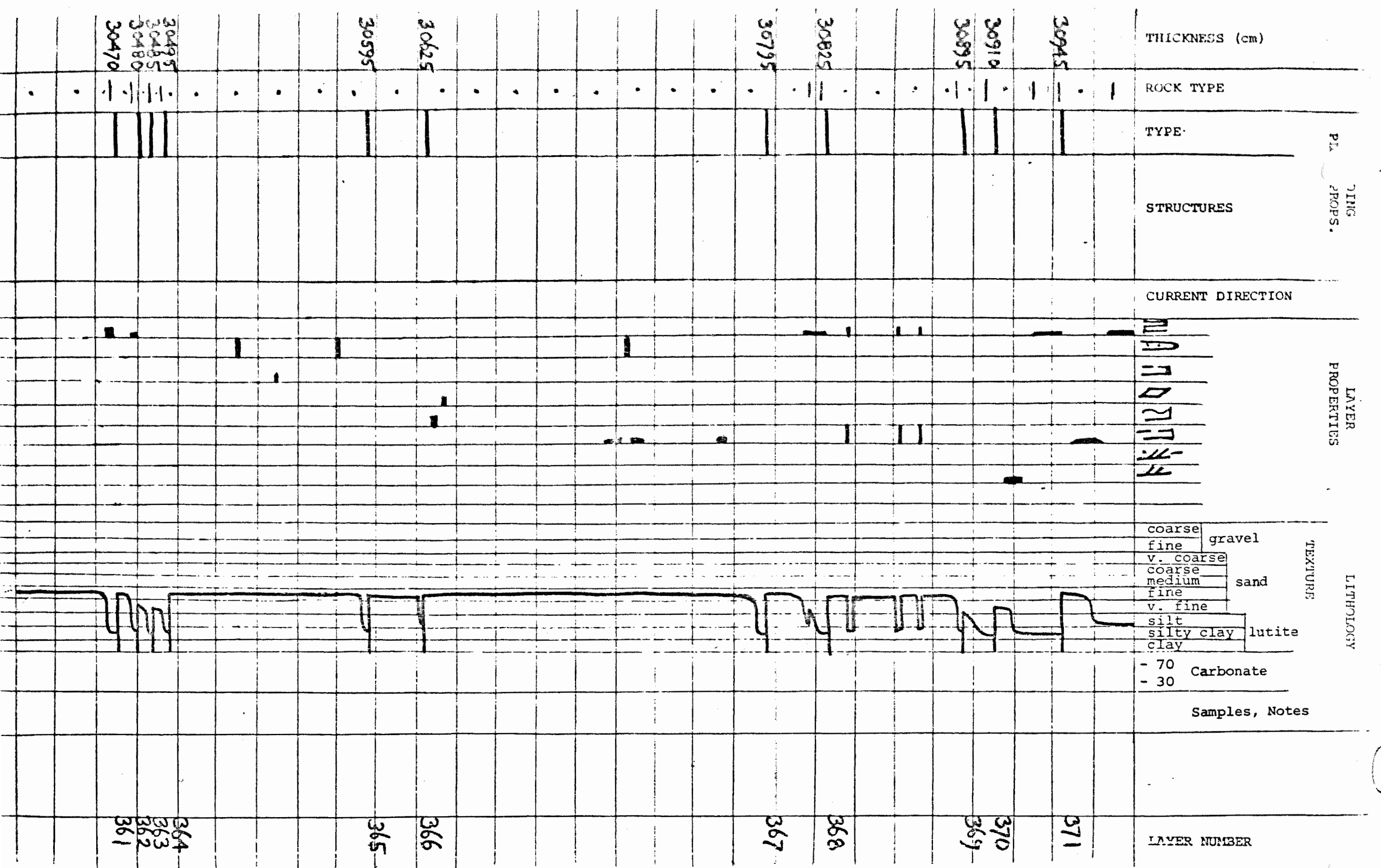
THICKNESS (cm)
28780
28910
28955
28980
29000
29230
ROCK TYPE
TYPE
STRUCTURES
amalgamated
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
53
338
339
340
341
342
343
LAYER NUMBER


THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
- 70
- 30
Carbonate
Samples, Notes
LAYER NUMBER
29330
29470
29665
29690
pinches out laterally
1.5 cm
slightly altered
faulting displacement?
344
345
346
347
348
349
350
351

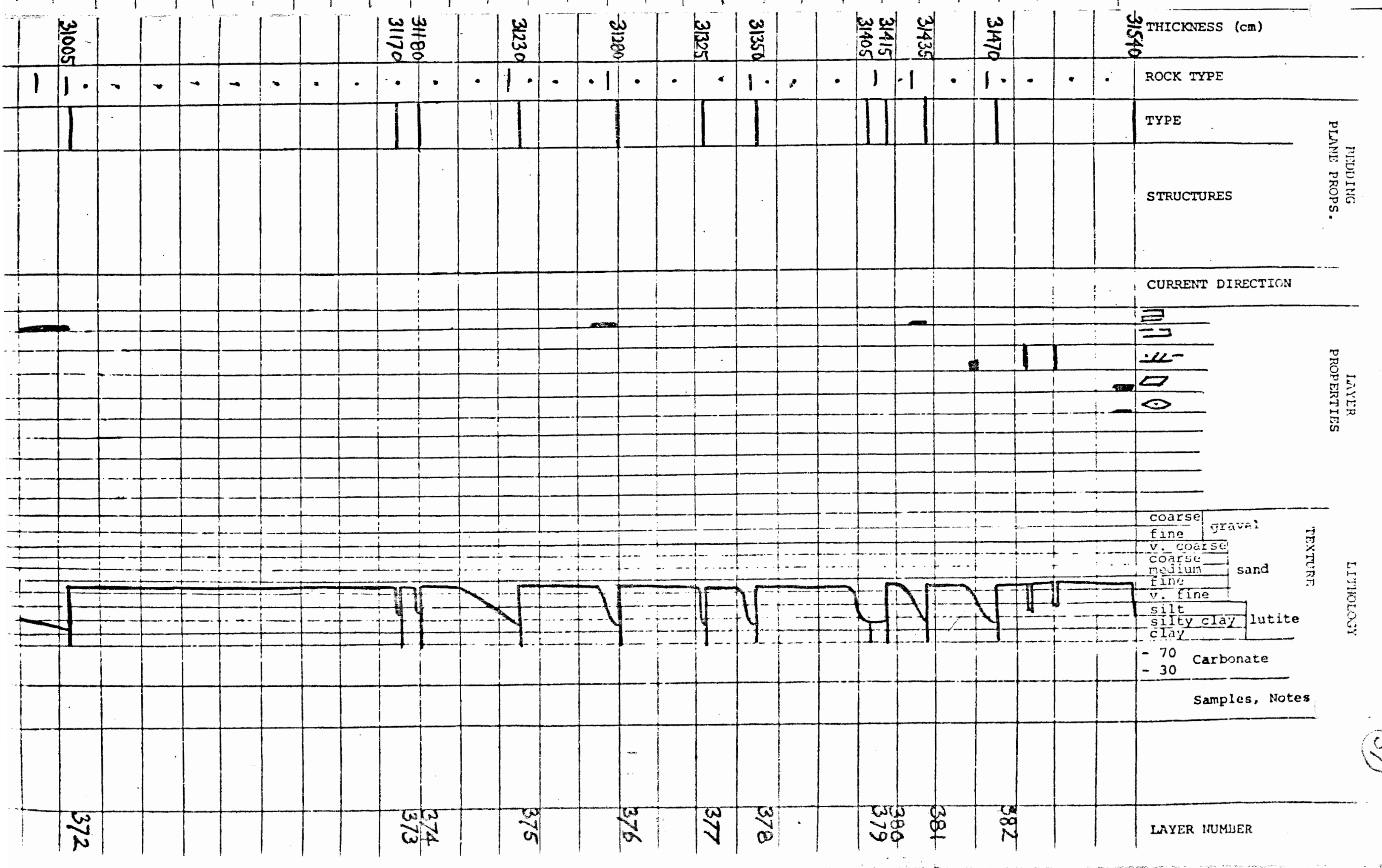
(54)


THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
- 70
- 30
Carbonate
Samples, Notes
LAYER NUMBER
29870
29920
29945
29970
30225
30290
30315
30345
30370
10 cm
amalgamated
amalgamated
27 x 3 cm
352
353
354
355
356
357
358
359
360

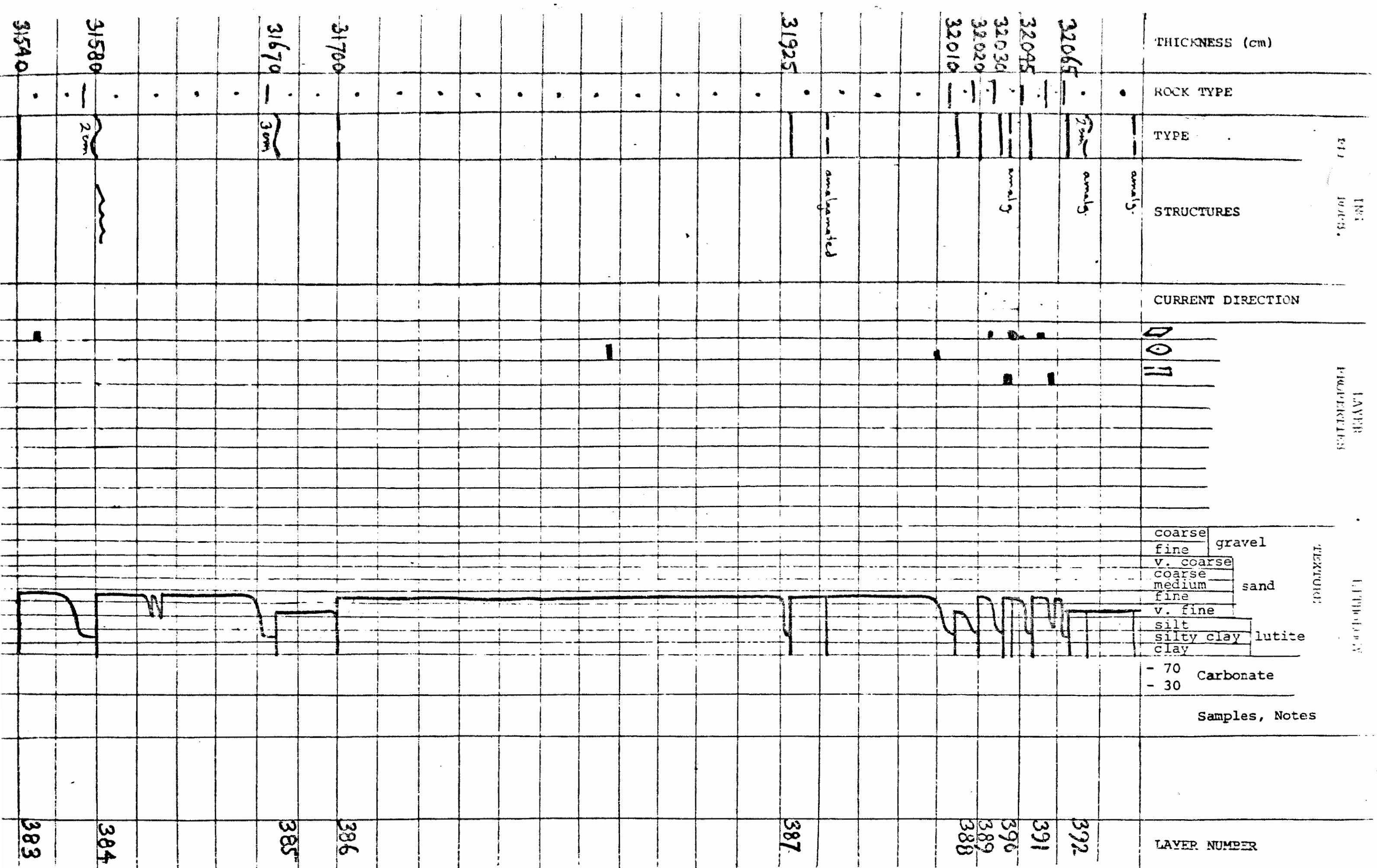
(55)



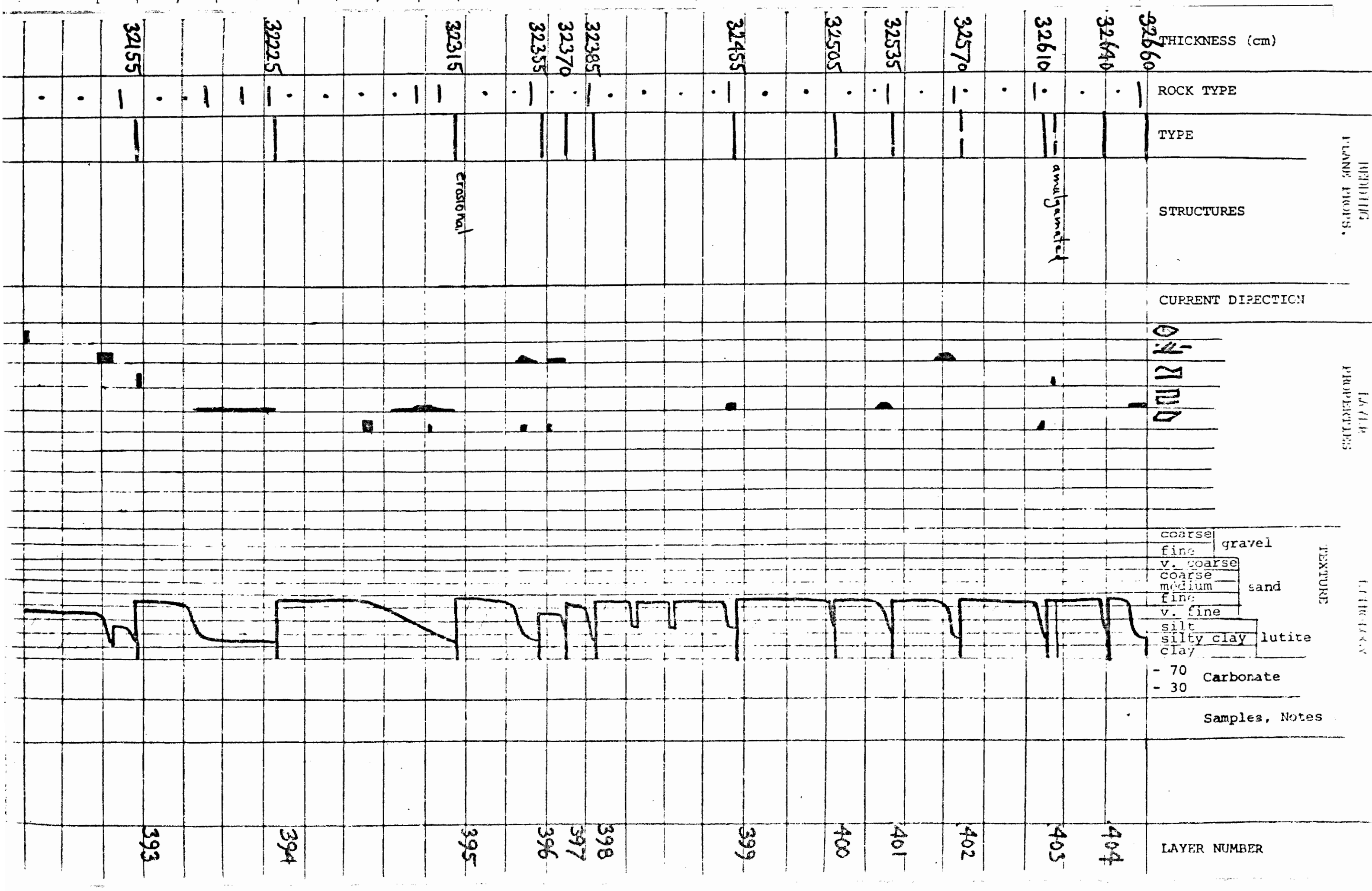
30470
30480
30485
30495
30595
30625
30795
30825
30895
30910
30945
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
56
361
362
363
364
365
366
367
368
369
370
371
LAYER NUMBER



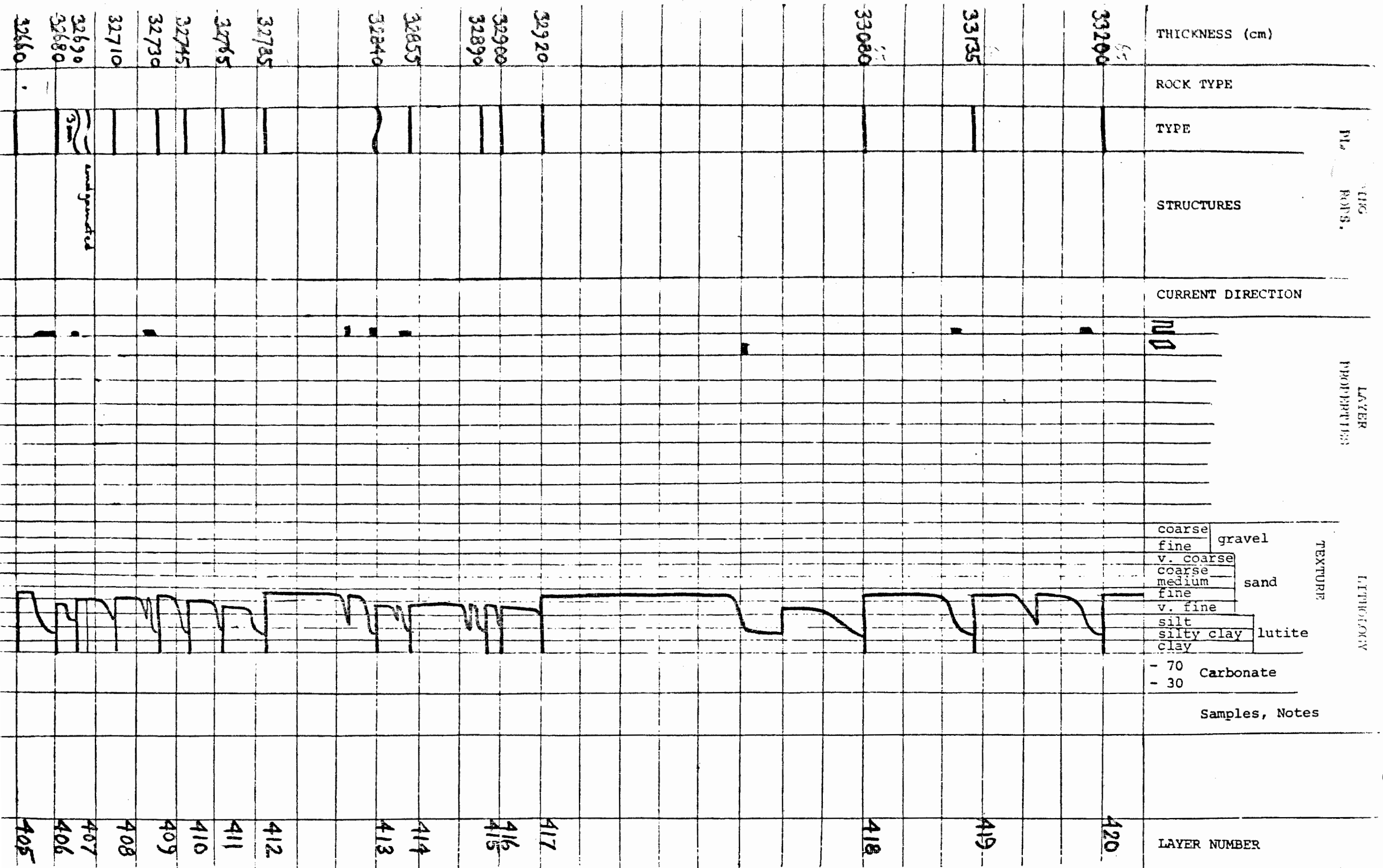
31005
31170
31180
31230
31280
31325
31350
31405
31415
31435
31470
31540
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
57
372
373
374
375
376
377
378
379
380
381
382
LAYER NUMBER


THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
LAYER NUMBER
31540
31580
31670
31700
31925
32010
32020
32030
32045
32065
2cm
3cm
2cm
amalgamated
amalg
amalg.
amalg.
383
384
385
386
387
388
389
390
391
392

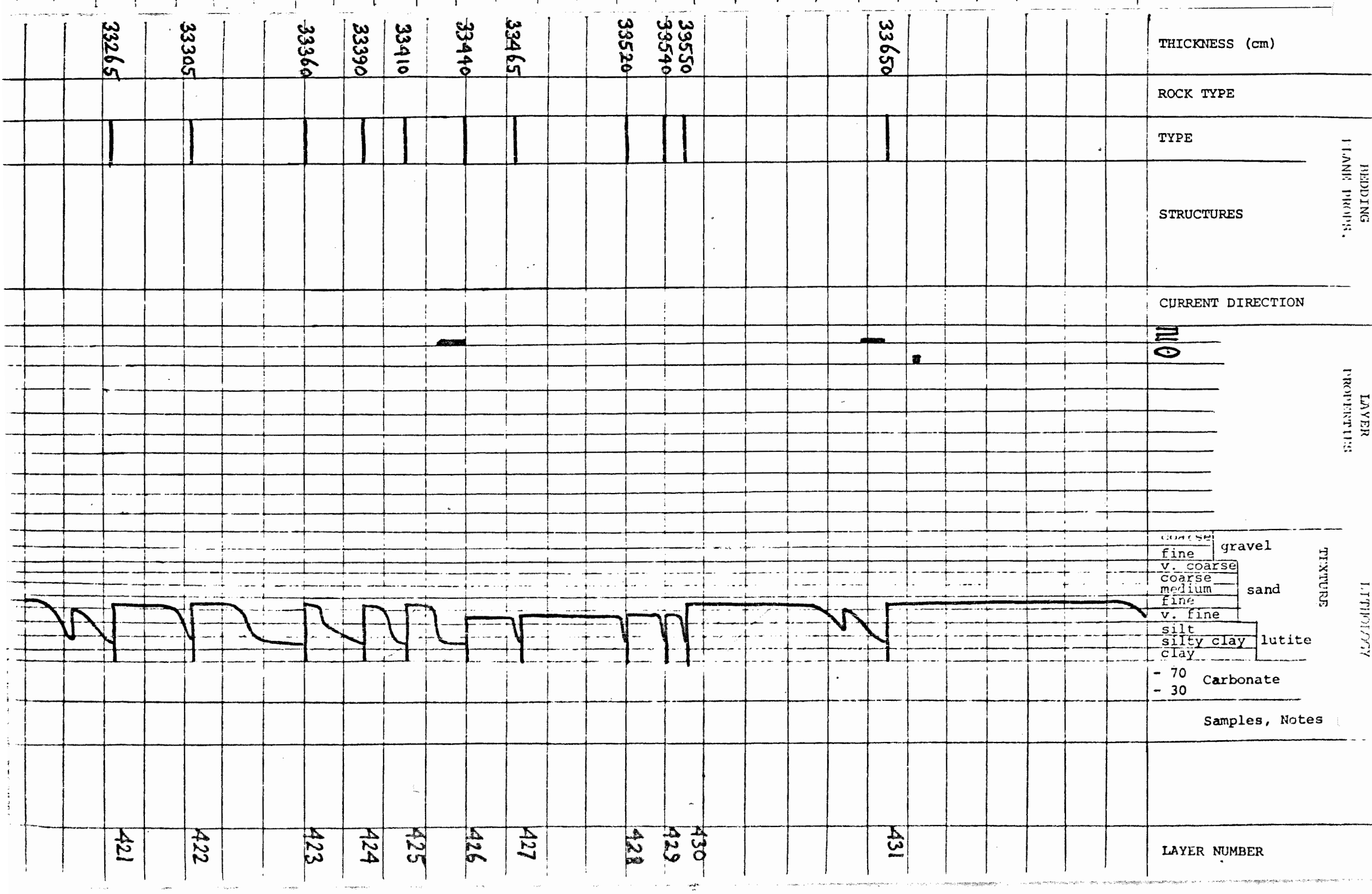
58


THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
LAYER NUMBER
32155
32225
32315
32355
32370
32385
32455
32505
32535
32570
32610
32640
32660
erosional
amalgamated
393
394
395
396
397
398
399
400
401
402
403
404

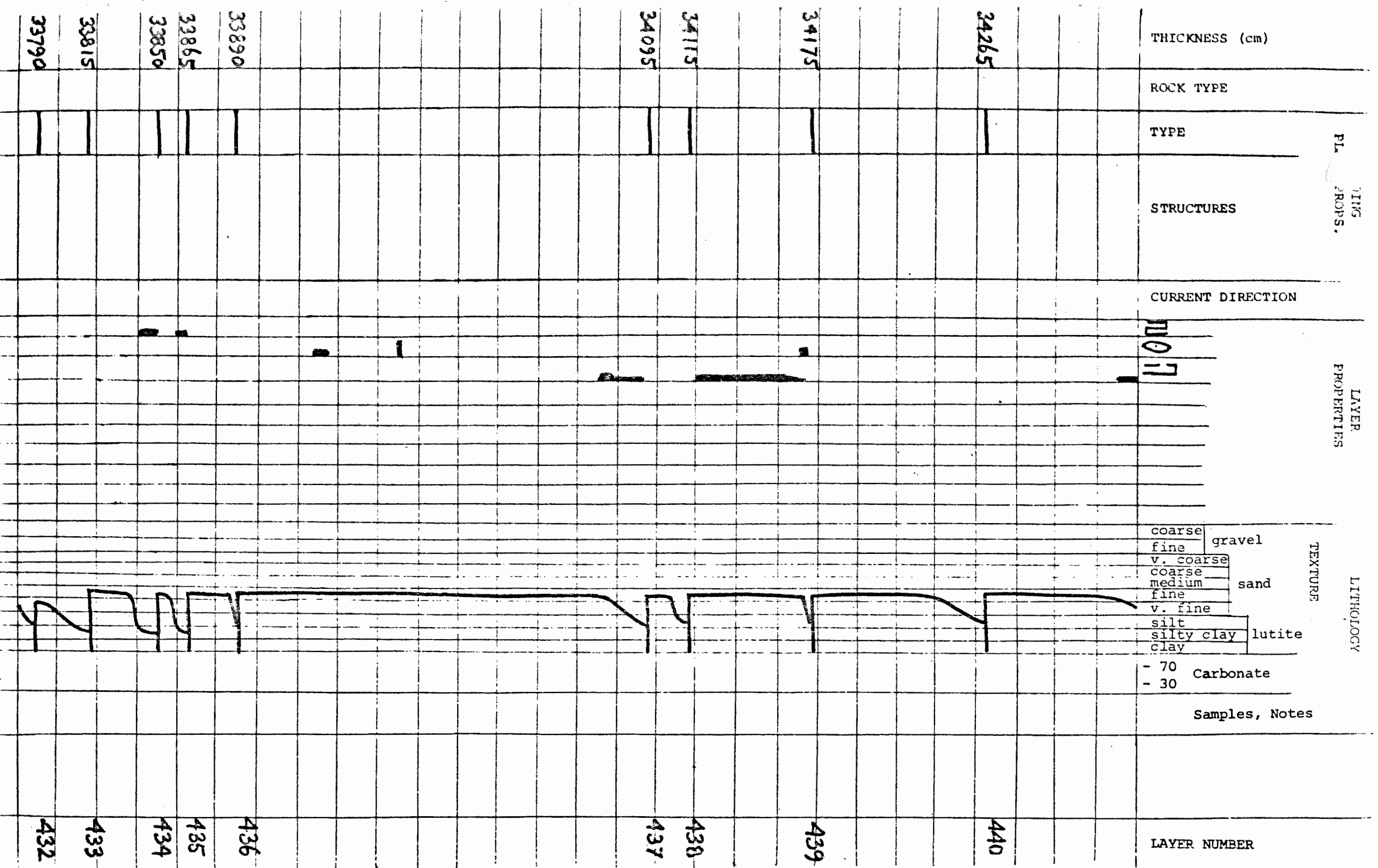
59

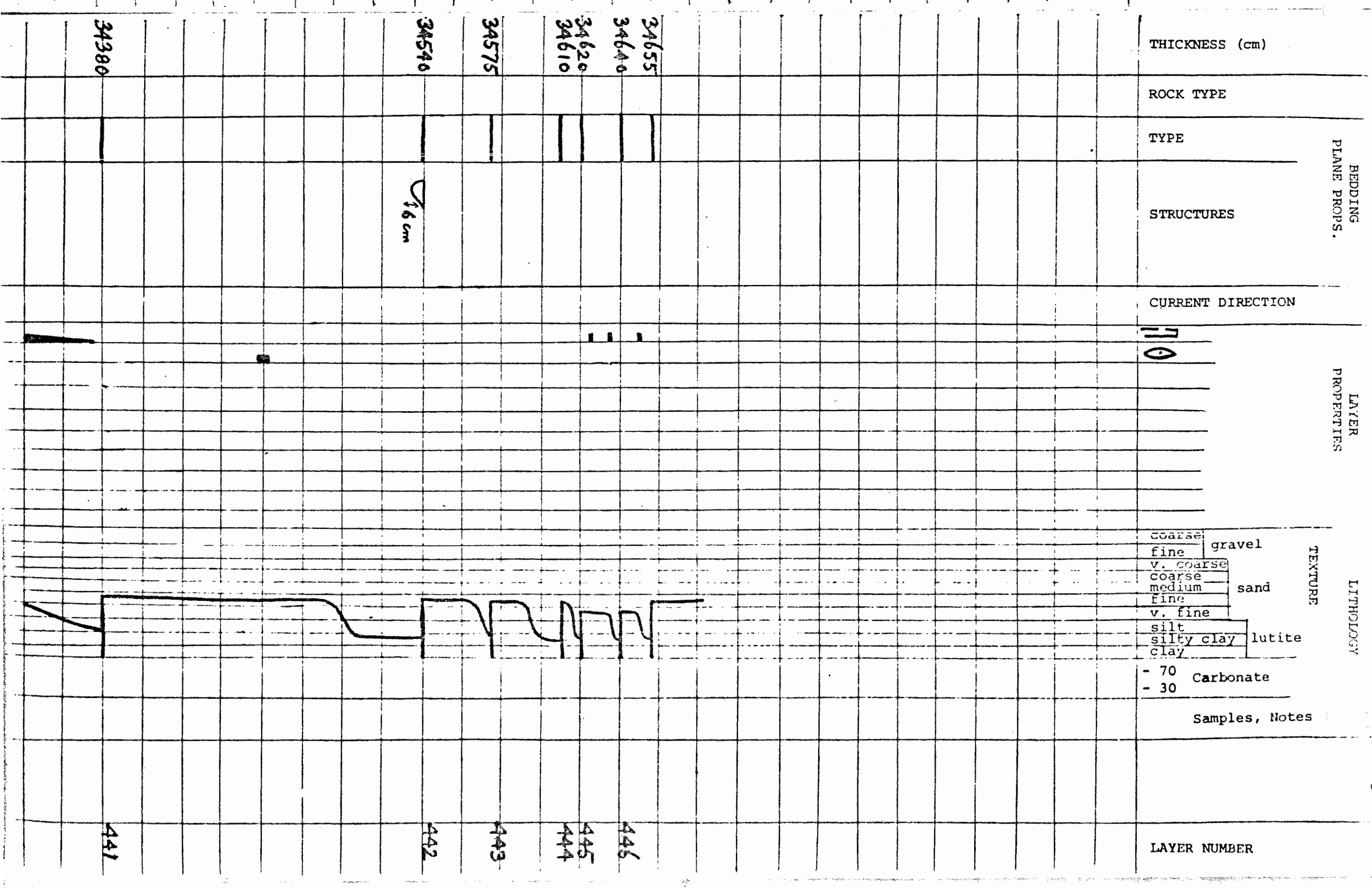

THICKNESS (cm)
32660
32690
32680
32710
32730
32745
32765
32785
32840
32855
32890
32900
32920
33080
33135
33200
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
LAYER NUMBER

60


THICKNESS (cm)
33265
33305
33360
33390
33410
33440
33465
33520
33540
33550
33650
ROCK TYPE
TYPE
BEDDING PLANE PROPS.
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
v. fine
sand
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
421
422
423
424
425
426
427
428
429
430
431
LAYER NUMBER

61


33790
33815
33850
33865
33890
34095
34115
34175
34265
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
62
432
433
434
435
436
437
438
439
440
LAYER NUMBER


34380
34540
34575
34610
34620
34640
34655
16 cm
THICKNESS (cm)
ROCK TYPE
TYPE
STRUCTURES
BEDDING PLANE PROPS.
CURRENT DIRECTION
LAYER PROPERTIES
coarse
fine
gravel
v. coarse
coarse
medium
fine
sand
v. fine
silt
silty clay
clay
lutite
TEXTURE
LITHOLOGY
- 70
- 30
Carbonate
Samples, Notes
63
441
442
443
444
445
446
LAYER NUMBER

DEPARTMENT OF GEOLOGY
DALHOUSIE UNIVERSITY
HALIFAX, NOVA SCOTIA
CANADA
B3H 4J1

DALHOUSIE UNIVERSITY, DEPARTMENT OF GEOLOGY

B.Sc. HONOURS THESIS

Author: John D. Dwyer

Title: Depositional Analysis of a Section of the Lower Meguma (Lower Paleozoic), Ship Harbour, Nova Scotia

Signature of author

John Dwyer

Date:

March 15th 1978

Estimated Time Spent on Thesis:

Mapping and Field Work -

7 weekends	fall 76 - mapping
3 "	March 77 - mapping
1 1/2 "	fall 77 - notes, photos

Computer work -

1 1/2 weeks	May 77 - punching cards, obtaining expanded field
2 weeks	fall-winter 77-78 - BDM Power Spectral program plus time determining best program for analysis

Visual and Hand Analysis -

1 week

Readings -

Summer 76, winter 76-77 time permitting - background reading
winter 77-78 - 2 weeks research

Writing -

1 week	winter 77-78
3 weeks	Feb.-March 78


Sand layer thickness (cm)
bed number
700 cm