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STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE MIDDLE DEVONIAN WATT MOUNTAIN FORMATION UTIKUMA LAKE AREA, ALBERTA

BY ©

JOHN BOURAK

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE MIDDLE DEVONIAN WATT MOUNTAIN FORMATION UTIKUMA LAKE AREA, ALBERTA submitted by JOHN BOURAK in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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ABSTRACT

Within the Nipisi field area located in north-central Alberta, Middle Devonian Watt Mountain Formation sediments accumulated in a north-south trending trough shaped feature. This Muskeg trough evolved throughout Middle Devonian time as a result of salt solution collapse in the underlying Muskeg Formation. The Muskeg trough fill consists of six cycles of deposition which record the progradation and abandonment of lacustrine braid-delta deposits.

Four recurring facies associations collectively suggest that the Watt Mountain Formation sediments in the Muskeg trough fill were deposited in a lacustrine braid-delta paleoenvironment. The four associations are: (1) lacustrine deposits, consisting dominantly of mudstones which were mostly deposited in the central and eastward b in area, (2) marginal lacustrine deposits, which were poorly developed and included fluvial mouth-bar, beach, and barrier deposits, (3) interdistributary deposits, consisting of a wide range of facies and sequences, (4) channel deposits, comprising the braided fluvial system sourced from the east.

Production in the Nipisi oil field is from the stratigraphically trapped Middle Devonian (Givetian) Gilwood Sandstone Member of the Watt Mountain Formation. The interbedding of the Gilwood Sandstone Member with Watt Mountain mudstones suggest that sedimentation occurred in cyclical paleoenvironmental conditions. Each of the Gilwood Sandstone Member depositional periods was attributed to tectonic activity associated with the Peace River Arch, while the Watt Mountain Formation mudstones were primarily deposited during relatively quiescent periods. The reservoir is present in six laterally continuous arkosic sandstone-dominated zones which vary in areal distribution. The distribution of each layer was controlled by the shape of the Muskeg trough and variations in the hydrologic conditions that existed during sedimentation.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 INTRODUCTION

1.1 Introduction

Oil production in the Nipisi field is from the Middle Devonian (Givetian) Gilwood Sandstone Member of the Watt Mountain Formation. Nipisi is a stratigraphically trapped reservoir located on the eastward flank of the ancestral Peace River Arch. Extensive development of this reservoir has significantly increased the well control available for use in geological studies, and has provided an opportunity to reevaluate the complex distribution of Watt Mountain Formation sediments.

Successful future exploitation of the Nipisi field is dependent on the understanding of the areal distribution and continuity of the Gilwood Sandstone Member and the effect of structural controls. Therefore, the major goal of this thesis is to gain these understandings by developing a depositional history that explains Watt Mountain Formation sedimentation in the Nipisi field area.

1.2 Study Area and Historical Development

This study is of the Watt Mountain Formation in the unitized outline of Nipisi Gilwood Unit No. 1, located in Townships 78 to 81, Ranges 7 to 9W5M, approximately 273 km (170 miles) northwest of Edmonton (Fig. 1.1). Currently, the unitized area covers approximately 300 km^2, and contains 330 producing oil wells and 76 injectors.

The discovery of the Nipisi field in 1965 was due to a prompt northward extension of the Gilwood play that followed the discovery of the Mitsue Oil field in 1964. The Nipisi field was unitized (Nipisi Gilwood Unit No. 1) in 1969, to enable the implementation of a waterflood maintenance scheme. In 1978, the Nipisi field was evaluated for the possibility of a miscible flood development project, and in 1984, the

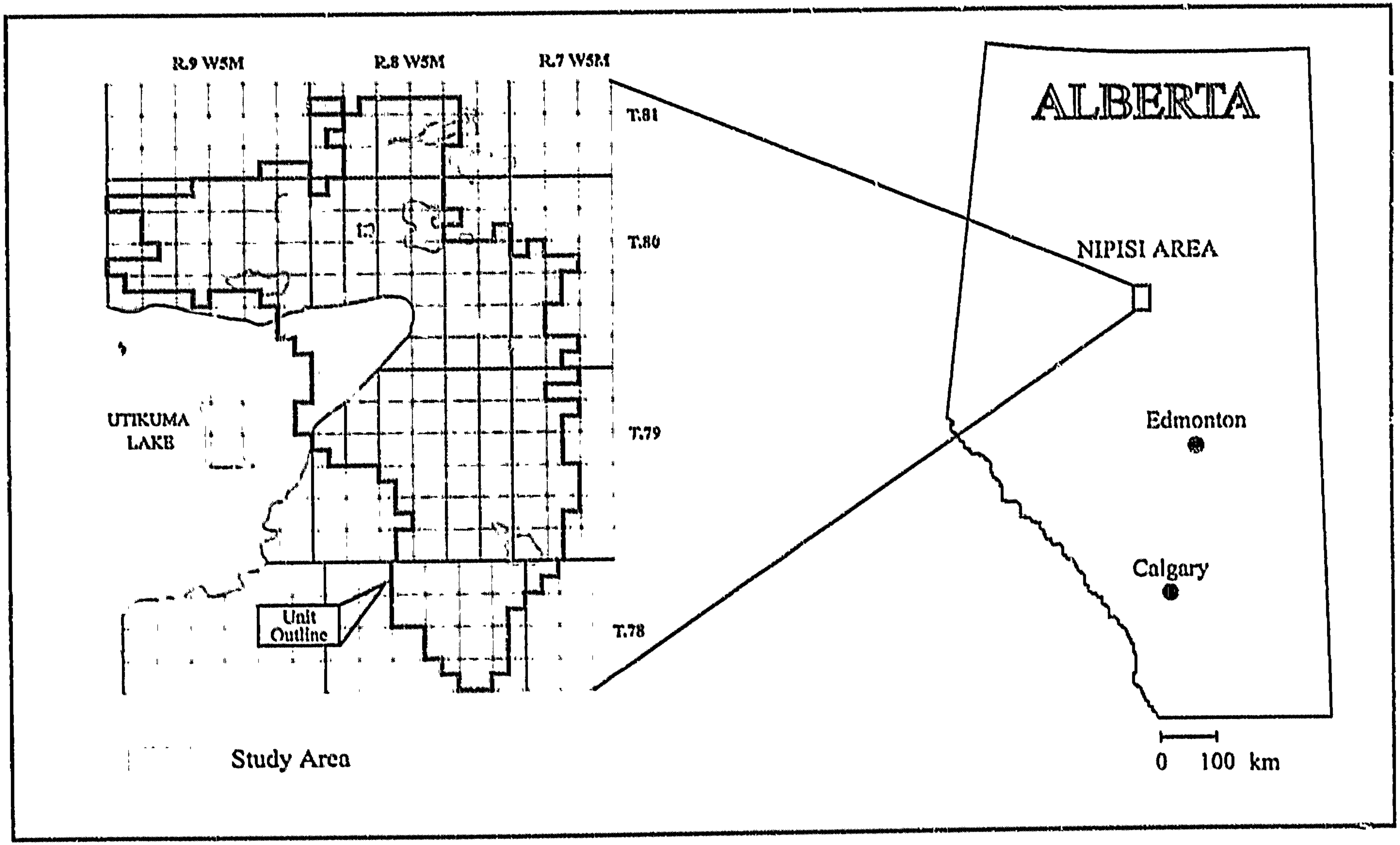


Figure 1.1 Study area location map illustrating the Gilwood Unit outline.

first miscible flood test area, named Stage I, was initiated to determine its effectiveness. Favorable production performance in Stage I prompted two further stages of miscible flood development: Stage II in 1986, and Stage III in 1988 (Fig. 1.2).

1.3 Goals and Objectives

The major goals of this thesis are to gain an understanding of the distribution and depositional nature of the Gilwood sandstones, and develop a geological model that will aid in the exploitation strategies of the Gilwood sandstone reservoir in the Nipisi field area.

The primary objectives were:

(1) to define sedimentary facies and vertical facies relationships in the Watt Mountain Formation;

(2) to develop a depositional facies model for the Watt Mountain Formation,

(3) to determine the influence and origin of the structural controls imposed on the Watt Mountain Formation;

(4) to map the distribution of the Gilwood Sandstone Member reservoir zones, and,

(5) to develop a depositional history of the Watt Mountain Formation.

The objectives of this study were accomplished by developing an extensive database using 52 core descriptions and 303 digitized mechanical well logs in the Nipisi field area (Fig. 1.3).

(1) Drill core descriptions

A total of fifty-two drill cores in the Nipisi field area were examined in Calgary at either the Energy Resource Conservation Board core research facility or the Shell

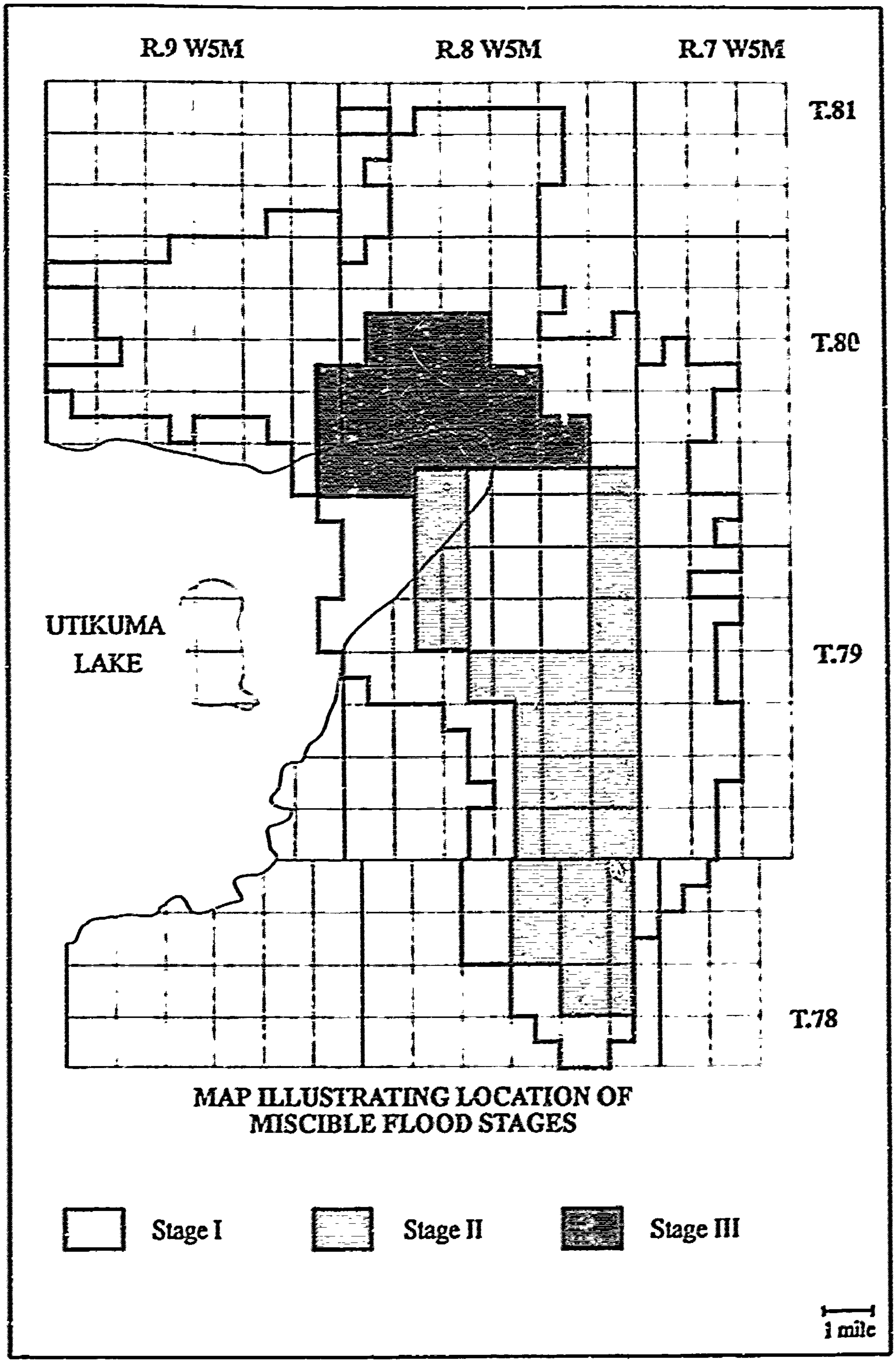


Figure 1.2 Location of miscible flood stages.

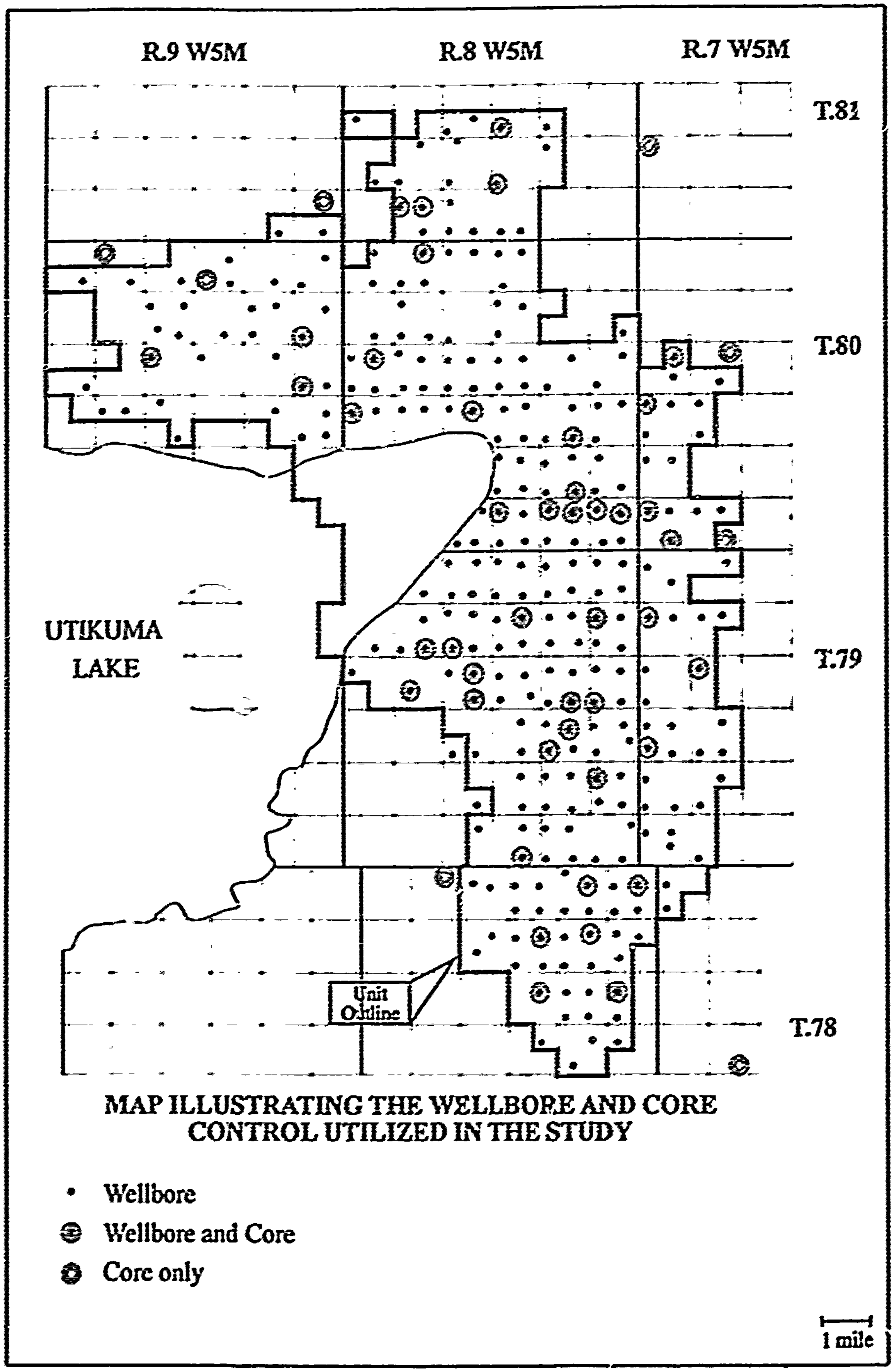


Figure 1.3 Map illustrating the wellbore and core control utilized in the study.

Canada core research center (Appendix A). The drill core descriptions include reference to:

(1) lithology,

(2) grain size and sorting characteristics,

(3) physical and biogenic sedimentary structures, and

(4) fauna content.

(2) Well logs

Digitized mechanical well logs from 303 wells were used to generate a subsurface database. The primary logs used included the Gamma Ray, Spontaneous Potential, Sonic, and Caliper. Before using these logs for correlations, they were normalized, expanded into a vertical scale of 1.15 m/cm, and calibrated with drill core data. The Spontaneous Potential and Gamma Ray logs proved to be the most useful, however, the Gamma Ray log was distorted in its reflection of shale content in the feldspathic sandstones. Once the database was generated, it was used to construct a collection of maps that illustrated the structural attitude of various paleosurfaces, and the three-dimensional distribution of the reservoir zones contained in the Watt Mountain Formation.

1.4 Previous Research

Research on the Watt Mountain Formation has been performed on both regional and local scales surrounding the ancestral Peace River Arch, and has provided published information on the petrology, sedimentology, and possible origins.

The Watt Mountain Formation was first named by Law (1955), and the Gilwood Sandstone as a member of the Watt Mountain Formation by Guthrie (1956) Guthrie

(1956) also referred to the Manning Wash on the north flank of the Peace River arch as a Gilwood equivalent. Greenwalt (1956) discussed the differentiation of the Granite Wash from the Manning or Gilwood, and Sikabonyi and Rodgers (1959) believed these two sands were time equivalents (Rottenfusser, 1974). A regional analysis of the Elk Point Group was presented by Suska (1963), who studied the Elk Point Group and Cambrian rocks of North-Central Alberta. The petrology and mineralogy of the Watt Mountain Formation in the Mitsue-Nipisi area have been studied by Kramers (1967), and Kramers and Lerbekmo (1967). Thachuk (1968) studied the sedimentology and depositional environments of the Watt Mountain Formation to determine the feasibility of waterflooding the Nipisi Oil field reservoir. He proposed that the sediments were deposited in a deltaic environment, and that they could be divided into 4 zones, each separated by a continuous shale bed. Shawa (1969) studied the Gilwood sandstone in the Nipisi field and proposed a deltaic origin for these sediments based on observations of textural analysis, paleocurrent analysis, sedimentary structures, and sandstone geometry. Nelson (1970) examined the cementing relationships in the Gilwood in the Mitsue oil field. Pugh (1972) discussed the relationship of the Gilwood Sandstone Member to both older coarse clastic detritus and to the Precambrian regolith. Jansa and Fischbuch (1974) discussed the evolution of Middle and Upper Devonian sediments in the Sturgeon - Mitsue area Alberta. Rottenfusser (1974), and Rottenfusser and Oliver (1977), described the petrology and depositional environments of the Watt Mountain Formation of Northern Alberta. Alcock and Benteau (1976) studied the physical characteristics and mineralogy of the Watt Mountain sediments and concluded that the Gilwood in the Nipisi field area was deposited in a fan-like deltaic system. They also divided the Nipisi field into three depositional realms. 1) alluvial plain, 2) delta plain and 3) delta front. Gibbs (1984) published an undergraduate thesis on the stratigraphy of the Gilwood in the Loon Creek area, in Alberta. Horn *et al.* (1985) published an abstract that suggested the Middle Devonian Gilwood sandstones of the Watt Mountain Formation in the Utikuma-Nipisi field area was deposited in a fan-delta setting.

1.5 Nomenclature

McGehee (1949) was the first to use the name Elk Point Formation after describing rock units located near Elk Point in east-central Alberta. Belyea (1952) gave the Elk Point Formation group status, and Workman (1953) further divided the Elk Point into Upper and Lower portions. The Watt Mountain Formation is part of the Upper Elk Point Group and was defined by Law (1955):

> "This is the uppermost unit of the Elk Point and corresponds approximately with Workman's (1953) upper variable unit. It consists of a maximum of 155 feet of shale, siltstone, sandstone, arkose, limestone breccia, anhydrite and dolomite. The lithologic character of the unit is controlled to a large extent by the distance from the Peace River landmass." (p. 1951)

Law (1955) described the Watt Mountain Formation in the California Standard's Steen River No. 2-22-117-5W6 well, completed in April of 1953. In this well, the Watt Mountain Formation starts at a depth of 1356.9 m, is 18.5 m thick, and completely cored.

Guthrie (1956) designated the Gilwood Sandstone as a member of the Watt Mountain Formation in his discussion of the lithology and stratigraphy of the Gilwood in the Giroux Lake area, in Alberta. He defined and described the Gilwood Member in the Stanolind Giroux Lake well in 6-20-65-20W5. In the 6-20 well, the Gilwood Member is 10.4 m thick, starts at a depth of 3068.6 m, and has two cored intervals, 3070.7 to 3071.9 and 3072.2 to 3085.9 m. Guthrie (1956) refers to the Gilwood as "an outwash of arkosic sands over the surface of older formations wedging out around the Peace

River land mass." He restricted the term "Gilwood" to the outwash sand because in areas proximal to the Arch there was difficulty in distinguishing between the Granite Wash and the Gilwood sand. Many workers, beginning with Suska (1963), refer to the Gilwood Sandstone instead of the Gilwood Member. This more descriptive notation is used in the petroleum industry to such an extent that the Gilwood Member is now mainly called the Gilwood Sandstone Member. This thesis will concur with the industry usage of Gilwood Sandstone Member for the sandstones in the Watt Mountain Formation.

Rottenfusser (1974) discussed the nomenclature problem that existed before the early 1970's in naming the sandstones in the Watt Mountain Formation north and south of the Peace River Arch. These sandstones were found to be correlative, but the Peace River Arch was used as a barrier to create separate names. The sandstones in the Watt Mountain Formation were referred to as Manning Sand north of the Peace River Arch and Gilwood Sandstone south of the Arch. However, the term Manning Sand has since been dropped from active use.

1.6 Stratigraphy and General Geology

The Elk Point Group represents the Middle Devonian of the Nipisi field area (Fig. 1.4). Law (1955) divided the Upper Elk Point Group into three formations. Keg River at the base, Muskeg in the middle, and Watt Mountain at the top. The Keg River consists of a Lower Keg River open marine limestone unit and an Upper Keg River reefal limestone unit. The open marine limestones developed during a transgression that began at the beginning of Keg River deposition, and the development of carbonate build-ups in the Upper Keg River deposits occurred during a period of moderate shallowing (McCamis and Griffith, 1967). Open marine conditions during Keg River deposition were followed by restricted conditions and the deposition of the evaporitic Muskeg

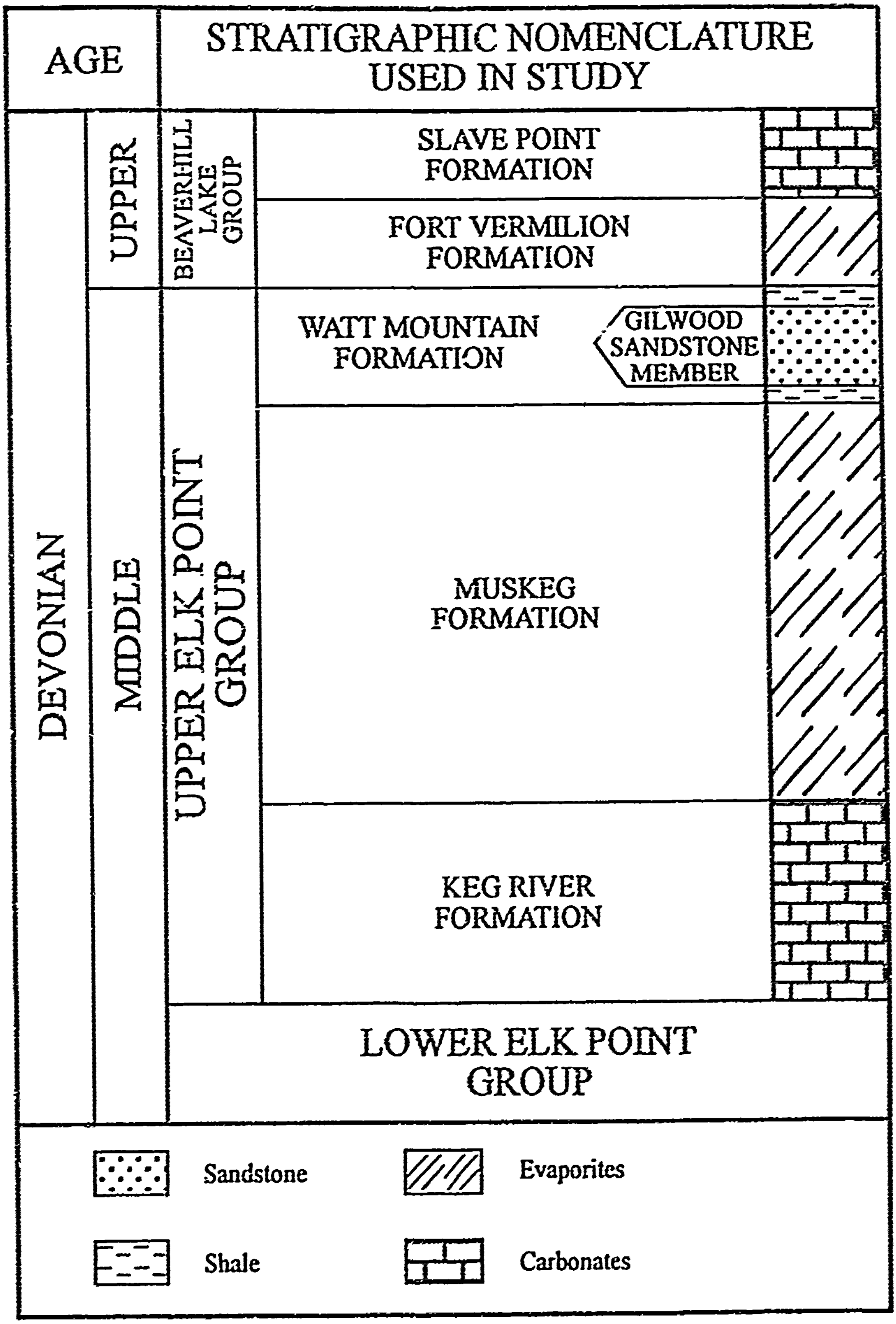


Figure 1.4 Stratigraphic nomenclature used in this study together with dominant formation and member lithology. Adapted from Bassett and Stout, 1967.

Formation. The Muskeg Formation consists of a basal salt deposit, and an upper unit of interbedded anhydrite and evaporitic dolomite. A regional uplift over the Peace River Arch and West Alberta Ridge resulted in the deposition of a regressive sandstone and shale sequence making up the Watt Mountain Formation (Bassett and Stout, 1967). The sandstones, defined as the Gilwood Member by Guthrie (1956), were deposited in cyclic sequences associated with tectonic activity associated with the Peace River Arch (Cant, 1988). After deposition of the Watt Mountain clastics, a standstill, or slight regression of the sea, resulted in the deposition of evaporites that make up the overlying Upper Devonian Fort Vermilion Formation. This slight regression was followed by a main transgressive phase of the late-middle Devonian, which deposited the limestones of the Slave Point Formation (Jansa and Fischbuch, 1974).

1.7 General Setting and Tectonic Framework

A regional framework for the deposition of Watt Mountain Formation is discussed here to place the study area in its appropriate paleogeographic setting. Devonian sediments of the Interior Plains and eastern Rocky Mountains were deposited on a slowly subsiding tectonic shelf bordering the Canadian Shield (Bassett and Stout, 1967). During the Middle Devonian, the Elk Point Sea covered most of Alberta, Saskatchewan, and Manitoba, and was partially separated from the sea over British Columbia by the exposed Western Alberta Ridge and Peace River High (Fig. 1.5) (Nelson, 1970). These two exposed highs strongly influenced the deposition of Middle Devonian sediments (Bassett and Stout, 1967).

The study area is located approximately 30 kilometers east of the eastern flank of the Peace River Arch, a feature that was tectonically active over a 500 m.y. period (O'Connell *et al.*, 1990). The proximity of the Nipisi field area to this activity was

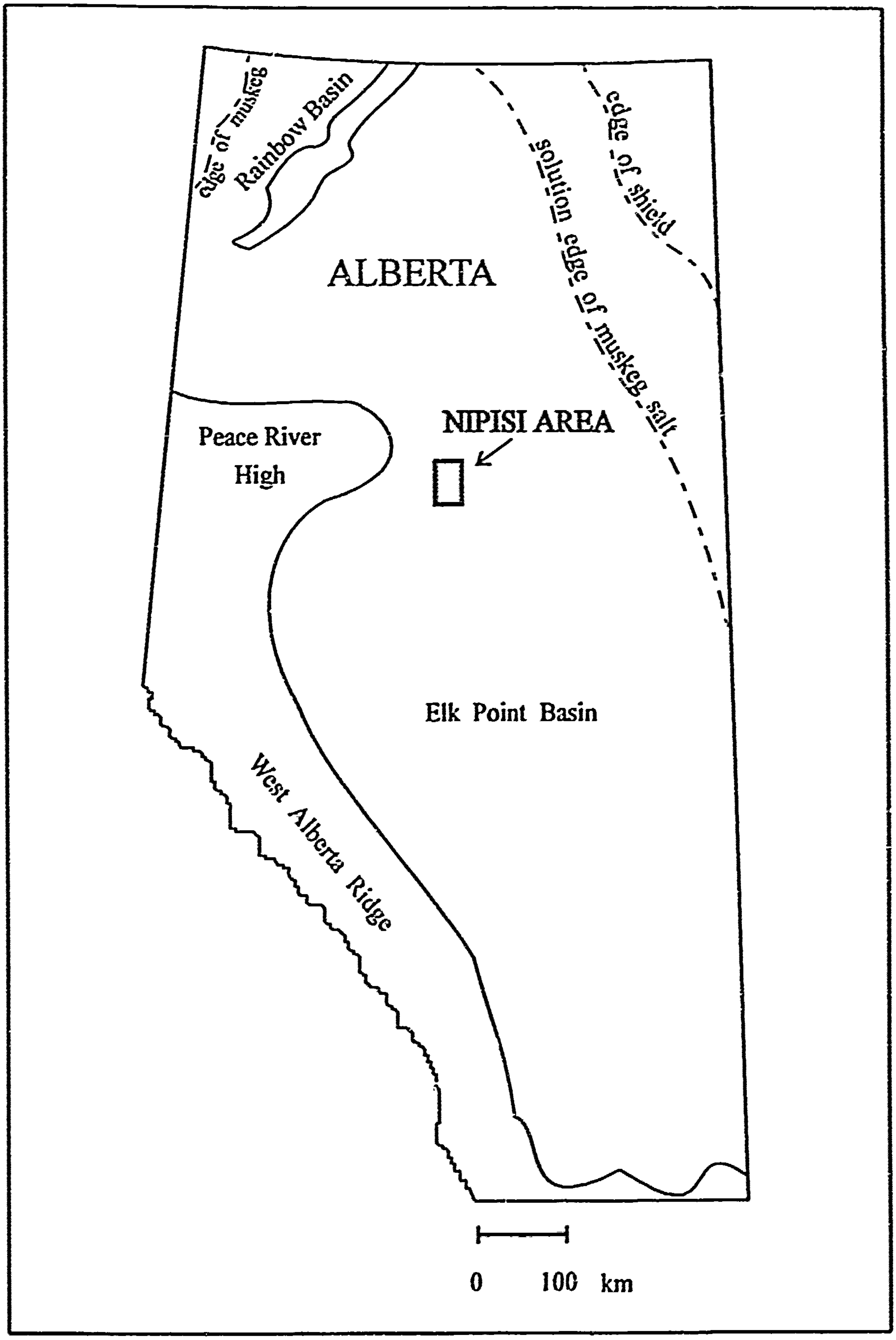


Figure 1.5 Middle Devonian tectonic and regional framework map of Alberta. Adapted from Bassett and Stout (1967).

undoubtedly a factor in the development of the present structural attitude of the Middle Devonian sediments in this area. The Peace River Arch is a major crustal structure that consists of uplifted Precambrian rock, and is associated with many faults that cut the overlying Devonian, Mississippian, and Pennsylvanian sediments (Cant, 1988).

The exact timing of the Arch's initial phase of uplift is uncertain, but evidence of sandy Middle Cambrian units terminating against the Arch suggests that the initiation of the Peace River Arch had occurred by the Mid-Cambrian (Pugh, 1972, Cant, 1988). Silurian sediments preserved to the north, northwest, and southwest of the Peace River Arch indicates that it was emergent at this time (Norford, 1990). By the Middle to Late Devonian the first episode of normal faulting occurred (Cant, 1988). These faults generated local topographical relief which enhanced the erosional activity on the Peace River Arch. This erosion was the source of the clastic debris that accumulated at Nipisi. Cant (1988) suggested that the interbedding of these clastics with other Elk Point Group sediments indicates that several distinct episodes of tectonism occurred during this time However, Basset and Stout (1967) and Geldsetzer (1990) believe that the development of the clastics occurred during a major regressive hiatus in the basin.

The Arch persisted as a positive tectonic feature until the slow transgression that started during Upper Devonian time gradually transgressed the elevated areas (Sikabonyi and Rodgers, 1959). Besides gradual eustatic sea level rise, the burial of the Arch may also have also occurred through subsidence or a combination of the two (O'Connell *et al*, 1990). Although the Arch was no longer emergent, faulting and subsidence continued throughout the Mississippian and Pennsylvanian, and it was not until the end of Pennsylvanian-Permian deposition that major structures became inactive (Cant, 1988). Because the Arch was the source of Gilwood clastics, stratigraphic and structurally trapped Gilwood reservoirs occur in close proximity to it (Figs. 1.6 and 1.7).

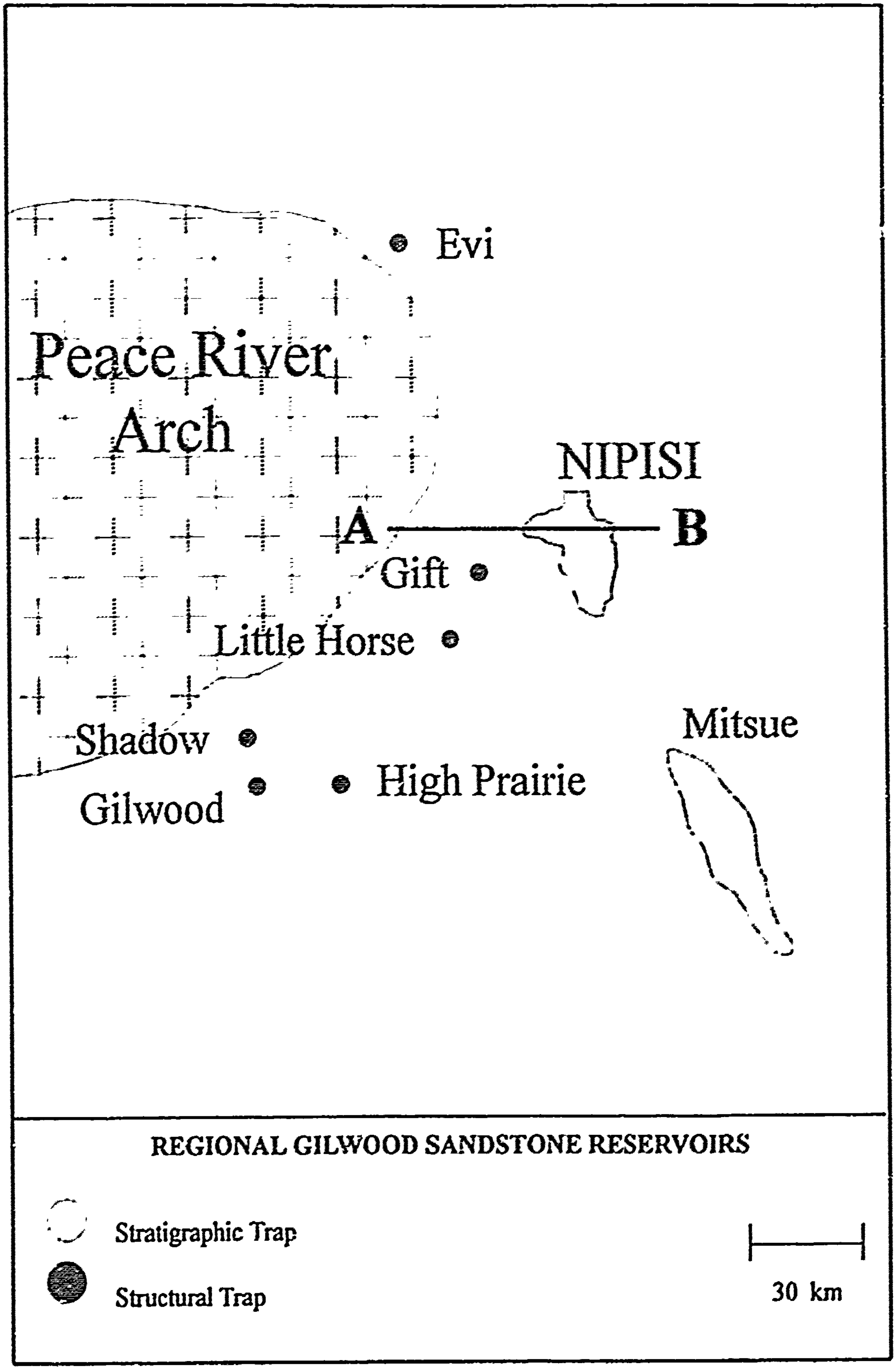


Figure 1.6 Location of regional Gilwood Sandstone reservoirs.

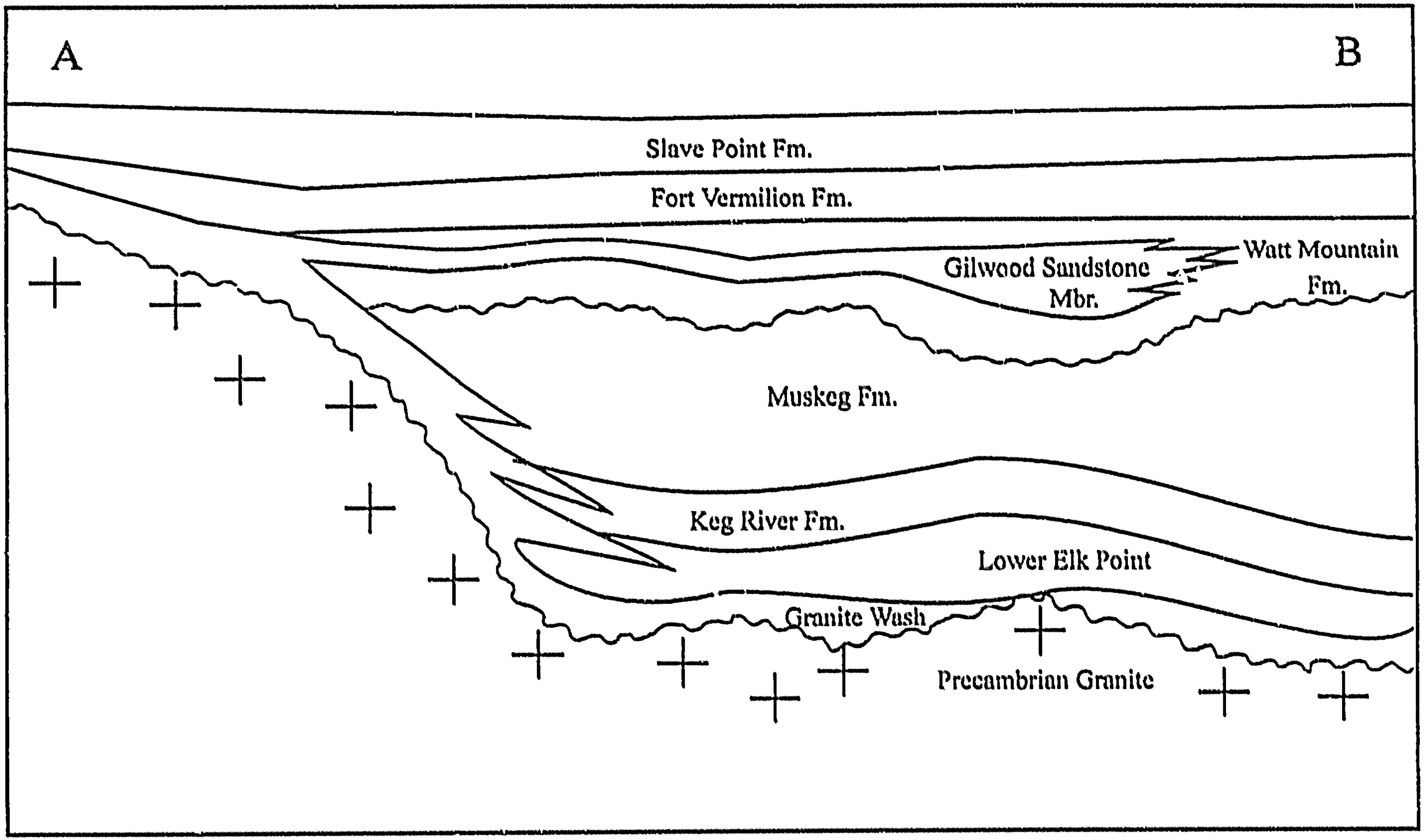


Figure 1.7 Schematic cross section A-B (referenced in Fig. 1.6) illustrating Elk Point sediments onlapping the Peace River Arch in the Nipisi area. Adapted from Shawa (1969).

1.8 Division of the Watt Mountain Formation

With limited well control, Thachuk (1968) divided the Watt Mountain Formation into 4 zones, each containing one or more sandstone beds. However, the present study shows that it is possible to divide the sandstone-dominated units into 6 discrete correlatable zones (Figure 1.8).

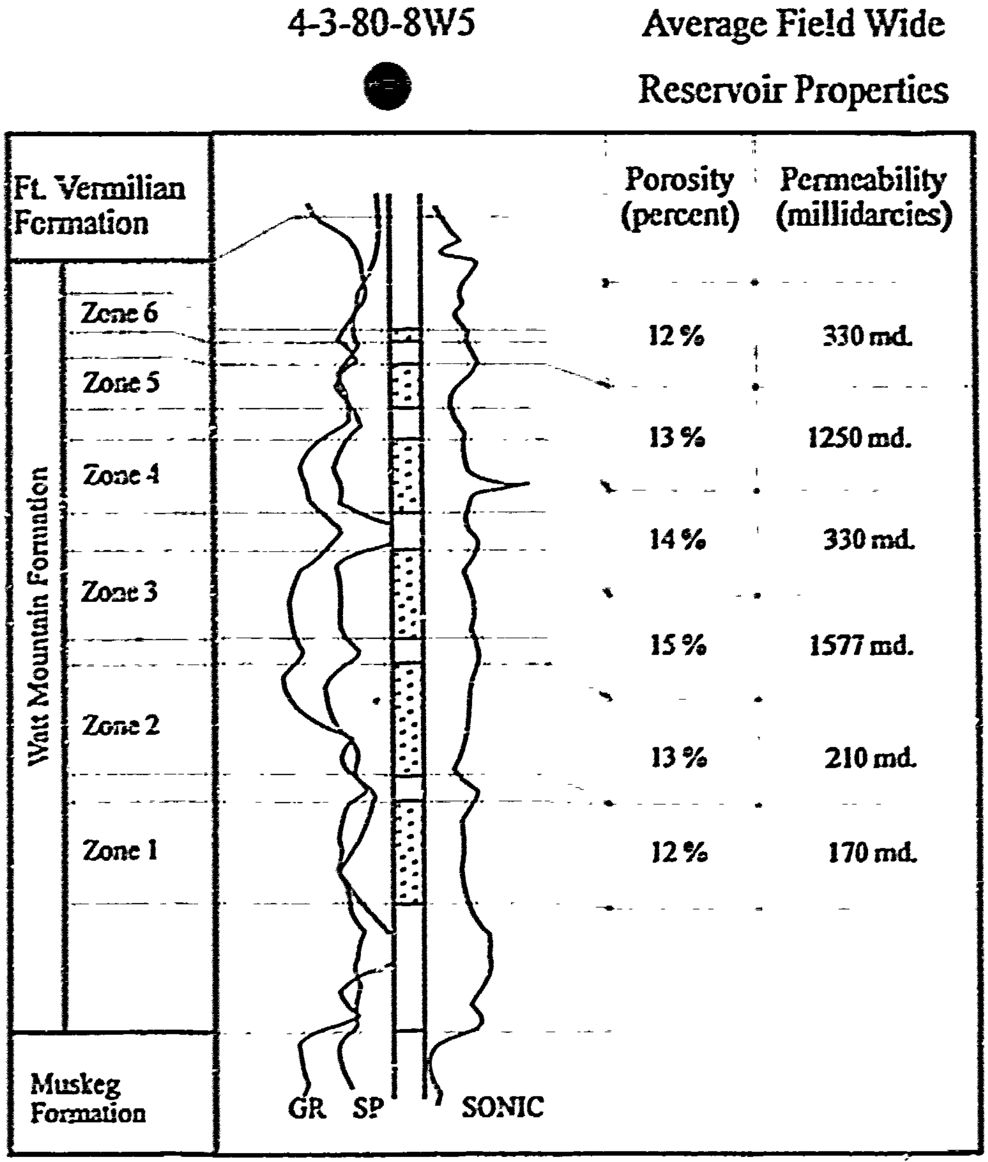


Figure 1.8 Illustration of the six Gilwood Sandstone Member zones of the Watt Mountain Formation together with average reservoir properties

CHAPTER 2 COMPOSITION OF WATT MOUNTAIN SEDIMENTS

2.1 Sandstones

The average composition of the Gilwood Sandstone Member in the Nipisi field area has been documented by Kramers and Lerbekmo (1967), Thachuk (1967), and Alcock and Benteau (1976). Because of this writer's division of the Gilwood into 6 correlatable zones, 2 thin sections from each zone were evaluated to determine if any of the zones had a distinct mineralogical difference. The results showed that all zones had similar mineralogic characteristics, suggesting a similar source for all episodes of clastic deposition in the Nipisi Field area (Table 2.1).

Mineral	Average %
Quartz	57.5
Feldspars	24.8
Carbonate	4.1
Anhydrite	6.8
Accessories	<1.0

Table 2.1 Average Mineralogy of Watt Mountain Sandstones based on all published compositional data.

On the basis of their compositional range, the Gilwood sandstones are classified as arkoses and subarkoses according to the mineralogic classification system for sandstones used by McBride (1963). Accessory minerals and rock fragments generally make up less than 1 percent of the sandstones, and can include detrital biotite, chert, igneous-metamorphic rock fragments, and shale fragments (Kramers and Lerbekmo, 1967).

2.2 Mudstones

The mineralogy of the Watt Mountain Formation mudstones was analyzed using x-ray diffraction techniques at Shell Canada's Research Centre in Calgary, Alberta. Eight samples from four wells were processed for bulk analysis, and one sample was further analyzed to separate the clay fraction (Table 2).

Clays in the mudstone samples included illite, kaolinite, and chlorite. Illite was the main clay component in all 8 samples, averaging 36%, kaolinite and chlorite were clearly subordinate. This ranking is consistent with the findings of Kramers and Lerbekmo (1967), Rottenfusser (1974), and Alcock and Benteau (1976). The large amounts of illite reflects the abundance of potassium-rich minerals found in the Gilwood sands. Potassium rich clays like illite are generated at the expense of potassium rich minerals and potassium poor clays (Retallack, 1990).

Alcock and Benteau (1976) analyzed samples from three wells in the Nipisi area and reported that a high dolomite content compared to calcite was a characteristic feature of Watt Mountain Formation mudstones in the Nipisi area. In this thesis, half the processed samples detected only <1% dolomite, and calcite was found in amounts up to 13%. The combined results reflect a broader view of carbonate content in the Nipisi Field, a view that corresponds with Watt Mountain Formation mudstone compositional values in other field areas. Rottenfusser (1974) analyzed Watt Mountain Formation mudstones north of the Peace River Arch, and proved a relationship between higher proportions of calcite and proximity to freshwater limestone deposits. Thinner limestones with a similar appearance were found in the Nipisi area, and may also be the source of local increases in carbonate content. Quartz and potassium feldspar was detected in all samples, and their abundance is directly related to the sand and silt content of the mudstones.

Location 12-24-78-08W5

Depth	Qtz	Plag	K-feld	Calc	Dol	Anhy	Sid	Pyr	Kaol	ill	Chl
5676 ft	17	-	4	-	20	-	-	-	7	52	-
5686 ft	25	-	4	1	41	2	-	-	4	23	-

Location 10-27-78-08W5

Depth	Qtz	Plag	K-feld	Calc	Dol	Anhy	Sid	Pyr	Kaol	Ill	Chl
5699.5 ft	10	-	5	12	-	-	<1	-	-	63	10
5699.6 ft	7	-	4	13	-	-	<1	-	-	67	9

Location 12-20-79-08W5

Depth	Qtz	Plag	K-feld	Calc	Dol	Anhy	Sid	Pyr	Kaol	Ill	Chl
5543.8 ft	36	2	7	-	14	3	-	2	11	24	-
5564.2 ft	30	-	28	10	<1	3	-	2	1	25	-

Location 12-21-80-09W5

Depth	Qtz	Plag	K-feld	Calc	Dol	Anhy	Sid	Pyr	Kaol	Ill	Chl
5636 ft	35	-	51	9	<1	2	<1	-	-	2	-
5647 ft	30	-	28	10	<1	3	-	2	1	25	-

Table 2.2 Mineralogy of Watt Mountain Formation Mudstones
From X-ray Diffraction Analysis.

2.2.1 Relationship of Composition and Colour

Based on the G.S.A. colour chart, the Watt Mountain Formation mudstones are present in solid and variegated varieties of medium gray (N 5), olive-gray (5 Y 4/1), pale-green (10 G 6/2), grayish-green (5 G 5/2), dark reddish-brown (10 R 3/4), dusky-red (5 Y 3/4), and black. Although there is a coloured variety of mudstones, at all sandstone- mudstone contacts the colour was always green. An attempt was made to determine if the green colouration was a result of mineralogical differences.

Four pairs of mudstone samples, one red and one green, were taken from the same well location and analyzed with x-ray diffraction techniques to determine the mineralogy. In the 10-27 well, the possible error of sampling from different types of mudstones was decreased by taking samples of each colour 4 cm apart. The data provided no evidence to suggest that the colour difference was caused by differences in mineralogy (Table 2.2). Kramers and Lerbekmo (1967) also found no correlation between total iron content and colour of the mudstones in Watt Mountain Formation mudstone samples in the Mitsue field. They concluded that colour differences were caused by different oxidation states of the iron present. The theory that colour is independent of total iron content and dependent on $Fe^{3+}:Fe^{2+}$ has been demonstrated by workers including Tomlinson (1916), Pettijohn (1975), and McBride (1974). Potter *et al.* (1980) concluded from Van Houten's (1973) work that the colour in sediments can be changed so easily that it is usually of depositional or diagenetic origin rather than detrital. The exact cause of the green colouration occurring at all mudstones-sandstone contacts is unknown, but because of their similar mineralogy and the presence of green reaction zones at all sandstone-mudstone contacts, it is likely that the green colouration has a diagenetic origin.

CHAPTER 3 FACIES DESCRIPTIONS AND INTERPRETATIONS

3.1 The Facies Concept

Although the word facies is seen regularly in published work, it has been used in the wrong context so often that its usefulness as a geologic term has been hampered. Conceptual problems of the term have centered on its misuse as a purely descriptive term, and its use in branches of scientific work other than sedimentary geology.

Facies is a Latin word derived from *facia* or *facies* meaning the external appearance or look of something (Teichert, 1958; Walker, 1984). It was initially introduced into the geologic literature by Nicolaus Steno in 1669 to signify the entire aspect of the earth's surface during an interval of geologic time. Modern scientific usage of the facies concept was derived from comparative stratigraphic studies done in 1838 by Swiss geologist, Amand Gressly (Teichert, 1958). Although Gressly is regarded as the founder of the facies concept, another geologist, Prevost, can rightly be regarded as a co-founder (Teichert, 1958). Prevost independently deduced similar principles to that of Gressly at around the same time, but by using only simple reasoning and observation (Teichert, 1958). A translation of Gressly's definition was given by Teichert (1958), and reads as follows:

> "To begin with, two principal facts characterize the sum total of the modifications which I call facies or aspects of a stratigraphical unit: one is that certain lithological aspect of a stratigraphic unit is linked everywhere with the same paleontological assemblage, the other is that from such an assemblage fossil genera and species common in other facies are invariably excluded."

The core of Gressly's 1838 facies concept was the interdependence of lithological and paleontological information. Scientists commonly separate the lithological and paleontological aspects of by using terms like "lithofacies" and "biofacies", however, these concepts are intermixed (Middleton, 1978). Gressly also implied that facies were to be areally unrestricted. For example, Middleton (1978) pointed out an exemplary example of the use of facies by De Raaf *et al.* (1965), who subdivided a group of three formations into a cyclic repetition of facies distinguished by "lithological, structural and organic aspects detectable in the field."

The term "facies" is a purely descriptive one representing the sum of primary lithological and paleontological properties of a stratigraphic unit, and is to be used in an areally unrestricted sense. Individual facies are important for providing insight toward the hydrodynamic and ecological conditions at time of deposition. The most common misuse of the facies concept is the application of facies to assumed environmental conditions rather than to reconstructing environments by means of the study of facies (Middleton, 1978).

3.2 Facies Descriptions and Interpretations

Lithological, sedimentological, and paleontological features were used to define eight distinct facies in the Watt Mountain Formation in the Nipisi field area. The following is a description of those eight facies and the interpreted paleohydrodynamic conditions that generated them. The significance of the paleontological features will be discussed more thoroughly in Chapter 4.

3.2.1 Facies 1 - Black Shale

Description

Facies 1 is a distinctive black shale that ranges from 0.03 - 0.45 m in thickness (Fig 3.1). The shale contains thin (<1 mm) horizontal laminations and was typically very

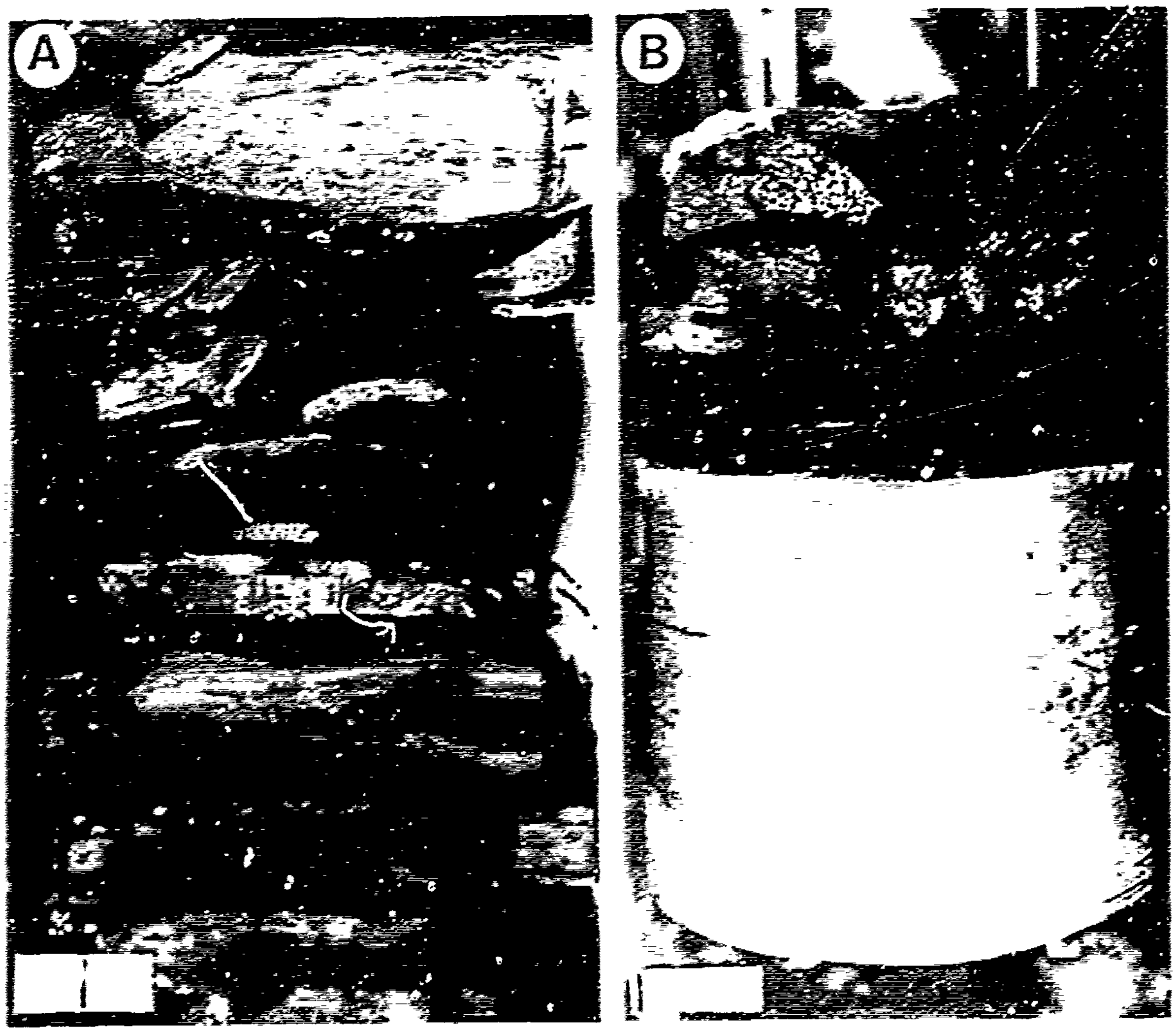


Figure 3.1 Facies 1 (Black Shale Facies)

A) Typical black fissile shale of facies 1. Note the contact with an overlying grayish green mudstone 2.5 cm from top of core. The photograph is from 4-25-80-9W5, 1695.8 m. Scale bar is 2 cm.

B) Contact of black shale with underlying anhydritic shale of the Muskeg Formation. The photograph is from 4-18-79-7W5, 1717.0 m. Scale bar is 2 cm.

fissile. It was located at or near the basal contact of the Watt Mountain Formation where it predominantly occurs as a single bed, but occasionally it was interbedded with a tan to variegated-in-colour anhydritic shale. Both upper and lower bedding contacts are always sharp and planar. No biogenic sedimentary structures were observed in the black shales, however, body fossils identified as *Lingula* occur in moderate amounts

Interpretations:

These laminated black shales are vertically accreted deposits reflecting the process of suspension settling in a very low energy environment The lack of silt or sand-sized particles suggests that the energy levels remained low throughout deposition In order for these shales to develop their black colouration they must contain >3% organic carbon (Potter *et al.*, 1980). Because organic matter is best preserved in anaerobic conditions, black shales are mostly interpreted to represent deposition at water depths greater than 50 meters (McCollum, 1988). However, Selley (1985) demonstrated that stratification of the water column and development of anoxic condition can occur in shallow water environments.

This facies has a distinct lack of diverse benthic fauna and biogenic structures, suggesting that ecological conditions were largely unfavorable for the survival of most organisms.

3.2.2 Facies 2 - Mudstone

Description:

Facies 2 is composed of mudstones that are commonly silty and sandy, and exist in a variety of colours including solid and variegated shades of grayish green, dusky red, and rarely gray (Fig. 3.2 (A-D)) Average units are 1.5 m thick, and thicknesses range

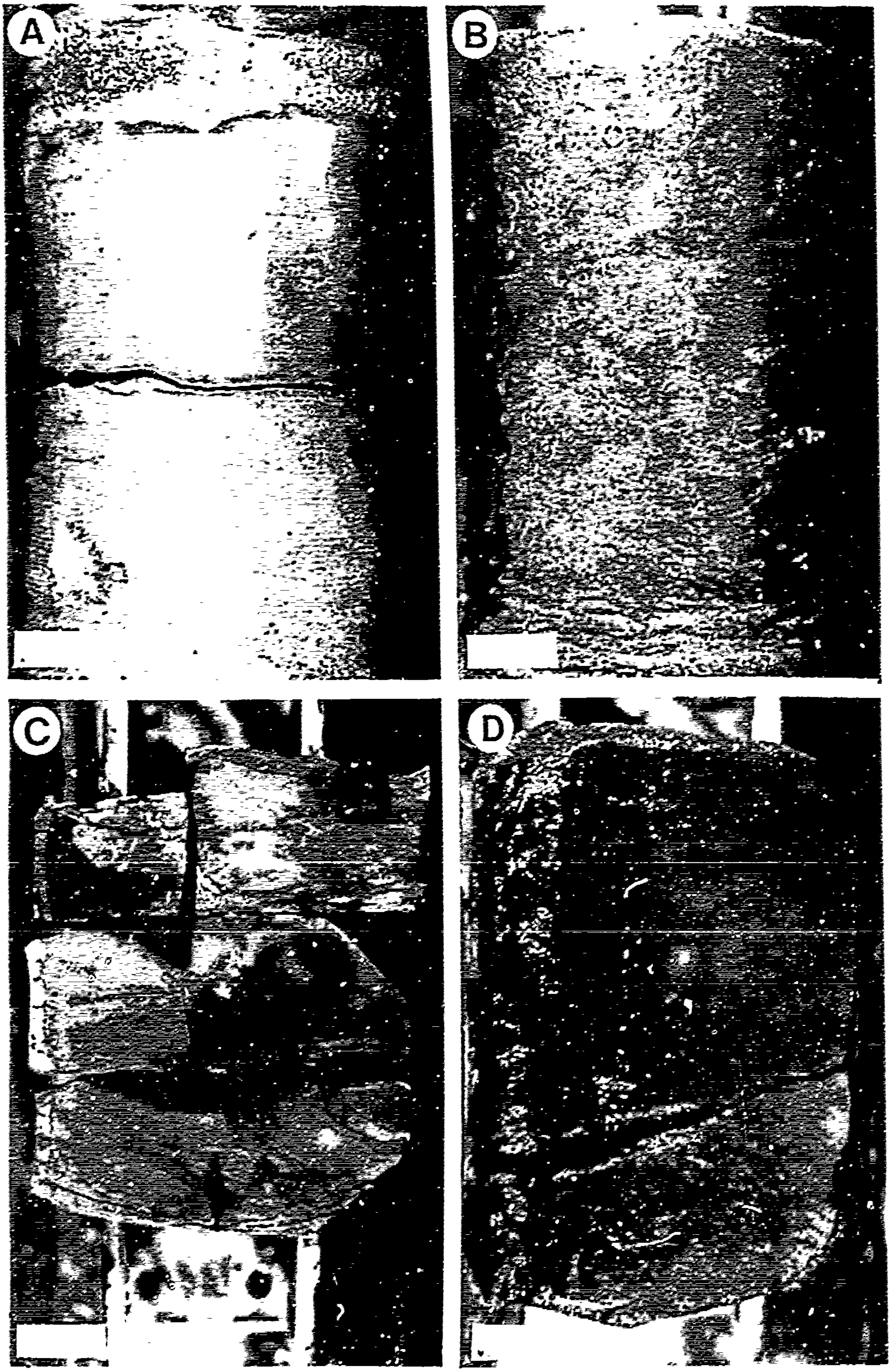
Figure 3.2 (A-D) Facies 2 (Typical Green and Red Mudstone)

A) Pale green mudstone with scattered fine to coarse sand sized grains at the base, and a thin (1.5 cm) sandstone bed near the top of core. The photograph is from a mudstone unit below Gilwood zone 2 in 4-18-79-7W5, 1715.6 m. Scale bar is 2 cm.

B) Dusky green silty mudstone with sparse sand size grains. The photograph is from the uppermost mudstone unit in the Watt Mountain Formation in 10-21-79-8W5, 1739.2 m. Scale bar is 2 cm.

C) Dark reddish brown blocky mudstone. The photograph is from a mudstone unit below Gilwood zone 2 in 10-21-79-8W5, 1744.0 m. Scale bar is 2 cm.

D) Dark reddish brown blocky mudstone. The photograph is from a mudstone unit below Gilwood zone 5 in 4-25-80-9W5, 1718.4 m. Scale bar is 2 cm.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from a few cm to 5.2 m. Single mudstone beds are displayed in units of alternating colours of red and green, separated by either sharp or gradational contacts. Mudstone beds are typically bounded above and below by sandstones. Lower mudstone-sandstone contacts can be sharp or gradational, while upper contacts are always sharp and occasionally scoured. Scattered sandstone grains ranging from very fine to very coarse are present in the majority of mudstone beds. These scattered grains may exist throughout the facies or in localized areas, and are mostly found near the upper and lower contacts.

Slickensided surfaces are present in these mudstones. They are best viewed on the plane view of a vertical core where they can either cover the entire surface area, or are smaller (<1 cm), diffuse, and randomly arranged. Associated with the small slickensides is a crumbly texture, as opposed to a typical blocky texture of mudstones without slickensides.

The mudstones occasionally contain polygonal and irregular shaped cracks, which were most often filled with a fine-grained sandstone (Fig. 3.2 (E-F)). Sand filled cracks in red mudstones exhibit a thin (1-3 mm) green coloured zone at the edges of the crack that enhanced its visibility. Some mudstones contain nodules that are typically brecciated, but whole forms up to 2.5 cm in diameter were also observed (Fig. 3.2 (G-H)). The mudstones of this facies also contain very rare sand filled vertical fractures (Fig. 3.2 (J)).

In the mudstones are rare, scattered, and randomly oriented calcareous intraclasts and calcareous zones. They are either spherical, elongate, or irregular in shape, and have maximum diameters ranging from 0.2 to 2.5 cm (Fig. 3.2 (K)).

Figure 3.2 (E-H) Facies 2 (Mudcracks and Irregular Shaped Nodules)

E) Sand filled polygonal shaped mud cracks in a variegated dark reddish brown and pale green mudstone. The photograph is a bedding plane view of a mudstone unit below Gilwood zone 2 in 4-18-79-7W5, 1715.9 m. Scale bar is 2 cm.

F) Small irregular shaped mudcracks filled with a very-fine grained sand, in a variegated dark reddish brown and pale green mudstone. Note how the visibility of the mudcracks is enhanced by the presence of a thin (1 mm) pale green reaction zone. The photograph is a bedding plane view of a mudstone unit below Gilwood zone 2 in 4-18-79-7W5, 1715.9 m. Scale bar is 2 cm.

G) Brecciated appearance of a dark reddish brown mudstone. Note an original spherical shape (S) associated with the brecciated area. The photograph is from a mudstone unit just above Gilwood zone 1 in 10-19-80-7W5, 1691.1 m. Scale bar is 2 cm.

H) A septarian concretion developed in a dark reddish brown mudstone. The photograph is from a mudstone unit above Gilwood zone 1 in 10-19-80-7W5, 1689.5 m. Scale bar is 2 cm

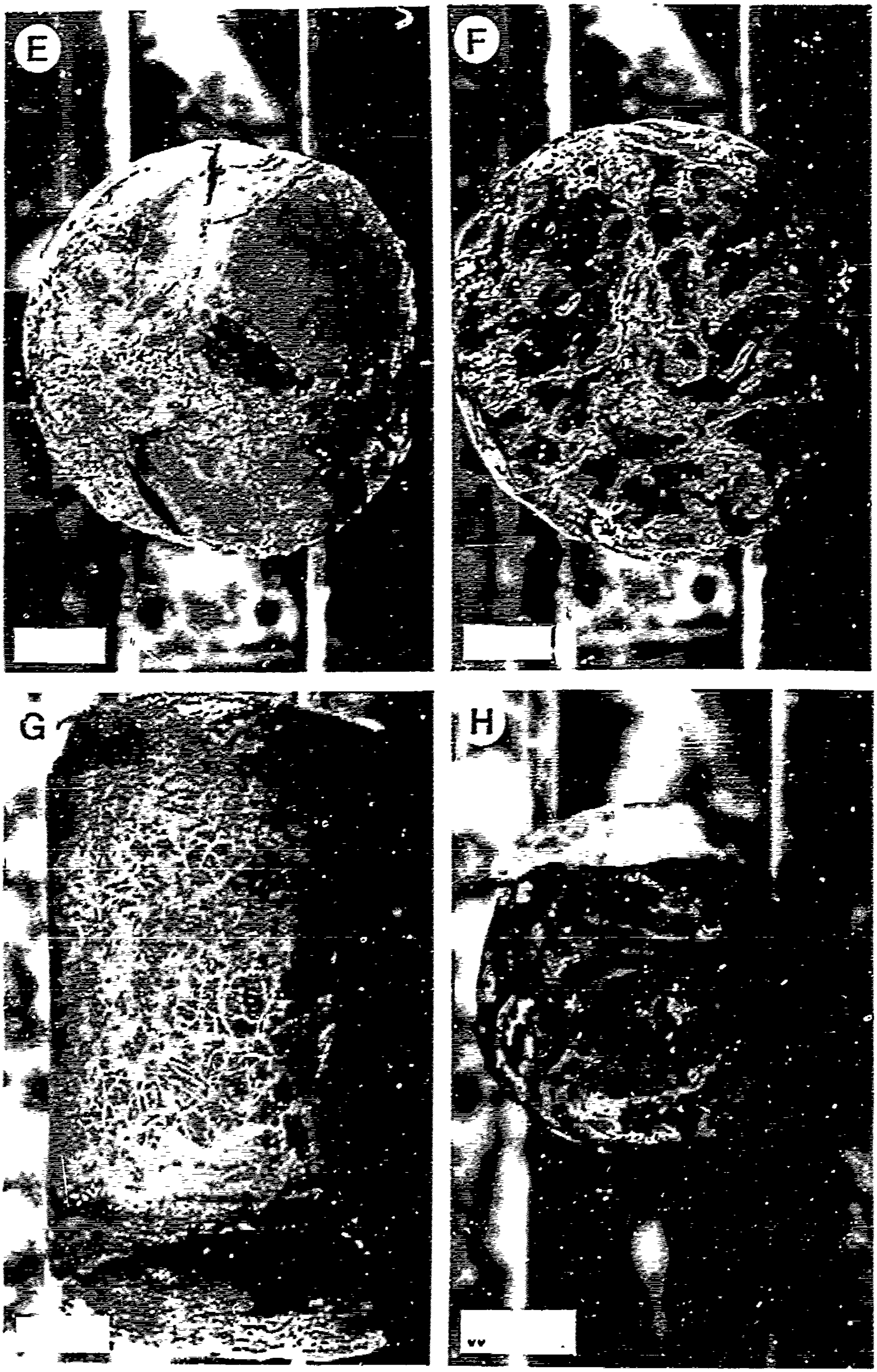
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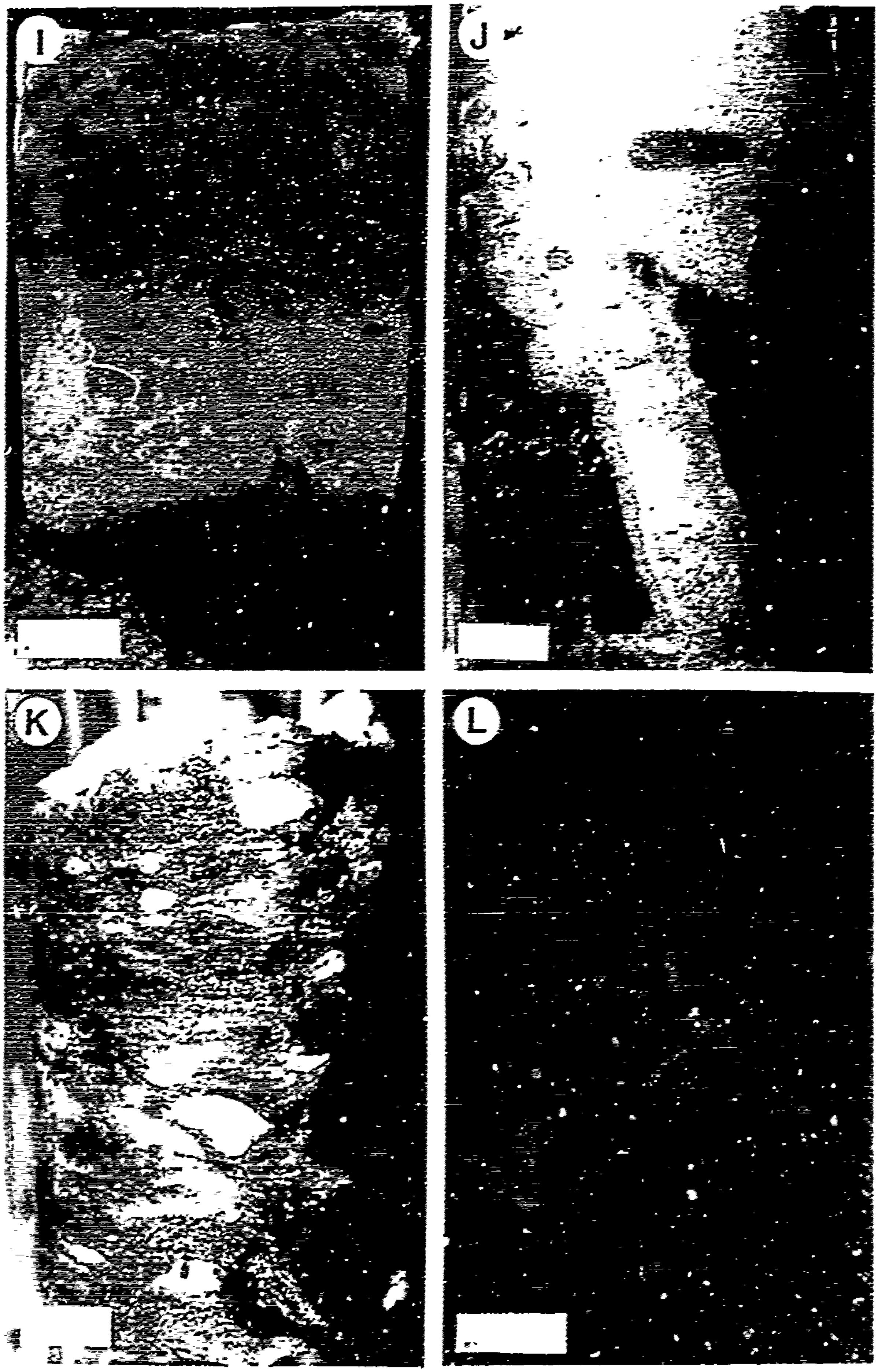
Figure 3.2 (I-L) Facies 2 (Fractures and Calcareous Clasts)

I) Vertical micro-desiccation cracks occurring across a gradational contact separating a lower pale green mudstone and an upper dark reddish brown mudstone. The photograph is from a mudstone unit directly above the upper contact of Gilwood zone 2 in 4-18-79-7W5, 1724.7 m. Scale bar is 2 cm.

J) Large sand-filled fracture passing through a dark reddish brown and pale green mudstone. This fracture initiated from a sandstone bed located 8 cm below bottom of photograph. Note the pale green alteration zone at the edge of the fracture. The photograph is from a mudstone unit above Gilwood zone 1 in 10-21-79-8W5, 1744.8 m. Scale bar is 2 cm.

K) Variegated dark reddish brown and grayish green mudstone with scattered calcareous clasts. The photograph is from a mudstone unit just above Gilwood zone 4 in 10-21-79-8W5, 1734.8 m. Scale bar is 2 cm.

L) Mottled grayish green and dark reddish brown silty mudstone with scattered fine- to coarse-grain sand. The photograph is from a silty mudstone unit above Gilwood zone 2 in 6-20-79-8W5, 1743.3 m. Scale bar is 2 cm.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Interpretations:

The mudstones are vertically accreted deposits interpreted to reflect deposition in a low energy setting by suspension fallout. Suspension fallout is associated with either temporally or spatially decreasing suspension transport (Harms *et al.*, 1982). The presence of scattered silty and sandy zones in the mudstone suggests that the hydrodynamic conditions of the system fluctuated, and were occasionally increased to levels that allowed the transportation of silt and sand sized particles. Scattered coarse grains may also indicate a proximity to relatively strong currents (Harms *et al.*, 1982). Because the silt and sand grains remained scattered and were not shaped into thin beds, current velocities remained low enough to prevent the movement of grains on the bed after they settled.

Accessory features in this facies indicate the existence of post-depositional alteration of the mudstones. The red coloured mudstones suggest that post-depositional oxidation occurred since almost no modern streams transport truly red alluvium (Van Houten, 1973). Oxidation reactions mainly occur in well drained soils, but may also occur in coarse-grained shallowly buried materials circulated by oxygenated water (Retallack, 1990). The persistence of green mudstones at all sandstone-mudstone contacts is a diagenetic feature (McBride, 1974), clearly shown when green coloured mudstones transect red mudstone bedding.

The two sizes of slickensides represent two distinct origins. Slickensides covering the entire surface area of core are interpreted to represent movement along a possible fault plane, while the smaller types are interpreted to be stress cutans. Stress cutans are indicated by randomly arranged diffuse slickensides (Retallack, 1990). These stress cutans can be formed in clayey soils where peds (aggregates of soil) are repeatedly heaved past one another by swell-shrink during wetting and drying episodes, or they may be formed after burial when compaction also causes peds to be crushed against each other (Smith, 1990; Retallack, 1990).

The mud cracks are interpreted to be formed due to shrinkage or desiccation of muds during subaerial exposure, however, desiccation can occur in both subaerial and subaqueous environments. Desiccation resulting in the development of polygonal or rectilinear networks of cracks occurs when interstitial waters are removed, causing mineral grains to become densely aggregated (Potter *et al.*, 1980). Mudcracks have been reported to occur in both horizontal surfaces or on hill slopes as steep as 38 degrees (Plummer and Gostin, 1981). The complex nodular forms of the red mudstone are interpreted to be septarian nodules. Fluctuations of oxygenation in paleosols may induce septarian cracking, a process which results in brecciation of the nodules (Retallack, 1990).

Similar descriptions of calcareous nodules have been described under various terms, including concretion, nodule, cornstone, and kankar. The formation of these nodules is interpreted by most workers to be during early diagenesis above the water table, and some have related them to soil-forming processes (McBride, 1974). Soil nodules and concretions are commonly formed in dry, well drained soils, and reflect the availability of oxygen at the time of formation (Retallack, 1990).

3.2.3 Facies 3 - Small-Scale Cross-Stratified Sandstone

Description

Facies 3 is characterized by thin beds (<8 cm) of cross-laminated sandstone (Fig 3.3) that is commonly muddy and chiefly fine- to very fine-grained. Cross-stratification is dominated by asymmetrical tabular forms, but more complex slightly symmetrical

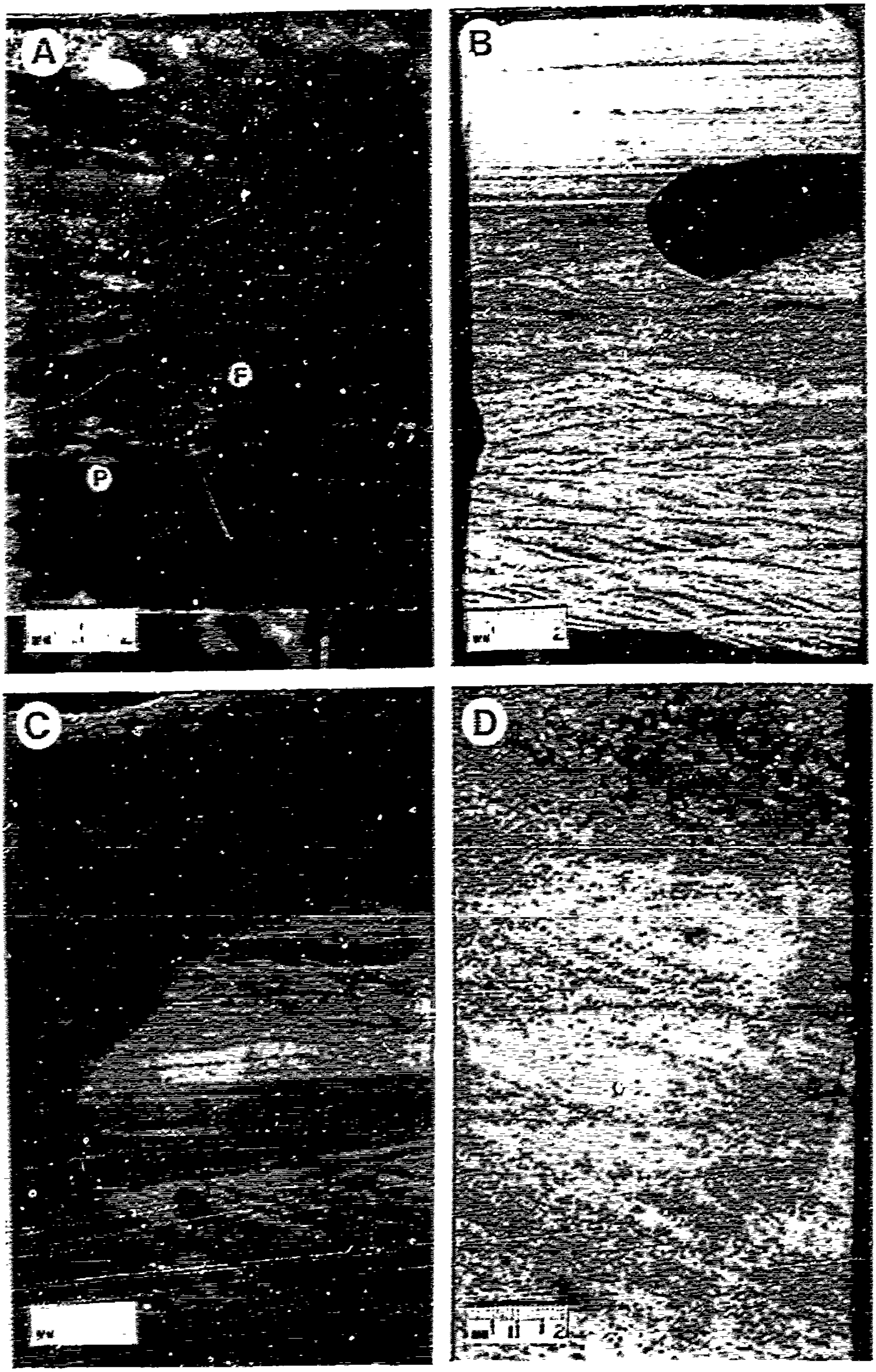
Figure 3.3 Facies 3 (Small-Scale Cross-Stratified Sandstone)

A) Fine-grained, small-scale cross-stratified sandstone with current and combined flow ripples. Note the near planar grayish green mud parting (p) and the mud flasers (f). The photograph is from the upper part of a finning upward sandstone within Gilwood zone 1 in 1-32-78-8W5, 1729.1 m. Scale bar is 2 cm.

B) Fine-grained, small-scale cross-stratified sandstone illustrating climbing ripples formed in 1.5 cm sets. Note the planar laminated sandstone overlying the small-scale cross-stratified sandstone. The photograph is from the lower portion of a coarsening upward sequence developed in Gilwood zone 2 in 4-18-79-7W5, 1732.8 m. Scale bar is 2 cm.

C) Photograph illustrating the close relationship between fine-grained small-scale cross-stratified sandstones and planar laminated sandstones. The photograph is from a lower part of Gilwood zone 3 in 12-25-79-8W5, 1719.8 m. Scale bar is 2 cm.

D) Medium grained, small-scale cross-stratified sandstone. The photograph is from Gilwood zone 1 in 12-30-79-7W5, 1711.7 m. Scale bar is 2 cm.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cross-stratification can be present. The asymmetrical tabular-shaped cross stratification is internally composed of high-angle (>20°) cross beds with set thicknesses of <3 cm, and cosets ranging up to a maximum of 8 cm. The shape of the lower bounding surface varies from straight to curved, and can be inclined up to an angle of 10°. The upper bounding surface is similar to the lower except gradational forms may also exist. This facies is not a very common one. It is usually associated with the planar laminated sandstone facies, and is dominantly located in the upper beds of fining upward sequences which are initiated by large-scale cross-bedded sandstones.

Thin (1 mm to 5 mm) mud drapes and discontinuous mud flasers occur in this facies. They are present as laminations in the sets and cosets of the small-scale cross-laminated sandstone. The drapes have lower contacts that are sharply conformable to the lower bounding surface, and upper contacts that are either sharp or scoured. Convolute bedding in the form of slumping occurs rarely, and it may produce a near vertical appearance to the fabric of sediment. Angular mudstone intraclasts ranging in size from 0.2 to 3 cm are associated with the slump features.

Interpretations:

The cross-laminated sandstones are interpreted to be the result of migrating small-scale current and combined flow ripples. An abundance of asymmetrical form-sets suggests the domination of low velocity unidirectional currents. The minimum and maximum current velocities needed to generate small ripples is dependent on mean sediment size. For very fine- to fine-grained sediment small ripples are generated at current velocities of 15 to 60 cm/s (Harms *et al.*, 1982). Climbing-ripple (ripple drift) cross-lamination suggests rapid deposition in sediment laden waters (Moslow and Tillman, 1986). Combined flow ripples are an intermediate form of ripple influenced by both currents and waves. Allen (1984), suggested that combined flow ripples are generated in shallower waters than wave ripples. The lack of well developed wave ripples suggests that this facies was probably generated in a current dominated setting.

3.2.4 Facies 4 - Cross-Stratified Sandstone

Description

Representatives of facies 4 are widespread, numerous, and characterized by trough and planar cross-stratified sandstone (Fig. 3.4 (A-H)). The cross-bedded sandstones occur in solitary or grouped sets making up sedimentary units from 0.15 to 2.5 m thick, and average approximately 1.2 m. Lower bed contacts are either sharp or scoured, and upper bed contacts either sharp or gradational. The planar-tabular sets have both unidirectional and bi-directional dip directions.

The sandstones are subrounded to angular and range from fine- to very coarse-grained. They commonly contain scattered coarse to pebbly sized grains and exhibit rapid and extreme vertical changes in grain-sizes. Sorting is typically poor to very poor in the coarse grained sands, and moderate to poor in the medium-grained sand. Well-sorted sandstones are rare and tend to occur in medium-grained sand. The primary type of cross-bedding is planar-tabular. These cross-beds have apparent foreset dips of 10° - 30° that are either tangential or non-tangential with the lower bounding surface. Trough cross-beds display concave-up foresets that are tangential to the underlying surface and increased in inclination upward to maximum apparent dips of 35°. In both types of cross-bedding individual foresets commonly exhibit normal grading, distinguished by differences in colour, grain size, and degree of cementation.

Mud clasts are commonly found in the sandstones of facies 4. They are either subrounded, angular, or lenticular in shape, and have maximum diameters or lengths that

Figure 3.4 Facies 4 (Large-Scale Cross-Stratified Sandstone)

A) Medium-grained, large-scale planar cross-stratified sandstone Note the grayish green mud clasts and mud clast molds aligned along bedding plane. Also note the cementing of the coarser grained foresets. The photograph is from Gilwood zone 1 in 10-32-80-8W5, 1709.2 m. Scale bar is 2 cm.

B) Medium-grained, large-scale cross-stratified sandstone. Note the fish bones. The photograph is from Gilwood zone 2 in 1-32-78-8W5, 1730.9 m. Scale bar is 2 cm.

C) Medium-grained, large-scale cross-stratified sandstone. The photograph is from 2-3-78-8W5, 1782.4 m. This location is 3 miles south of the study area. Scale bar is 2 cm.

D) Fine- medium-grained, large-scale cross-stratified sandstone. Note the high angle of the cross-beds and the coarser grained cemented lag. The photograph is from Gilwood zone 4 in 4-10-81-8W5, 1671.2 m. Scale bar is 2 cm.

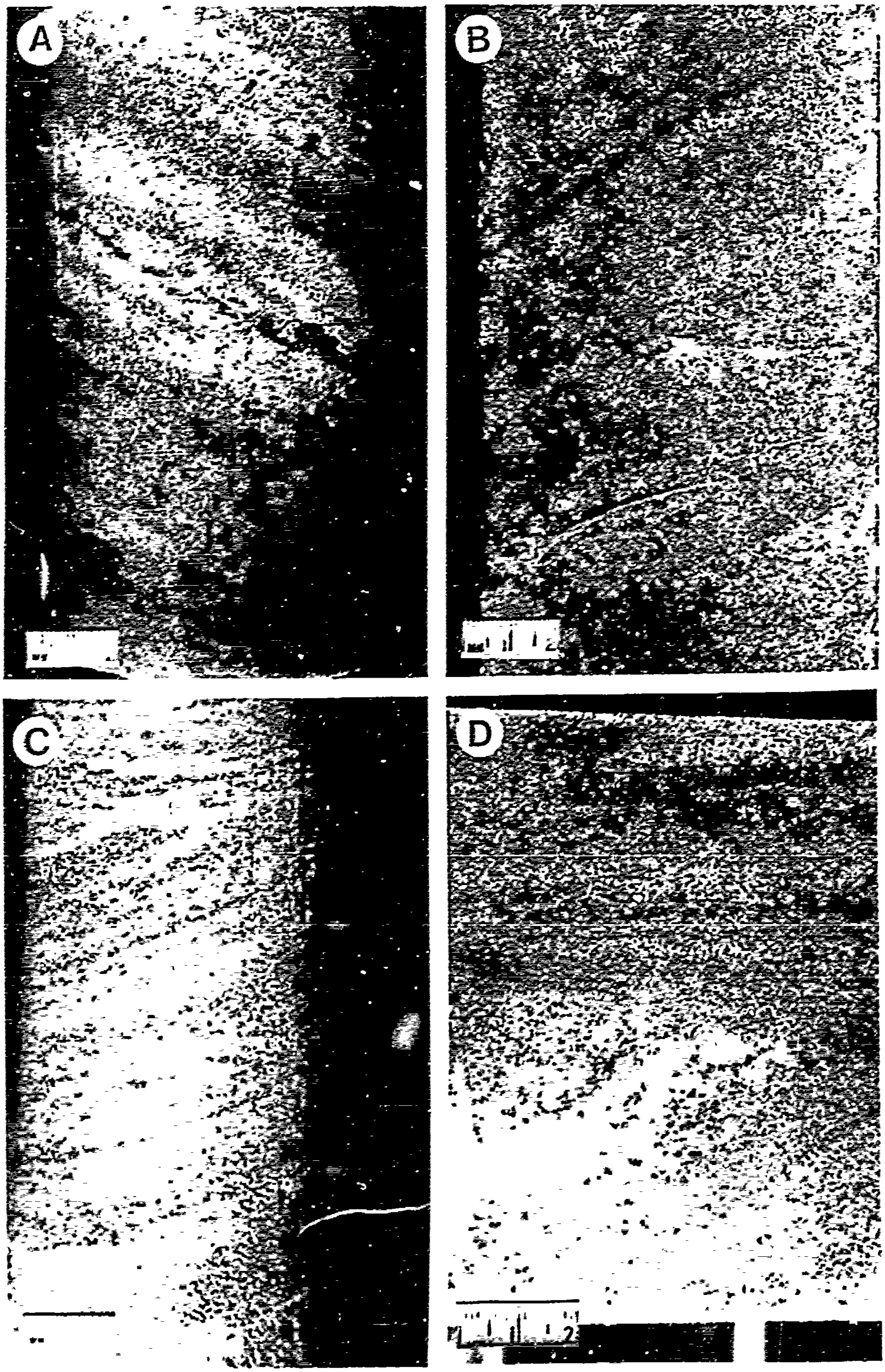
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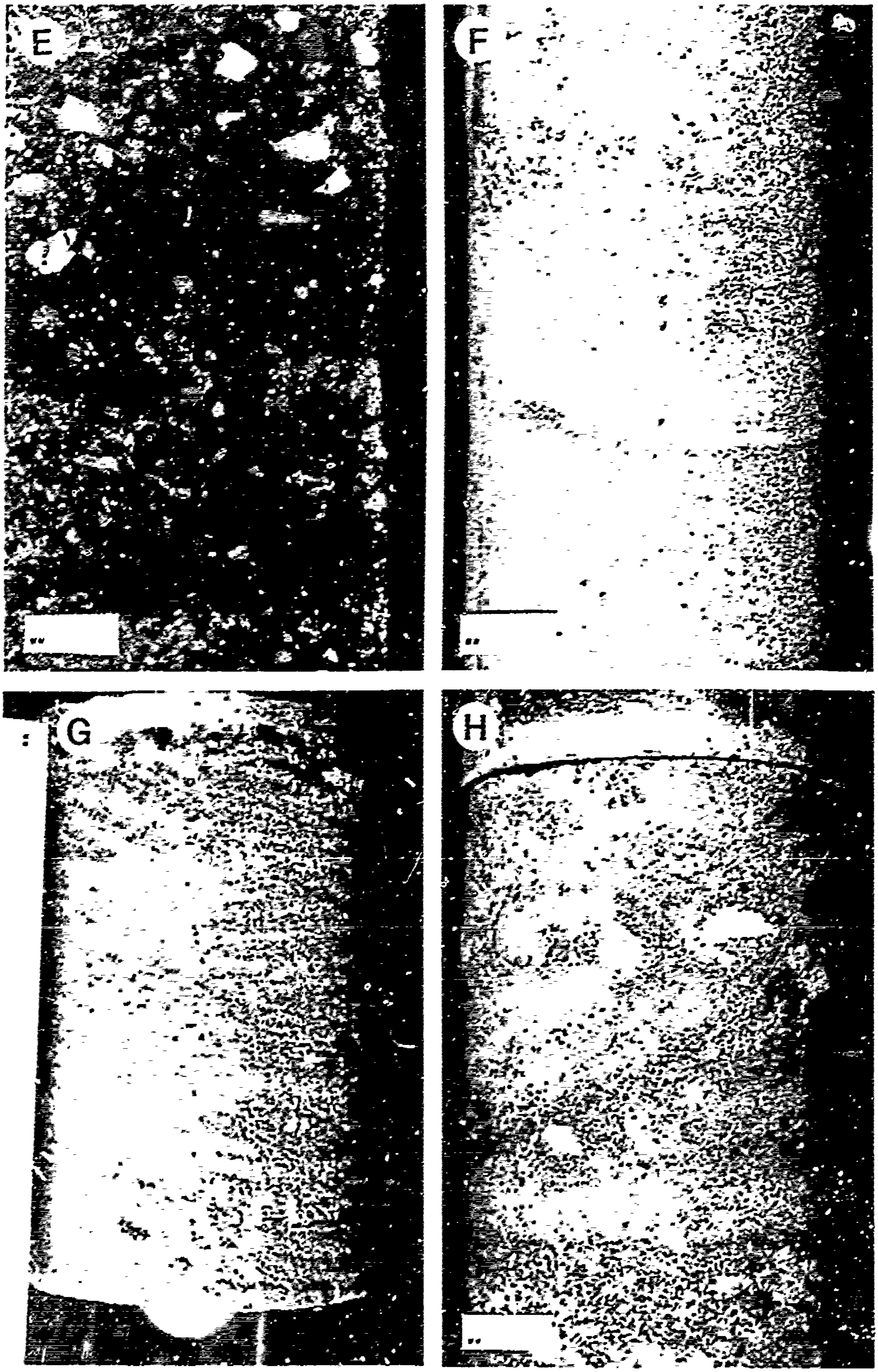
Figure 3.4 Facies 4 (Large-Scale Cross-Stratified Sandstone)

E) Coarse-grained to pebbly cross-stratified sandstone. The photograph is from the base of Gilwood zone 5 in 10-22-78-8W5, 1738.5 m. Scale bar is 2 cm.

F) Medium-grained, large-scale trough cross-stratified sandstone. The photograph is from the base of Gilwood zone 2 in 4-25-80-9W5, 1724.0 m. Scale bar is 2 cm.

G) Coarse-grained, large-scale trough cross-stratified sandstone. Note the cementing of the coarser grained zones. The photograph is from 12-1-80-8W5, 1706.8 m. Scale bar is 2 cm.

H) Medium- coarse-grained, large-scale cross-stratified sandstone. Note the scattered pebbles and the sharp planar upper contact. The photograph is from the upper part of Gilwood zone 5 in 4-10-81-8W5, 1671.2 m. Scale bar is 2 cm.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range from 0.2 to 5.0 cm. They typically exist randomly oriented near the base of cross-bedded units. However, smaller clasts that had a tendency to align with foreset laminae can be located anywhere in the cross-stratified sandstones. Mud clasts are generally preserved, but occasionally the mud was removed leaving only the partial filling of a mud clast mold. The colour of the smaller clasts (0.2 to 2 cm) was either black or shades of green similar to those found in the Watt Mountain Formation mudstones, while the larger (2 to 5 cm) clasts were only black.

Interpretations:

This facies contains cross-stratified sandstones interpreted to be the product of migrating bars or dunes generated by unidirectional fluvial currents. Planar-tabular cross-stratified sandstones with parallel dipping foresets result from down current migration of straight crested (2-dimensional) bars or dunes, while trough cross-stratification is generated by down current migration of sinuous crested (3-dimensional) bars or dunes (Harms *et al.*, 1982). In reality, all bed forms have three-dimensional geometry. However, when describing bed forms from a standpoint of fluid flow, those with a length or breadth that is large compared to their height are referred to as two-dimensional (Allen, 1968). Friend (1965) suggested that the origin of groups of sets of cross-strata is the result of the passage of groups of megaripples, each moving as a result of simultaneous deposition of cross-strata downstream and erosion of material upstream.

Dunes may be generated on the bar tops during low water stages (Miall, 1977). They are asymmetrical flow-transverse bedforms very similar to small ripples in geometry and movement, but are an order of magnitude larger (Middleton and Southard, 1984). The relationship between the sediment size and flow velocity determines whether a dune or ripple will be generated. With increasing mean sediment size, dunes are preferred over ripples at lower flow velocities. For the sediment sizes described in this facies, the lowest range of flow velocity needed to generate dune bedforms ranges from approximately 35 to 65 cm/s (Harms *et al.*, 1982). For grain sizes less than medium to coarse, an increase in flow velocity will produce a change in bedforms from current ripples, to dunes, to a plane bed (upper stage). For sands with a mean grain size greater than medium to coarse, ripples can no longer be generated, and with an increase in flow velocity, bedforms will change from plane beds (lower stage), to dunes, to plane beds (upper stage) (Allen, 1984). Migrating, straight-crested (2-dimensional) dunes produce tabular cross-bedding, and with a higher flow velocity, migrating sinuous-crested (3-dimensional) dunes, commonly linguoid in form, will produce trough cross-bedding (Harms *et al.*, 1982).

The rapid manner in which grain sizes and sedimentary structures change in this facies suggests that it was subject to rapid and variable flow conditions. The distribution of grain size and sedimentary structures suggests that both increases and decreases in flow velocities occurred, sometimes changing very rapidly. Fining upward cycles generally record the waning or progressive decrease in flow velocities, coarsening upward stratification is the result of increased flow velocities. The rare occurrence of mudstone partings contained in the cross-bedded sandstones suggests that current velocities were rarely reduced sufficiently enough for deposition of muds from suspension.

Mudstone intraclasts are interpreted to be rip-up clasts locally derived from either reworking desiccated mud crack-generated fragments or by the hydraulic erosion of cohesive mud laminae or beds The occurrence of angular mud clasts suggests that transportation before deposition was minimal, because mud clasts round rapidly during transport (Smith, 1972).

3.2.5 Facies 5 - Planar-Laminated Sandstone

Description:

Facies 5 is characterized by very fine- to coarse-grained planar to low-angle (<5°) laminated sandstone (Fig. 3.5). Laminae defined by slight changes in grain size and mineralogy, range in thickness from 1 to 9 mm. Pale yellowish brown laminations are composed of sand, grayish green laminations are shale, and the black laminations are mica. The sandstones are poorly- to moderately well-sorted, and may contain scattered coarse to very-coarse grains of quartz, feldspar, and angular green shale clasts (< .5 cm in diameter). Bed thicknesses range from 0.5 to 9 cm and have lower truncation surfaces that are planar or scoured. Upper contacts are found to be either planar, scoured, or gradational. Although this facies dominantly occurs as a single isolated bed, it was associated with facies 3 (small-scale cross-stratified sandstone), and also locally interbedded with laminated and thinly bedded green mudstones in the upper portion of this facies.

Accessory features include thin (< .5 cm) horizontal to wavy mud laminations and flasers, scattered coarser grains and pebbles, and convolute bedding. Rare fish plates are also present.

Interpretations.

The planar laminated sandstone facies is interpreted to represent sediment transport under upper flow conditions. Planar laminated beds can be generated over large areas in either tractional forces generated in lower flow (38 to 58 cm/s) and upper flow velocities (60 to 175 cm/s), or through deposition from suspension fall out. A specific origin for the generation of plane laminations can be ambiguous. However, certain criteria can aid in developing correct interpretations

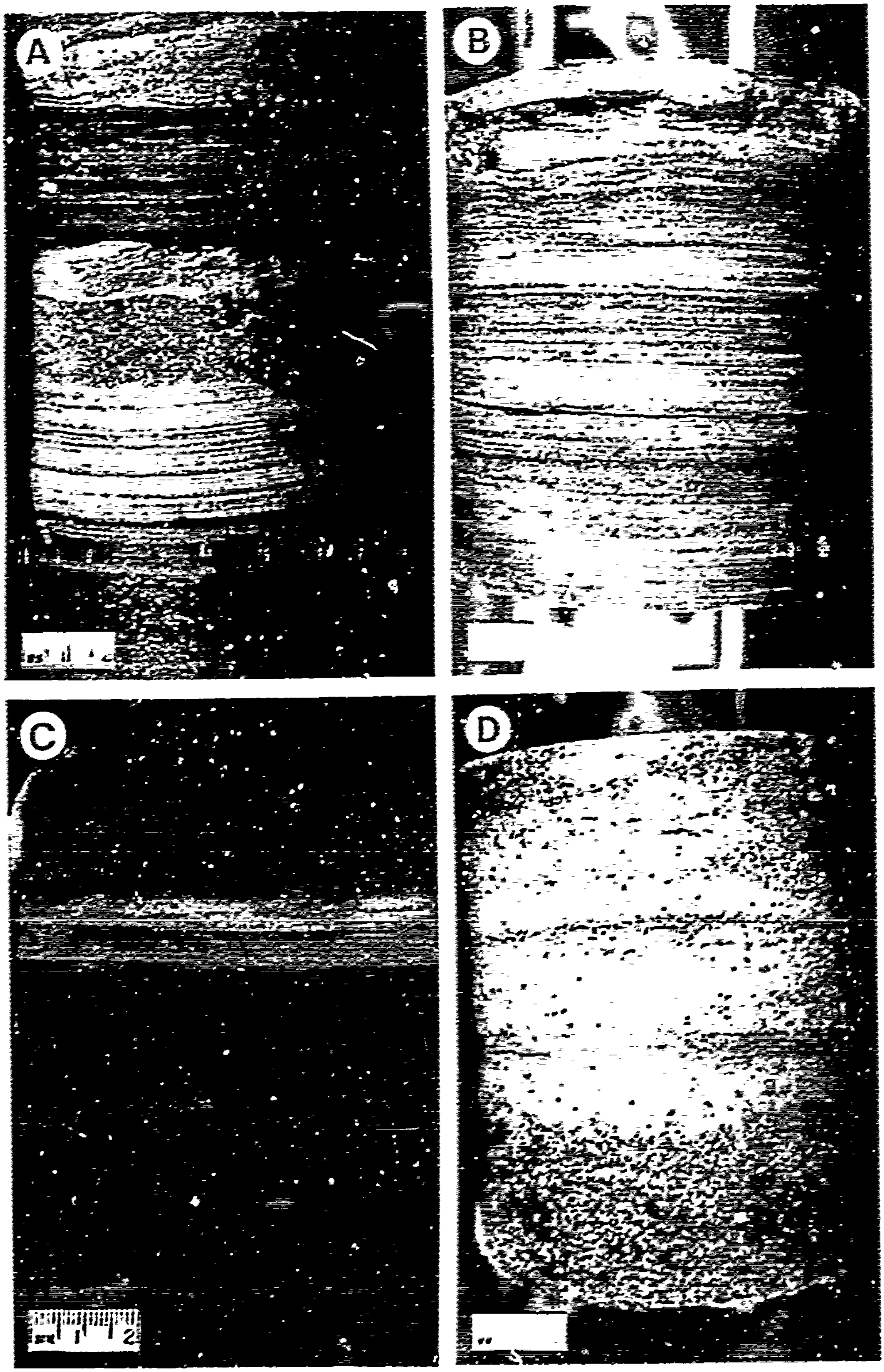
Figure 3.5 Facies 5 (Planar-Laminated Sandstone)

A) Very fine-grained micaceous planar-laminated sandstone. Note the 2 cm massive zone in the center of photograph with scoured base, and the 3 coarse sand grains in the upper planar laminated zone. The photograph is from the top of Gilwood zone 2 in 4-28-79-8W5, 1741.5 m. Scale bar is 2 cm.

B) Very fine-grained micaceous planar-laminated sandstone. The photograph is from Gilwood zone 5 in 4-18-79-7W5, 1704.7 m. Scale bar is 2 cm.

C) Very fine-grained planar-laminated sandstone. The photograph is from the top Gilwood zone 2 in 10-36-78-8W5, 1709.1 m. Scale bar is 2 cm.

D) Medium-grained planar-laminated to thinly bedded sandstone. Note the cyclic finning upward cycles. The photograph is from the top of Gilwood zone 1 in 10-32-80-8W5, 1708.0 m. Scale bar is 2 cm.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Deposition of planar laminated beds by tractional forces rather than suspension fall out can be deduced by the existence of sharp erosional lower bounding surfaces. If the plane laminated beds were generated by suspension fall out, a draping effect over the nonplanar substrate would be produced (Harms *et al.*, 1982). In addition, material coarser than fine sand size cannot be generated through suspension fall out since the current velocities needed to spread out the sediment for substantial distances would create tractional forces. Fine sand sized material can only generate plane laminated beds in upper flow regime conditions. However, if it has been decided that tractional forces were involved in generating the plane laminated beds in sediment sizes ~0.7 to 2 mm, additional criteria are needed to distinguish between upper and lower flow origins. If the planar bed is substantially thick it is unlikely that lower-stage transport rates were involved, and when planar laminated beds are interbedded with trough cross-stratified sands an upper-stage condition is suggested (Harms *et al.*, 1982).

The thin mud laminations suggest that the hydrodynamic conditions experienced brief decreases in flow velocity allowing the deposition of the finer muds. The occasional scattered coarse grains in the fine-grained planar laminated sandstones is a reflection of brief increases in flow velocity capable of transporting coarser-grained sediment.

Convolute bedding is the result of the expelling of pore fluid during the earliest stages of sediment consolidation. These type of structures are most commonly associated with water-laid sediments in a setting prone to high rates of sedimentation which prevents excessive packing of the sands (Allen, 1984).

3.2.6 Facies 6 - Massive Sandstone

Description:

The massive sandstone facies is a minor one characterized by a structureless sandstone that is very fine- to coarse-grained, and poorly- to well-sorted (Fig. 3.6). Bed thicknesses range from a few cm to 0.9 m. Lower bed contacts are scoured or gradational, and upper bed contacts are sharp or gradational. The massive sandstones can exist as solitary isolated beds, but they were mostly associated with other facies. The well-sorted massive sandstones are interbedded with facies 5 (planar laminated sandstone), and the poorly-sorted sandstones, that could also include scattered mud and limestone clasts, are often associated with facies 4 (cross-stratified sandstones).

Interpretations:

Rapid deposition without subsequent tractional transport is the mechanism that likely generated the massive fabric of this facies. Rapid deposition resulted in the development of the poorly-sorted massive sandstones, located at the bases of fining upward cycles. This rapid deposition is supported by the presence of scattered mudstone and calcareous intraclasts. The moderately- to well-sorted massive sandstones are interbedded with planar laminated sandstones, suggesting an association with upper flow regime conditions. Beynon (1991), suggested that rapid deposition in upper flow conditions can suppress the formation of planar laminated beds and result in the generation of a massive fabric.

The appearance of a massive fabric is not always the result of massive fabric generating processes. A massive appearance may be the result of difficulty in recognizing poorly developed sedimentary structures. Renault and Owen (1991) noted

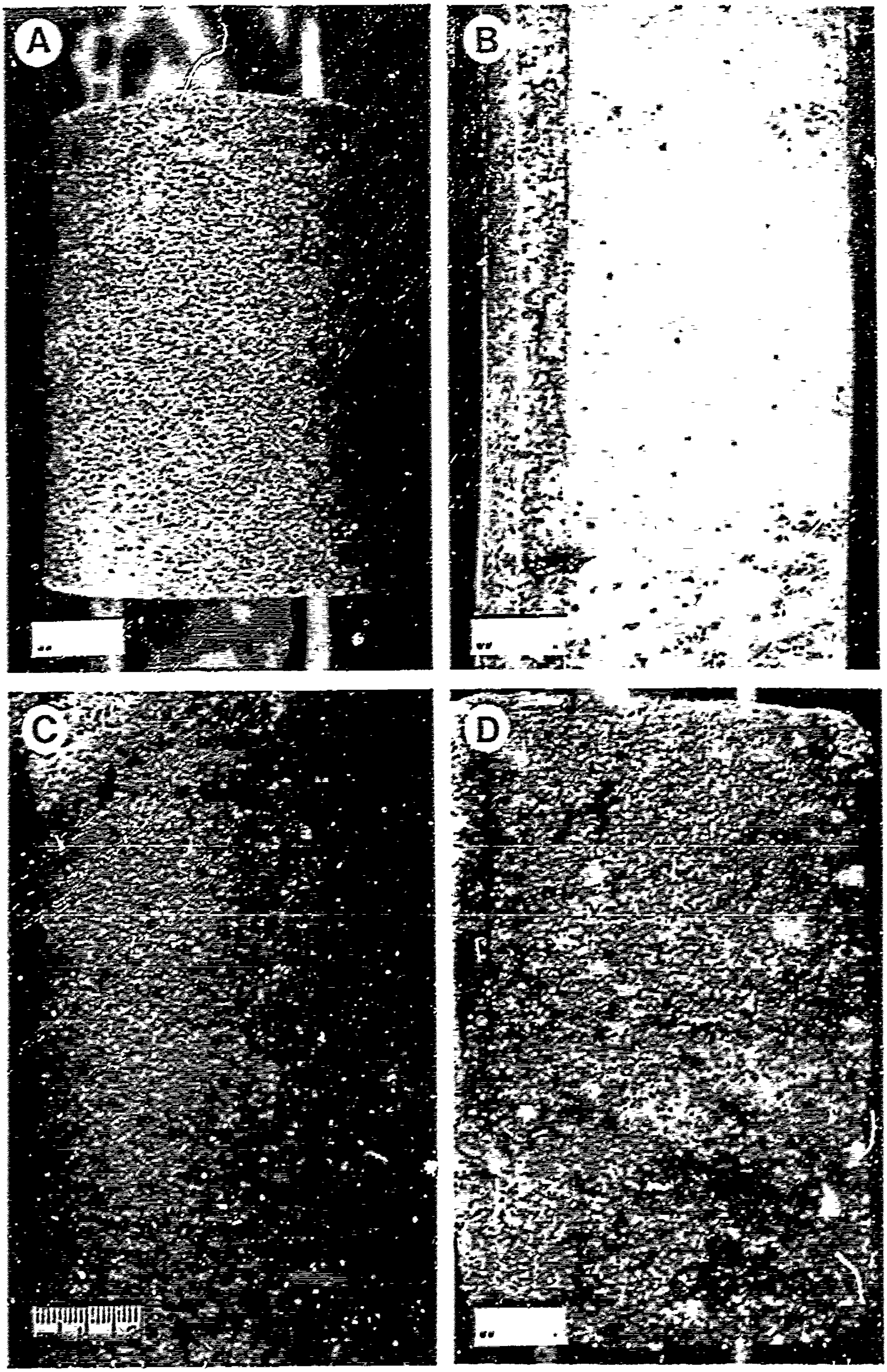
Figure 3.6 Facies 6 (Massive Sandstone)

A) Medium-grained well sorted massive sandstone. The photograph is from Gilwood zone 5 in 12-20-79-8W5, 1691.9 m. Scale bar is 2 cm.

B) Coarse-grained massive sandstone with abundant feldspar. Note that this massive zone is well cemented. The photograph is from Gilwood zone 2 in 4-25-80-9W5, 1721.4 m. Scale bar is 2 cm.

C) Medium-grained well sorted massive sandstone. The photograph is from the base of Gilwood zone 3 in 4-28-79-8W5, 1740.8 m. Scale bar is 2 cm.

D) A coarse-grained massive sandstone overlying a cross-bedded sandstone. Note the pebble size clasts scattered throughout the core and the cemented coarser zones contained in the lower cross-bedded sandstone. The photograph is from Gilwood zone 3 in 2-21-79-8W5, 1745.2 m. Scale bar is 2 cm.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that sedimentary structures in small modern beach bars on Lake Bogoria are poorly developed, and in some cases the sandstones, granules, or pebbles, may appear massive

3.2.7 Facies 7 - Interbedded Sandstone and Mudstone

Description.

Facies 7 is a minor facies characterized by a platy to thinly interbedded massive to laminated mudstone and very fine- to coarse-grained sandstone (Fig. 3.7). Interbed thicknesses range from 0.6 to 10 cm, and decrease upward in the interbedded unit. Rare scattered coarse grains occur in both the sandstone and mudstone interbeds.

The sandstones range in grain size from very fine-grained sand to pebbles. The sandstones are poorly- to moderately-sorted, and some thicker beds may exhibit normal grading. Internal stratification of the sandstones is demonstrated by a variety of sedimentary structures, but in a particular interbedded unit it usually consists of either planar-horizontal and low-angle cross-stratified sandstones, or structureless sandstones. Rare mudstone intraclasts with textures similar to the underlying mudstones can occur in the sandstones. The basal contacts of the sandstone interbeds are generally sharp and planar, or scoured. Mudstone beds are massive to laminated and are commonly very sandy. In the mudstones are occasional isolated lenticular sand bodies and extremely rare small cracks filled with fine-grained sandstone. A cross-sectional view of these cracks displays an irregular shape with a sub-vertical to vertical orientation, which extended downward approximately 0.5 cm from the base of an overlying sandstone unit. Basal contacts of the mudstone beds are typically sharp and conformable to the underlying sandstone, but gradational forms also exist.

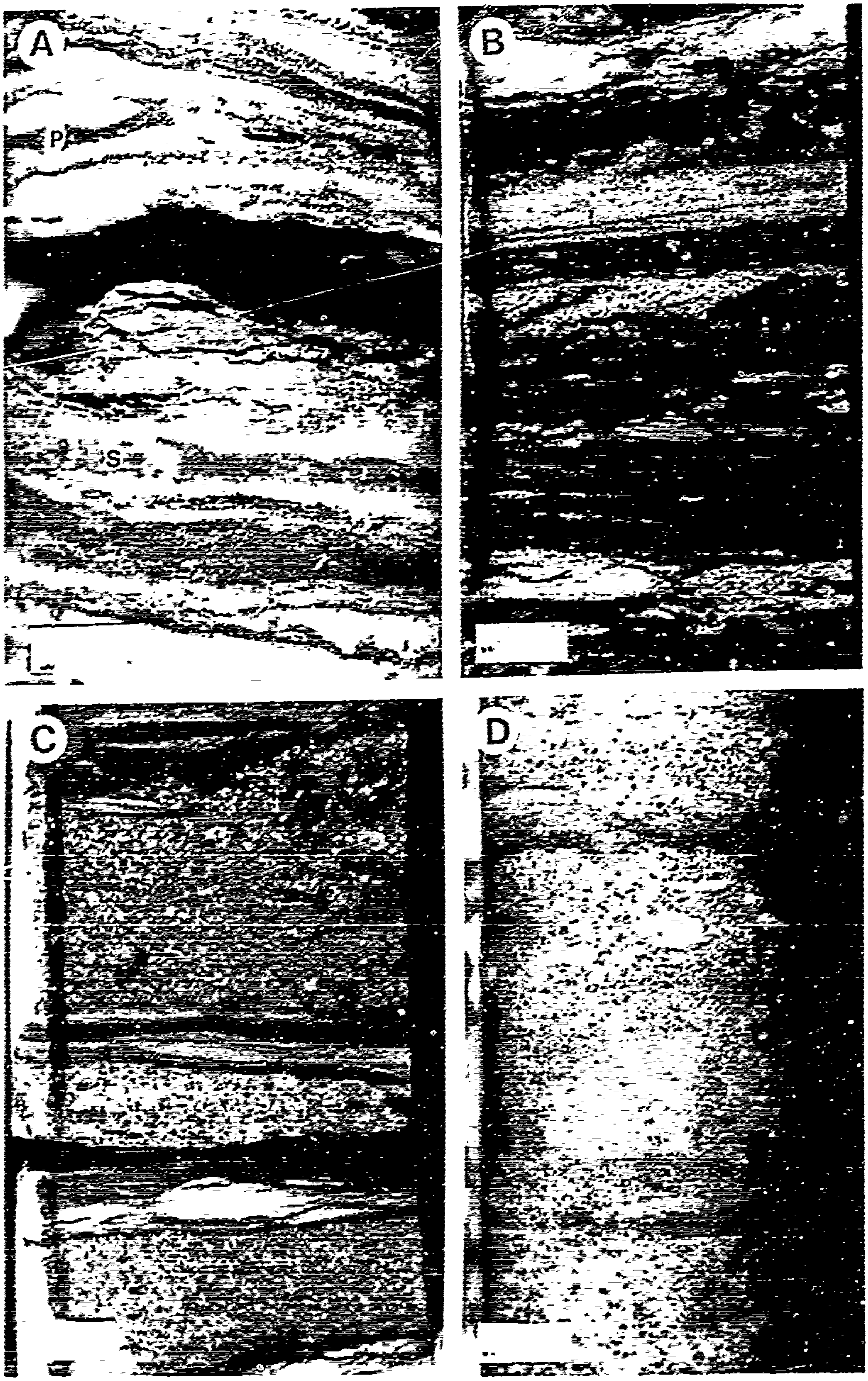
Figure 3.7 Facies 7 (Interbedded Sandstone and Mudstone)

A) Thinly interbedded fine-grained sandstones and grayish green mudstones (Type A). Note the shrinkage cracks (S) and the rare occurrence of *Planolites* (P). The photograph is from the base of Gilwood zone 5 in 4-18-79-7W5, 1708.1 m. Scale bar is 2 cm.

B) Thinly interbedded fine-grained sandstones and grayish green mudstones (Type A). Note the planar laminated sandstone bed (L), syneresis cracks, and the scattered coarse grains. The photograph is from the upper part of Gilwood zone 2 in 10-19-80-8W5, 1716.1 m. Scale bar is 2 cm.

C) Interbedded coarse-grained poorly sorted sandstones and grayish green mudstones (Type B). Note the massive appearance of the sandstone interbeds. The photograph is from Gilwood zone 3 in 10-19-80-8W5, 1745.2 m. Scale bar is 2 cm.

D) Interbedded coarse-grained poorly sorted sandstones and grayish green mudstones (Type B). Note the massive appearance of the sandstone interbeds. The photograph is from a unit below Gilwood zone 2 in 12-18-80-8W5, 1725.3 m. Scale bar is 2 cm.


A
P
S
B
C
D

Fish remains in the form of plates are present. Biogenic structures are extremely rare and are limited to occurrences of *Planolites*.

Interpretations:

The interbedded nature of the sandstones and mudstones is a result of alternating depositional processes. The mudstones are simply a result of suspension fallout during periods of low energy, while the sandstones represent a variety of depositional processes. Planar and low angle cross-stratified sandstones reflect varied flow velocities during deposition involving tractional transport. The planar horizontal beds with sharp lower contacts are generated in upper flow tractional settings similar to facies 5, while the cross-laminated sands represent sediment transport in lower flow tractional settings similar to facies 3. Poorly sorted massive sandstone interbeds consisting of medium- to coarse-grained sandstones reflect rapid deposition through suspension fallout without subsequent tractional transport. The high relief exhibited on the upper sandstone contacts of some massive sandstone interbeds suggests that some of these deposits may have been formed by mass emplacement. Mass emplacement can result when the concentration of settling sediment becomes unstable on an inclined surface (Harms *et al.*, 1982).

The small fine-grained sand-filled cracks are interpreted to be shrinkage cracks whose origin has not been determined. Shrinkage cracks can form at the sediment-air interface by desiccation processes and at the sediment-water interface or substratally by syneresis processes (Plummer and Gostin, 1981).

3 2 8 Facies 8 - Mixed Sand and Mud

Description

Facies 8 is characterized by a homogenous mixture of sand and mud (Fig 3 8) The mixture has varying sand to mud ratios that can increase or decrease upward Muds are typically green, and the sands, which vary from fine to very-coarse, are poorly sorted The facies can be up to 1 4 m thick and dominantly occurred near sandstone-mudstone contacts Rarely the mixed sand and mud had a convoluted fabric Commonly associated with this facies are modest amounts of scattered calcareous clasts ranging in size from 0 2 to 3 cm, and partially cemented calcareous zones up to 20 cm thick The calcareous clasts were irregular in shape, micritic, and were found to replace and surround clastic grains

Interpretations

The mixed sand and mud deposits are interpreted to reflect a rapid decrease in flow velocity, which resulted in decreased flow competence and the immediate deposition of sediment Rapid decreases in flow velocity can occur when sediment-laden fluvial currents enter relative stationary deposits of water However, in order for three dimensional mixing and appreciable sediment deposition to occur at the point of interaction, the two mixing waters must be equally dense (Elliott, 1986).

Scattered calcareous intraclasts are interpreted to be rip-up clasts, which were derived from either caliche or fresh water limestone deposits The calcareous cemented zones have the characteristics of caliche deposits formed above the water table in aridland soils (Retallack, 1990)

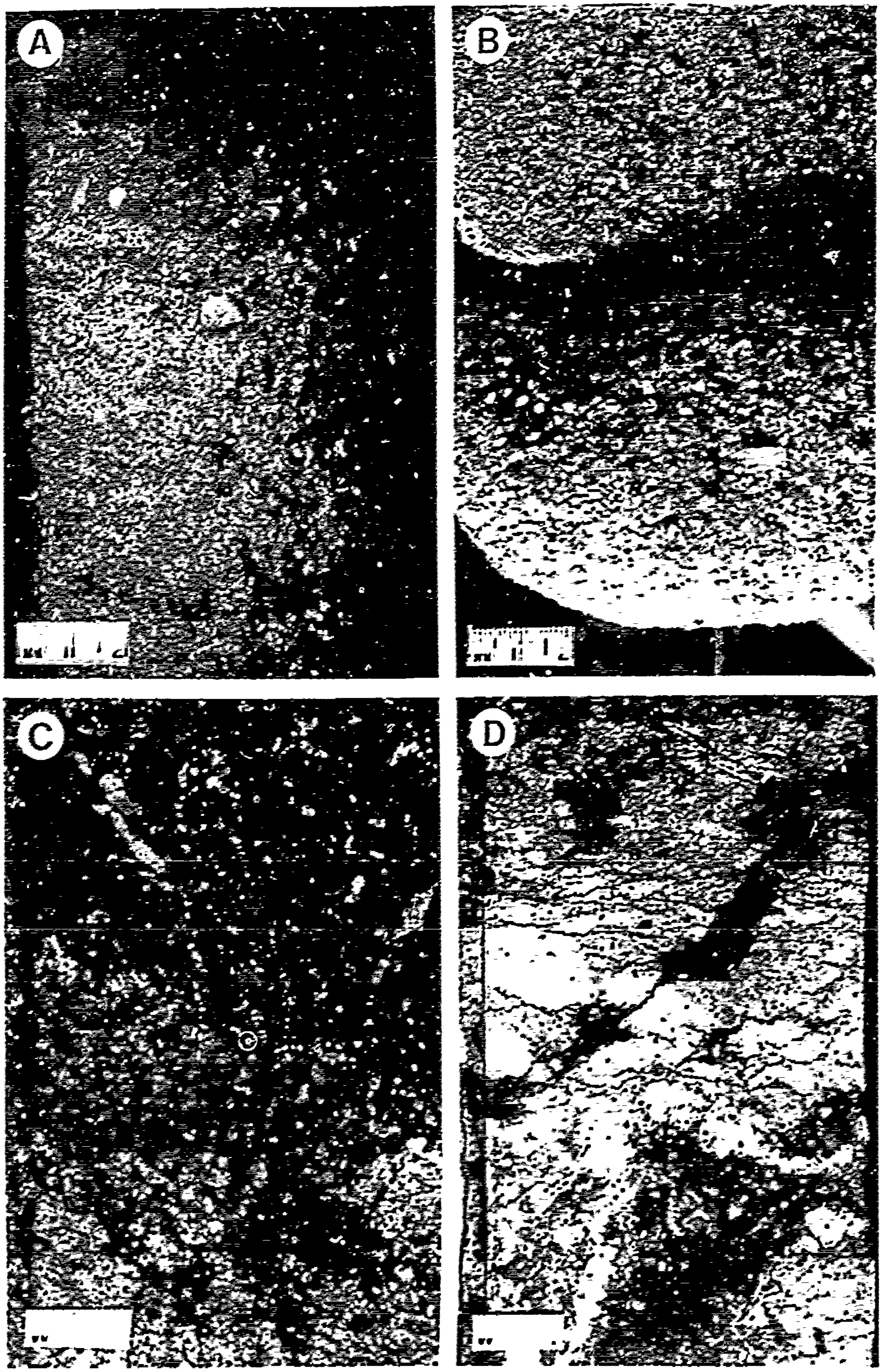
Figure 3.8 Facies 8 (Mixed Sand and Mud)

A) Mixed sand and mud illustrating an upward decrease in sand content Note the few scattered pebbles. The photograph is from Gilwood zone 4 in 4-28-79-8W5, 1735.6 m. Scale bar is 2 cm.

B) Thoroughly intermixed coarse-grained sand and grayish green mud The photograph is from Gilwood zone 3 in 10-27-79-8W5, 1724.8 m. Scale bar is 2 cm.

C) Mixed fine- to coarse-grained sand and grayish green mud Note the moderate amount of calcareous cement. The photograph is from Gilwood zone 3 in 10-27-79-8W5, 1724.3 m. Scale bar is 2 cm

D) Mixed fine- to coarse-grained sand and grayish green mud. Note the dense concentrations of calcareous cement The photograph is from a unit below Gilwood zone 5 in 2-21-79-8W5, 1739.0 m Scale bar is 2 cm.


A
B
C
D

3.2.9 Limestone

The following limestone description is not a facies in the definable sense, but is a localized unit with a recognizable "state."

Description.

Thick (up to 45 cm) solid calcareous zones containing scattered fine- to coarse-grained sand occur in 12-18-80-8W5 and 10-21-79-8W5 (Fig. 3.9). These limestone deposits have a nodular habit and are light gray to cream in colour. Separating the nodules are continuous and discontinuous mudstone laminations.

Interpretations:

Based on the appearance, thickness, and intimate association with lacustrine deposits, these limestones are interpreted to represent accumulations of freshwater carbonates. In shallow waters (<10m), carbonate production is dominantly biogenic or bioinduced (Platt and Wright, 1991). These carbonates were probably deposited in small localized standing bodies of water where charophyte/algal mounds grew. Rottenfusser (1974) analyzed limestones with a similar appearance in the Watt Mountain Formation north of the Peace River Arch, and through isotopic and petrographic analysis he interpreted them to be freshwater in origin.

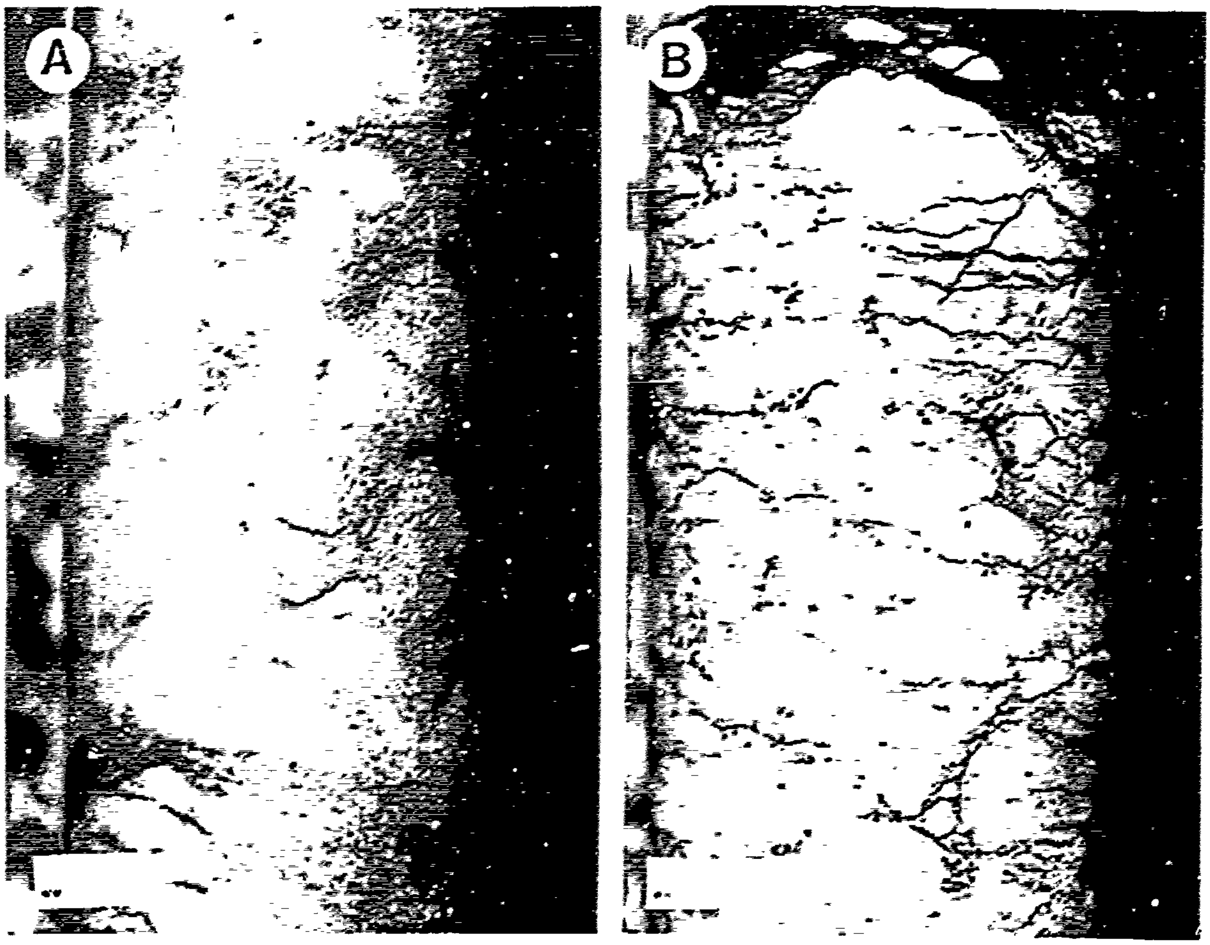


Figure 3.9 Limestones

A) Photograph is part of a 45 cm thick calcareous zone developed below Gilwood zone 2 in 12-18-80-8W5, 1723 6 m Note the nodular habit and thin discontinuous shale laminations Scale bar is 2 cm

B) Dense calcareous zone developed in the upper part of a fine-grained sandstone unit Note the scattered sand grains, discontinuous mudstone laminations, and the upper contact with a overlying grayish green mudstone The photograph is from the top of Gilwood zone 3 in 10-21-79-8W5, 1738 5 m Scale bar is 2 cm

CHAPTER 4 WATT MOUNTAIN FAUNA AND ICHNOLOGY

4.1 Introduction

Paleontological data from the Nipisi field area has been published by Tkachuk (1967), Kramers and Lerbekmo (1967), and Alcock and Benteau (1976). The combination of these studies provided a very comprehensive account of the total fossil content in Watt Mountain Formation. The writer has confirmed the identification of phosphatic brachiopods (*Lingula*), fish remains of the order Antiarchi, and arthropods of the order Conchostraca. The following discussion will examine the environmental significance of all fauna contained in the Watt Mountain Formation of the Nipisi field area, including those identified by the writer, and those referenced in previous studies.

4.2 Watt Mountain Fauna

The phosphatic brachiopods identified as *Lingula* only existed in the basal black shale facies (Facies 1). When *Lingula* and other normally benthic forms are found in black shale environments they are usually interpreted to be epiplanktic (Ettensohn & Barron, 1981). McCollum (1988) however, suggested that a *Lingula* infauna may develop in a shallow epeiric sea with reduced salinity. This interpretation is favored for *Lingula* occurring in the Nipisi field area because similar conditions likely existed during time of deposition. Considering the thin black shale facies is encased between evaporites and lacustrine mudstones, both of which are shallow water deposits, it is unlikely that during the limited time of black shale deposition, a significant deepening event occurred in the area. The reduced salinity conditions required for the existence of *Lingula* in McCollum's (1988) model probably developed in the Nipisi area when periods of elevated fresh water inflow caused the mixing of fresh and marine waters.

Of the fifty-two cores examined, thirty-three contained fish remains in the form of plates, scales, bones, and teeth. Fish remains were mostly present in the lower 0.3 m of mudstone deposits, and only rarely in the sandstones or the middle to upper portions of mudstone deposits. Thachuk (1967) identified these fish remains to be from the order Antiarchi and family Asterolepidae. These were armored fish considered to have been bottom-living forms that inhabited fresh to possibly brackish waters (Thachuk, 1967). Middle to Upper Devonian fish remains from other areas have similarly been interpreted to have fresh to brackish water origins. Devonian "fish beds" from the Old Red Sandstone deposits of Scotland and Ireland were interpreted as freshwater lake deposits (Trewin, 1986). Gordon (1988) however, stated that although most fish from the Middle to Upper Devonian Catskill Magnafacies have been assumed to represent freshwater species, some evidence suggested that the fish may have lived in brackish to even marine conditions.

Combining the observations of Thachuk (1967), and Alcock and Benteau (1976), two types of charophytes, *Eochara wickendeni*, and *Chovanella burgessi*, have been identified in the Watt Mountain Formation mudstones and in some of the upper Gilwood sandstones. Charophytes are calcareous green algae of the genus *Chara* that can be found in both modern and ancient lakes (Dean and Fouch, 1983). They are common on lake margins were they grow on low energy substrates down to 15-20 m depth (Cohen and Thouin, 1987). Because they contain both internal and external $CaCO_3$, charophytes are a major source of biogenic carbonate (Dean and Fouch, 1983).

Alcock and Benteau (1976) classified samples of Conchostracas from Nipisi as *Asmussia membranacea*, and *Ulugkemia sinuata*. Conchostracas are crustaceans that commonly live in ponds or other small temporary bodies of water. A few species however, have also been located in coastal salt flats (Robison and Kaesler, 1987).

4.2 Ichnology

Trace fossils can be found throughout a range of marine and nonmarine environments, and examples of trace fossil assemblages have been documented in rocks of similar and older age than the Watt Mountain Formation (cf. Bradshaw, 1981, Vos, 1981, Pollard *et al.*, 1982, Gordon, 1988). During examination of cores from the Watt Mountain Formation only very rare examples of *Planolites*, a feeding burrow of a infaunal deposit-feeder, were identified (Ekdale *et al.*, 1984). This single ichnogenera is known to occur in both continental and marine environments, and has also been interpreted to be a facies-independent burrow (Gruszczynski, 1985). Therefore, limited information can be directly obtained by the existence of *Planolites*.

Trace fossils can survive in a range of conditions varying from marine to nonmarine, therefore, a distinct lack of them in the Nipisi field area can indirectly provide insight into the environmental conditions that existed during sedimentation of the Watt Mountain Formation in this area. The survival and abundance of invertebrate tracemakers is mainly dependent on factors such as temperature, food supply, moisture levels, salinity, substrate characteristics, and intensity of wave or current agitation (Frey and Pemberton, 1987). Therefore, the limited occurrence of tracemakers suggests that not all of the above mentioned factors were continuously favorable for their survival. Considering the facies making up the Watt Mountain Formation deposits, it is unlikely that factors such as moisture levels, substrate characteristics, or intensity of wave and current agitation would be factors that could inhibit trace fossil occurrence throughout deposition of these facies. Therefore, temperature and food supply are the likely candidates, which may suggest that either paleoclimatic conditions were too hot, or there was a lack of food supply during sedimentation of the Watt Mountain Formation.

4.3 Palynology

Extremely rare fragments of primitive plants, *Psilophytes*, were identified in the cores examined in the Nipisi field area. This lack of flora was consistent with the findings of other workers who have studied the Watt Mountain Formation in the vicinity of the Peace River Arch. Paylnologic processing by Alcock and Benteau (1976) on three wells in the Nipisi field area revealed only some wood and cuticle. Rottenfusser (1976) discovered limited flora north of the Peace River Arch, and Kramers and Lerbekmo (1967) discovered limited flora in the Mitsue field area. However, during the Middle Devonian other parts of the world were lush with greenery. This indicates that plant growth was somehow discouraged in the Peace River Arch region, perhaps by very hot and dry conditions that occurred over much of the area during this time (Nelson, 1970). These hot and dry conditions are supported by Witzke and H ckel (1988) who placed most of Middle Devonian Euramerica in an arid evaporitic belt.

CHAPTER 5 VERTICAL FACIES ASSOCIATIONS AND INTERPRETATIONS

5.1 Introduction - Facies Association

The term "facies association" was originally defined by Potter in 1959 as "a collection of commonly associated sedimentary attributes" (Miall, 1984) The purpose of this chapter is to describe and interpret the most common sequential associations of the eight facies presented in Chapter 3 An individual facies may provide some evidence to suggest an environment of deposition, but most facies are not exclusively generated in any one environment (Harms *et al.*, 1982). Therefore, in order to increase the significance of an environmental interpretation, it should be based on a grouping of facies that represent recurring facies associations, or genetically related sequences (Collinson, 1969, Walker, 1992). The eight facies in Chapter 3 that represented recurring structures, textures, and biological attributes, were qualitatively grouped into 4 facies associations. The facies in each association were then collectively interpreted with the intent of determining the major paleoenvironment

5.1.1 Facies Association 1 (Lacustrine Deposits)

Description.

Facies association 1 is characteristically dominated by red or green coloured mudstones (Facies 2) that contain accessory features such as stress cutans, calcareous nodules, and mud cracks Silty to sandy zones, and thin (2 to 11 cm) fine-to medium-grained sandstone interbeds are common in the mudstones (Fig 5 1) Internally, the sandstone interbeds are characterized by either planar-laminated (Facies 3) or small-scale cross-stratified sandstones (Facies 5) This association ranges from a few cm to approximately 5 m in thickness, with the thickest deposits located on the eastern edge of

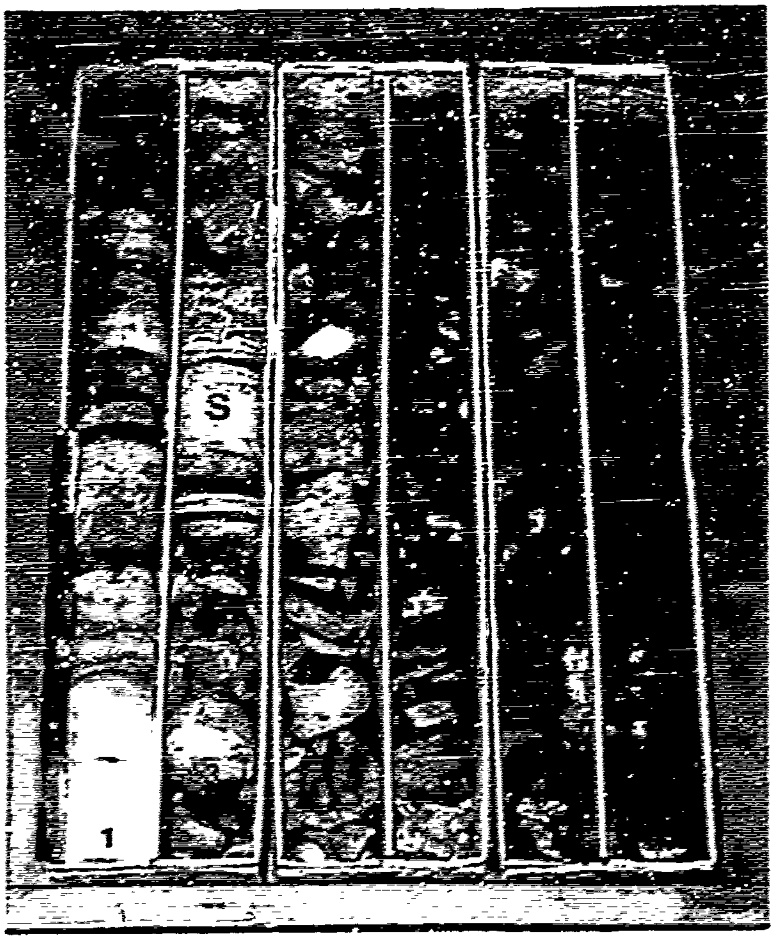


Figure 5.1 Facies Association 1

Cored sequence illustrating the typical siltstones and mudstones of Facies Association 1. This relatively thick sequence with limited sandy zones has developed because of its distal location from the western sourced clastics. The deposits illustrated in the photo include:

1-2 Upper fine-grained sandstone of Gilwood zone 1 gradationally overlain by 10 cm of pale green mudstone. This thin mudstone is a typical illustration of the invariable presence of green coloured mudstones at all mudstone-sandstone contacts.

2-3 Dark reddish brown blocky mudstone exhibiting septarian cracking.

3-4 Blocky mudstone dominantly grayish green with scattered dark reddish brown patches. Fish scales and small slickensides were present above the sandy zone (s).

4-5 Dark reddish brown blocky mudstone that is fissile in part.

The photograph is from 10-19-80-7W5, 1691.4-1686.8 m. Scale bar is 40 cm.

the Nipisi field and become progressively thinner toward the west Fish fragments and *Chara* were the most prevalent fauna.

Interpretations:

Facies association 1 is interpreted to represent an accumulation of deposits in a fresh to brackish water lacustrine environment. This interpretation is based on the lithologic, paleontologic, and sedimentologic characteristics of the facies in this association (Fig. 5.2).

The mudstone deposits that accumulated by suspension fallout in a relatively low energy hydrologic system (Chapter 3) are interpreted to have been deposited in a lacustrine setting. The presence of charophytes and Conchostracas in the mudstones also supports this lacustrine interpretation since they can both be associated with lakes or small temporary bodies of water (Alcock and Benteau, 1976, Dean and Fouch, 1983) The water chemistry of this lake was likely variable, but the presence of fish fragments of the order Antiarchi in the mudstones suggested that fresh to brackish water conditions existed (Thachuk, 1967). Additionally, because the mudstones dominantly lacked lamination and only fish fragments and not intact fish skeletons were found, deposition was likely from a relatively shallow dominantly unstratified lake (Rogers and Astin, 1991).

The presence of sandy mudstone zones, thin sandstone beds, and subaerially exposed areas in the mudstones, suggests rapidly changing hydrodynamic conditions Although hydrodynamic changes can occur in both lacustrine and marine environments, lacustrine settings are more susceptible to rapid climatically and tectonically controlled fluctuation because they commonly have narrow facies belts (Platt and Wright, 1991) Subaerial exposure is also a very common feature in lacustrine environments resulting

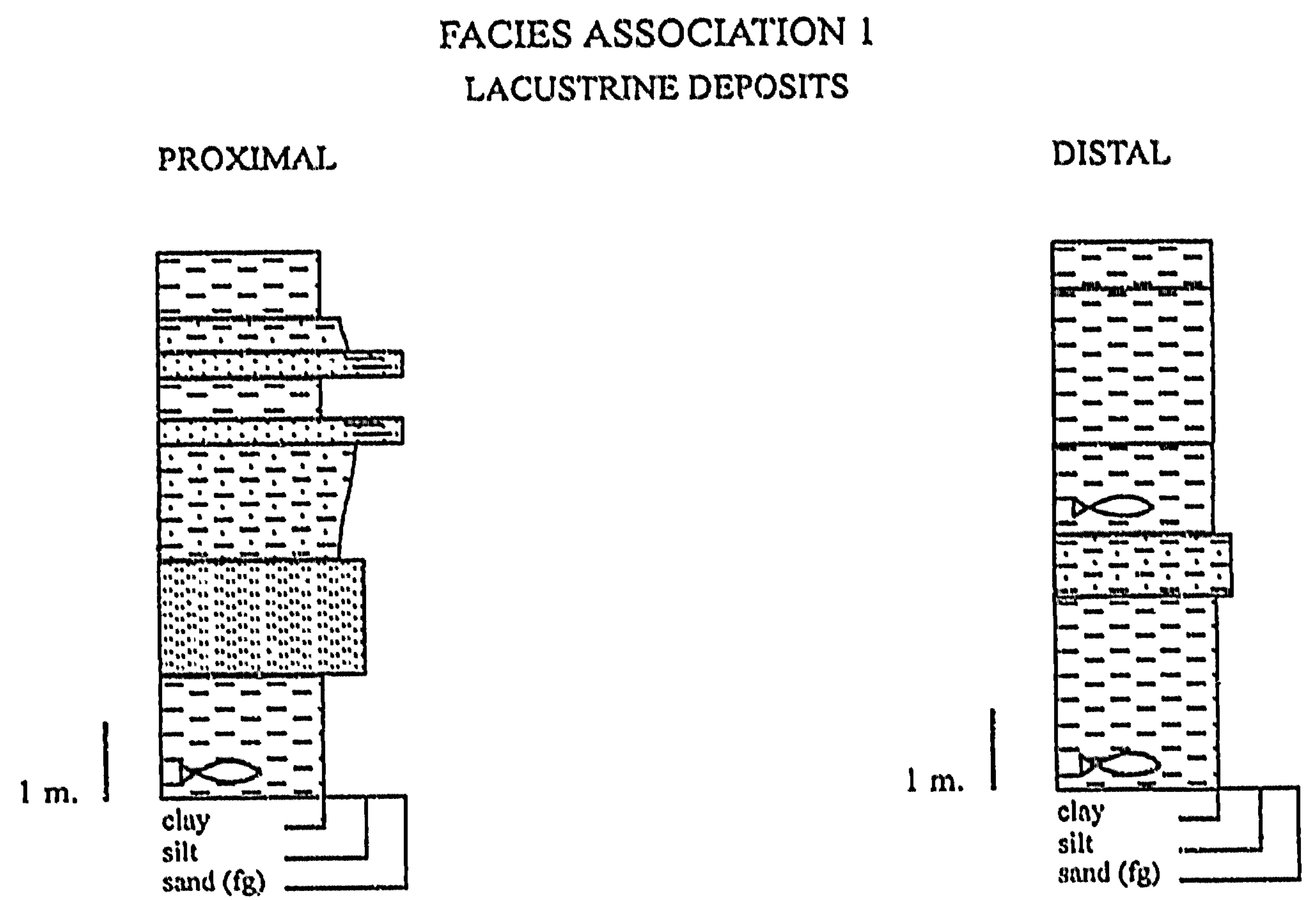


Figure 5.2 Schematic illustration of the typical proximal and distal lacustrine deposits relative to the braid delta plain. Note the decrease in siltstone and sandstone beds in the distal deposits. Description of symbols located in legend of appendix

from oscillations in lake level and shoreline positions (Allen and Collinson, 1986). The lack of evaporites in the Watt Mountain Formation despite frequent subaerial exposure is very significant. It suggests that the lakes were composed of fresh water, which would have inhibited any evaporite formation (Tucker, 1991).

Watt Mountain Formation mudstones and associated sandstone interbeds lack evidence indicating active tidal or strong wave processes. Although large lakes closely resemble shallow seas in processes of deposition and facies patterns, negligible tidal effects and lower wave energies are two differences that can distinguish lacustrine from marine environments (Picard and High, 1972).

5.1.2 Facies Association 2 (Marginal Lacustrine Deposits)

Description:

Facies association 2 is characterized by a coarsening and thickening upward succession of sandstone and mudstone (Fig. 5.3), and is limited in occurrence relative to the fining upward successions in the Watt Mountain Formation. An idealized succession begins with a lower massive mudstone (Facies 2) that grades upward into a mixed silty to sandy mudstone (Facies 8), followed by a unit of interbedded sandstone and mudstone, and an upper unit of thick-bedded coarsening upward sandstone. However, the units of mixed silty to sandy mudstone (Facies 8) and interbedded sandstone and mudstone may be absent. The termination of facies association 2 is indicated when the coarsening upward succession is replaced by either lacustrine deposits or less commonly, scour-based fining upward sandstones.

The upper thick bedded sandstone unit dominates this facies association. It consists of a coarsening upward fairly- to well-sorted sandstone that may be up to 2

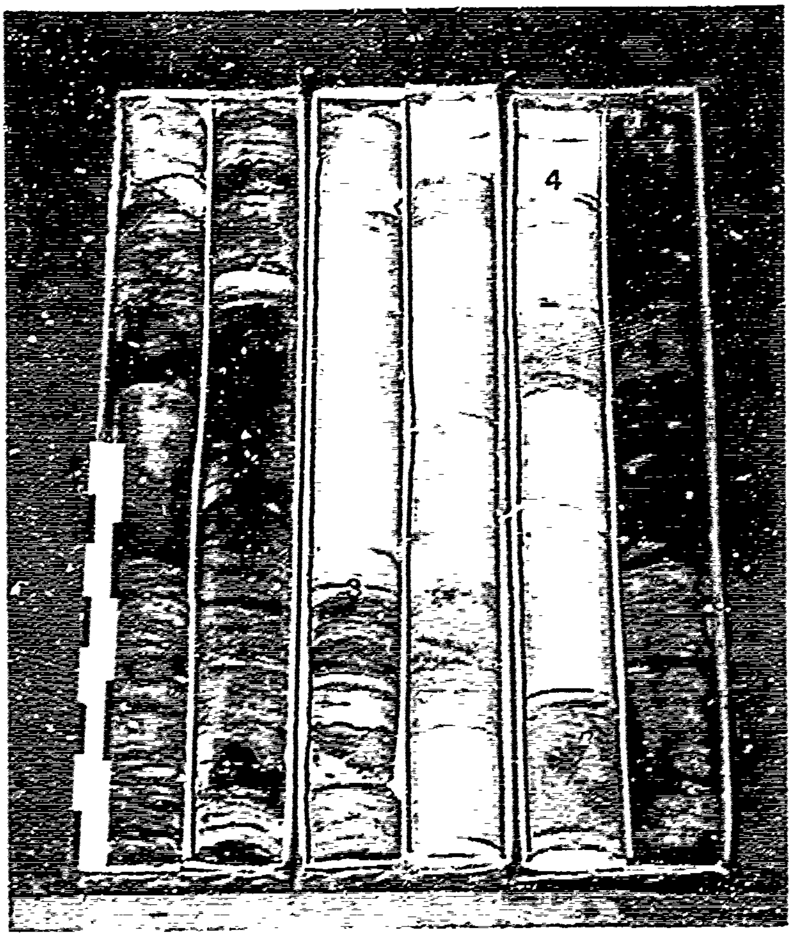


Figure 5.3 Facies Association 2

Cored sequence illustrating a coarsening upward succession of Facies Association 2

1-2 A lower mudstone

2-3 A middle interbedded sandstone and mudstone unit. The sandstone interbeds consist of fine-grained planar laminated and small-scale cross bedded sandstones

3-4 An upper thick bedded coarsening upward sandstone dominated by large scale cross bedding. A fish plate occurs in the upper 0.3 m of this unit

4-5 An overlying mudstone unit

The photograph is illustrating Gilwood Zone 5 in 12-26-79-7W5, 1600.6-1604.9 m

Scale bar is 30 cm

meters in thickness. Grain sizes are typically in the medium- to coarse-grain range, but may also be fine-grained or pebbly. Internally the sandstones contain intra-erosive surfaces, and although cross-bedded sandstones (Facies 4) dominate, massive (Facies 6) and planar-laminated (Facies 5) sandstones are present. In the sandstones are mudstone clasts, occasional mudstone laminations, and very rare occurrences of fish remains.

When present, the lower mixed silty to sandy mudstone (Facies 8) and the interbedded sandstone and mudstone portion of facies association 2 are typically 0.3 to 1.0 m in thickness. The i its commonly show upward increases in the relative proportion o tone. Sandstone interbeds range from very fine- to medium-grained, typically composed of either massive (Facies 6), parallel laminated (Facies 5), or small scale ripple cross-laminated (Facies 3) sandstones. The mudstone interbeds are mostly green, massive, and contain varying amounts of scattered sand grains and fish remains.

Interpretations:

Facies association 2 (Fig. 5.4) is interpreted to represent deposits generated on lacustrine margins, such as fluvial mouth bars, beaches, spits, and barriers. The fluvial mouth bars formed when fluvial systems entered the lake basin, while the beaches, spits, and barriers, formed by processes commonly associated with low- to intermediate wave energy marine environments (Lin Changsong *et al.*, 1991; Allen and Collinson, 1986).

The classic view of deposits generated by prograding mouth bars is often summarized in a single, coarsening-upwards sequence, however, in reality there are bound to be large- and small-scale variations in facies (Elliot, 1986). The upper thick bedded sandstones which represent proximal mouth bar or channel deposits are always preserved in the Nipisi examples. However, rarely present are the distal bar deposits

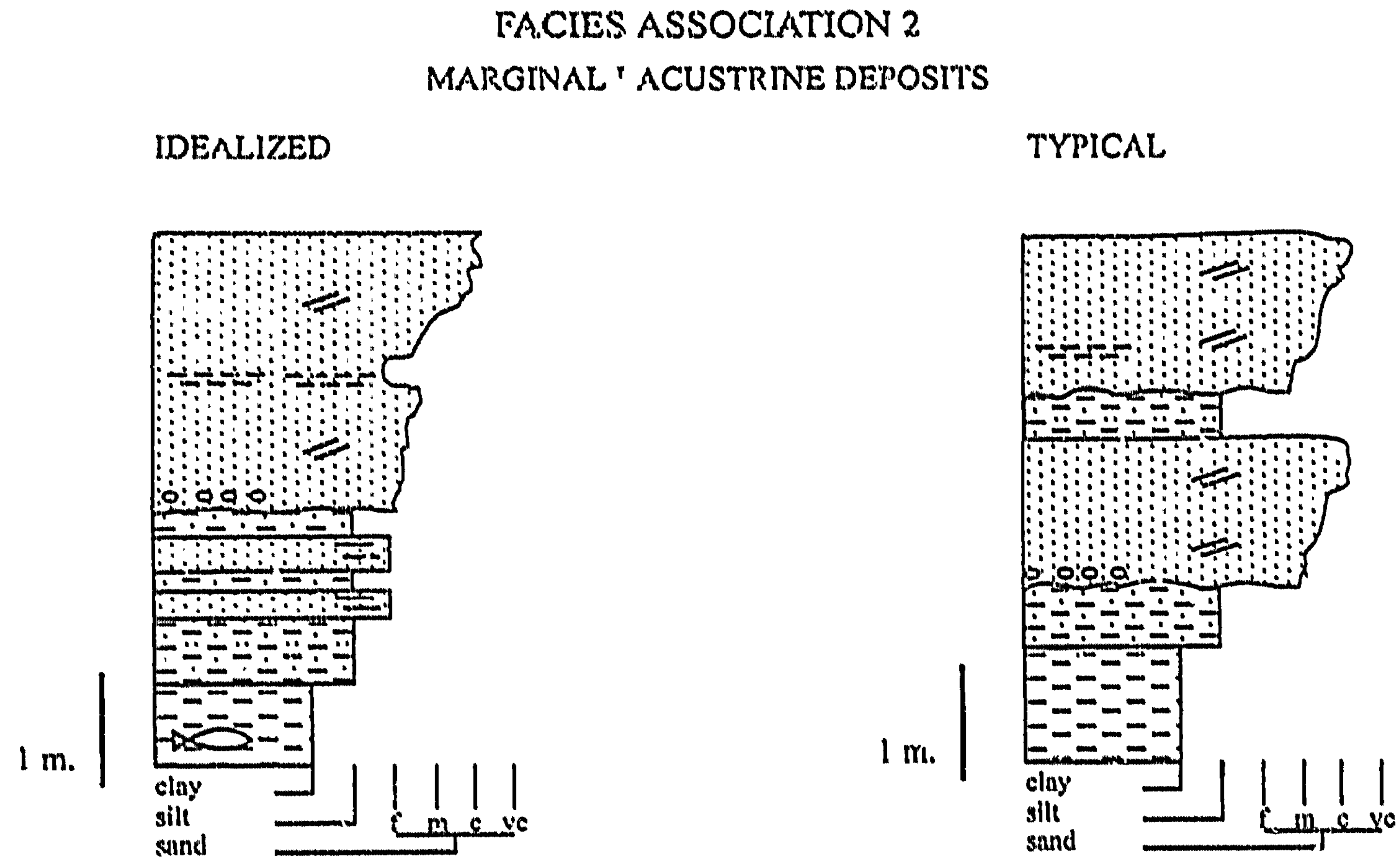


Figure 5.4 Schematic illustration of ᴀ idealized and typical marginal lacustrine facies association. Description of symbols located in legend of appendix.

represented by the sandy mudstones and interbedded sandstones and mudstones at the bases of these coarsening-upward successions.

Partial sorting exhibited in some sandstones is a result of minor reworking of sands along the marginal lacustrine areas by waves which dominated the shorelines during the quiescent periods between basin infill stages. These shorelines are interpreted to have occurred in relatively shallow waters. Renaut and Owen (1991) showed that beaches could form in fresh or saline shallow lakes with a mean depth of only 5.5 m.

The limited occurrence of this facies association can be attributed to the lack of tidal and high wave energies, and difficulty in recognition. Marginal lacustrine deposits are difficult to recognize because rapidly fluctuating lake levels may obscure the identification of shoreline processes. Fluctuating levels continually transform shoreline configurations to an extent that effectively inhibits the development of broad progradational shoreline sequences (Picard and High, 1972). In addition, recognition of these littoral deposits also depends greatly on the degree of post-depositional modification (Renaut and Owen, 1991).

5.1.3 Facies Association 3 (Interdistributary Deposits)

Description.

The successions characterizing facies association 3 exhibit considerable variation in facies sequences, consisting of both sandstones and mudstones in a wide range of relative proportions (Fig. 5.5). A general sequence includes a mudstone unit (Facies 2), and variable amounts of fining and coarsening upward sandstone interbeds. The mudstones (Facies 2) commonly contain accessory features such as mud cracks, stress cutans, and calcareous zones and intraclasts, while the sandstone interbeds consist of

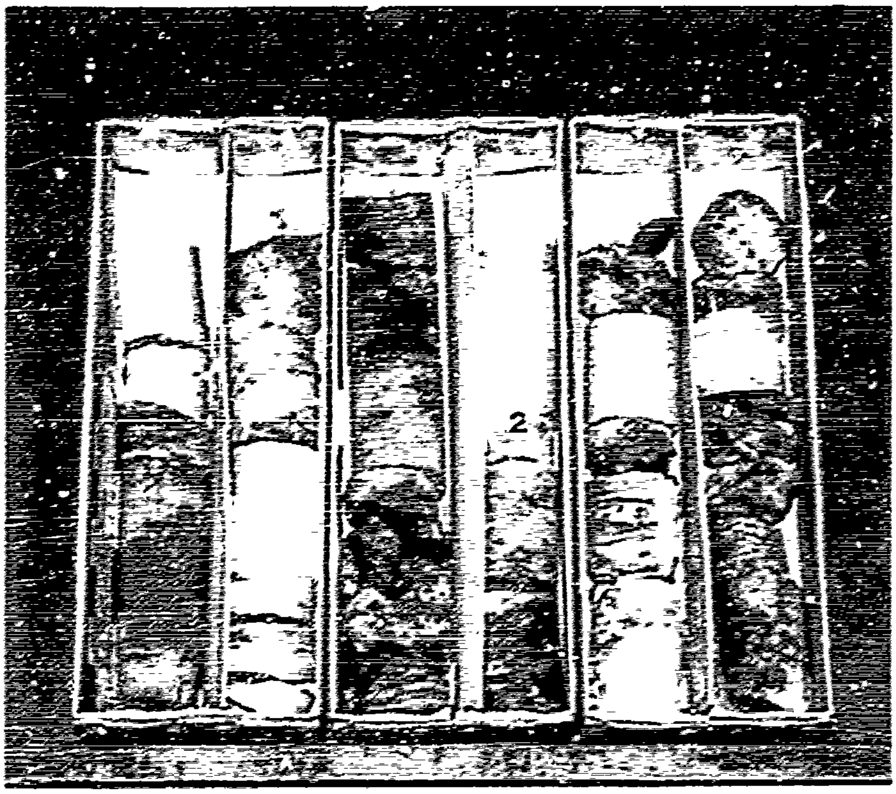


Figure 5.5 Facies Association 3

Cored sequence illustrating the deposits representative of Facies Association 3 The photograph demonstrates the cyclic deposition of silty to sandy mudstone deposits and thin fine- to coarse-grained sandstones This particular sequence includes 4 fining upward cycles (labeled 1-4) Each cycle contains a lower sharp based sandstone dominated unit overlain by a mixed sandstone and mudstone followed by a sandy mudstone containing scattered calcareous clasts and small slickensides

The photograph is illustrating Gilwood zone 5 in 10-32-80-8W5, 1697 3-1701 5 m (2 5 m of mudstone is missing at 1700 5 m) Scale bar is 40 cm.

very fine- to coarse-grained cross-laminated (Facies 3) and cross-stratified (Facies 4) sandstones that range up to 0.45 m in thickness

Interpretations

Facies association 3 is interpreted to represent an accumulation of deposits generated in the interdistributary areas in the lacustrine braid-delta plain Interdistributary areas are generally enclosed shallow bodies of water that are quiet or even stagnant, and periodically intruded by deposits normally located in the river channels. The wide range of facies and sequences is a result of the variety of processes, including overbank flooding and crevassing, that can be responsible for the filling of interdistributary areas (Fig 5 6) (Galloway, 1981, Elliott, 1986)

The mudstone deposits in this association reflect the deposition of fines by suspension fall out during relative quiescent periods in the interdistributary areas, while the sandy bedforms are interpreted to be crevasse events Crevasse events can generate both coarsening and fining upward sequences that represent progradation and gradual abandonment respectively (Miall, 1985). Deposition in the upper part of interdistributary bay-fill sequences may be indicated by an increased abundance of current generated structures similar to those of facies 3 (cross-laminated sandstone), which is a result of the increasing in energy of the shallower water as the bay fills with sediment (Horn *et al.*, 1978)

5.1 3 Facies Association 4 (Channel Deposits)

Description

Facies association 4 is characterized by the stacking of fining upward and, less commonly, coarsening upward cycles, which together can generate sandstone-dominated

FACIES ASSOCIATION 3
INTERDISTRIBUTARY DEPOSITS

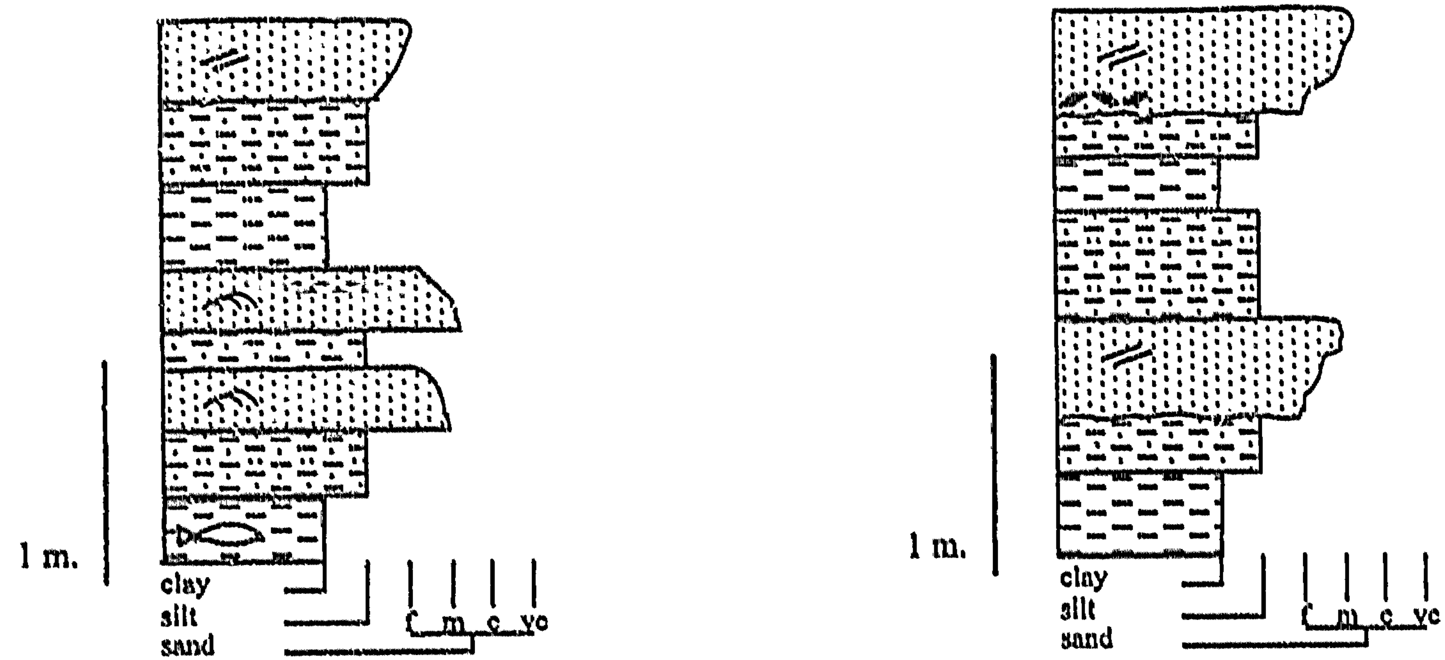


Figure 5.6 Schematic illustrations of interdistributary deposits. Notice the fining and coarsening upward sandstone interbeds. Description of symbols located in legend of appendix.

units up to a few meters thick (Fig. 5.7). Individual cycles are dominated by large-scale cross-stratified sandstones, and are commonly separated by either thin deposits of mudstone (Facies 2) or minor scour surfaces.

A typical fining upward succession begins with a sharp scoured base of low relief (<2 cm) and a coarse grained lag containing randomly oriented mud clasts. Immediately following is a middle unit consisting of large-scale cross-stratified sandstones (Facies 4), and an upper unit made up of cross- and planar-laminated sandstones (Facies 3 and 5 respectively).

Interpretations:

The stacking of fining and coarsening upward sandstone-dominated cycles which characterize this facies association (Fig. 5.8) is a reflection of repetitious channel establishment and abandonment at a given site, and can be attributed to factors intrinsic to the fluvial regime (Allen, 1970). Additional features in these deposits such as the rapid changes in facies showing increases and decreases in flow velocity, and the relatively low abundance of trough cross-stratification relative to planar cross-stratification, are features characteristic of braided channel deposits (Moody Stuart, 1966, Smith, 1970). Similar associations also interpreted to represent braided channel deposits have been described by Boothroyd and Nummedal (1978), Pollard *et al.* (1982), and Fernandez *et al* (1988). Braided river systems are characterized by many channels separated by bars or small islands, and when compared with meandering rivers, they have a lower sinuosity, coarser sediment load, and higher width/depth ratio (Miall, 1977)

The development of the braided pattern is a result of complex interactions between sediment supply and water discharge (Collinson, 1986) Braided patterns are preferentially formed under fluvial environments containing excess sediment load and

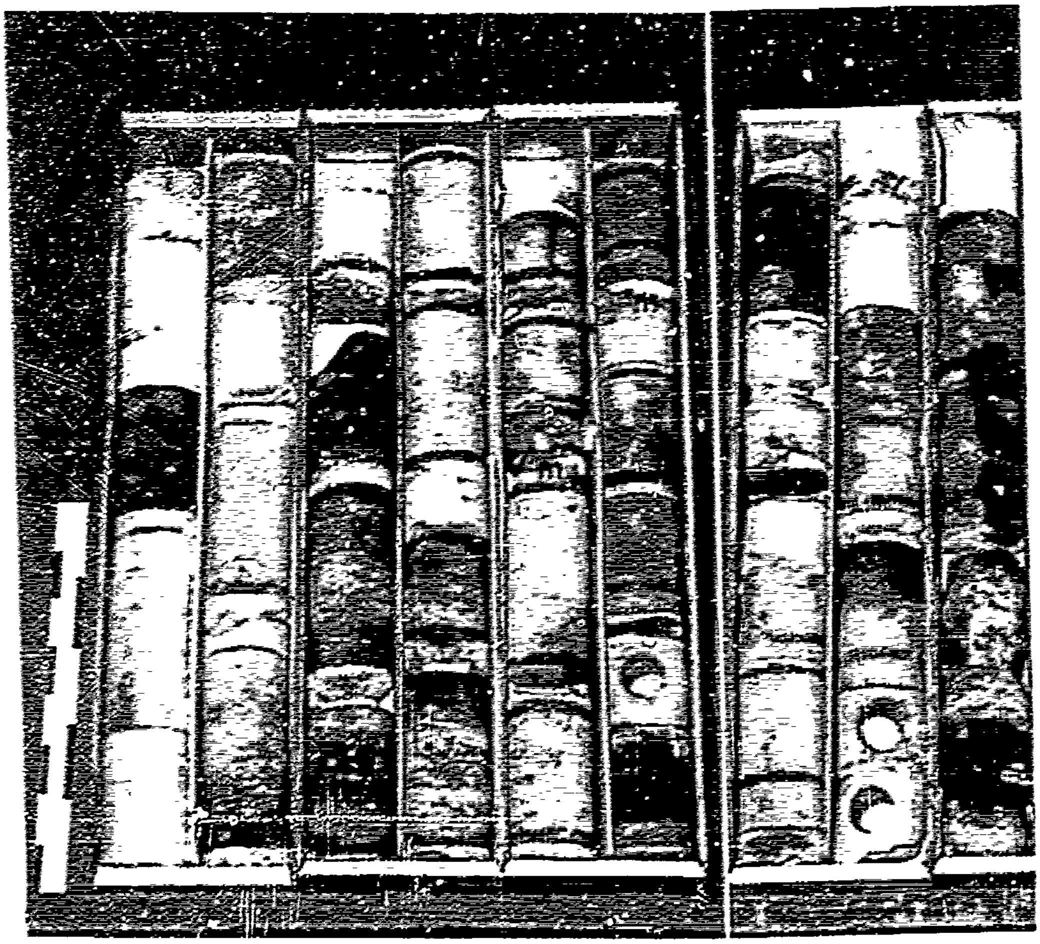


Figure 5.7 Facies Association 4

Cored sequence illustrating stacked fining upward successions representative of Facies Association 4 Within the 3 large-scale fining upward cycles (1-2, 2-3, 3-4) there are numerous fining upward and occasional coarsening upward sub-cycles reflecting rapid fluctuations in flow velocity The tops of the fining upward sub-cycles occasionally include mudstone (m) This lack of mudstone results in the deposition of a relatively continuous sandstone unit Fining upward sequences are dominated by large scale cross-bedding in the lower medium- to coarse-grained sandstones, and these grade into an upper finer-grained small-scale cross-stratified or planar-stratified sandstone

The photograph is from 2-3-79-8W5, 1731 7-1727 1 m (Gilwood zones 3 and 4) Scale bar is 40 cm

FACIES ASSOCIATION 4

CHANNEL DEPOSITS

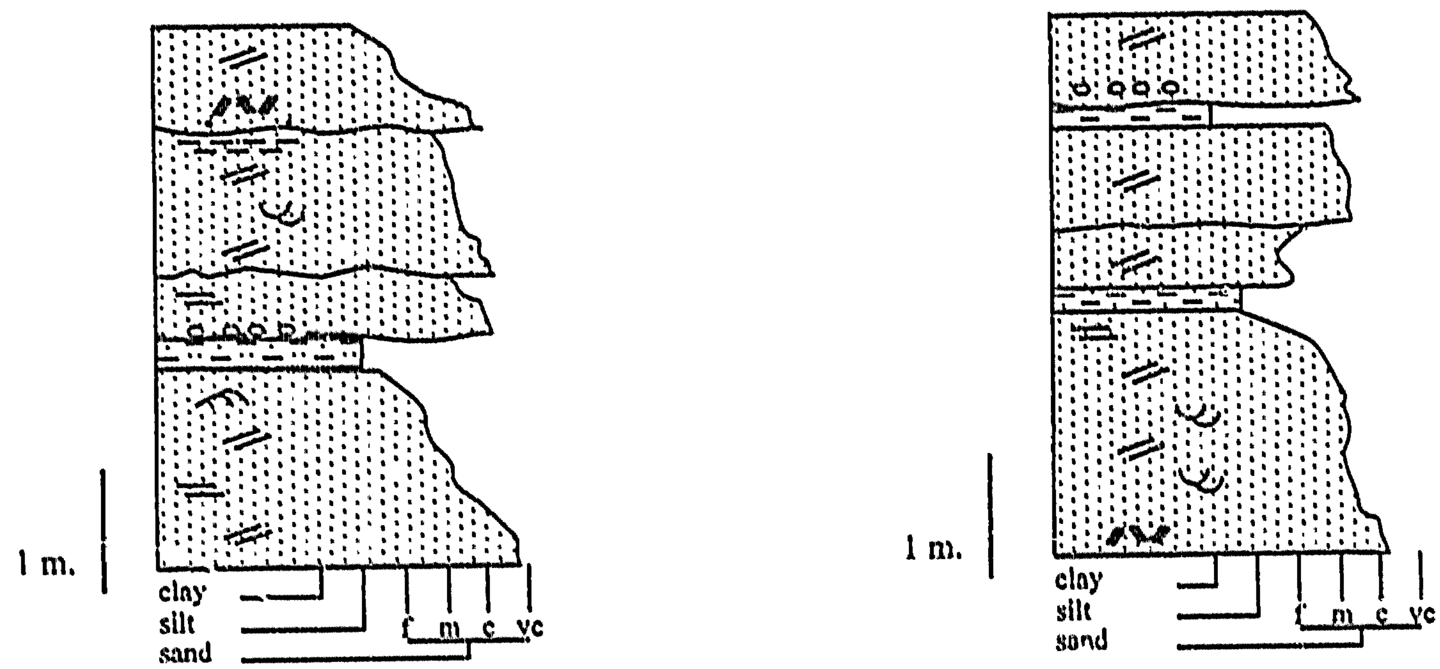


Figure 5.8 Schematic illustration of typical braid-delta distributary channel deposits. Note the stacking of fining upward cycles and rapid changes in sediment type. Description of symbols located in legend of appendix

highly variable discharge rates (Smith, 1970, Boggs, 1987, Miall, 1992). They result from the splitting of flow initiated by the development of mid-channel bars and islands that temporarily store the excess sediment that is available when a river no longer has the capacity or energy to carry its sediment load (Miall, 1992). Given adequate sediment supply, the development of low sinuosity channels is common in arid climates where sporadic discharge rates are common (Elliott, 1986; Miall, 1992).

The lack of flora in sediments of the Watt Mountain formation (Chapter 4) was a significant factor toward the development of braided channels. Braided channel patterns are favored in non-vegetated sediment because of the limited ability to confine channels. Channel banks containing vegetated sediments are more cohesive than non-vegetated banks and result in the development of channels that tend to form meandering rather than braided patterns (Cotter, 1978). Smith (1976) concluded that non-vegetated sediment could be 20,000 times less stable than sediment with 16-18% by volume plant root (Fedo and Cooper, 1989). By decreasing bed load grain size, enhancing fine sediment production, and by increasing bank stability, vegetated sediment has the ability to retard erosion, decrease sediment yield, total runoff, discharge, and flood peaks for a given precipitation period (Schumm, 1968, Cotter 1978).

5.2 Depositional Facies Model For Watt Mountain Sediments

The definition of a facies model was given as "a general summary of a specific sedimentary environment..." by Walker (1984). Based on the four recurring facies associations 1) Lacustrine Deposits, 2) Marginal Lacustrine Deposits, 3) Braid-Delta Plain Interdistributary Deposits, and 4) Braid-Delta Plain Channel Deposits, in the sediments of the Watt Mountain Formation in the Nipisi field area, a lacustrine braid-delta facies model is suggested

The term braid-delta was defined by McPherson *et al.* (1987) to represent delta formation where braided fluvial systems prograde into standing bodies of water This type of delta, which has been previously classified as a fan-deltas, has similar shoreline and subaqueous components as a fan-delta, but has been separately classified because of its distinctly different subaerial components. Subaerial components of a fan-delta include an alluvial fan consisting of interbedded sheetflood, debris-flow, and braided-channel deposits, while a braid-delta consist entirely of braided-river or braid-plain deposits (McPherson *et al.*, 1987). Soegaard (1990) suggested that these differences are a direct consequence of the basin margin gradient. Therefore, fan-deltas are more restricted to areas where steep alluvial-fan gradients can be maintained while braid-deltas are not

A hydrologically balanced system occurs when evaporation and outflow is equal to inflow and precipitation. In the deposits of the Watt Mountain Formation there is evidence suggesting that major periodic changes occurred in the paleoenvironmental conditions. These changes significantly impacted the subcomponents of the lacustrine braid-delta system by changing the hydrologic balance, which is an important control on facies development (Platt and Wright, 1991). The stacking of repetitive facies sequences indicated that the paleoenvironmental conditions were cyclic, with each cycle represented by facies development in either periods when inflow exceeds evaporation or when evaporation exceeds inflow. During these changing conditions it is uncertain whether all facies associations were in existence continuously throughout Watt Mountain deposition Two end-member paleoenvironmental models (A and B) are suggested for the Nipisi area (Fig 5 9). Model A illustrates the paleoenvironment when inflow exceeded evaporation while in model B evaporation exceeded inflow

In model A (Fig 5 9), channels in the braid-plain prograded into the lacustrine basin and limited the accumulation of lacustrine deposition to the distal areas This high

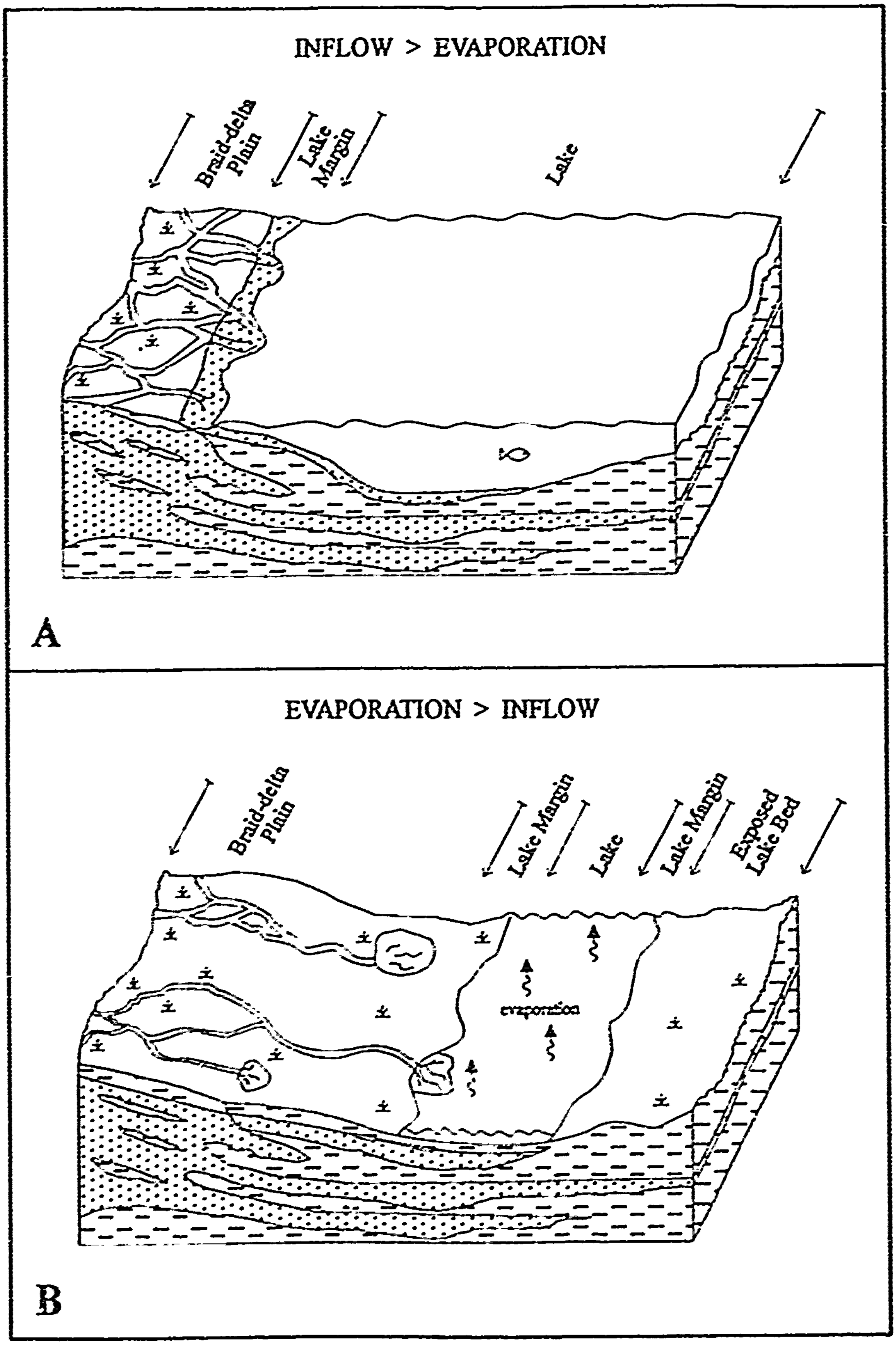


Figure 5.9 Two end member paleoenvironmental models for the Nipisi field area. (Modified from Rodgers and Astin, 1991)

inflow resulted in elevated lake levels and a landward shifting of the paleoshorlines and their associated facies. At the highest levels the lake may have had outlets, however, the maximum depth of the lake and possible spill level that limited it must remain the subject of speculation. When the braid-plain reached the margins of the lake, individual channels either generated marginal lacustrine deposits or continued subaqueously Billi *et al* (1991) explained two processes that allowed the formation of subaqueous channels, both of which may have occurred at Nipisi The first process initially required braided distributary channels to cut into the lake bottom when it was exposed to subaerial conditions during dry spells. This would make it much easier for channels to continue subaqueously when more humid conditions were re-established, because there would be a pre-established channel path. The alternative hypothesis involved strong hyperpycnal flows that allowed the formation of subaqueous channels since they could easily scour into the lacustrine clays as they entered the lake.

In model B (Fig. 5.9), lowered levels of inflow relative to evaporation resulted in the shifting of paleoshorelines and the exposure of previously submerged areas During this evaporation phase it was likely that the lake was hydrologically closed, and the lack of prograding channels allowed the deposition of lacustrine deposits throughout the basin, including those areas previously dominated by sandstone deposition The extreme limit of exposure during the evaporation phase may have been extensive, but the existence of isolated occurrences of fresh water carbonates suggests that small isolated bodies of water remained for some length of time

CHAPTER 6 STRUCTURE

6.1 Regional and Local Structure

Searching for a geological datum in northern Alberta, Rottenfusser (1974) constructed a structure map on the top of the Slave Point Formation with a 200 feet (61 meter) contour interval. The map covered a 15 square township area and illustrated that the Slave Point top was a nearly planar surface with a dip to the southwest of 4.7 m/km, and was suitable for use as a datum. The regional structure in the Nipisi area (approximately 2.75 square townships) was determined using a 10 m contour interval on this surface (Fig. 6.1), and although there are some distortions to the regularity of the contours, a southwest dip of approximately 5.4 m/km was calculated.

Rottenfusser (1974) expressed concern over using the top of the Watt Mountain Formation as a datum north of the Peace River Arch. His concerns were based on the difficulty in distinguishing between the Watt Mountain and overlying Slave Point Formation, and uncertainties in how flat-lying the top of the Watt Mountain Formation was. Within the Nipisi area, the top of the Watt Mountain Formation can be correlated with confidence, and many workers have used this surface as a datum. The similarity between the Watt Mountain and Slave Point formations structure contour maps, with the exception of some increased nosing of the contours in the northern part of the field, suggests that the top of the Watt Mountain Formation is also a reasonably flat surface (Fig. 6.2). Thachuk (1967) proved that the nosing of contours was a reflection of significant basement topography, which was in excess of 60 meters in the northern Nipisi area.

The contact between the Watt Mountain Formation and the underlying Muskeg Formation is an erosional unconformable surface (Alcock and Benteau, 1976). Although

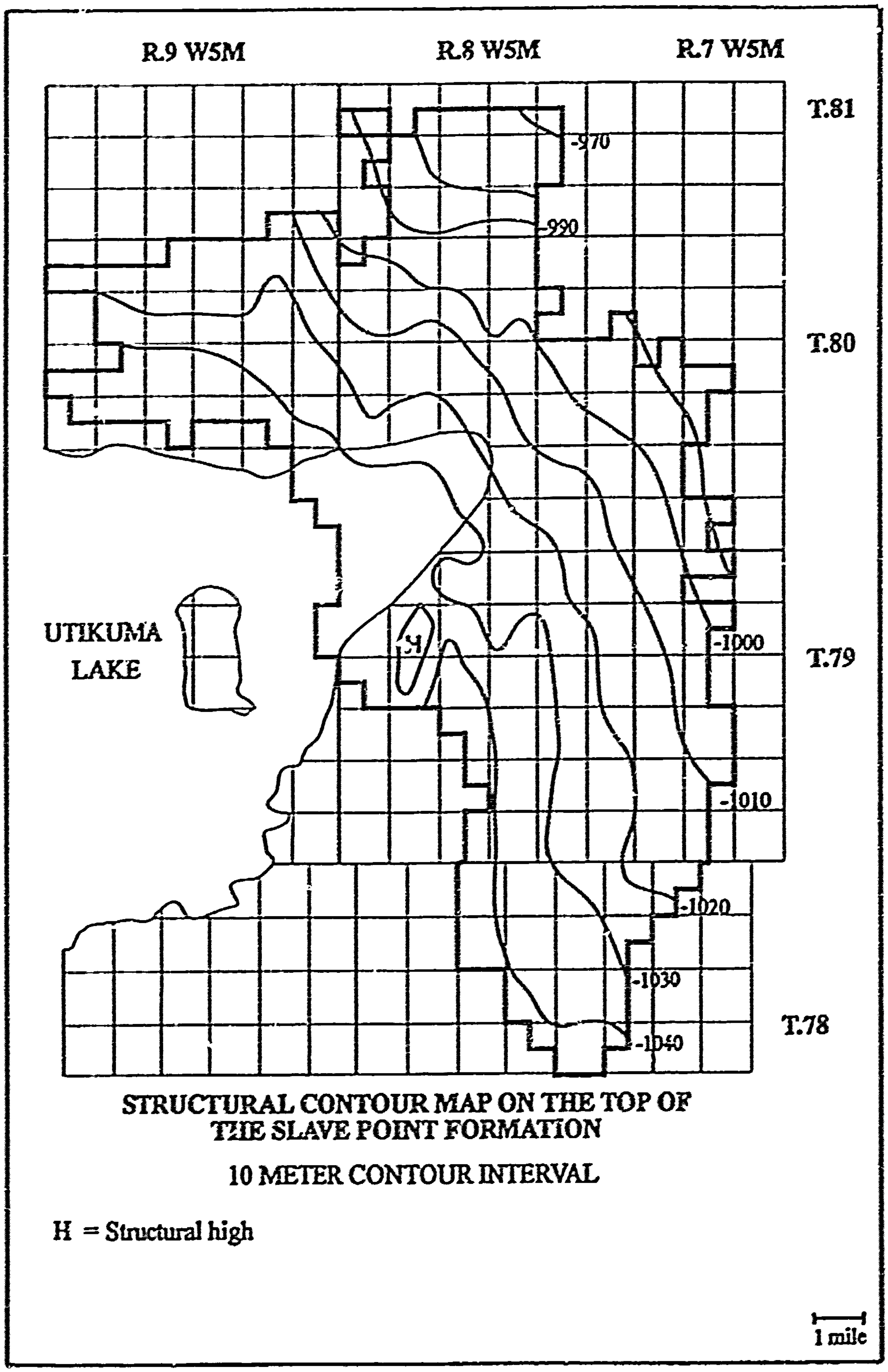


Figure 6.1 Structural contours on the top of the Slave Point Formation.

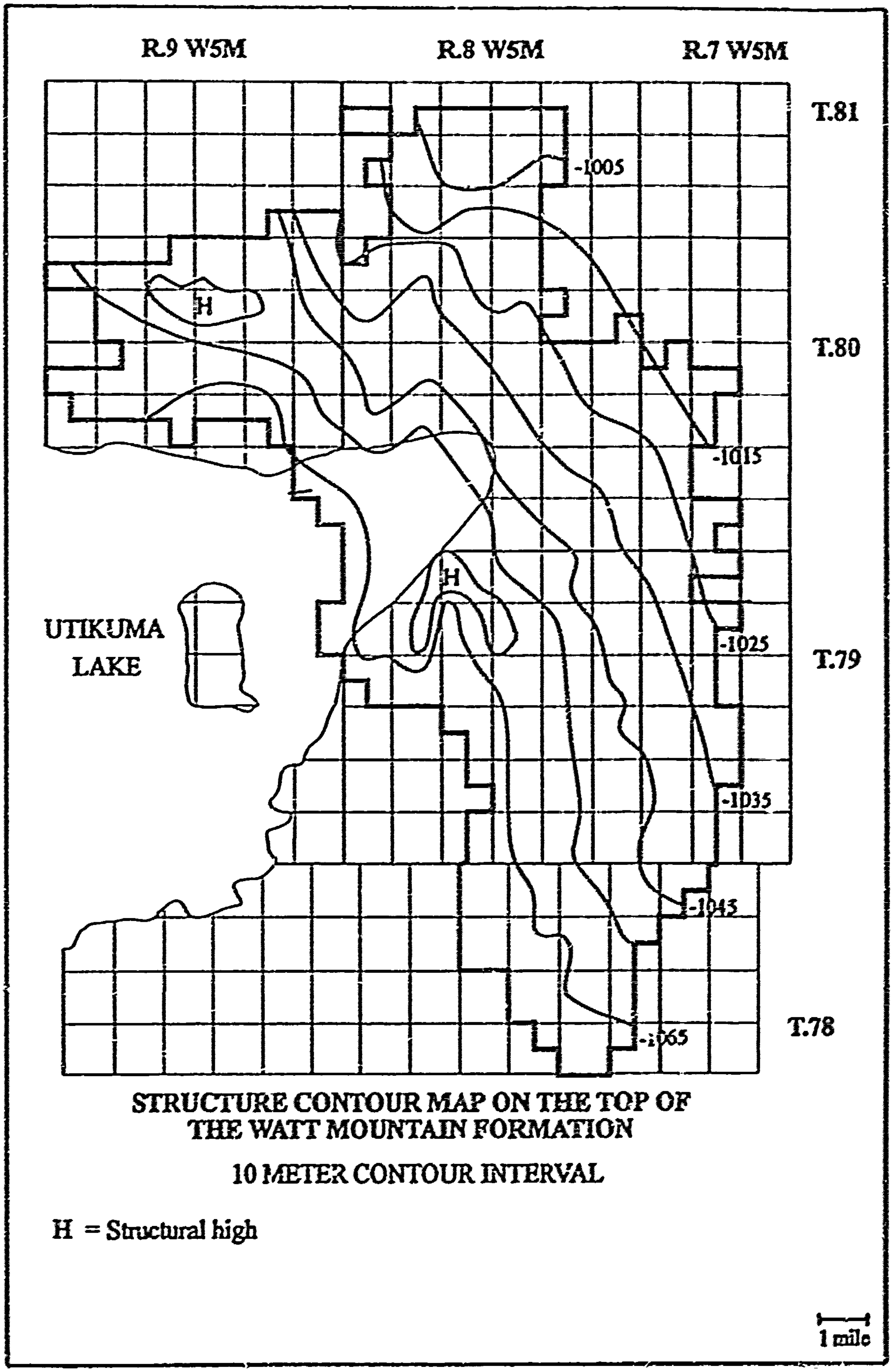
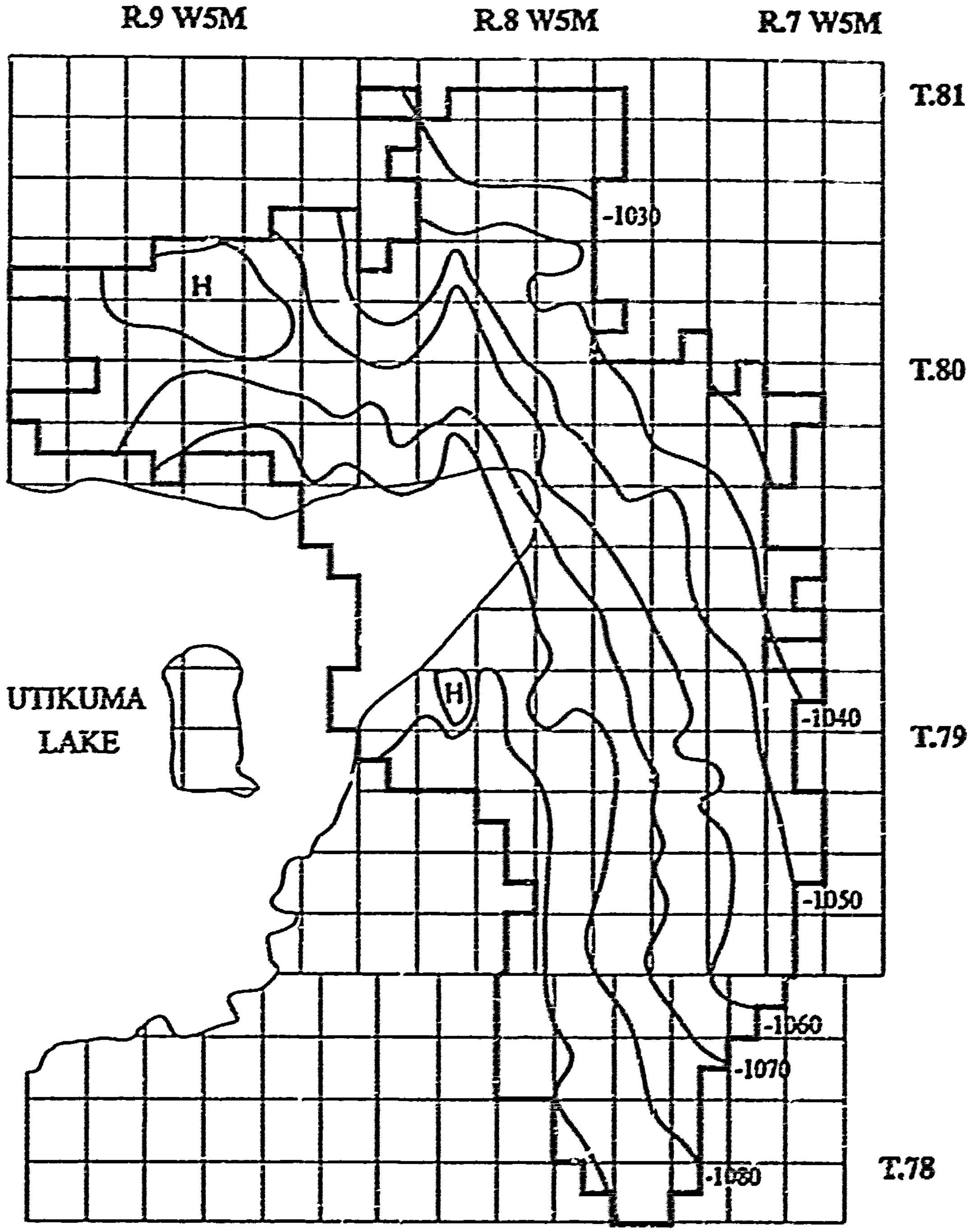


Figure 6.2 Structural contours on the top of the Watt Mountain Formation.

there is a similarity between the structural pattern of the Muskeg Formation top (Fig. 6.3) and the top of the Slave Point and Watt Mountain formations, the top of the Muskeg Formation has a significantly larger averaged southwest structural dip of 7.3 m/km on the eastern part of the field. This difference suggests that the structure of the Muskeg Formation was affected by events additional to those that generated the regional structure in the Nipisi field. A restored structure map of the top of the Muskeg Formation, using the depositionally flat Slave Point Formation as a datum, illustrates a north-south trending trough-like feature within the Nipisi field area (Fig. 6.4). This trough-like feature is clearly visible in a three-dimensional paleostructure diagram of the Muskeg Formation using the Watt Mountain Formation as a datum (Fig. 6.5). The trough resulted in the thick Watt Mountain sediment accumulation in the Nipisi area. A Watt Mountain Formation isopach (Fig. 6.6) illustrates the relationship between thickness of the Watt Mountain Formation and deepness of the trough.

6.2 Origin of Muskeg Trough

Previous studies have suggested that the Muskeg trough was the result of salt solution collapse prior to deposition of the Watt Mountain Formation (Thachuk, 1967 and Alcock and Benteau, 1976). Thachuk (1967) suggested that the salt solution occurred in the thick salt bed located at the base of the Muskeg Formation. Evidence for this was illustrated in an isopach map of this basal salt, which showed the existence of an erosional salt edge located approximately in the center of the Muskeg trough. This basal salt is important because it is the thickest salt bed in the Muskeg Formation. The present study shows, however, that there are many other thinner salt beds that appear to have been removed by salt dissolution, and these also contributed to the thinning of the Muskeg Formation over the Nipisi area.



STRUCTURAL CONTOUR MAP ON THE TOP OF THE MUSKEG FORMATION

10 METER CONTOUR INTERVAL

H = Structural high

Figure 6.3 Structural contours on the top of the Muskeg Formation.

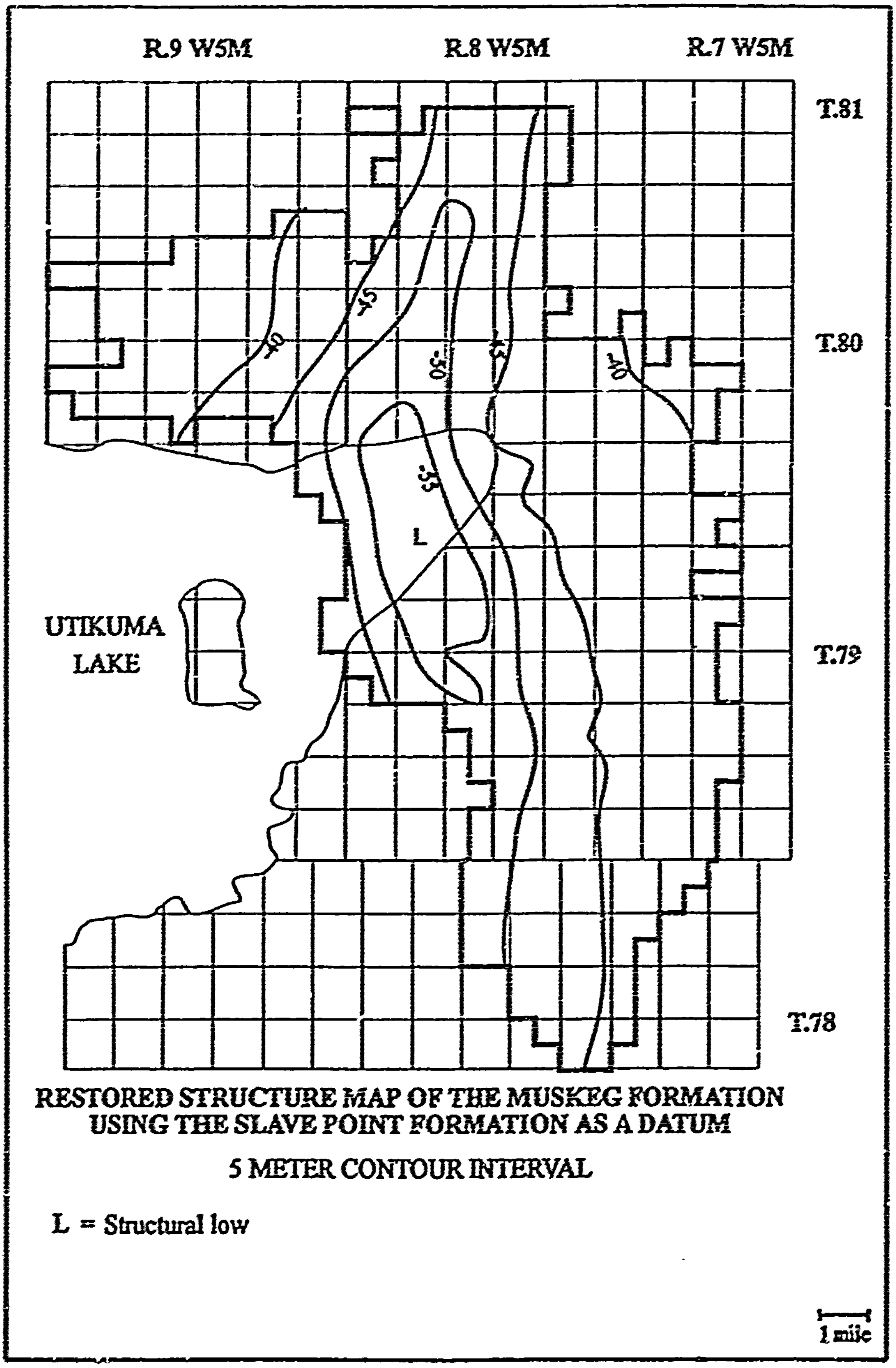
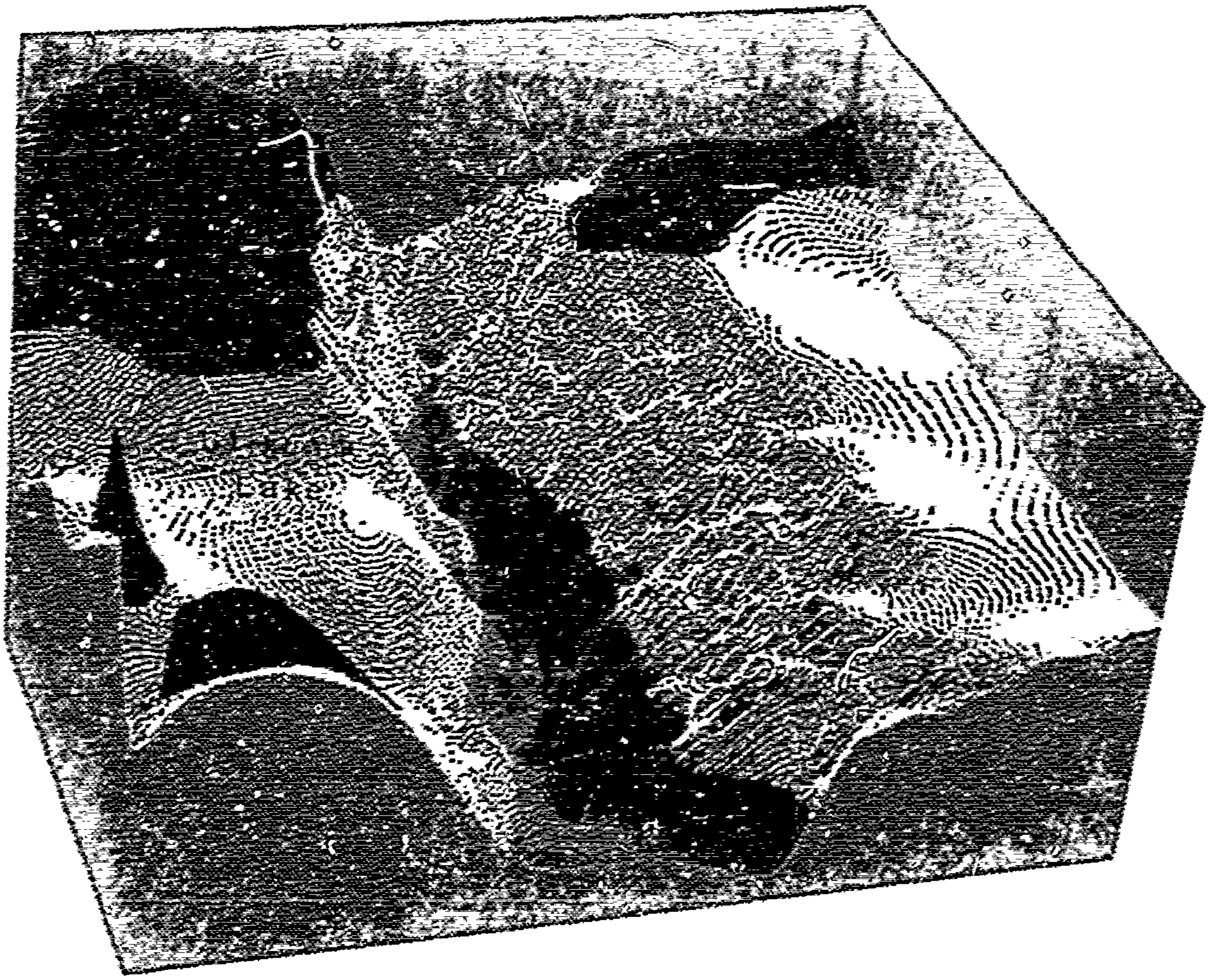


Figure 6.4 Restored Muskeg Fm. structure map using Slave Point Fm. as datum.



Topographical low (Base of Muskeg trough)

Topographical high

Figure 6.5 Three dimensional block diagram illustrating the paleostructure of the Muskeg Formation at the end of Watt Mountain time

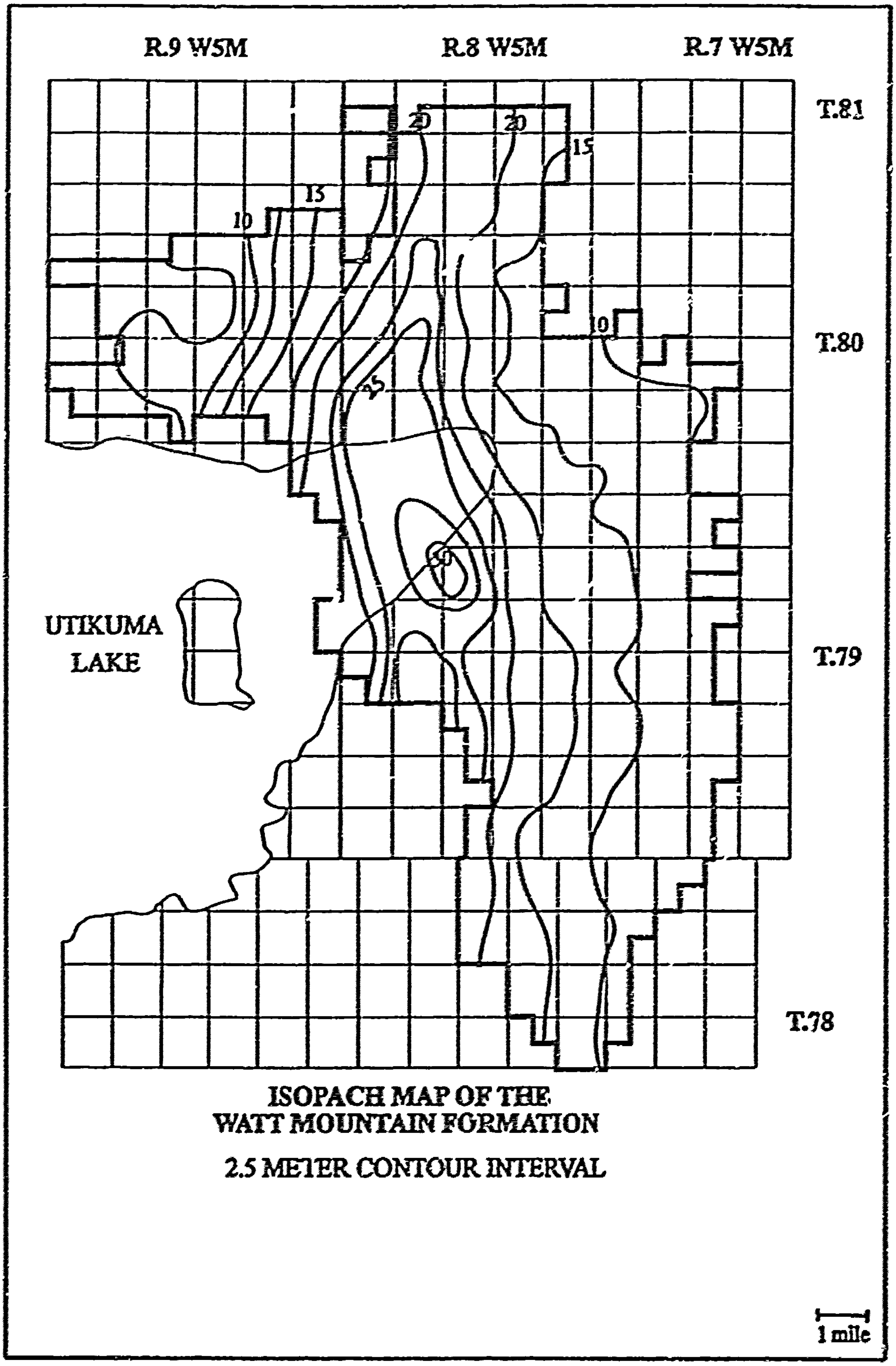


Figure 6.6 Isopach map of the Watt Mountain Formation.

An isopach map of the Muskeg Formation (Fig. 6.7) illustrates that the whole formation gradually thins in a westward direction, therefore, it is not surprising that the total accumulation of salt within the Muskeg Formation would also thin in this direction as demonstrated by Thachuk's isopach map of the lower Muskeg salt (Thachuk, 1967). A problem exists though, as to what causes the increased thickness of the Muskeg Formation to the west of Thachuk's (1976) zero salt edge. To the west of the zero salt edge, there is no lower salt left to explain the increased thickness of the Muskeg Formation. However, the increased thickness of the Muskeg Formation on the western side of the Nipisi area can be explained if all salts in the Muskeg Formation are thought to have contributed to the salt solution collapse. A total salt isopach map was generated by using a 65 µs/ft cutoff on the sonic log (Fig. 6.8). The map illustrates that the thickening of the Muskeg Formation on the western side of the Muskeg trough is associated with a thickening of total salt accumulation.

6.3 Timing of Salt Solution Collapse

The timing of salt solution has been documented by previous workers to have occurred prior to Watt Mountain Formation deposition during a period of Muskeg subaerial exposure (Thachuk, 1967 and Alcock and Benteau, 1976). It is possible that parts of the Nipisi field area experienced limited collapse during this Muskeg exposure period, but detailed mapping of the 6 Gilwood zones suggested that collapsing also occurred during the deposition of the Watt Mountain Formation. In this study, collapse was recorded at the end of Gilwood zone 2, Gilwood zone 4, and at the end of Watt Mountain deposition (Fig 6.9, 6.10, 6.11). A progression of collapse at these time intervals can be demonstrated (Figs. 6.12 to 6.16).

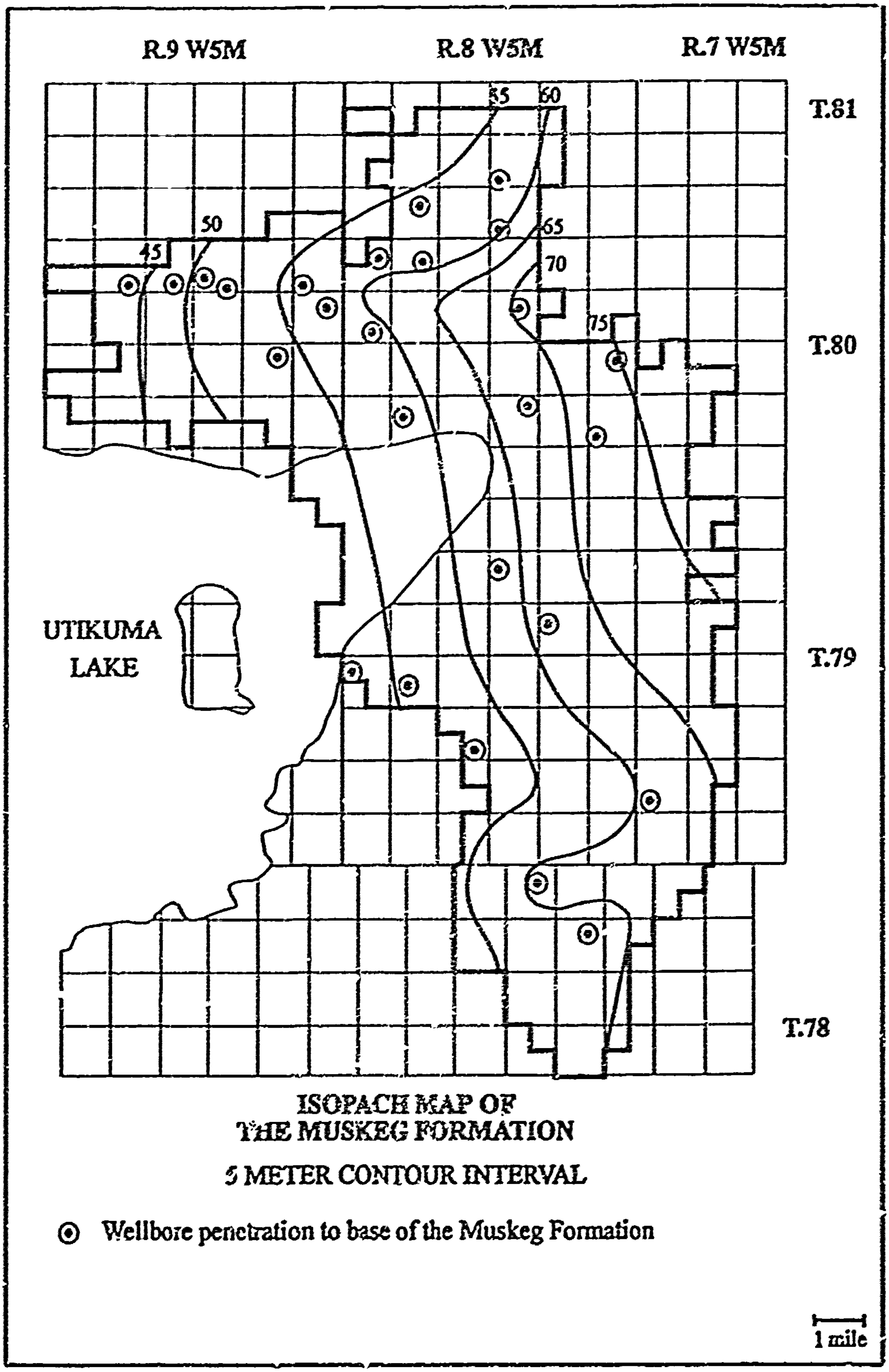


Figure 6.7 Isopach map of the Muskeg Formation

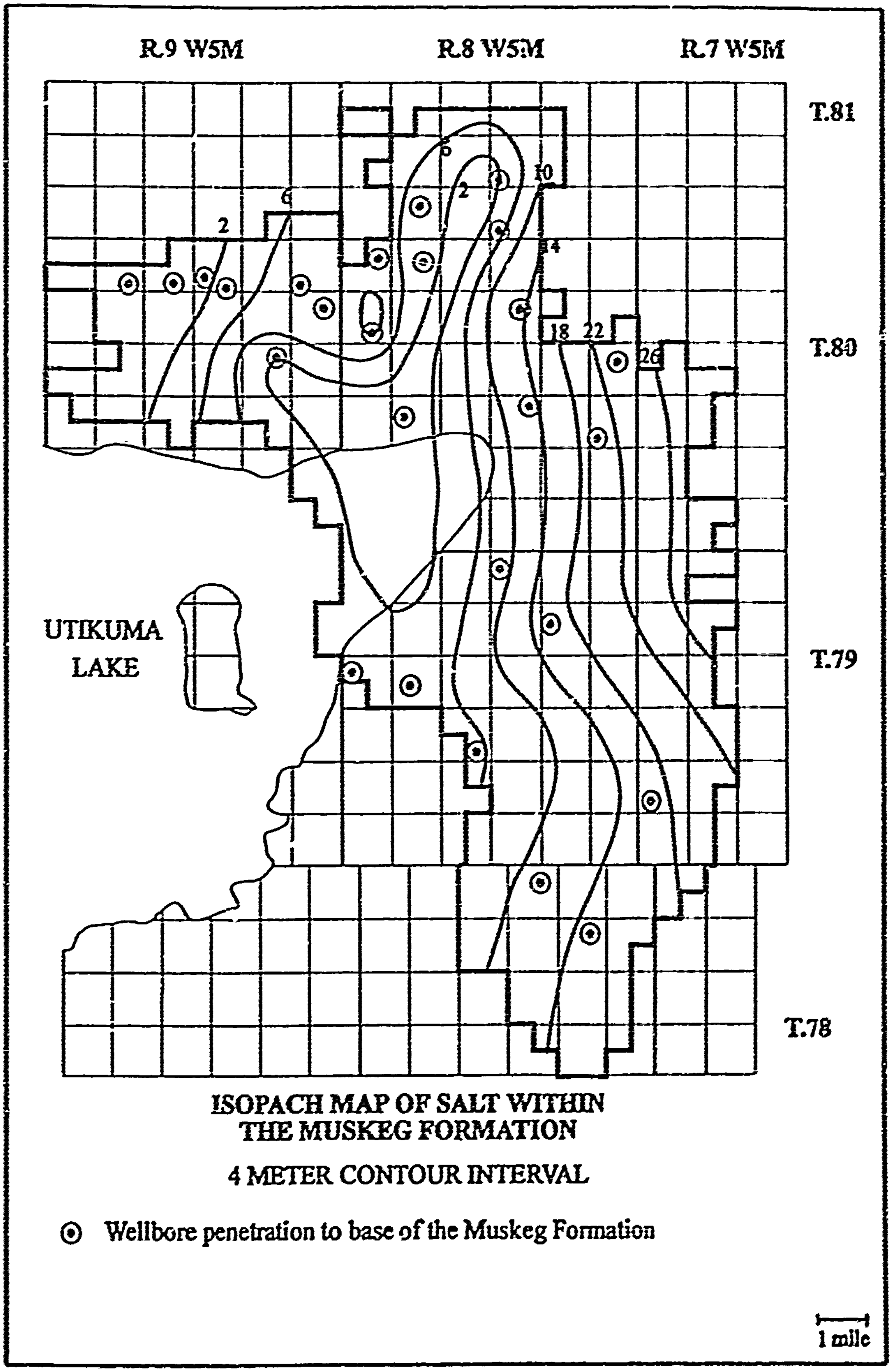


Figure 6.8 Isopach map of salt within the Muskeg Formation.

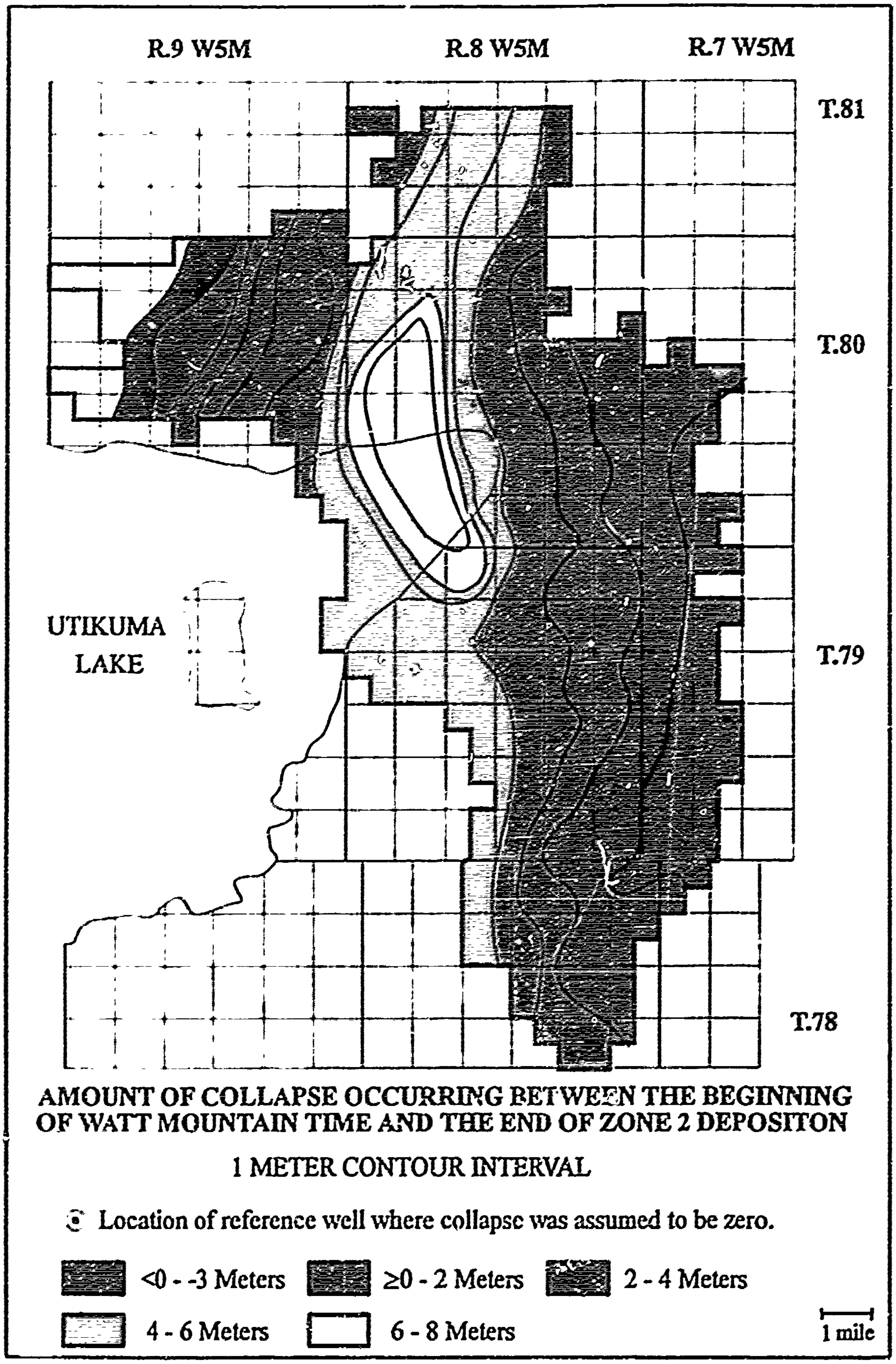


Fig. 6.9 Contour map illustrating the amount of collapse occurring between the beginning of Watt Mountain time and the end of Gilwood Zone 2 deposition.

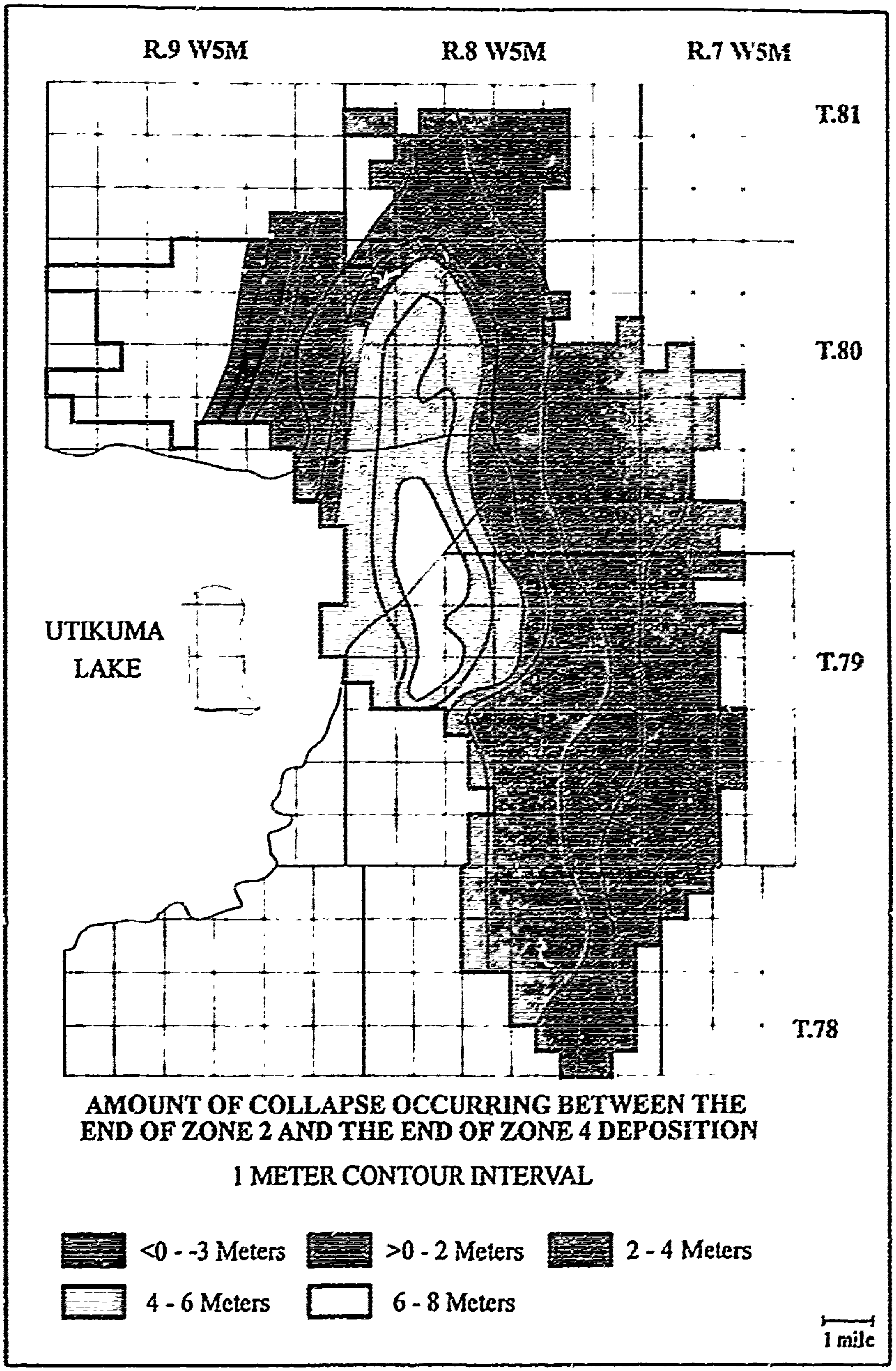


Fig. 6.10 Contour map illustrating the amount of collapse occurring between the end of Gilwood Zone 2 and the end of Gilwood Zone 4 deposition.

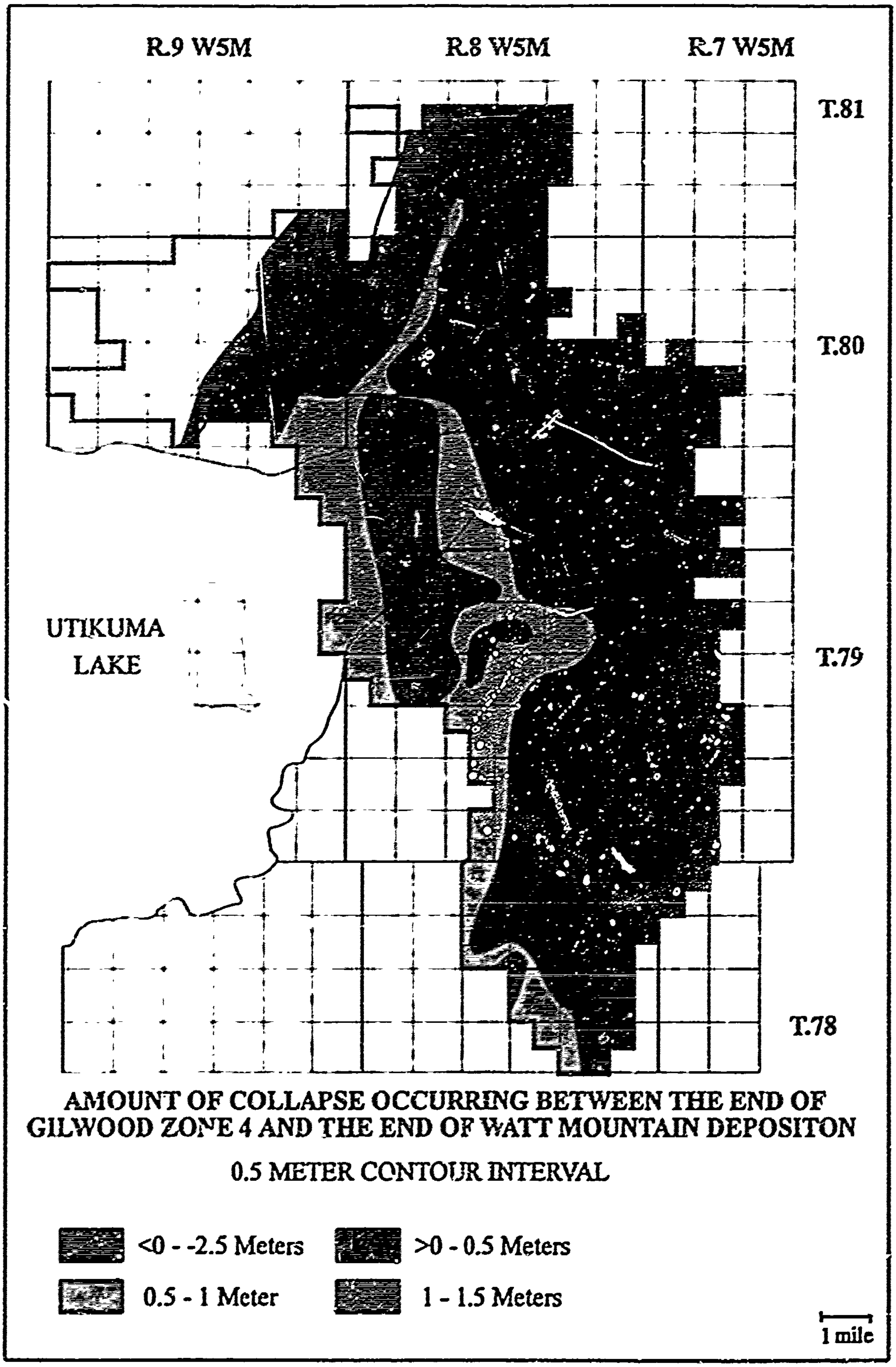


Fig. 6.11 Contour map illustrating the amount of collapse occurring between the end of Gilwood Zone 4 and the end of Watt Mountain deposition.

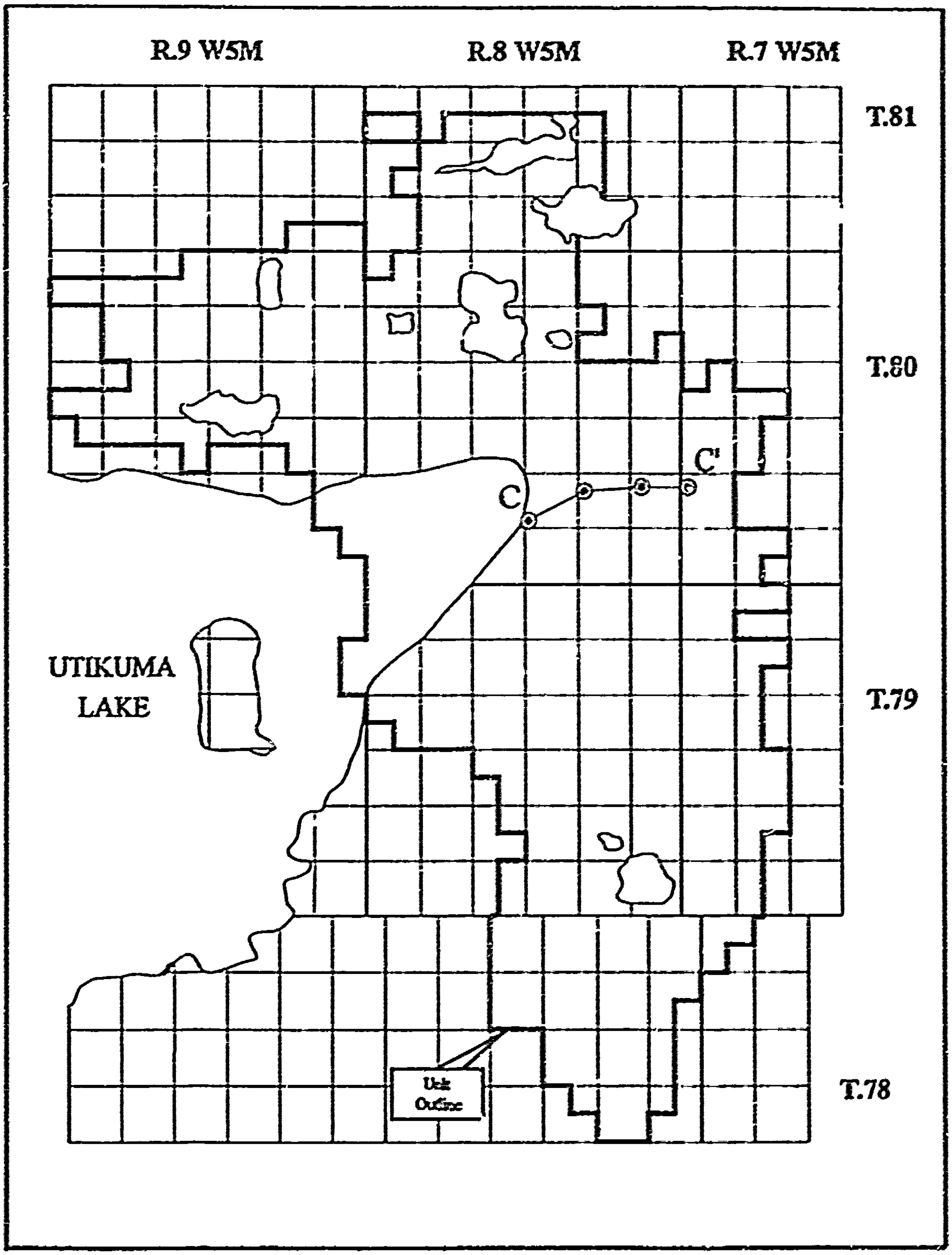


Figure 6.12 Reference map for cross sections C -C' illustrated in figures 6.13 - 6.16.

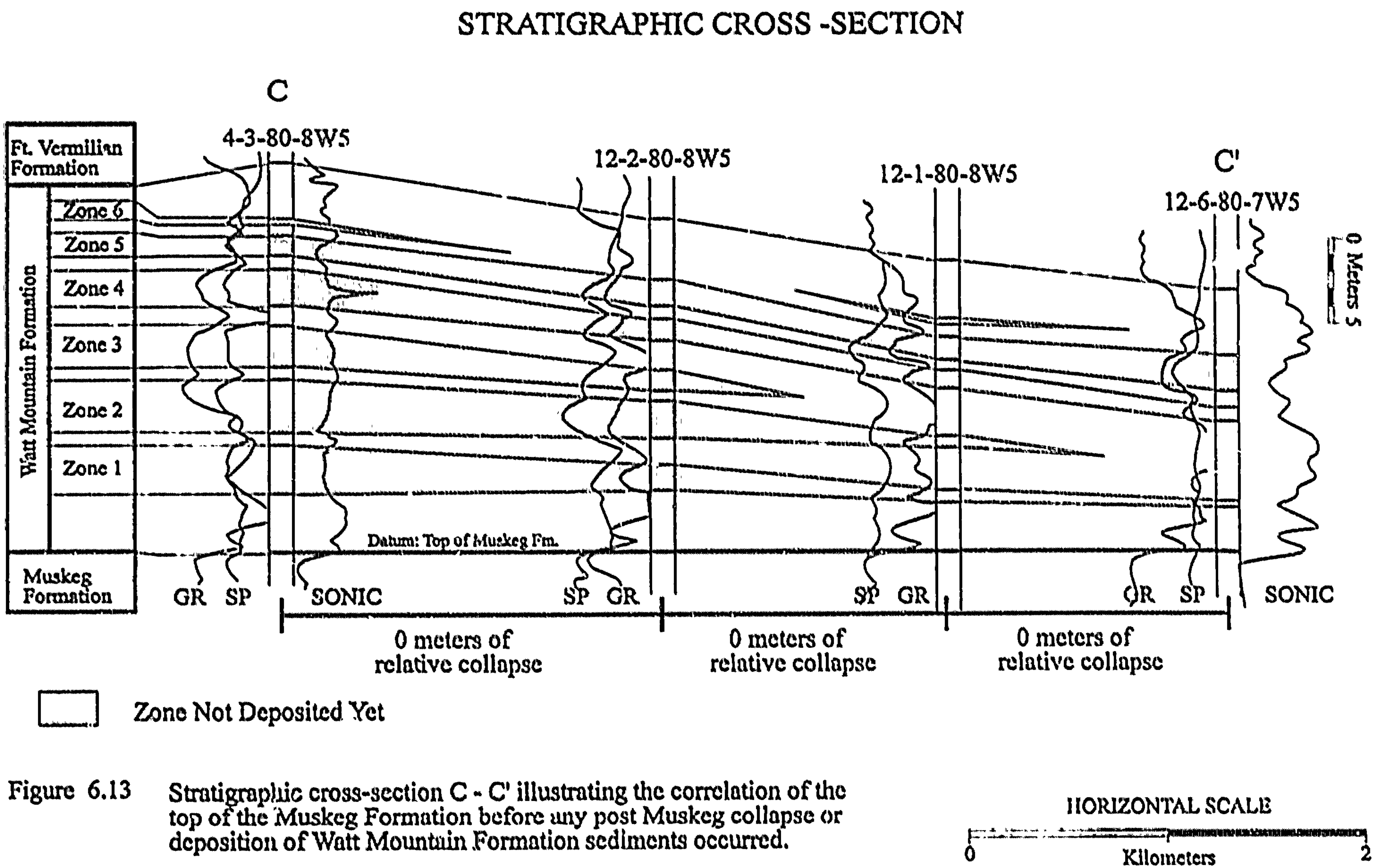


Figure 6.13 Stratigraphic cross-section C - C' illustrating the correlation of the top of the Muskeg Formation before any post Muskeg collapse or deposition of Watt Mountain Formation sediments occurred.

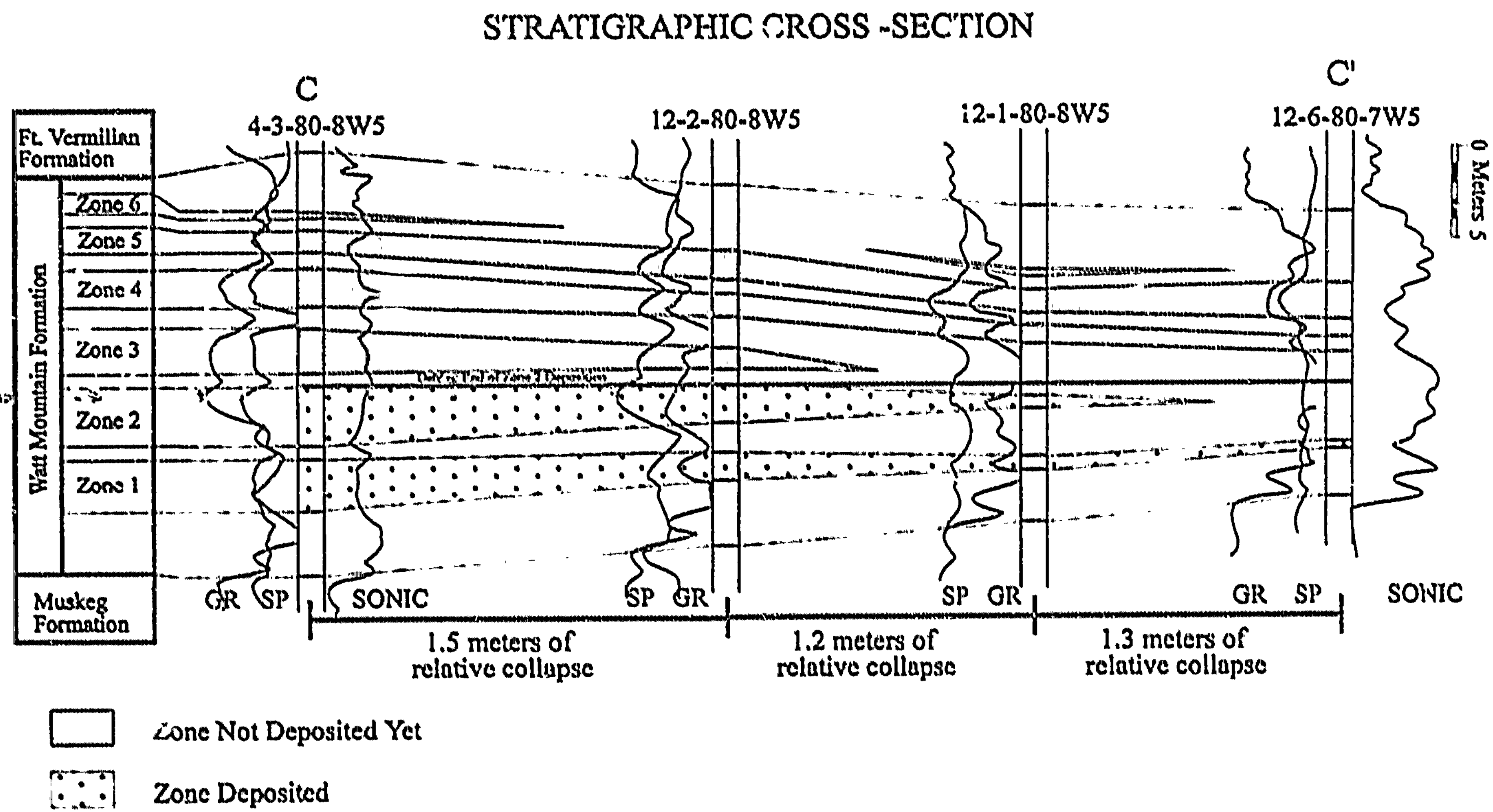


Figure 6.14 Stratigraphic cross-section illustrating the correlation of Gilwood zones and the amount of relative post Muskeg collapse between wells by the end of Gilwood zone 2 deposition.

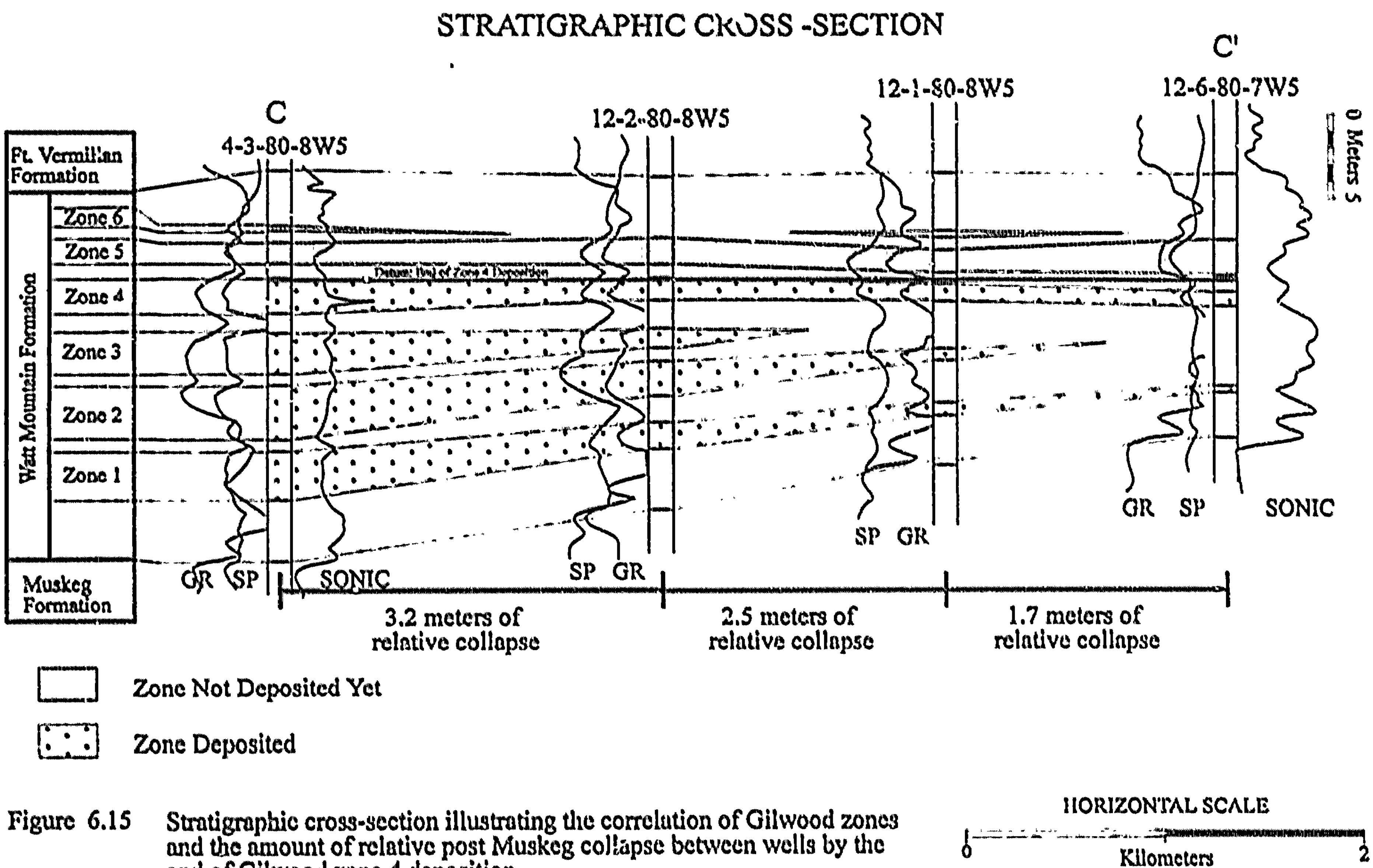


Figure 6.15 Stratigraphic cross-section illustrating the correlation of Gilwood zones and the amount of relative post Muskeg collapse between wells by the end of Gilwood zone 4 deposition.

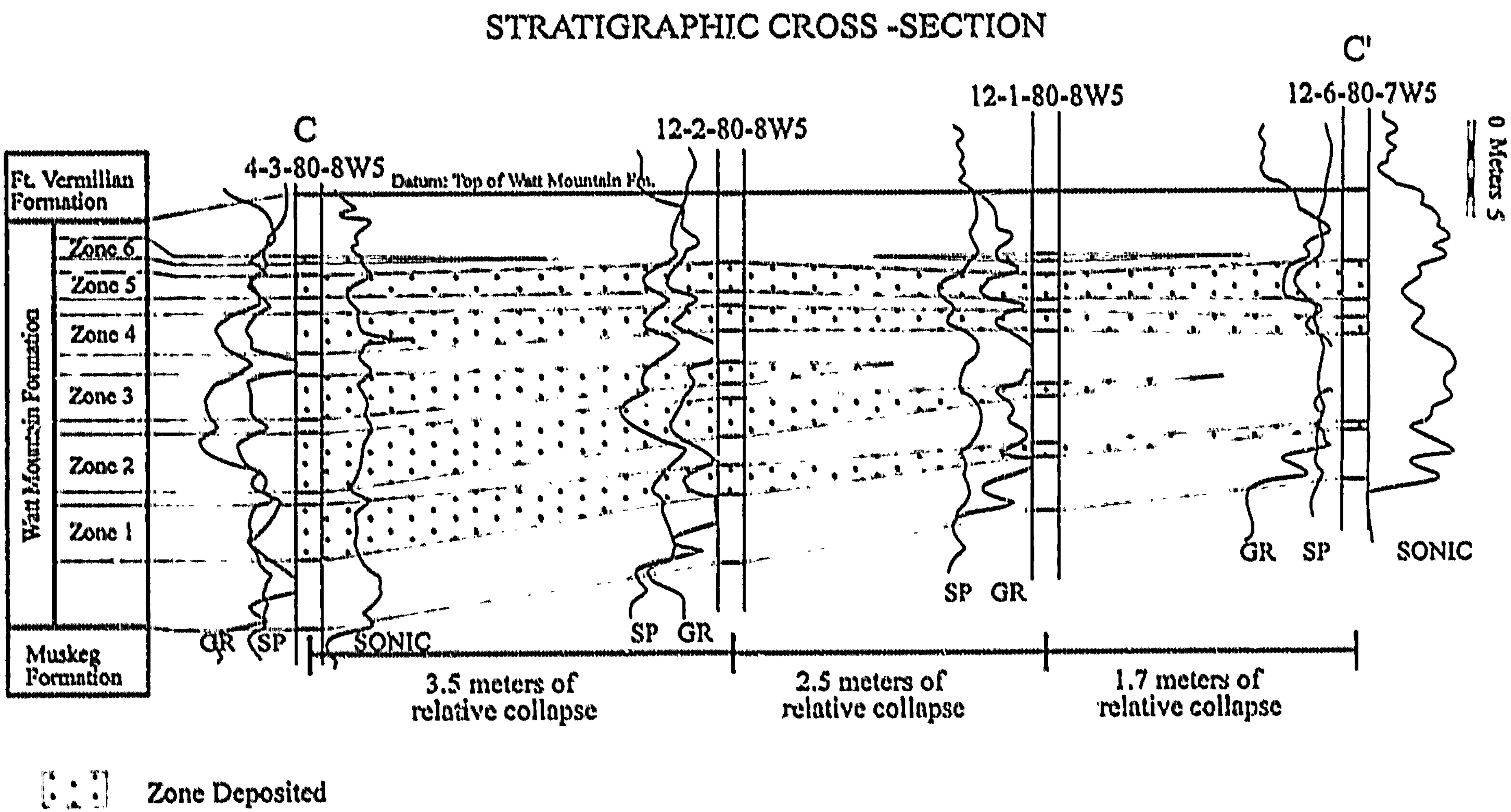


Figure 6.16 Stratigraphic cross-section illustrating the correlation of Gilwood zones and the amount of relative post Muskeg collapse between wells by the end of Watt Mountain deposition.

CHAPTER 7 DISTRIBUTION OF WATT MOUNTAIN SEDIMENTS

7.1 Introduction

The sediments in the Watt Mountain Formation in the Nipisi field have been divided into four facies associations that collectively suggested that sedimentation occurred in a lacustrine braid-delta system. Braid-delta deposits have high lateral continuity, and on a large scale they commonly produce sheet-like bodies over the length and width of the flood plain (McPherson *et al.*, 1987). In the Nipisi field, six laterally continuous sandstone-dominated zones have been identified. The paleogeographic distribution, relative sand body geometry and thickness of each zone, were found by constructing an isopach map of each (Figs. 7.1 to 7.6). Separating the six sandstone-dominated zones were mudstone deposits. These deposits were also laterally continuous, however, there were rare occurrences where these mudstones were absent, resulting in the stacking of one Gilwood zone over another.

The complexity of the vertical assemblages that make up the Watt Mountain Formation in the Nipisi field suggested that paleoenvironmental changes occurred during sedimentation of the Watt Mountain Formation. These were attributed to changes in the climate and tectonic setting, which are the two fundamental controls that influence the evolution of any basin (Reynolds *et al.*, 1989). Climate may influence the evaporation to precipitation ratio, discharge rates, and modes of sediment transport, while tectonic activity may control the basin geometry (Anadon *et al.*, 1991).

In describing the distribution of the Watt Mountain sediments an attempt was made to include the relative importance of the factors associated with the climate and tectonic controls.

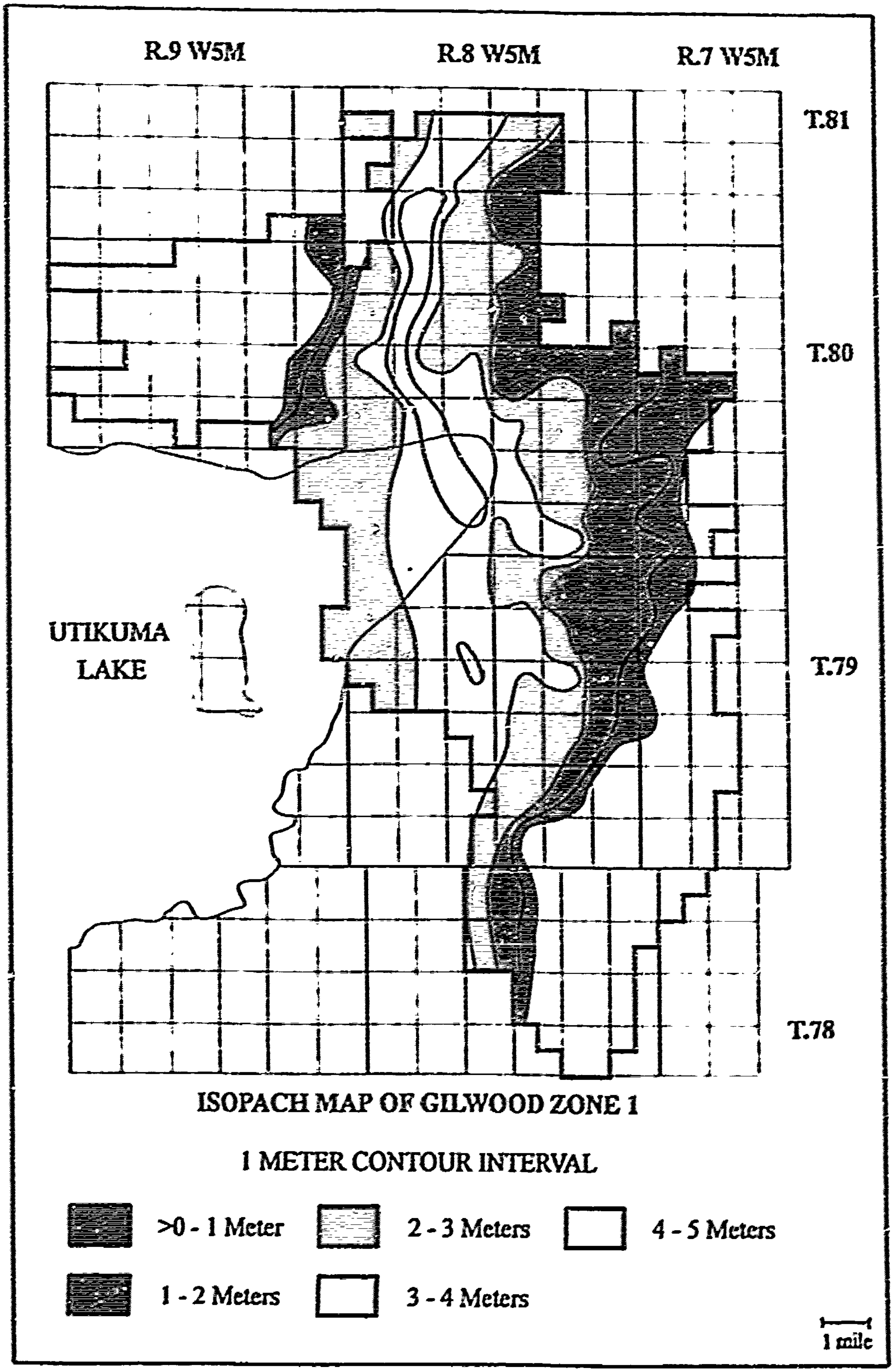


Figure 7.1 Isopach map of Gilwood Zone 1.

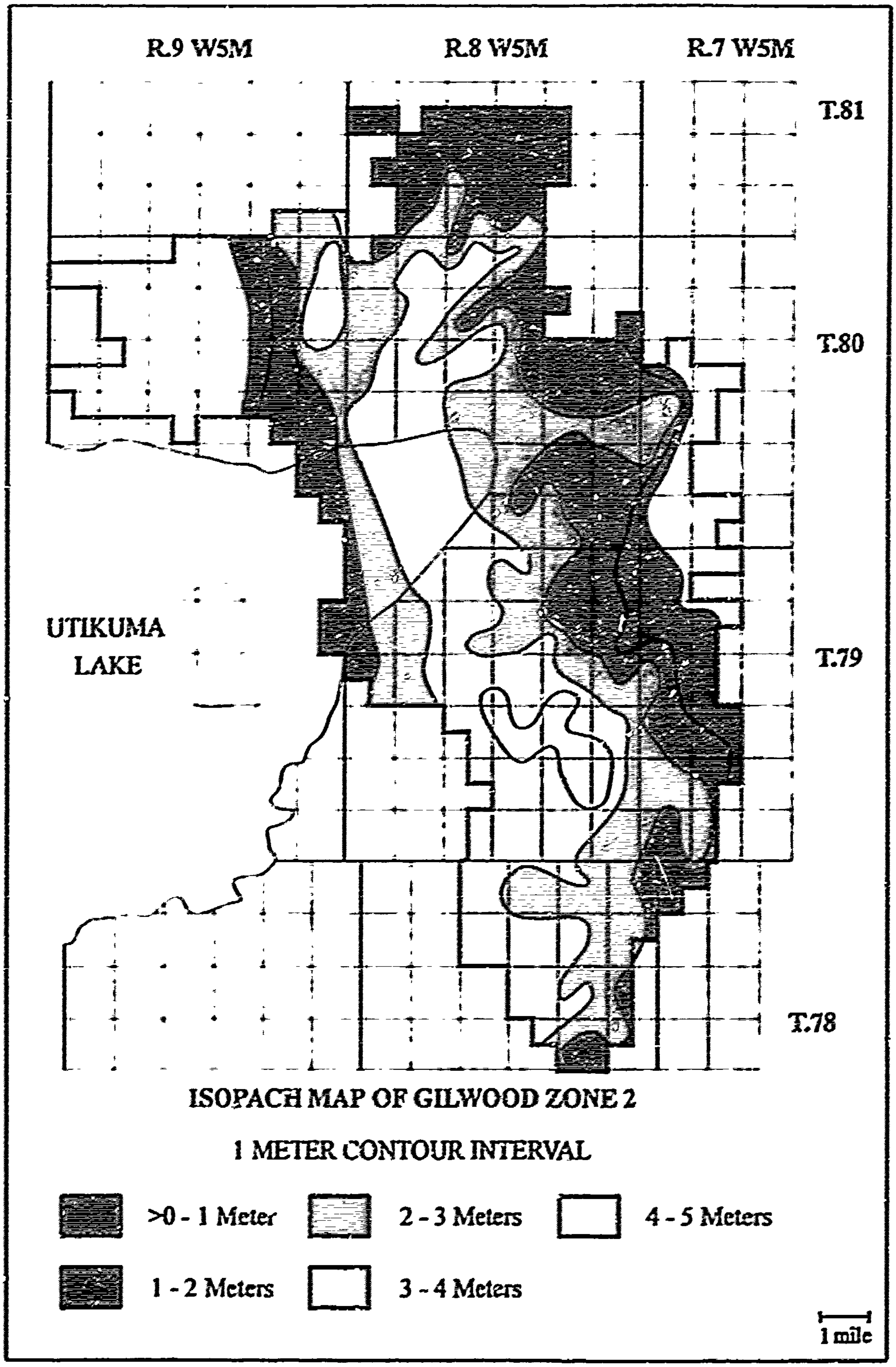


Figure 7 2 Isopach map of Gilwood Zone 2.

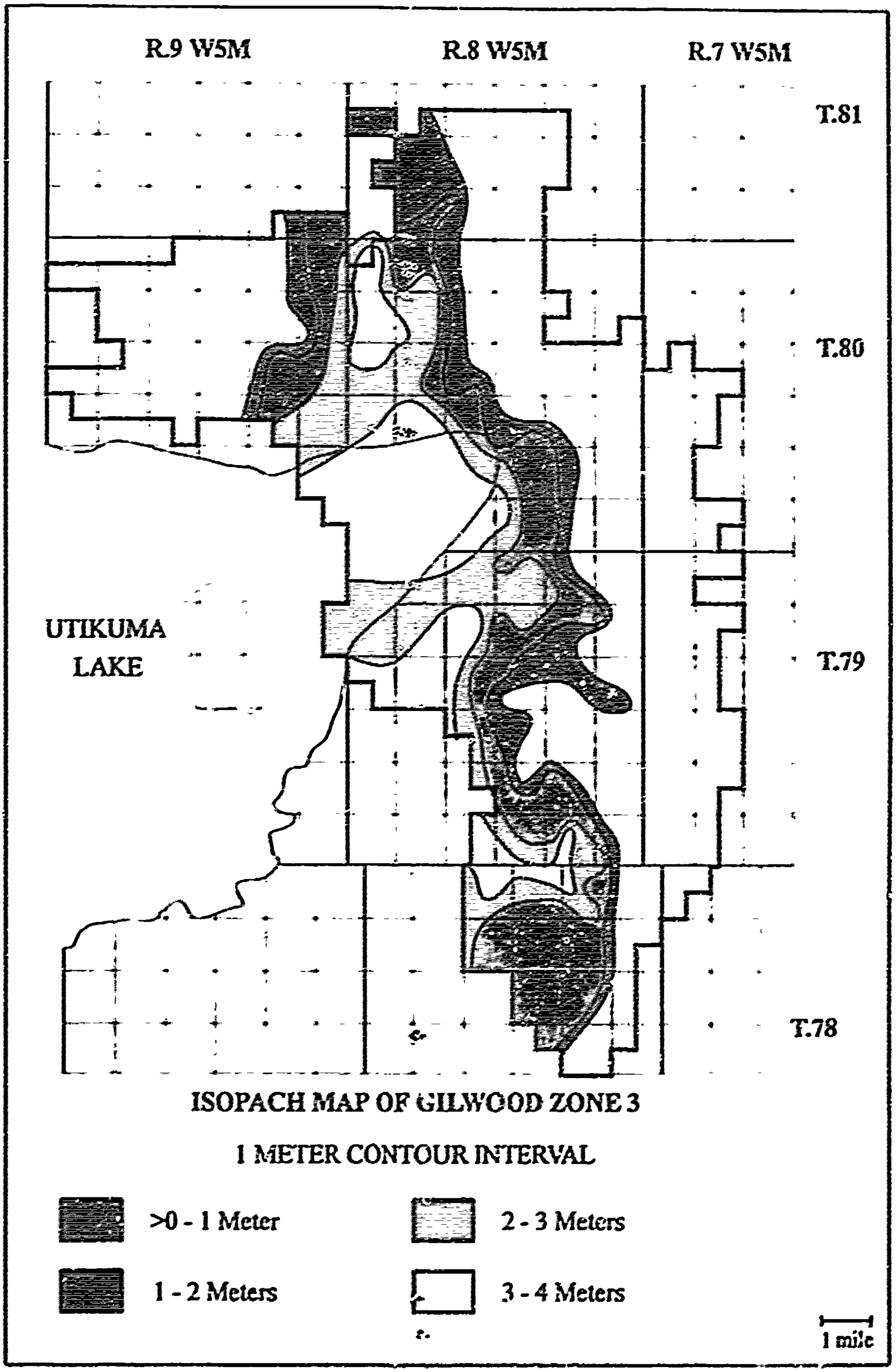


Figure 7 3 Isopach map of Gilwood Zone 3

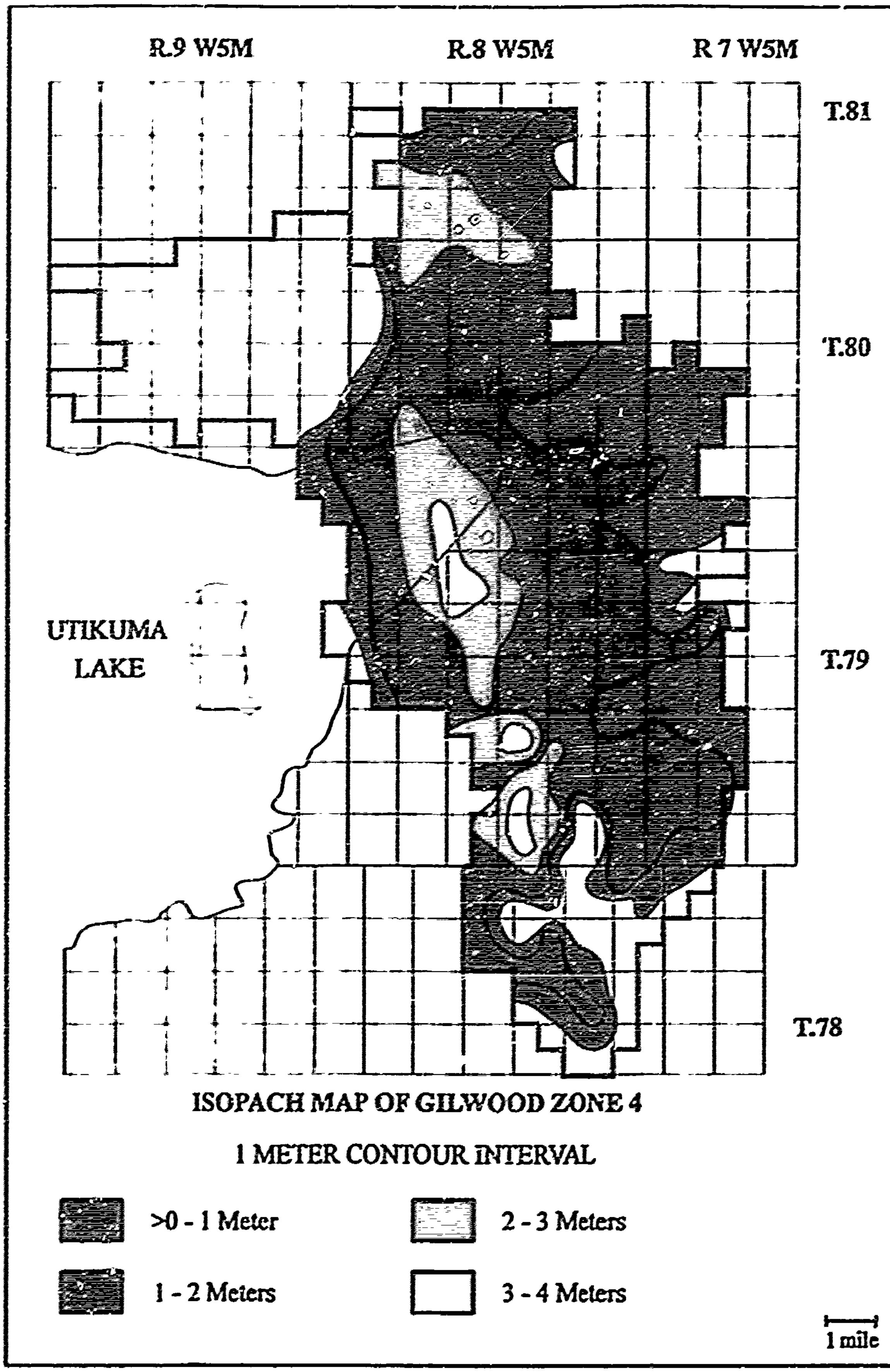


Figure 7.4 Isopach map of Gilwood Zone 4.

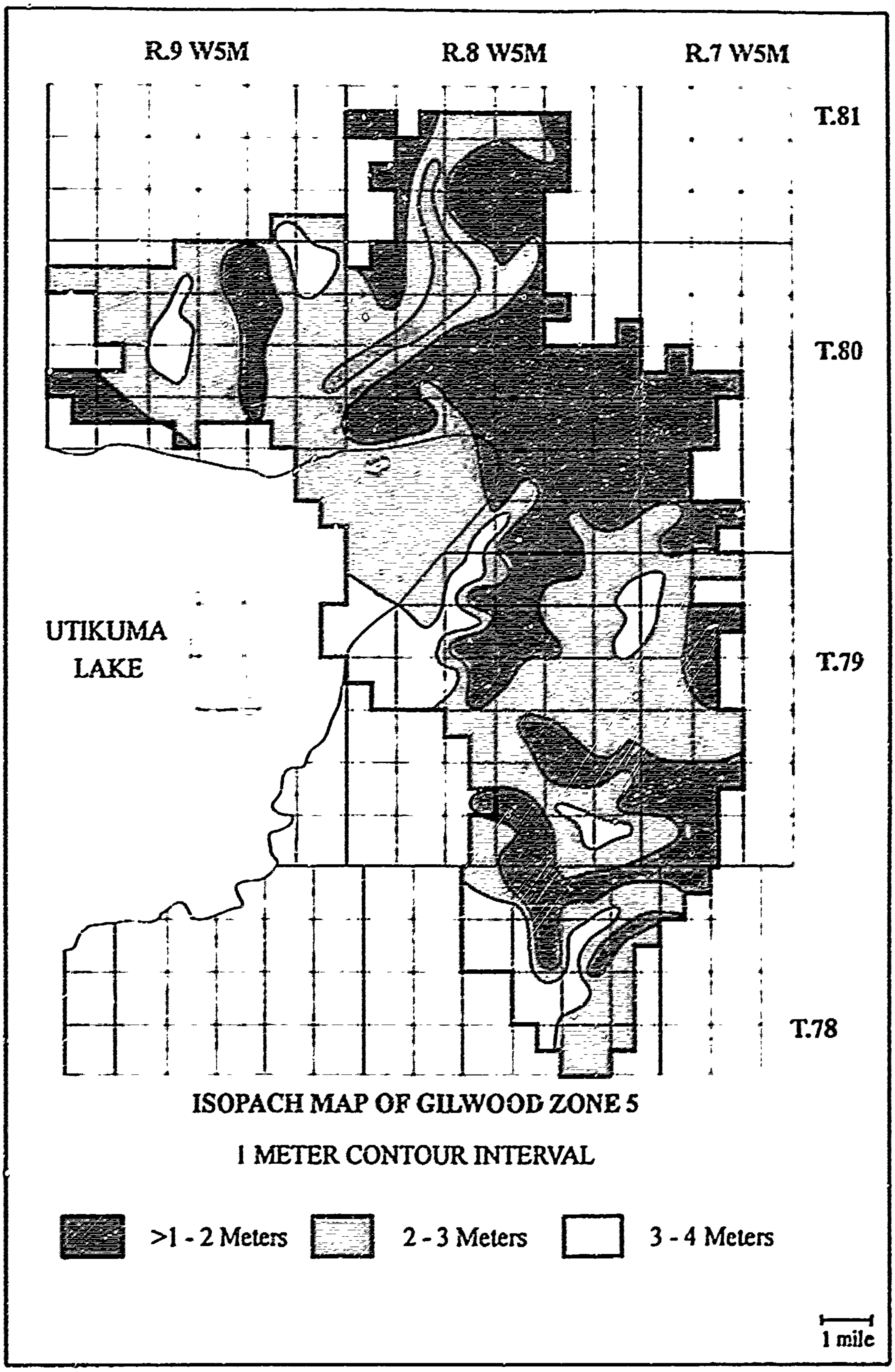


Figure 7.5 Isopach map of Gilwood Zone 5

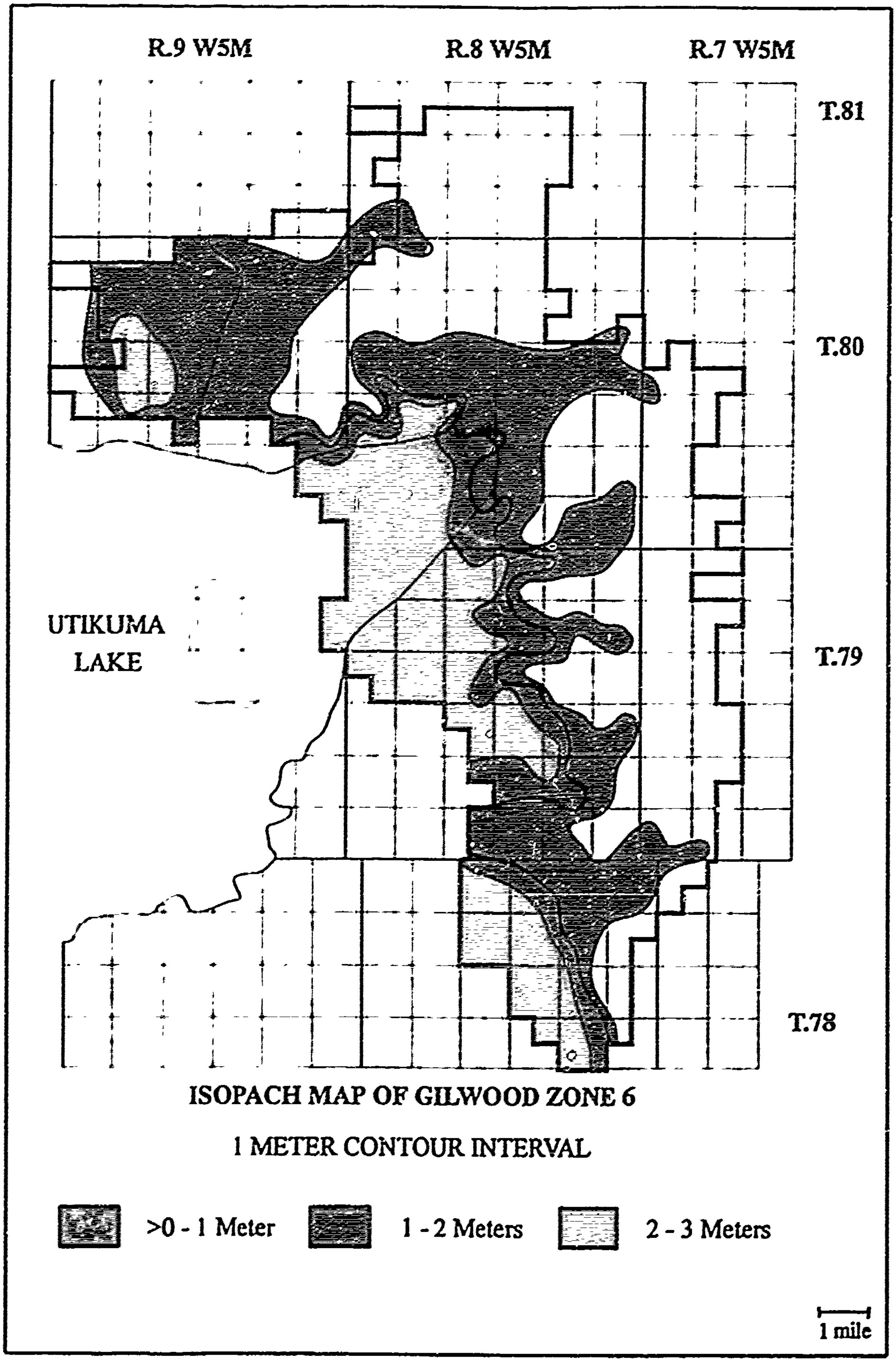


Figure 7 6 Isopach map of Gilwood Zone 6.

7.2 Distribution of the Gilwood Sandstone Zones

Each of the six Gilwood zones represent a period of high clastic input sourced from the west. Gilwood zones 1 and 3 are the most areally restricted of the six zones, suggesting that the Muskeg trough strongly influenced the distribution of these sediments by confining them as they prograded into the Nipisi area. The eastward tonguing of sediment in Gilwood zone 2, and the extension of Gilwood zone 4 out to the eastern limits of the Nipisi field, suggest some periods of Gilwood deposition were less influenced.

The differences in the areal distribution of the sandstone zones is strongly dependent on the shape of the Muskeg trough prior to deposition of the zone, and the amount of sediment deposited. Eastward progradation of a Gilwood zone deposit can only be achieved through progressive filling of the trough. Therefore, when the relief of the trough before deposition was small, less sediment was needed for the progradation across the Nipisi area than when the trough's relief was large. The lack of preservation of Gilwood zones 1 to 4 in the northwestern corner of the Nipisi field area is a result of successive deposition over this area, which resulted in the erosion of all but the upper two Gilwood zones (5 and 6).

The amount of collapse that occurred between the end of Gilwood zone 4 and the end of Watt Mountain Formation deposition was relatively minimal (Fig. 6.11). This resulted in the progradation of Gilwood zones 5 and 6 into the Nipisi area without the distribution of their sediment being significantly influenced by the Muskeg trough. Therefore, the depositional pattern and eastward progradation of these two zones across the Nipisi field was mainly controlled by the energy of the hydrologic system.

Gilwood zone 5 illustrates extensive complex tonguing emanating from a northwestern to western source with no apparent north south trend. Gilwood zone 6 is the last major episode of sandstone deposition recorded in the Watt Mountain Formation. The limited eastward progradation of this zone compared to Gilwood zone 5 suggested that the energy of this depositional system was significantly less.

7.4 Distribution of Watt Mountain Mudstones

The Watt Mountain Formation mudstones represent lacustrine deposits (Facies Association 1) that accumulated throughout the Nipisi field area during quiescent periods. These mudstones formed laterally continuous beds that effectively separate each of the Gilwood zones. During high inflow periods, sandstone deposits dominated the western areas of the Nipisi field, and mudstone accumulations were limited to areas beyond the sandstones westward progradational limits. The thicknesses of the laterally continuous mudstones that effectively separate the Gilwood zones are illustrated in Table 7.1.

Between Gilwood Zones	Thickness (meters)	
	Average	Range
1 , 2	1.3	0.0 - 2.3
2 , 3	1.1	0.0 - 3.4
3 , 4	2.0	0.3 - 3.0
4 , 5	0.9	0.0 - 1.2
5 , 6	1.1	0.6 - 2.4

Table 7.1 Thickness of mudstone units separating Gilwood zones.

A trend in the distribution of sedimentary structures in the mudstones was also observed. The mudcracks and stress cutans, interpreted to represent subaerial exposed areas, mostly developed where isopach values of the underlying Gilwood zone were small. These small isopach values were associated with areas around the fringe of the trough, which are also the first areas to become exposed when lake levels dropped.

CHAPTER 8 DEPOSITIONAL HISTORY OF THE WATT MOUNTAIN FM.

8.1 Introduction

The Elk Point sea covered the Nipisi field area during early Watt Mountain Formation deposition as suggested by the existence of a basal black shale facies (Facies 1) containing distinct marine fauna. However, most of the Watt Mountain Formation's sediments do not contain evidence to suggest deposition occurred in a marine setting. The vertical facies associations determined in Chapter 5 suggested that deposition occurred in a lacustrine braid-delta setting.

The interbedding of the Gilwood Sandstone Member with the Watt Mountain Formation mudstones clearly suggested sedimentation occurred during episodes of fluctuating paleoenvironmental conditions. These fluctuating conditions occurred in cycles that generated a recurring sequence of deposits that consisted of three stages of deposition. The first stage is a sandstone dominated deposit that makes up the Gilwood zones. This was followed by a second mudstone dominated stage that was deposited during a quiescent period, and a final stage that reflected a period of exposure. The spatial distribution of these deposits was a combined reflection of differing degrees of influence on sedimentation by the Muskeg trough, and the energy and duration of the hydrologic system. The following interpretive depositional history is a sequence of paleoenvironmental conditions that likely existed during Watt Mountain deposition. It was determined by integrating the distribution of facies associations and the depositional patterns of the Gilwood zones and Watt Mountain Formation mudstones.

8.2 Depositional History

The lacustrine braid-delta setting in the Nipisi area was initiated by salt solution collapse in the Muskeg Formation in early Watt Mountain deposition. This developed a north-south trending trough in the center of the Nipisi field which, during a regressive phase in the Elk Point sea, formed an isolated body of water, or lake. After formation of this lake, changes occurred in the type of sediment being deposited. In the Nipisi area, the change was from black shale containing a distinct marine fauna to a variegated mudstone containing fish that were believed to have proliferated under fresh to brackish conditions. However, the conditions for the survival of these fish deteriorated as the ratio of evaporation to inflow increased. This resulted in a progressive lowering of the lake and exposure of previously submerged areas, as indicated by the presence of stress cutans and mud cracks in the mudstones that underlie Gilwood zone 1.

Gilwood zone 1 represented the first major influx of coarse-grained sediment into the Nipisi field area, and the beginning of the first depositional cycle in the Watt Mountain Formation. The restricted sand body geometry of the first stage of deposition (Gilwood zone 1) was attributed to significant relief in the trough which limited the progradation of braided channels. Changes in the paleoenvironmental conditions terminated Gilwood zone 1 deposition and initiated stage 2, which was the deposition of mudstones throughout the Nipisi area. This rapid change in the paleoenvironmental conditions likely caused a rapid demise of the fish living in the lake, since their remains were only located in the lower 0.3 m of this mudstone unit. The existence of a high evaporation to inflow ratio progressed the cycle of sedimentation into stage three, where continual drops in lake levels resulted in the development of soils around the fringes of the lake. Most modern lakes are bounded by subaerial erosion surfaces with some degree of soil development (Picard and High, 1972). The existence of the fresh water carbonates located in the center of the trough indicated that some areas remained submerged. It is unknown whether these submerged areas were localized ponds or the continued presence of a very shallow lake in the center of the trough.

Gilwood zone 2 was the beginning of a second depositional cycle. This second cycle was very similar to the first. However, a lower relief in parts of the trough, resulted in stage 1 deposits (Gilwood zone 2) to be more widespread and extend farther southeastward than Gilwood zone 1 stage 1 deposits. Stage 2 and 3 deposits of this cycle were very similar to cycle one. Abundant fish remains in the first 0.3 m of the overlying mudstone indicated rapid deterioration of favorable living conditions, and a lowered lake level again resulted in the exposure of mudstones and the development of soils in the fringes of the Nipisi field area.

Prior to the beginning of the third depositional cycle there was a significant event of salt solution collapse in the Muskeg Formation that resulted in an extremely limited aerial distribution of Gilwood zone 3 (Fig 7.3). The northwestern to western sourced sediment of Gilwood zone 3 was confined to a narrow north-south-trending band that followed along the axis of the trough. The existence of some sandy mudstone zones in stage 2 deposits of this depositional cycle suggests that smaller streams continued to supply sediment to the lake. However, the water conditions still deteriorated significantly enough to make the lake waters unfavorable for the survival of fish. A result of evaporation exceeding inflow was the development of soils around the fringing areas of the Nipisi field during stage 3 of this cycle.

Before the beginning of cycle 4 deposition there was only minor salt solution collapse. Therefore, the significant collapse occurring before cycle 3 is almost directly related to the amount of collapse illustrated in Figure 6.10, which is the amount of collapse occurring between the end of Gilwood zone 2 and the end of Gilwood zone 4 deposition. The limited relief occurring before cycle 4 restricted the amount of excess thickening that normally occurred along the axis of the trough, and consequently a more widespread distribution of sandstones developed. Stage 2 was very short resulting in the deposition of a thin mudstone. Although stage 2 was dominated by mudstones, the significant number of sandy mudstone zones suggests a continued presence of inflow into the lacustrine basin. The lack of stress cutans in these mudstone deposits signifies that lake levels did not drop enough to cause submerged areas to become exposed for soil development (stage 3).

The fifth cycle of deposition in the Watt Mountain Formation began with the deposition of Gilwood zone 5. The distribution of this zone (Fig. 7.4), suggests that zone 5 deposition was not influenced by the trough . The lack of major relief in the trough removed one of the major depositional controls imposed on clastic sediments entering the lacustrine area. Sandstones were deposited on a slightly sloped braid-delta plain, forming a broad sheet-like sandstone with thicker, complex eastward-extending tongues. Beginning at the deposition of zone 5, there was a significant change in the depositional setting of the Nipisi field area. Although stage 2 mudstones developed, they had a blocky grayish-green to olive-gray colour, which was distinctly different from the stratigraphically lower mudstone deposits that were primarily variegated red and green in colour. This difference in colour may be associated with a change from a primarily subaerial oxidizing environment, or a subaqueous one with input of continental oxidized sediments, to a primarily subaqueous environment (Martini *et al.*, 1991). Very little collapse occurred between the beginning of Gilwood zone 4 and the end of Watt Mountain deposition (Fig. 6.11). Gilwood zone 6 is the last major clastic pulse of sedimentation reflected in the Watt Mountain Formation, and it's depositional pattern reflects the lack of depositional control imposed by the trough (Fig. 7.6).

CHAPTER 9 SUMMARY AND CONCLUSIONS

The Middle Devonian Watt Mountain Formation within the Nipisi oil field area, consists of a complex succession of lacustrine braid-delta deposits. This paleoenvironmental interpretation was based on the existence of four recurring facies associations. (1) lacustrine deposits, (2) marginal lacustrine deposits, (3) interdistributary deposits, and (4) channel deposits. The complex succession of deposits was subdivided into six cycles of deposition, which record the progradation and abandonment of lacustrine braid-delta deposits. An idealized cycle is internally characterized by three stages of deposition. The first or lower stage is dominated by sandstone deposits, followed by a mudstone dominated middle stage, and an upper stage which reflects deposits exhibiting evidence of subaerial exposure.

The stage one sandstone deposits consist of channel and marginal lacustrine deposits which prograded across a low gradient braid-delta plain during periods of sandstone influx. These periods of influx have been attributed to tectonic activity associated with the Peace River Arch. Channel sandstone deposits prograded eastward, away from the Arch, forming laterally continuous sheets of sandstone across the Nipisi area. In the distal areas beyond the sandstone progradational limits, lacustrine mudstone deposits were also being accumulated. However, the stage two lacustrine mudstone deposits which separated each of the Gilwood sandstone zones dominantly accumulated in the periods between sandstone influx.

The distribution of braid-delta deposits was strongly controlled by the shape of the Muskeg trough, which was a depression that developed in the center of the Nipisi field area through dissolution of salts within the underlying Muskeg Formation. Dissolution related subsidence occurred prior to and during Watt Mountain deposition, modifying the amount of relief in the Muskeg trough. The effect of this relief on

Gilwood sandstone zone deposition is reflected in the depositional patterns of these deposits. Gilwood sandstone zone deposits strongly influenced by the trough were restricted in their areal extent, while zones less influenced had wider areal distributions because of their ability to freely prograde across the Nipisi field area. The understanding of the paleoenvironment and depositional history of Watt Mountain Formation sediments in the Nipisi field area provided information that was essential in determining that Nipisi oil is distributed within a layered reservoir. The knowledge that each of these layers has different reservoir characteristics and areal distribution will aid in developing exploitation strategies.

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APPENDIX

LEGEND FOR APPENDIX

LITHOLOGY

- Sandstone
- Silty Sandstone
- Muddy Sandstone
- Siltstone
- Sandy Silt
- Muddy Silt
- Mudstone
- Sandy Mudstone
- Silty Mudstone
- Anhydrite
- Breccia
- Missing Core

Lithologic Modifiers

- Sandy
- Micaceous (Mc)
- Pebble Horizon
- Silty
- Feldspar Clasts (Fld)
- Scattered Limestone
- Muddy
- Pyrite (Py)
- Dense Limestone
- Mud Clasts
- Paleosol (Psl)
- Small Mud Clasts
- Brecciated

Physical Structures

- Climbing Ripples
- Current Ripples
- Stylolites
- Trough Cross Bedding
- Massive Bedding
- Stress Cutans
- High Angle Lamination
- Low Angle Lamination
- Slickensides (Slks)
- Horizontal Lamination
- Grading, fining upward
- Churned Bedding
- Minor Cemented Horizon (xxxxxx)
- Grading, coarsening upward

Fossils

- Brachiopod
- Fish Scales
- Fish Bone
- Fish Remains

Relative Porosity

- Poor 4 - <9%
- Fair 9 - <14%
- Good 14 - <19%
- Excellent >19%

Contact Type

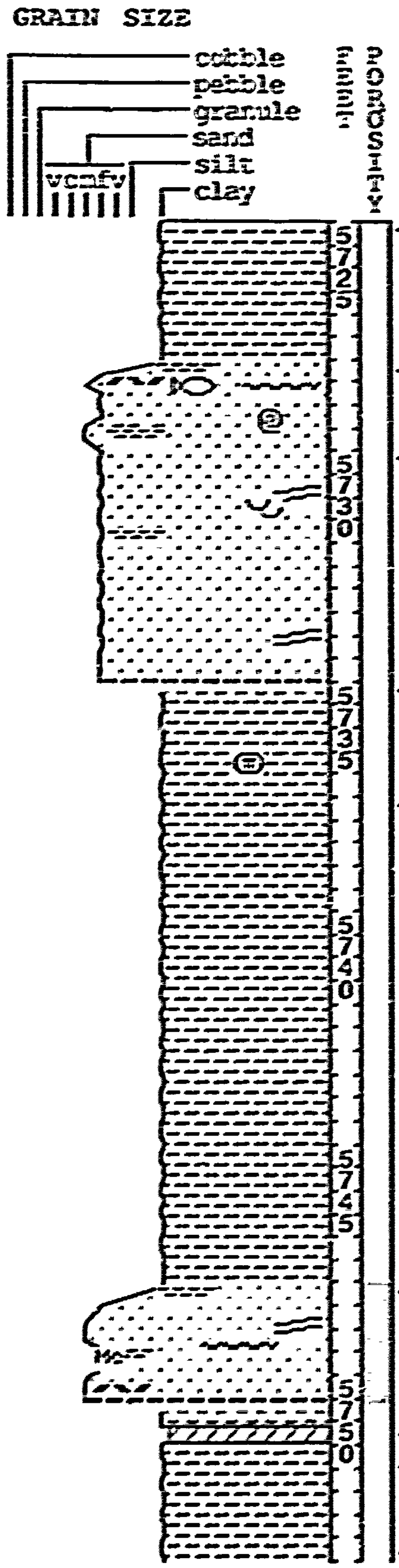
- Sharp
- Scoured
- Uncertain
- Undulating

ABBREVIATIONS USED IN CORE DESCRIPTIONS

abnt	abundant	mass	massive
bcmg	becoming	md	mud
bdng	bedding	mdst	mudstone
bds	beds	mdy	muddy
blk	black	mg	medium grain
blky	blocky	mnr	minor
brn	brown	msng	missing
btm	bottom	mxd	mixed
calc	calcareous	ol	olive
cg	coarse grain	pbl	pebbles
cgs	coarse grains	pl	pale
cmtd	cemented	psbl	possible
conv	convoluted	pyb	pale yellowish brown
disc	discontinuous	rdsh	reddish
dk	dark	rmdr	remainder
drb	dark reddish brown	seqc	sequence
dsky	dusky	sh	shale
feld	feldspar	slks	slickensides
fg	fine grain	slst	siltstone
fltg	floating	sl	slightly
fsl	fissile	sndy	sandy
fract	fracture	srtd	sorted
fnt	faint	ss	sandstone
grd	grade	sty	stylolites
grn	green	thnly	thinly
grns	grains	thru	throughout
grysh	grayish	tr	trace
hzntl	horizontal	twds	towards
intb	interbedded	vfg	very fine grain
intlam	interlaminated	v	very
ip	in part	vp	very poor
lam	laminations	wd	wood
lamd	laminated	wxy	waxy
lrg	large	ylsh	yellowish

Pan Am A-1

2-17-78-7w5 Core mostly rubble



dsky grn hrd blky sh

base 19cm is conv - low angle xbdng w/ mud clasts and flasers,scat cg feld clasts, 16cm of fg conv well sorted ss grad from below, upper 17cm is intbd ss&sh cm scale, ss bds fin up, base cg-peb upper bds fg, fish plates present in upper unit

fg ss w/ abnt mic thru, bdng varies thru from low > xbdng, pos trough, occas mud lams, generally well sorted

grysh grn hrd - med blky sh, bot contact w/ d/b is gradational for 15cm , few fish scales at start of pure grysh grn sh

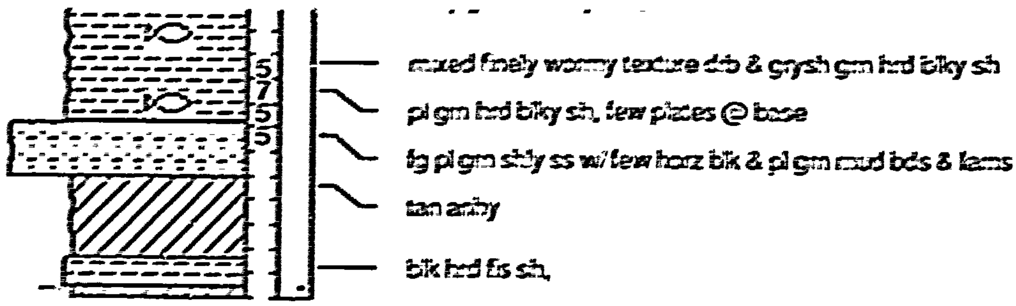
d/b hrd blky sh , bot 10cm is grysh grn hrd blky sh

mainly low > xbdd ss, multiple fin up seq, crsr cmtd bands, shly to top, shly lams are mic

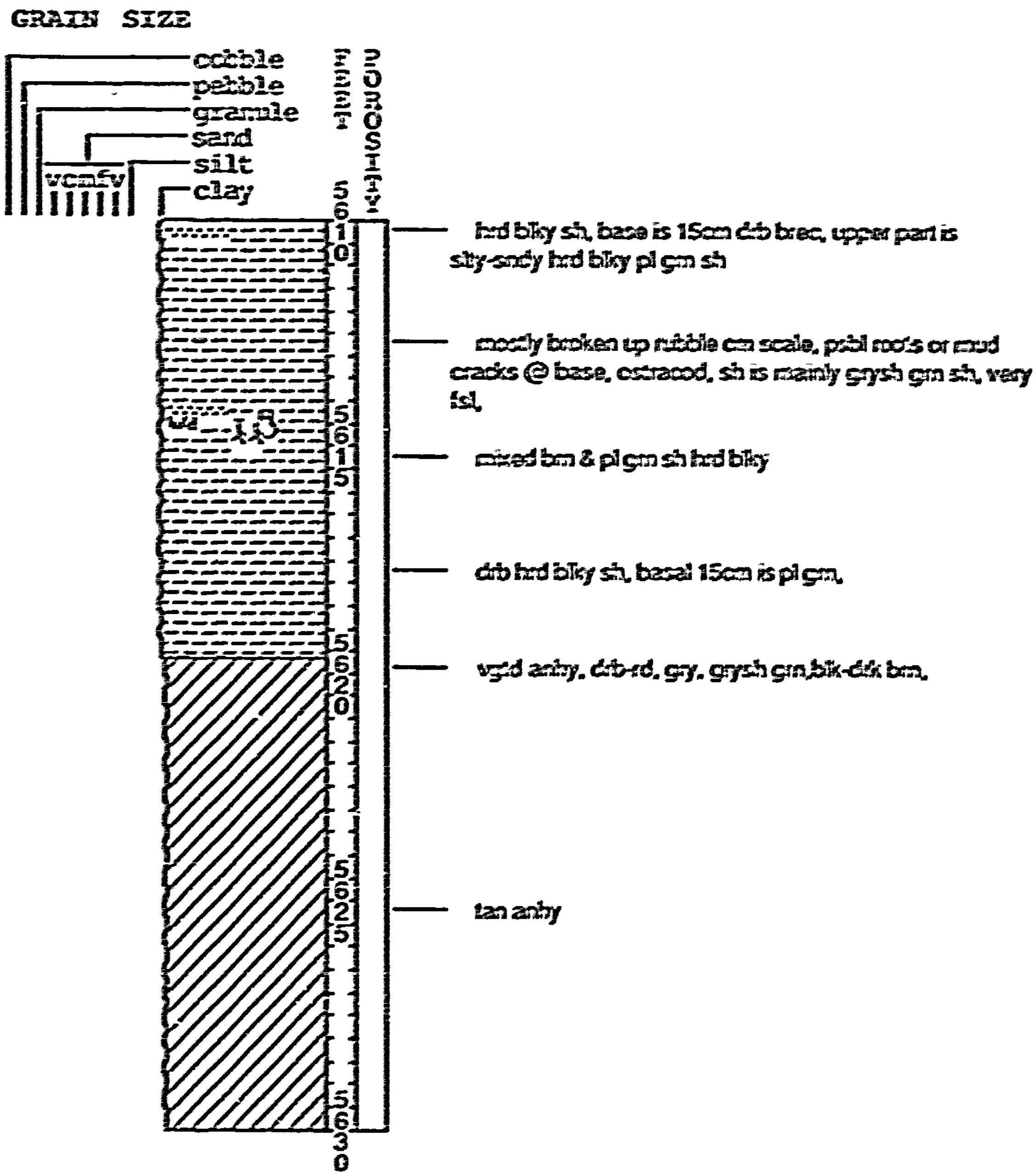
tan anhy sh hrd blky

d/b hrd blky sh

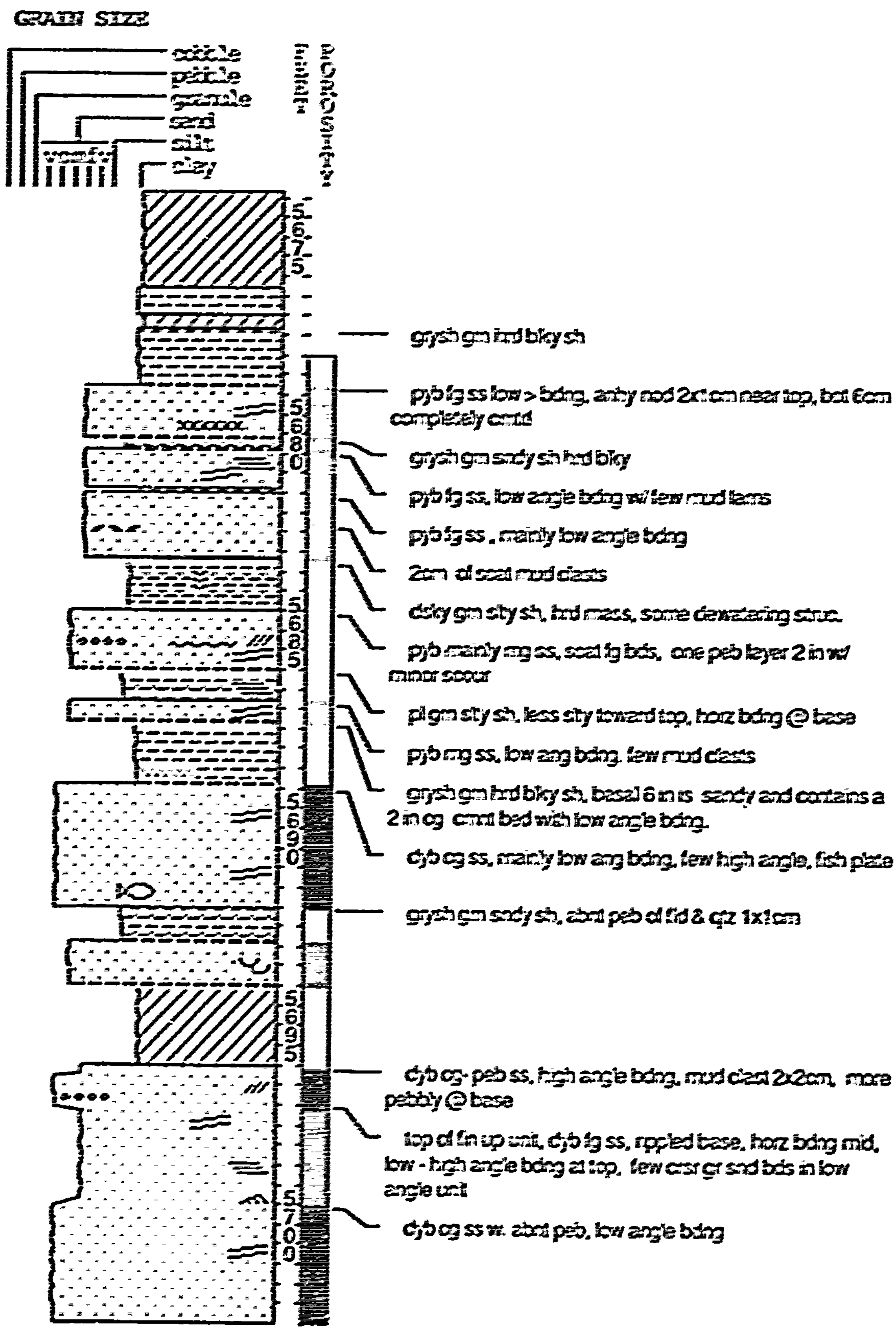
dsky grn hrd blky fsl to sh w/ fish plates

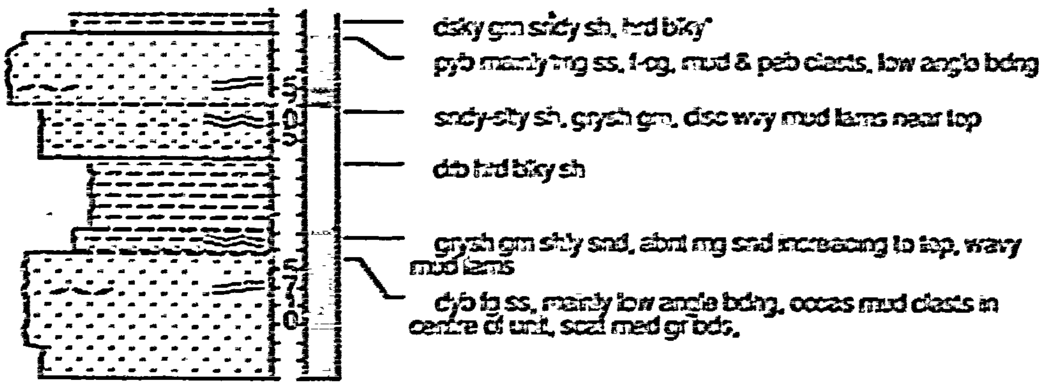

5
7
5
5
mixed finely wormy texture dolo & grysh grn hrd blky sh
pl grn hrd blky sh, few pistes @ base
fg pl grn slty ss w/ few horz blk & pl grn mud bds & lams
tan anhy
blk hrd fis sh,

Pan Am D1 Nipisi
4-34-78-7w5

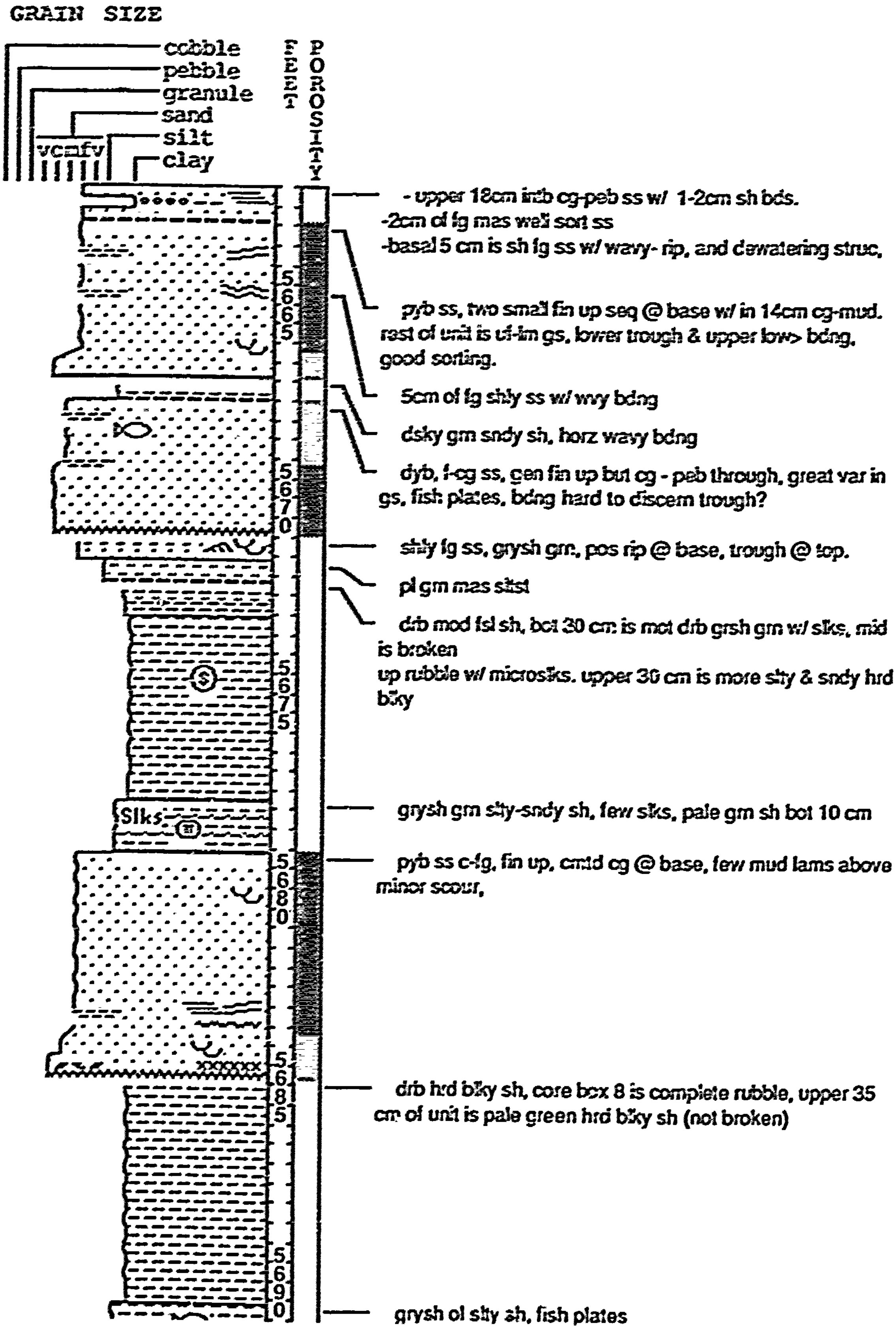


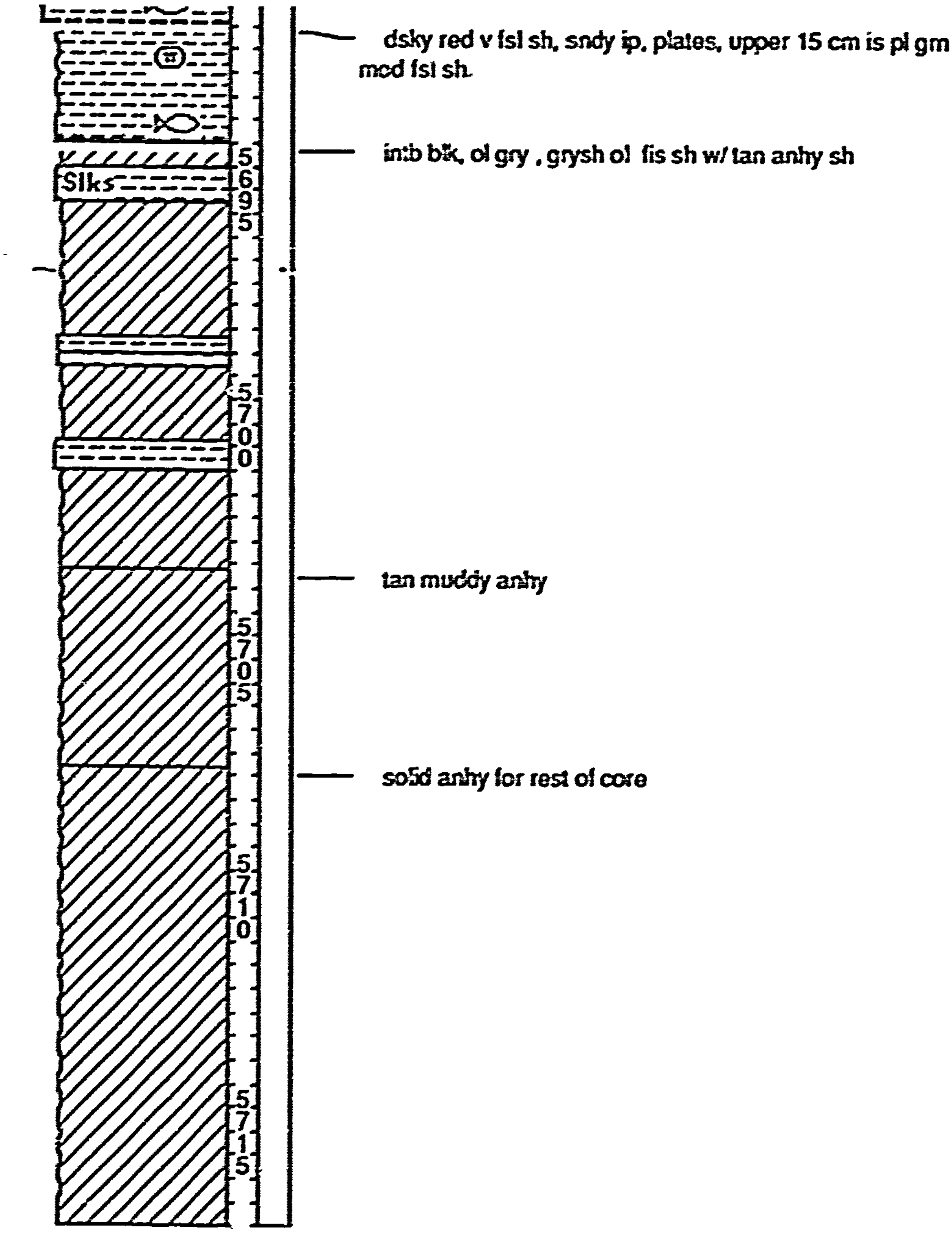
Shell et al Nipisi
10-22-78-8w5




dsky grn sndy sh, hrd blky
pyb mainly fmg ss, f-cg, mud & peb clasts, low angle bdng
sndy-slty sh, grysh grn, disc wvy mud lams near top
dtb hrd blky sh
grysh grn slty snd, abnt mg snd increasing to top, wavy mud lams
dyb fg ss, mainly low angle bdng, occas mud clasts in centre of unit, scat med gr bds.

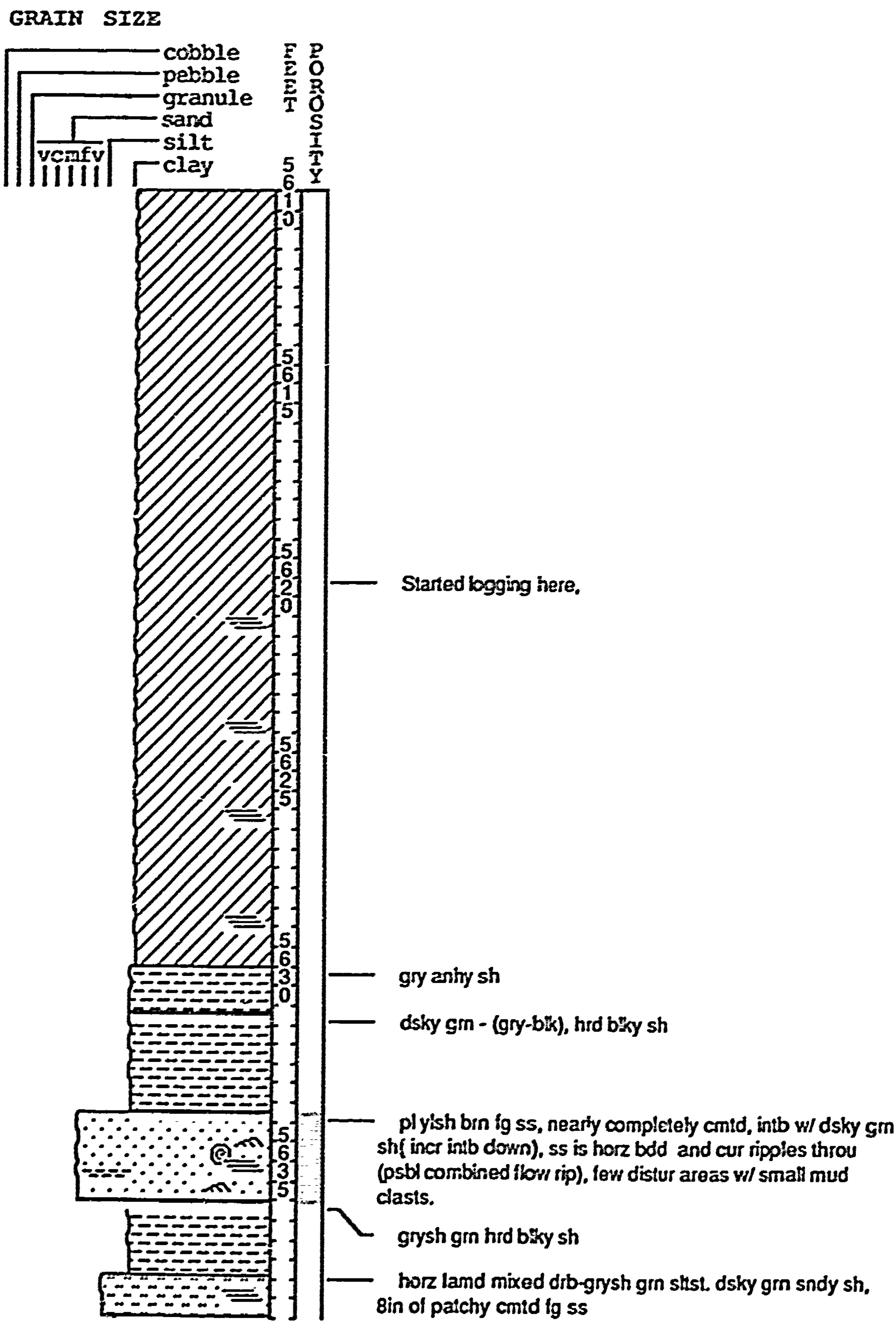
Shell et al Nipisi
12-24-78-8w5

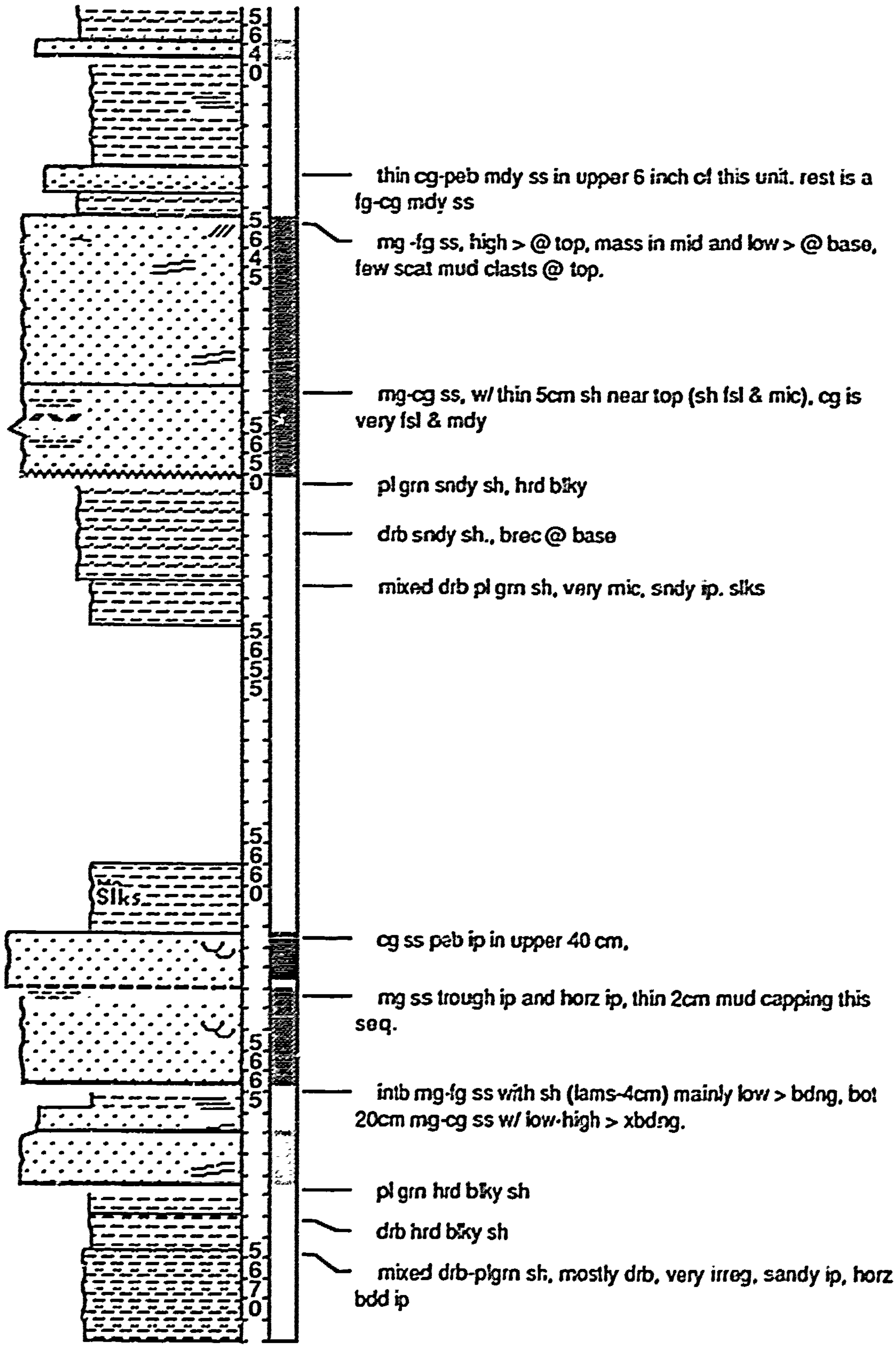




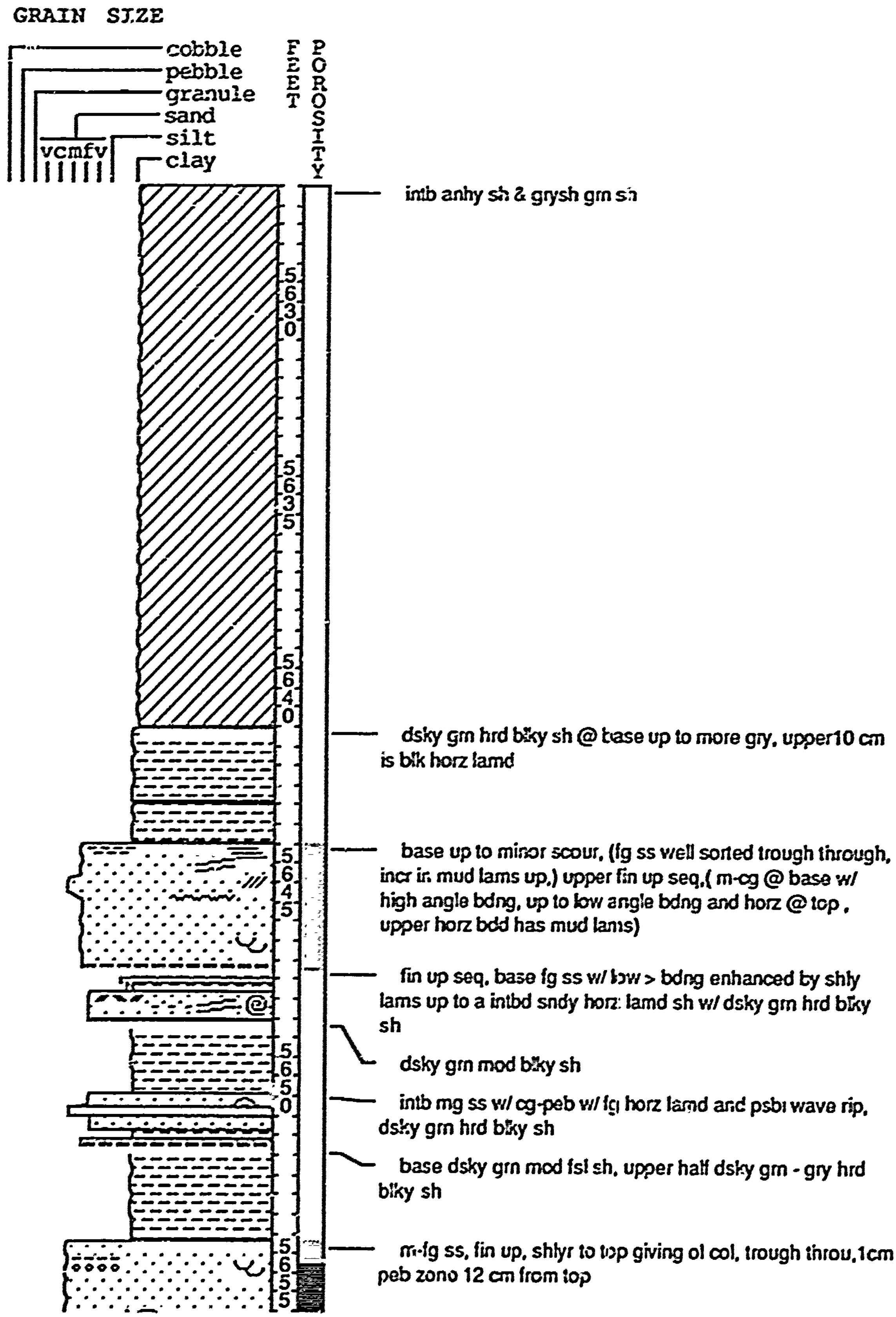
Slks
5695
5700
5705
5710
5715
dsky red v fsl sh, sndy ip, plates, upper 15 cm is pl grn mod fsl sh
intb blk, ol gry, grysh ol fis sh w/ tan anhy sh
tan muddy anhy
solid anhy for rest of core

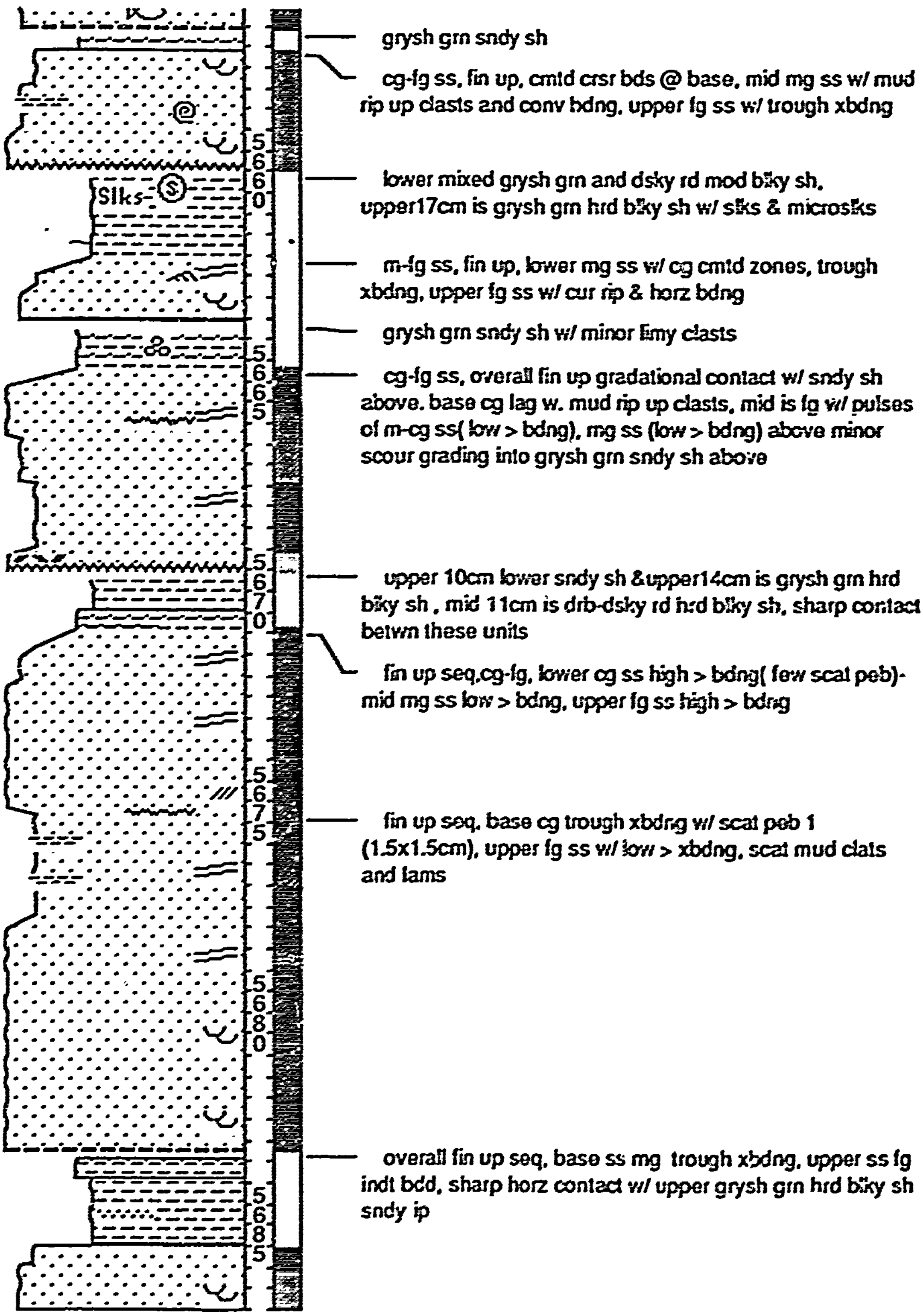
Mobil SW Nipisi Mobil SW NIPISI
10-26-78-8w5



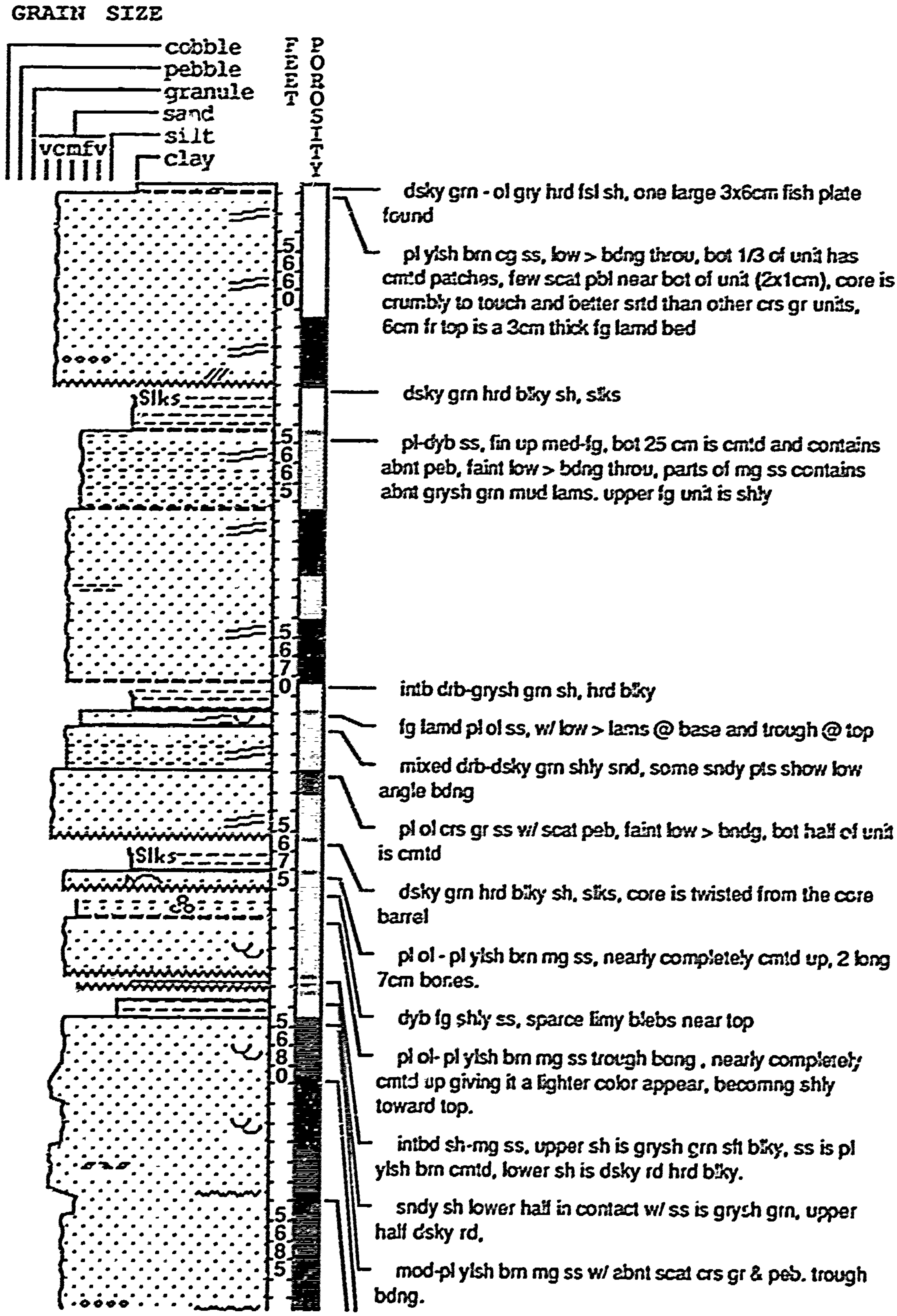

5640
thin cg-peb mdy ss in upper 6 inch of this unit. rest is a fg-cg mdy ss
5645
mg -fg ss, high > @ top, mass in mid and low > @ base, few scat mud clasts @ top.
mg-cg ss, w/ thin 5cm sh near top (sh fsl & mic). cg is very fsl & mdy
5650
pl grn sndy sh, hrd blky
drb sndy sh., brec @ base
mixed drb pl grn sh, very mic, sndy ip. slks
5655
5660
Slks
cg ss peb ip in upper 40 cm.
mg ss trough ip and horz ip, thin 2cm mud capping this seq.
5665
intb mg-fg ss with sh (lams-4cm) mainly low > bdng, bot 20cm mg-cg ss w/ low-high > xbdng.
pl grn hrd blky sh
drb hrd blky sh
5670
mixed drb-plgrn sh, mostly drb, very irreg, sandy ip, horz bdd ip

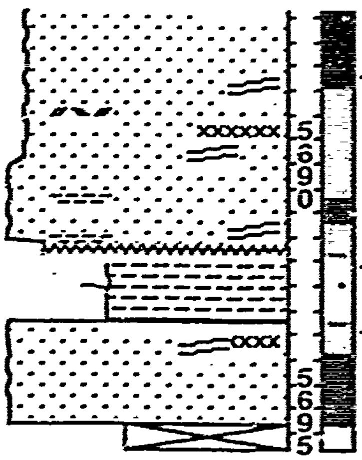
Amoco Unit 213
10-27-78-8w5




grysh grn sndy sh
cg-fg ss, fin up, cmtd crsr bds @ base, mid mg ss w/ mud rip up clasts and conv bdng, upper fg ss w/ trough xbdng
5660
lower mixed grysh grn and dsky rd mod blky sh, upper17cm is grysh grn hrd blky sh w/ slks & microslks
Slks
m-fg ss, fin up, lower mg ss w/ cg cmtd zones, trough xbdng, upper fg ss w/ cur rip & horz bdng
grysh grn sndy sh w/ minor lmy clasts
5665
cg-fg ss, overall fin up gradational contact w/ sndy sh above. base cg lag w. mud rip up clasts, mid is fg w/ pulses of m-cg ss(low > bdng), mg ss (low > bdng) above minor scour grading into grysh grn sndy sh above
5670
upper 10cm lower sndy sh &upper14cm is grysh grn hrd blky sh , mid 11cm is drb-dsky rd hrd blky sh, sharp contact betwn these units
fin up seq,cg-fg, lower cg ss high > bdng(few scat peb)-mid mg ss low > bdng, upper fg ss high > bdng
5675
fin up seq, base cg trough xbdng w/ scat peb 1 (1.5x1.5cm), upper fg ss w/ low > xbdng, scat mud clats and lams
5680
overall fin up seq, base ss mg trough xbdng, upper ss fg indt bdd, sharp horz contact w/ upper grysh grn hrd blky sh sndy ip
5685

C. Norex et al NIPISI
16-32-78-8w5





fin up cg -mg dyb ss w/ few scat mud clasts and peb. faint trough bdng and upper 30cm of box is broken up cgss rubble

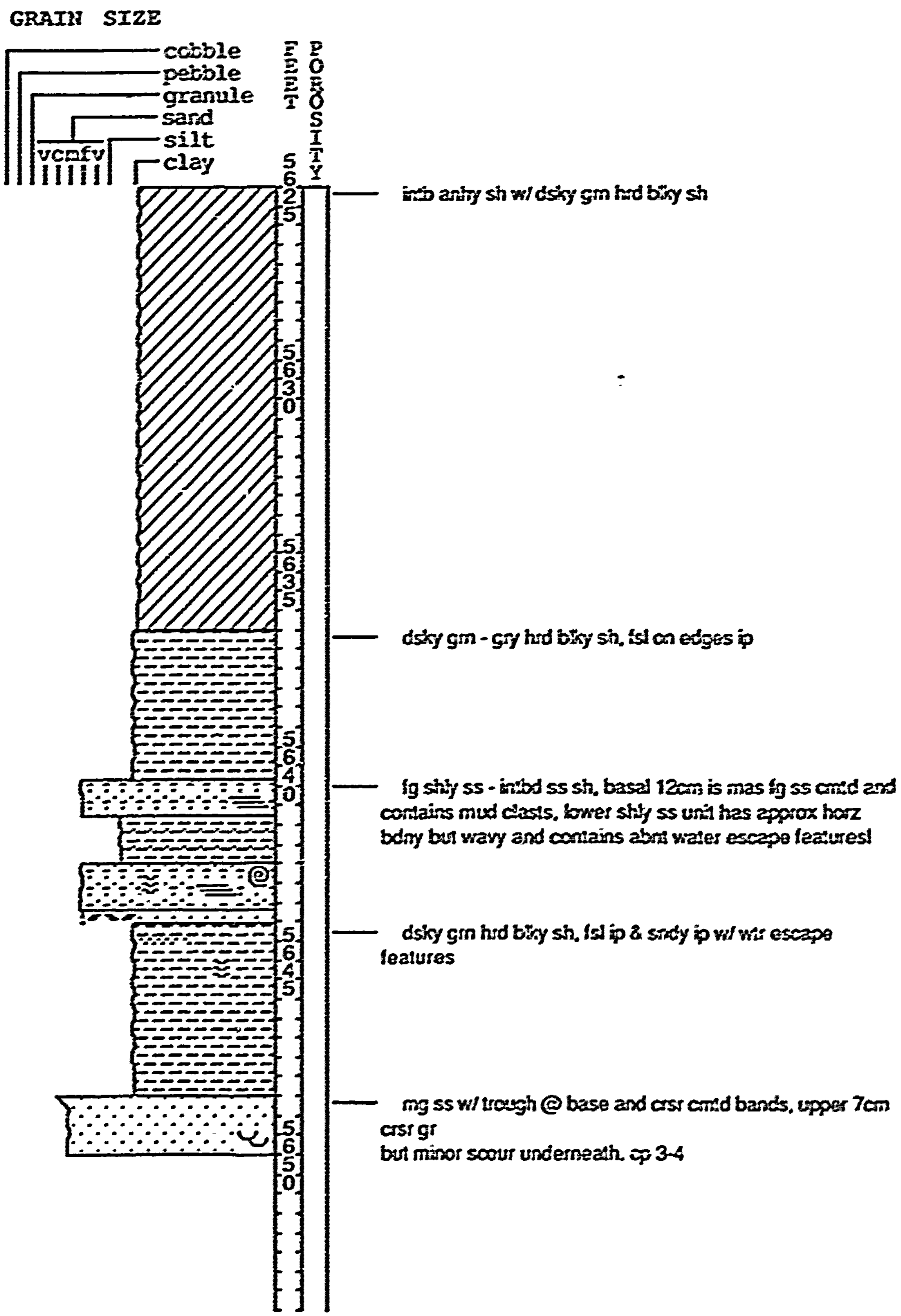
mainly mg ss w sparce cmtd zones showing low > bdng. gen bdng can not be seen giving mas appear, two peb horizons w/ peb 4x2cm (yes)

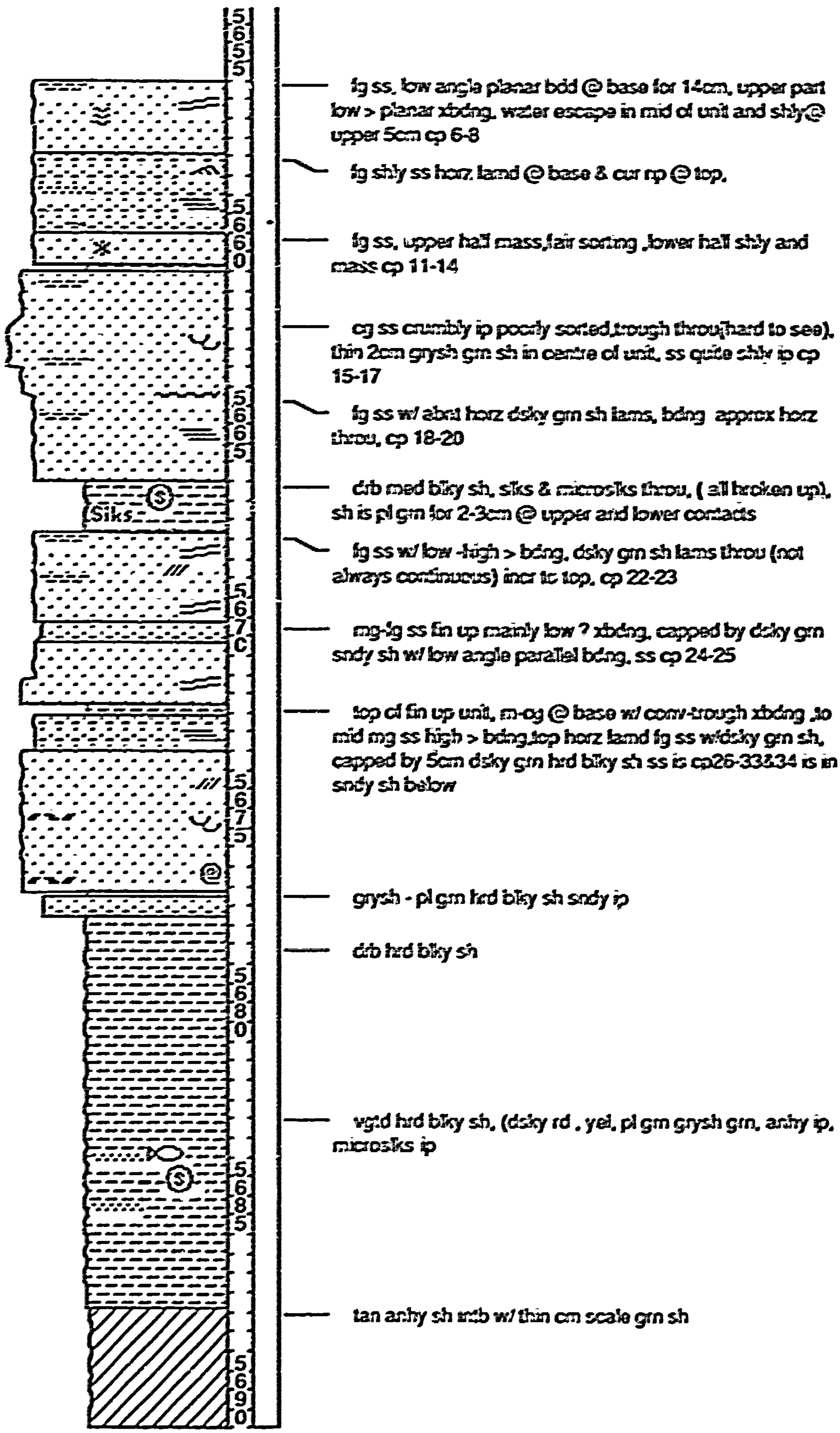
dyb ss fin up, crs-mg ss, mainly low > bdng, scat cmtd zones following bdng, scat small mud clasts 1x1cm, scat thin mud bds in lower part,.5-3cm

mixed drb-grysh grn hrd blky sh, very slty&sndy at base,

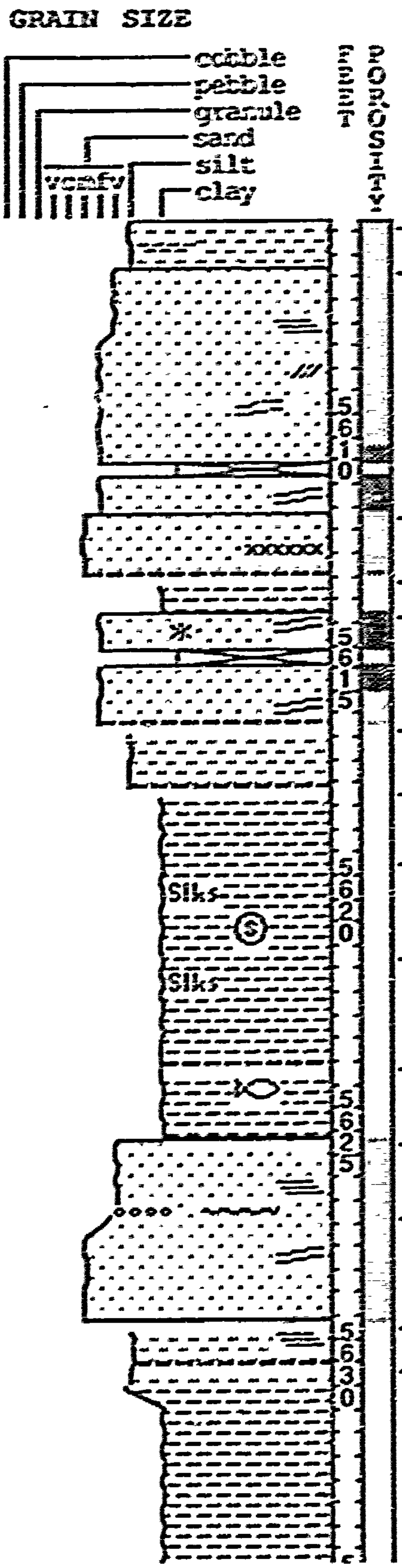
pl - dyb cg ss abnt cmtd patches and low > bdng through

Texaco Texcan Nipisi
10-35-78-8w5




5565
5660
5665
5670
5675
5680
5685
5690
Siks
fg ss, low angle planar bdd @ base for 14cm, upper part low > planar xbdng. water escape in mid of unit and shly@ upper 5cm cp 6-8
fg shly ss horz lamd @ base & cur rp @ top.
fg ss, upper half mass,fair sorting ,lower half shly and mass cp 11-14
cg ss crumbly ip poorly sorted,trough throu(hard to see). thin 2cm grysh grn sh in centre of unit, ss quite shly ip cp 15-17
fg ss w/ abnt horz dsky grn sh lams, bdng approx horz throu, cp 18-20
drb med blky sh, slks & microslks throu, (all broken up), sh is pl grn for 2-3cm @ upper and lower contacts
fg ss w/ low -high > bdng, dsky grn sh lams throu (not always continuous) incr to top, cp 22-23
mg-fg ss fin up mainly low ? xbdng, capped by dsky grn sndy sh w/ low angle parallel bdng, ss cp 24-25
top of fin up unit, m-cg @ base w/ conv-trough xbdng ,to mid mg ss high > bdng,top horz lamd fg ss w/dsky grn sh, capped by 5cm dsky grn hrd blky sh ss is cp26-33&34 is in sndy sh below
grysh - pl grn hrd blky sh sndy ip
drb hrd blky sh
vgtd hrd blky sh, (dsky rd , yel, pl grn grysh grn, anhy ip, microslks ip
tan anhy sh intb w/ thin cm scale grn sh

Shell et al Nipisi
10-36-78-8w5



This core contained many boxes of rubble therefore a caution should be used when determining depths and thicknesses. pl grn vfg ss-sltst with abnt grsh grn sh lams disc and wavy. mg ss lag at top

pl ysh brn fg-vfg ss well sorted, sed struc incld planar horz, low >, high >, cmrd.

mg pl ysh brn ss nearly completely cmtd, two 1cm anhy clasts near top

grysh grn mod fis sh. 5cm mg ss at base cemtd up

pl ysh brn fg ss excellent sorting, mainly low angle lams, mass ip

grsh grn mas sltst, sndy ip

dsky rd sh broken up rubble hd blky

dsky rd sh hrd blky, brec appear ip, slks and micro slks

dsky rd sh grsh grn ip sl fis, abnt slks and micro slks, grn sh is wxy.

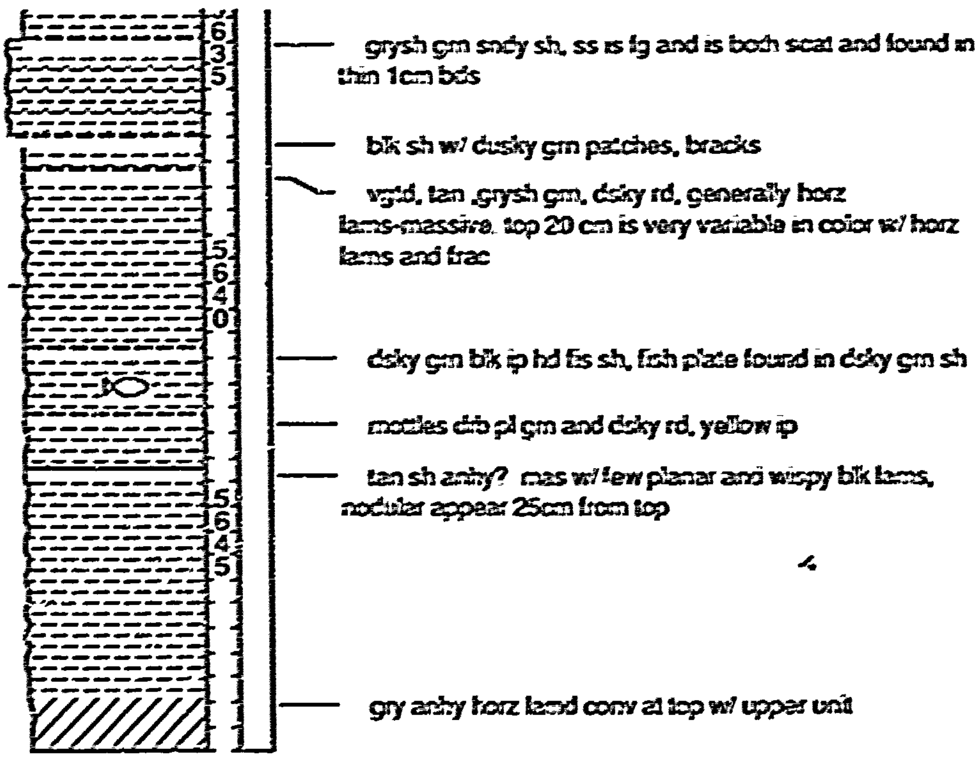
very broken up, dsky grn sh.

mainly vfg ss with fg-mg beds and scat crs gr ip. muddy ip shown by blk lams cont and disc

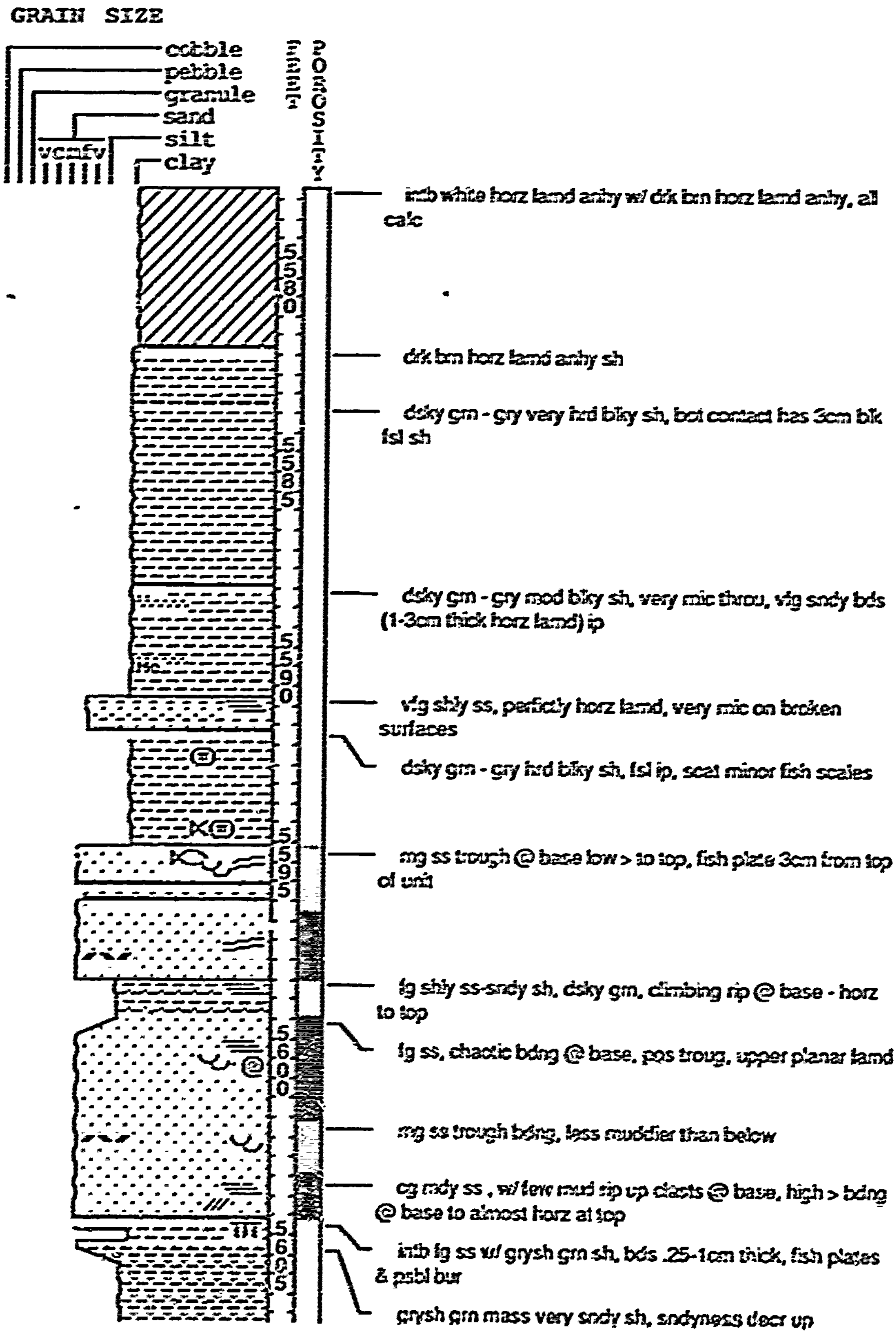
mg ss with some fg beds and crs gr beds and scat grains, overall fin up mainly planar xbeds, most is cemented

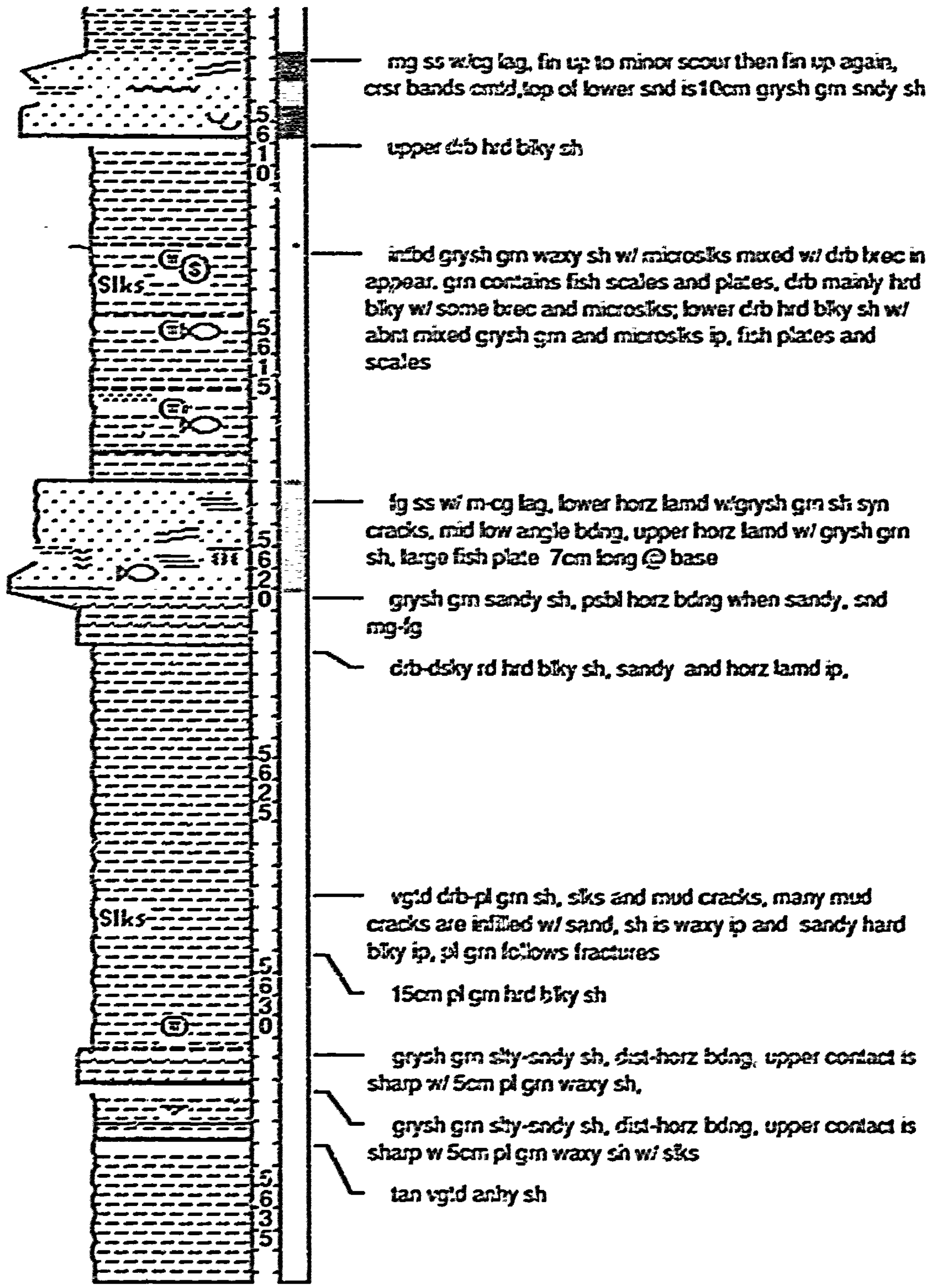
grsh grn sltst w/ disc approx horz lams

drb hd blky sh, broken into sm blky pieces through except upper 15cm which is more silty

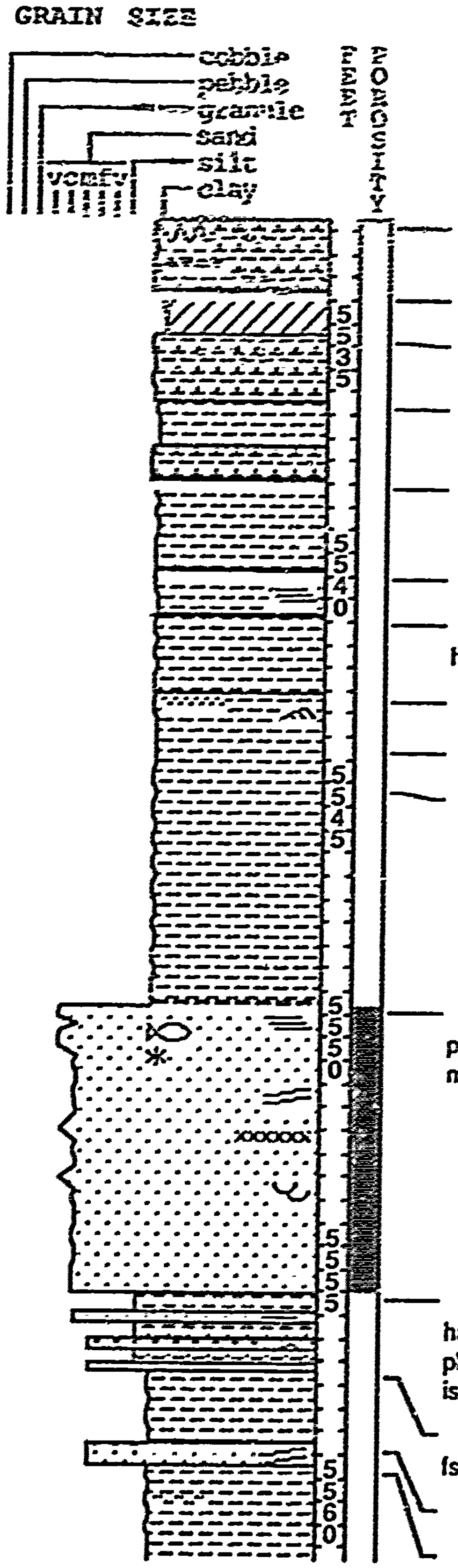

6
3
5
5
6
4
0
5
6
4
5
grysh grn sndy sh, ss is fg and is both scat and found in thin 1cm bds
blk sh w/ dusky grn patches, bracks
vgtd, tan ,grysh grn, dsky rd, generally horz lams-massive. top 20 cm is very variable in color w/ horz lams and frac
dsky grn blk ip hd fis sh, fish plate found in dsky grn sh
mottles drb pl grn and dsky rd, yellow ip
tan sh anhy? mas w/ few planar and wispy blk lams, nodular appear 25cm from top
gry anhy horz lamd conv at top w/ upper unit

Amoco Unit 353 Nipisi
4-18-79-7w5




Slks
Slks
5610
5615
5620
5625
5630
5635
mg ss w/cg lag, fin up to minor scour then fin up again, crsr bands cmtd, top of lower snd is 10cm grysh grn sndy sh
upper drb hrd blky sh
infbd grysh grn waxy sh w/ microslks mixed w/ drb brec in appear. grn contains fish scales and plates, drb mainly hrd blky w/ some brec and microslks; lower drb hrd blky sh w/ abnt mixed grysh grn and microslks ip, fish plates and scales
fg ss w/ m-cg lag, lower horz lamd w/grysh grn sh syn cracks, mid low angle bdng, upper horz lamd w/ grysh grn sh, large fish plate 7cm long @ base
grysh grn sandy sh, psbl horz bdng when sandy, snd mg-fg
drb-dsky rd hrd blky sh, sandy and horz lamd ip.
vgtd drb-pl grn sh, slks and mud cracks, many mud cracks are infilled w/ sand, sh is waxy ip and sandy hard blky ip, pl grn follows fractures
15cm pl grn hrd blky sh
grysh grn slty-sndy sh, dist-horz bdng, upper contact is sharp w/ 5cm pl grn waxy sh,
grysh grn slty-sndy sh, dist-horz bdng, upper contact is sharp w 5cm pl grn waxy sh w/ slks
tan vgtd anhy sh

HB BA Nipisi
12-20-79-7w5



calc sh w/ anhy, breciated ip, dyb @ base tan @ top

solid anhy

calc sh horz lamd, dyb-ol gry

ol gry hrd bky sh @ top and bk very fsl @ base

ol gry hrd very fsl sh

dyb-tan anhy sh hrd bky horz lamd

grysh grn sh, general discription for whole unit, v fsl ip, hrd bky ip

grysh grn sndy sh, starved rip,

grysh grn soft fis sh just below the sndy sh

med - hrd fis sh

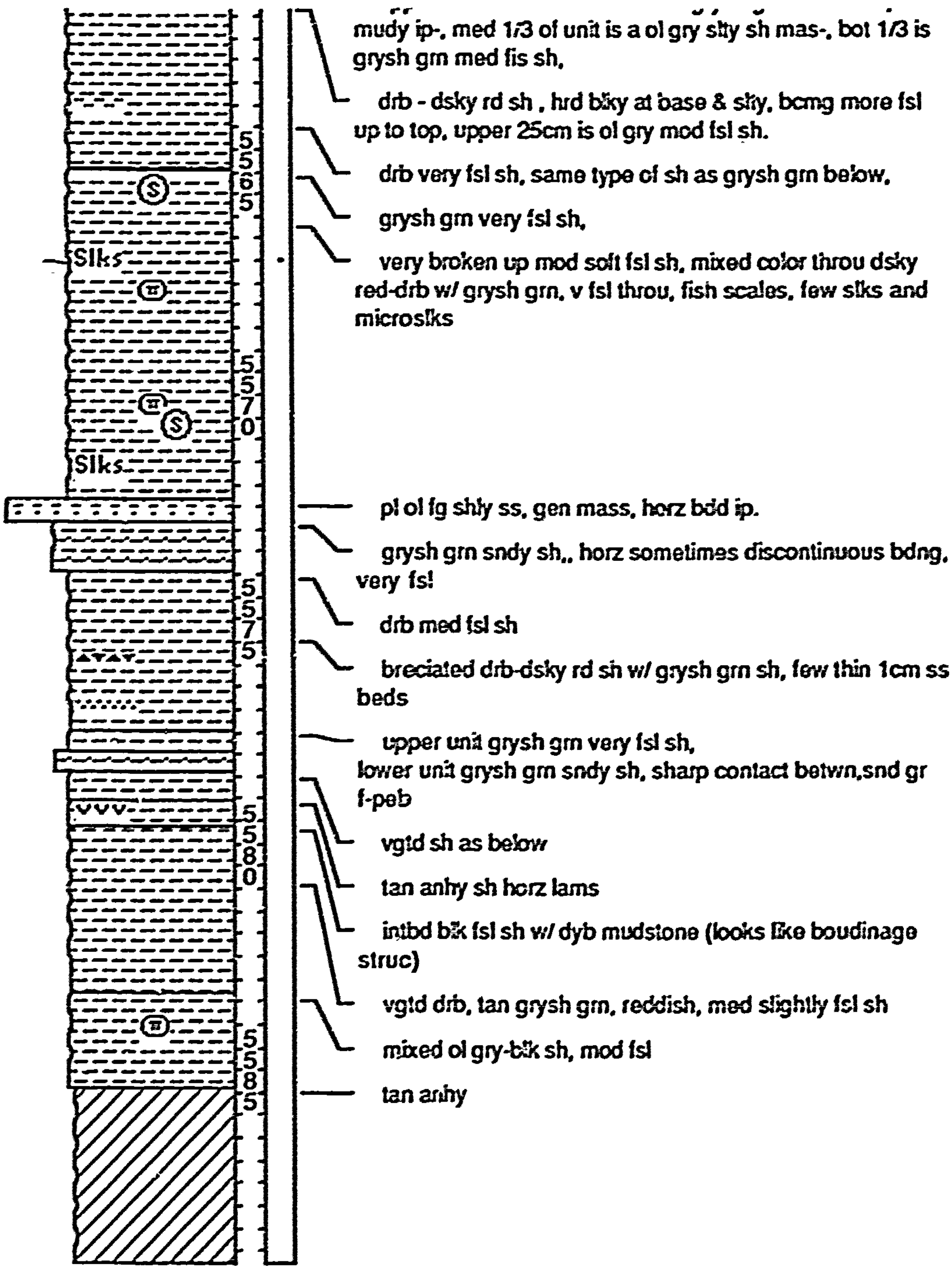
dyb um-lcg ss, trough @ base, low angle in mid, and planar bdng @ top,
mass ip, fair porosity throu, few smtd patches of crsr gr ss

intbd grysh grn sndy sh 4-10cm w/ pyb shly ss 2-5cm ss has
planar bdng & starved climbing ripples, mostly fg, upper ss is mg

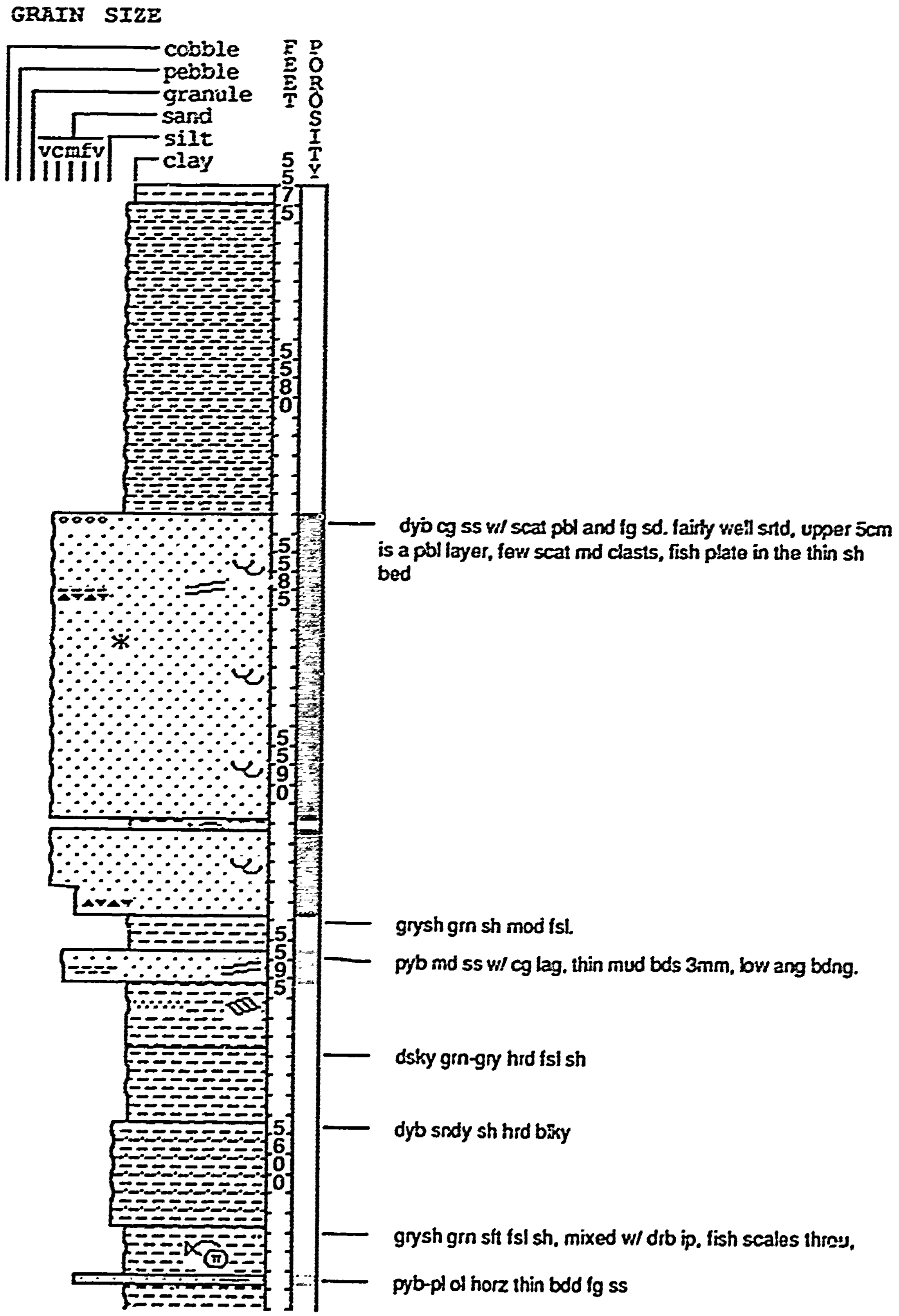
upper half mixed drb&grysh grn mod fsl sh, lower half mod fsl grysh grn

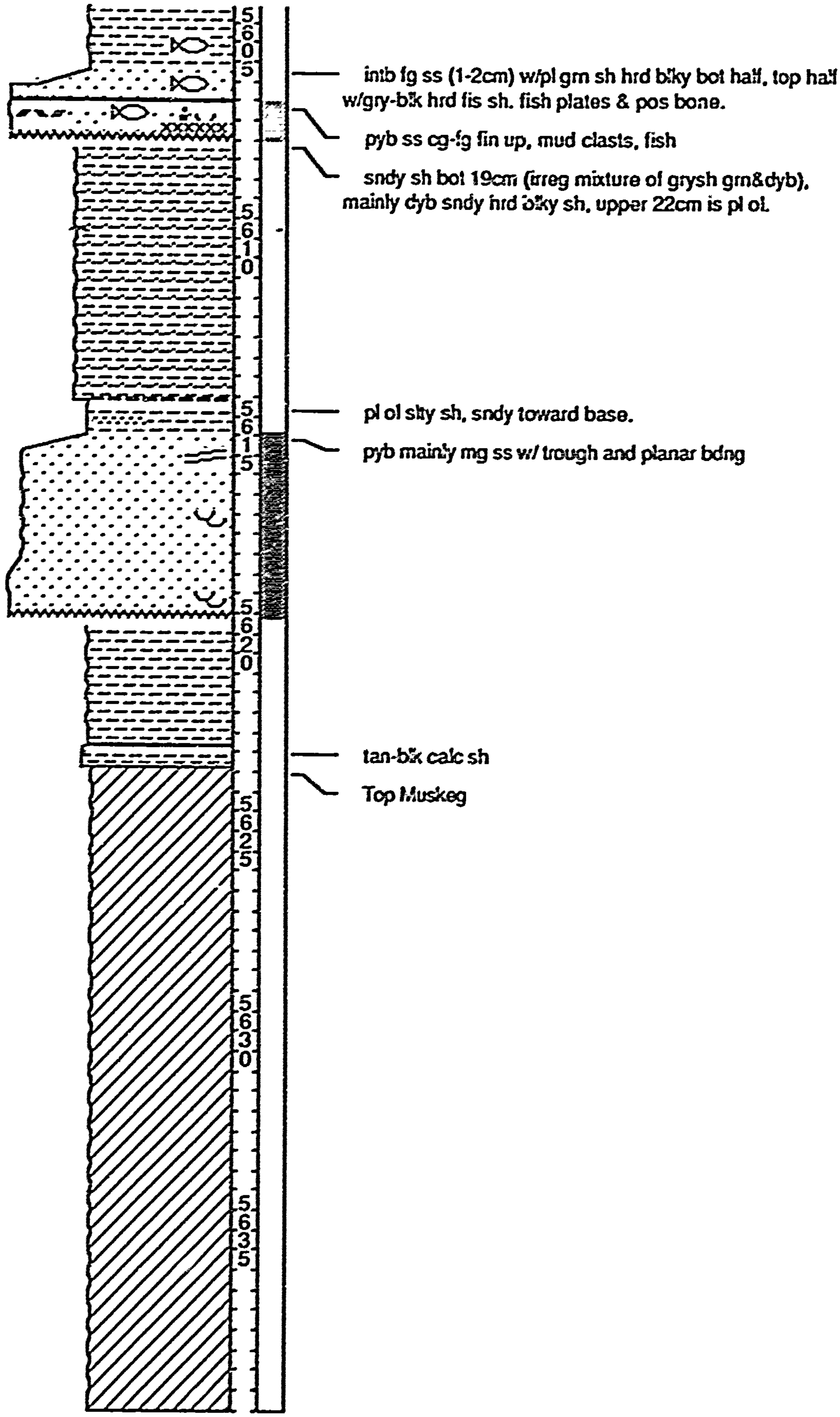
grysh grn shly snd, wavy low angle bdng,

upper 1/3 of unit is mixed drb & grysh grn soft fsl sh

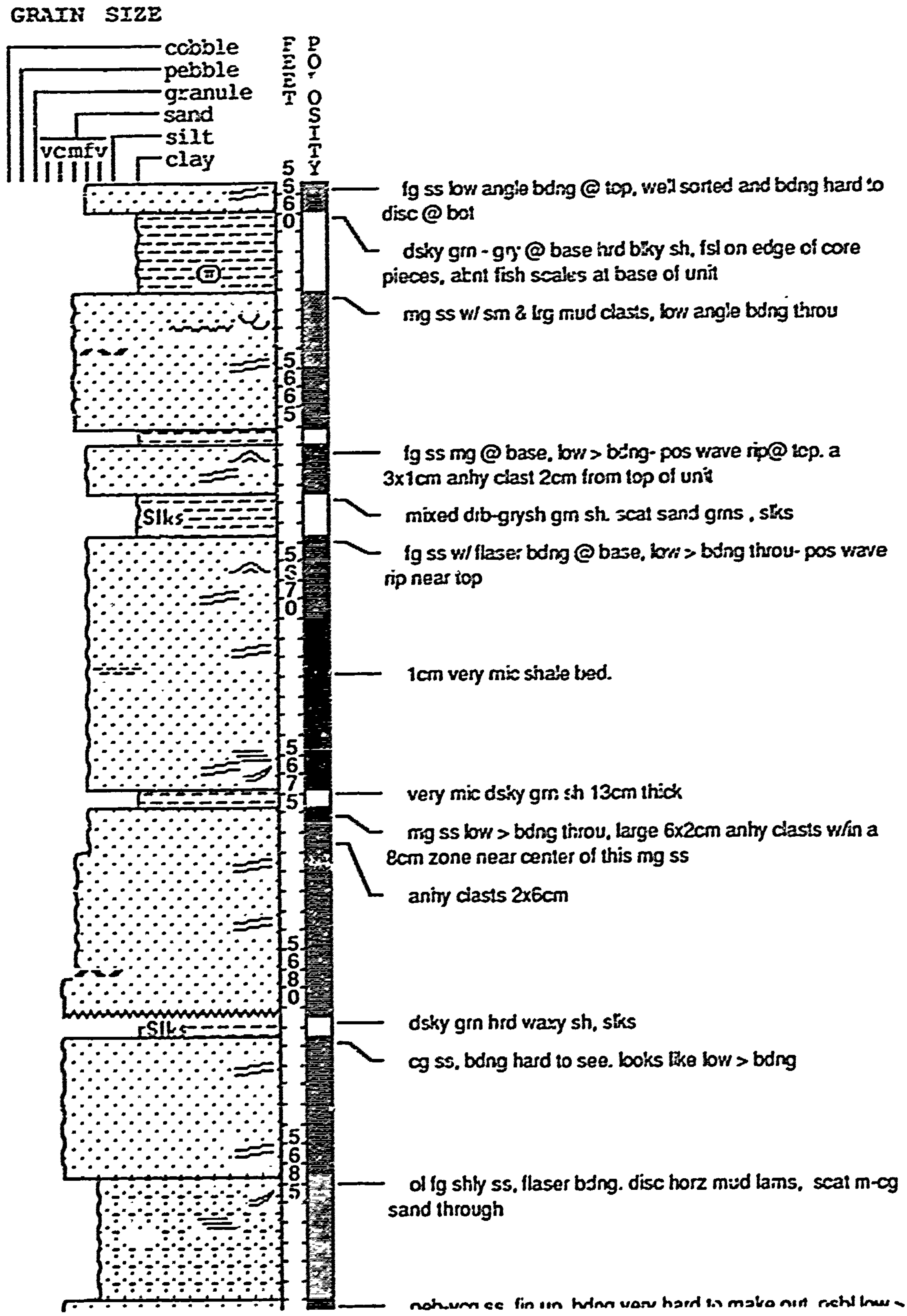

5565
5570
5575
5580
5585
Slks
Slks
mudy ip-, med 1/3 of unit is a ol gry slty sh mas-, bot 1/3 is grysh grn med fis sh,
drb - dsky rd sh , hrd blky at base & slty, bcmg more fsl up to top, upper 25cm is ol gry mod fsl sh.
drb very fsl sh, same type of sh as grysh grn below,
grysh grn very fsl sh,
very broken up mod soft fsl sh, mixed color throu dsky red-drb w/ grysh grn, v fsl throu, fish scales, few slks and microslks
pl ol fg shly ss, gen mass, horz bdd ip.
grysh grn sndy sh,, horz sometimes discontinuous bdng, very fsl
drb med fsl sh
breciated drb-dsky rd sh w/ grysh grn sh, few thin 1cm ss beds
upper unit grysh grn very fsl sh,
lower unit grysh grn sndy sh, sharp contact betwn,snd gr f-peb
vgtd sh as below
tan anhy sh horz lams
intbd blk fsl sh w/ dyb mudstone (looks like boudinage struc)
vgtd drb, tan grysh grn, reddish, med slightly fsl sh
mixed ol gry-blk sh, mod fsl
tan anhy

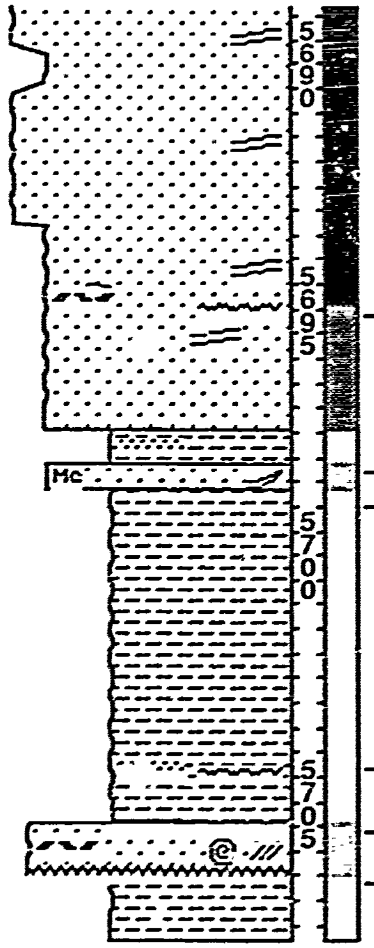
FPC Nipisi
12-30-79-7w5




5600
5610
5615
5620
5625
5630
5635
intb fg ss (1-2cm) w/pl grn sh hrd blky bot half, top half w/gry-blk hrd fis sh. fish plates & pos bone.
pyb ss cg-fg fin up, mud clasts, fish
sndy sh bot 19cm (irreg mixture of grysh grn&dyb), mainly dyb sndy hrd blky sh, upper 22cm is pl ol.
pl ol slty sh, sndy toward base.
pyb mainly mg ss w/ trough and planar bdng
tan-blk calc sh
Top Muskeg

Amoco Unit 216
2-3-79-8w5





[illegible]
throu well srtd for gr size, psbl wave rip. some subrounded grns

fg ss, uf-med at base, low angle bdng through, ss grns are somewhat rounded, and pos wave rip near top. sorting is excellent in places and makes bdng hard to see

fg ss indet bdng pos wave-cur rip

drb hrd bky sh, upper 10cm is pl grn

4cm f-mg ss w/ scoured base.
15cm of pl grn waxy sh underneath ss, & mixed drb-pl grn down to next ss.

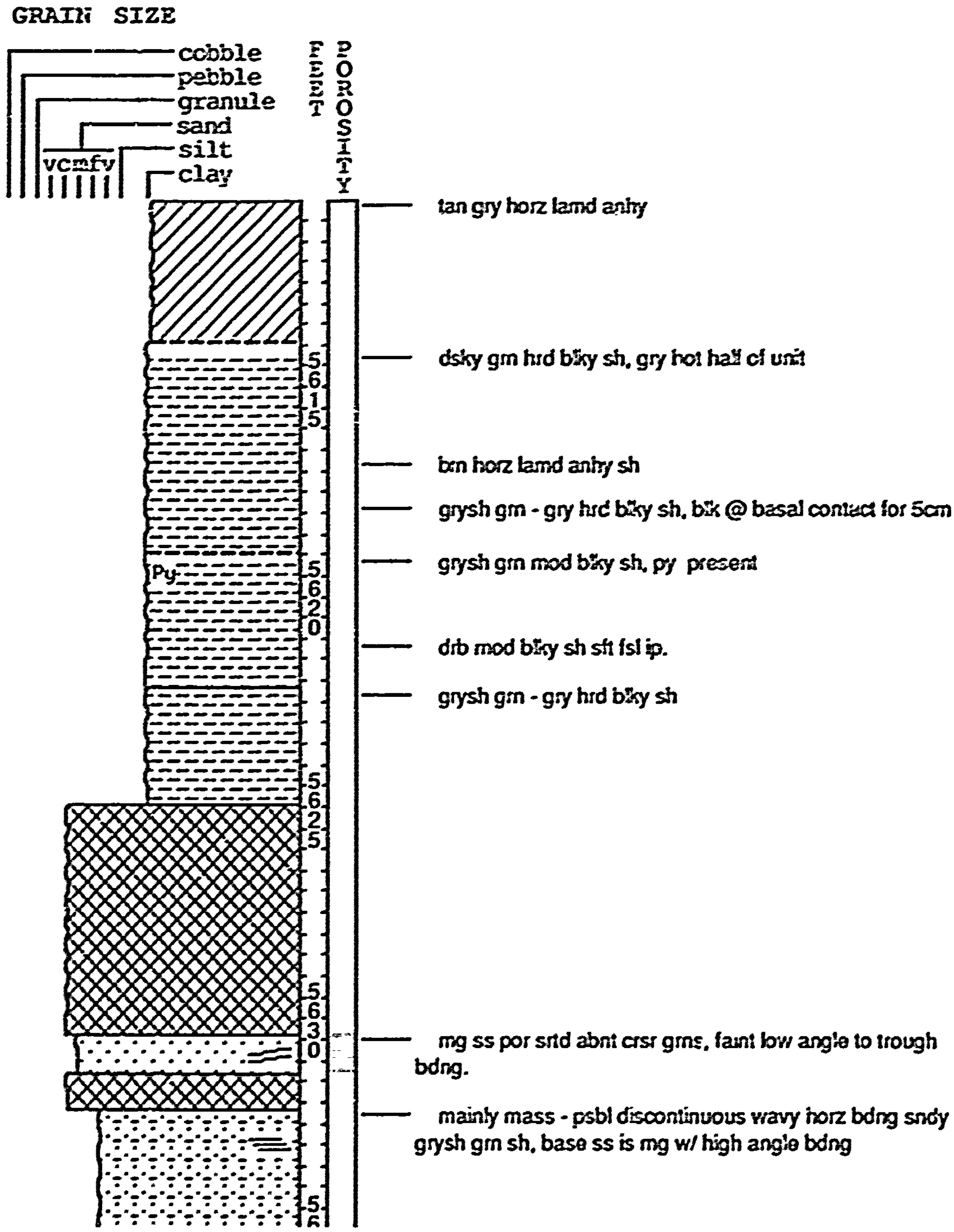
mg ss completely cmtd, high > bdng - churned, one large mud clast, almost a bed in centre of unit. upper contact is w/ 5cm pl grn sh

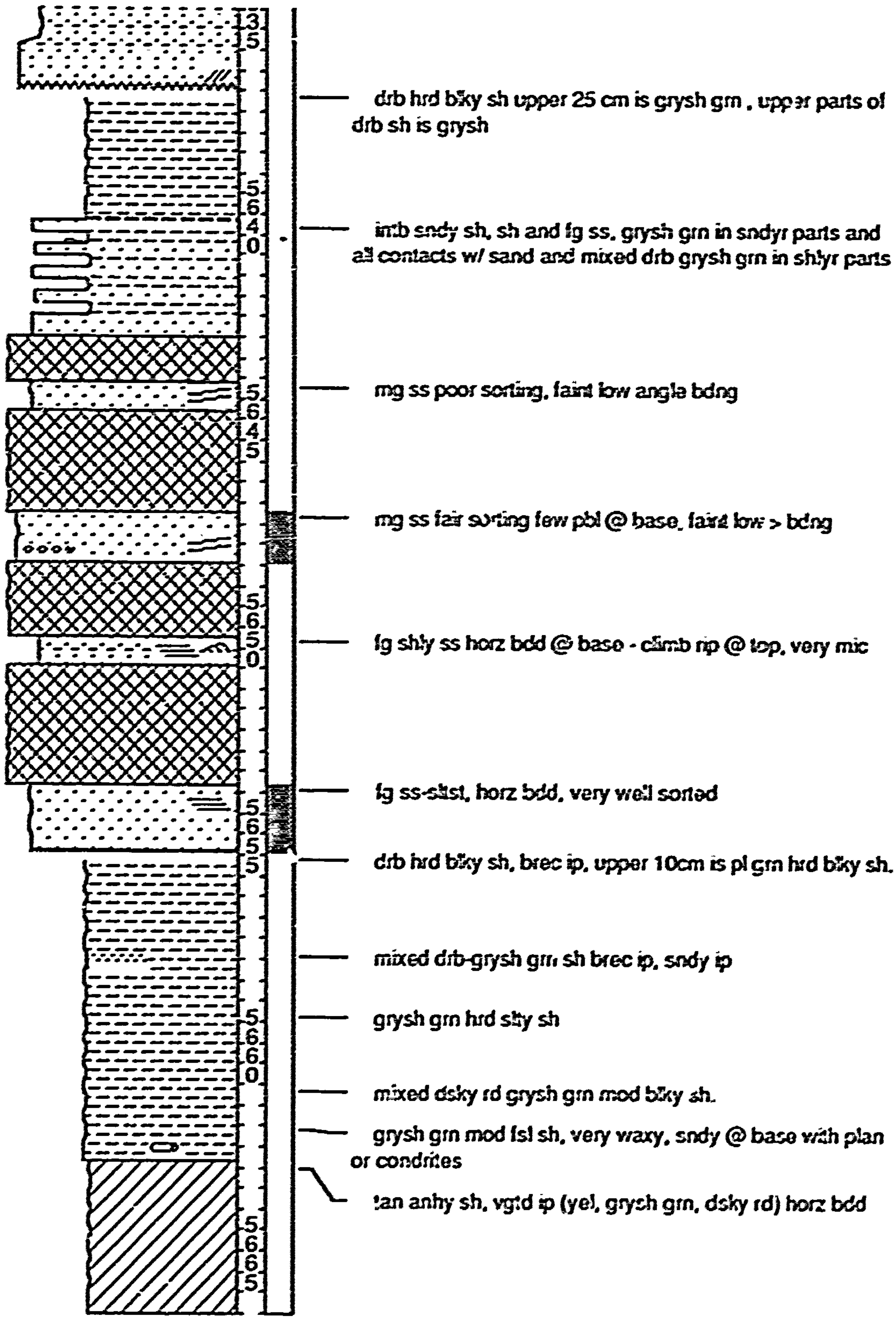
mixed pl grn-dsky rd sh, upper 13 cm is pl grn only

Amoco Unit 310

12-12-79-8w5 SS Covered by Wax

Remarks: Almost all ss is covered by orange wax to preserve original reservoir characteristics

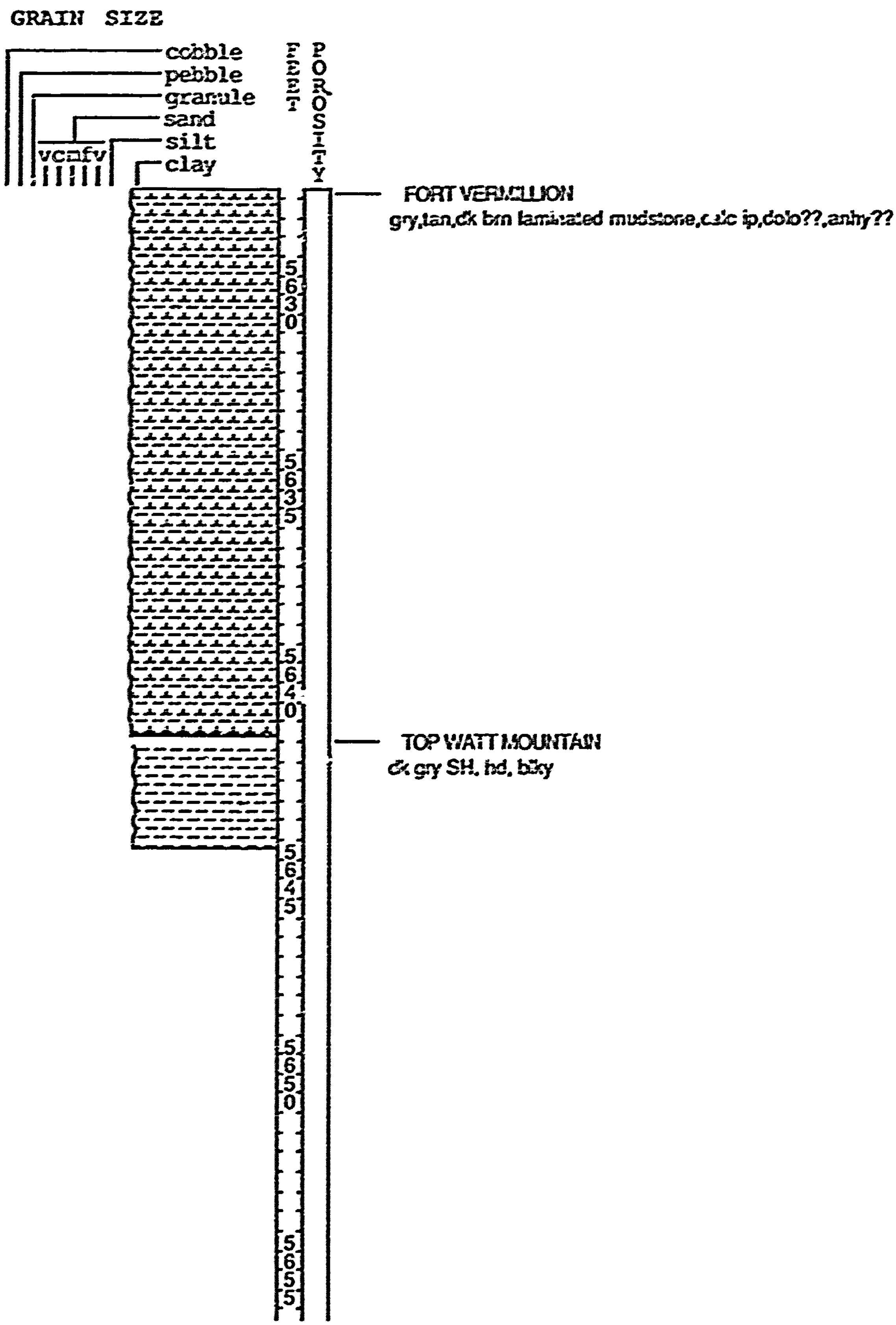


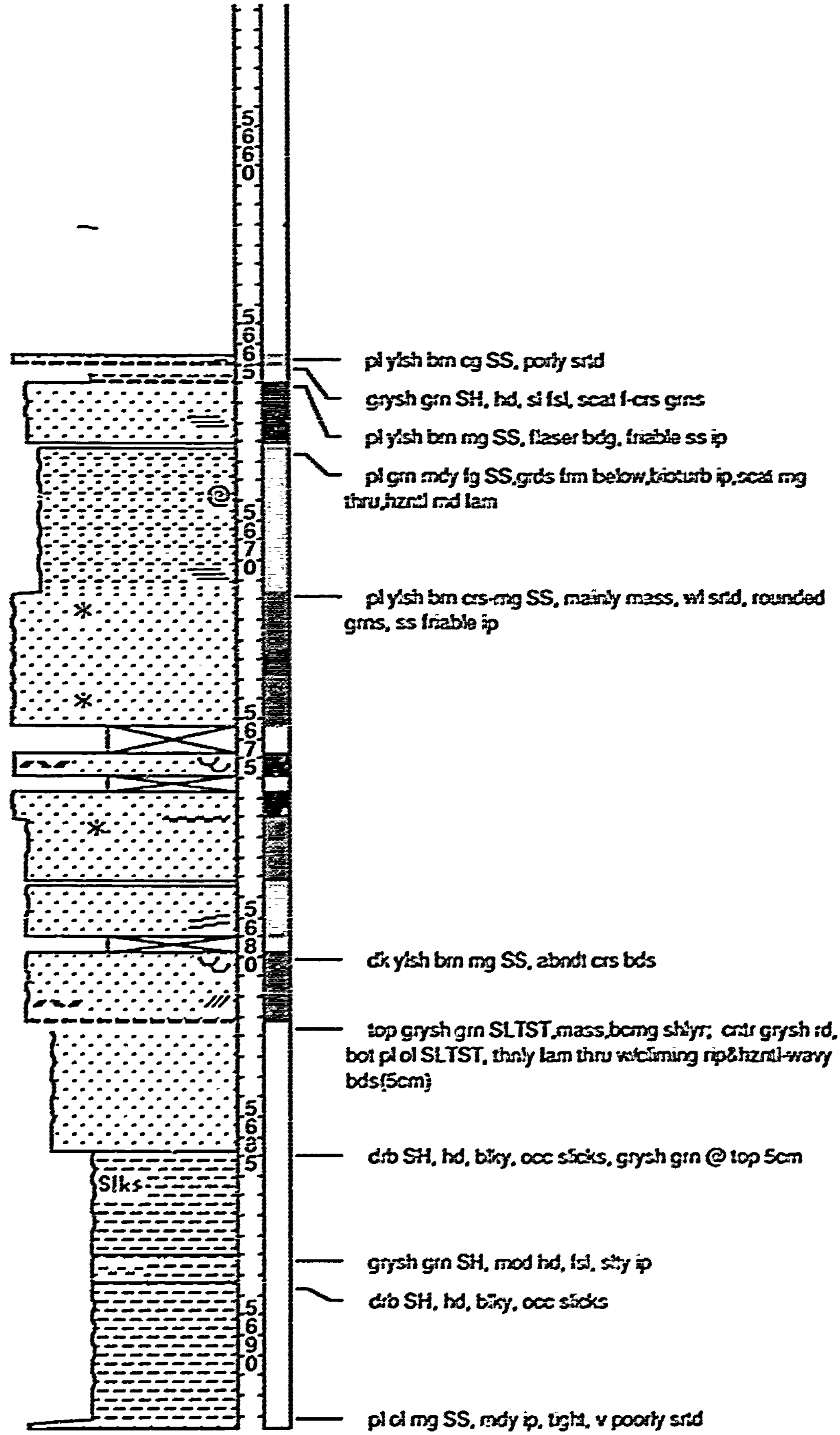


35
drb hrd blky sh upper 25 cm is grysh grn , upper parts of drb sh is grysh
5640
intb sndy sh, sh and fg ss, grysh grn in sndyr parts and all contacts w/ sand and mixed drb grysh grn in shlyr parts
mg ss poor sorting, faint low angle bdng
5645
mg ss fair sorting few pbl @ base, faint low > bdng
5650
fg shly ss horz bdd @ base - climb rip @ top, very mic
fg ss-sltst, horz bdd, very well sorted
5655
drb hrd blky sh, brec ip, upper 10cm is pl grn hrd blky sh.
mixed drb-grysh grn sh brec ip, sndy ip
grysh grn hrd slty sh
5660
mixed dsky rd grysh grn mod blky sh.
grysh grn mod fsl sh, very waxy, sndy @ base with plan or condrites
tan anhy sh, vgtd ip (yel, grysh grn, dsky rd) horz bdd
5665

Shell et al Nipisi

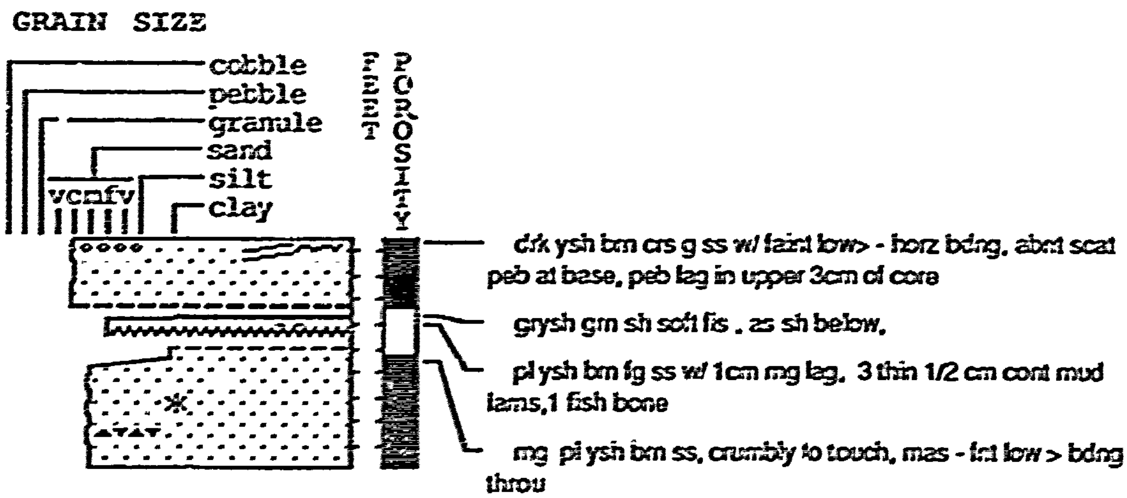
4-14-79-8w5



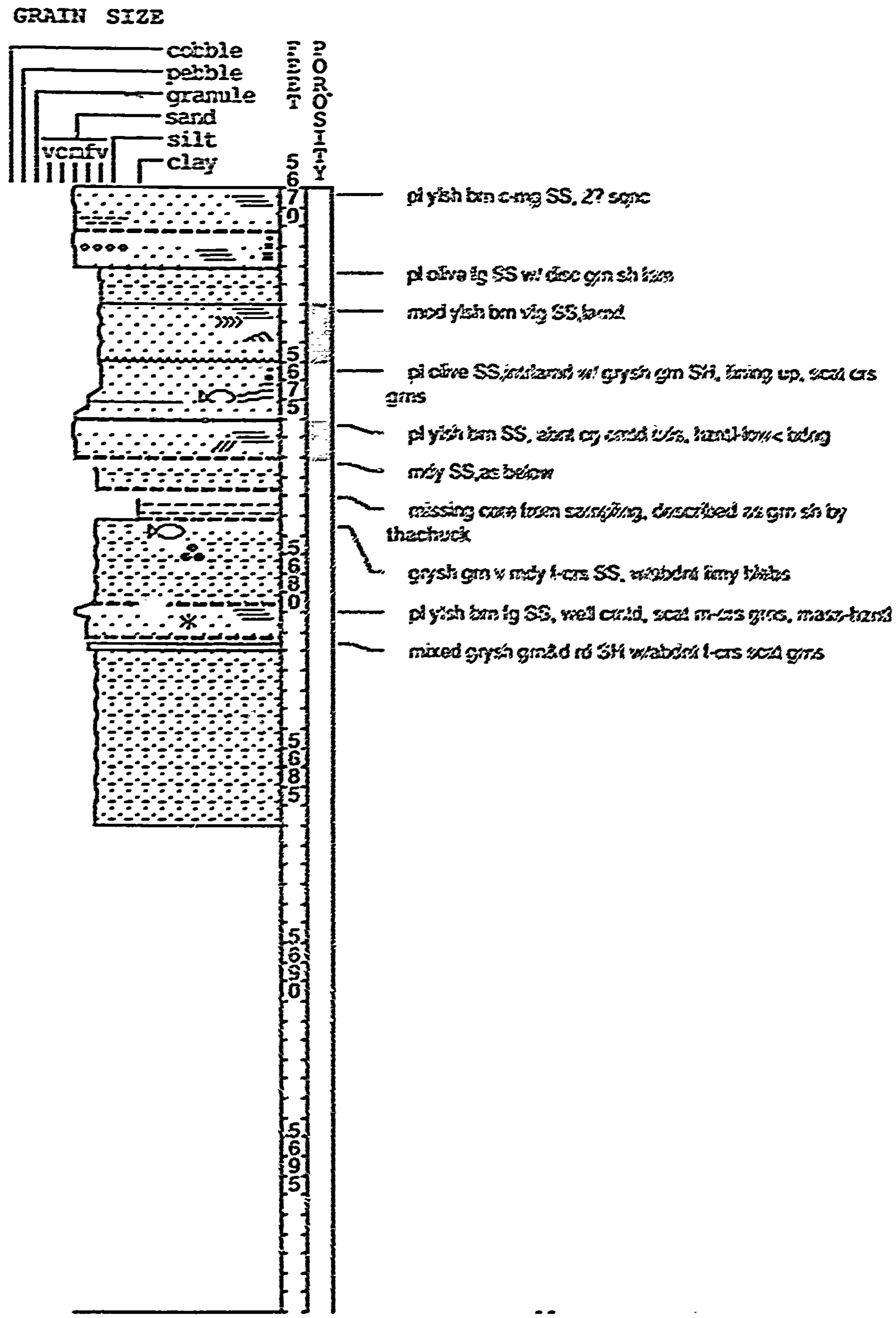

5660
5665
pl ylsh brn cg SS, porly srtd
grysh grn SH, hd, sl fsl, scat f-crs grns
pl ylsh brn mg SS, flaser bdg, friable ss ip
pl grn mdy fg SS,grds frm below,bioturb ip,scat mg thru,hzntl md lam
5670
pl ylsh brn crs-mg SS, mainly mass, wl srtd, rounded grns, ss friable ip
5675
5680
dk ylsh brn mg SS, abndt crs bds
top grysh grn SLTST,mass,bcmg shlyr; cntr grysh rd, bot pl ol SLTST, thnly lam thru w/climing rip&hzntl-wavy bds(5cm)
5685
drb SH, hd, blky, occ slicks, grysh grn @ top 5cm
Slks
grysh grn SH, mod hd, fsl, slty ip
drb SH, hd, blky, occ slicks
5690
pl ol mg SS, mdy ip, tight, v poorly srtd

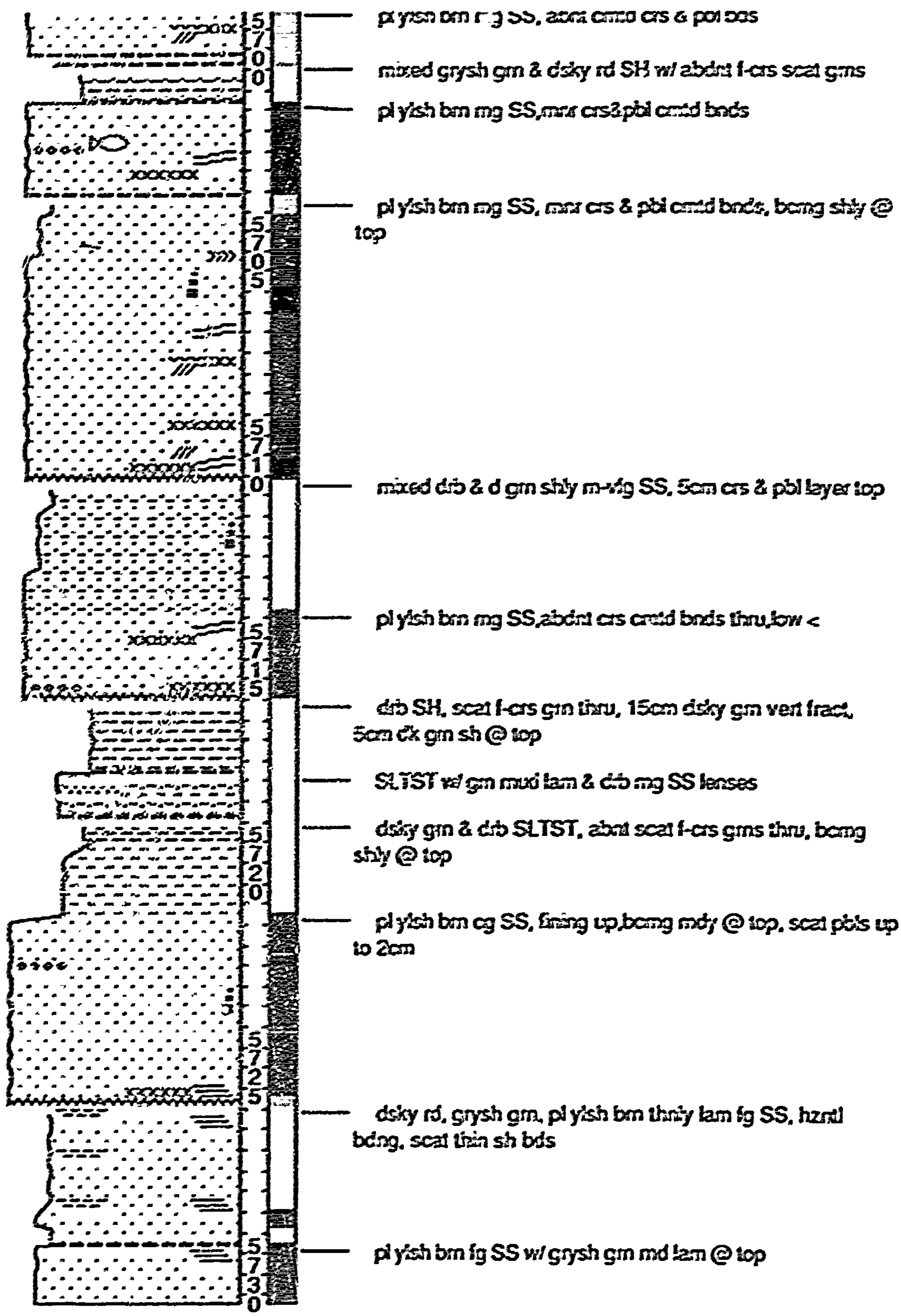
Amoco Unit 285 Nipisi

10-14-79-8w5

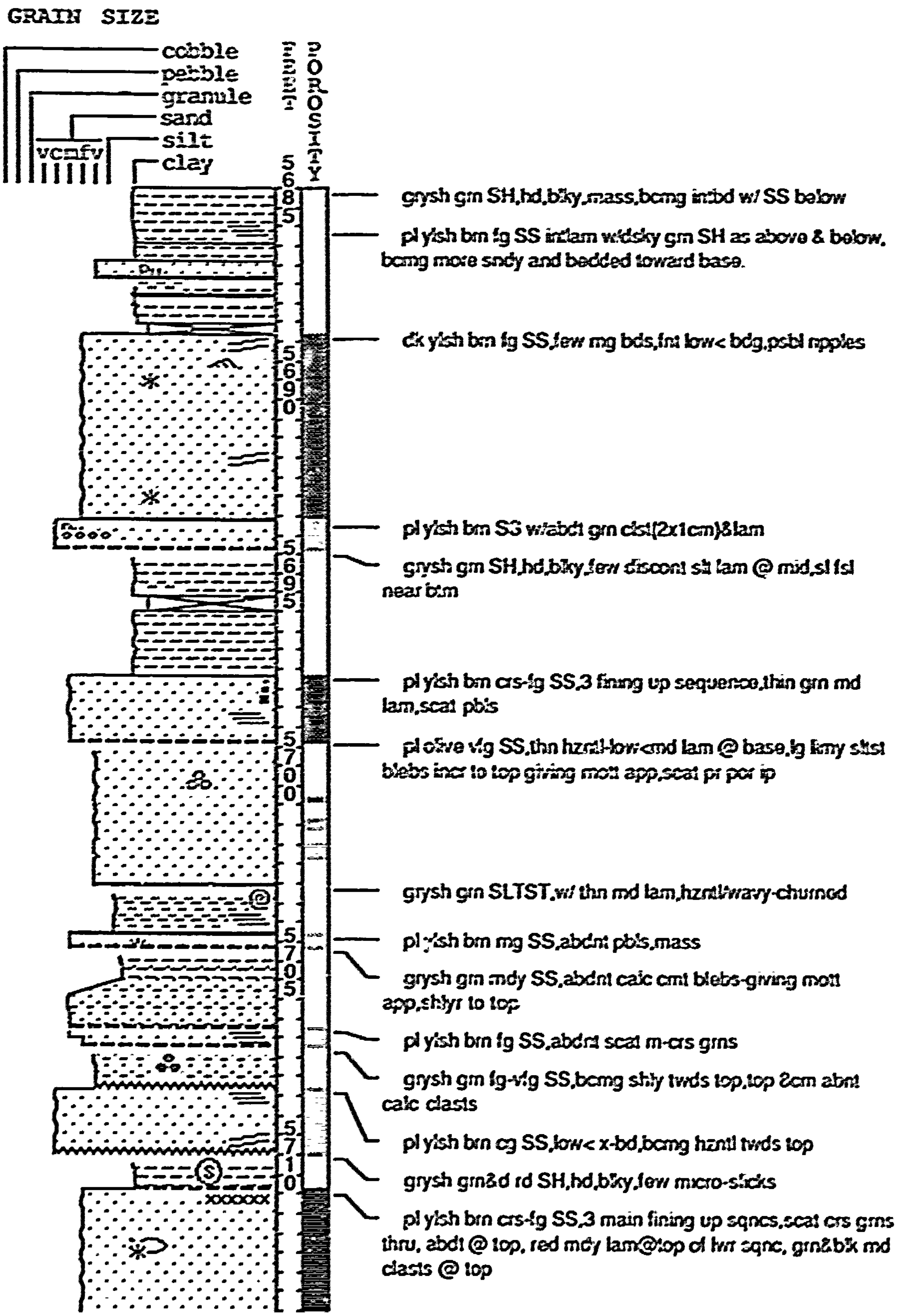


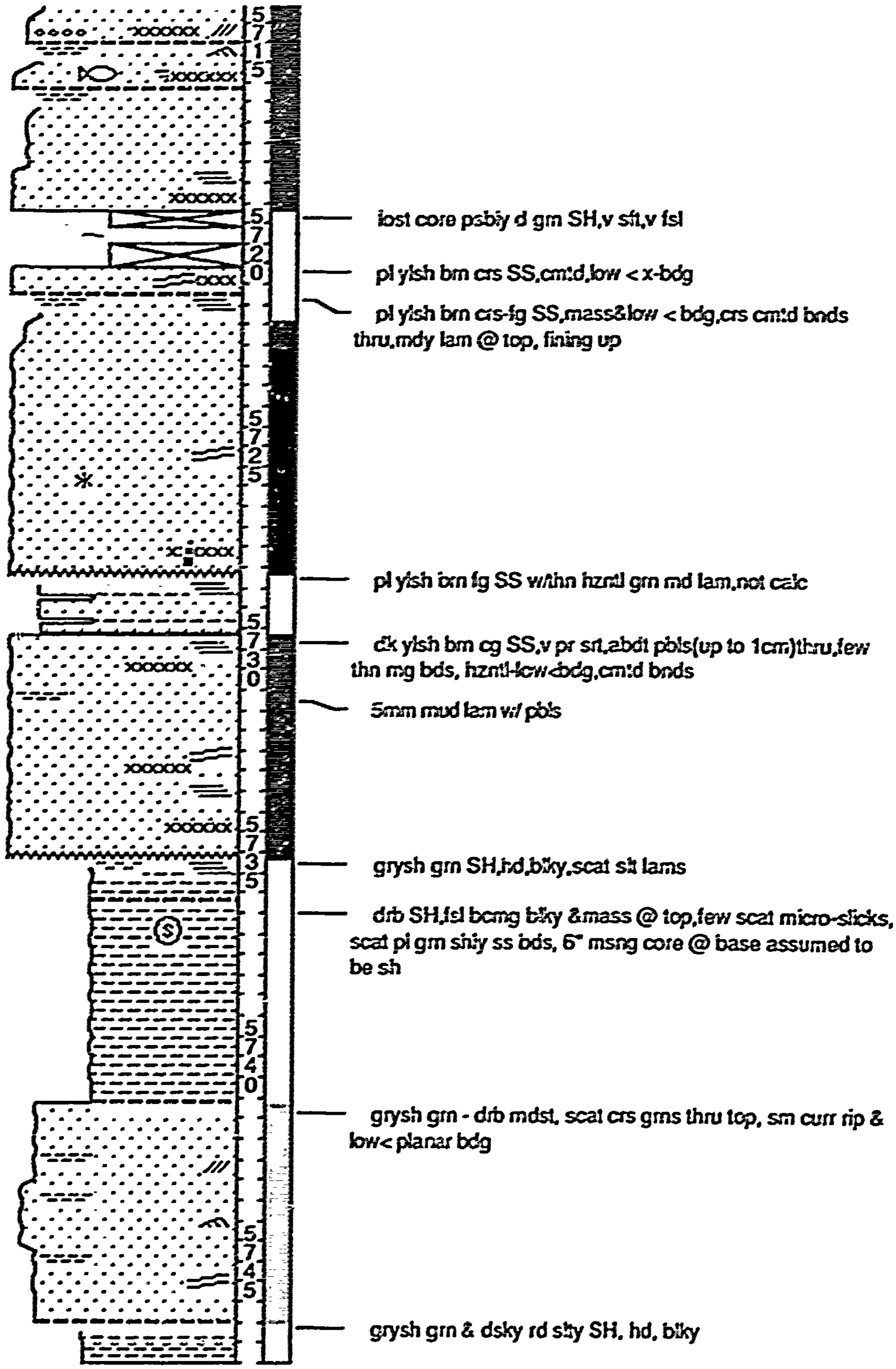
Shell et al Nipisi
6-20-79-8w5 depths may be out



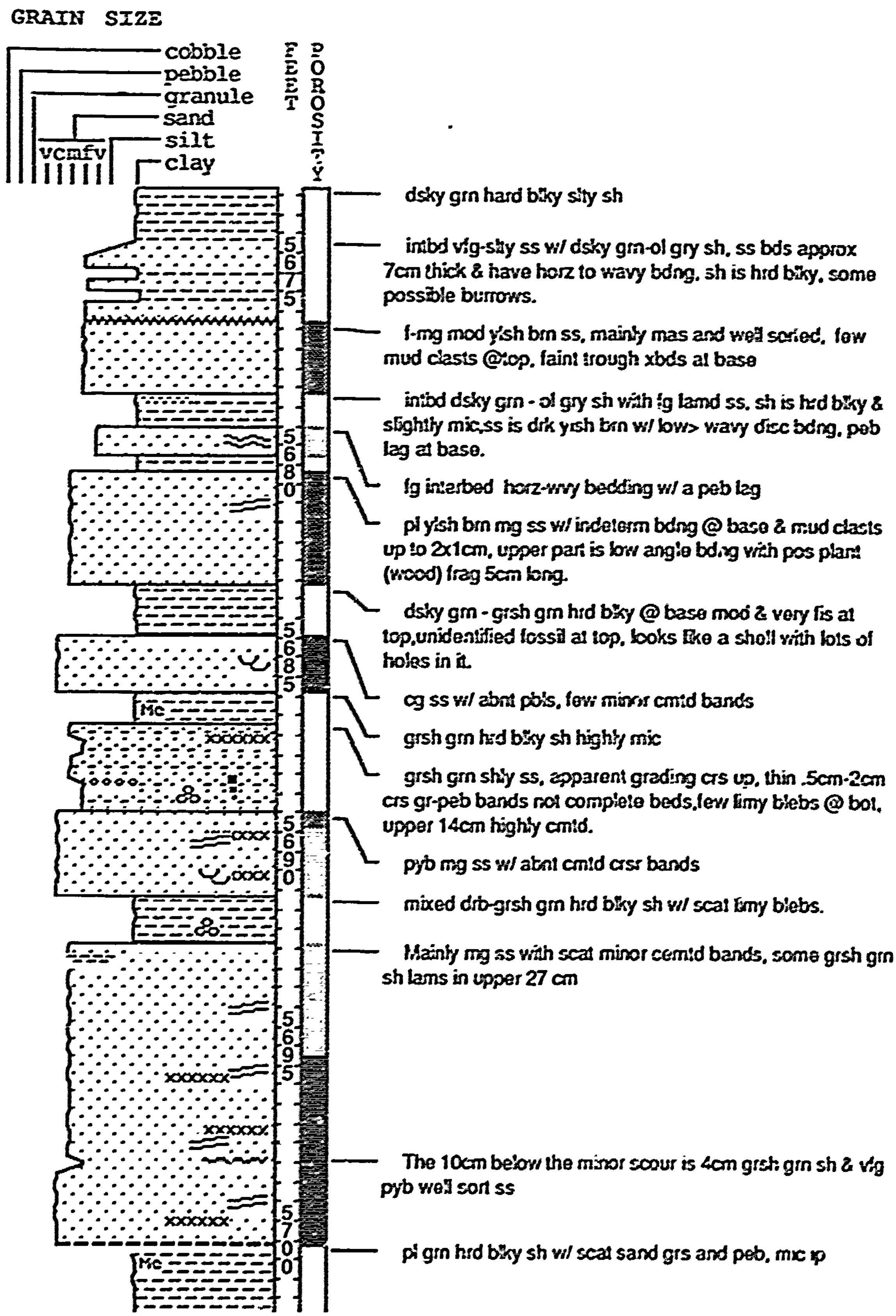

5700
5705
5710
5715
5720
5725
5730
pl ylsh brn mg SS, abdnt crntd crs & pbl bds
mixed grysh grn & dsky rd SH w/ abdnt f-crs scat grns
pl ylsh brn mg SS, mnr crs&pbl crntd bnds
pl ylsh brn mg SS, mnr crs & pbl crntd bnds, bcmg shly @ top
mixed drb & d grn shly m-vfg SS, 5cm crs & pbl layer top
pl ylsh brn mg SS, abdnt crs crntd bnds thru, low <
drb SH, scat f-crs grn thru, 15cm dsky grn vert fract, 5cm dk grn sh @ top
SLTST w/ grn mud lam & drb mg SS lenses
dsky grn & drb SLTST, abnt scat f-crs grns thru, bcmg shly @ top
pl ylsh brn cg SS, fining up, bcmg mdy @ top, scat pbls up to 2cm
dsky rd, grysh grn, pl ylsh brn thnly lam fg SS, hzntl bdng, scat thin sh bds
pl ylsh brn fg SS w/ grysh grn md lam @ top

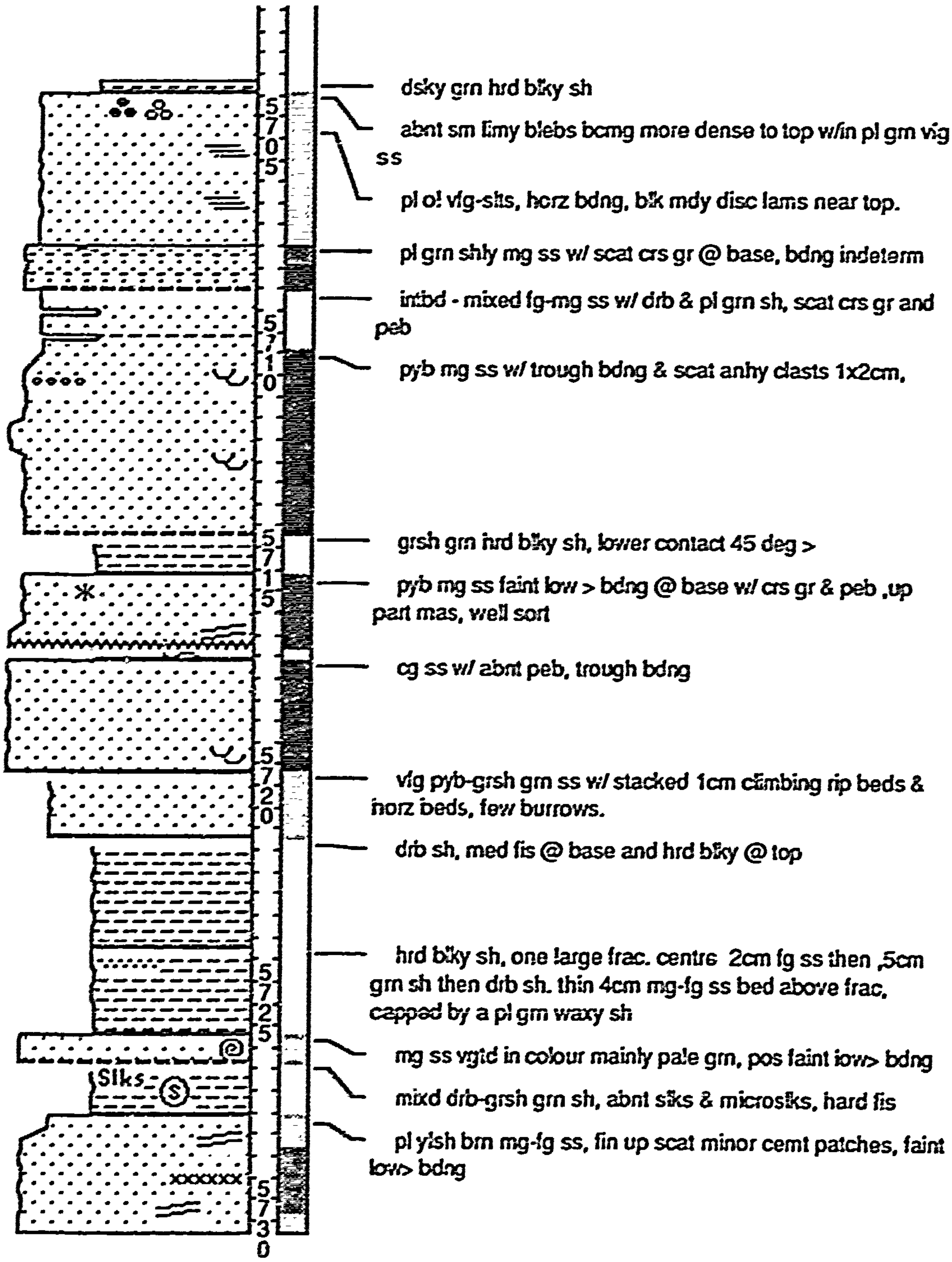
Shell et al Nipisi
2-21-79-8w5 Thachuk's TYPE LOG




5715
lost core psbly d grn SH,v slt,v fsl
5720
pl ylsh brn crs SS,cmtd,low < x-bdg
pl ylsh brn crs-fg SS,mass&low < bdg,crs cmtd bnds thru,mdy lam @ top, fining up
5725
pl ylsh brn fg SS w/thn hzntl grn md lam,not calc
5730
dk ylsh brn cg SS,v pr srt,abdt pbls(up to 1cm)thru,few thn mg bds, hzntl-low<bdg,cmtd bnds
5mm mud lam w/ pbls
5735
grysh grn SH,hd,blky,scat slt lams
drb SH,fsl bcmg blky &mass @ top,few scat micro-slicks, scat pl grn slty ss bds, 6" msng core @ base assumed to be sh
5740
grysh grn - drb mdst, scat crs grns thru top, sm curr rip & low< planar bdg
5745
grysh grn & dsky rd slty SH, hd, blky

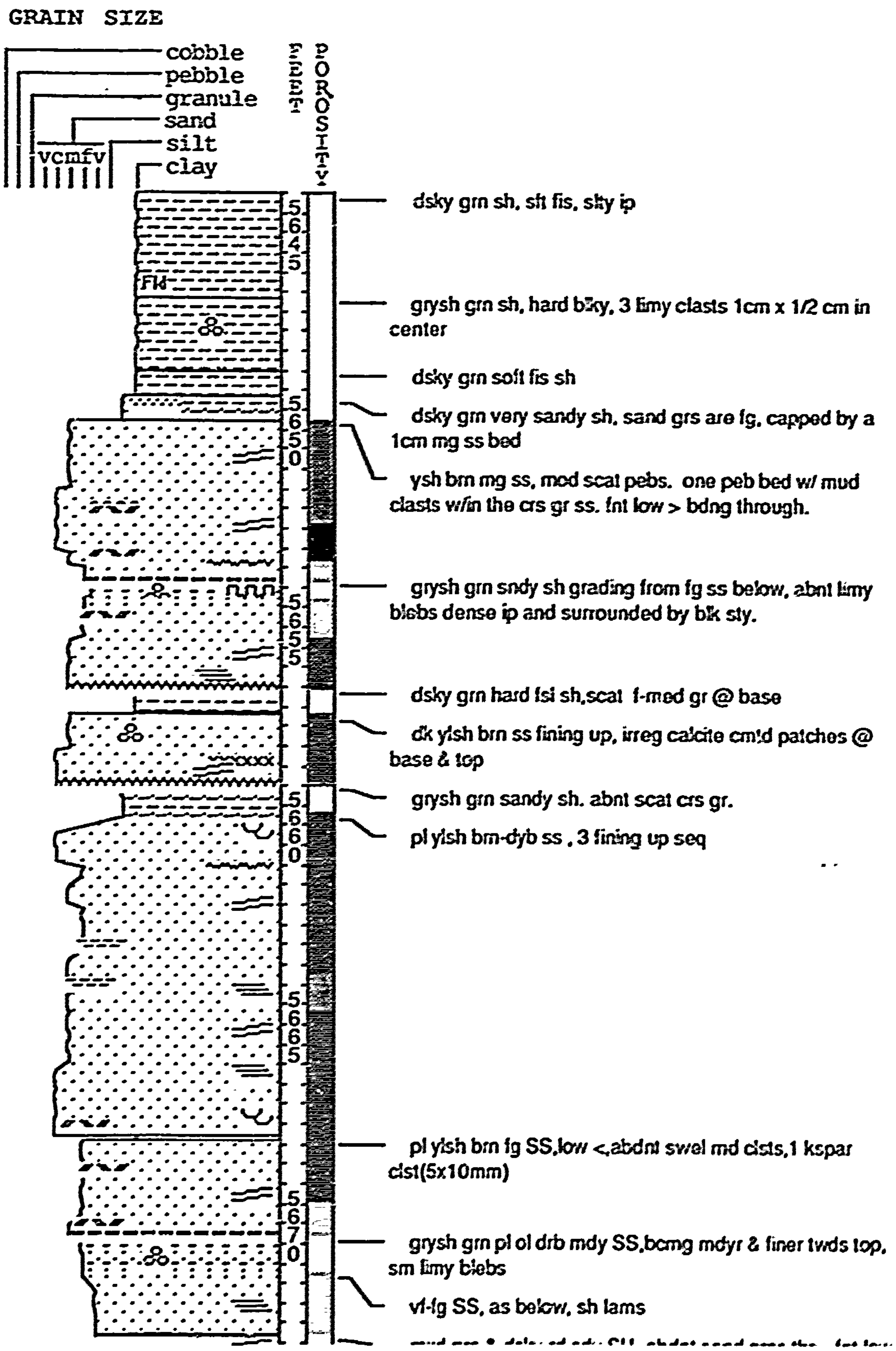
Amoco Unit 152
10-21-79-8w5

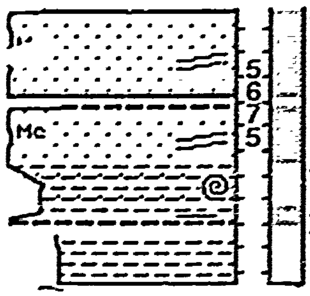



dsky grn hrd blky sh
abnt sm lmy blebs bcmg more dense to top w/in pl grn vlg ss
pl ol vlg-slts, horz bdng, blk mdy disc lams near top.
5705
pl grn shly mg ss w/ scat crs gr @ base, bdng indeterm
intbd - mixed fg-mg ss w/ drb & pl grn sh, scat crs gr and peb
5710
pyb mg ss w/ trough bdng & scat anhy clasts 1x2cm.
grsh grn hrd blky sh, lower contact 45 deg >
5715
pyb mg ss faint low > bdng @ base w/ crs gr & peb ,up part mas, well sort
cg ss w/ abnt peb, trough bdng
5720
vlg pyb-grsh grn ss w/ stacked 1cm climbing rip beds & horz beds, few burrows.
drb sh, med fis @ base and hrd blky @ top
hrd blky sh, one large frac. centre 2cm fg ss then ,5cm grn sh then drb sh. thin 4cm mg-fg ss bed above frac, capped by a pl grn waxy sh
5725
mg ss vgtd in colour mainly pale grn, pos faint low> bdng
Slks
mixd drb-grsh grn sh, abnt slks & microslks, hard fis
pl ylsh brn mg-fg ss, fin up scat minor cemt patches, faint low> bdng
5730

Amoco Unit 286 Nipisi

2-23-79-8w5





bdng

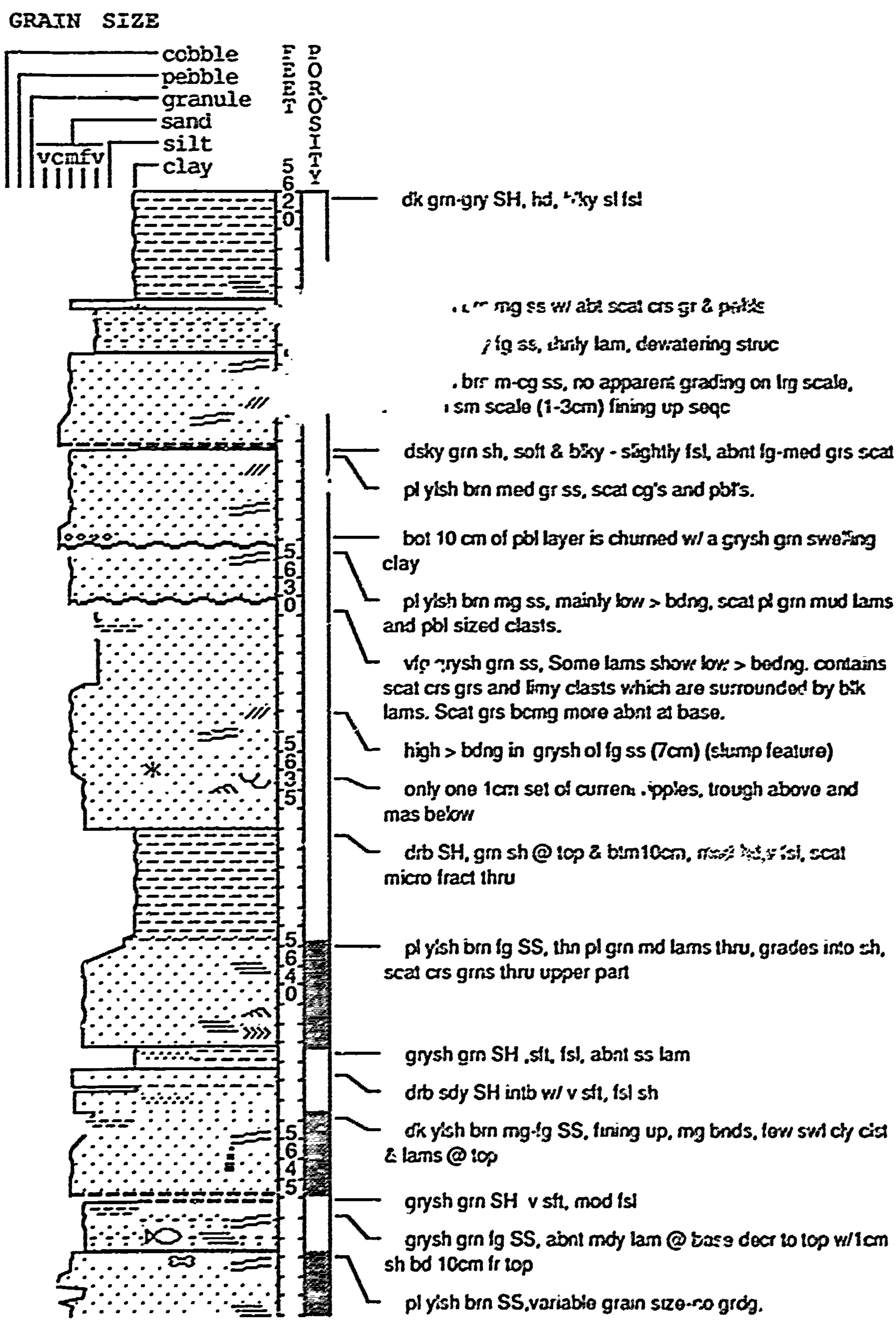
pl ylsh brn-drb vfg SS, thnly lamd w/mica, low< -hzntl lams

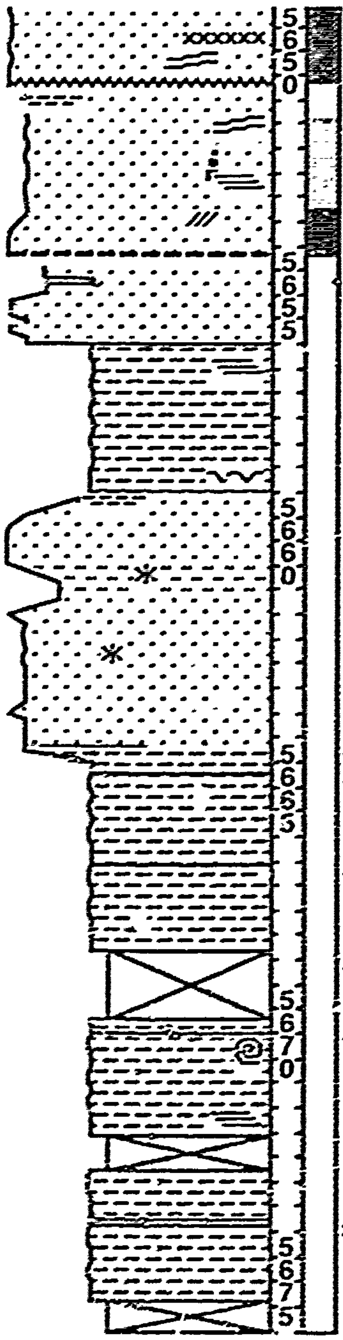
pl ol & grysh grn & drb sh, f-mg sdy SH, chumed (slumped) @ base

pl ol vfg SS, thnly hzntl lam

drb SH, hd, bky, mass

Shell et al Nipisi
4-24-79-8w5





pl grn fg SS, thnly lam w/ pl grn md @ top, hzntl bdg, scat med grns within 1cm along bdg planes;btm foot-dk ylsh brn mg-fg SS, high angle mg bdng thru

rtbd pl ylsh brn vf-mg SS w/ d grn MD & pl olive SLT

dk rdsh brn SH,fsl, micro-fract thru, dess cracks @ base

drb grd into pl grn mg SS,v pr srt,scat grns f-crs thru, mdy @ top

pl grn SLTST,hd,mass,scat f-m grns thru,top contact sharp colour change but gradational grain size change

pl grn fg SS,dsky rd @ top,svrl sqnces w/ mg 'lags', mass

pl grn SH, md hd, v fsl, scat grns

drb SH, mod hd, fsl, scat grns @ top

dsky grn SH, mod hd, v fsl, waxy lp, some dsky rd @ base

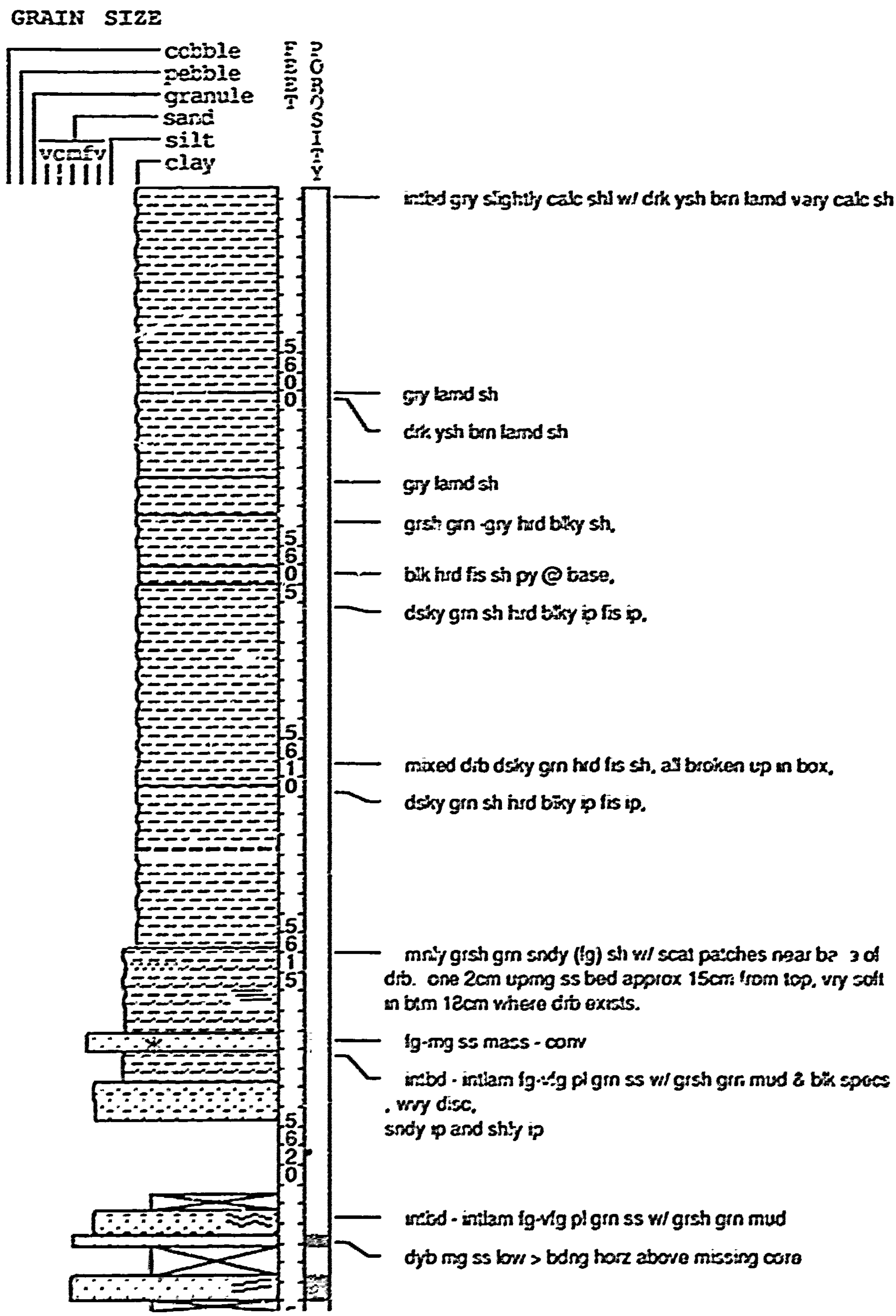
2.7' of missing core in last 10.3' of core

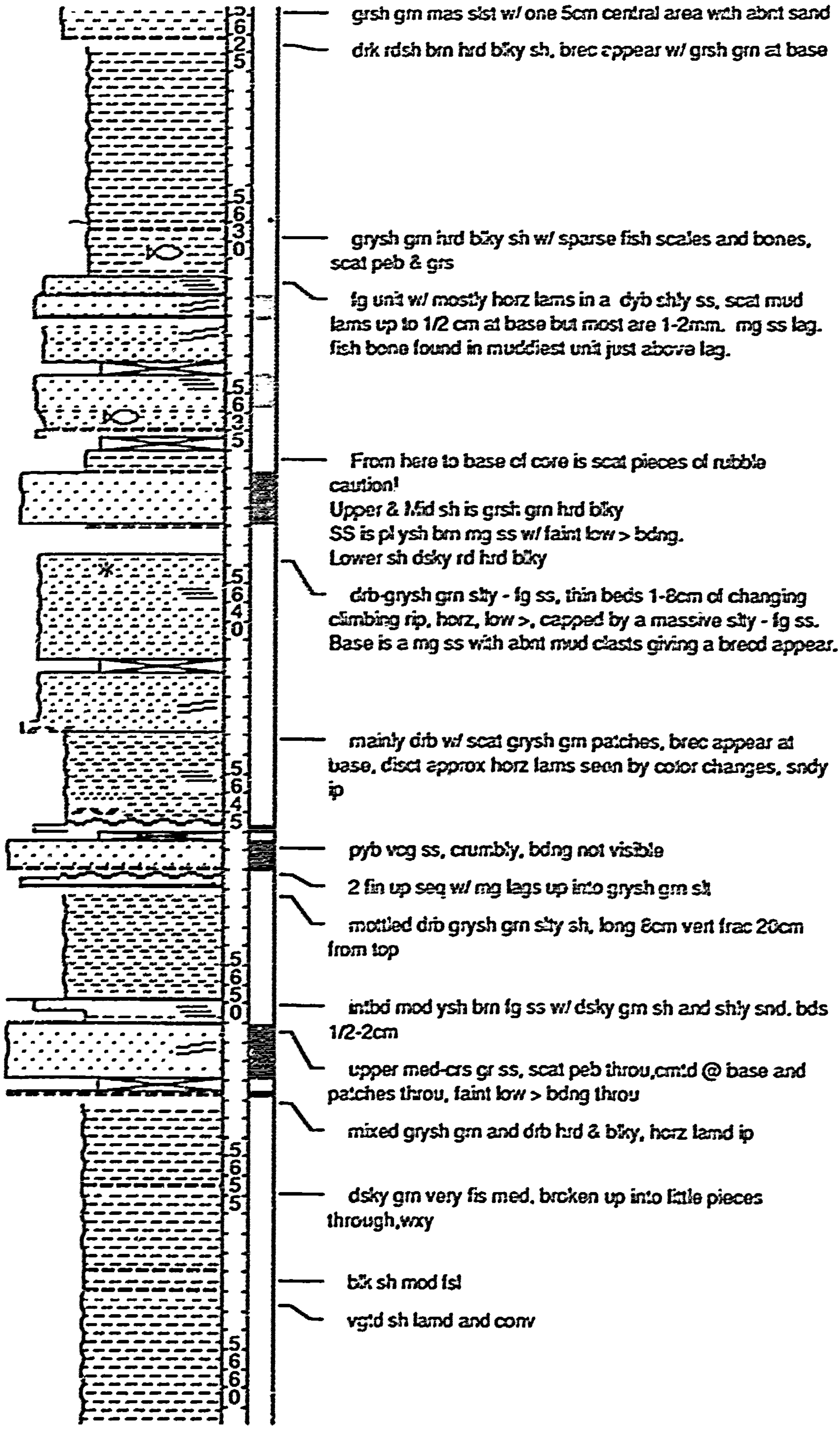
pl ylsh brn SH lam w/ dk gry sh;some intrlamd grysh brn-pale ylsh brn-dk rdsh brn &grysh olive shales @top & base, hzntl-convoluted

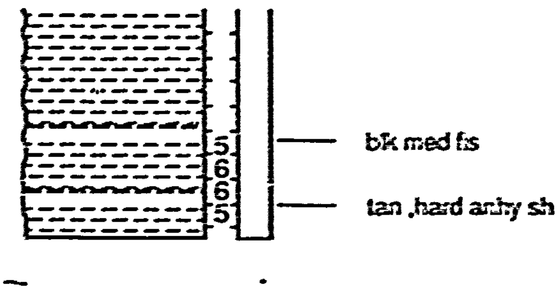
blk SH, sft, v fsl, abnt scales, tr armour

pl ylsh brn anhy SH. psbl top Muskeg??

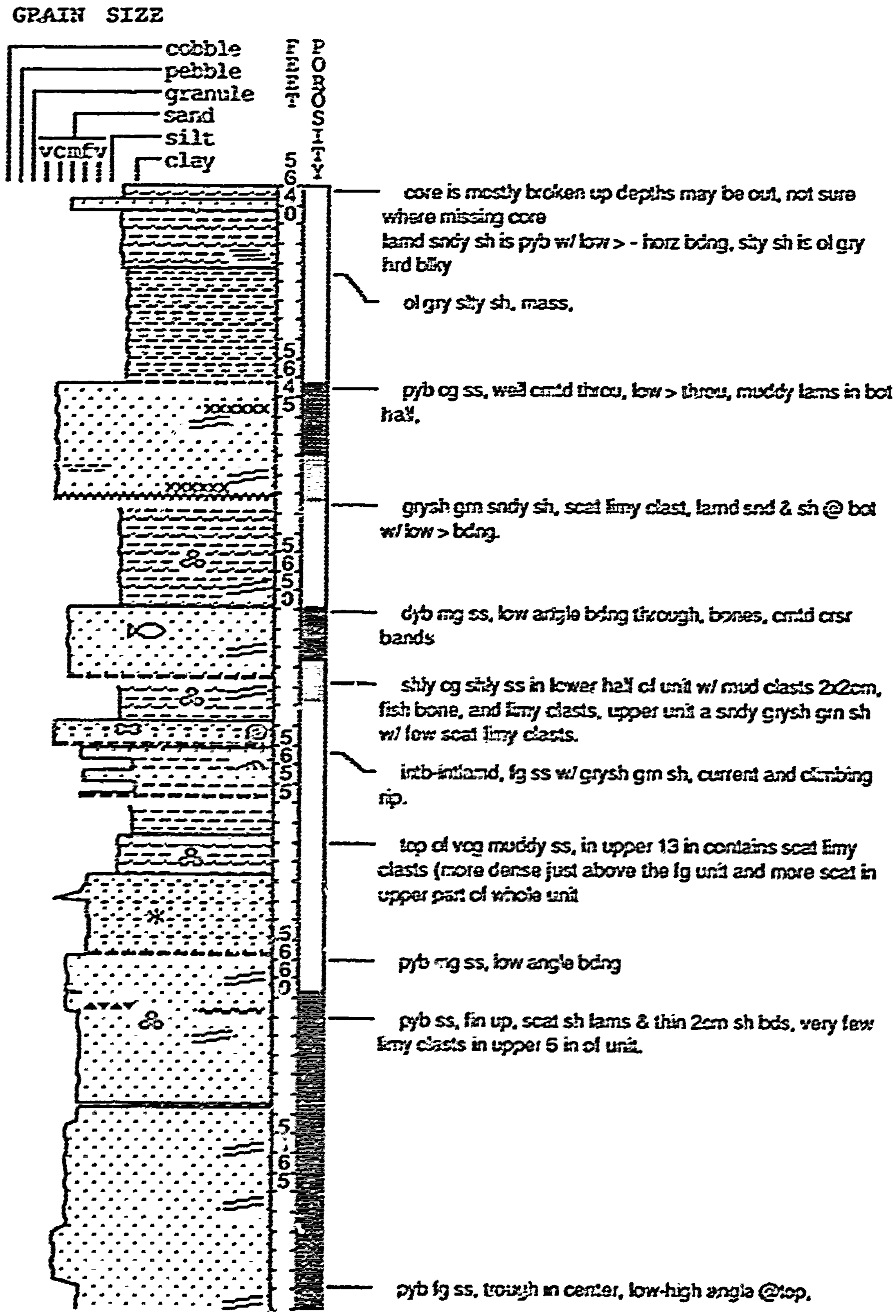
Shell et al Nipisi
12-25-79-8w5

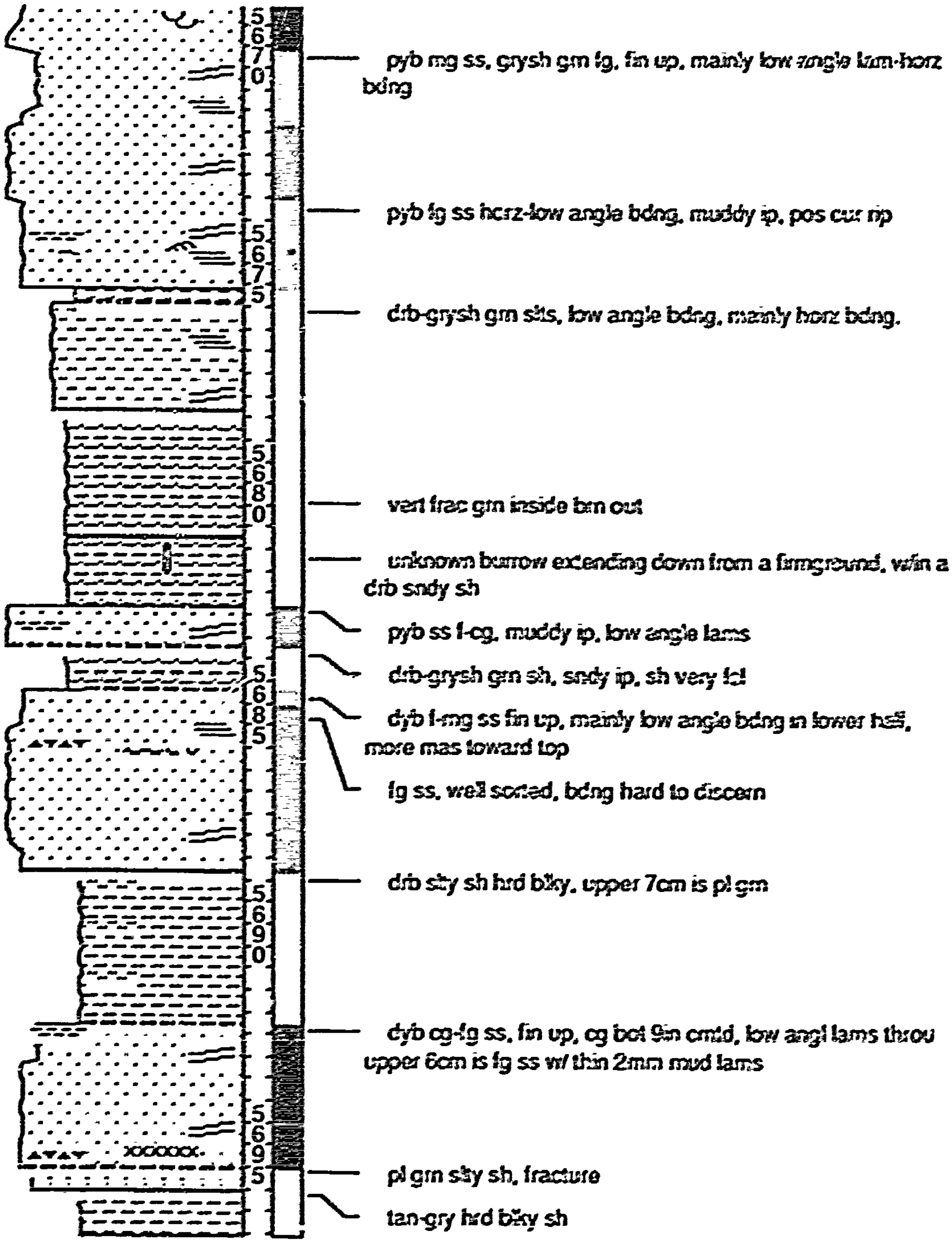



5625
5630
5635
5640
5645
5650
5655
5660
grsh grn mas slst w/ one 5cm central area with abnt sand
drk rdsh brn hrd blky sh. brec appear w/ grsh grn at base
grysh grn hrd blky sh w/ sparse fish scales and bones, scat peb & grs
fg unit w/ mostly horz lams in a dyb shly ss, scat mud lams up to 1/2 cm at base but most are 1-2mm. mg ss lag. fish bone found in muddiest unit just above lag.
From here to base of core is scat pieces of rubble caution!
Upper & Mid sh is grsh grn hrd blky
SS is pl ysh brn mg ss w/ faint low > bdng.
Lower sh dsky rd hrd blky
drb-grysh grn slty - fg ss, thin beds 1-8cm of changing climbing rip, horz, low >, capped by a massive slty - fg ss. Base is a mg ss with abnt mud clasts giving a breccl appear.
mainly drb w/ scat grysh grn patches, brec appear at base, disct approx horz lams seen by color changes, sndy ip
pyb vcg ss, crumbly, bdng not visible
2 fin up seq w/ mg lags up into grysh grn slt
mottled drb grysh grn slty sh, long 8cm vert frac 20cm from top
intbd mod ysh brn fg ss w/ dsky grn sh and shly snd. bds 1/2-2cm
upper med-crs gr ss, scat peb throu,cmtd @ base and patches throu, faint low > bdng throu
mixed grysh grn and drb hrd & blky, horz lamd ip
dsky grn very fis med. broken up into little pieces through,wxy
blk sh mod fsl
vgld sh lamd and conv


5
6
6
5
blk med fis
tan ,hard anhy sh

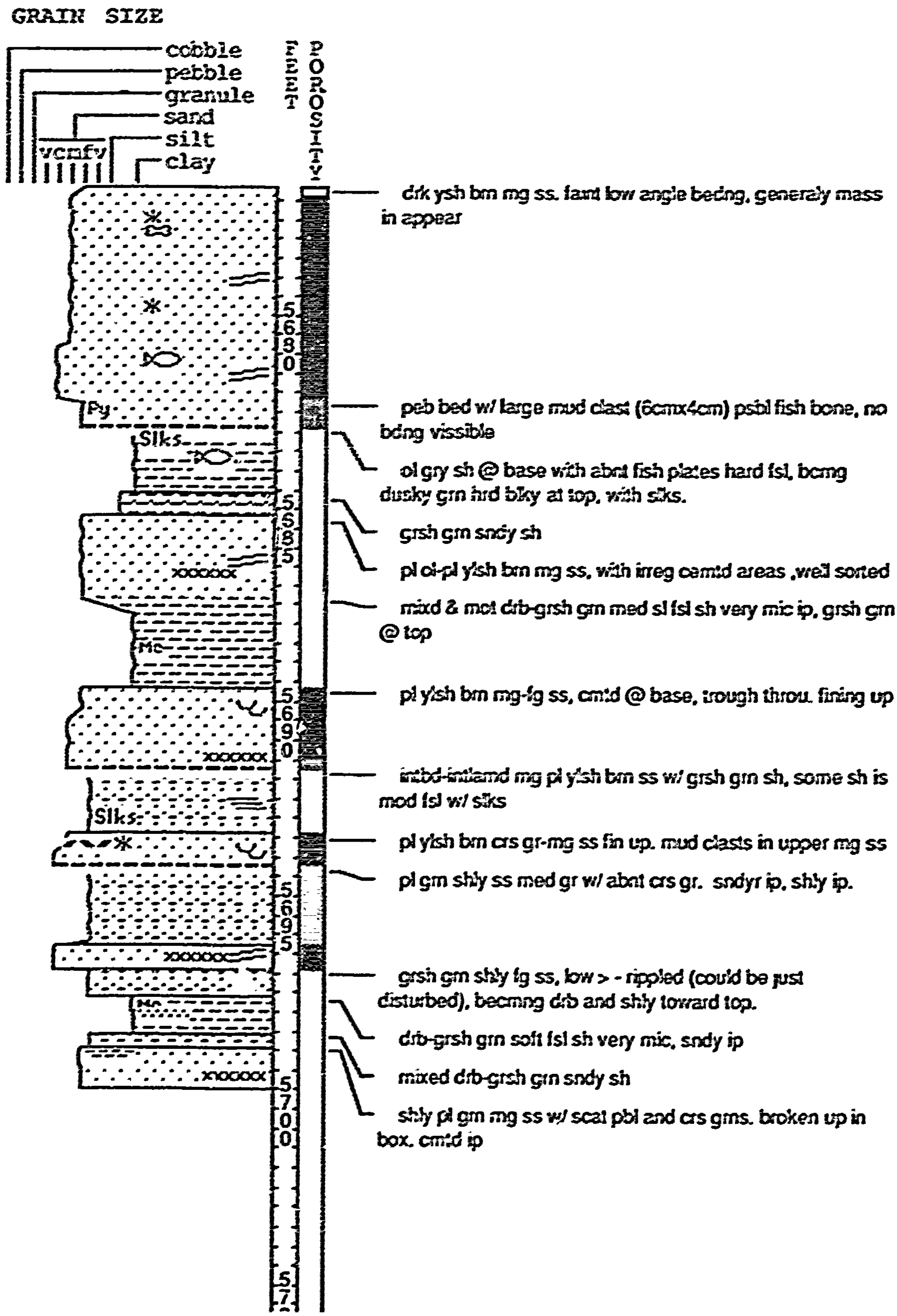
Shell et al Nipisi
10-27-79-8w5

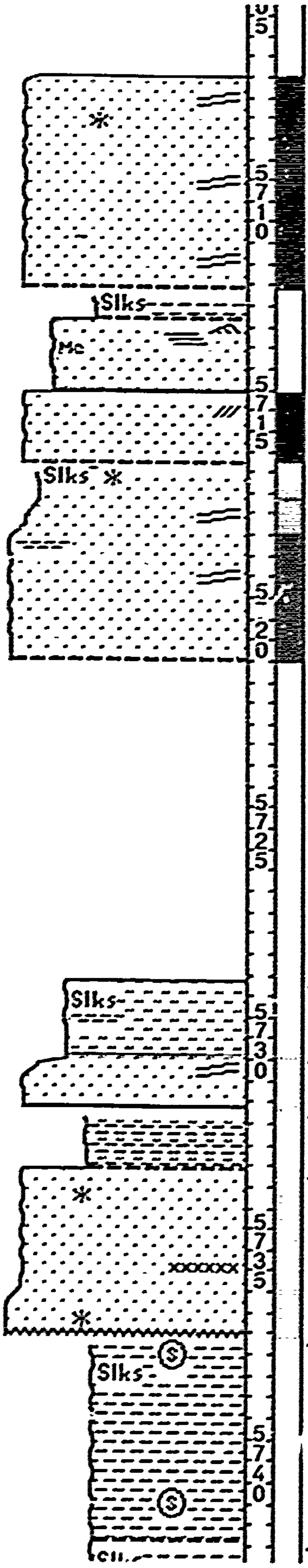



5670
5675
5680
5685
5690
5695
pyb mg ss, grysh grn fg, fin up, mainly low angle lam-horz bdng
pyb fg ss horz-low angle bdng, muddy ip, pos cur rip
drb-grysh grn slts, low angle bdng, mainly horz bdng.
vert frac grn inside brn out
unknown burrow extending down from a firmground, w/in a drb sndy sh
pyb ss f-cg, muddy ip, low angle lams
drb-grysh grn sh, sndy ip, sh very
dyb f-mg ss fin up, mainly low angle bdng in lower half, more mas toward top
fg ss, well sorted, bdng hard to discern
drb slty sh hrd blky, upper 7cm is pl grn
dyb cg-fg ss, fin up, cg bot 9in cmtd, low angl lams throu upper 6cm is fg ss w/ thin 2mm mud lams
pl grn slty sh, fracture
tan-gry hrd blky sh

Amoco Unit No. 121

4-28-79-8w5





pl ylsh brn-drk ylsh brn umed-lcrs gr ss. well sorted w/ subrounded -rnded grns. faint low > bdng @ mas in appear. upper 7cm is a fg lamd ss churned w/ ss below

drb med fis sh. abnt slks

vfg lamd ss . pl ylsh brn-grsh grn. mainly horz lamd w/ cur rip at base @ indeter rip in upper 10 cm (may be just desturbed bdng., scat peb @grns ip. very micaceous throught.

cg ss w/ abnt pbls. faint high > bdng seen in few disc cemt horz

pl ylsh-drk ylsh brn ss. cg-fg fining up. cg ss contains (thin sh bds 1cm, mud clasts and scat peb). low > bdng throu. fg ss is pl grn @ mass

getting muddier towards top. slks in uppermost shly part

drb sltst. grsh grn @ base. sndy ip shly ip w/ slks. mot drb grsh grn @ top

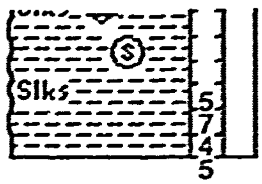
pl ysh brn mg-fg ss w/ cg cmtd bds. pos low > bdng. mud clast (3x2cm)

slty sh drb @ base & pl ol near top. scat micro frac

dyb crs-mg ss w/ scat pl ol cmtd irreg patches. mainly mass. fair sort

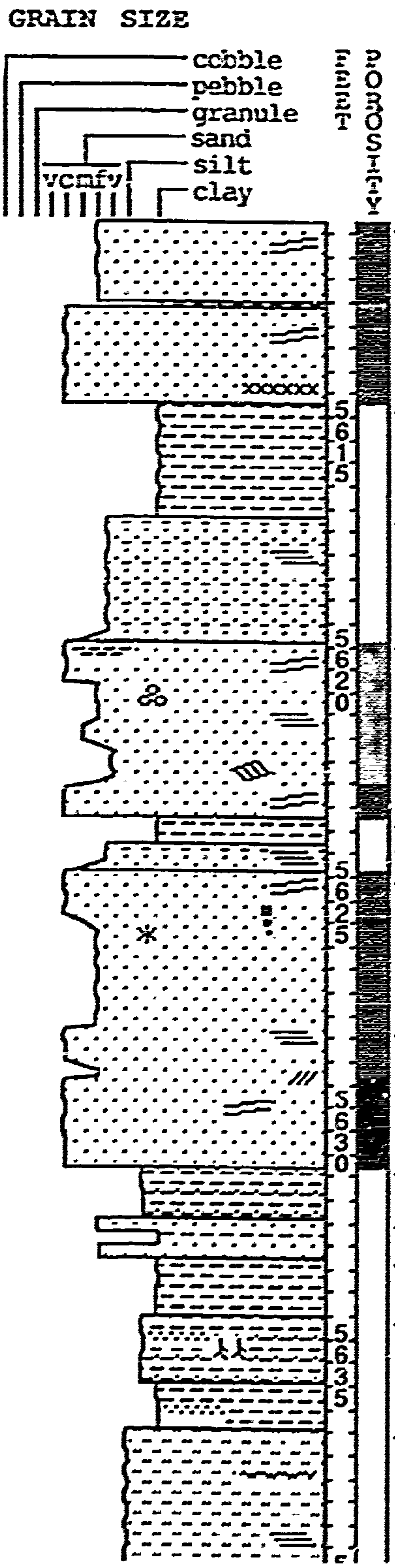
mainly drb med fsl sh. brec in appear. slks and micro slks throu. some of the grsh grn sh is very waxy.

mtbd d grn. d ylsh brn . blk sh w/ drb at base. horz lamd



through, scat brac in blk sh

Hamilton Nipisi
2-29-79-8w5



ss mg-fg, fin up, low angl bdng throu, fair sort ip, bot 6cm cemented

grysh grn hdr blky sh

fg shly ss w/ abnt scat crsr grns throu, ss content increases up, lower half is grysh grn with higher sh content (&swelling clays), upper half is more pl ylsh brn

pl-drk ylsh brn ss, 3 fin up seq. cgrss (low angle bdng), fg ss horz lamd with pos climbing rip

broken up pl grn hard blky sh, sandy ip.

dsky grn shly fg ss, horz lamd, few 2x1cm calcite clasts, mic

fg ss is pl - drk ylsh brn, its mdy ip making it pl grn, mas in appear but bdng hard to discern, appears to crsn up to cg ss with low > bdng

crs gr ss w/ mainly low > bdng, a thin 5cm fg unit & 5cm of crs gr above that shows high > bdng, upper part of crs gr unit is horz bdd

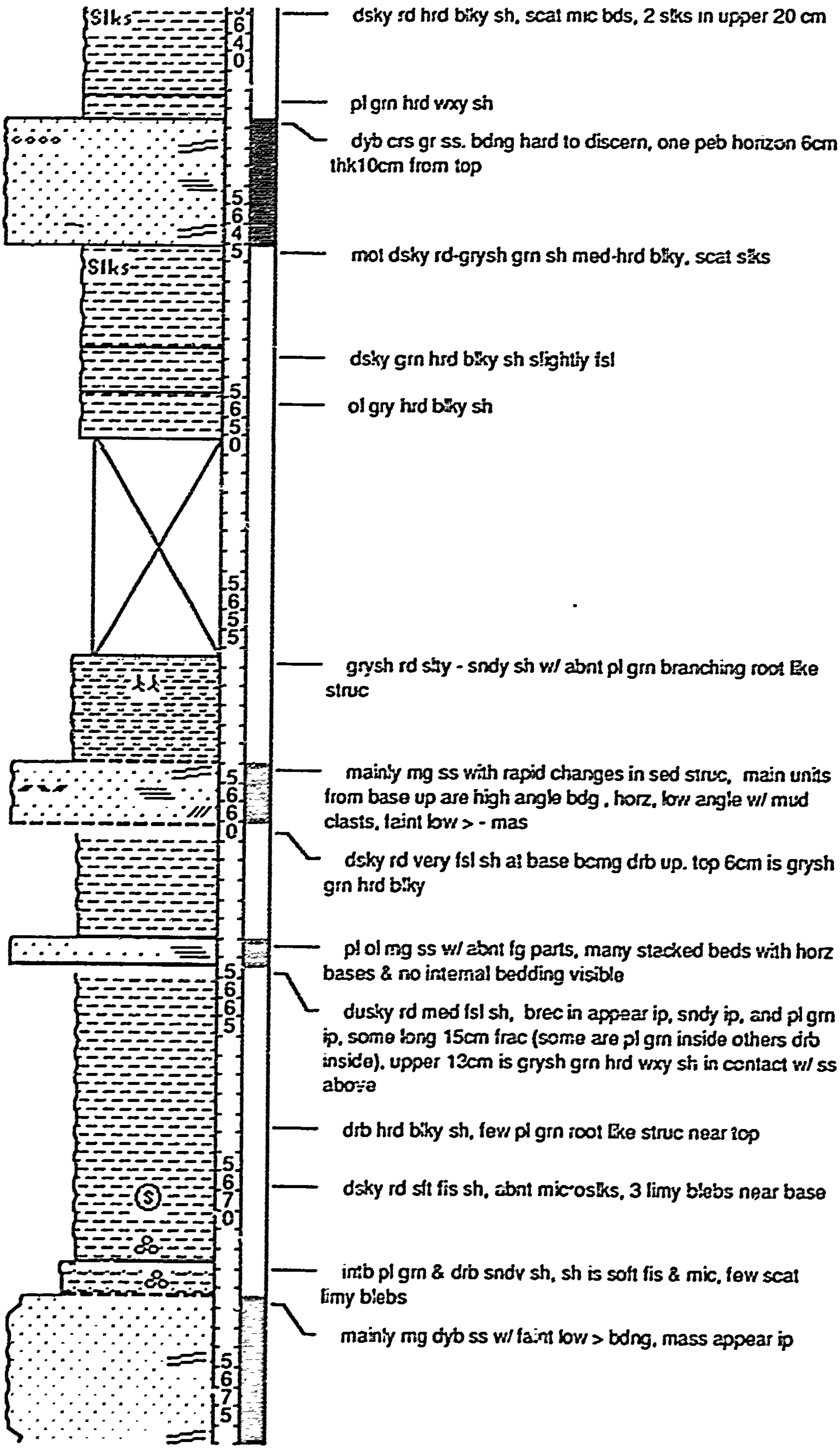
mixed dsky rd- grysh grn sh, mic ip, sndy ip, upper 6cm is grysh grn.

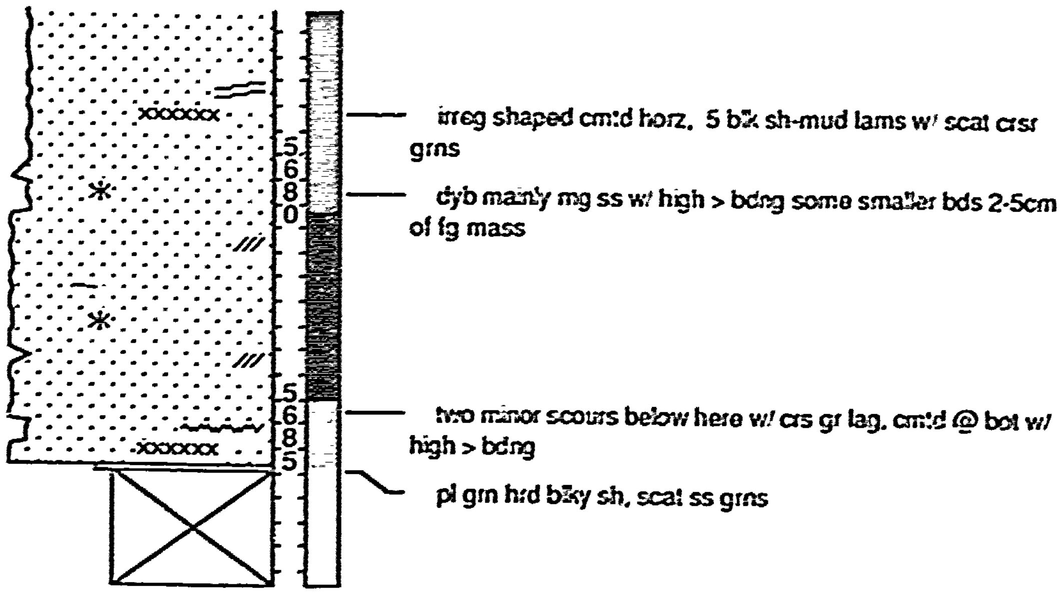
intbd pl ylsh brn fg ss w/ pl grn med fsl sh, ss is horz lamd w/
occas wtr escape struc

mot drb-dksy rd soft-med fis sh.

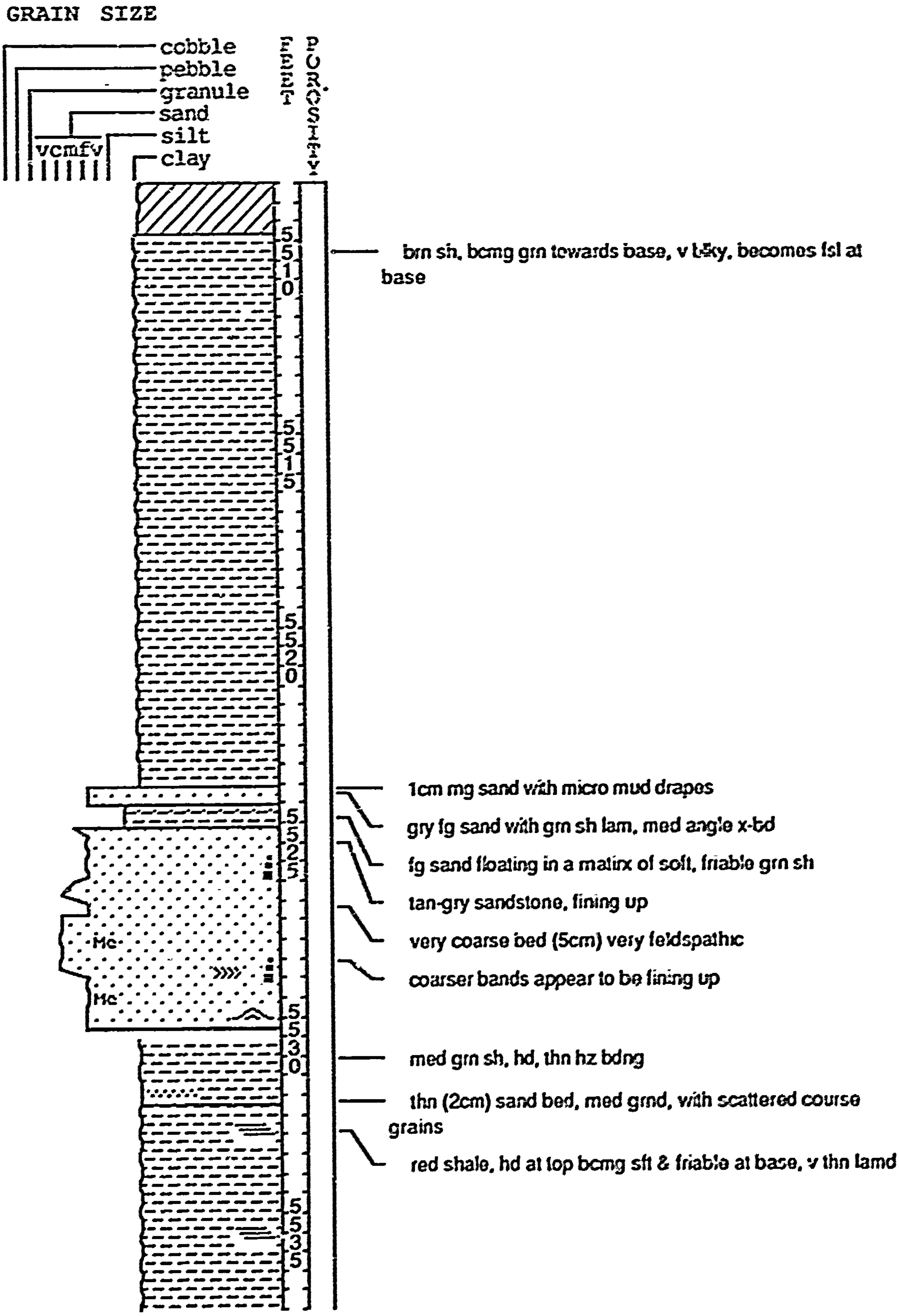
mot dsky rd and dsky grn sh, v slt and fis throu, becmg more sndy up

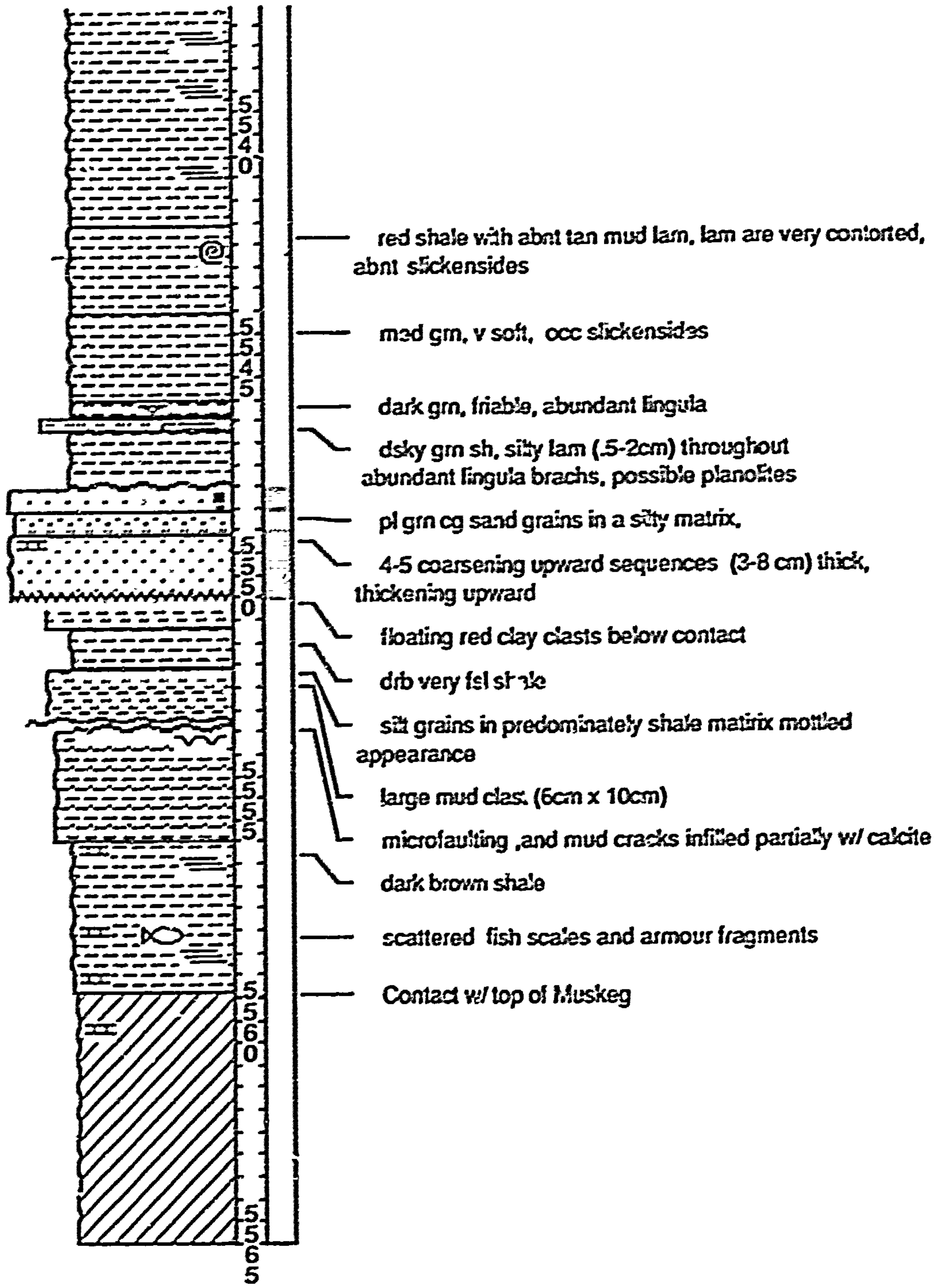
drb horz lamd sltst., scour is by more sltst, scat pl grn areas throu


Slks
640
dsky rd hrd blky sh, scat mic bds, 2 slks in upper 20 cm
pl grn hrd wxy sh
dyb crs gr ss. bdng hard to discern, one peb horizon 6cm thk10cm from top
5645
Slks
mot dsky rd-grysh grn sh med-hrd blky. scat slks
dsky grn hrd blky sh slightly fsl
5650
ol gry hrd blky sh
5655
grysh rd slty - sndy sh w/ abnt pl grn branching root like struc
5660
mainly mg ss with rapid changes in sed struc, main units from base up are high angle bdg, horz, low angle w/ mud clasts, faint low > - mas
dsky rd very fsl sh at base bcmg drb up. top 6cm is grysh grn hrd blky
pl ol mg ss w/ abnt fg parts, many stacked beds with horz bases & no internal bedding visible
5665
dusky rd med fsl sh, brec in appear ip, sndy ip, and pl grn ip, some long 15cm frac (some are pl grn inside others drb inside). upper 13cm is grysh grn hrd wxy sh in contact w/ ss above
drb hrd blky sh, few pl grn root like struc near top
5670
dsky rd slt fis sh, abnt microslks, 3 limy blebs near base
intb pl grn & drb sndy sh, sh is soft fis & mic, few scat limy blebs
mainly mg dyb ss w/ faint low > bdng, mass appear ip
5675

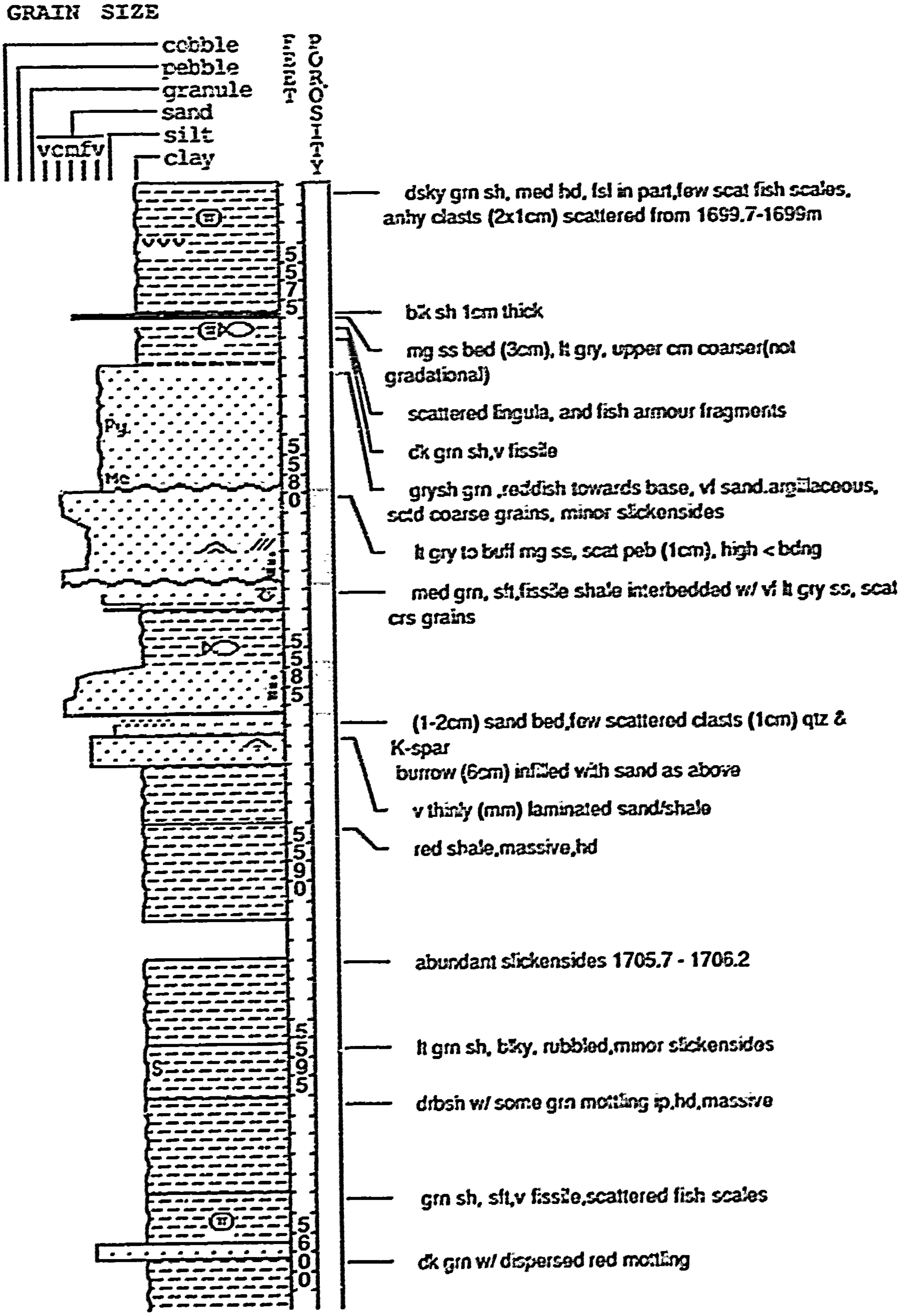

irreg shaped cmtd horz. 5 blk sh-mud lams w/ scat crsr grns
dyb mainly mg ss w/ high > bdng some smaller bds 2-5cm of fg mass
two minor scours below here w/ crs gr lag. cmtd @ bot w/ high > bdng
pl grn hrd blky sh, scat ss grns
5
6
8
0
5
6
8
5

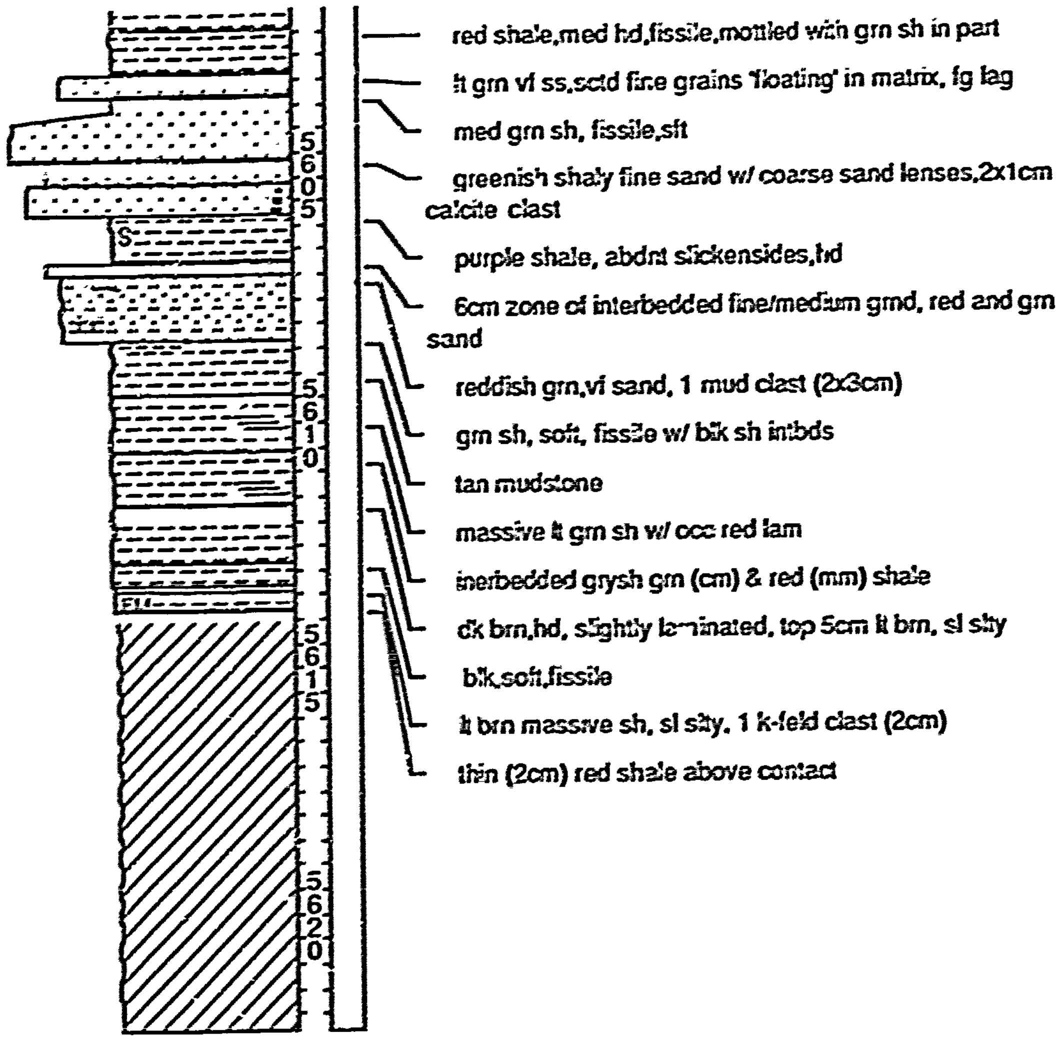
Cairn et al Nipisi
2-5-80-7w5



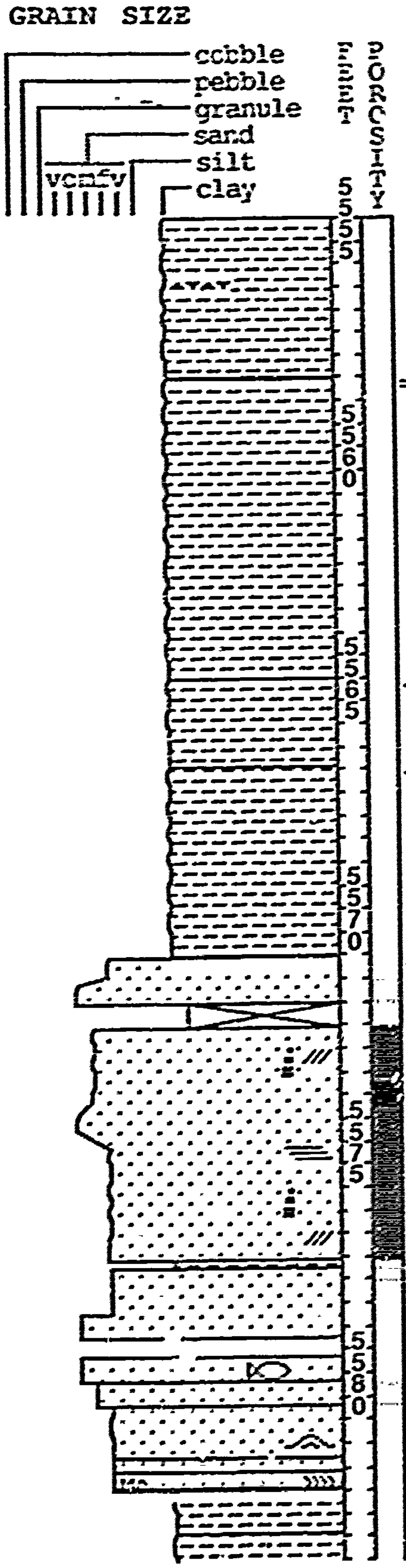

5540
5545
5550
5555
5560
5565
red shale with abnt tan mud lam, lam are very contorted, abnt slickensides
med grn, v soft, occ slickensides
dark grn, friable, abundant lingula
dsky grn sh, silty lam (.5-2cm) throughout abundant lingula brachs, possible planolites
pl grn cg sand grains in a silty matrix,
4-5 coarsening upward sequences (3-8 cm) thick, thickening upward
floating red clay clasts below contact
drb very fsl shale
silt grains in predominately shale matrix mottled appearance
large mud clast (6cm x 10cm)
microfaulting ,and mud cracks infilled partially w/ calcite
dark brown shale
scattered fish scales and armour fragments
Contact w/ top of Muskeg

Amoco Unit 378 Nipisi
2-6-80-7w5




red shale,med hd,fissile,mottled with grn sh in part
lt grn vf ss,sctd fine grains 'floating' in matrix, fg lag
med grn sh, fissile,slt
greenish shaly fine sand w/ coarse sand lenses,2x1cm calcite clast
purple shale, abdnt slickensides,hd
6cm zone of interbedded fine/medium grnd, red and grn sand
reddish grn,vf sand, 1 mud clast (2x3cm)
grn sh, soft, fissile w/ blk sh intbds
tan mudstone
massive lt grn sh w/ occ red lam
interbedded grysh grn (cm) & red (mm) shale
dk brn,hd, slightly laminated, top 5cm lt brn, sl slty
blk,soft,fissile
lt brn massive sh, sl slty, 1 k-feld clast (2cm)
thin (2cm) red shale above contact
5605
5610
5615
5620

Uno-Tex SOBC Nipisi
12-6-80-7w5



contact mkd by sh bcmg laminated with tan/brn shales

dusky grn sh,hd massive,sl fsl @ top

grysh grn sh,slt,v fsl

dusky grn sh,hd,massive,sl fsl @ top

pale ylsh brn sand, vcg@base,fining up to mg, bdg diff to discern but ranges from hztl to high angle, some x-bdg @ base

occ feldspar and qtz grains up to 1cm in diam to base

grysh grn, v slt, fissile

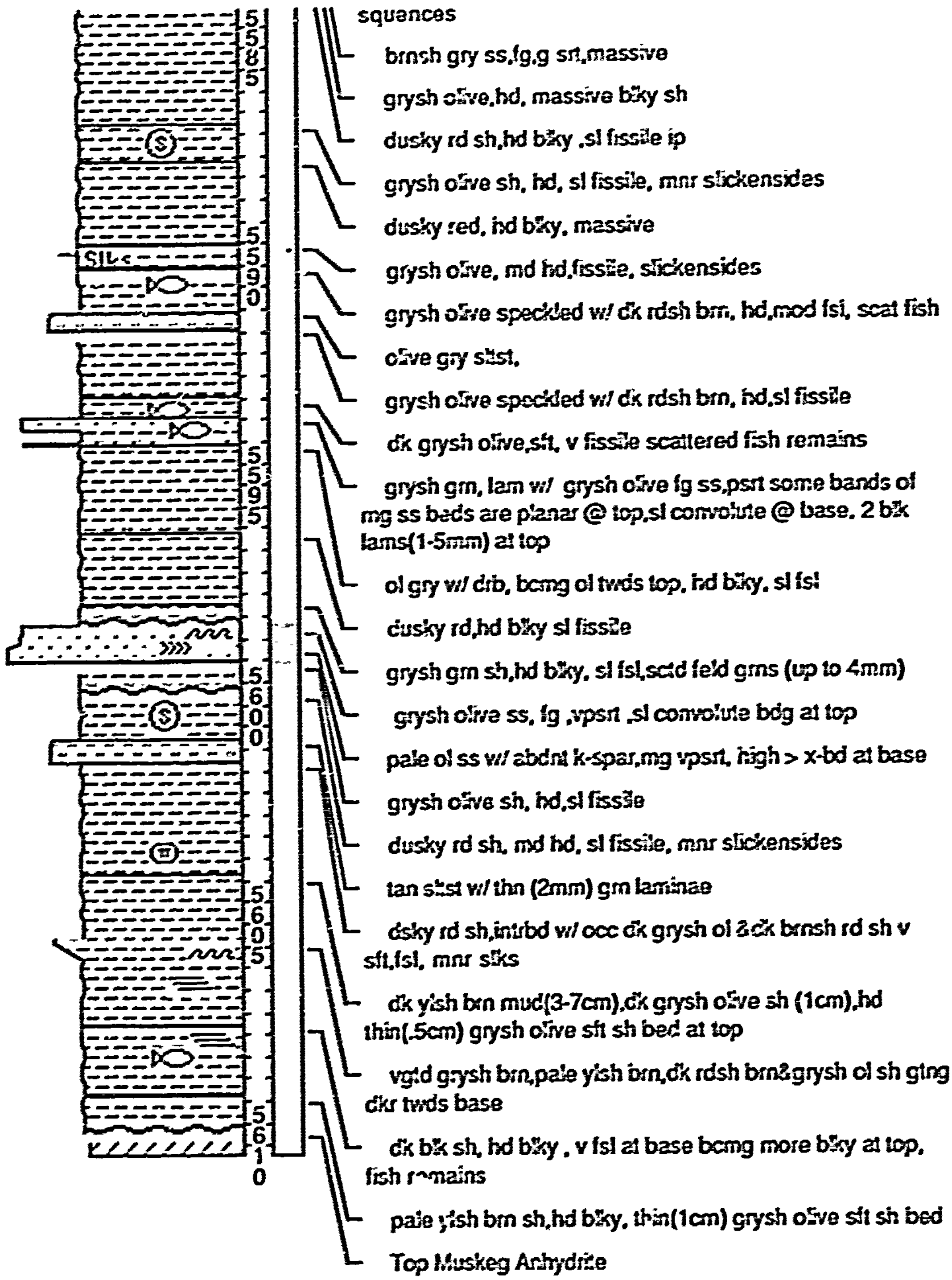
grysh brn ss,fg,mass, possible low > bdng, pr srt @base gd srt @ top

lam SH, blk @ base bcmg grysh grn @ top, hd @base bcmg slt and fsl@ top

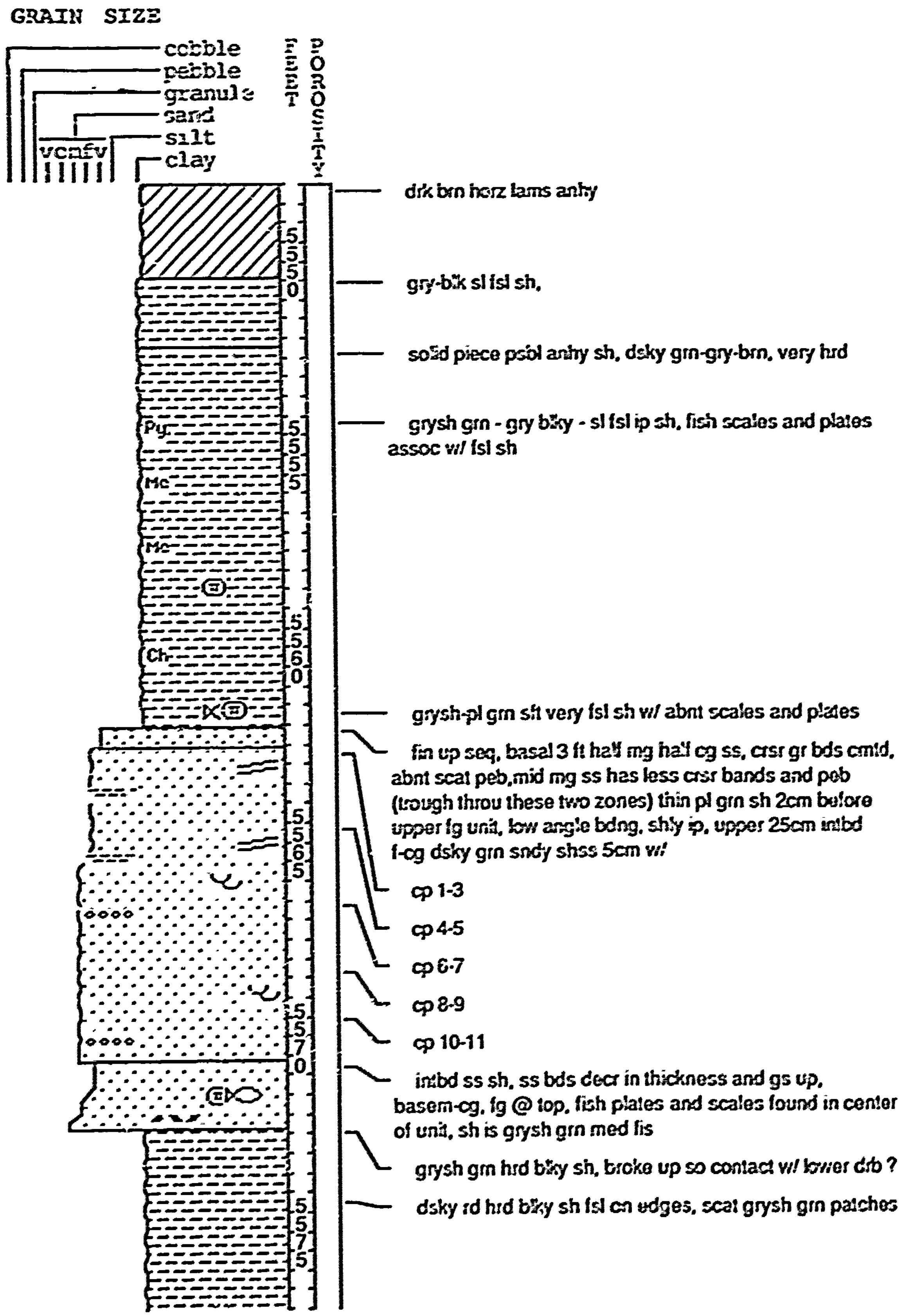
w/ SS,grysh olive,cg,poor srt, ss bcms less abndt twds top

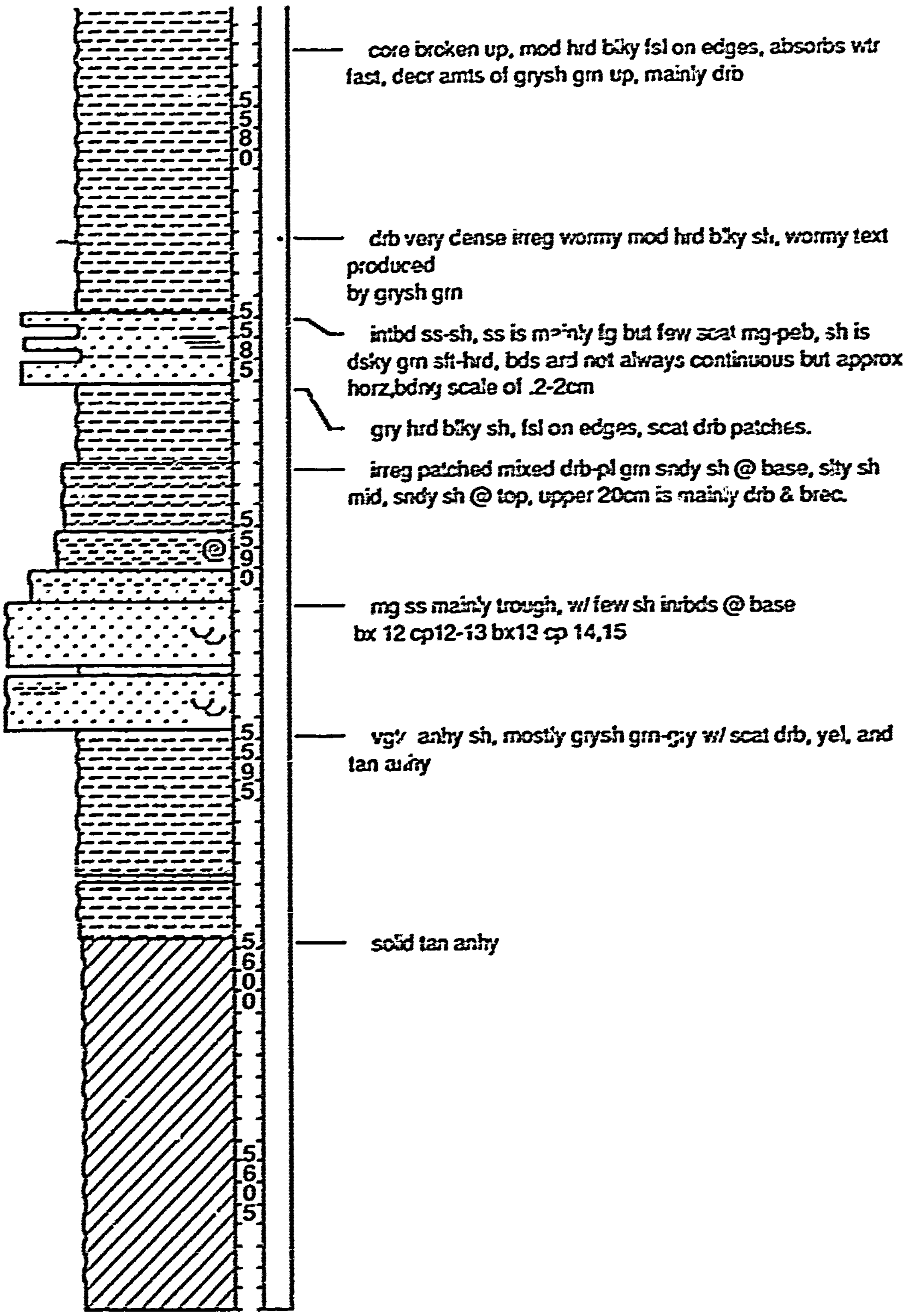
dk ylsh brn, mg, massive

grysh ol fg ss w/mnr 3cm sctd fining up brnsh olive

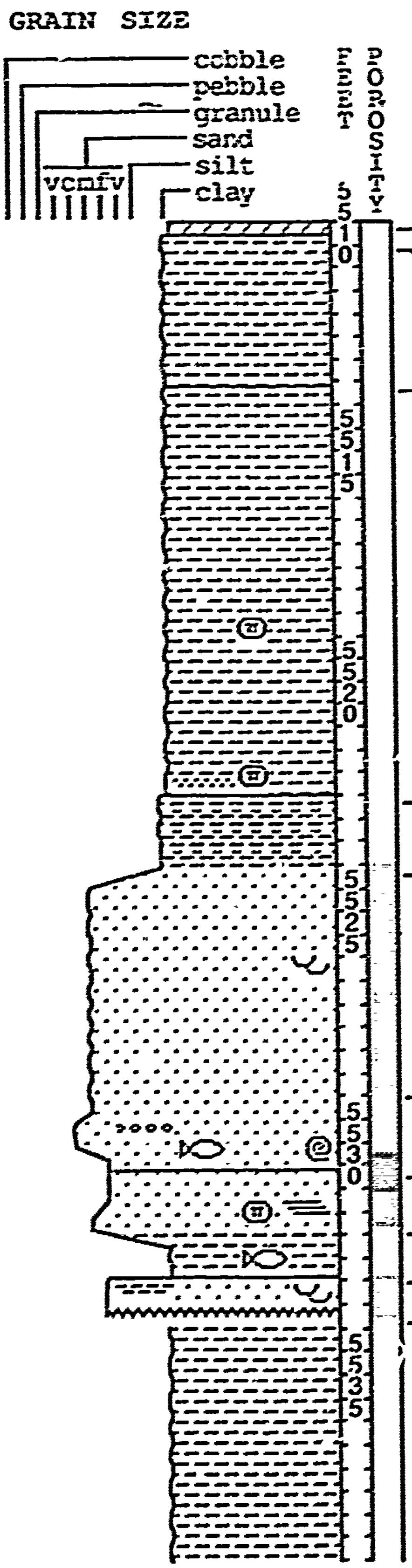

squances
brnsh gry ss,fg,g srt,massive
grysh olive,hd, massive blky sh
dusky rd sh,hd blky ,sl fissile ip
grysh olive sh, hd, sl fissile, mnr slickensides
dusky red, hd blky, massive
grysh olive, md hd,fissile, slickensides
grysh olive speckled w/ dk rdsh brn, hd,mod fsl, scat fish
olive gry sltst.
grysh olive speckled w/ dk rdsh brn, hd,sl fissile
dk grysh olive,slt, v fissile scattered fish remains
grysh grn, lam w/ grysh olive fg ss,psrt some bands of mg ss beds are planar @ top,sl convolute @ base. 2 blk lams(1-5mm) at top
ol gry w/ drb, bcmg ol twds top, hd blky, sl fsl
dusky rd,hd blky sl fissile
grysh grn sh,hd blky, sl fsl,sctd feld grns (up to 4mm)
grysh olive ss, fg ,vpsrt ,sl convolute bdg at top
pale ol ss w/ abdnt k-spar,mg vpsrt, high > x-bd at base
grysh olive sh, hd,sl fissile
dusky rd sh, md hd, sl fissile, mnr slickensides
tan sltst w/ thn (2mm) grn laminae
dsky rd sh,intrbd w/ occ dk grysh ol &dk brnsh rd sh v slt,fsl, mnr slks
dk ylsh brn mud(3-7cm),dk grysh olive sh (1cm),hd thin(.5cm) grysh olive slt sh bed at top
vgtd grysh brn,pale ylsh brn,dk rdsh brn&grysh ol sh grdg dkr twds base
dk blk sh, hd blky , v fsl at base bcmg more blky at top, fish remains
pale ylsh brn sh,hd blky, thin(1cm) grysh olive slt sh bed
Top Muskeg Anhydrite
Slks
5585
5590
5595
5600
5605
5610

Uno-tex Nipisi
12-18-80-7w5




5580
5585
5590
5595
5600
5605
core broken up, mod hrd blky fsl on edges, absorbs wtr fast, decr amts of grysh grn up, mainly drb
drb very dense irreg wormy mod hrd blky sh, wormy text produced by grysh grn
intbd ss-sh, ss is mainly fg but few scat mg-peb, sh is dsky grn slt-hrd, bds and not always continuous but approx horz,bdng scale of .2-2cm
gry hrd blky sh, fsl on edges, scat drb patches.
irreg patched mixed drb-pl grn sndy sh @ base, slty sh mid, sndy sh @ top, upper 20cm is mainly drb & brec.
mg ss mainly trough, w/ few sh intbds @ base
bx 12 cp12-13 bx13 cp 14,15
vgt anhy sh, mostly grysh grn-gry w/ scat drb, yel, and tan anhy
solid tan anhy

HBBA Nipisi
10-19-80-7w5



drk brn horz lamd anh sh, calc

drk grn brn gry, hrd blky sh w/ scat small cm anhy zones.

dsky grn mod blky sh, always md fis - soft around scale areas

pl-slightly grysh grn massive slty sh-sltstone

difficult to make out bdng, pos trough, definate fin up or dec in amt of pbls up, cmtd crsr bnds throu

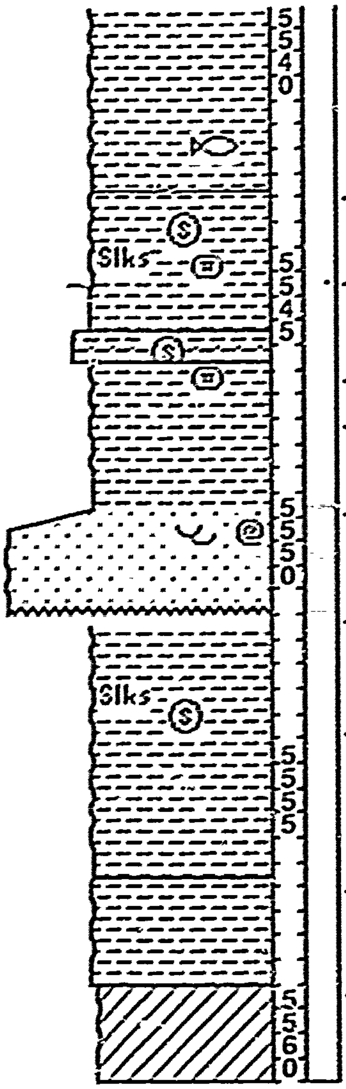
extrem var in gs, psbl trough bdng but more likely convoluted, scat pbls throu, abnt plates @ base of cg ss

intbd ss w/ sndy sh @ base and ss w/ sft fsl sh @ top,grad contact from below, lower ss bds are mg poor sorted up to 6cm thick, upper ss is fg well sorted up to 7cm thick, abnt fish plates w/in lower mg ss. bdng is horz-wavy through, (12cm base of ss above is same as this upper fg ss and contains sm .5cm mud clasts, is low angle bdd)

grysh grn med-hrd blky sh fsl on edges, abnt plates @ base.

mg ss trough throu w/ abnt sh lams & bds, cmtd throu

mainly med -sft blky sh fsl ip, scat grn worm patches decr up, upper 15cm is pl grn hrd blky



med - sft bky sh, finly mixed drb-grysh grn sh, slks & microslks, very irreg wavy circular texture in center of unit

grysh grn sft fsl sh w/ scat drb patchs, abnt scales at basal contact, hrdr in sndy part w/ abnt slks and microslks above sndy part

gry hrd bky sh w/ strange small scale wormy drb features throu

brec drb hrd bky sh, basal 12cm is grysh grn - pl grn.

fin up seq, mg-fg ss, psbl trough or convoluted bdng throu, gradational contact w/ above grysh grn sh

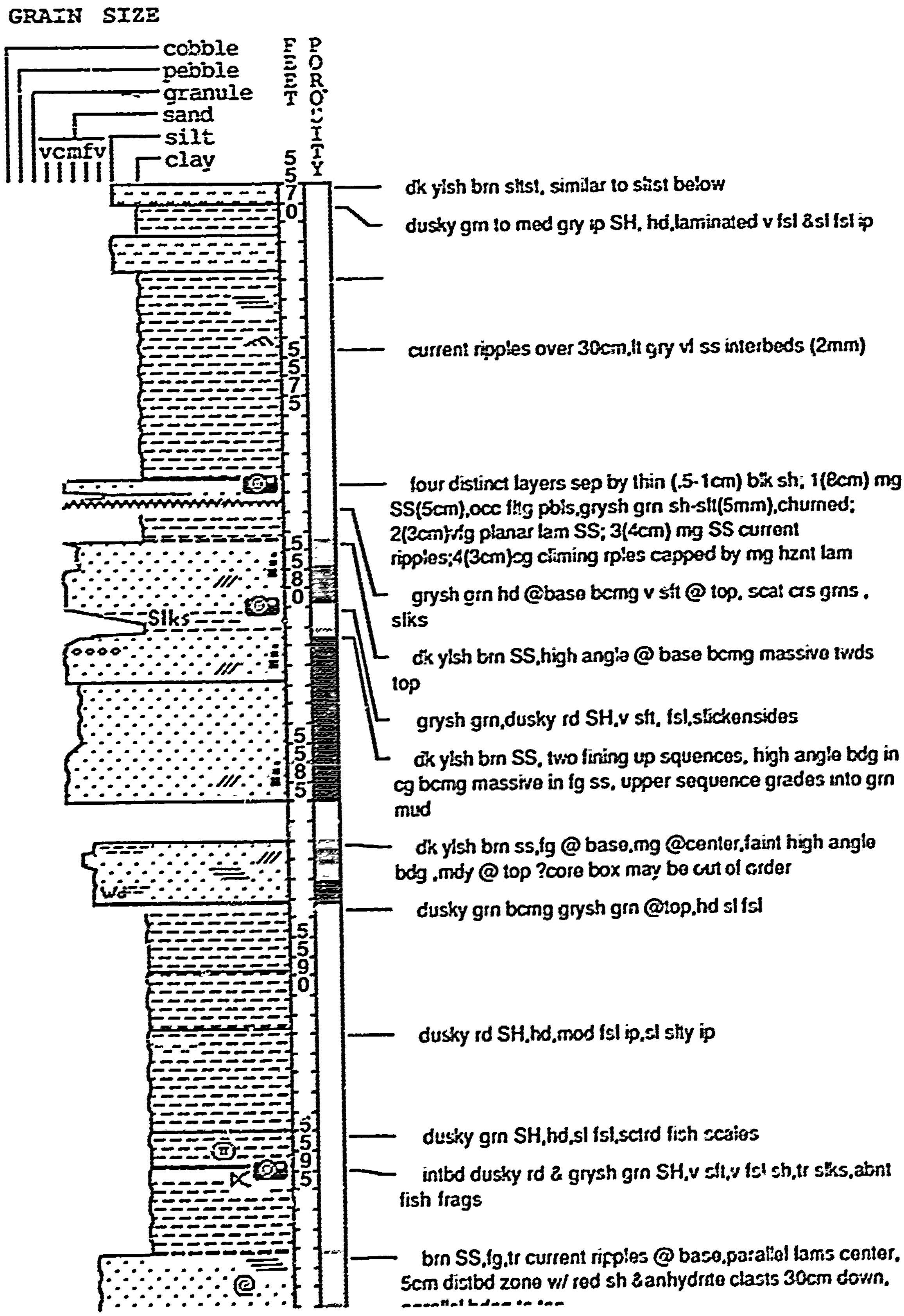
varying sh, bat 20cm very fis abnt slks and microslks, 6cm mixed pl grn sft sh w/ tan anhy, upper 37cm mainly drb hrd bky sh w/ one thin 1cm tan anhy bd, vgtd w/ pl grn upper 15cm, and 5cm only pl grn med hrd bky sh at upper contact

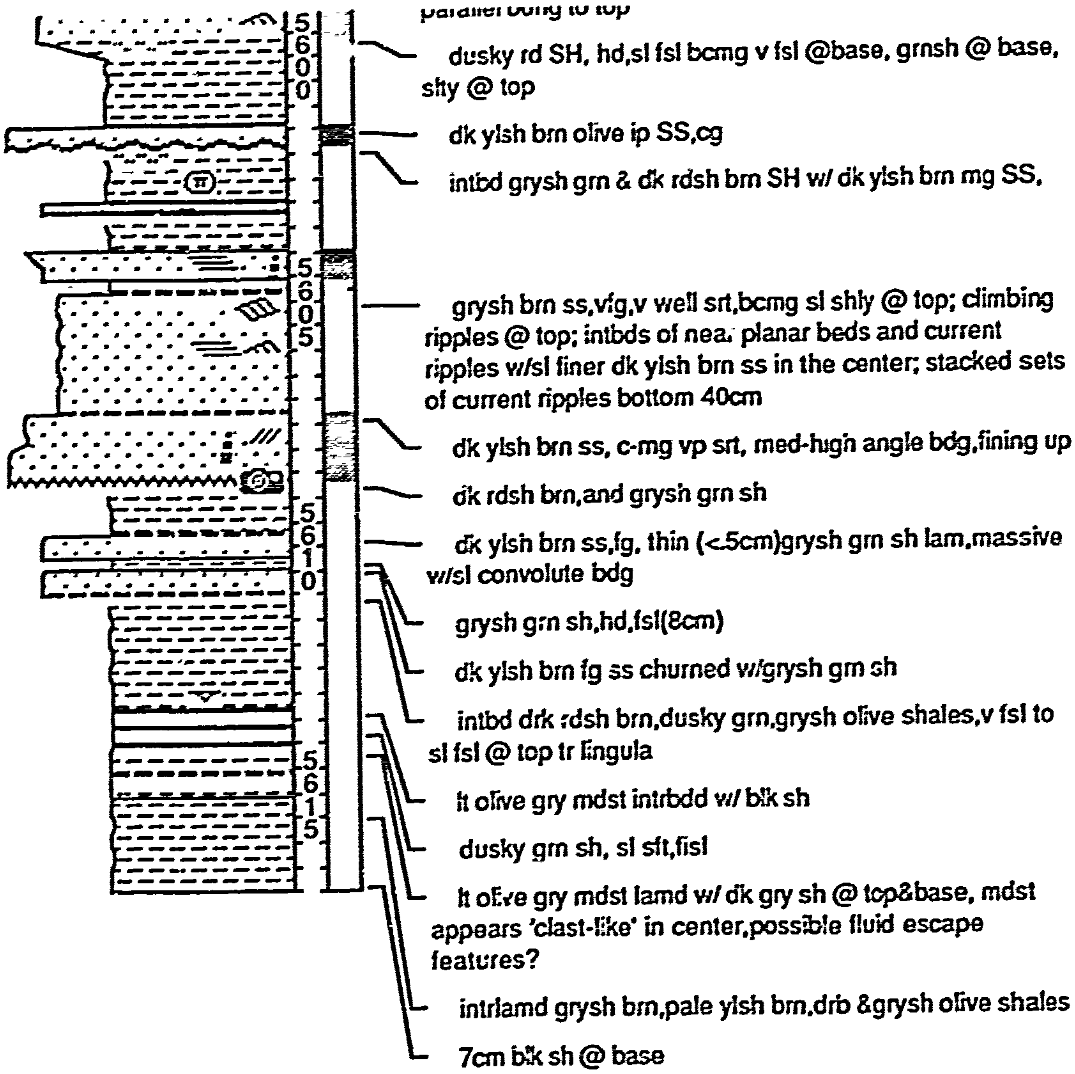
tan anhy sh, slty

blk fsl sh bot, drk grn w/ anhy clasts @ top hrd bky

tan anhy sh @ base pure anhy gry @ top

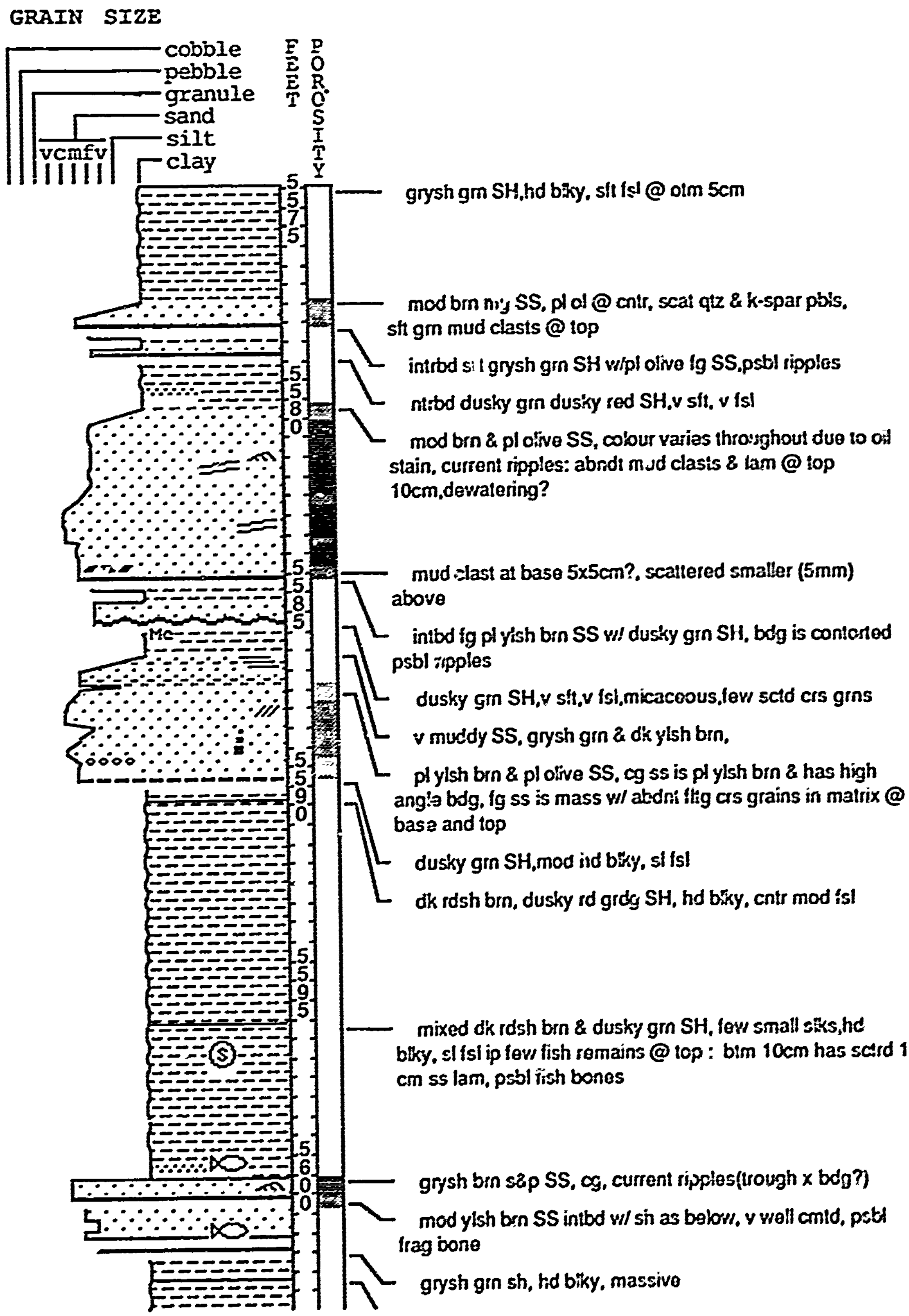
Hamilton Uno-Tex E Utik
10-1-80-8w5

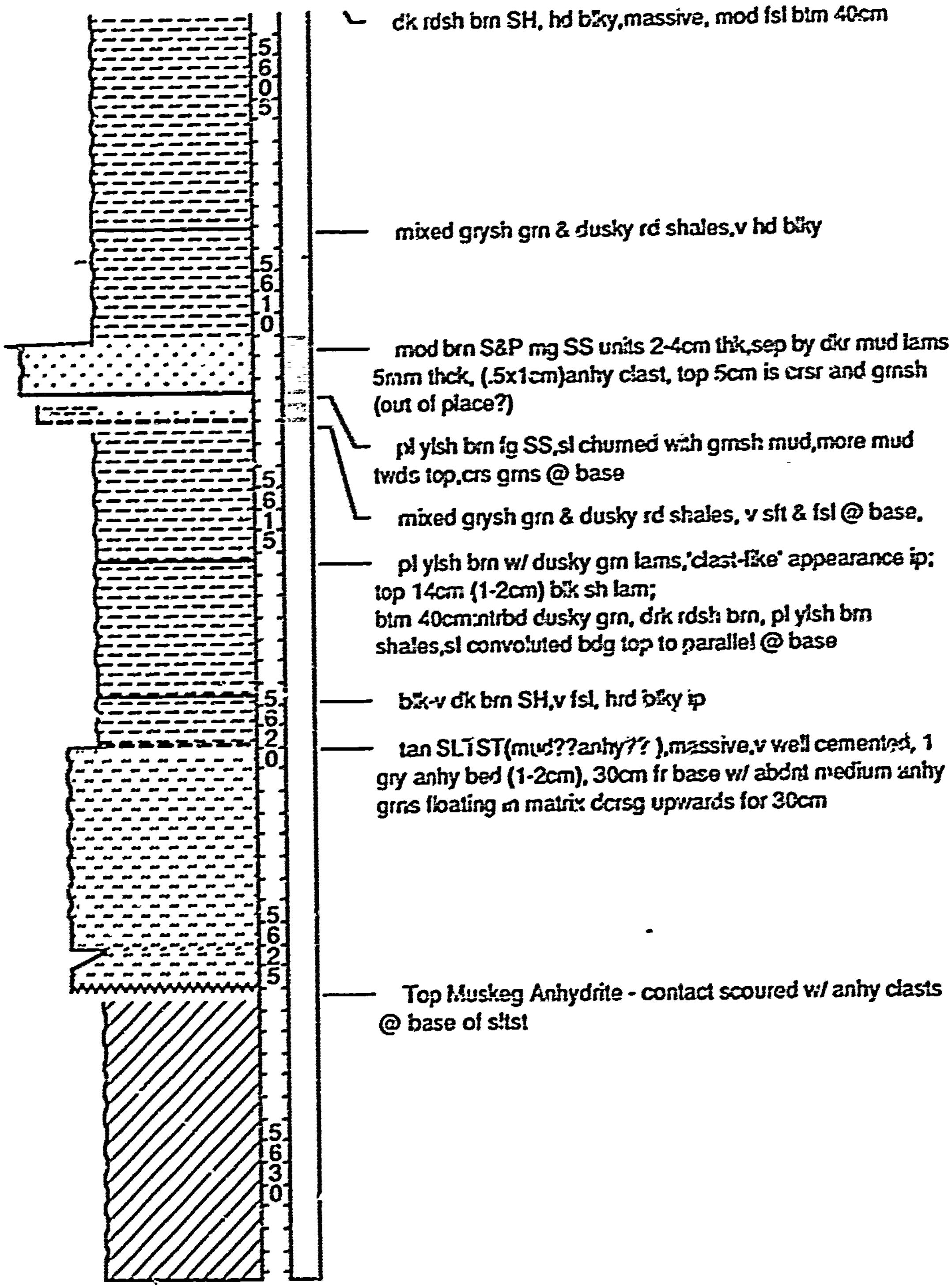



5600
5605
5610
5615
parallel bdng to top
dusky rd SH, hd,sl fsl bcmg v fsl @base, grnsh @ base, slty @ top
dk ylsh brn olive ip SS,cg
intbd grysh grn & dk rdsh brn SH w/ dk ylsh brn mg SS,
grysh brn ss,vfg,v well srt,bcmg sl shly @ top; climbing ripples @ top; intbds of near planar beds and current ripples w/sl finer dk ylsh brn ss in the center; stacked sets of current ripples bottom 40cm
dk ylsh brn ss, c-mg vp srt, med-high angle bdg,fining up
dk rdsh brn,and grysh grn sh
dk ylsh brn ss,fg, thin (<.5cm)grysh grn sh lam,massive w/sl convolute bdg
grysh grn sh,hd,fsl(8cm)
dk ylsh brn fg ss churned w/grysh grn sh
intbd drk rdsh brn,dusky grn,grysh olive shales,v fsl to sl fsl @ top tr lingula
lt olive gry mdst intrbdd w/ blk sh
dusky grn sh, sl slt,fisl
lt olive gry mdst lamd w/ dk gry sh @ top&base, mdst appears 'clast-like' in center,possible fluid escape features?
intrlamd grysh brn,pale ylsh brn,drb &grysh olive shales
7cm blk sh @ base

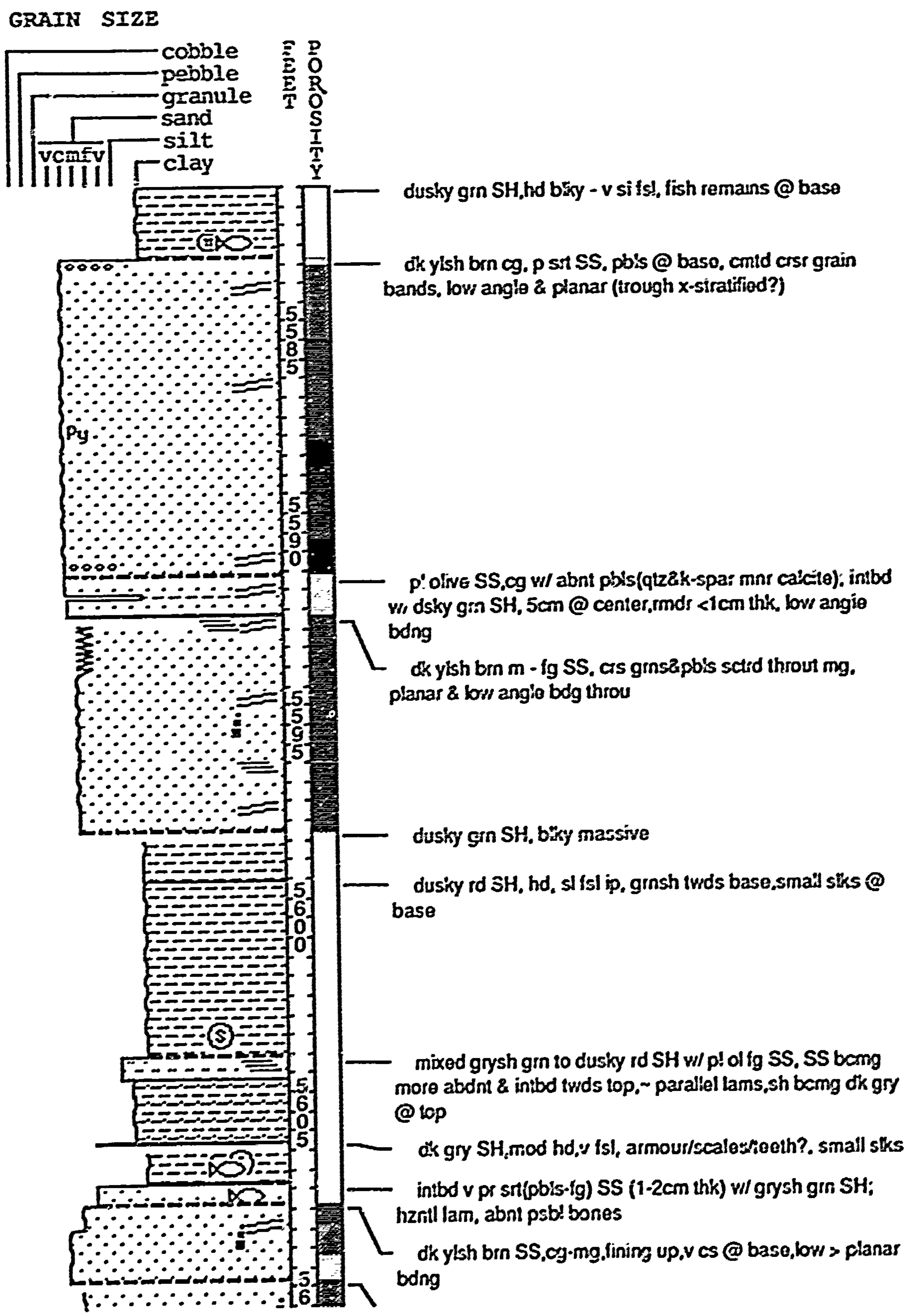
Amoco Unit 320 WIW Nipisi

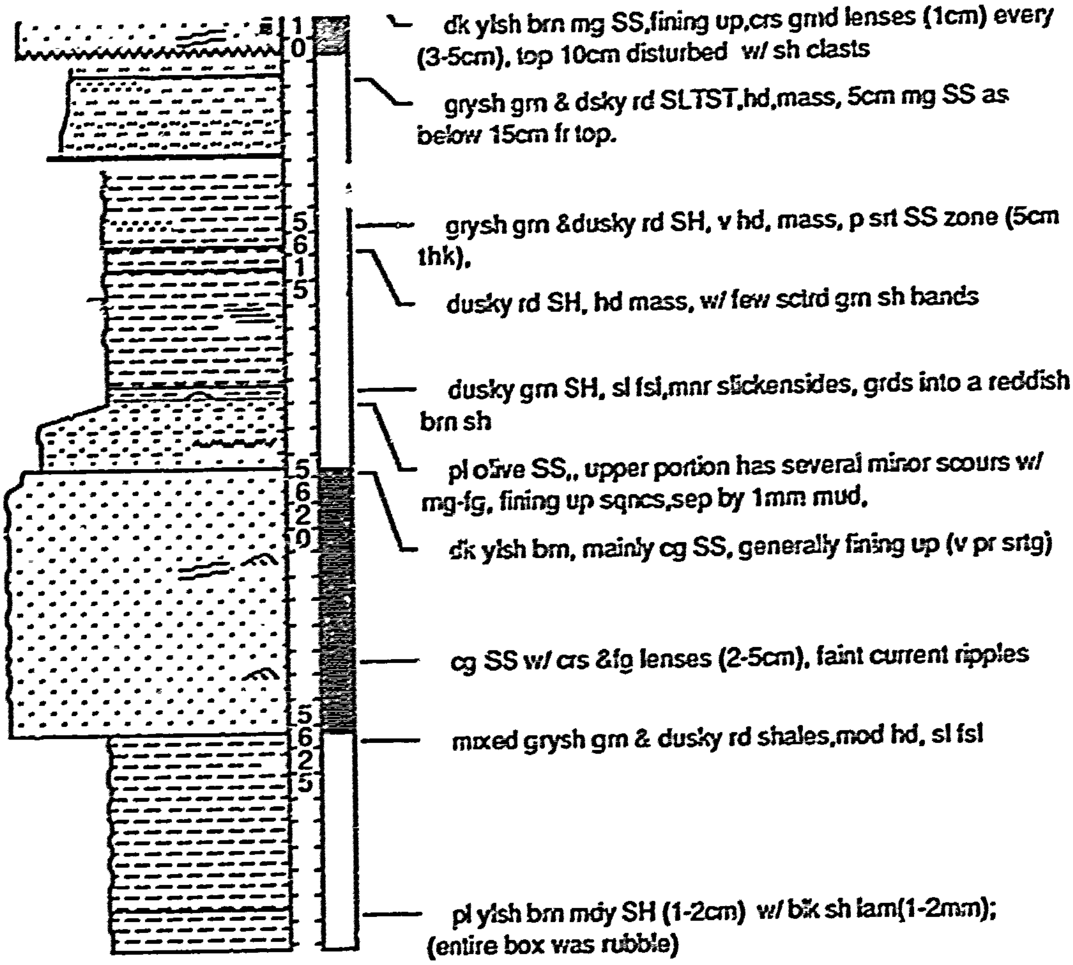
12-1-80-8w5




dk rdsh brn SH, hd blky,massive, mod fsl btm 40cm
5605
mixed grysh grn & dusky rd shales,v hd blky
5610
mod brn S&P mg SS units 2-4cm thk,sep by dkr mud lams 5mm thck, (.5x1cm)anhy clast, top 5cm is crsr and grnsh (out of place?)
pl ylsh brn fg SS,sl churned with grnsh mud,more mud twds top,crs grns @ base
mixed grysh grn & dusky rd shales, v sft & fsl @ base.
5615
pl ylsh brn w/ dusky grn lams,'clast-like' appearance ip; top 14cm (1-2cm) blk sh lam; btm 40cm:mtrbd dusky grn, drk rdsh brn, pl ylsh brn shales,sl convoluted bdg top to parallel @ base
blk-v dk brn SH,v fsl, hrd blky ip
5620
tan SLTST(mud??anhy??),massive,v well cemented, 1 gry anhy bed (1-2cm), 30cm fr base w/ abdnt medium anhy grns floating in matrix dcrsg upwards for 30cm
5625
Top Muskeg Anhydrite - contact scoured w/ anhy clasts @ base of sltst
5630

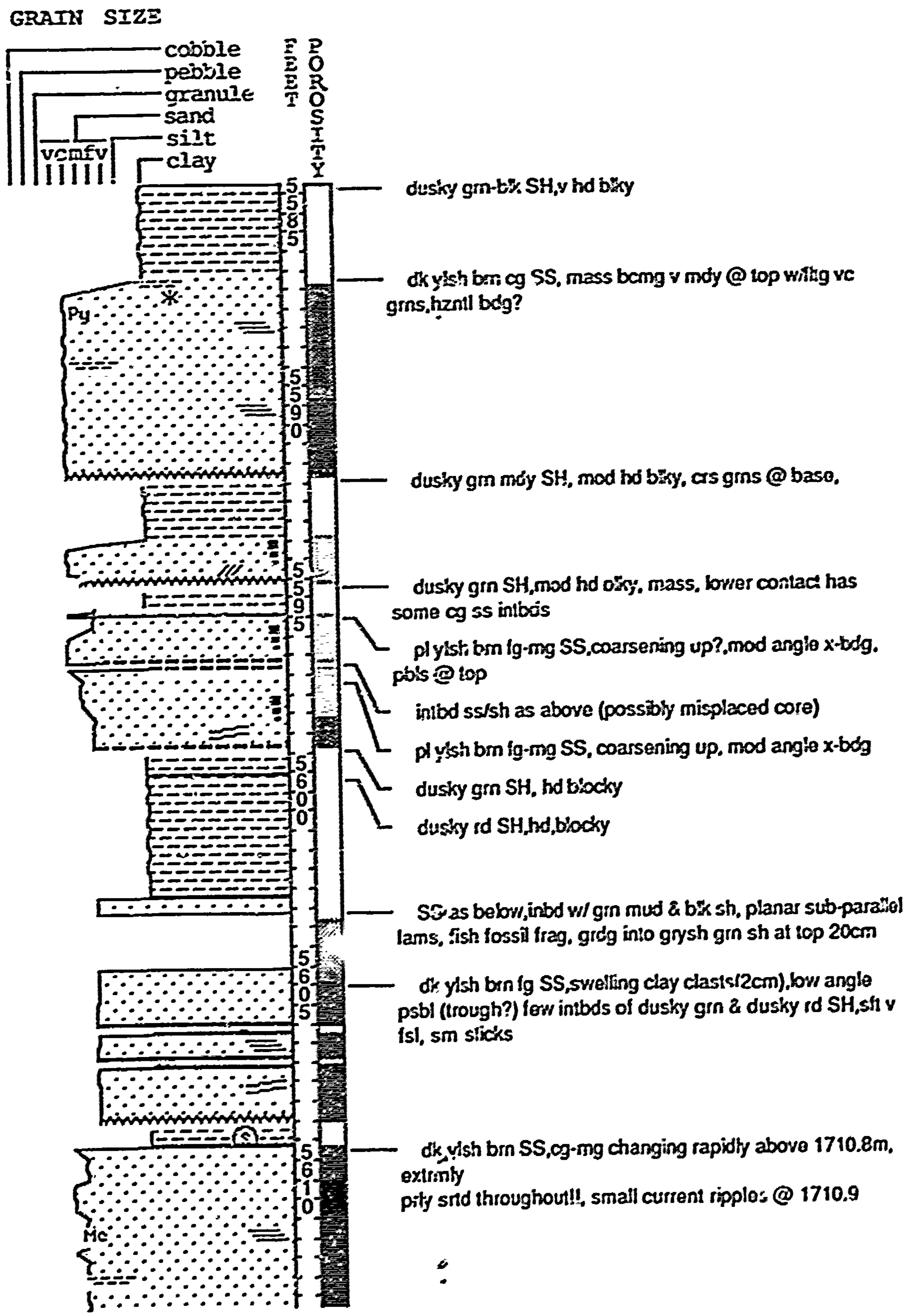
Amoco NGU Unit 293 Nipisi
10-2-80-8w5

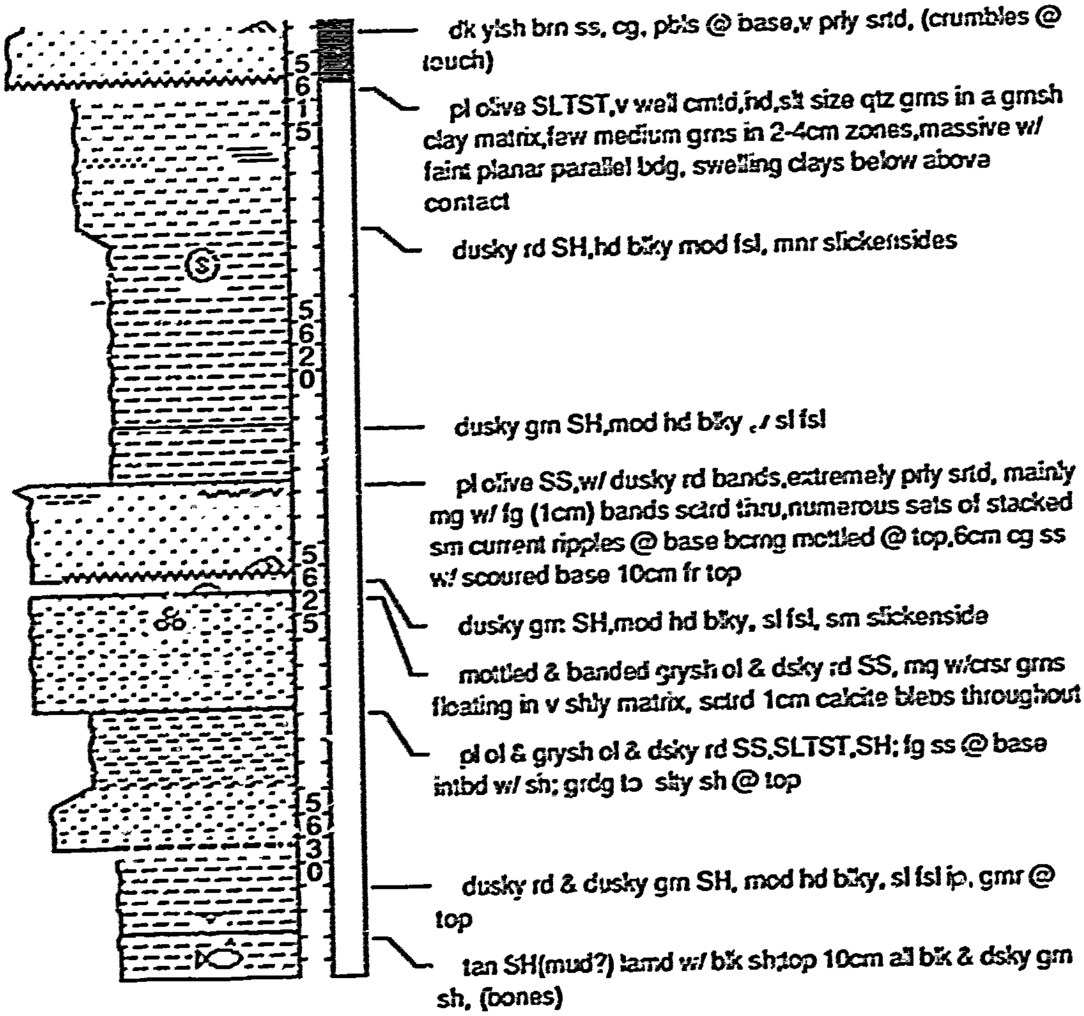



dk ylsh brn mg SS,fining up,crs grnd lenses (1cm) every (3-5cm), top 10cm disturbed w/ sh clasts
grysh grn & dsky rd SLTST,hd,mass, 5cm mg SS as below 15cm fr top.
grysh grn &dusky rd SH, v hd, mass, p srt SS zone (5cm thk).
dusky rd SH, hd mass, w/ few sctrd grn sh bands
dusky grn SH, sl fsl,mnr slickensides, grds into a reddish brn sh
pl olive SS,, upper portion has several minor scours w/ mg-fg, fining up sqncs,sep by 1mm mud.
dk ylsh brn, mainly cg SS, generally fining up (v pr srtg)
cg SS w/ crs &fg lenses (2-5cm), faint current ripples
mixed grysh grn & dusky rd shales,mod hd, sl fsl
pl ylsh brn mdy SH (1-2cm) w/ blk sh lam(1-2mm); (entire box was rubble)
5615
5620
5625

Amoco Unit 264 Nipisi

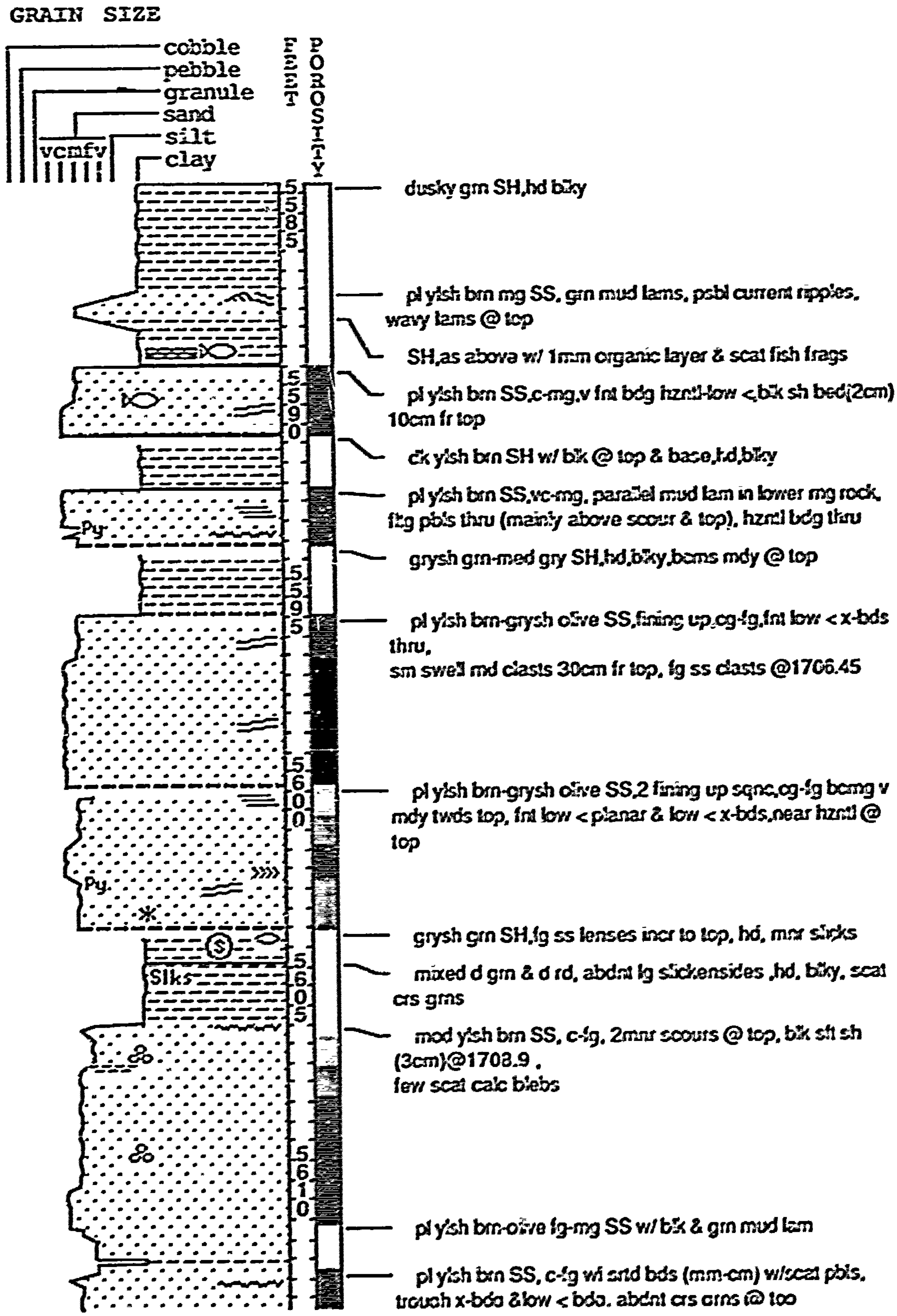
12-2-80-8w5

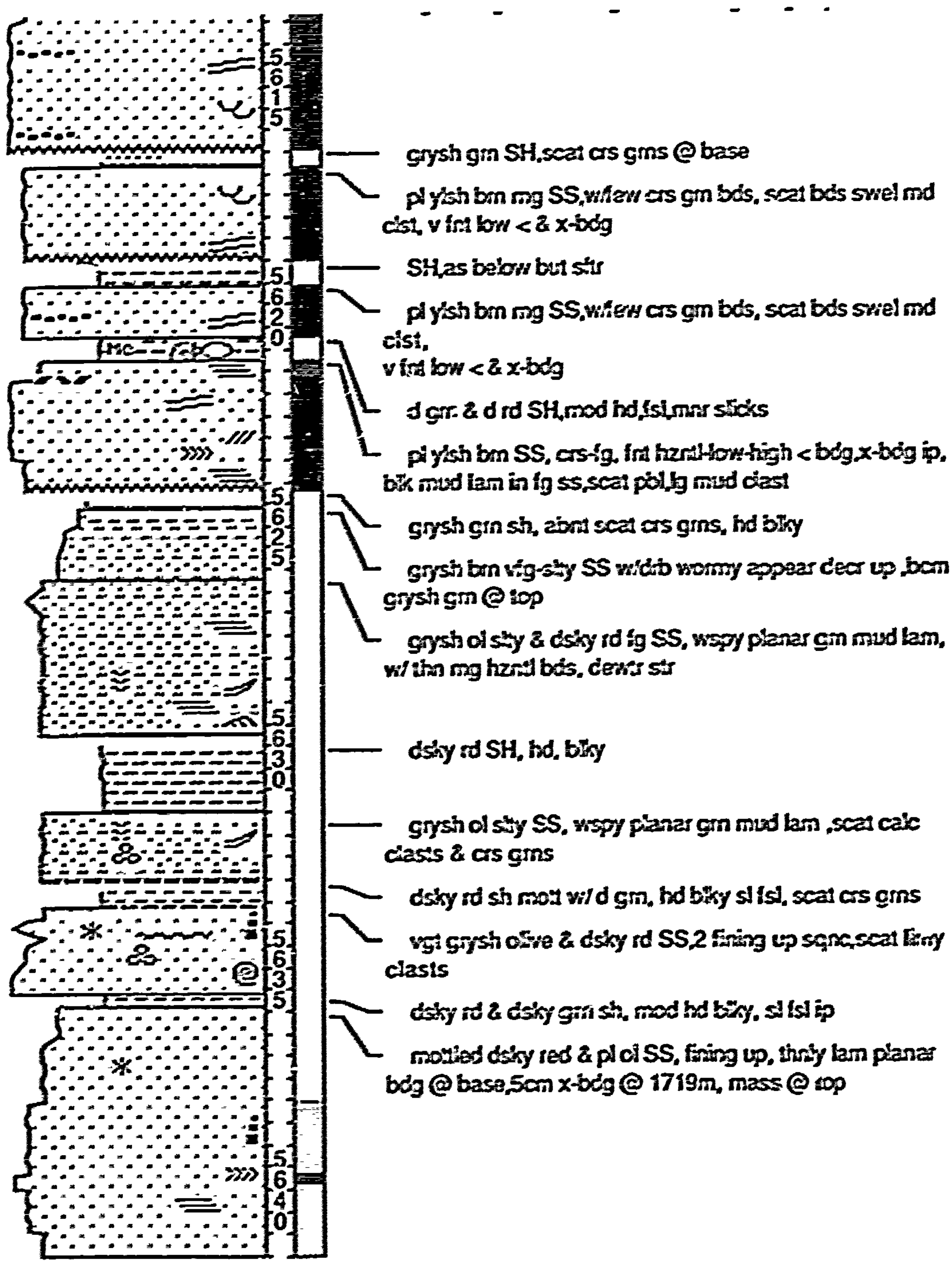



5615
5620
5625
5630
dk ylsh brn ss, cg, pbls @ base,v prly srtd, (crumbles @ touch)
pl olive SLTST,v well cmtd,hd,slt size qtz grns in a grnsh clay matrix,few medium grns in 2-4cm zones,massive w/ faint planar parallel bdg, swelling clays below above contact
dusky rd SH,hd blky mod fsl, mnr slickensides
dusky grn SH,mod hd blky w/ sl fsl
pl olive SS,w/ dusky rd bands,extremely prly srtd, mainly mg w/ fg (1cm) bands sctrd thru,numerous sets of stacked sm current ripples @ base bcmg mottled @ top,6cm cg ss w/ scoured base 10cm fr top
dusky grn SH,mod hd blky, sl fsl, sm slickenside
mottled & banded grysh ol & dsky rd SS, mg w/crsr grns floating in v shly matrix, sctrd 1cm calcite blebs throughout
pl ol & grysh ol & dsky rd SS,SLTST,SH; fg ss @ base intbd w/ sh; grdg to slty sh @ top
dusky rd & dusky grn SH, mod hd blky, sl fsl ip, gmr @ top
tan SH(mud?) lamd w/ blk sh;top 10cm all blk & dsky grn sh, (bones)

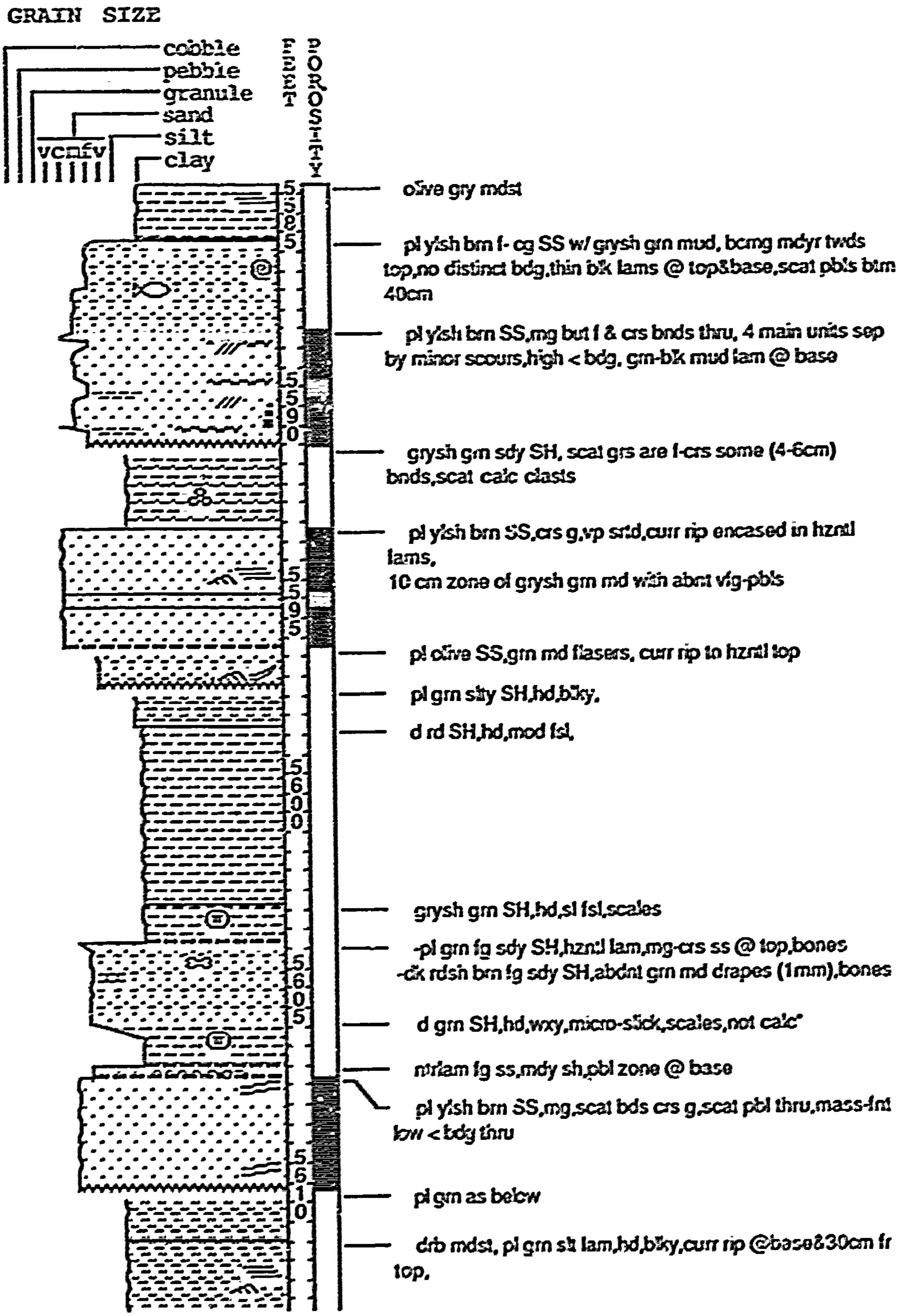
Amoco Unit No. 193

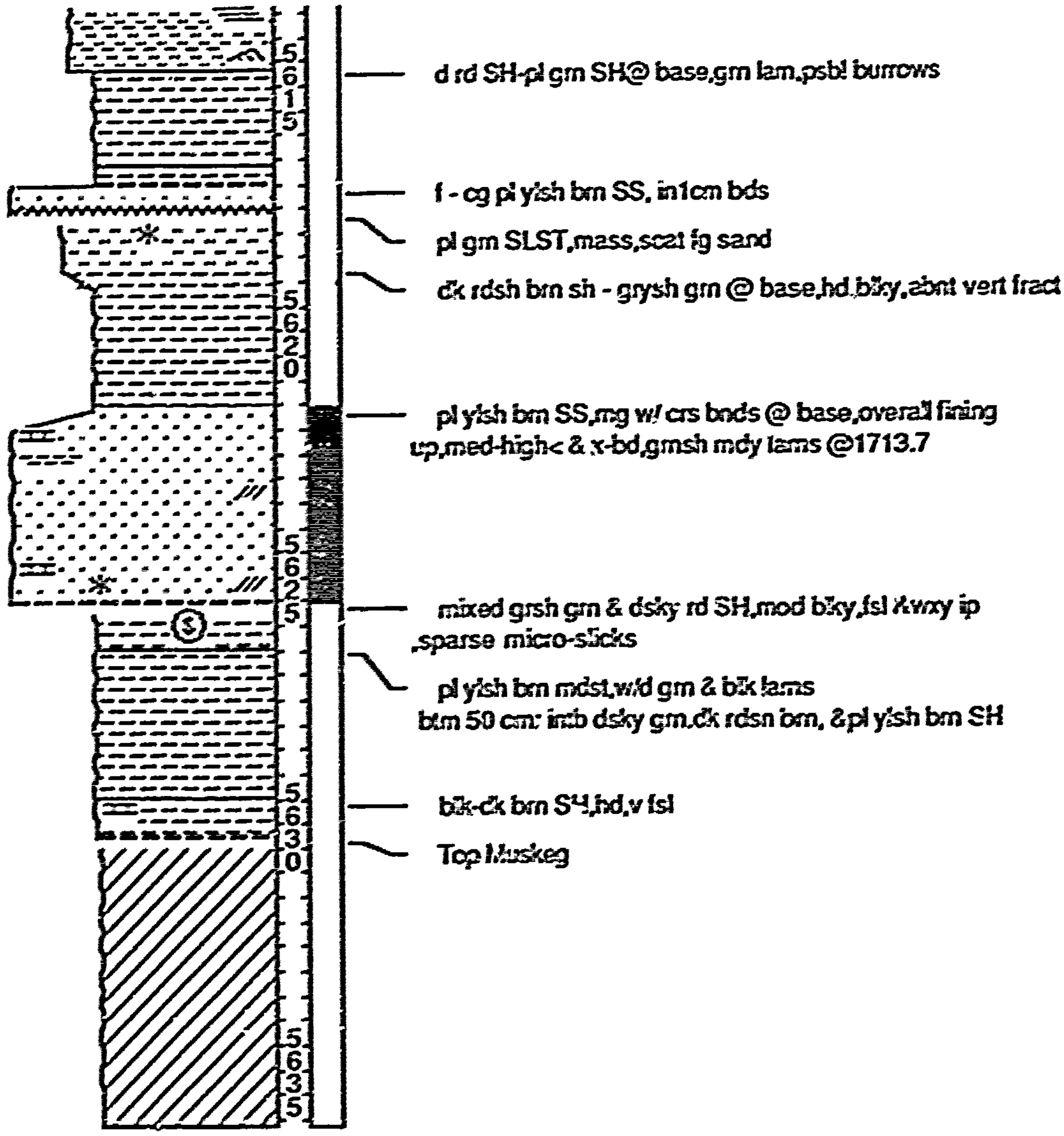
12-3-80-8w5




5615
5620
5625
5630
5635
5640
grysh grn SH,scat crs grns @ base
pl ylsh brn mg SS,w/few crs grn bds, scat bds swel md clst, v fnt low < & x-bdg
SH,as below but sltr
pl ylsh brn mg SS,w/few crs grn bds, scat bds swel md clst, v fnt low < & x-bdg
d grn & d rd SH,mod hd,fsl,mnr slicks
pl ylsh brn SS, crs-fg, fnt hzntl-low-high < bdg,x-bdg ip, blk mud lam in fg ss,scat pbl,lg mud clast
grysh grn sh, abnt scat crs grns, hd blky
grysh brn vfg-slty SS w/drb wormy appear decr up ,bcm grysh grn @ top
grysh ol slty & dsky rd fg SS, wspy planar grn mud lam, w/ thn mg hzntl bds, dewtr str
dsky rd SH, hd, blky
grysh ol slty SS, wspy planar grn mud lam ,scat calc clasts & crs grns
dsky rd sh mott w/ d grn, hd blky sl fsl, scat crs grns
vgt grysh olive & dsky rd SS,2 fining up sqnc,scat lmy clasts
dsky rd & dsky grn sh, mod hd blky, sl fsl ip
mottled dsky red & pl ol SS, fining up, thnly lam planar bdg @ base,5cm x-bdg @ 1719m, mass @ top

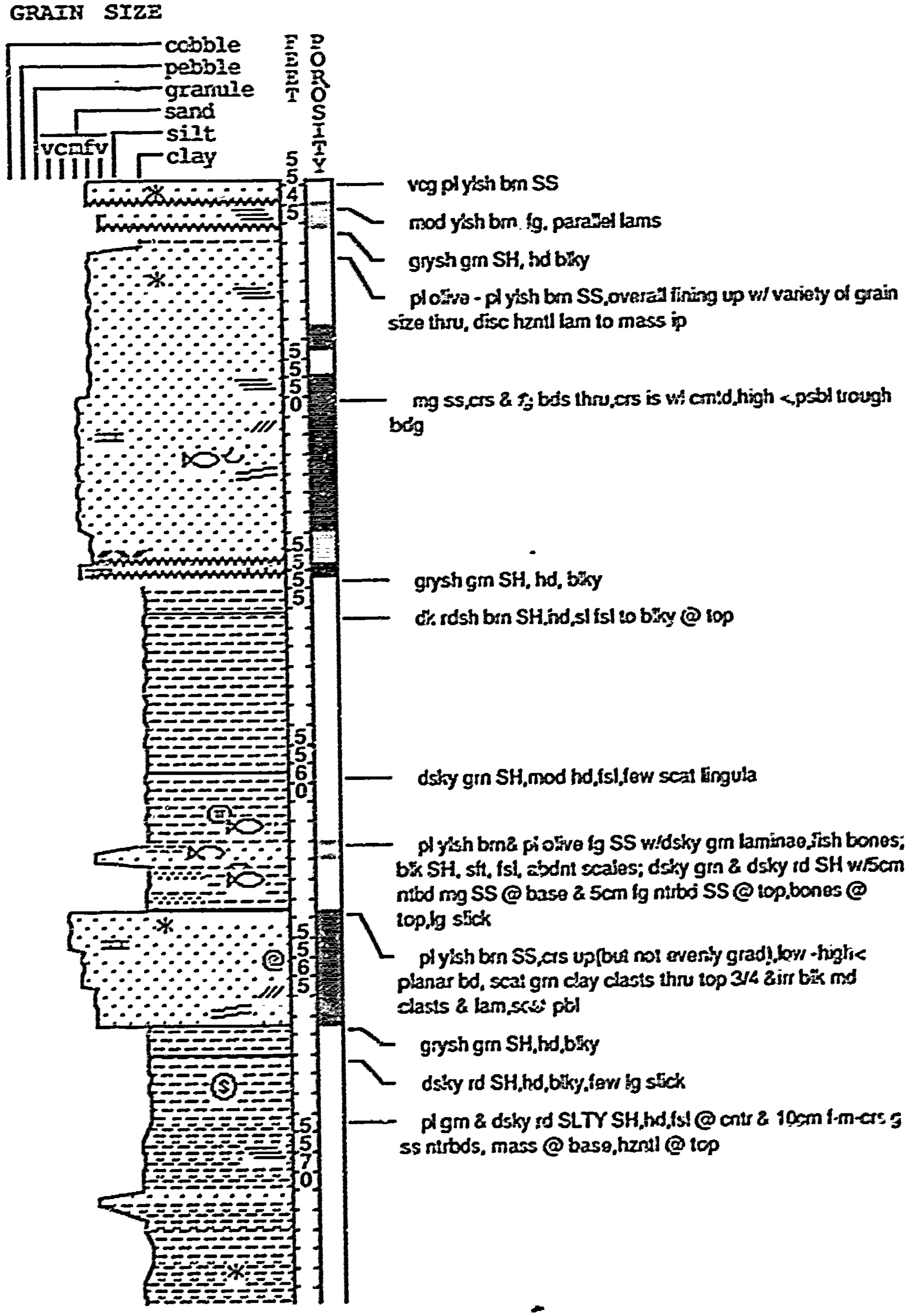
Amoco NGU Unit 294
2-11-80 -8w5

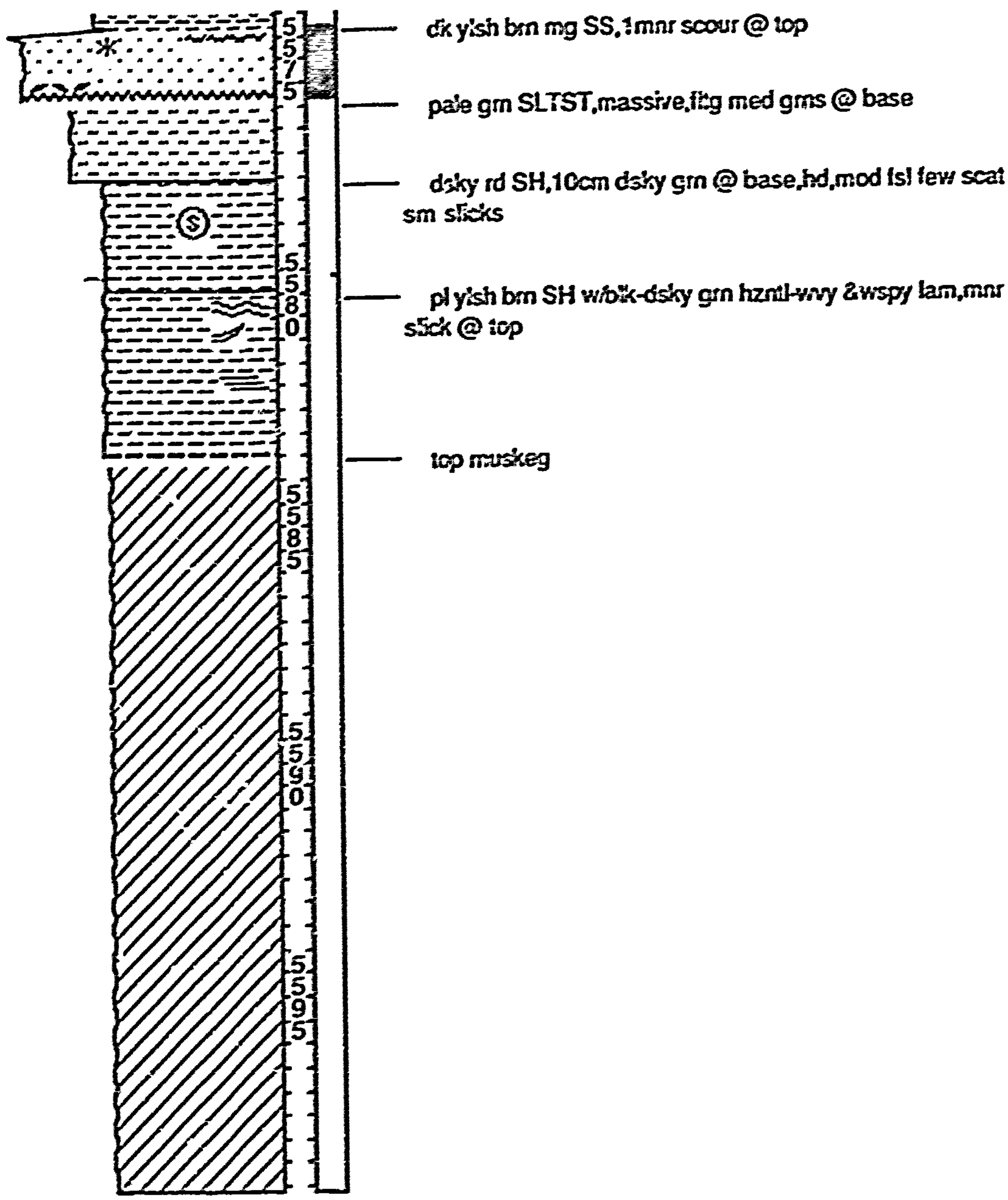



5615
5620
5625
5630
5635
d rd SH-pl grn SH@ base,grn lam,psbl burrows
f - cg pl ylsh brn SS, in1cm bds
pl grn SLST,mass,scat fg sand
dk rdsh brn sh - grysh grn @ base,hd,blky,abnt vert fract
pl ylsh brn SS,mg w/ crs bnds @ base,overall fining up,med-high< & x-bd,grnsh mdy lams @1713.7
mixed grsh grn & dsky rd SH,mod blky,fsl wavy ip ,sparse micro-slicks
pl ylsh brn mdst,w/d grn & blk lams
btm 50 cm: intb dsky grn,dk rdsh brn, &pl ylsh brn SH
blk-dk brn SH,hd,v fsl
Top Muskeg

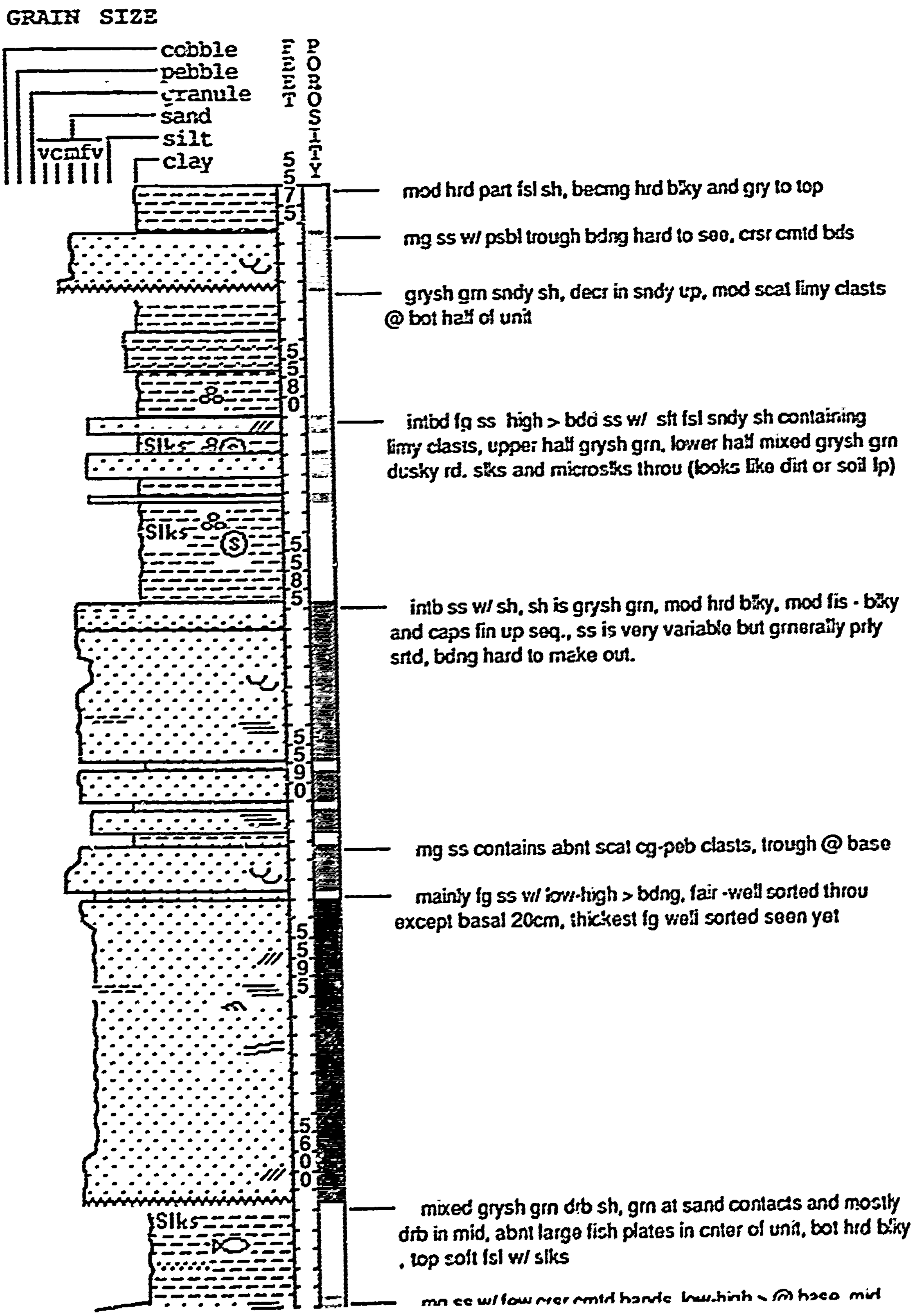
Amoco Unit 296 Nipisi

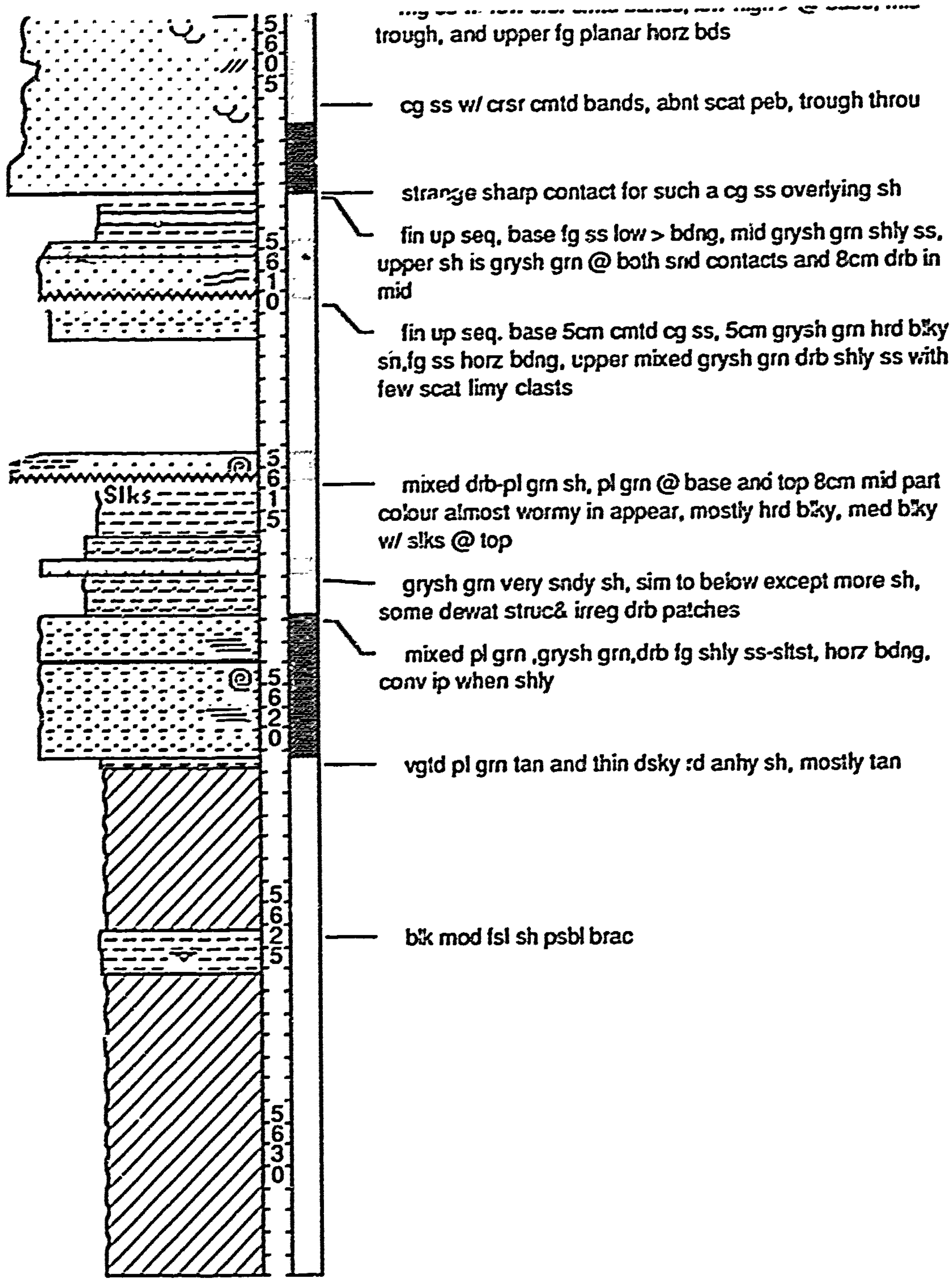
2-14-80-8w5 note: 1.5m lost core??



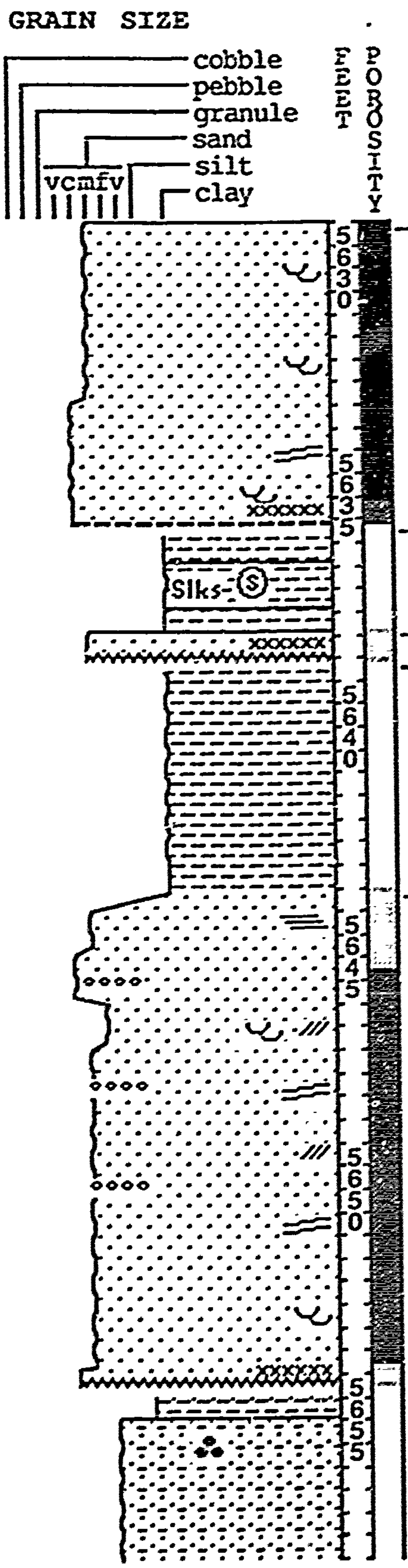

5557
dk y'sh brn mg SS,1mnr scour @ top
pale grn SLTST,massive,fltg med grns @ base
dsky rd SH,10cm dsky grn @ base,hd,mod fsl few scat sm slicks
5580
pl y'sh brn SH w/blk-dsky grn hzntl-wvy &wspy lam,mnr slick @ top
top muskeg
5585
5590
5595

Pacific Nipisi
10-16-80-8w5




trough, and upper fg planar horz bds
5605
cg ss w/ crsr cmtd bands, abnt scat peb, trough throu
strange sharp contact for such a cg ss overlying sh
fin up seq, base fg ss low > bdng, mid grysh grn shly ss, upper sh is grysh grn @ both snd contacts and 8cm drb in mid
5610
fin up seq. base 5cm cmtd cg ss, 5cm grysh grn hrd bky sh, fg ss horz bdng, upper mixed grysh grn drb shly ss with few scat limy clasts
Slks
5615
mixed drb-pl grn sh, pl grn @ base and top 8cm mid part colour almost wormy in appear, mostly hrd bky, med bky w/ slks @ top
grysh grn very sndy sh, sim to below except more sh, some dewat struc& irreg drb patches
mixed pl grn ,grysh grn,drb fg shly ss-sltst, horz bdng, conv lp when shly
5620
vgtd pl grn tan and thin dsky rd anhy sh, mostly tan
5625
blk mod fsl sh psbl brac
5630

Mobil NW Nipisi
12-18-80-8w5



mg ss w/ abnt crsr grs, bdng hard to see, mainly trough, grns subrounded & fair sorted parts

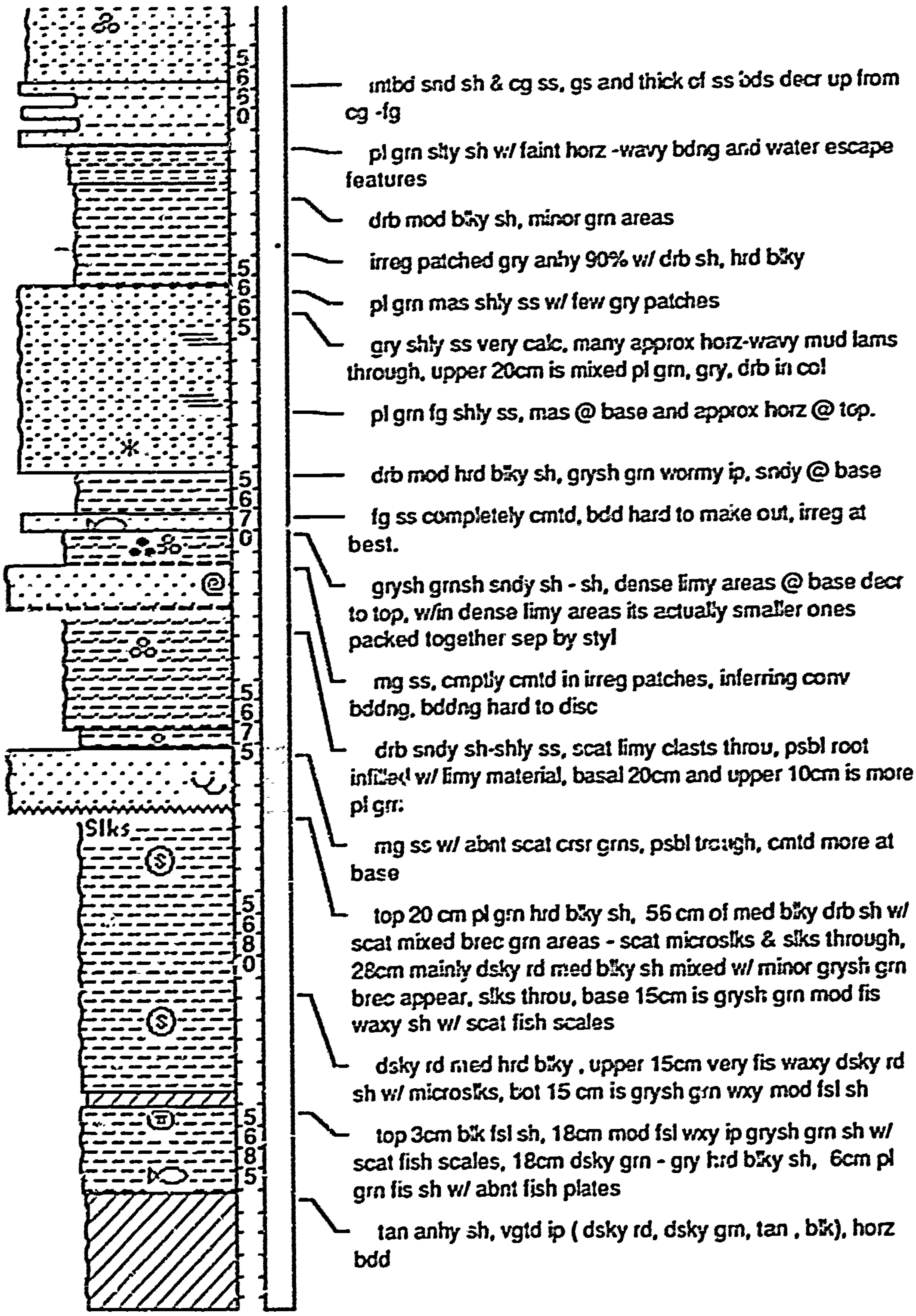
up- pl grn hrd bky sh, mid- mod hrd bky sh w/ slks & microslks, bot- pl grn mod hrd bly - fis ip sh w/ minor microslks

cmtd mg ss irreg bdng, scoured base, pebble zone3cm @ top but fins up

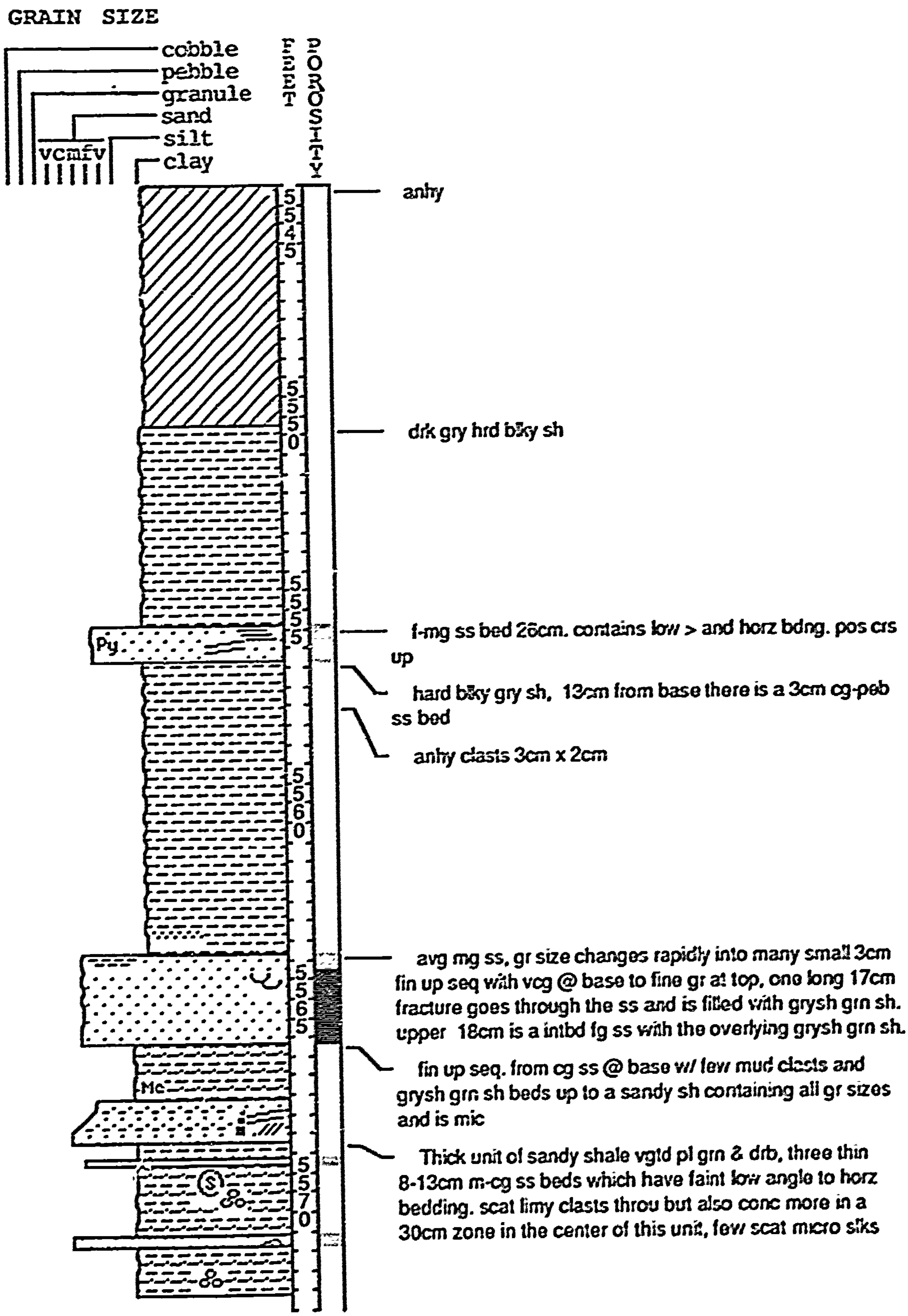
mixed drb-grysh grn med bky sh, mostly drb, slky through, thin 8cm sndy zone is more pl grn

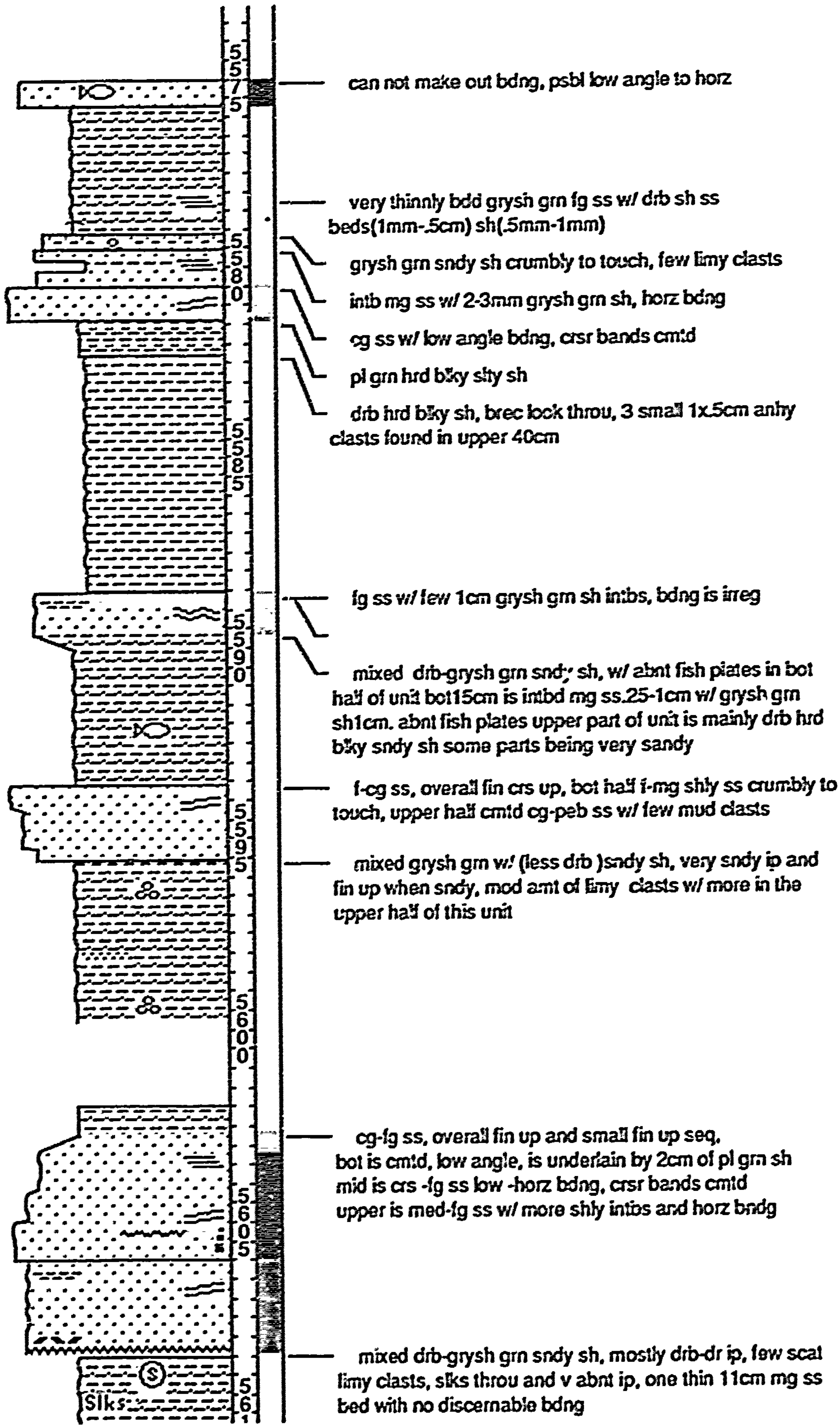
mainly mg ss with very abnt crsr gr cmtd zones and scat snd grs, few peb zones, great variablity in gr size although they do fin up, sed struc incl trough, low & high > bdng, and horz bdng at top of unit. core is broke up into many small peices for core analysis

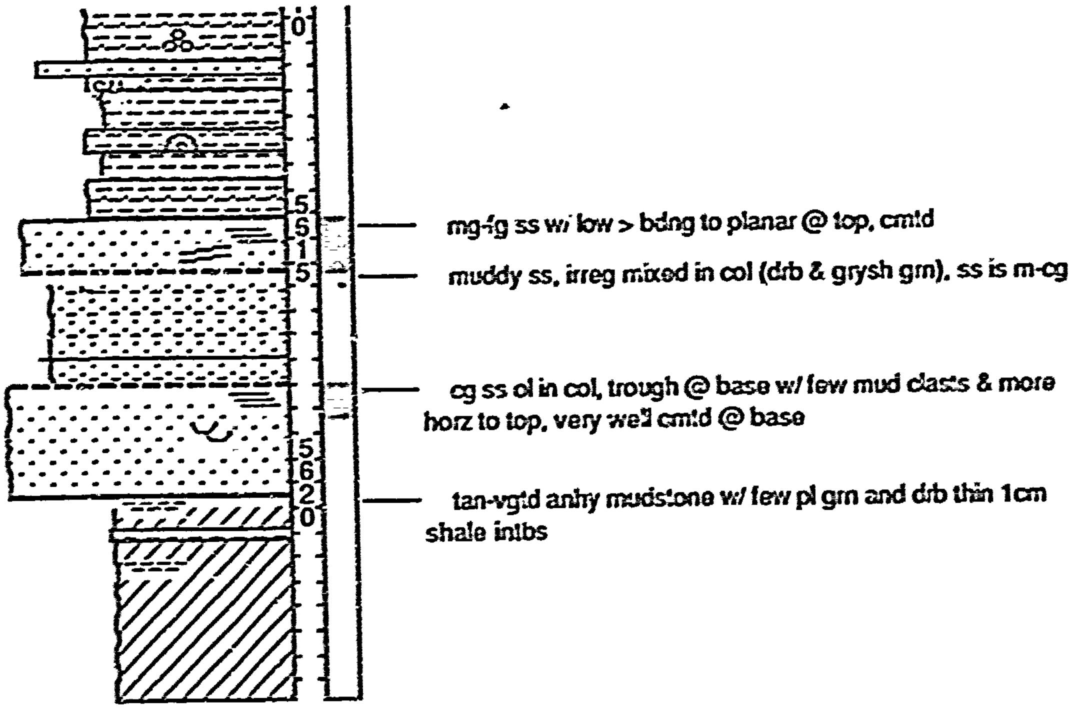
up 15cm grysh grn sndy sh w/ 1 limy clast, 45cm of large irreg shaped limy areas sep by disc sh lams, limy area very dense, rest is grysh grn shly ss fg w/ few scat limy area, and pos horz-wavy bdng.


5660
intbd snd sh & cg ss, gs and thick of ss bds decr up from cg -fg
pl grn slty sh w/ faint horz -wavy bdng and water escape features
drb mod bky sh, minor grn areas
irreg patched gry anhy 90% w/ drb sh, hrd bky
5665
pl grn mas shly ss w/ few gry patches
gry shly ss very calc, many approx horz-wavy mud lams through, upper 20cm is mixed pl grn, gry, drb in col
pl grn fg shly ss, mas @ base and approx horz @ top.
5670
drb mod hrd bky sh, grysh grn wormy ip, sndy @ base
fg ss completely cmtd, bdd hard to make out, irreg at best.
grysh grnsh sndy sh - sh, dense limy areas @ base decr to top, w/in dense limy areas its actually smaller ones packed together sep by styl
5675
mg ss, cmptly cmtd in irreg patches, inferring conv bddng, bddng hard to disc
drb sndy sh-shly ss, scat limy clasts throu, psbl root infilled w/ limy material, basal 20cm and upper 10cm is more pl grn
Slks
mg ss w/ abnt scat crsr grns, psbl trough, cmtd more at base
5680
top 20 cm pl grn hrd bky sh, 56 cm of med bky drb sh w/ scat mixed brec grn areas - scat microslks & slks through, 28cm mainly dsky rd med bky sh mixed w/ minor grysh grn brec appear, slks throu, base 15cm is grysh grn mod fis waxy sh w/ scat fish scales
dsky rd med hrd bky, upper 15cm very fis waxy dsky rd sh w/ microslks, bot 15 cm is grysh grn wxy mod fsl sh
5685
top 3cm blk fsl sh, 18cm mod fsl wxy ip grysh grn sh w/ scat fish scales, 18cm dsky grn - gry hrd bky sh, 6cm pl grn fis sh w/ abnt fish plates
tan anhy sh, vgtd ip (dsky rd, dsky grn, tan , blk), horz bdd

Atlantic Muskwa
10-32-80-8w5

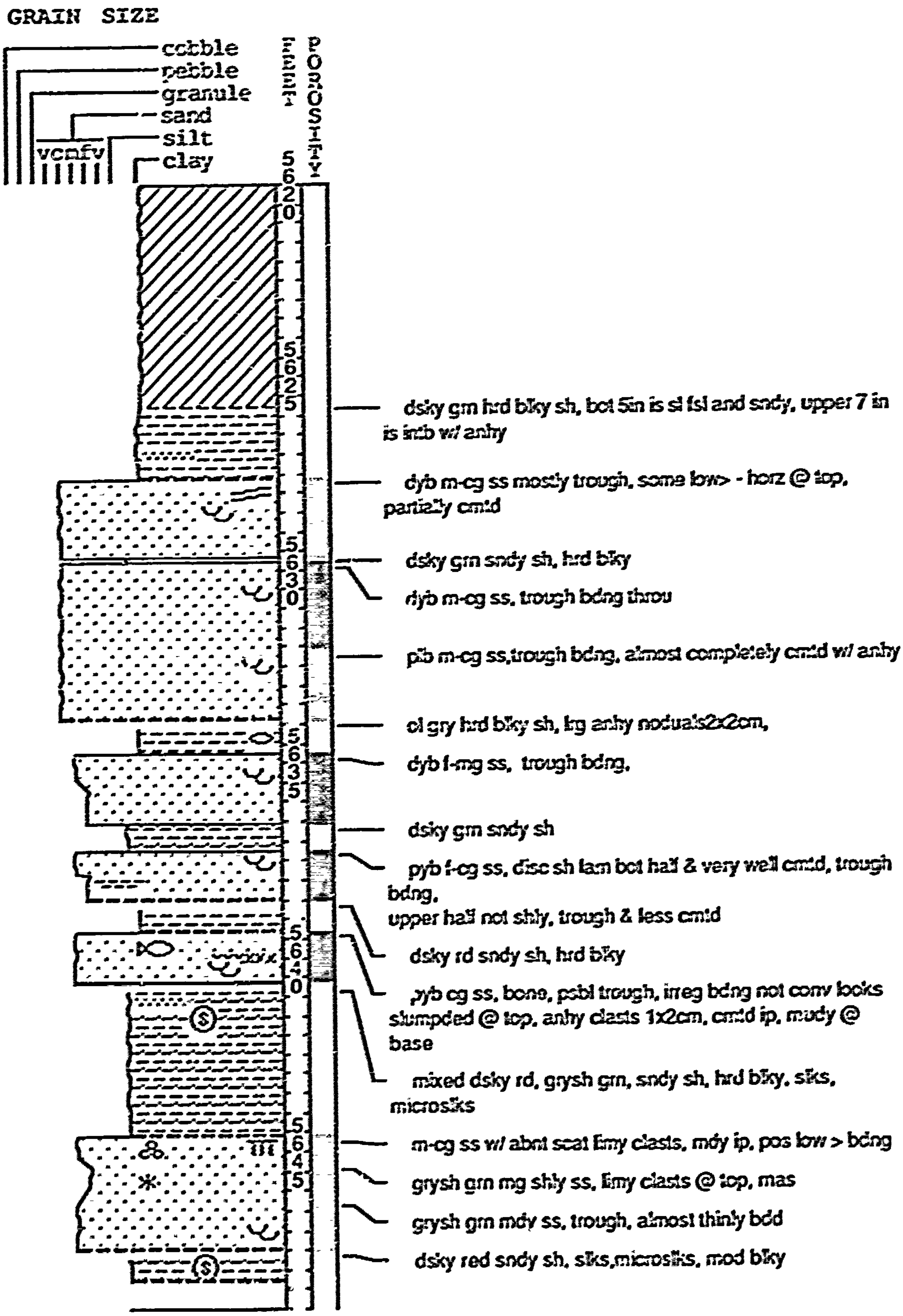


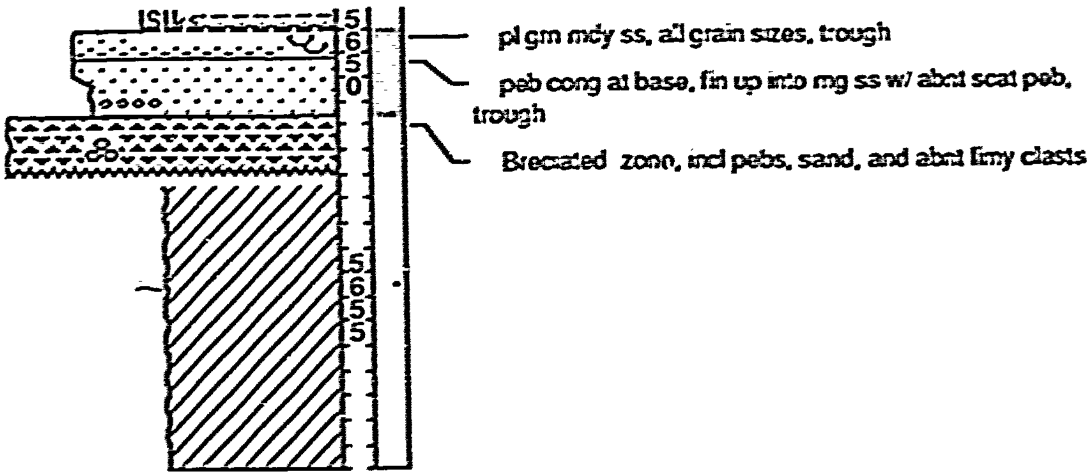

5575
can not make out bdng, psbl low angle to horz
very thinnly bdd grysh grn fg ss w/ drb sh ss beds(1mm-.5cm) sh(.5mm-1mm)
5580
grysh grn sndy sh crumbly to touch, few limy clasts
intb mg ss w/ 2-3mm grysh grn sh, horz bdng
cg ss w/ low angle bdng, crsr bands cmtd
pl grn hrd blky slty sh
drb hrd blky sh, brec look throu, 3 small 1x.5cm anhy clasts found in upper 40cm
5585
fg ss w/ few 1cm grysh grn sh intbs, bdng is irreg
5590
mixed drb-grysh grn sndy sh, w/ abnt fish plates in bot half of unit bot15cm is intbd mg ss.25-1cm w/ grysh grn sh1cm. abnt fish plates upper part of unit is mainly drb hrd blky sndy sh some parts being very sandy
f-cg ss, overall fin crs up, bot half f-mg shly ss crumbly to touch, upper half cmtd cg-peb ss w/ few mud clasts
5595
mixed grysh grn w/ (less drb)sndy sh, very sndy ip and fin up when sndy, mod amt of limy clasts w/ more in the upper half of this unit
5600
cg-fg ss, overall fin up and small fin up seq. bot is cmtd, low angle, is underlain by 2cm of pl grn sh mid is crs -fg ss low -horz bdng, crsr bands cmtd upper is med-fg ss w/ more shly intbs and horz bndg
5605
mixed drb-grysh grn sndy sh, mostly drb-dr ip, few scat limy clasts, slks throu and v abnt ip, one thin 11cm mg ss bed with no discernable bdng
S
Slks
561


mg-fg ss w/ low > bdng to planar @ top, cmtd
muddy ss, irreg mixed in col (drb & grysh grn), ss is m-cg
cg ss ol in col, trough @ base w/ few mud clasts & more horz to top, very well cmtd @ base
tan-vgtd anhy mudstone w/ few pl grn and drb thin 1cm shale intbs

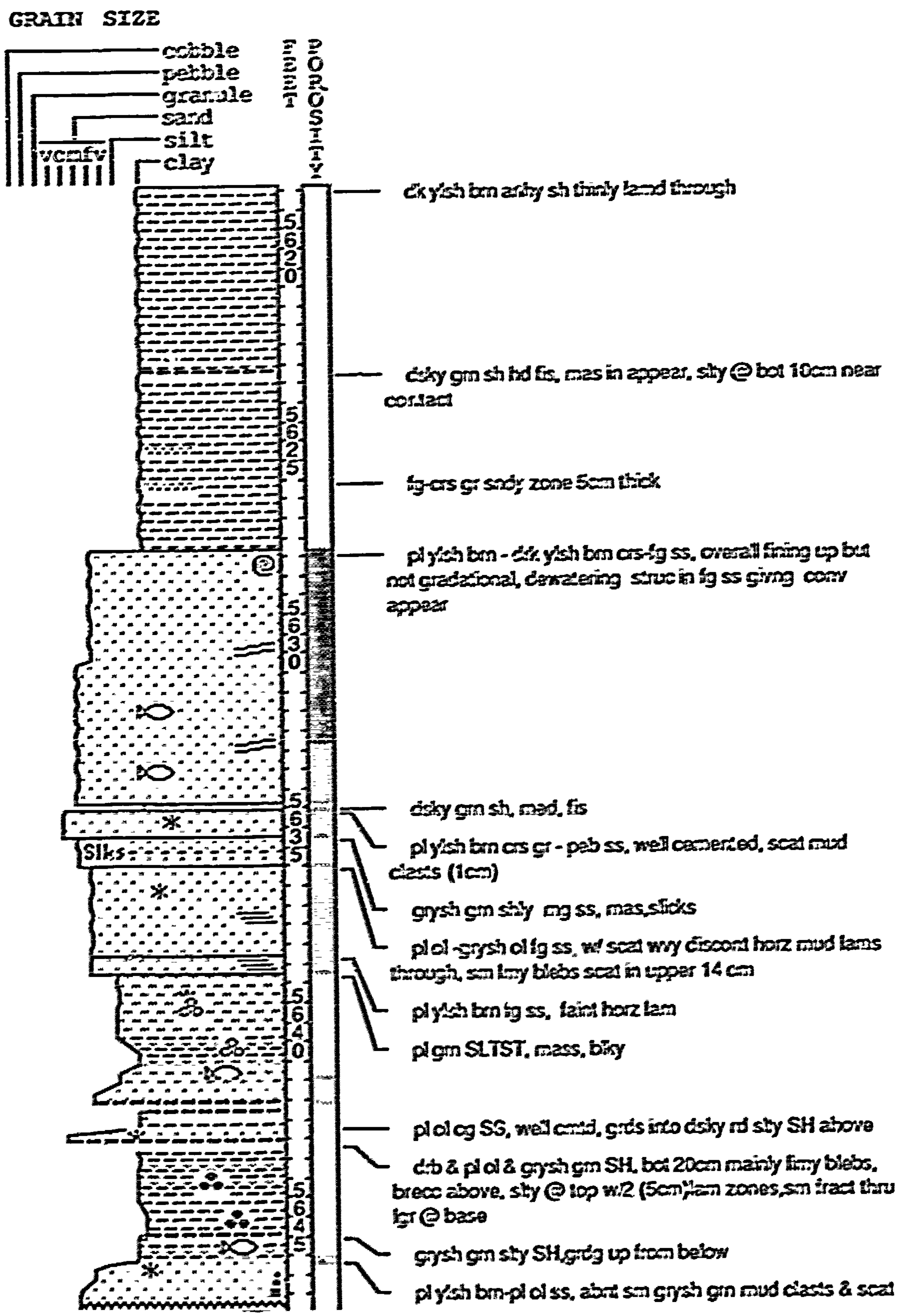
Mobil Utik Nipisi

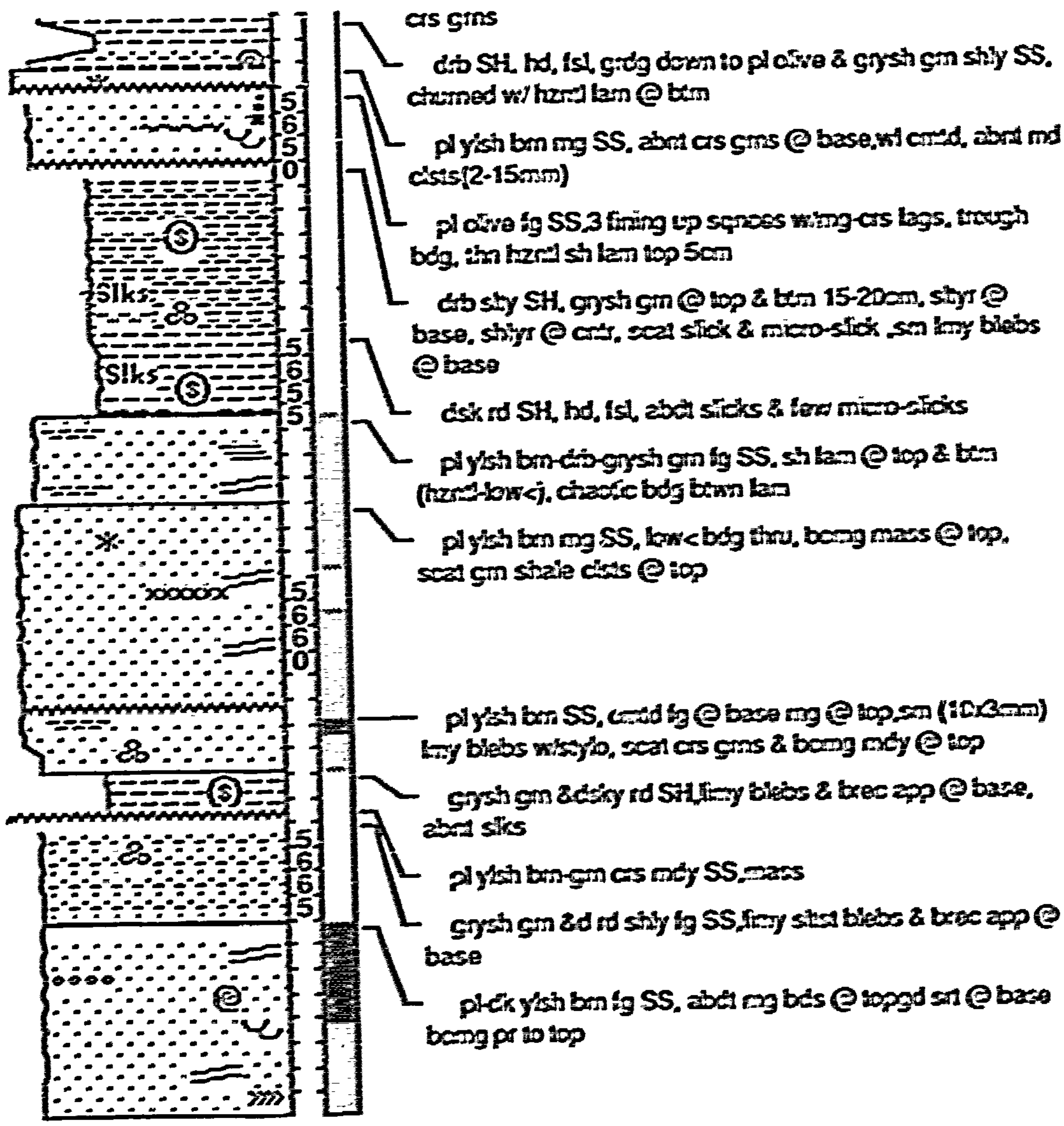
12-21-80-9w5 Depth's may be out



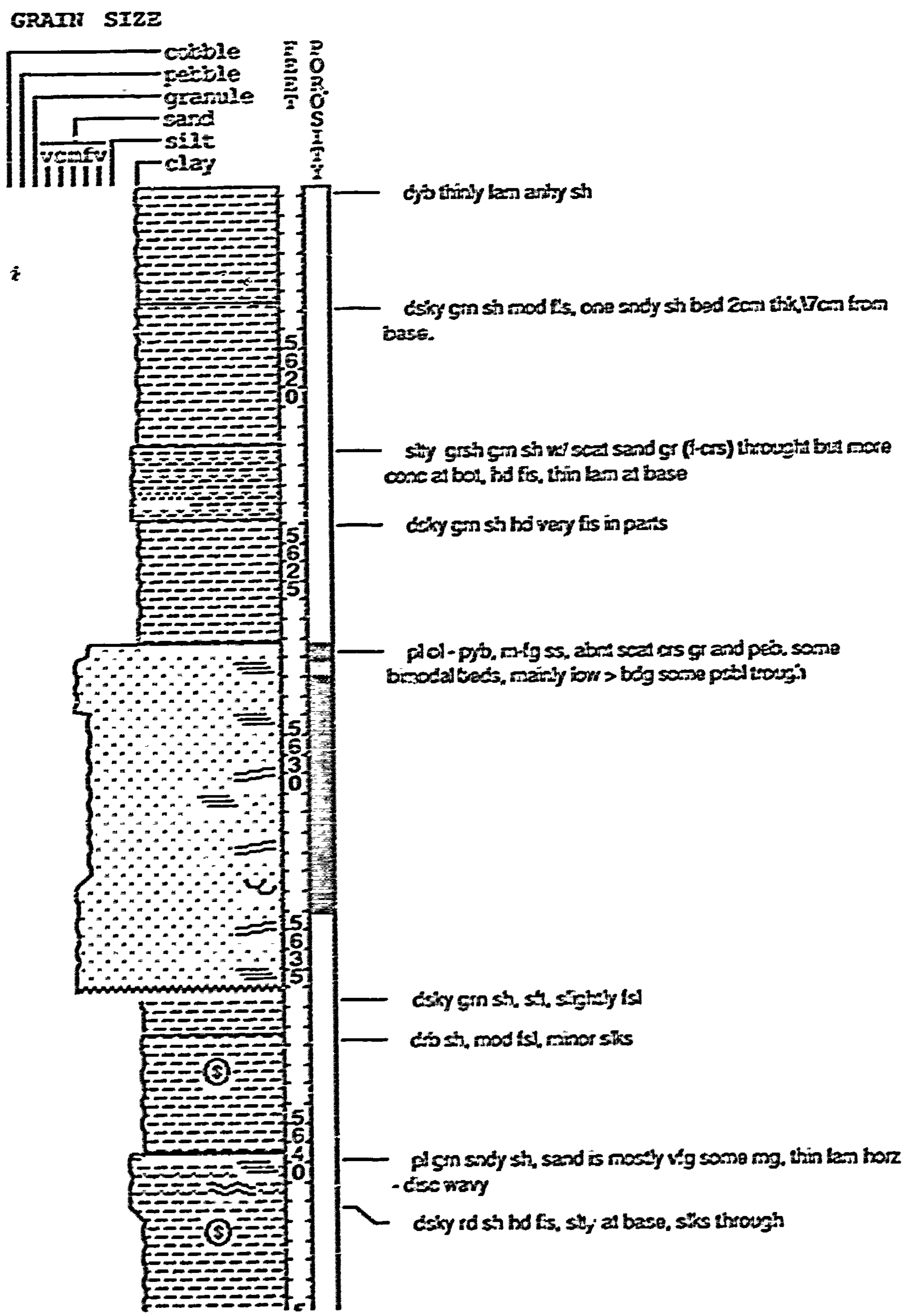

ISILS
5
6
5
0
5
6
5
5
pl gm mdy ss, all grain sizes, trough
peb cong at base, fin up into mg ss w/ abnt scat peb, trough
Brecciated zone, incl pebs, sand, and abnt limy clasts

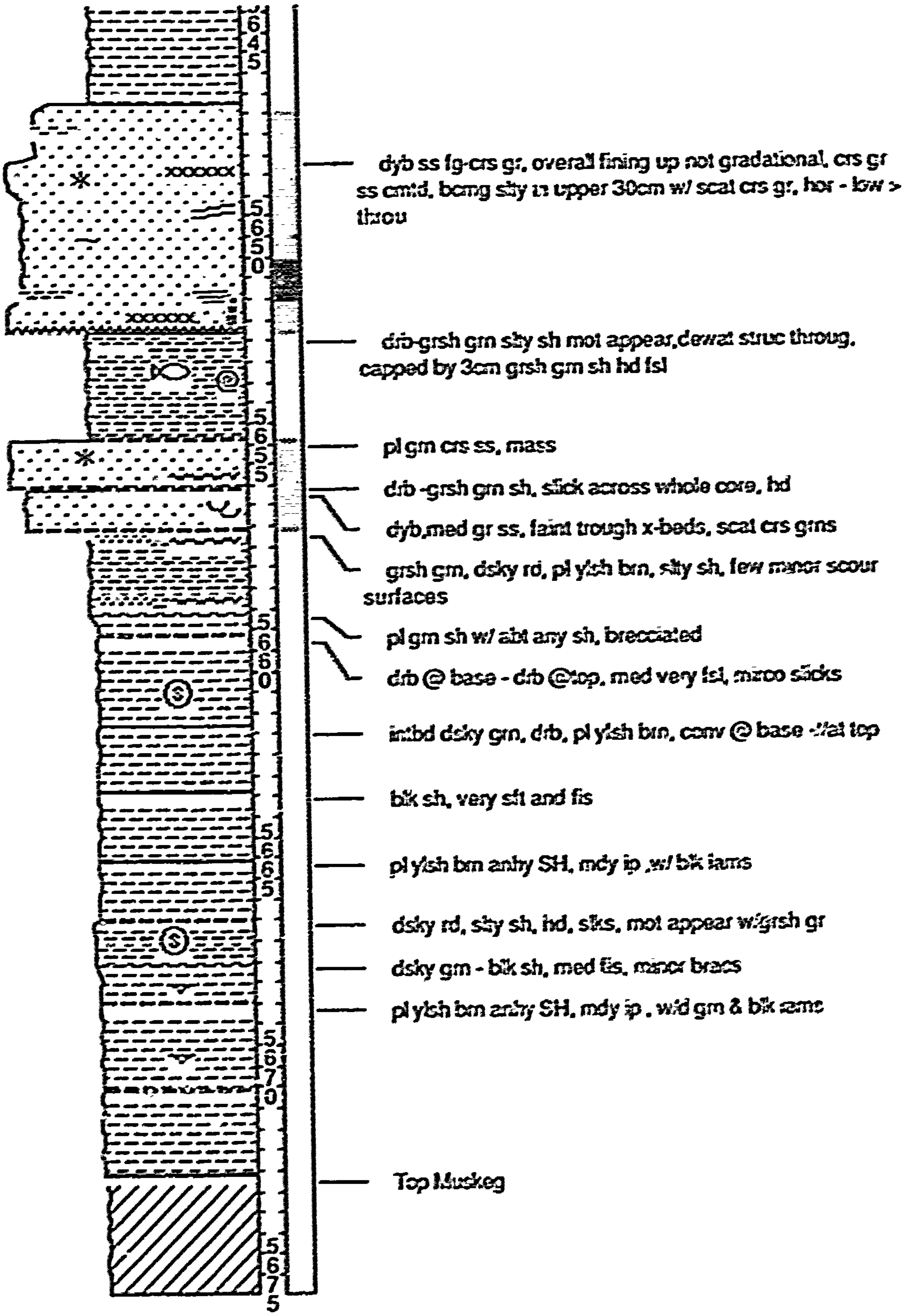
4-24-80-9w5


GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
vcmfv
POROSITY
5620
5625
5630
5635
5640
5645
Slks
dk ylsh brn anhy sh thinly lamd through
dsky grn sh hd fis, mas in appear, slty @ bot 10cm near contact
fg-crs gr sndy zone 5cm thick
pl ylsh brn - dk ylsh brn crs-fg ss, overall fining up but not gradational, dewatering struc in fg ss giving conv appear
dsky grn sh, mod, fis
pl ylsh brn crs gr - peb ss, well cemented, scat mud clasts (1cm)
grysh grn slty mg ss, mas,slicks
pl ol -grysh ol fg ss, w/ scat wvy discont horz mud lams through, sm lmy blebs scat in upper 14 cm
pl ylsh brn fg ss, faint horz lam
pl grn SLTST, mass, blky
pl ol cg SS, well cmtd, grds into dsky rd slty SH above
drb & pl ol & grysh grn SH, bot 20cm mainly lmy blebs, brecc above, slty @ top w/2 (5cm)'lam zones,sm fract thru
lgr @ base
grysh grn slty SH,grdg up from below
pl ylsh brn-pl ol ss, abnt sm grysh grn mud clasts & scat

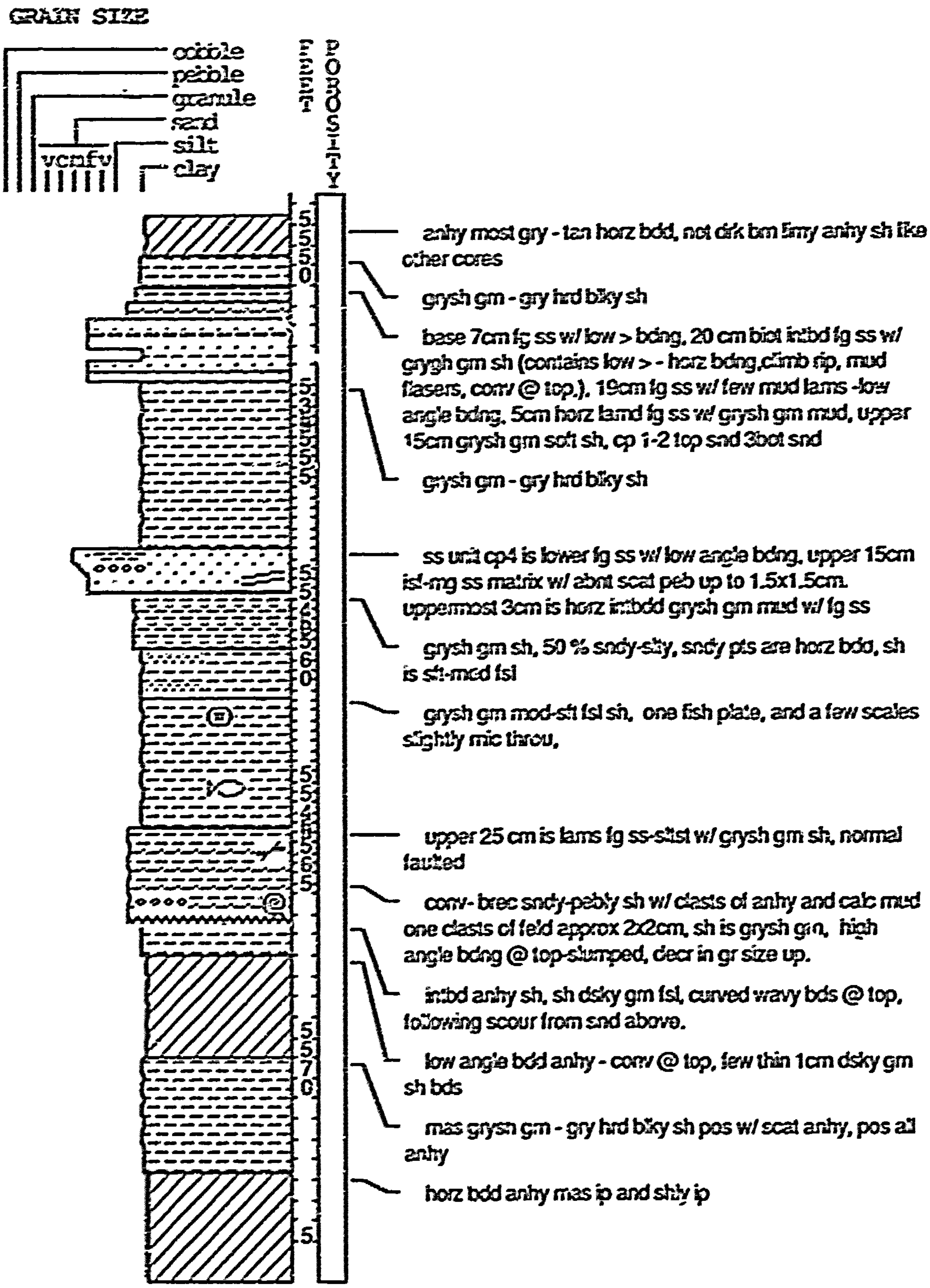

crs grns
drb SH, hd, fsl, grdg down to pl olive & grysh grn shly SS, churned w/ hzntl lam @ btm
5 6 5 0
pl ylsh brn mg SS, abnt crs grns @ base,wl cmtd, abnt md clsts(2-15mm)
pl olive fg SS,3 fining up sqnces w/mg-crs lags, trough bdg, thn hzntl sh lam top 5cm
Slks
drb slty SH, grysh grn @ top & btm 15-20cm, sltyr @ base, shlyr @ cntr, scat slick & micro-slick ,sm lmy blebs @ base
Slks
5 6 5 5
dsk rd SH, hd, fsl, abdt slicks & few micro-slicks
pl ylsh brn-drb-grysh grn fg SS, sh lam @ top & btm (hzntl-low<j, chaotic bdg btwn lam
pl ylsh brn mg SS, low< bdg thru, bcmg mass @ top, scat grn shale clsts @ top
5 6 6 0
pl ylsh brn SS, cmtd fg @ base mg @ top,sm (10x3mm) lmy blebs w/stylo, scat crs grns & bcmg mdy @ top
grysh grn &dsky rd SH,lmy blebs & brec app @ base, abnt slks
5 6 6 5
pl ylsh brn-grn crs mdy SS,mass
grysh grn &d rd shly fg SS,lmy stst blebs & brec app @ base
pl-dk ylsh brn fg SS, abdt mg bds @ topgd srt @ base bcmg pr to top

Arco IOE Nipisi
4-25-80-9w5

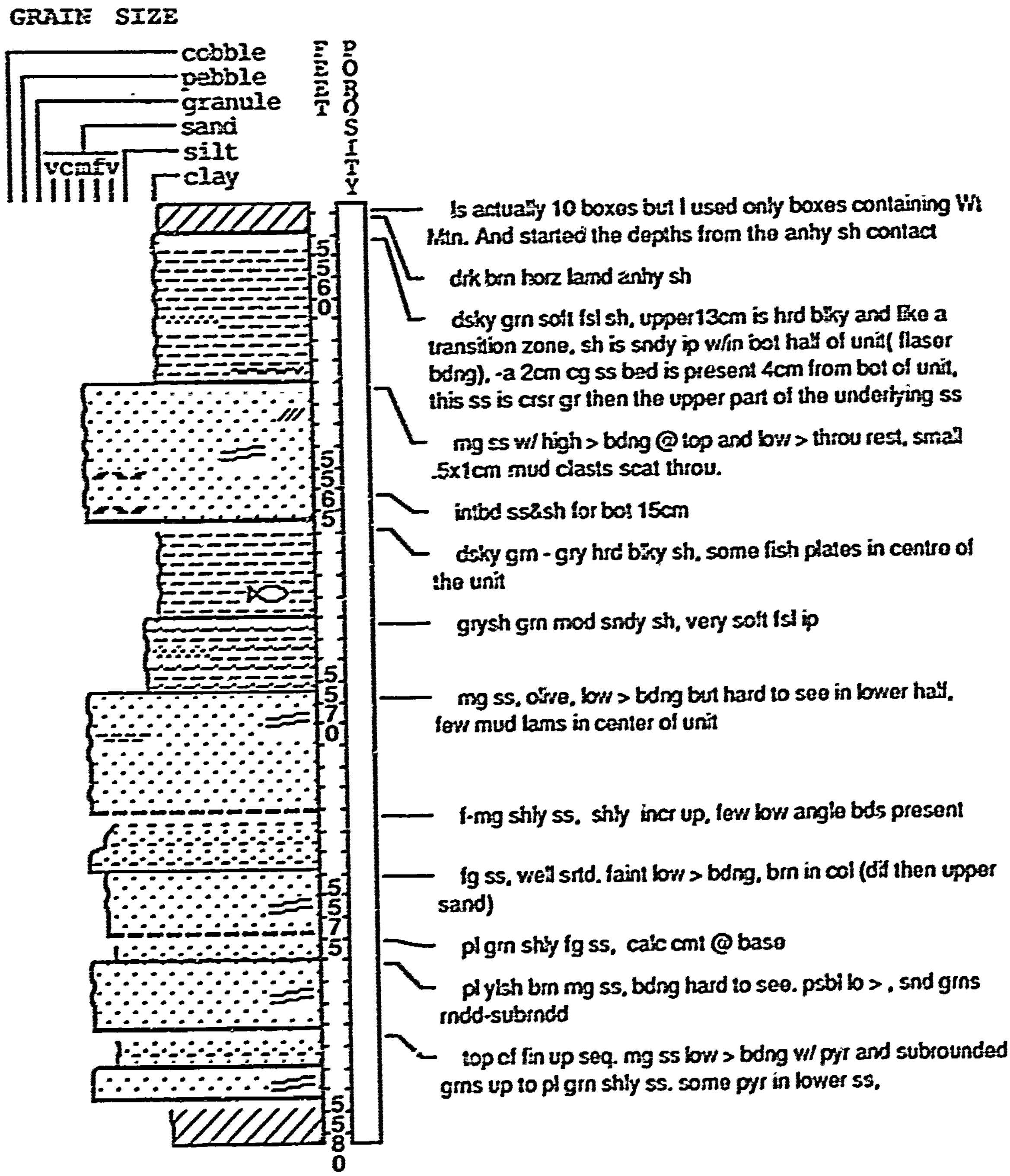



6
4
5
dyb ss fg-crs gr, overall fining up not gradational, crs gr ss cmtd, bcmg slty in upper 30cm w/ scat crs gr, hor - low > throu
5
6
5
0
drb-grsh grn slty sh mot appear,dewat struc throug, capped by 3cm grsh grn sh hd fsl
5
6
pl grn crs ss, mass
5
5
drb -grsh grn sh, slick across whole core, hd
dyb,med gr ss, faint trough x-beds, scat crs grns
grsh grn, dsky rd, pl ylsh brn, slty sh, few minor scour surfaces
5
6
6
0
pl grn sh w/ abt anhy sh, brecciated
drb @ base - drb @top, med very fsl, micro slicks
intbd dsky grn, drb, pl ylsh brn, conv @ base - flat top
blk sh, very sft and fis
5
6
6
5
pl ylsh brn anhy SH, mdy ip ,w/ blk lams
dsky rd, slty sh, hd, slks, mot appear w/grsh gr
dsky grn - blk sh, med fis, minor brecs
pl ylsh brn anhy SH, mdy ip , w/d grn & blk lams
5
6
7
0
Top Muskeg
5
6
7
5

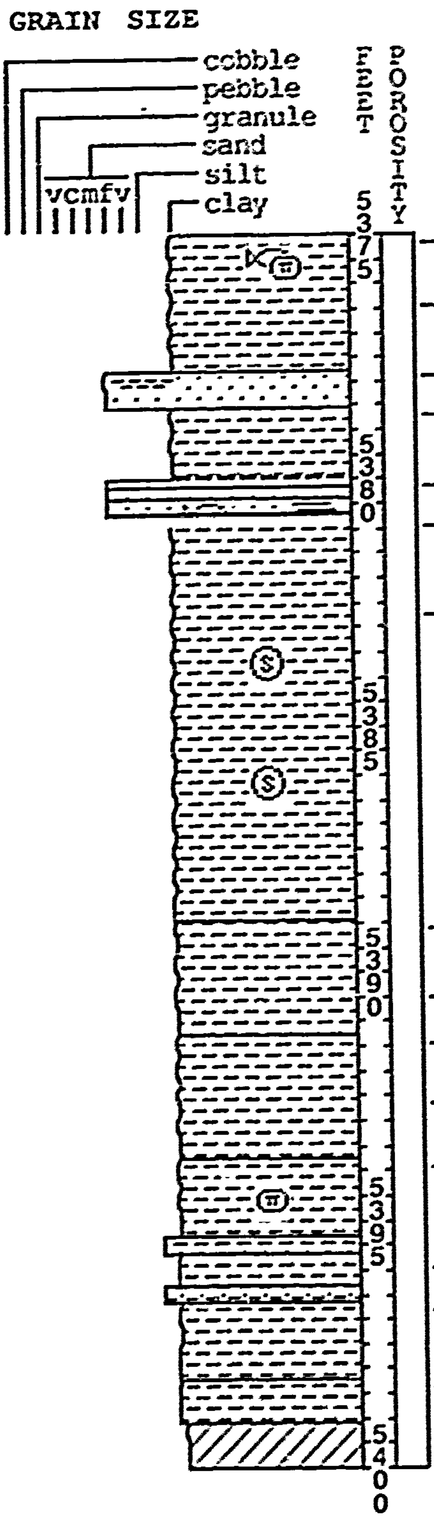
Pan Am H-2 Nipisi
12-32-80-9w5



Amoco Et Al Nipisi
5-34-80-9w5



Pan Am G-1 Nipisi
13-7-81-7w5



grysh grn mod fsl, med-waxy sh, very abnt fish plates, & scales

dsky grn - gry hrd b̃ky sh - sltst, base 5cm has abnt scales and mod fsl

fg ss approx hzntl wavy bdng, mud flasers, ss content and gr decr up.

base 17cm is mod fsl dsky grn sh, upper part is pl grn hrd b̃ky sltstn

shly ss, fish plate at base of unit

grysh grn hrd b̃ky sh, scat small drb specs ip,

drb -dsky rd hrd b̃ky sh, scat slks (minor in number)

grysh grn - pl grn hrd b̃ky sh

gradational contact zone for 30cm, mainly grysh grn some drb

mottled drb - dsky rd mod fsl sh

drb hrd b̃ky sh, gradational contact from below mottled for17cm

med fis grysh grn sh w/ few drb spots, hrdr in sndy areas, large 5x3cm anhy clast in center of unit, sndy spots are fg ss, scat minor fish scales

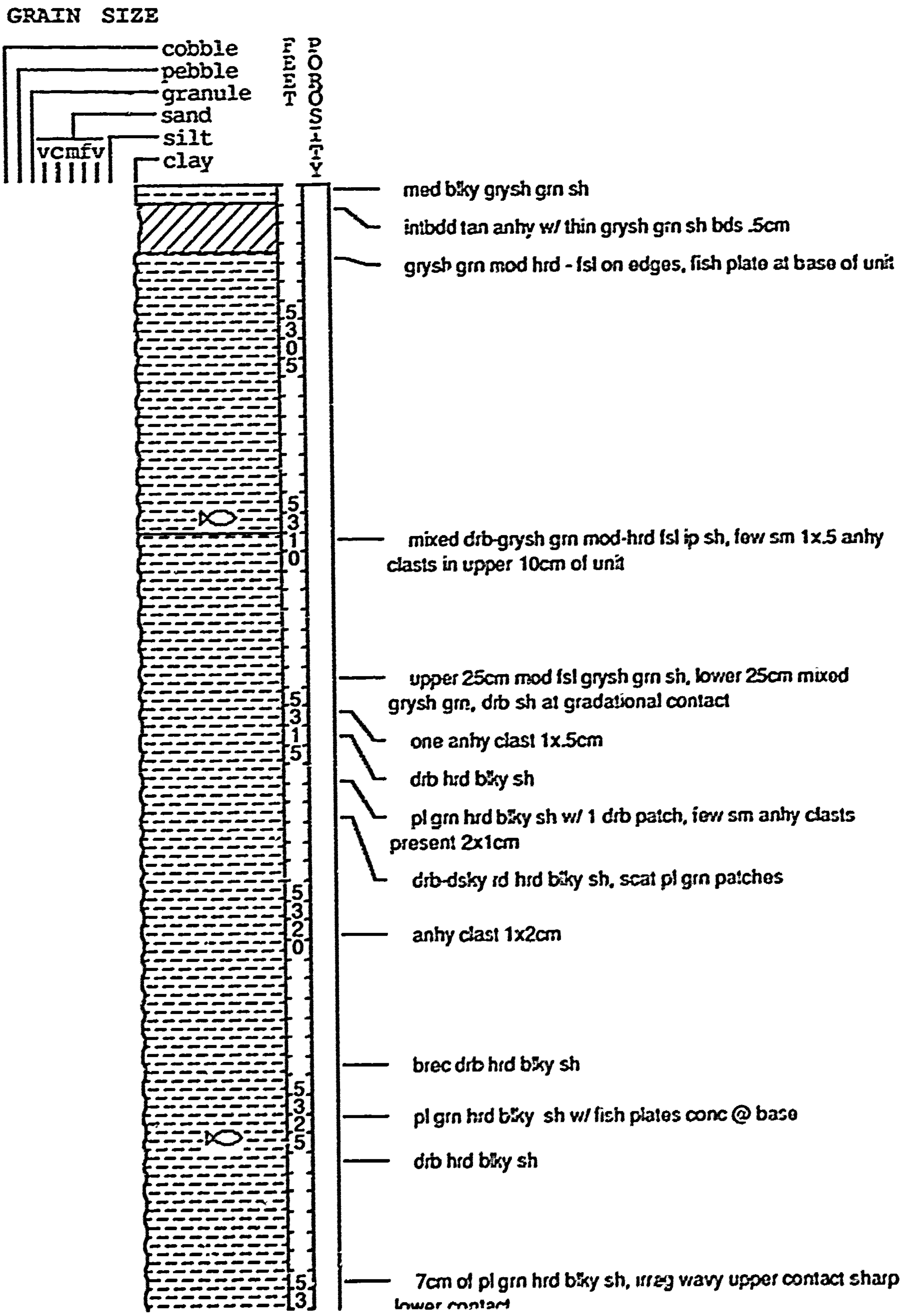
anhy clast 5x3 cm

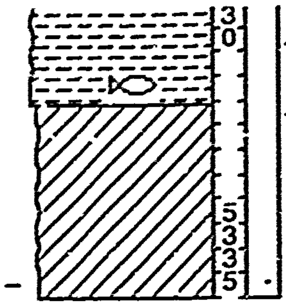
mixed & mot drb & grysh grn hrd b̃ky sh, grnish upper 5cm in contact with sndy unit

dsky grn - gry hrd b̃ky sh

tan anhy w/ horz bdd gry anhy bds

Pacific et al Nipisi
10-20-81-7w5



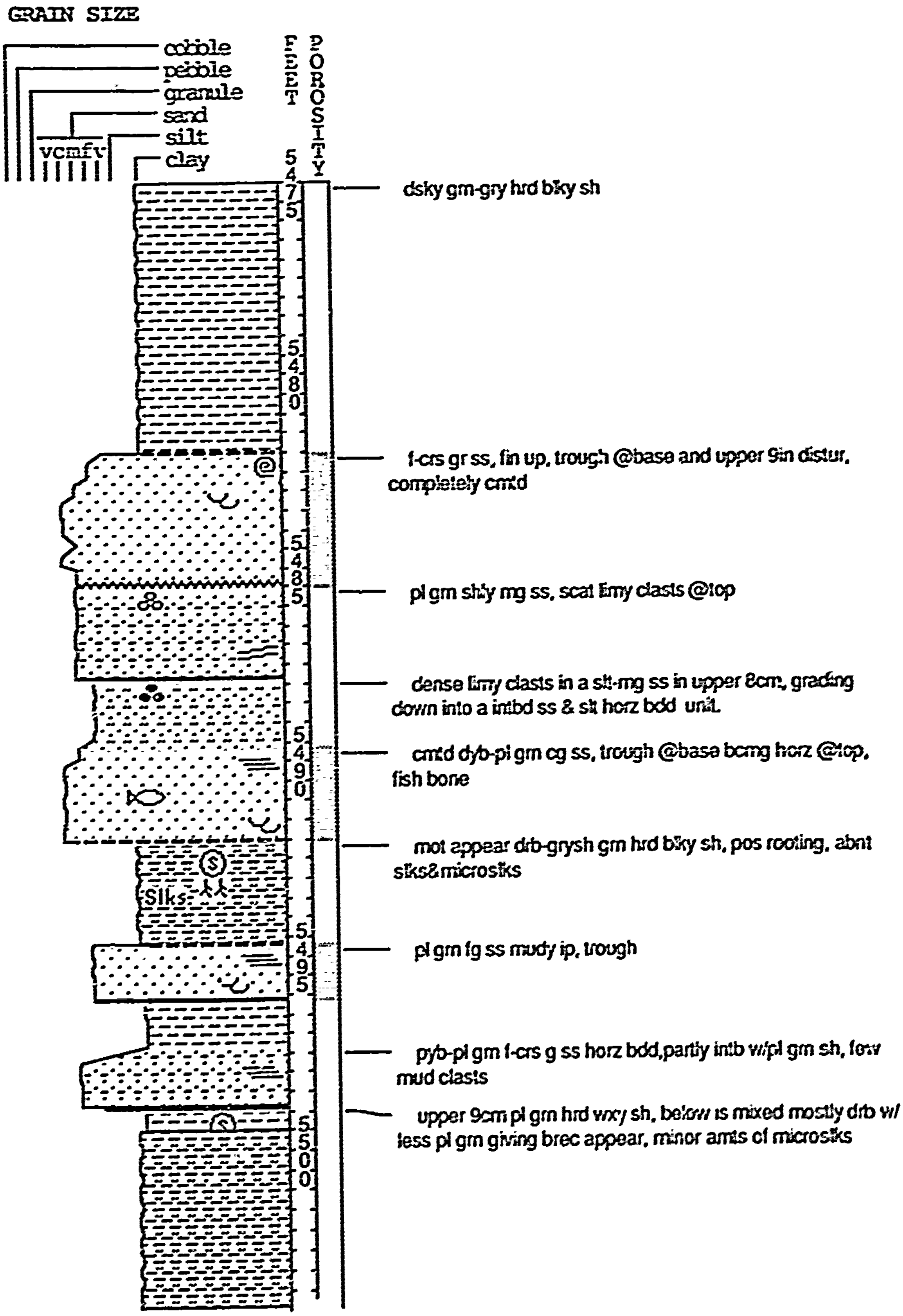


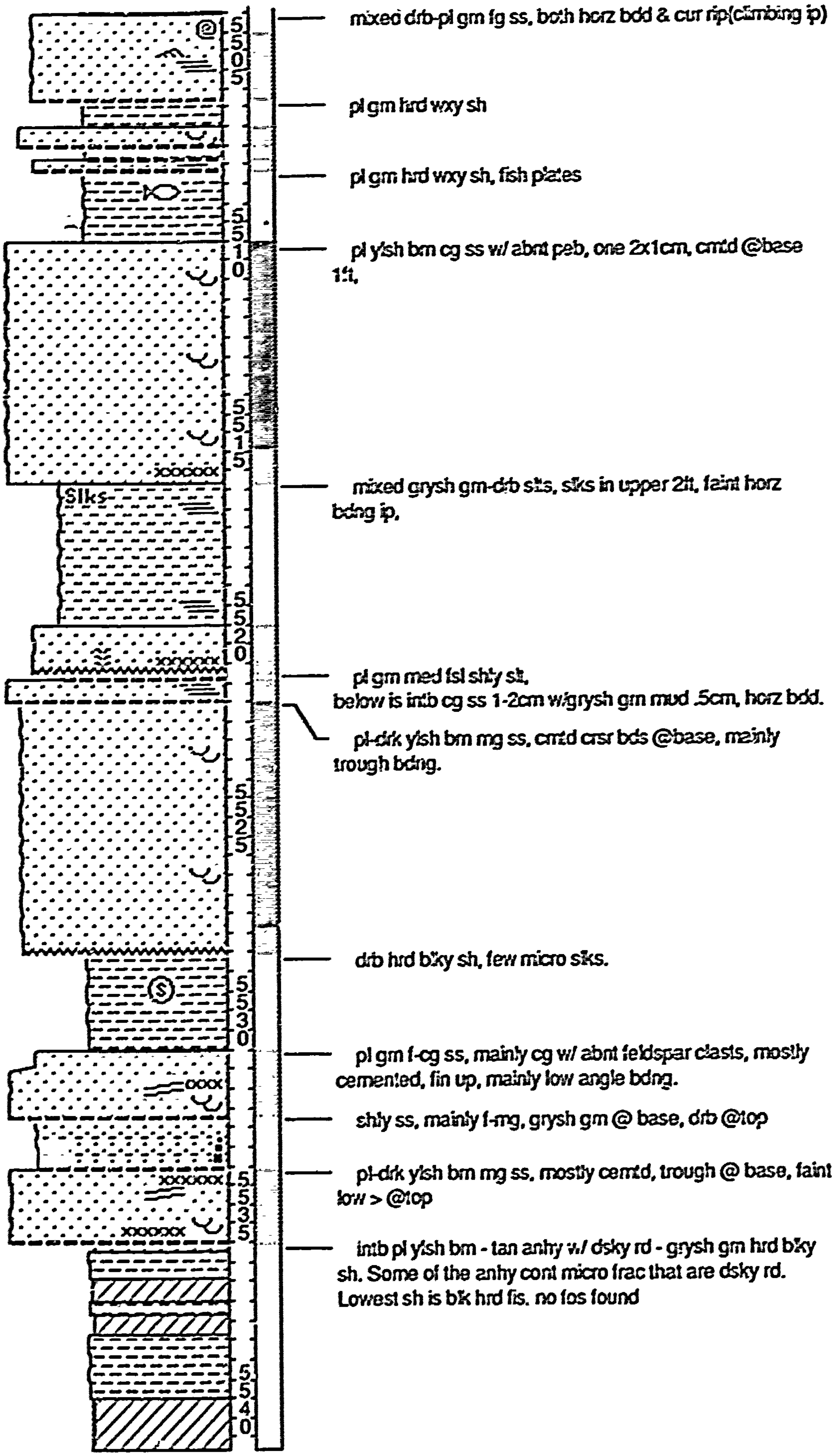
bot pl grn hrd blky sh w/ plates, grad up to drb brec in appear hrd blky sh

tan anhy, upper 24cm is brec w/ pl grn sh

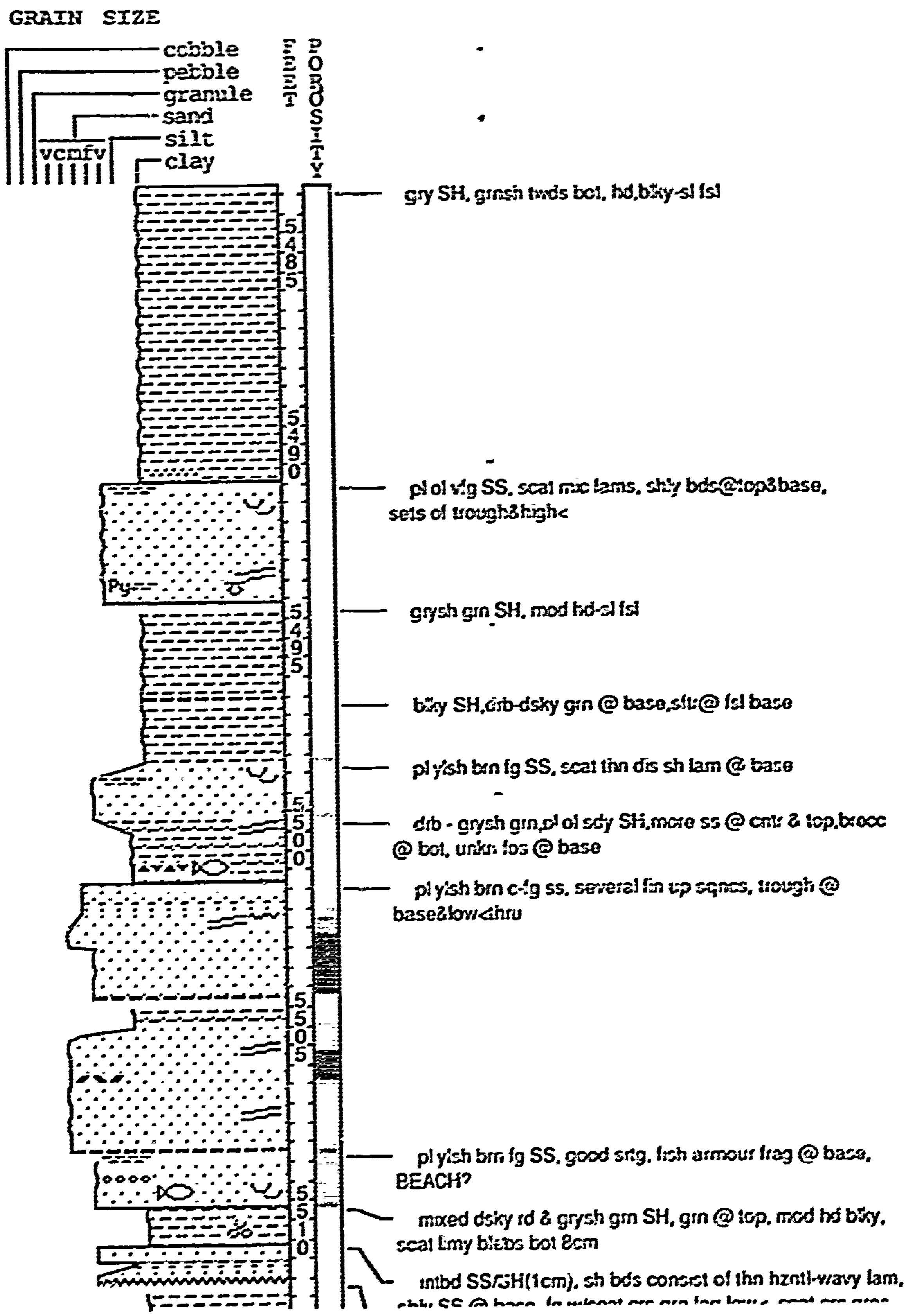
Atlantic IOE Nipisi

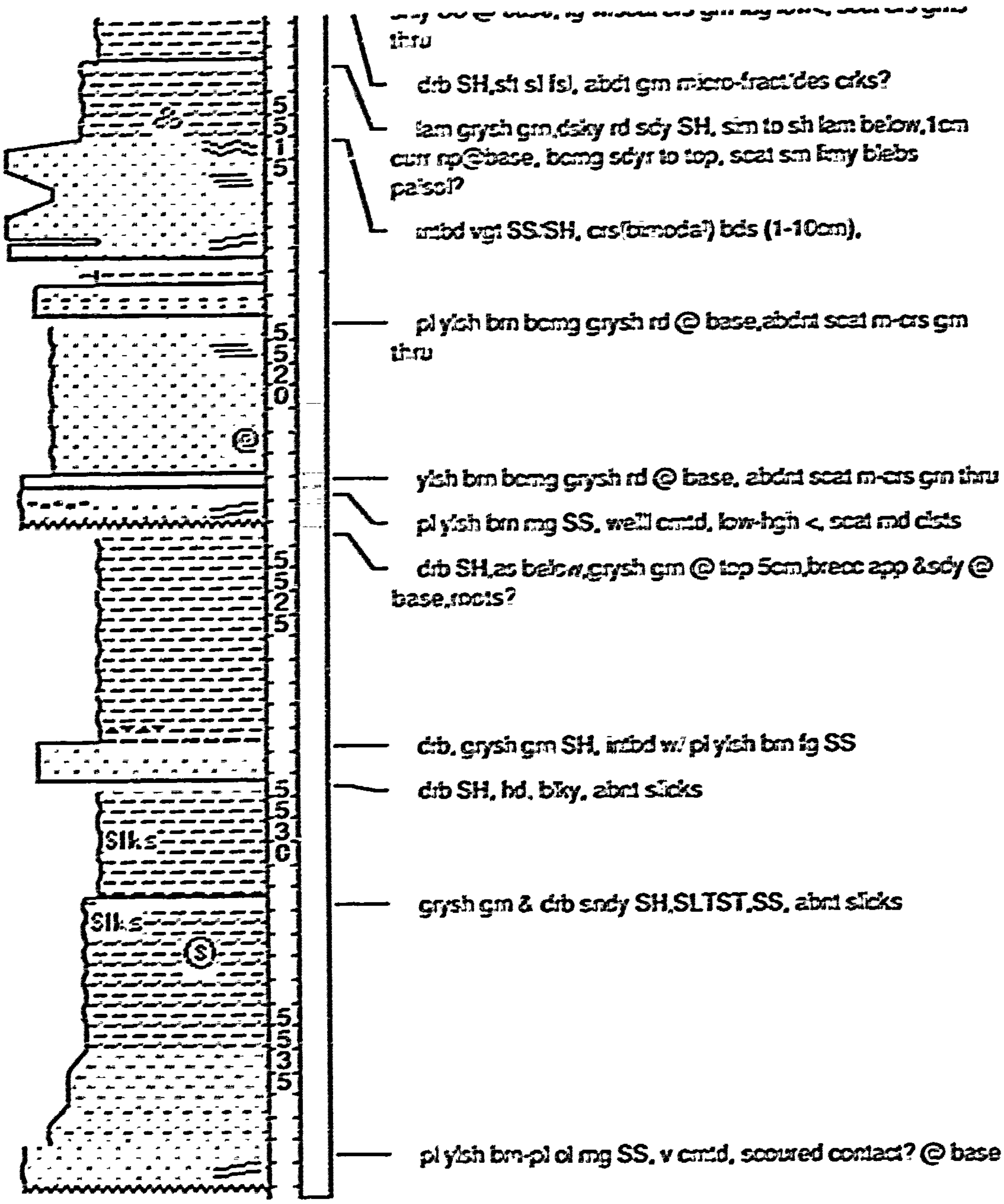
10-5-81-8w5




5505
5510
5515
5520
5525
5530
5535
5540
Slks
mixed drb-pl grn fg ss, both horz bdd & cur rip(climbing rp)
pl grn hrd wxy sh
pl grn hrd wxy sh, fish plates
pl ylsh brn cg ss w/ abnt peb, one 2x1cm, cmtd @base 1ft.
mixed grysh grn-drb slts, slks in upper 2ft, faint horz bdng rp.
pl grn med fsl shly slt.
below is intb cg ss 1-2cm w/grysh grn mud .5cm, horz bdd.
pl-drk ylsh brn mg ss, cmtd crsr bds @base, mainly trough bdng.
drb hrd blky sh, few micro slks.
pl grn f-cg ss, mainly cg w/ abnt feldspar clasts, mostly cemented, fin up, mainly low angle bdng.
shly ss, mainly f-mg, grysh grn @ base, drb @top
pl-drk ylsh brn mg ss, mostly cemtd, trough @ base, faint low > @top
intb pl ylsh brn - tan anhy w/ dsky rd - grysh grn hrd blky sh. Some of the anhy cont micro frac that are dsky rd. Lowest sh is blk hrd fis. no fos found

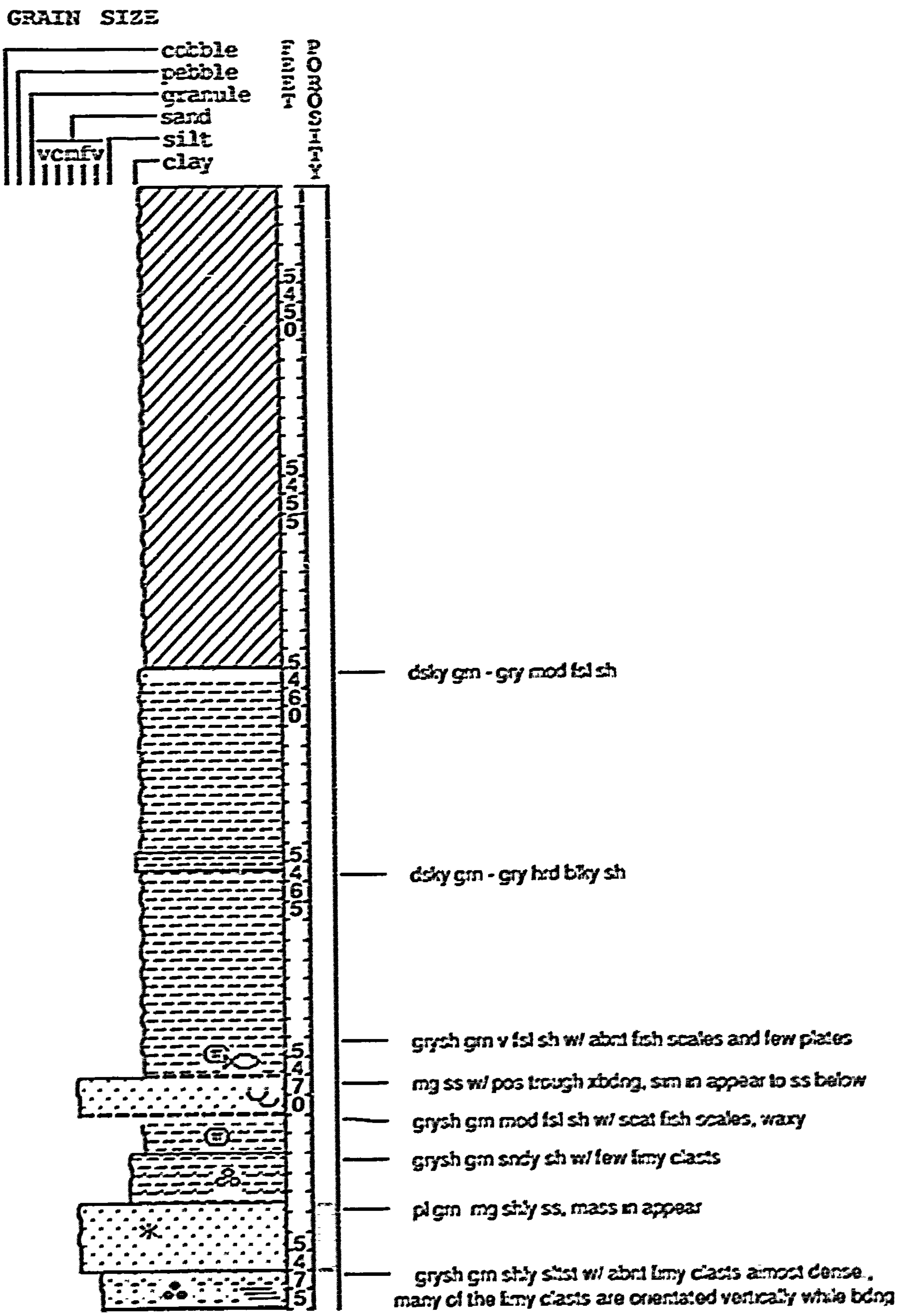
ARCO IOE NIPISI
12-5-81-8w5

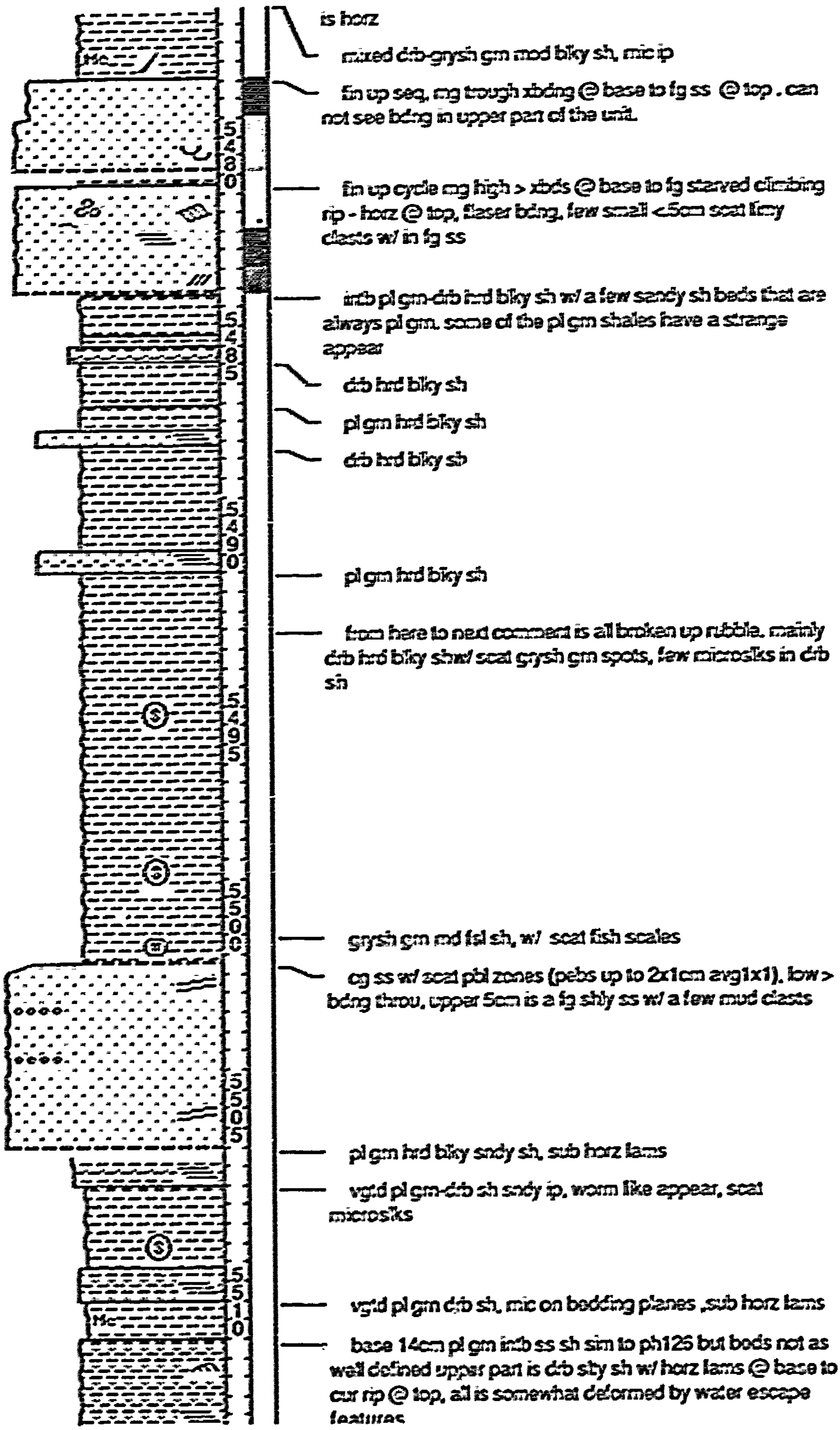



thru
drb SH,slt sl fsl, abdt grn micro-fractides crks?
lam grysh grn,dsky rd sdy SH, sm to sh lam below,1cm curr rip@base, bcmg sdyr to top, scat sm lmy blebs palsol?
intbd vgt SS/SH, crs(bimodal) bds (1-10cm).
pl ylsh brn bcmg grysh rd @ base,abdnt scat m-crs grn thru
ylsh brn bcmg grysh rd @ base, abdnt scat m-crs grn thru
pl ylsh brn mg SS, well cmtd, low-hgh <, scat rnd clsts
drb SH,as below,grysh grn @ top 5cm,brecc app &sdy @ base,roots?
drb, grysh grn SH, intbd w/ pl ylsh brn fg SS
drb SH, hd, blky, abnt slicks
grysh grn & drb sndy SH,SLTST,SS, abnt slicks
pl ylsh brn-pl ol mg SS, v cmtd, scoured contact? @ base
Slks
5
5
1
5
2
0
3

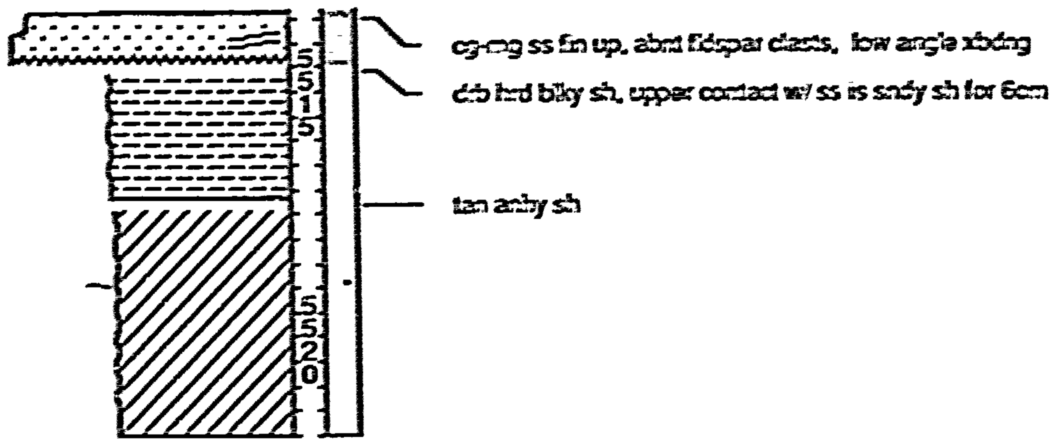
Atlantic Muskwa

4-10-81-8w5



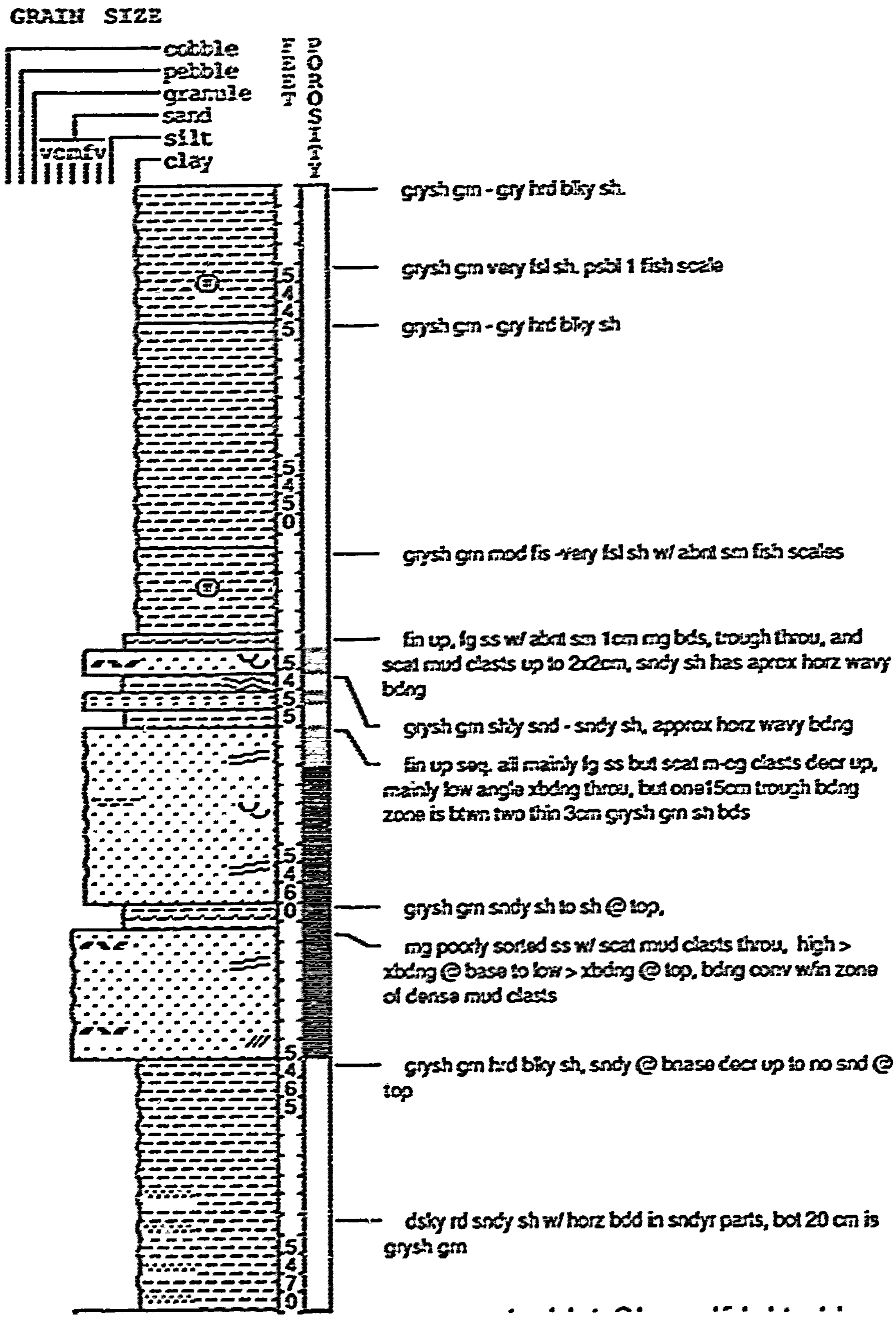


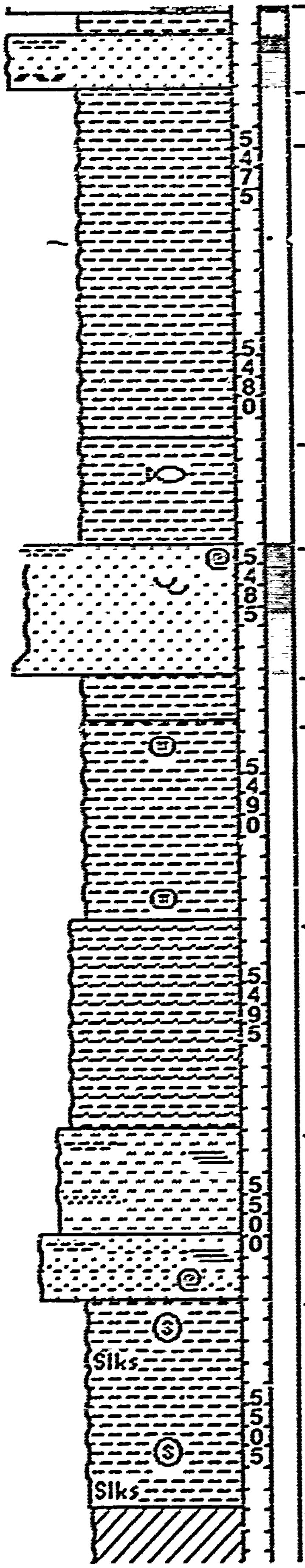
is horz
mixed drb-grysh grn mod blky sh, mic ip
fin up seq, mg trough xbdng @ base to fg ss @ top . can not see bdng in upper part of the unit.
5480
fin up cycle mg high > xbds @ base to fg starved climbing rip - horz @ top, flaser bdng, few small <5cm scat lmy clasts w/ in fg ss
intb pl grn-drb hrd blky sh w/ a few sandy sh beds that are always pl grn. some of the pl grn shales have a strange appear
5485
drb hrd blky sh
pl grn hrd blky sh
drb hrd blky sh
5490
pl grn hrd blky sh
from here to next comment is all broken up rubble. mainly drb hrd blky shw/ scat grysh grn spots, few microslks in drb sh
5495
5500
grysh grn md fsl sh, w/ scat fish scales
cg ss w/ scat pbl zones (pebs up to 2x1cm avg1x1). low > bdng throu. upper 5cm is a fg shly ss w/ a few mud clasts
5505
pl grn hrd blky sndy sh, sub horz lams
vgtd pl grn-drb sh sndy ip, worm like appear, scat microslks
5510
vgtd pl grn drb sh, mic on bedding planes ,sub horz lams
base 14cm pl grn intb ss sh sim to ph125 but beds not as well defined upper part is drb slty sh w/ horz lams @ base to cur rip @ top, all is somewhat deformed by water escape features


5
5
1
5
5
5
2
10
cg-mg ss fin up, abnt fldspar clasts, low angle xbdng
dsb hrd blky sh, upper contact w/ ss is sndy sh for 6cm
tan anhy sh

Atlantic Muskwa

4-15-81-8w5 Slabbed





ss- mg ss w/ mud clasts @ base and fish plates, bdng hard to see but bips low > and almost conv, ss cml incr to base thin sh 9cm is hrd blky & grysh grn.

grysh grn mod fsl sh to hrd blky @ top

drb mod fsl sh, mainly broken up rubble

mixed drb-grysh grn mod blky sh fsl ip, abnt fish plates and scales, bot 5cm is pl grn only, core is broken up rubble

fin up m-fg ss trough throu, top 11cm is shly and conv, many scat mg snd in lower half of unit

grysh grn hrd blky sh, bot 10cm of unit is drb, contact is grad

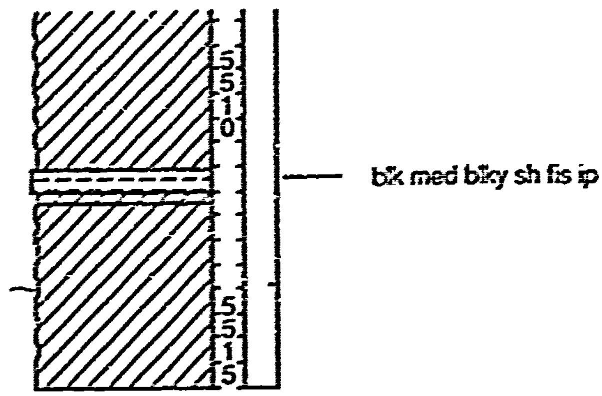
mixed drb-grysh grn mod fsl sh blky ip, scat fish scales throu, sndy ip, core is all broken up rubble

mostly drb hrd blky sndy sh w/ few grysh grn patchy areas

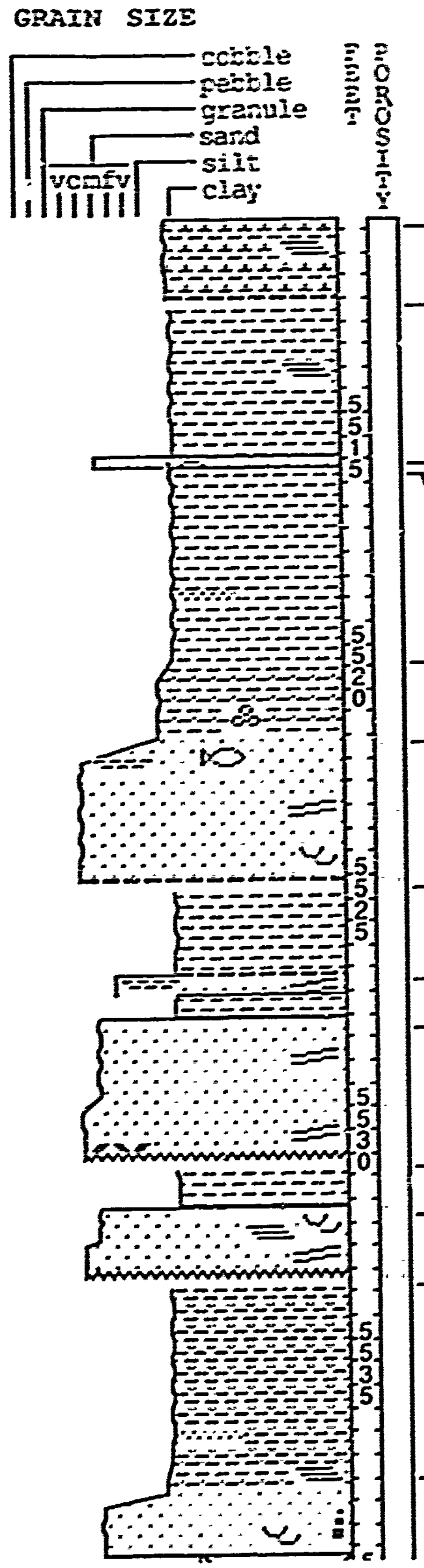
fin up unit, base conv shly fg ss, intb shly ss w/ grysh grn sh scale(1cm bds) horz bdd, upper sltst- shly sltst horz bdd to slightly wavy to top

drb-dsky rd mod blky sndy sh fsl ip, slks and microslks, few snd filled frac which are pl grn in col, upper 5cm is grysh grn bcmg mic to top

wavy horz bdd [illegible]b anhy sh, vgtd drb-tan & grysh grn ip, brec tan anhy at contact w/ upper sndy sh


5
5
1
0
blk med blky sh fis ip
5
5
1
5

Pan Am M-2 Nipisi
10-1-81-9w5



mixed cl gry-dyb horz lamd calc sh.

cl gry hrd bky sh. core box is rubble.

6cm dyb ss. well cmtd. scoured base. vert frac. bdng not vis psbl horz.

cl gry hrd bky sh., few thin .5cm sndy layers

dsky grn sndy sh. bcmg more sndy up. trace of limy clasts 1x.5cm @base

pyb cg ss. trough @ base and trough-low angle throu rest. upper 20cm is more muddier occas horz mud lams & fish bone. very var gr size throu many small 4cm fin up seq

pl grn hrd bky sh, same as thin sh unit below

pyb fg ss w/ sh lams. low angle bdng

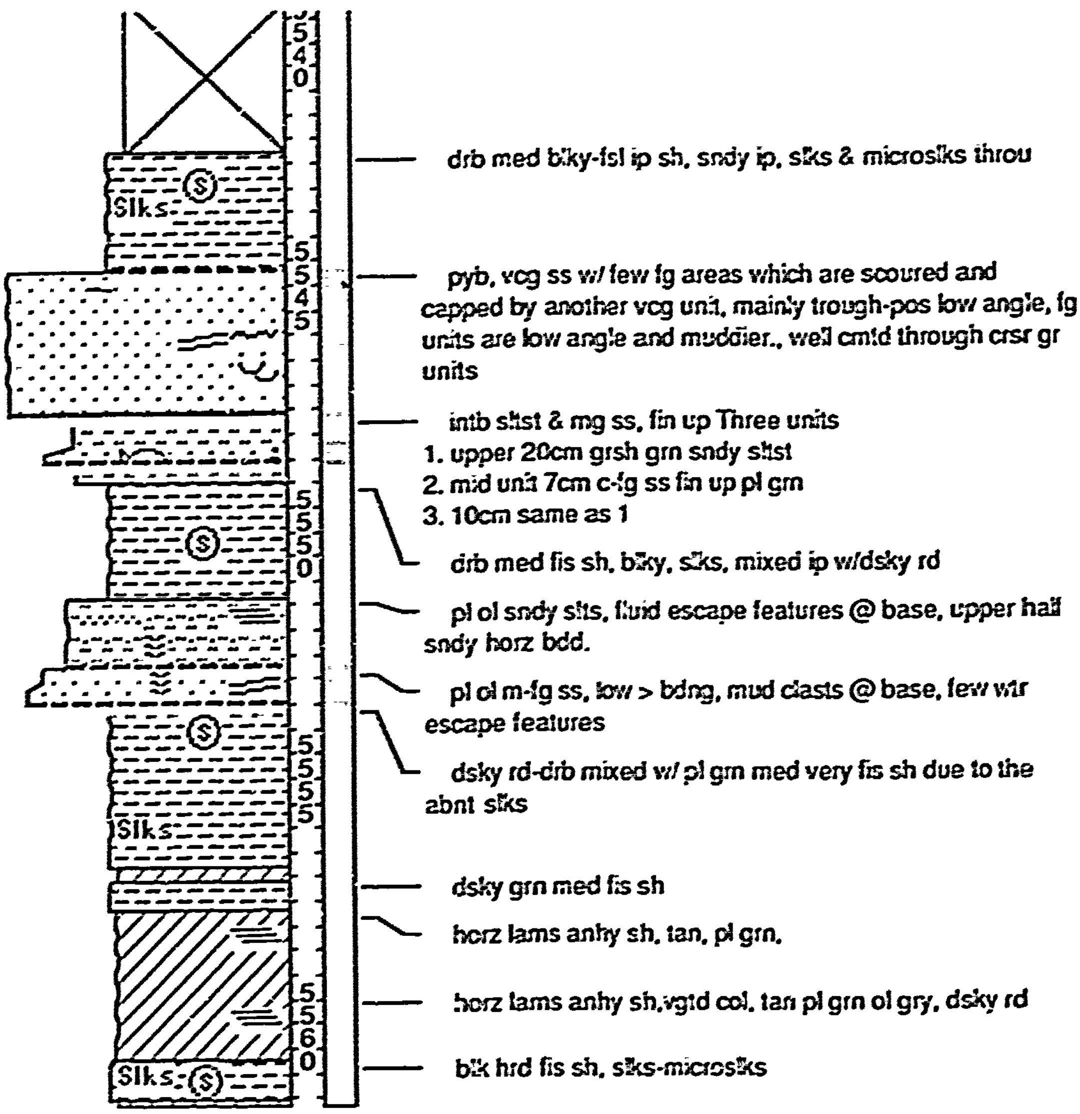
pl cl c-mg ss. low > thru. psbl high > @ base. sh rip up clasts @ base.

hrd bky sh. drb in mid and pl grn @ contacts with sand above and below

pyb vc-fg ss fin up. low angle bdng @ base. horz bdng @ top w/ mud lams.troughs near top

mainly drb-dsky rd sh sndy ip. grysh grn ip as blotches & top 5cm which is in contact w/ upper sand.

grysh grn sndy sh. horz-low angl bdng. ss below is pyb f-vcg ss. multiple fin up seq each 10cm. mud clast. muddier to top


drb med bky-fsl ip sh, sndy ip, slks & microslks throu
Slks
5545
pyb, vcg ss w/ few fg areas which are scoured and capped by another vcg unit, mainly trough-pos low angle, fg units are low angle and muddier., well cmtd through crsr gr units
intb sltst & mg ss, fin up Three units
1. upper 20cm grsh grn sndy sltst
2. mid unit 7cm c-fg ss fin up pl grn
3. 10cm same as 1
5550
drb med fis sh, blky, slks, mixed ip w/dsky rd
pl ol sndy slts, fluid escape features @ base, upper half sndy horz bdd.
pl ol m-fg ss, low > bdng, mud clasts @ base, few wtr escape features
dsky rd-drb mixed w/ pl grn med very fis sh due to the abnt slks
5555
Slks
dsky grn med fis sh
horz lams anhy sh, tan, pl grn.
horz lams anhy sh,vgtd col, tan pl grn ol gry, dsky rd
5560
blk hrd fis sh, slks-microslks
Slks