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THE UNIVERSITY OF ALBERTA

Sedimentology and Clay Mineralogy of the Glauconitic Sandstone, Suffield Heavy Oil Sands, Southeastern Alberta

(C) by

Barbara J. Tilley

A THESIS

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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Supervisor

Date October 13, 1982

Abstract

Heavy gravity oil occurs in the Glauconitic Sandstone of the Lower Cretaceous Mannville Group in the Suffield area southeastern Alberta The Glauconitic Sandstone ranges in thickness from zero to over 45 metres and has a pay zone averaging 20 metres thick The thickest sandstones occur in a northwest to southeast trending broad arch which represents an ancient shoreline position with the sea to the east Facies present in the sandstone include in ascending order coarsening-upward sandstone medium- to coarse-grained sandstone laminated sandstone argillaceous sandstone carbonaceous sandstone and shale and very fine grained sandstone siltstone and shale These facies represent in order the lower middle shoreface middle shoreface upper shoreface-foreshore backshore marsh and lagoonal or continental zones of a progradational beach system The environment is microtidal with the sandstone belt including the reservoir dissected by few tidal inlets and channels

The thickness of the pay zone depends upon the amount of structural movement on local basement faults during subsequent deposition as well as the facies distribution Movement on basement faults may also have resulted in the continuous abnormally thick progradational beach sequence

The Glauconitic Sandstone is a litharenite composed of quartz chert other sedimentary rock fragments and trace amounts of feldspar Kaolinite is the dominant clay mineral present in all sandstones Depotassified chloritized illite and interstratified illite-smectite occur in minor amounts and smectite abundance varies from a trace in the oil saturated sandstones to 10% in some sandstones below the oil water interface Chlorite is present in trace amounts The paragenetic sequence is (1) first stage calcite cementation and pyrite crystallization (2) quartz cementation and kaolinite growth (3) second stage calcite cementation feldspar leaching minor kaolinite illite crystallization and still later precipitation of calcite crystals and (4) smectite chlorite growth and hydrocarbon emplacement

The abundance of detrital kaolinite present in the sandstone is the main control on its reservoir quality The laminated facies has the best reservoir qualities high porosity low clay content and good lateral continuity Authigenic phases such as kaolinite quartz and deformed rock fragments cause only minor reduction in porosity and permeability

The argillaceous or bioturbated facies, characterized by irregular argillaceous zones, has poor reservoir qualities.

The main concern related to fluid sensitivity is the dispersion of fine kaolinite. Pyrite and Fe-chlorite are sensitive to acidization, but occur in minor amounts. An increase in temperature of the reservoir during combustion may cause a reduction in permeability as a result of formation of smectite, and the dissolution and reprecipitation of silica.

Acknowledgements

This study is based on core from the Suffield Heavy Oil Pilot project operated by Alberta Energy Company with AOSTRA, Dome Petroleum and Westcoast Petroleum as partners. I would like to thank each of these companies for their permission to examine and freely sample the confidential project core and for access to other confidential geological information. Without this access and permission to publish the findings, this thesis would not have been possible. Brian Wells, Allan Olhauser and Bill Male were very helpful in providing materials and information in relation to the SHOP project and their comments at various stages helped guide the direction of study. I also acknowledge the various suggestions made by members of the SHOP project technical committee during monthly meetings.

Fred Longstaffe at the University of Alberta supervised the project with particular emphasis on the mineralogy section and provided constructive criticism of various drafts of the manuscript. Brian Hein suggested improvements on an early draft of the thesis. John Kramers supervised the project at the Alberta Geological Survey. Gary Wightman, [illegible], Peter [illegible], Ray Rahmani, Brian Rottenfusser, [illegible] and Grant Mossop all offered advise and criticism at various stages throughout the study.

Numerous people provided technical support both at the Research Council and at the University of Alberta. Thin sections, SEM mounts, [illegible] extractions and grain size analyses were done by Tim Berezniuk, Max Baaske, [illegible] and Campbell [illegible]. A survey of the clay mineralogy was provided by XRD analyses run by Susan [illegible]. Diane Caird at the University of Alberta [illegible] and [illegible] processed and ran samples for detailed x-ray diffraction and powder camera analyses. [illegible] data was processed by Bruno [illegible]intergasser and interpreted by [illegible]. Most diagrams were drafted by the Research Council drafting department and photographic plates were printed by Leslie [illegible], Sandra Walser and [illegible] Dugan provided varied technical assistance and Joan Chechouk, Linda [illegible], Kathy Skogg and [illegible] Binda typed the tables and figure captions. I wish to express my appreciation to all of these people and to all others who helped in any way.

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I. INTRODUCTION

Heavy gravity oil (13° API) occurs in the Glauconitic Sandstone of the Lower Cretaceous Mannville Group in southeastern Alberta. This study is based largely on cores from the Suffield Heavy Oil Pilot (SHOP) project. The pilot, which taps the Glauconitic Sandstone, is located north of Medicine Hat on the northwestern corner of a Special Oil Production Area within the Suffield Military Range (Fig. 1). The experimental aspect of the SHOP project is the application of in situ wet combustion in a reservoir where the oil zone is underlain by water. The project consists of an inverted five spot pattern (Fig. [illegible]) with the production wells [illegible] an area of [illegible]. The pilot is operated by Alberta Energy Company with Alberta Oil Sands Technology and Research Authority, Home Petroleum and Westcoast Petroleum as partners.

A. Purpose of this Study

[illegible] cores include the entire Glauconitic [illegible] zone. The purpose of this study [illegible] these [illegible] development [illegible] understanding of the [illegible] SHOP project [illegible] study were to:

1. Determine the depositional environment [illegible]

2. [illegible]

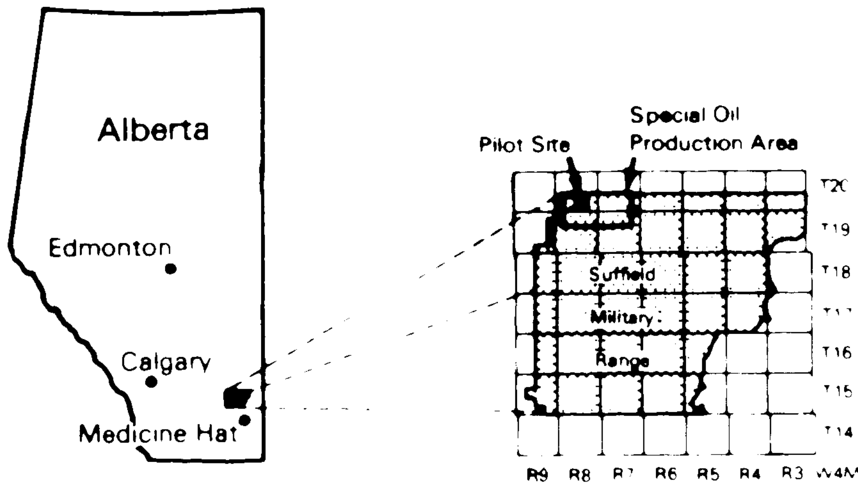


FIGURE 1 Location of the Suffield Heavy [illegible] project

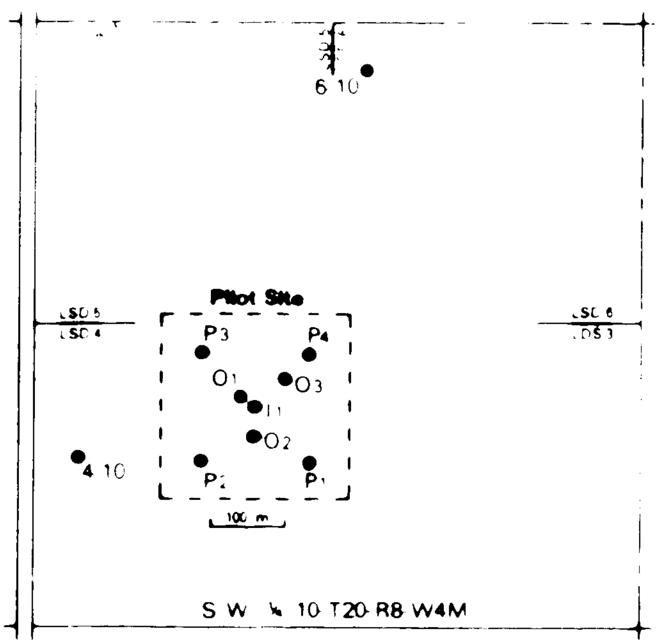


FIGURE 2 Map of the SHOP project site showing the location of the Production, [illegible] and observation wells.

reservoir is essential especially where large volumes of fluids are pumped through a formation at high temperatures as in the wet combustion recovery process.

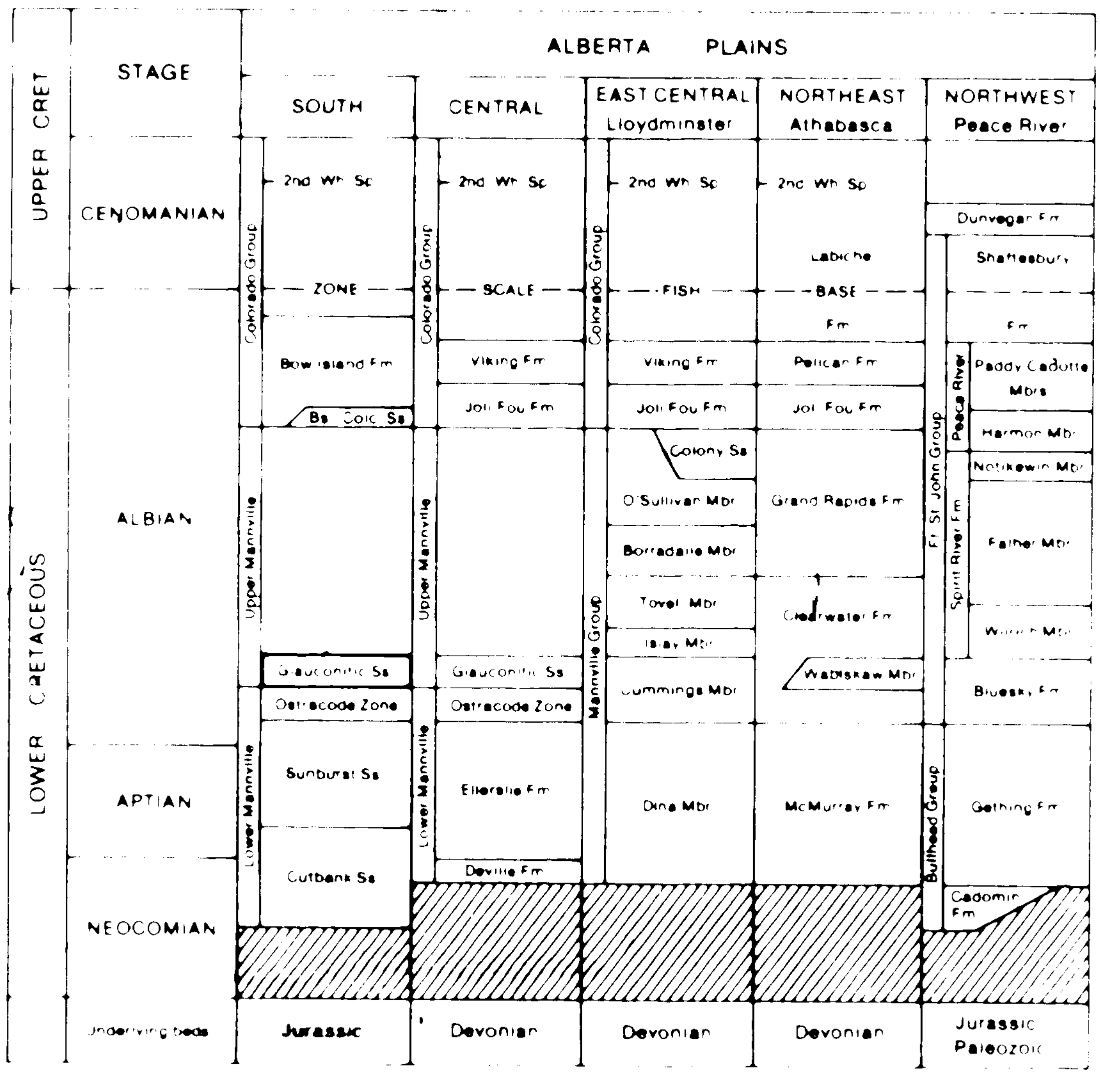
B. Geological Setting

The Glauconitic Sandstone occurs at the base of the Lower Cretaceous Upper Mannville Formation. It is underlain by calcareous sediments of the "ostracode zone"[1] and overlain by a continental sequence of sand, silt, shale and coal in south and central Alberta (Fig. 3). In the SHOP project area the Glauconitic Sandstone is 45 metres thick with an average pay thickness of 20 metres. Thick sandstone (>15m) occurs in a broad arch extending to the northwest and southeast of the pilot site (Map 1 in pocket). This belt of sandstone, which is 5 to 10 kilometres wide and a minimum of 35 kilometres long, is the focus of this study. A less extensive belt of thinner sandstone occurs four miles to the east of the major sandstone belt but was not studied in detail. The stratigraphic equivalent of the Glauconitic Sandstone to the west of the thick sandstone belt is an [illegible] sequence of thin sandstone, siltstone, shale and coal and to the east the sandstone is [illegible] character.

C. History of the Term "Glauconitic Sandstone"

The Glauconitic Sand Series was first described in the Edmonton [illegible] Stettler area by Layer (1949) who divided the Mannville Group sediments into the [illegible] Series, Glauconitic Sand Series, and the Quartz Sand Series. Loranger (1951) began the division of the Glauconitic Sand Series into the Glauconitic Sand at the top and the Ostracode Zone. [illegible] Alberta Society of Petroleum Geologists (1960) [illegible] workers studying the Mannville Group correlated the glauconitic sand unit over a large part of Alberta. It has been correlated with the Bluesky Formation in northwest Alberta, the Wabiskaw Member of the Clearwater Formation in northeast Alberta and the upper part of the Cummings Member in east central Alberta (Fig. 3; Rudkin, 1964). In local areas throughout Alberta the Glauconitic Sandstone has been called the Bluesky, Wabiskaw, Glauconitic [illegible]

[1] The ostracode zone was originally described by Loranger (1951) as a biostratigraphic zone. Years of incorrect usage of the term ostracode zone has resulted in its common recognition as a lithostratigraphic unit correlative to the Calcareous Member of the southern Foothills (Rudkin, 1964).



UPPER CRET
LOWER CRETACEOUS
STAGE
CENOMANIAN
ALBIAN
APTIAN
NEOCOMIAN
Underlying beds
ALBERTA PLAINS
SOUTH
CENTRAL
EAST CENTRAL
Lloydminster
NORTHEAST
Athabasca
NORTHWEST
Peace River
2nd Wh Sp
ZONE
SCALE
FISH
BASE
Colorado Group
Upper Mannville
Lower Mannville
Mannville Group
Ft St John Group
Bullhead Group
Peace River
Spirit River Fm
Dunvegan Fm
Labiche
Shaftesbury
Fm
Bow Island Fm
Bs Colo Ss
Viking Fm
Joli Fou Fm
Pelican Fm
Paddy Cadotte Mbrs
Harmon Mbr
Notikewin Mbr
Colony Ss
O'Sullivan Mbr
Grand Rapids Fm
Borradaile Mbr
Falher Mbr
Tovel Mbr
Clearwater Fm
Islay Mbr
Glauconitic Ss
Cummings Mbr
Wabiskaw Mbr
Bluesky Fm
Ostracode Zone
Sunburst Ss
Ellerslie Fm
Dina Mbr
McMurray Fm
Gething Fm
Cutbank Ss
Deville Fm
Cadomin Fm
Jurassic
Devonian
Jurassic
Paleozoic

Islay and Kerkhoff

Glauconitic Sandstone is not an approved geological name for a formation. In 1959 Workman proposed the term Bluesky Formation be re-defined and extended from the Peace River region to designate the sandstone previously called the Glauconite Sandstone. He advocated an approved geological name for the Glauconitic Sandstone for the following reasons (1) the unique stratigraphic position of the Glauconitic Sand (2) its widespread occurrence (3) its importance to the oil and gas industry (4) because glauconite can not always be detected in it and (5) there are other glauconite sands in the Blairmore[1] (Workman 1959). His proposal was largely ignored by later workers who perpetuated the terms Glauconitic Sandstone (Rudkin 1964, Herbaly 1974), Glauconite Sandstone (Conybeare 1976) and Glauconite Sand (Holmes and Rivard 1976). As can be seen, there is no consistent title used for this sandstone.

Since the Glauconitic Sandstone in the study area contains only trace amounts of glauconite, the term glauconitic is a misnomer. However, the name Glauconitic Sandstone is recognized by the operators in the area and various other workers in southern Alberta. In order to avoid confusion, the term Glauconitic Sandstone will be continued in this thesis.

D. Previous Work

The Glauconitic Sandstone in the Suffield area of southeastern Alberta was examined briefly by Herbaly (1974) and Holmes and Rivard (1977). Herbaly (1974) described the sandstone (>100 ft thick) as an almost dune like development cut by silt filled channels. Holmes and Rivard (1977) studied cores from two pools in the Jenner field (Twps 20 & 21, Rge 8 W4) and interpreted the sandstone as a barrier island deposit representing the last marine deposition of the Upper Mannville section. They also described the petrology of the sandstone.

Regional studies indicate that the percentage of glauconite in the Glauconitic Sandstone decreases east of the 5th meridian and south of Edmonton (Glaister 1959 and Conybeare 1976). The sandstone is predominantly marine in the Edmonton area and

[1]Blairmore is the Mannville equivalent in the southern Foothills.

becomes more nonmarine towards the south The thickness of the sandstone ranges from an average of 6 to 9 metres to greater than 30 metres and changes markedly over a distance of a few kilometres (Conybeare 1976 Workman 1958)

Individual field studies provide some understanding of the regional variation in depositional environment The Glauconitic Sandstone in southernmost Alberta (Twps 1 15 Rges 16 20 W4) has been interpreted as representing floodplain and channel deposits (Herbaly 1974 and Brown 1976) Herbaly (1974) also postulated channel deposition in the Countess field area (Twps 18 20 Rges 15 17 W4 In the Little Bow area (Twps 14 & 15 Rge 20 W4) Hermanson et al (1982) described subtidal marine bars locally cut by channels in the Carbon field (Twp 29 Rge 22) the Glauconitic Sandstone has been interpreted as a tidal channel (Conybeare 1976

E **Methods**

The eight cores from the SHOP project which form the basis of this study were examined described in detail and sedimentary facies were defined Core logs for each well are included in Appendix A A total of 42 samples representing units of varying lithology grain size sedimentary structures or oil saturation within each well were analyzed for grain size properties and examined in thin section and by scanning electron microscopy (SEM) for mineralogy texture pore morphology and diagenesis A survey of the clay minerals present in the < 2 micrometre size fraction of the SHOP project sandstones was obtained from X ray diffraction analyses performed by Alberta Research Council

In order to obtain a regional perspective on the sedimentary environment represented by the Glauconitic Sandstone and to observe any regional mineralogical variations cores from a total of 7? wells surrounding the pilot site were also examined Unfortunately many of these cores are only 10 to 20 metres long and include only the mid portion of the Glauconitic Sandstone Therefore the sequence of facies could only be defined from the SHOP project cores and correlated to regional wells wherever there was sufficient core Thirty five samples representing 15 regional wells were examined in thin section and by SEM A detailed clay mineralogical study involved XRD of these samples as well as re-examination of sandstone samples from well O2 XRD procedures for these analyses are described in Appendix B

A sandstone thickness map for the Glauconitic Sandstone (Map 1) was computer-generated from a data base of 758 wells The sand thickness for each well was determined based on the 70 per cent sand/shale line on the gamma-ray logs

Twelve shale or silty-shale samples from below within and above the Glauconitic Sandstone were selected for palynological analysis The samples were examined for palymorphs and dinoflagellates by C Singh

II FACIES ANALYSIS

A Facies Descriptions

The Glauconitic Sandstone consists of six lithological facies[1]. In ascending order these include coarsening upward sandstone, medium- to coarse-grained sandstone, laminated sandstone, argillaceous sandstone, carbonaceous sandstone and shale, and fine-grained sandstone, siltstone and shale. Although these facies have been defined entirely on the basis of the eight cores from the SHOP project, they are generally applicable within the regional framework. Three cores (wells [illegible], [illegible] and [illegible]) from the SHOP project include almost the entire Glauconitic Sandstone interval, whereas cores from wells in the regional setting generally include only small portions of the interval. The most important variations within facies are described as subfacies. These subfacies apply to local phenomena which are of limited lateral extent.

The grain mineralogy of the Glauconitic Sandstone is fairly uniform (Table [illegible]), consisting of quartz, approximately equal proportions of chert and other sedimentary rock fragments, and trace amounts of feldspar. Only mineralogical anomalies are discussed in the facies descriptions. The distribution of facies within the SHOP project wells relative to geophysical logs is shown in Figures 4 and 5. A summary of grain size analyses for samples representing each facies is given in Table [illegible]. Table [illegible] is a summary of porosities for each facies.

Facies 6 Coarsening-upward sandstone

Facies 6 is the lowermost unit of the Glauconitic Sandstone and lies gradationally above the Ostracode zone. It consists of a siltstone or very fine-grained sandstone which gradually coarsens upwards to fine-grained sandstone. The sandstone is [illegible] well sorted and contains [illegible] to [illegible] percent clay. Subfacies [illegible] comprises [illegible] of the total thickness. Subfacies 6b is characterized by a light grey, light to very fine-grained sandstone which has well defined laminations (Plate [illegible]). Carbonaceous debris commonly outlines laminations, especially in the lower portion of facies 6. Sedimentary structures include horizontal planar laminations, cross-laminations, wave

[1]Facies are defined on the basis of observed lithologic variations within the Glauconitic Sandstone and the descriptions include all the characteristics that make an environmental interpretation possible. See Krumbein and Sloss (1963) for a detailed discussion of the definition of facies.

Table [illegible] Grain Percentages Based [illegible]

Facies	Sample	Log Depth	Quartz	[illegible]	Rock Fragments	Feldspar	[illegible]aques
3a	147	911.3	[illegible]	[illegible]	[illegible]	4	
3c	148	912.3	6[illegible]	[illegible]	[illegible]		[illegible]
3d	149	915.3	6[illegible]	[illegible]	[illegible]		[illegible]
4	[illegible]51	929.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]52	940.5	3[illegible]	4	[illegible]		
6a	[illegible]53	944.2	[illegible]	[illegible]	[illegible]		
6[illegible]	[illegible]55	953.4	68			4	[illegible]
6c	[illegible]54	[illegible]52.6	[illegible]		[illegible]	[illegible]	[illegible]

300 po[illegible] were counted for each se[illegible]

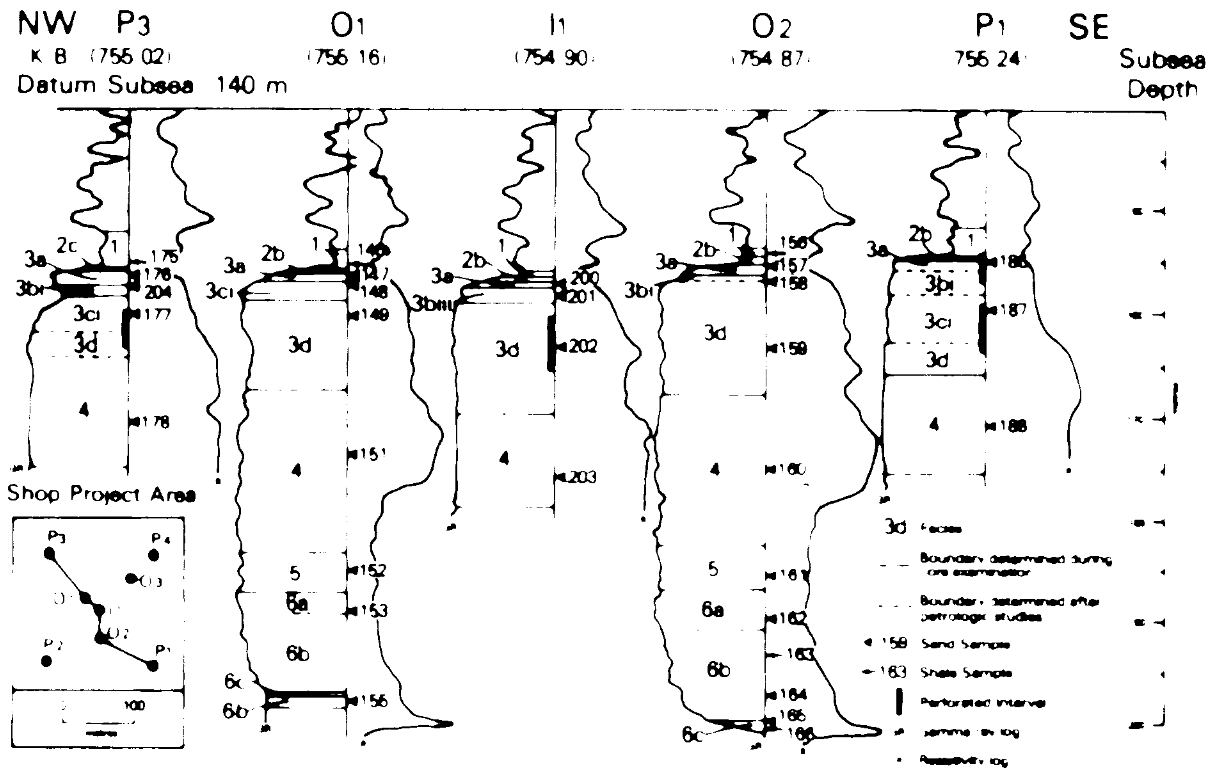


FIGURE 4. Northwest ... showing the ... geophysical ...

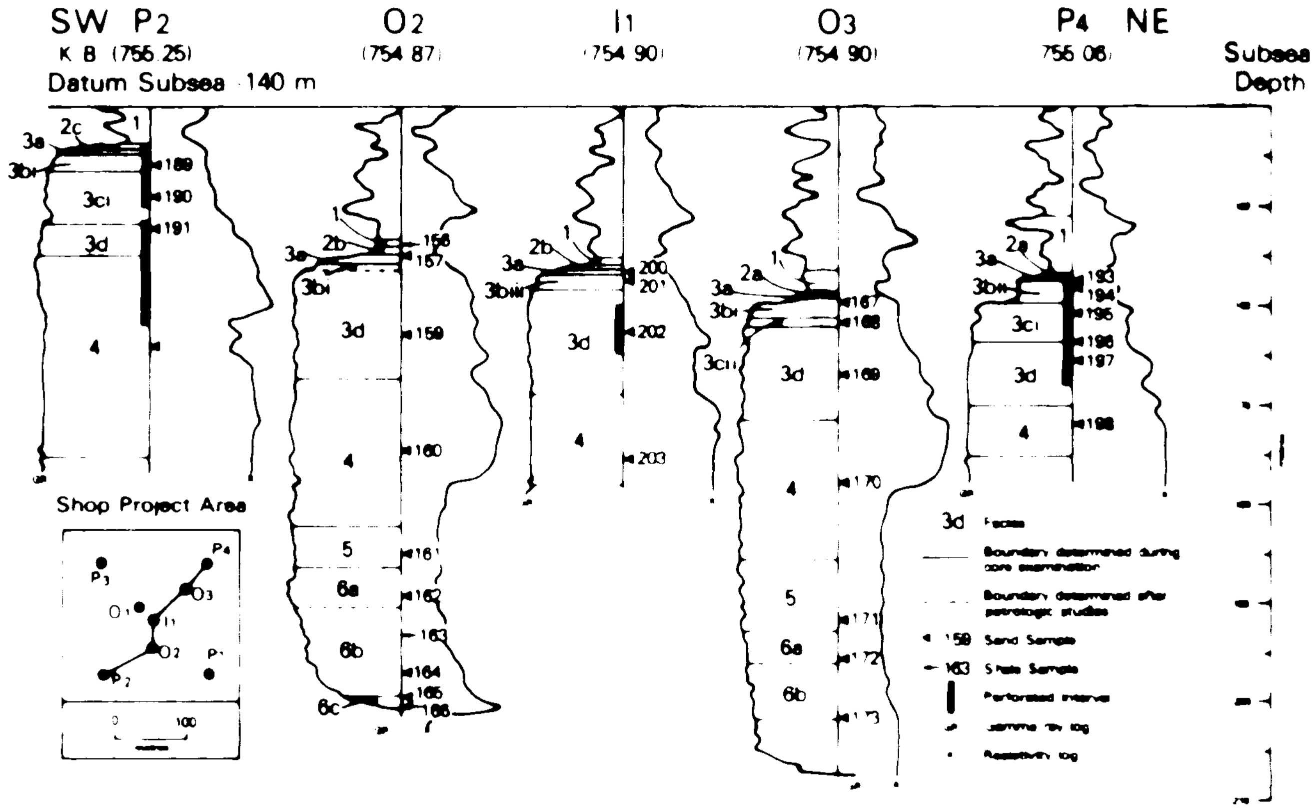


FIGURE [illegible] Southwest–[illegible]rtheast [illegible] [illegible] the [illegible] area, show[illegible] the [illegible] sam[illegible]es [illegible] the [illegible]eophys[illegible]

Table 2. Summary of Grain Size Analyses

Sample[1]	Facies	Depth (m)[2] Log	Depth (m)[2] Drilling	Composition (wt %) Sand	Silt	Clay	Grain Size (µm) Median	Mean	Largest	Standard Deviation
Well [illegible]0										
[illegible]	3a	[illegible]	[illegible]	73.06	[illegible]	[illegible]	[illegible]	[illegible]	350	[illegible]
[illegible]	[illegible]	912.[illegible]	912.[illegible]	83.8[illegible]	6.56	9.6[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	3d	915.[illegible]	915.[illegible]	[illegible]	6.[illegible]	5.94	[illegible]	90	[illegible]	[illegible]
[illegible]	[illegible]	929.[illegible]	929	86.6[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	940.5	940.6	97	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6a	944.[illegible]	944.[illegible]	86.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6[illegible]	951.[illegible]	[illegible]	65.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Well [illegible]										
[illegible]	3a	[illegible]	[illegible]	69.[illegible]	[illegible]	[illegible]	[illegible]	66	00	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	3d	[illegible]	[illegible]	89	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	929.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6[illegible]	[illegible]	[illegible]	[illegible]	18.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Well [illegible]										
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	92[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6a	950.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6[illegible]	956.[illegible]	[illegible]	[illegible]	[illegible]	5.50	[illegible]	[illegible]	[illegible]	[illegible]
Well [illegible]										
[illegible]	[illegible]	[illegible]	[illegible]	58.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	926.[illegible]	[illegible]	86.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Well [illegible]										
89	3[illegible]	90[illegible]	90[illegible]	6[illegible]	16.70	5.84	39	[illegible]	[illegible]	[illegible]
90	[illegible]	904.[illegible]	90[illegible]	[illegible]	18.42	8.44	[illegible]	6	[illegible]	[illegible]
9[illegible]	3d	90[illegible]	908.[illegible]	84.9[illegible]	[illegible]	1.26	[illegible]	[illegible]	00	[illegible]
9[illegible]	4a	919.6	920.[illegible]	86.[illegible]	9.8	[illegible]	[illegible]	9[illegible]	[illegible]	[illegible]
Well [illegible]										
[illegible]	3a	[illegible]	909.[illegible]	62.03	16.[illegible]	2[illegible].80	[illegible]28	[illegible]	50	[illegible]
204	3b	912.[illegible]	912.[illegible]	76.26	14.[illegible]	9.59	[illegible]49	[illegible]	[illegible]00	[illegible]
[illegible]	3[illegible]	915.[illegible]	915.[illegible]	75.80	16.[illegible]	[illegible]	[illegible]	68	[illegible]	[illegible]
[illegible]	4	926.0	926	90.[illegible]	[illegible].58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Well [illegible]										
[illegible]	3a	913.0	913.0	36.5[illegible]	35.36	28.[illegible]	[illegible]	[illegible]	50	[illegible]
94	3b	913.[illegible]	914.0	66.6[illegible]	17.79	15.60	[illegible]	48	50	[illegible]
9[illegible]	3[illegible]	916.[illegible]	916.[illegible]	67.84	15.38	16.[illegible]	[illegible]	46	[illegible]000	[illegible]
9[illegible]	3[illegible]	919.[illegible]	918.[illegible]	77.07	13.0[illegible]	9.92	[illegible]	6[illegible]	[illegible]000	[illegible]
9[illegible]	3d	92[illegible]	923.3	84.26	[illegible]	[illegible]	[illegible]66	90	[illegible]000	[illegible]
98	4	92[illegible].9	928.[illegible]	90.[illegible]	6.99	2.8[illegible]	[illegible]	[illegible]	500	[illegible]
Well [illegible]										
200	3a	9[illegible]	909.[illegible]	75.22	14.78	0.00	[illegible]66	8[illegible]	20[illegible]	[illegible]
20[illegible]	3b	912.[illegible]	910.[illegible]	82.[illegible]	7.49	10.36	[illegible]	[illegible]	[illegible]	[illegible]
202	3d	91[illegible].8	915.5	91.3[illegible]	7.65	[illegible].04	[illegible]	[illegible]	50[illegible]	[illegible]
20[illegible]	4a	930.[illegible]	92[illegible]	92.27	7.18	[illegible]	[illegible]	[illegible]	[illegible]000	[illegible]

[1] Sample numbers not listed are either shale samples, carbonate cemented, or repetitions of samples already analyzed.
[2] Depth - Log depths correspond to depths on geophysical well logs.

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Table 3. Average Porosities[1]

				We[illegible]				
Facies	O1	O2	O3	P1	P2	P3	P4	[illegible]	Overall
3a	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
3b		[illegible]	[illegible]	[illegible]	13	[illegible]			[illegible]
3[illegible]					[illegible]		[illegible]		[illegible]
3c								22	22
3[illegible]	22			2[illegible]	2[illegible]	2[illegible]	2[illegible]		2[illegible]
3[illegible]			2[illegible]						2[illegible]
3[illegible]	2[illegible]	2[illegible]	26	[illegible]	25	2[illegible]	25	26	26
4	26	2[illegible]	29	28	2[illegible]	2[illegible]	29	2[illegible]	2[illegible]
5	25	25	29	-					26
6a	26	28	29	-					28
6b	23	22	2[illegible]		-				24
6c	15	10	-	-	-				[illegible]

[1] Values from core analyses by Core Laboratories-Canada Ltd.

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ripples (Plate [illegible]) and small scour and fill structures ([illegible] cm diameter). Burrows and bioturbated zones are rare in subfacies 6b and thin shale beds occur mainly in the lower portion. Bedding thickness is commonly greater than [illegible] centimetres. [illegible] The SHOP project cores do not penetrate the base of the [illegible] Sandstone but [illegible] subfacies 6b is at least [illegible] 9 metres thick.

Subfacies 6[illegible] [illegible] cemented siltstone [illegible] fine grained sandstone [illegible] commonly laminated [illegible] burrowed with some partially bioturbated [illegible] shale interbeds with syneresis cracks (Plate [illegible]). [illegible] cemented zone may represent the [illegible] Sandstone as suggested [illegible] may be underlain by at least [illegible] metres of the [illegible] carbonate cemented subfacies 6b [illegible]

Subfacies [illegible] in the upper [illegible] transition from facies [illegible] metre [illegible] bioturbated [illegible] structureless [illegible] laminated (Plate [illegible]) [illegible] subfacies 6b but [illegible] than facies [illegible]

Facies 5 Medium- to coarse-grained sandstone

[illegible]

[illegible]

[illegible] The actual contact between facies [illegible] seen [illegible] small pieces ranging from a few centimetres to ten[illegible] centimetres [illegible] commonly [illegible] at the [illegible] removed. Therefore [illegible] be [illegible] represented [illegible] gradational contact; coarser interbeds gradually becoming less abundant upwards.

Facies 4 Laminated sandstone

Facies 4 consists of a relatively clean (<4% [illegible] clay content) fine grained sandstone which characteristically has horizontal planar lamination and low angle cross lamination (Plate [illegible]). The sandstone is well sorted with concentrations of dark coloured heavy grains defining the lamination rather than significant grain size change. No shale laminations or beds are present. Higher angle laminations, bioturbated beds and disturbed laminations are minor [illegible] structures [illegible] beds and beds [illegible] (Plate [illegible]) are [illegible] whereas [illegible] horizontal planar laminations are [illegible] [illegible]

[illegible]

Facies 3 Argillaceous sandstone

[illegible]

subfacies 3d and limit its reservoir potential. Clay content varies from [illegible] to 6 percent in the samples analyzed from this subfacies. Angular, randomly oriented breccia blocks (Plate [illegible]) found in a [illegible] metre thick interval in well [illegible] are laminated. The matrix of the breccia is a slightly coarser, clay rich sandstone.

Subfacies 3[illegible] gradationally overlies subfacies 3d and represents the uppermost indication of bedding or lamination within the Glauconitic Sandstone (excluding facies 5). [illegible] differs from subfacies 3d in being more argillaceous [illegible] clay, and in lacking any regular bedding. The unit varies from [illegible] metres thick in well [illegible] to [illegible] metres thick in well [illegible] and is quite variable within a particular well. Zones in the sandstone may be bioturbated, structureless or [illegible] bedded (Plate [illegible]). Magnetite grains are concentrated along single [illegible] laminations [illegible] greenish [illegible] and for this reason [illegible] been distinguished [illegible] (Figure [illegible]).

[illegible]

[illegible]

[illegible]

[illegible]

Petrologically and texturally, subfacies 3bii is distinctive from the other facies. The thin section photograph on Plate 3.[illegible] demonstrates the preferential horizontal fabric resulting from compaction flattening of soft rock fragments and the orientation of elongate chert grains. Feldspars (K-feldspar and plagioclase) are more abundant than in other facies. Also, illite content is 5 percent, an abnormally high percentage for a zone with such low porosity. Average porosity from core analyses is [illegible] percent, an average lower than other facies.

Facies 3bii also occurs in the same stratigraphic position as subfacies 3b[illegible] but is distinguished from both 3b[illegible] and 3b[illegible] by its low angle planar laminations defined by coarse sand sized magnetite grains (Plate 2.4). It is present only in well [illegible] and [illegible] metres thick. The sandstone is light grey, fine grained and clay [illegible] clay, but [illegible] is relatively high [illegible]. The lower boundary of the unit is gradational and [illegible] defined. The uppermost few centimetres of the unit are bioturbated and [illegible] and there is a sharp irregular contact with the overlying argillaceous sandstone of facies [illegible].

[illegible]

Facies 2: Carbonaceous sandstone and shale

[illegible]

missing.

bioturbated. The transition from facies 3 to 2 is generally quite abrupt with an irregular boundary marked by a colour change from medium or light grey (facies 3) to dark grey (facies 2) (Plate 2.6). Carbonaceous material in the underlying facies 3a is commonly most abundant near this boundary.

Facies-1. Very fine grained sandstone, siltstone, and shale

A maximum of 6 metres of rock above facies 2 is represented in the SHOP project cores and is described here as facies 1. Lowermost facies 1 overlies facies 2 gradationally and consists of structureless or laminated, medium grey shale with light grey silt interlaminations (Plate 2.7). Very small burrows and ripples (< 1 mm) are present locally in the shale and carbonaceous chips are common. Silt interbeds and lenses gradually become more abundant upwards such that interbeds of shale and interlaminated silt and shale alternate on a one or two metre scale. Sedimentary structures (Plate 2.[illegible]) include ripples, planar laminations, burrow mottling to isolated burrows, contorted laminations, structureless beds, and rare rootlets. Pyrite is common as nodules averaging [illegible] centimetre in diameter and in pyrite rich laminations. The uppermost metre of [illegible] included [illegible] well [illegible] is a carbonate cemented very fine grained sandstone. Climbing ripples are outlined by carbonaceous debris. Microfaults and calcareous bioturbated shale interbeds are also present. This sandstone lies with a sharp flat contact on the underlying thick [illegible] m shale bed.

Regional Facies Descriptions

Although the facies descriptions in the preceding section are based entirely on [illegible] from the SHOP project wells, they can be adapted slightly to apply on a more regional scale. The characteristics of facies [illegible] on a regional scale are consistent with those described from the SHOP project [illegible]; however, facies [illegible] varies considerably [illegible]. [illegible] Generally, [illegible] fine grained sandstone interbedded with the coarsest grained material [illegible] may consist of pebbles [illegible] well [illegible]. [illegible] grained sandstone to medium grained sandstone. Structures are similar to those described from the SHOP project. Facies 4 may consist of medium to coarse grained sandstone [illegible] rather than fine grained sandstone but is always [illegible] angle planar laminated [illegible]. [illegible] facies [illegible] may be argillaceous but [illegible] general characteristics [illegible] sedimentary structures [illegible] bioturbated [illegible] structureless with only isolated laminated zones. A carbonaceous equivalent of facies 2 and a shale siltstone sequence of facies 1 are represented in most wells.

B. Facies Interpretation

The criteria suggesting the deposition of the Glauconitic Sandstone in the SHOP project area in a prograding shoreline and nearshore environment are abundant. 1) Palynological analysis of shales from immediately below the Glauconitic Sandstone indicate restricted marine depositional conditions (See section on Palynological Results). 2) The contact of the Glauconitic Sandstone with the ostracode zone is gradational with the lower portion of the Glauconitic Sandstone coarsening upwards from silt or very fine grained sandstone. 3) The zones present on a modern day beach (shoreface, foreshore, backshore) are all represented in the Glauconitic Sandstone (Fig. 6) and 4) The uppermost part of the sandstone contains carbonaceous root markings and coal and is overlain by low energy shales and siltstone of probable back barrier origin.

Well documented studies of modern barrier island systems have resulted in a relatively good understanding of sedimentary structures and other features of sediments in beach environments. Several review papers (eg. Elliott, 1978; Reinson, 198[illegible] and McCubbin, 1982) have both summarized the characteristics of barrier and strand plain sandstone facies which have been recognized in modern environments and described several ancient analogues. The most intensively studied modern barrier island environments are the East Coast and Gulf Coast examples in the United States described by LeBlanc and Hodgson (1959), Shepard (1960), Bernard, LeBlanc and Major (1962), Hoyt and Weimer (1963) and Kraft (19[illegible]). Other well known studies of modern shorelines include those by Hayes and Kana (1976) and Curray and Moore (1964). The following interpretation of each facies represented in the Glauconitic Sandstone is based on a comparison with facies from various barrier island settings described mainly in the review papers. A summary of the characteristics of each facies of the Glauconitic Sandstone described in the previous section is given in Table 4 and Figure [illegible].

Facies 6

Facies 6 represents the lower to middle shoreface zone. The very fine grained sandstone and thin shale interbeds in the lower part [illegible] were deposited in the lower

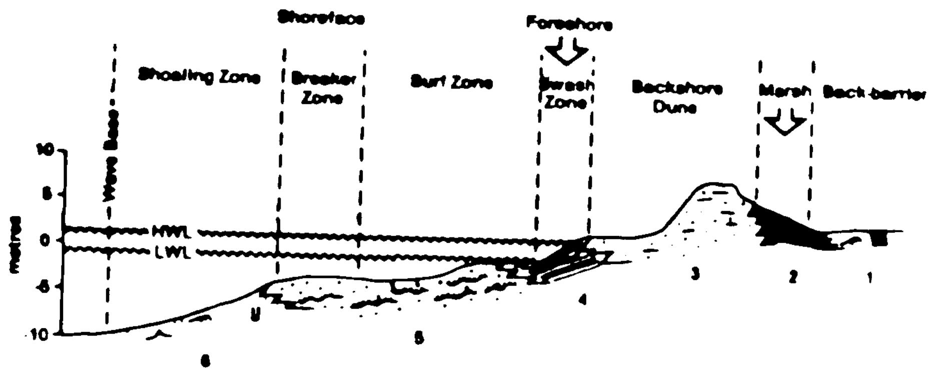


FIGURE 6a. Generalized profile of a barrier-beach environment showing the spatial relationships of the sedimentary facies and their positions on the shore. (Shore profile modified from Reinson, 1980)

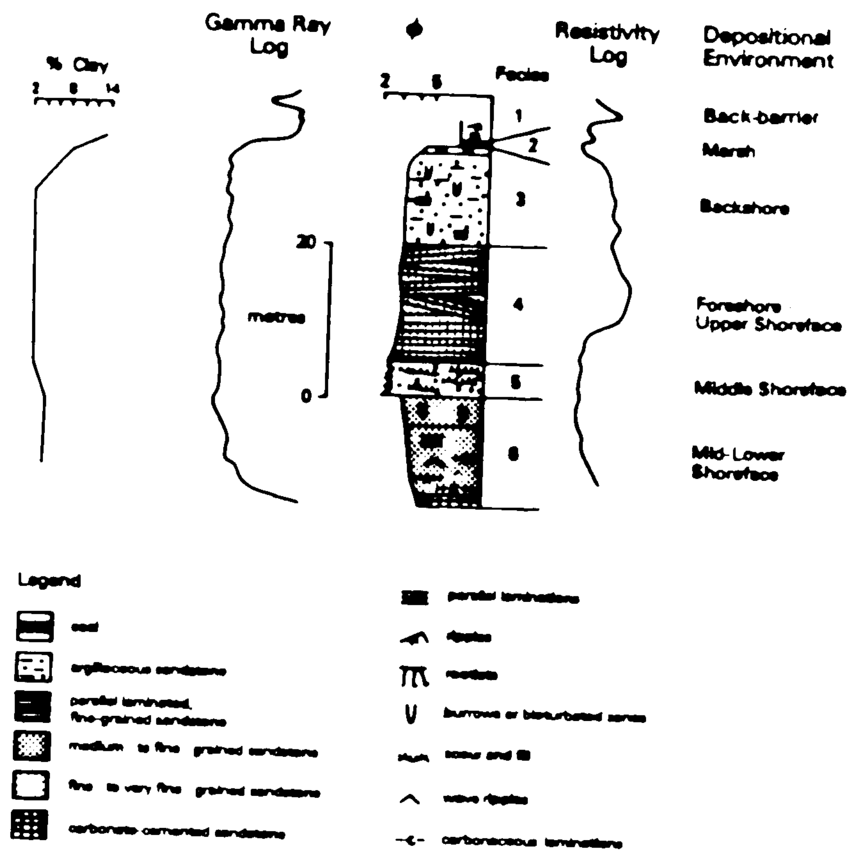


FIGURE 6b. Generalized litholog from SHOP project core showing the vertical sequence of facies, grain size, per cent clay, geophysical log shapes and the facies interpretations.

Table 4. Summary of Facies Descriptions

1 Very fine grained sandstone, siltstone and shale

Interlaminated siltstone and shale interbedded with shale and sandstone, laminated, structureless, rippled [illegible] mottled, contorted beds, burrows, pyrite, rare [illegible]

2 Carbonaceous sandstone and shale

Coal, carbonaceous shaly sandstone and sandy shale [illegible] coal chips, strongly bioturbated

3 Argillaceous sandstone

3a Very argillaceous sandstone [illegible] mottled, poorly sorted
3b Argillaceous sandstone, structureless [illegible] clay streaks
3c Green-grey sandstone, sharp base [illegible] less sandstone with coarse grained [illegible] cross-laminated sandstone with [illegible] horizontal fabric [illegible] illite abnormally abundant
3d Low angle, planar laminated [illegible] laminations defined by [illegible]
3e Argillaceous sandstone [illegible] structureless [illegible]
3f [illegible]

4 Laminated sandstone

Relatively clean, fine grained sandstone [illegible] planar laminated to low angle cross-laminated [illegible] disturbed laminations, bioturbated or structureless [illegible] highest and most continuous [illegible] saturations

5 Medium to coarse grained sandstone

Medium to coarse grained sandstone [illegible] bedded with fine grained sandstone, coarser beds have [illegible] bases and fine upwards to fine grained sandstone [illegible] the major component of the coarse grained sandstone [illegible] grain size

6 Coarsening upward sandstone

6a Fine grained sandstone [illegible] coarser than subfacies 6b, bioturbated, structureless [illegible]
6b [illegible] siltstone or very fine grained sandstone coarsening [illegible] fine grained sandstone well defined laminations [illegible] horizontal planar laminations, cross laminations, wave [illegible]
6c [illegible]

shoreface. In his review paper, Reinson (1984) described the lower shoreface as a relatively low energy transitional zone "where waves begin to affect the bottom but where offshore shelf or basinal depositional processes also occur". The coarsening upwards to fine grained sandstone represents the transition into the middle shoreface. The low angle cross laminations, horizontal planar laminations, wave ripples (Plate [illegible]) and scour and fill structures were produced by shoaling and breaking waves in this zone. The predominance of primary sedimentary structures in the shoreface zone of the [illegible] Sandstone contrasts with the bioturbated shoreface zone described by Bernard et al. (1962) for Galveston Island. The preservation of primary structure indicates a high wave energy setting where biogenic structures are not developed or have a low preservation potential [illegible]

The [illegible] element [illegible] probably [illegible] the [illegible] Sandstone after [illegible] the [illegible] zone. The [illegible] coarser general [illegible] structureless [illegible] bed (Plate [illegible]) represents a [illegible] of the middle shoreface [illegible]

Facies 5

The coarser material [illegible] breaker zone of the middle shoreface [illegible] coarser sandstone [illegible] the sequence [illegible] coarsening upward sandstone from the lower middle shoreface and laminated sandstone [illegible] the foreshore zone. Therefore the coarse sandstone [illegible] was deposited in the breaker zone.

Pebble beds [illegible] have [illegible] bases and [illegible]. These coarser beds suggest [illegible] shoreface [illegible] sedimentation.

Facies 4

The horizontal planar laminations and low angle [illegible] laminations [illegible] of the upper shoreface [illegible] sequence [illegible] 1984 [illegible] sedimentary structures [illegible] conditions of deposition such as occur in the wave zone. The swash backwash mechanism is mainly responsible for the subhorizontal to low angle planar laminations.

Facies 3

The depositional setting of facies 3 is the backshore zone of a beach. Subfacies 3d represents the transition from the foreshore to backshore zone. Periods of low energy conditions [illegible] areas have allowed significant bioturbation. The laminated [illegible] are probably [illegible] the banks of a small tidal creek [illegible] increase in [illegible] content [illegible] subfacies [illegible] the gradual decrease in energy conditions along with an increase in bioturbation.

[illegible]

[illegible]

[illegible]

The deposits are generally thin, ranging from a few centimeters to two metres for each overwash event. Facies [illegible] is [illegible] metres thick, perhaps representing one washover event. The bioturbation and rootlets at the top suggest the development of vegetation on a sand flat.

Energy of the backshore environment fluctuates between low during calm periods and high during storms. Vegetated zones occupy some of the area, whereas the areas [illegible]

Facies 2

[illegible]

Facies 3

[illegible]

Summary

[illegible]

III. PALYNOLOGY

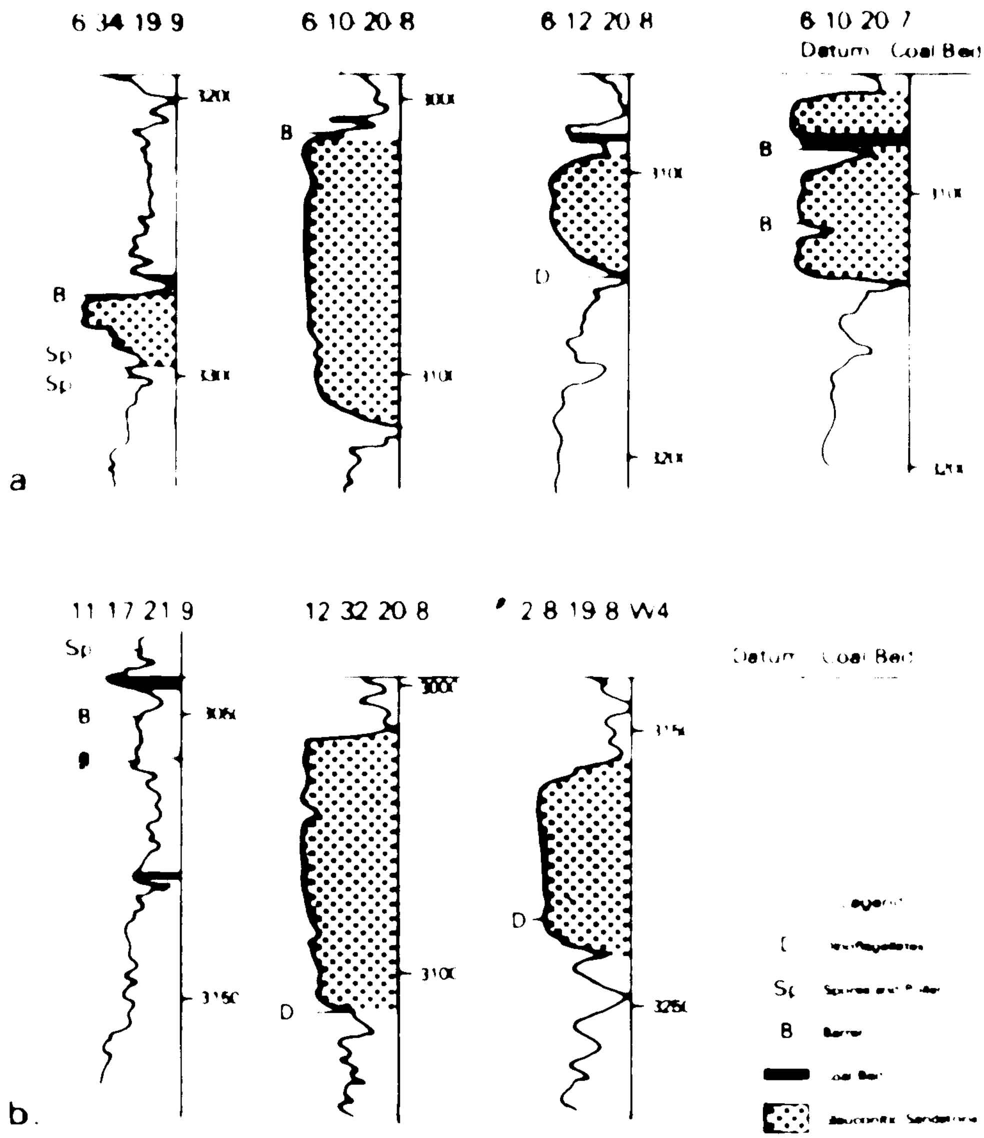
Palynological results provide additional support for an environmental interpretation based on sedimentary structures and other rock properties. Shale and silty shale samples from below, above and within the Glauconitic Sandstone in regionally spaced wells were examined for palymorphs and dinoflagellates. The distribution of samples within each well is indicated [illegible] figure [illegible] and the geographic position [illegible] figure [illegible].

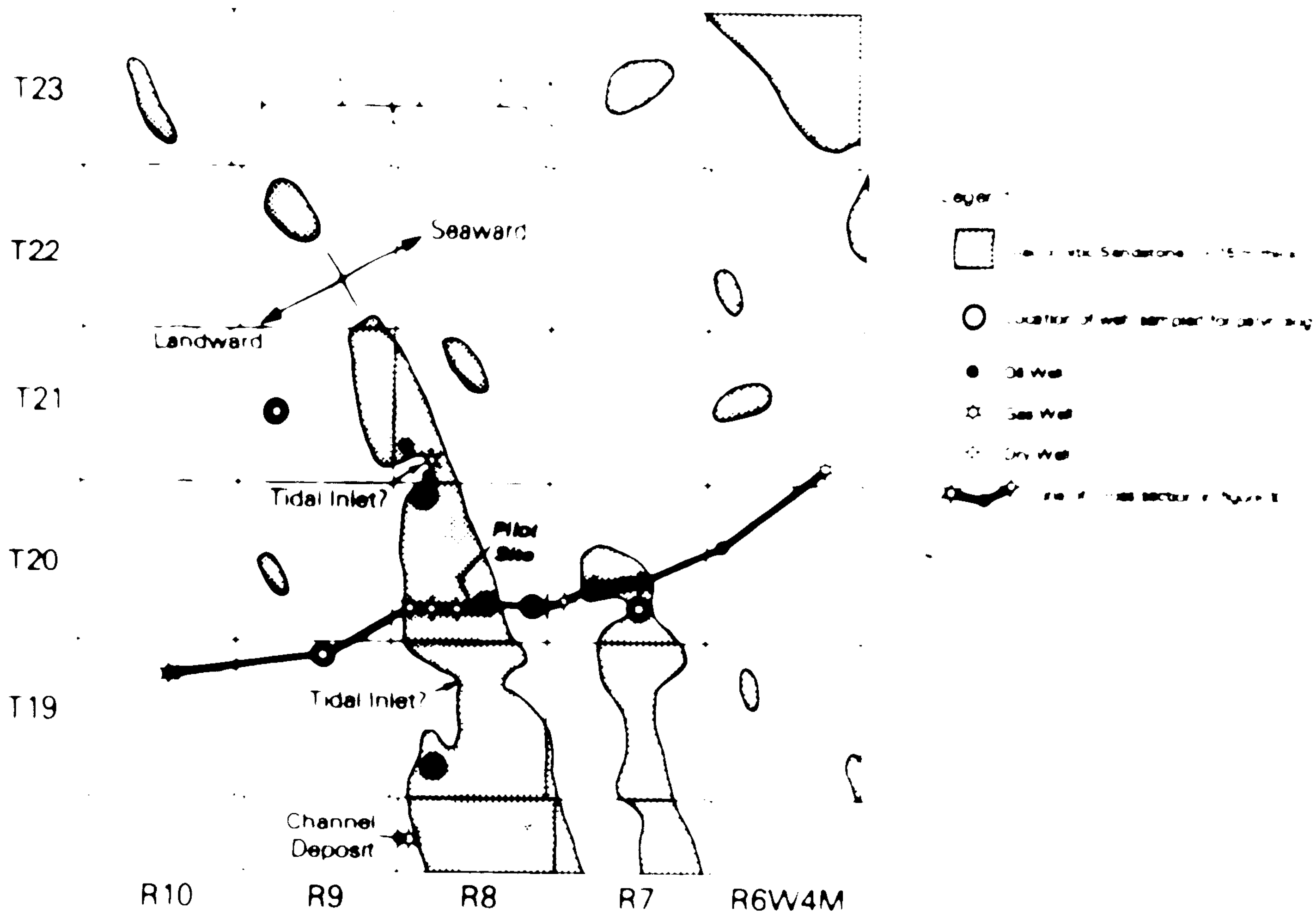
Samples containing dinoflagellates represent deposition in a marine environment [illegible] at the base [illegible] the Glauconitic Sandstone [illegible] these samples [illegible]

[illegible]

All other samples examined [illegible] dinoflagellates [illegible] and megaspores [illegible] samples at [illegible] the upper [illegible] the Glauconitic Sandstone [illegible] suggests [illegible] dinoflagellates [illegible] marine [illegible]

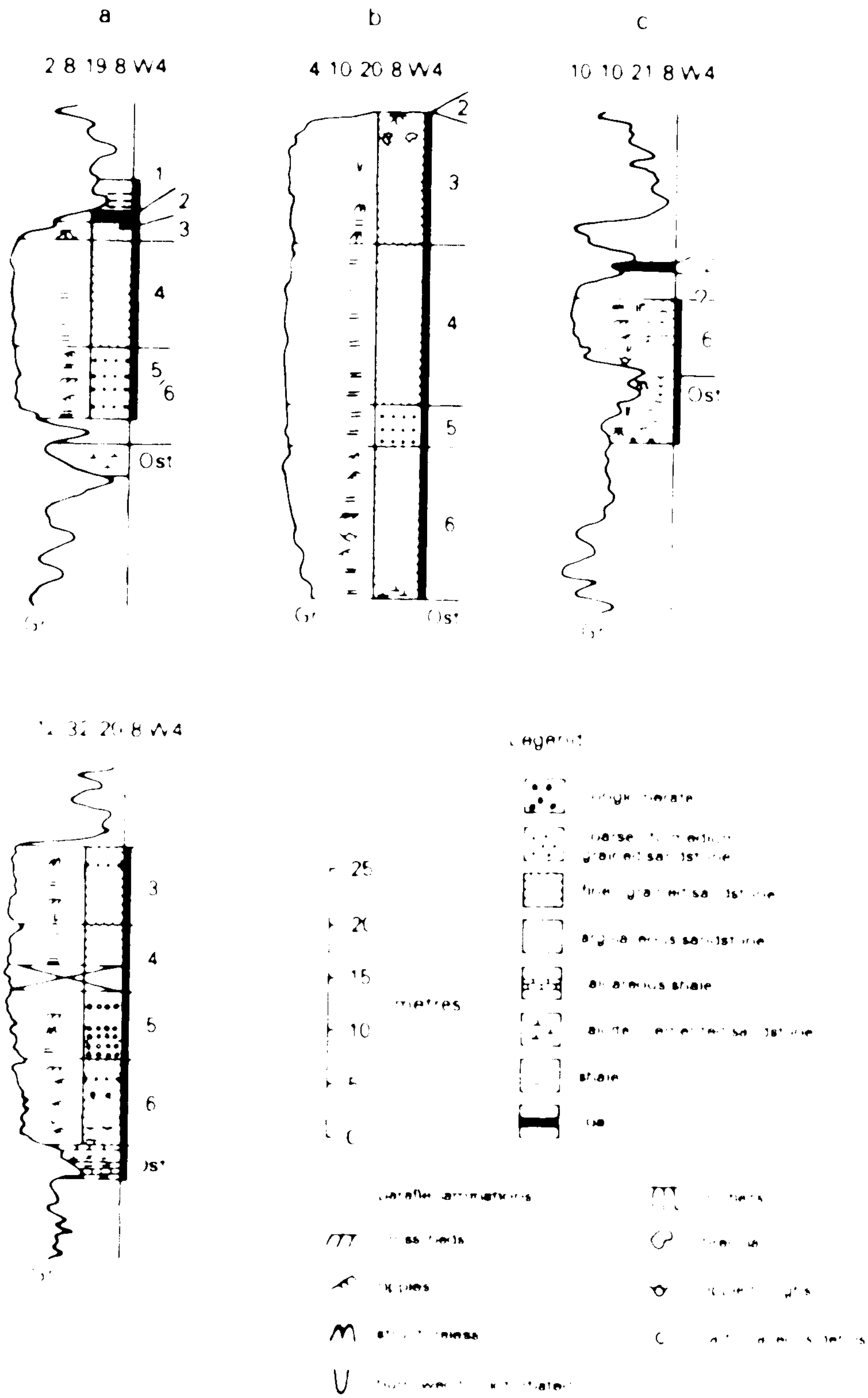
[illegible]


6 34 19 9
6 10 20 8
6 12 20 8
6 10 20 7
Datum Coal Bed
B
Sp
Sp
D
a
11 17 21 9
12 32 20 8
2 8 19 8 W4
Sp
B
D
b.


T23
T22
T21
T20
T19
Seaward
Landward
Tidal Inlet?
Pilot Site
Tidal Inlet?
Channel Deposit
R10
R9
R8
R7
R6W4M
Oil Well
Gas Well
Dry Well

e a prograding beach complex with restricted marine sediments at the base of the Glauconitic Sandstone to continental sediments at the top

IV. REGIONAL DEPOSITIONAL SETTING



a
b
c
2 8 19 8 W4
4 10 20 8 W4
10 10 21 8 W4
Ost
metres
25
15
10
shale

Figure [illegible] is a cross section of the Glauconitic Sandstone extending perpendicular to the sandstone belt (Fig. [illegible]). To the west of the sandstone belt the Glauconitic Sandstone is replaced by an interbedded sequence of thin sandstones, siltstones, shales and coal of continental origin. To the far east the Glauconitic Sandstone loses its distinctive character.

[illegible]

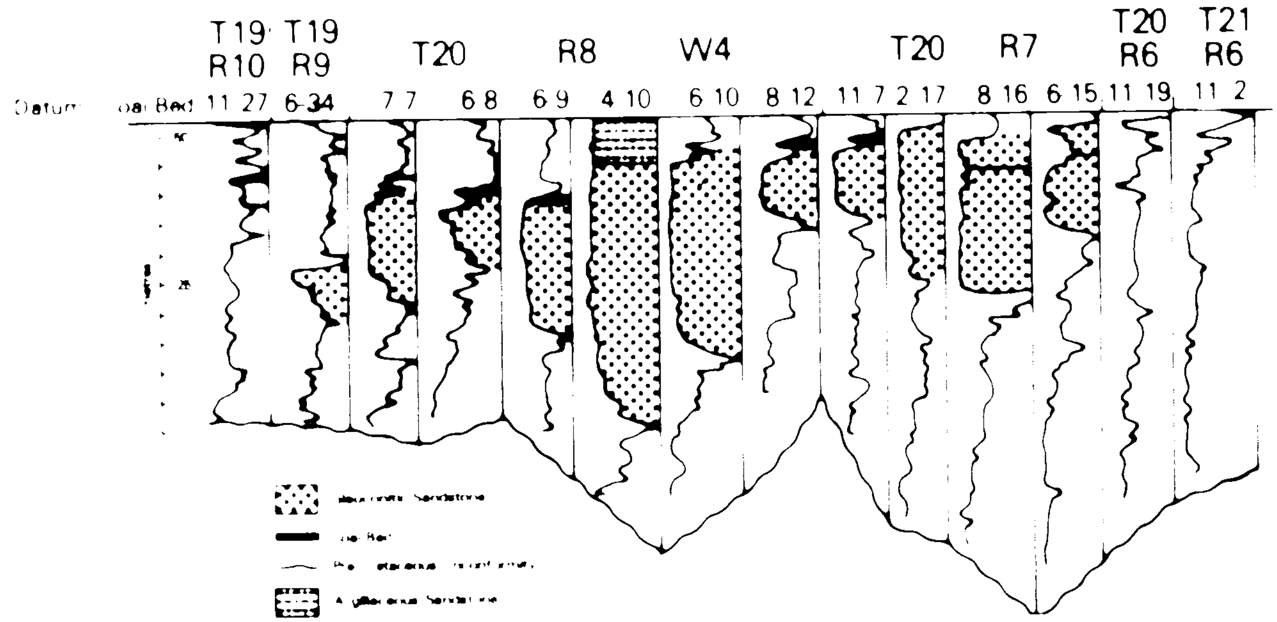
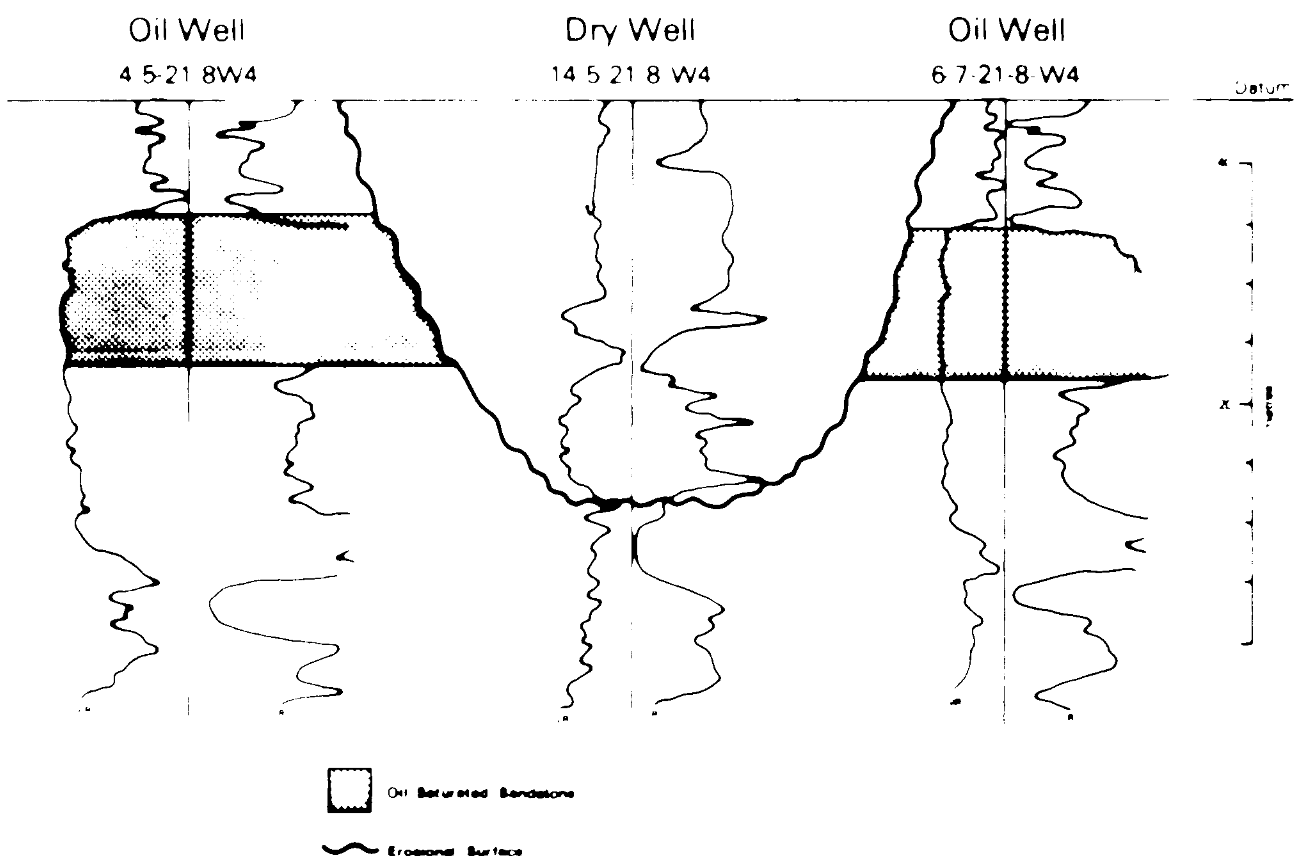


Figure [illegible] Schematic [illegible] stratigraphic cross section [illegible] illustrating the relative vertical [illegible] of sandstone bodies when the datum [illegible] bed was deposited. The cross-[illegible] is shown in Figure [illegible]. As the datum coal bed is not detectable [illegible] wells at [illegible]-16-20-[illegible]W4 and 11-19-20-[illegible]W4, positioning relative to adjacent wells [illegible] based [illegible] correlations [illegible] geophysical log shapes. The argillaceous sandstone [illegible] the [illegible]-20-[illegible]W4 well [illegible] equivalent to the [illegible] zone [illegible] HO[illegible] [illegible] wells.



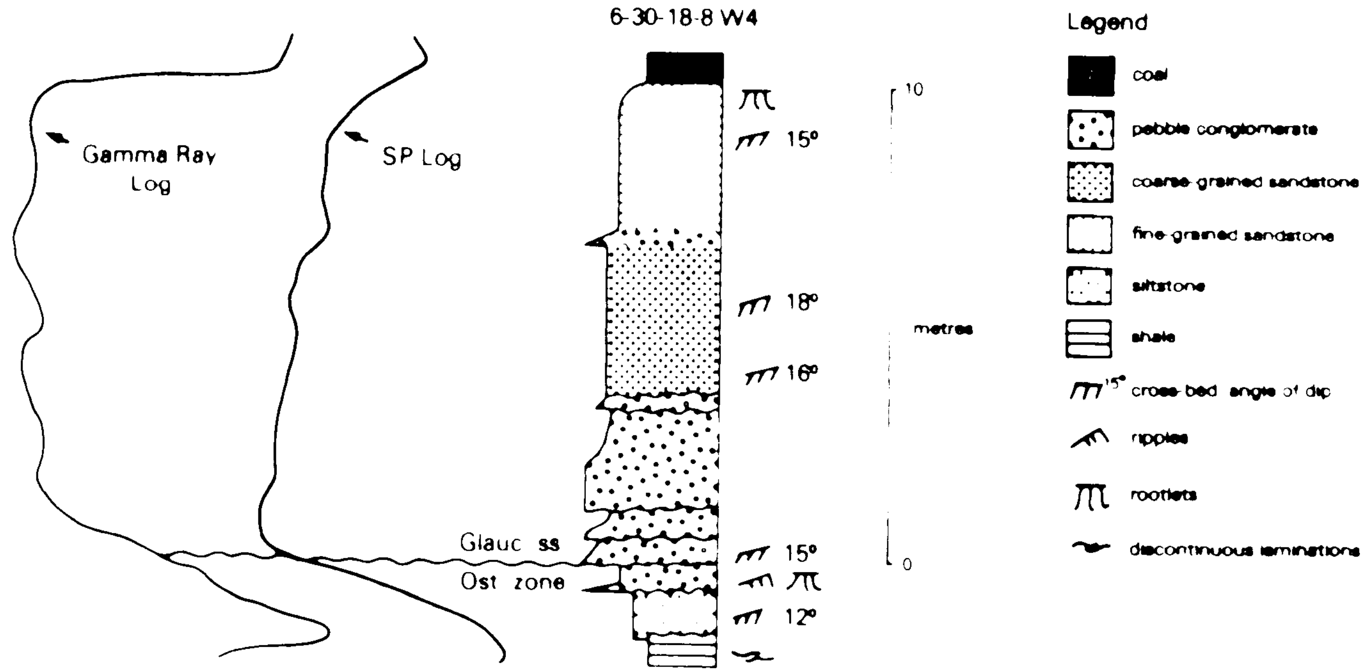
Oil Well
4 5-21 8W4
Dry Well
14 5 21 8 W4
Oil Well
6 7-21-8-W4
Datum
Oil Saturated Sandstone
Erosional Surface

dry, whereas wells immediately to the north and south (4-[illegible]-[illegible]-18 W4 and 6-[illegible]-[illegible]-18 W4, Fig. 11) have the typical Glauconitic Sandstone beach facies and are oil producers. The silty sandstone of the dry well represents a facies change from the beach facies in the surrounding wells and probably is the fill of an abandoned portion of a tidal inlet or the abandonment of a later stage fluvial channel. Similar abandoned portions of tidal inlets are described by Tye (1978) in South Carolina.

A [illegible] metre thick channel sandstone occurs at [illegible]-30-[illegible]-18 W4 (Fig. [illegible]). The base of the sandstone is erosional into the underlying calcareous silt, shale and sand of the Ostracode zone. The lower portion of the sandstone unit consists of a series of fining upward cycles with erosional bases, from cobbles and pebble conglomerates to coarse grained sandstone. In the upper portion of the unit the sandstone has fined upwards to fine grained sandstone and is topped by a rooted coal. [illegible] cross laminations dipping at about [illegible] degrees are the dominant sedimentary structures.

Other wells probably penetrate tidal inlet or channel deposits but unfortunately cores rarely include the base of the Glauconitic Sandstone. The difficulty in identifying channel versus beach deposits based on geophysical log character alone is demonstrated by the [illegible] W4 wells (Fig. [illegible]). The gamma ray log indicates a [illegible] coarsening upward sequence suggesting a beach deposit, whereas the [illegible] indicates a fining upward sequence suggesting a channel deposit for the same depth interval.

In summary, the depositional setting [illegible] barrier island [illegible] the seaward side [illegible] to the east. The thick sandstones [illegible] expected to extend [illegible] [illegible] [illegible] tidal inlet and channel [illegible]



6-30-18-8 W4
Gamma Ray Log
SP Log
Glauc ss
Ost zone
15°
18°
16°
15°
12°
10
metres
0
Legend
coal
pebble conglomerate
coarse grained sandstone
fine grained sandstone
siltstone
shale
15° cross bed angle of dip
ripples
rootlets
discontinuous laminations

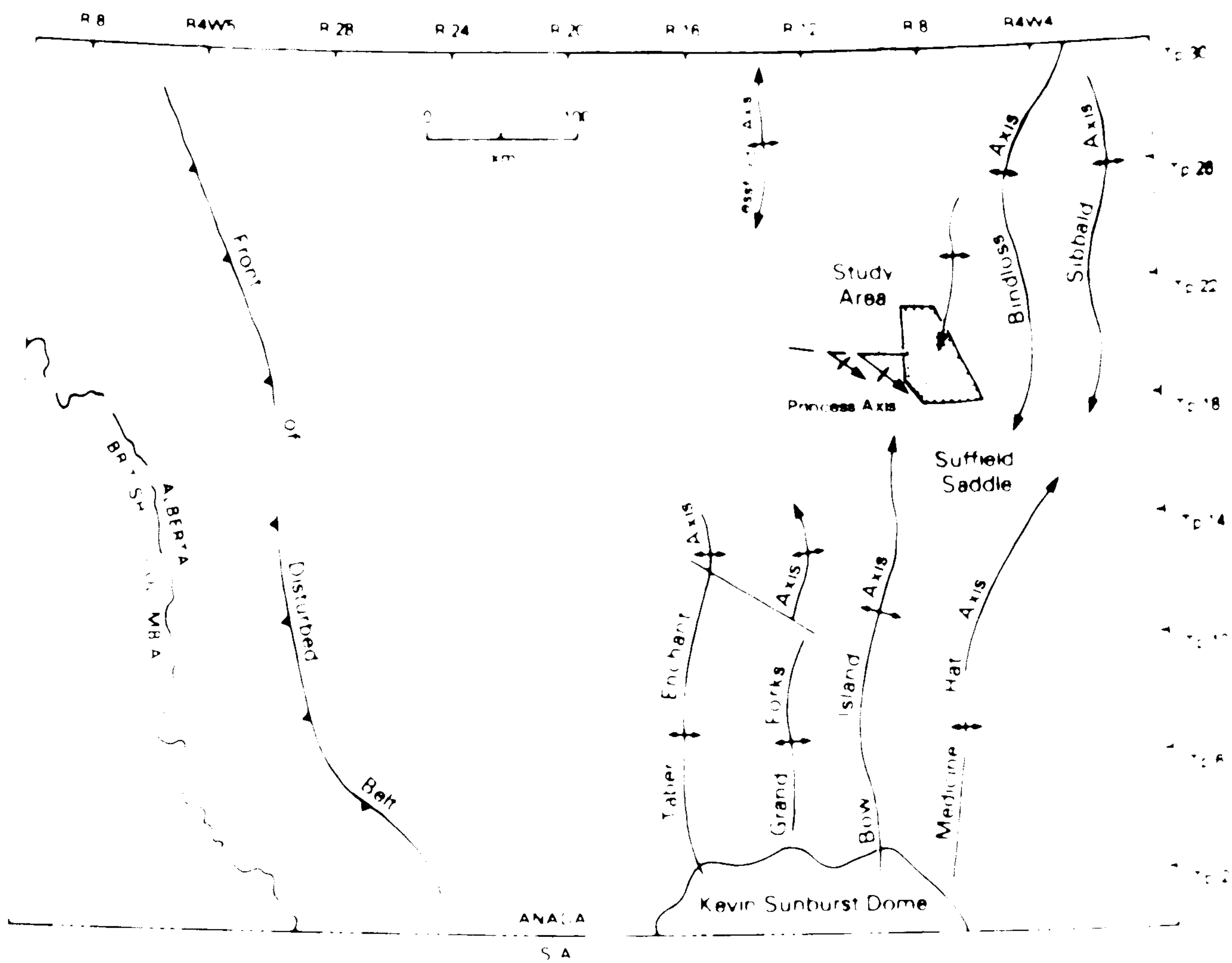
V. TECTONIC SETTING

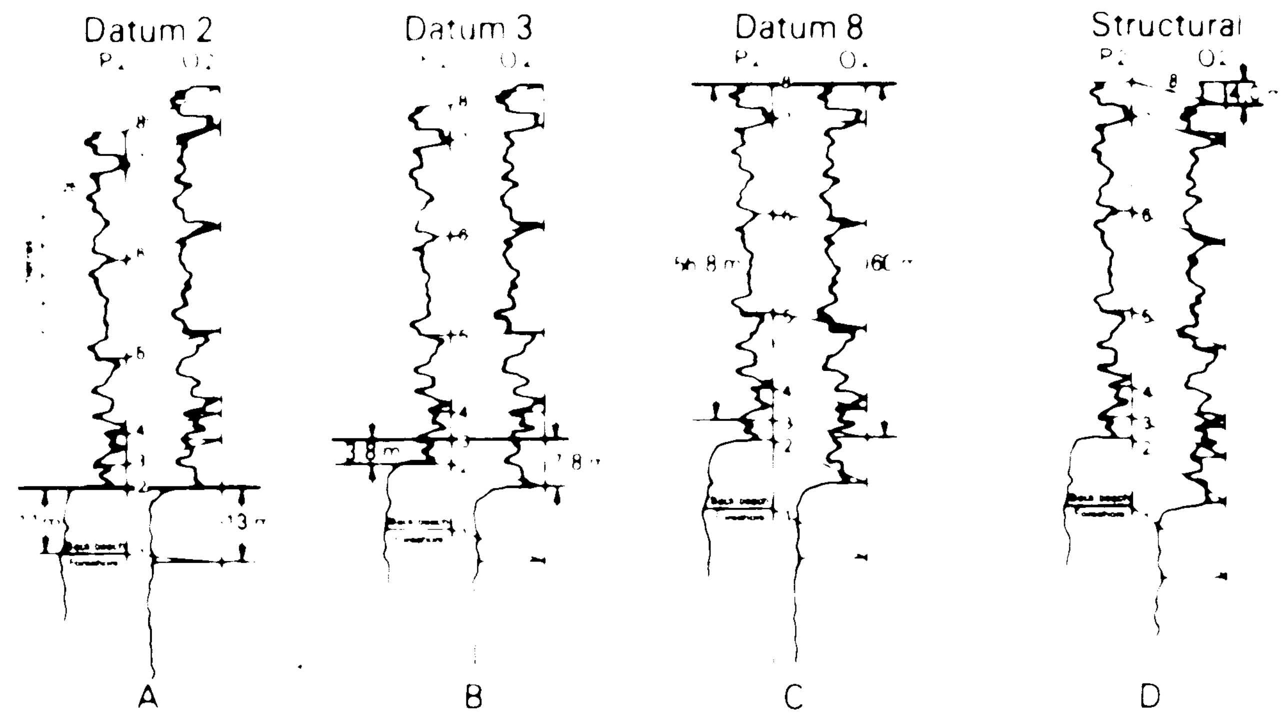
The study area is located immediately west of the North Battleford Arch, a northward extension of the Sweetgrass Arch. The westernmost ridge line from the arch extends into the northern portion of the study area (Fig. 13). Evidence for periods of uplift along the Sweetgrass Arch from late Precambrian time to the Tertiary is given by Herbaly (1974). By close examination of the rock units he noted that there were several cycles of uplift and erosion and long periods of nondeposition. The Sweetgrass Arch dipped southward from the North Battleford Arch during the [illegible] and [illegible] time as evidenced by subcrop patterns and thinning [illegible] over the axes of the positive trends. Maximum elevation of the arch occurred during the late Cretaceous and Early Tertiary Laramide orogeny (Tovell, 1958) [illegible] and resulted in the [illegible] of the [illegible] Saddle (Fig. [illegible]) [illegible] North Battleford Arch retained its original southward [illegible] evidence [illegible] faulting along the Sweetgrass [illegible] the Early Cretaceous. The present [illegible] types displaced Cretaceous [illegible] and Mississippian strata [illegible] Sweetgrass Arch [illegible].

A. SHOP Project Site

The dense [illegible] a small scale [illegible] movement associated with the North Battleford Arch [illegible] Mannville time.

[illegible] sandstone unit. Figure [illegible] shows these two [illegible] vertical positions. The horizontal to subhorizontal lines between the two [illegible] relative beds and represent surfaces which were near horizontal [illegible]


R 8
R4W5
R 28
R 24
R 16
R 8
R4W4
Tp 30
Tp 26
Tp 22
Tp 18
Tp 14
Tp 6
Tp 2
km
Axis
Sibbald
Axis
Bindloss
Study
Area
Princess Axis
Suffield
Saddle
Medicine Hat Axis
Bow Island Axis
Grand Forks Axis
Taber Enchant Axis
Kevin Sunburst Dome
Front of Disturbed Belt
ALBERTA
MBA
CANADA
U.S.A.


Datum 2
Datum 3
Datum 8
Structural
A
B
C
D

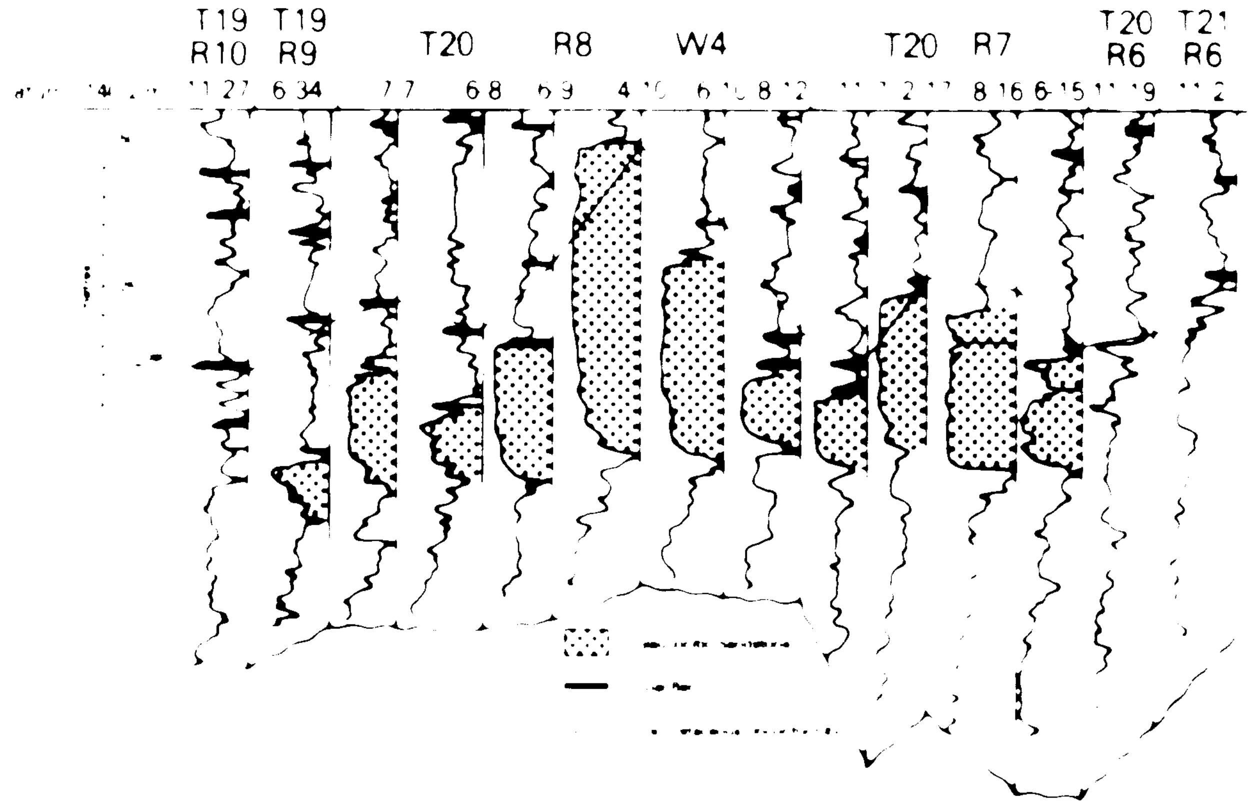
that particular datum. Figure 14A shows the position of the two wells with the carbonaceous bed on the top of the sandstone as the datum #2. Note that the interval from the top of the foreshore zone facies 4 to the carbonaceous bed at the top of the sand is thicker in well [illegible] metres. Figure 14B, where the datum [illegible] is shown, a thickening of 4 metres [illegible] datum #2 [illegible] #3. This is the interval of most significant thickening [illegible] upper Mannville deposits. Figure 14C shows the top of the Mannville [illegible] datum [illegible] metres [illegible] [illegible]

[illegible]

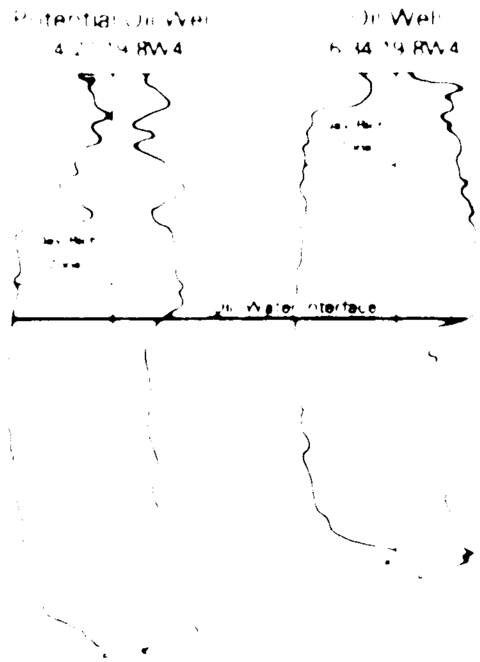
[illegible]

E. Regional Suffield Area

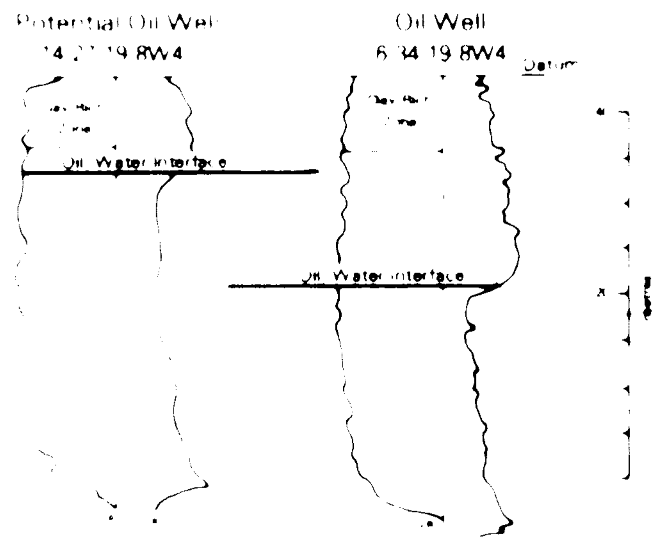
[illegible]


T19
R10
T19
R9
T20
R8
W4
T20
R7
T20
R6
R6

Petroleum Trapping Mechanism



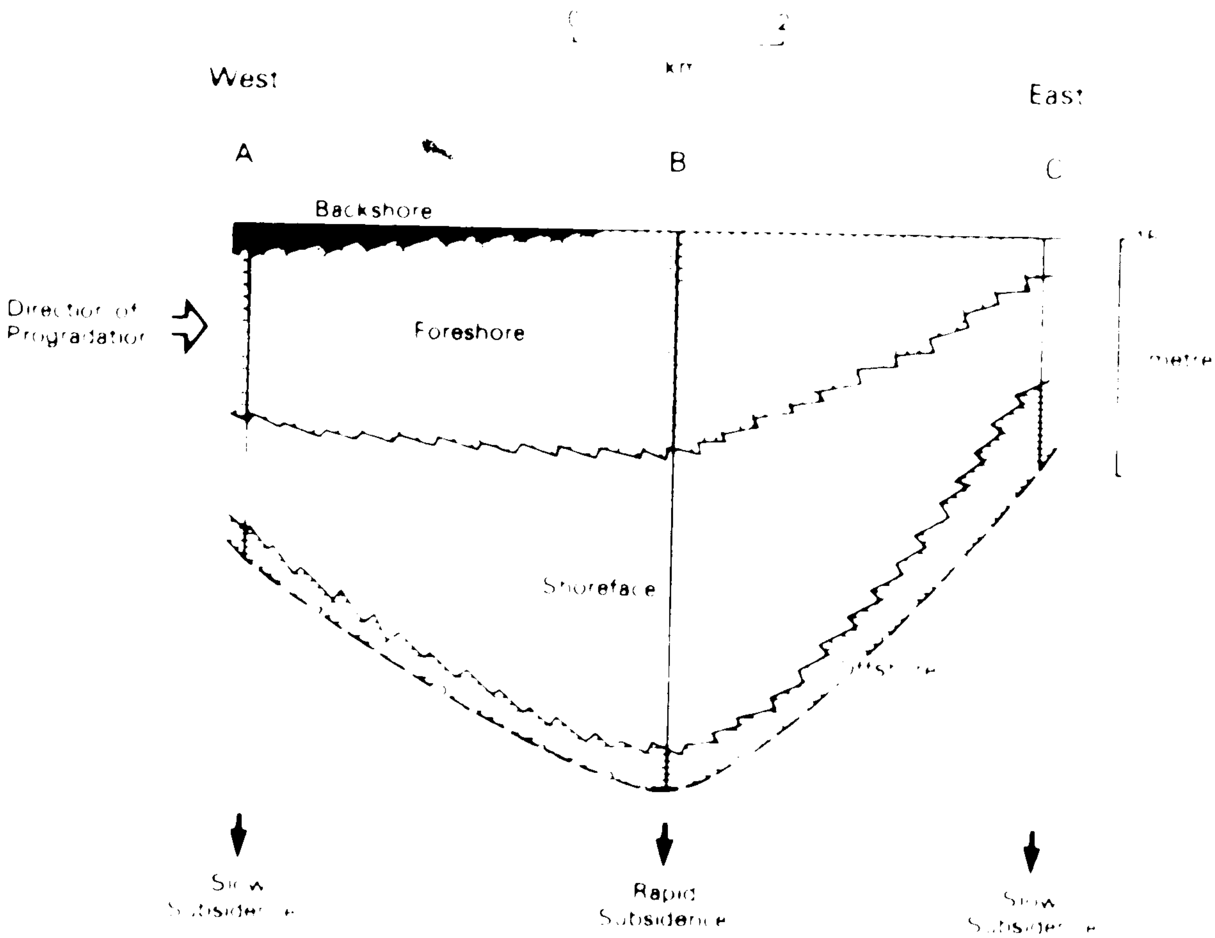
A Structural Cross Section



B Stratigraphic Cross Section

D Tectonic Control on the Glauconitic Sandstone Thickness

As mentioned previously, parts of the Glauconitic Sandstone are unusually thick for a beach sequence. In light of the evidence for tectonic activity immediately after deposition of the sandstone, it seems [illegible] that movement on basement faults was also responsible for controlling the rate of subsidence during deposition of the Glauconitic Sandstone. Figure [illegible] is a schematic cross section showing the thickening of sediment in a zone of relatively rapid subsidence. Wells A, B and C represent wells in the west, [illegible] and the east of the [illegible] sandstone belt respectively. The thicknesses of the facies representing the [illegible] are shown [illegible] representative [illegible]. The greater sediment [illegible] the result of [illegible] basement [illegible] sandstone.



West
East
A
B
C
Backshore
Foreshore
Shoreface
Rapid

VI. MINERALOGY

A. Bulk Mineralogy

Other sedimentary rock fragments consist of siltstone, shale and silty shale. Grains in the siltstone fragments are dominantly quartz with some chert. Some siltstone fragments have been so deformed that they are almost indistinguishable from the matrix (Plate 3). Rock fragments with a significant clay content tend to be deformed as a result of compaction (Plate 4). Rock fragments are most abundant [illegible] and [illegible] compaction [illegible] significant cause of porosity reduction.

Feldspar grains are present in minor amounts in most samples. [illegible]

[illegible]

B. Clay Mineralogy

Descriptive Clay Mineralogy

FINE PRINT

FINE PRINT

FINE PRINT

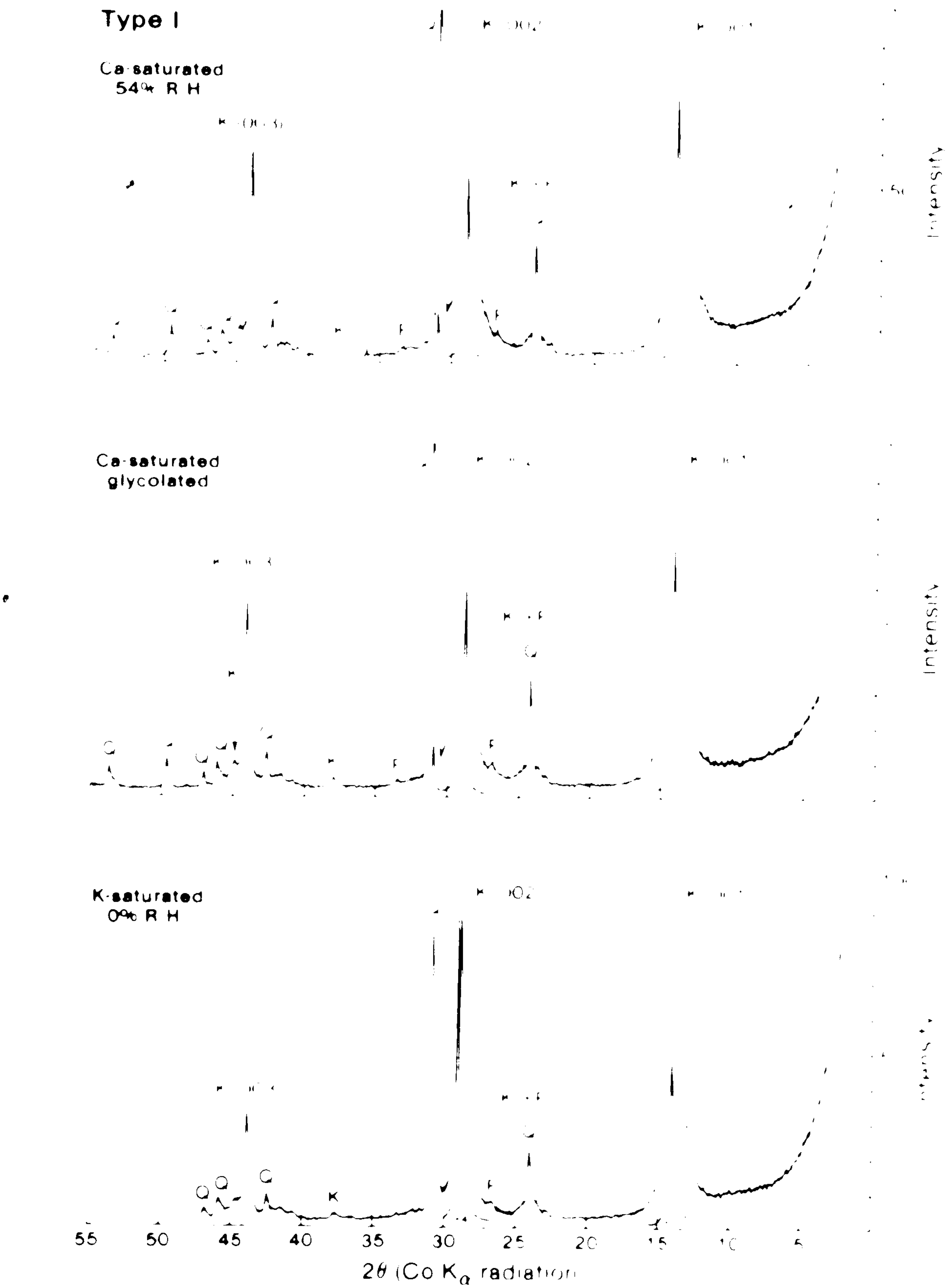
Assemblages [illegible] Minerals

Distribution of Clay Mineral Assemblages

trace amounts of smectite. Therefore, smectite in samples from this eastern sandstone belt is probably detrital in origin. The bentonitic shale probably represents deposition of a [illegible] ash. Its deposition may have occurred sometime after that of the shales within and immediately above the glauconitic sandstone of the western belt.

Figure [illegible] A and B

Typical X-ray diffractograms of the < [illegible] micrometre fraction for type [illegible] samples. Type [illegible] samples represent the most argillaceous sandstone at the top of the Glauconitic Sandstone (uppermost facies 3). This sample contains almost [illegible] per cent kaolinite (K), a minor amount of quartz (Q), and trace amount of feldspar (F). Basal reflections for the clay minerals are indicated in brackets after the symbol for the clay. The 7Å K [illegible] peak of kaolinite is sharp and intense. The clay symbols without adjacent bracket indicate nonbasal reflections.


Type I
Ca-saturated
54% R H
Ca-saturated
glycolated
K-saturated
0% R H
Intensity
Intensity
Q
Q
Q
Q
K
55
50
45
40
35
30
25
20
15
10
5
2θ (Co Kα radiation)

Type I cont.

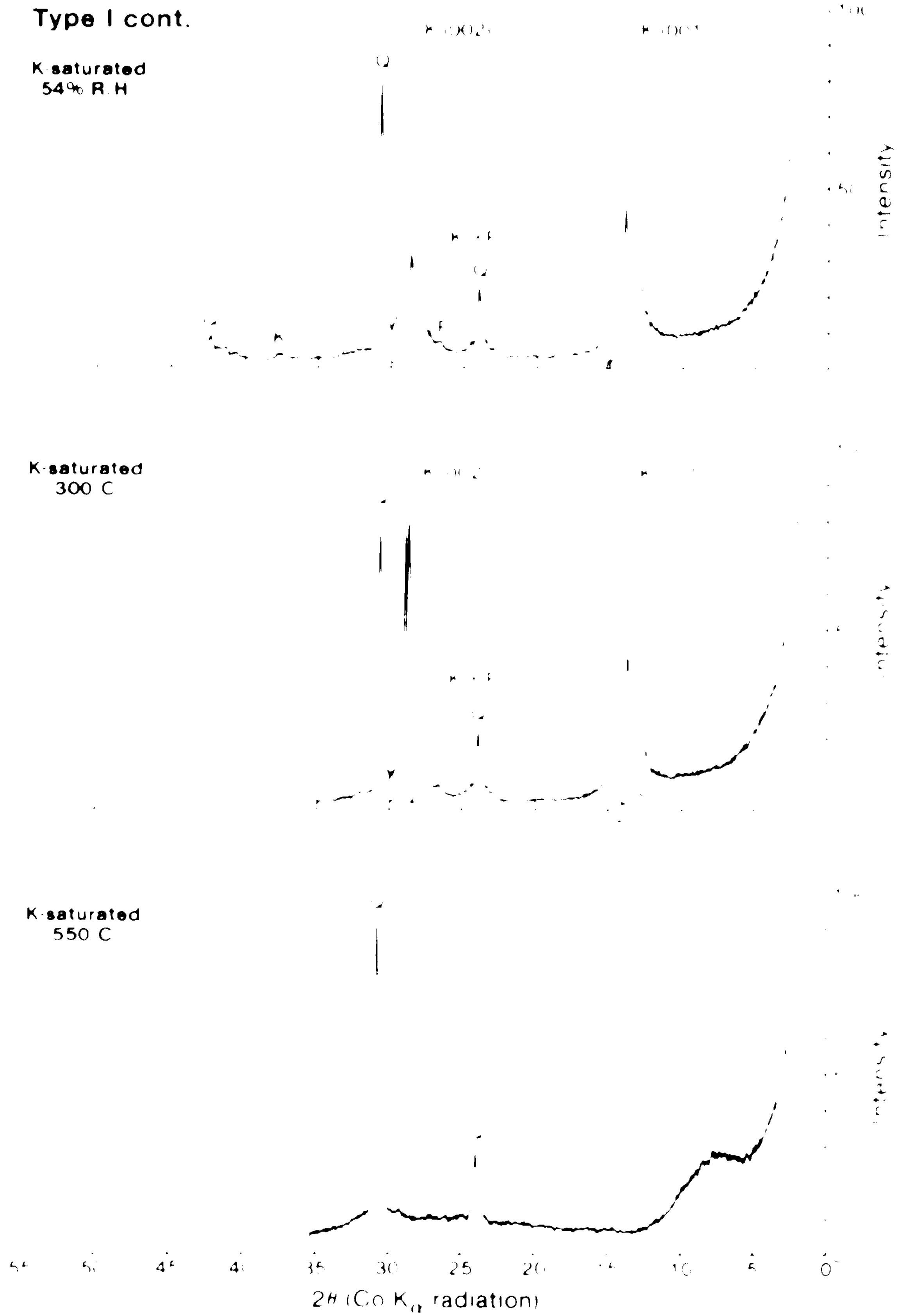
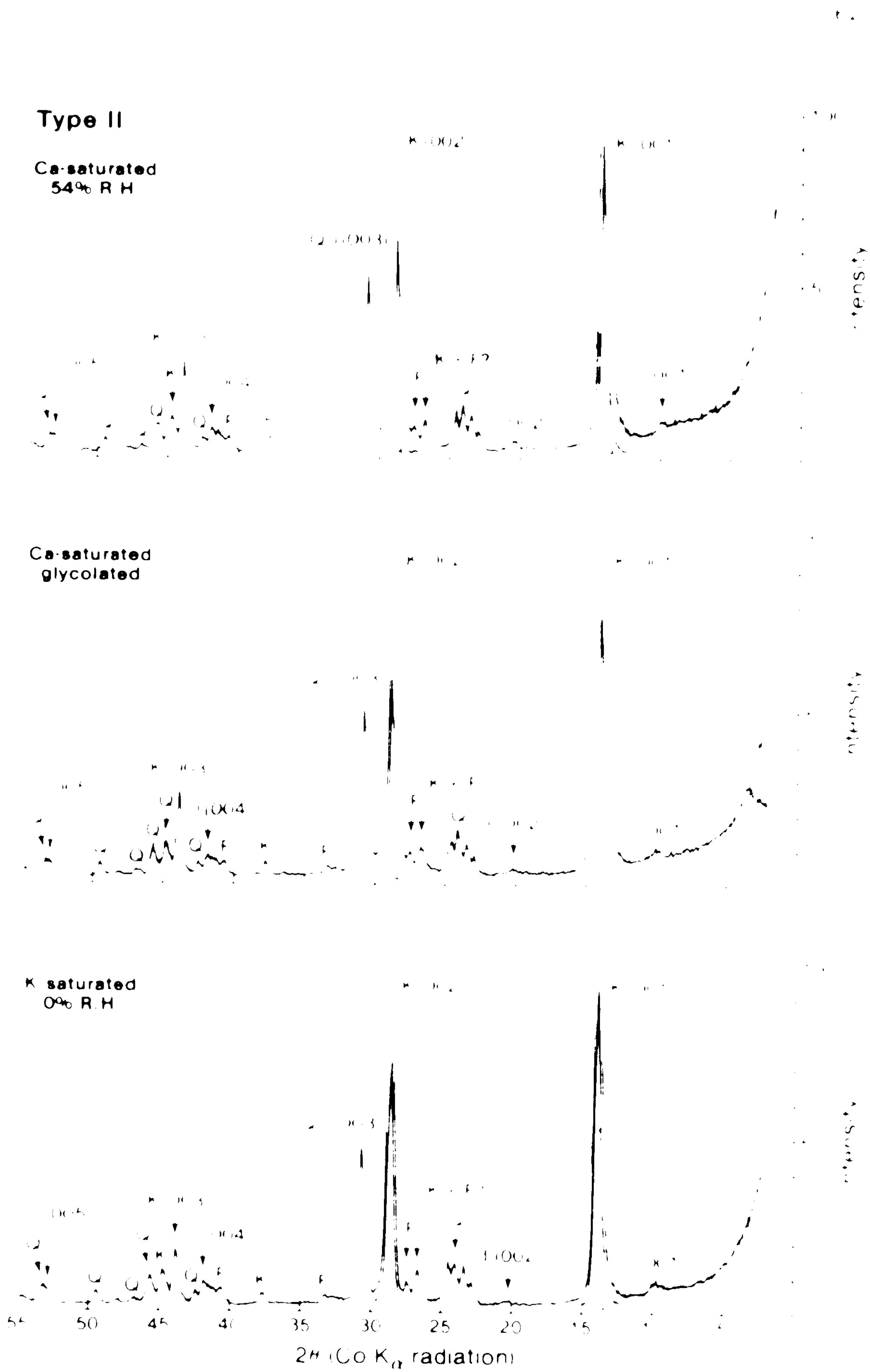

K-saturated
54% R.H
Q
Q
Intensity
K-saturated
300 C
Intensity
K-saturated
550 C
Intensity
35
30
25
20
10
5
0
2θ (Co Kα radiation)

Figure [illegible]9 A and B

Typical X-ray diffractograms of the <[illegible] micrometre fraction for type [illegible] samples. Type [illegible] samples represent sandstones of facies 3 located stratigraphically below those of type [illegible]. The total clay content in the sandstone is significantly lower than in type [illegible] samples. Illitic clay minerals ([illegible]) are present in trace amounts. The low angle asymmetry which remains on the 10A peak (001) after K saturation (Fig [illegible]9A) indicates the presence of chloritic material within the illitic phase.



Type II
Ca-saturated
54% R H
Ca-saturated
glycolated
K saturated
0% R.H
50
35
25
20
2θ (Co Kα radiation)

Type II cont.

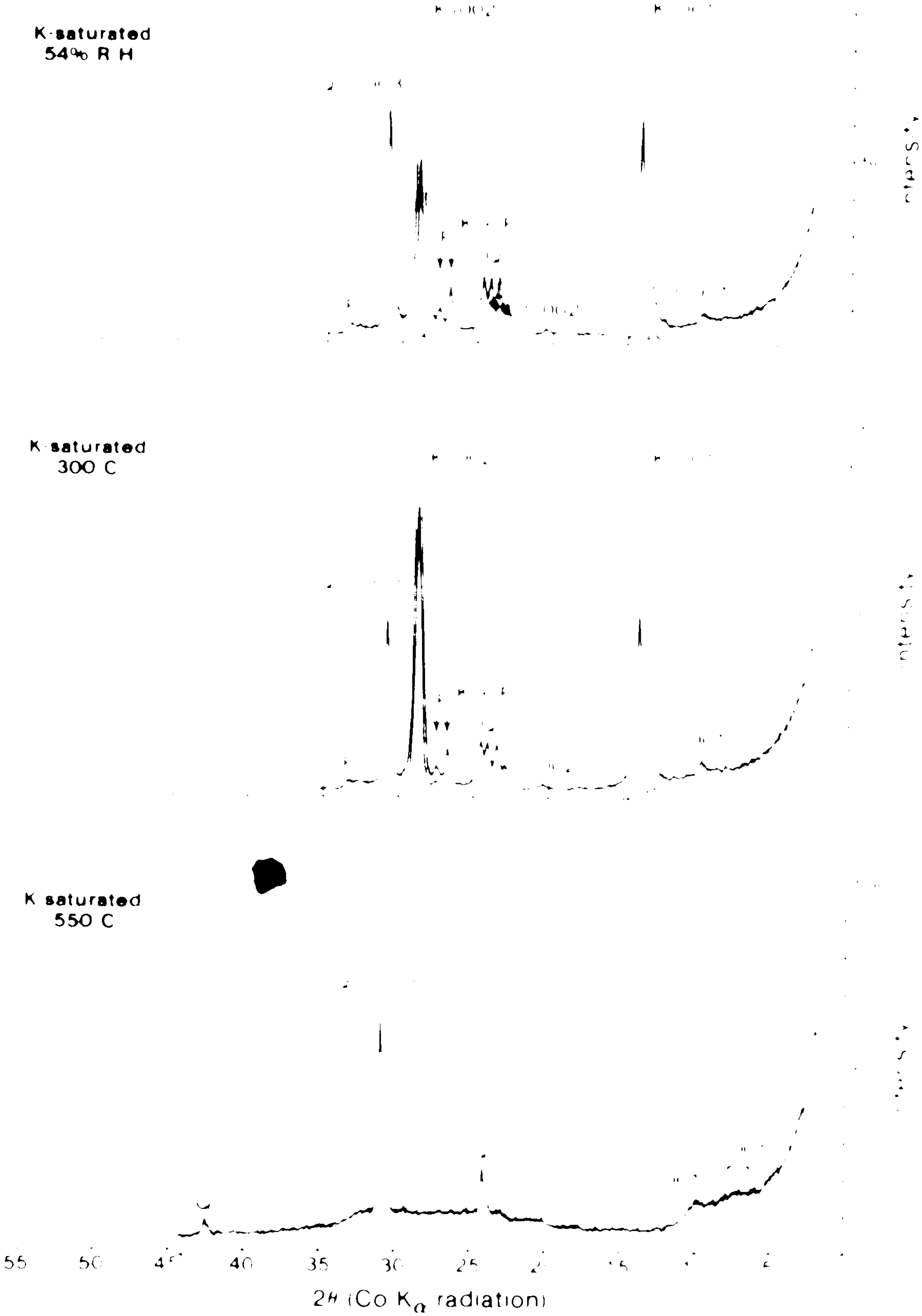

K-saturated
54% R H
K saturated
300 C
K saturated
550 C
55
50
40
35
2θ (Co Kα radiation)

Figure [illegible] A and B

X-ray diffractograms representative of shale samples from immediately above and below the Glauconitic Sandstone type II clay assemblage. This sample contains about 30% illite. The 10A (001) reflection is sharp (Ca disc, 54% humidity) but is asymmetrical toward its low angle side. The asymmetry extends from 10A to 15-16A. Upon saturation with ethylene glycol the 10A reflection remains sharp but the asymmetrical portion expands towards higher d-spacings and a broad peak is produced at 13-14A. The asymmetry and swelling properties may result from edge weathering of illite. The presence of chloritic material within the illite phase is indicated by the low angle asymmetry which remains on the 10A peak after K saturation [illegible] 10A lower part [illegible] upon heating to [illegible] (Fig. [illegible]B) [illegible] pattern the [illegible] collapsed [illegible]


Type III
Ca saturated
54% R H
K saturated
0% R H
radiation

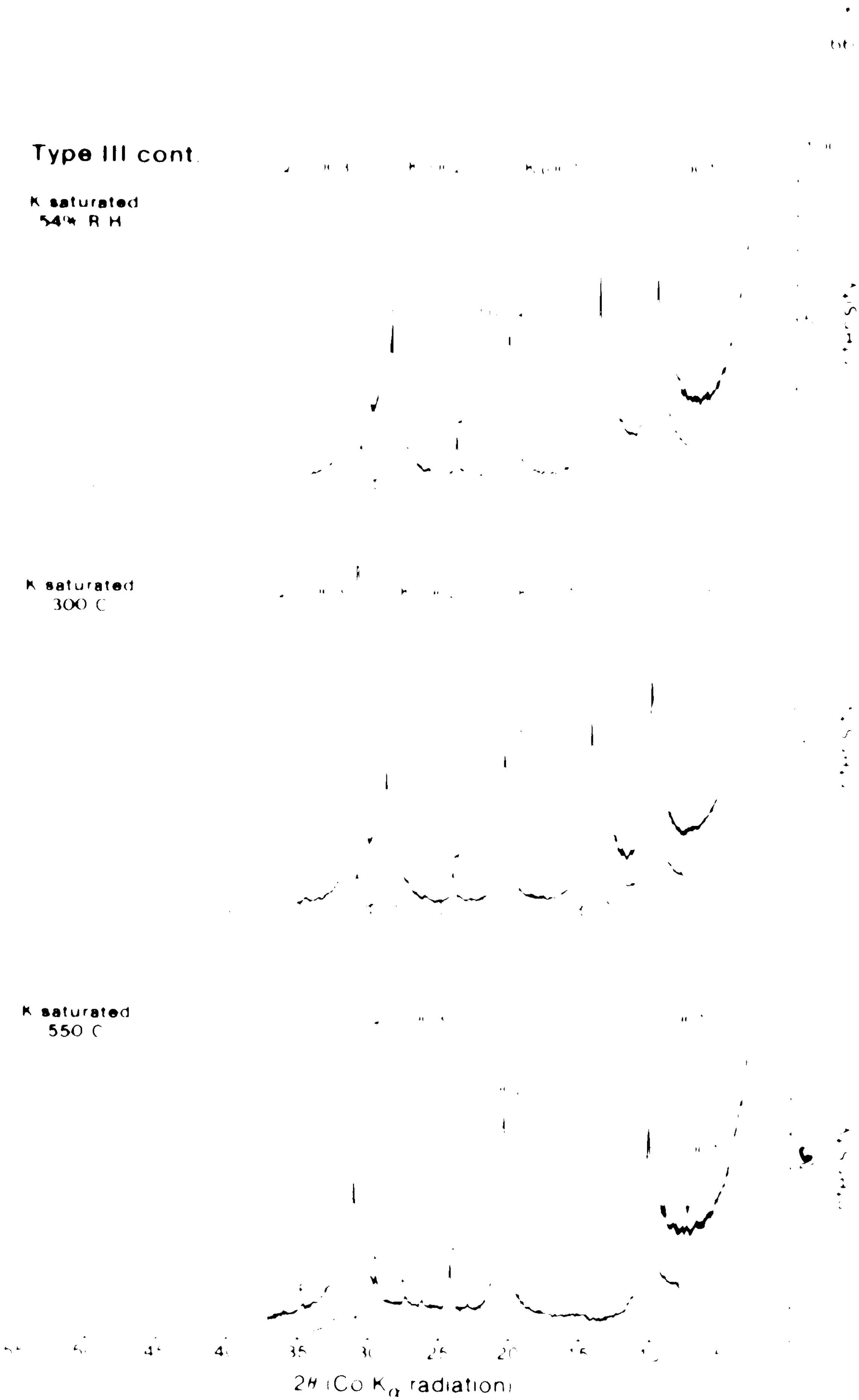
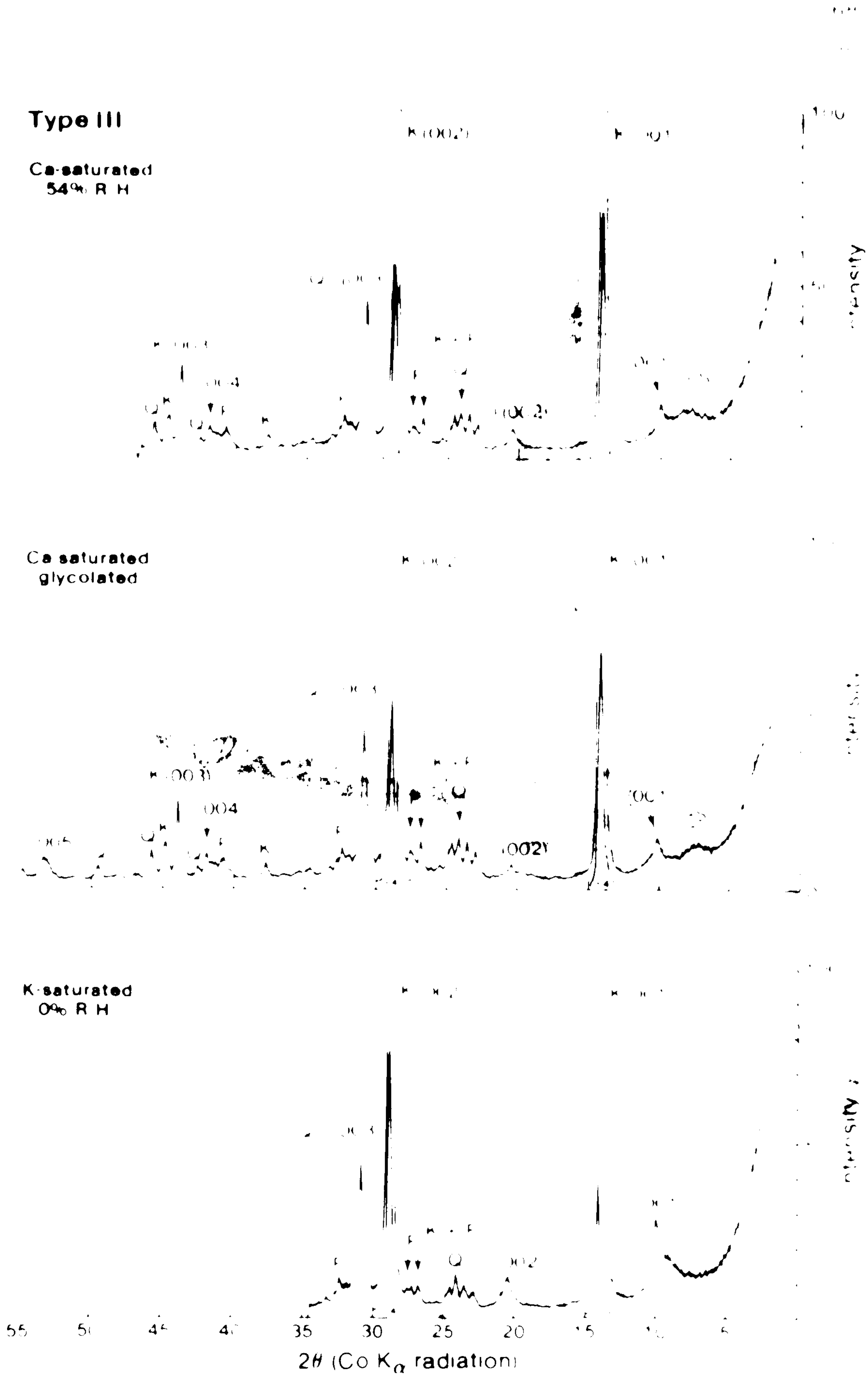

Type III cont.
K saturated
54% R H
K saturated
300 C
K saturated
550 C
35
25
20
2θ (Co Kα radiation)

Figure [illegible] A and B

X ray diffractograms representative of a very fine grained sandstone [illegible] facies [illegible] and a bioturbated sandstone of facies [illegible] type II clay assemblage. Both these sandstones probably have a significant detrital clay component. Note the broad peak at about 12A labelled [illegible] S on the Ca saturated 54% [illegible] pattern Fig [illegible] A. Upon glycolation the broad 12A reflection loses intensity and shifts to about 14A. Much material does not collapse completely to 10A when K saturated [illegible]% humidity. This behaviour results in a 10A peak which has greater intensity but is still broadly asymmetrical on the low angle side. This clay is probably a randomly interstratified illite smectite. The behaviour of the low angle reflections [illegible] heating Fig [illegible] B suggests that the clay is [illegible] [illegible]ized.


Type III
Ca-saturated
54% R H
Ca saturated
glycolated
K-saturated
0% R H
55
35
30
25
20
2θ (Co Kα radiation)

Type III cont

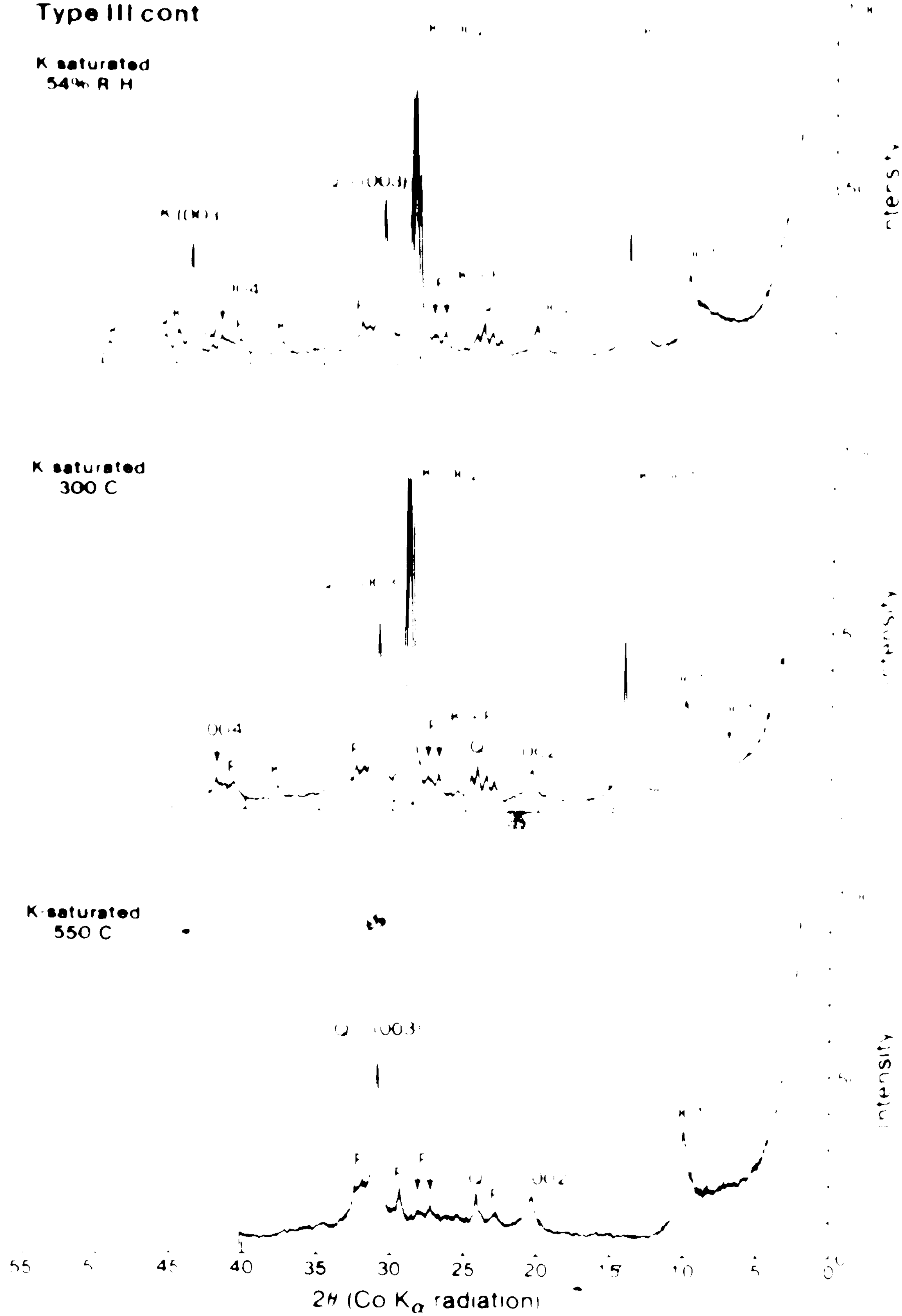
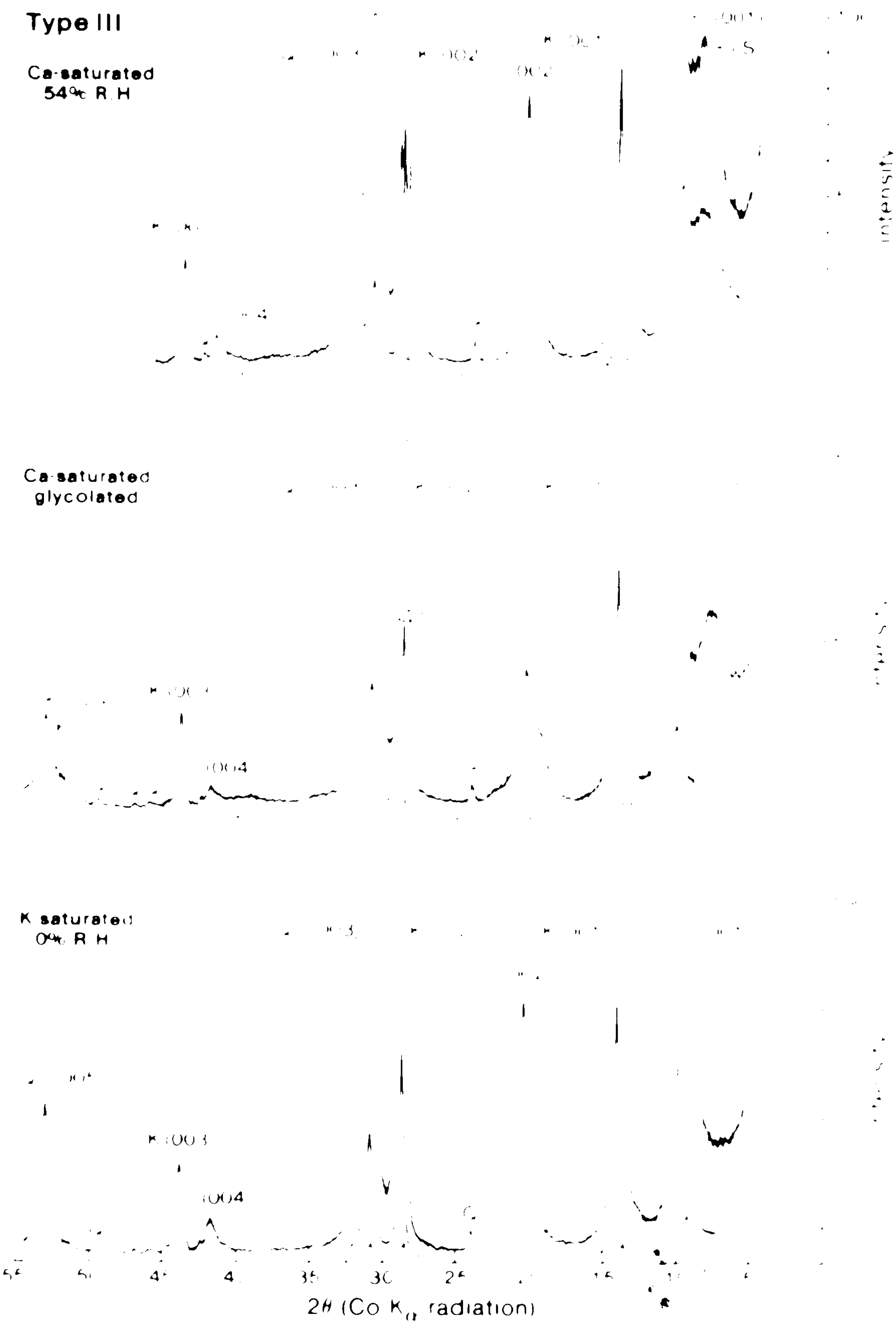


Figure 22A and B

X-ray diffractograms representing a shale interbed in the carbonate-cemented sandstone of facies 6, type II clay assemblage. This sample contains 55 per cent illite. Note the peak at 12A (labelled S). Upon glycolation the 12A reflection loses intensity and shifts to about 14A. This reflection probably represents a randomly interstratified illite-smectite.


Type III
Ca-saturated
54% R.H
Ca-saturated
glycolated
K saturated
0% R.H
004
004
40
35
30
2θ (Co Kα radiation)

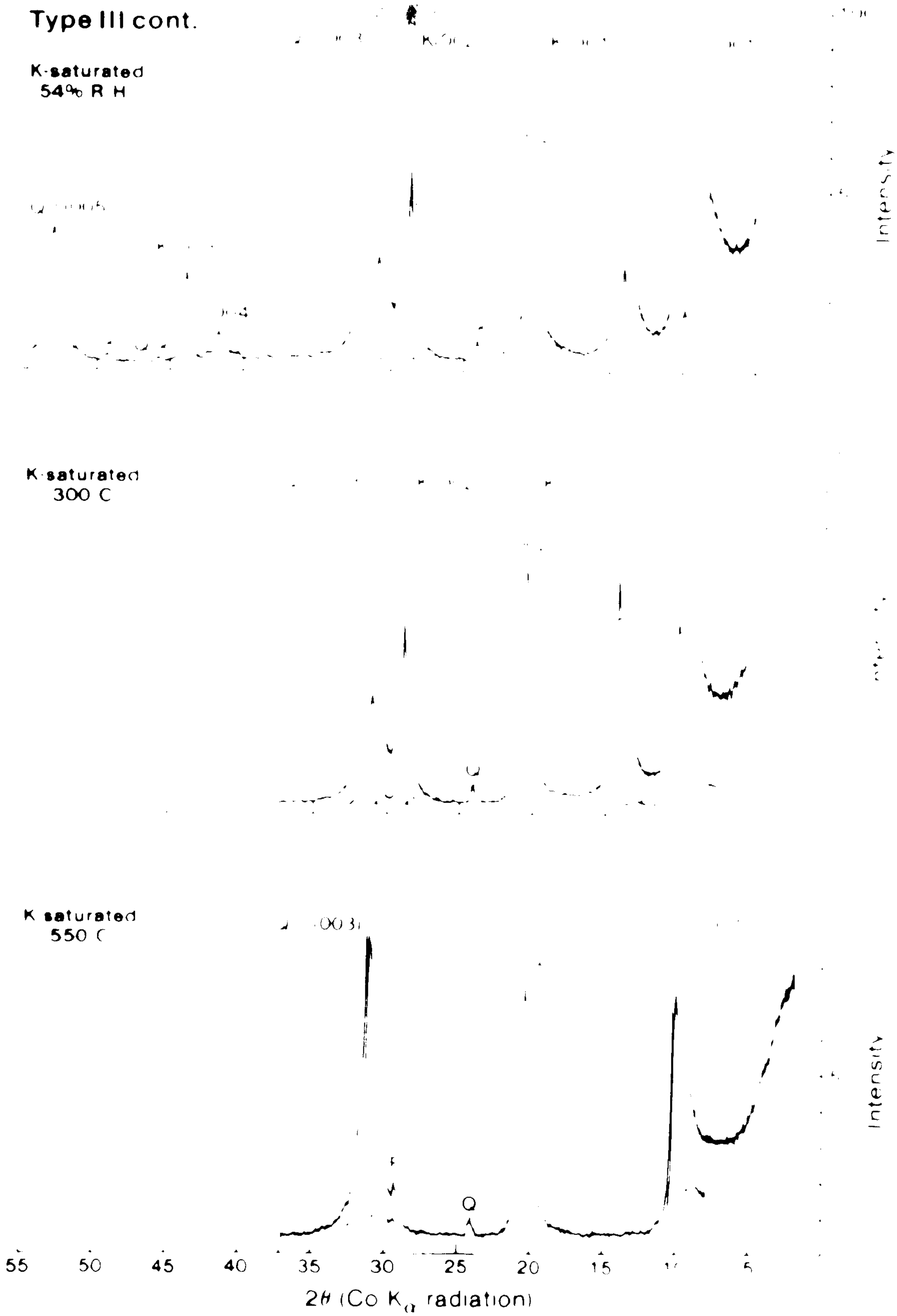
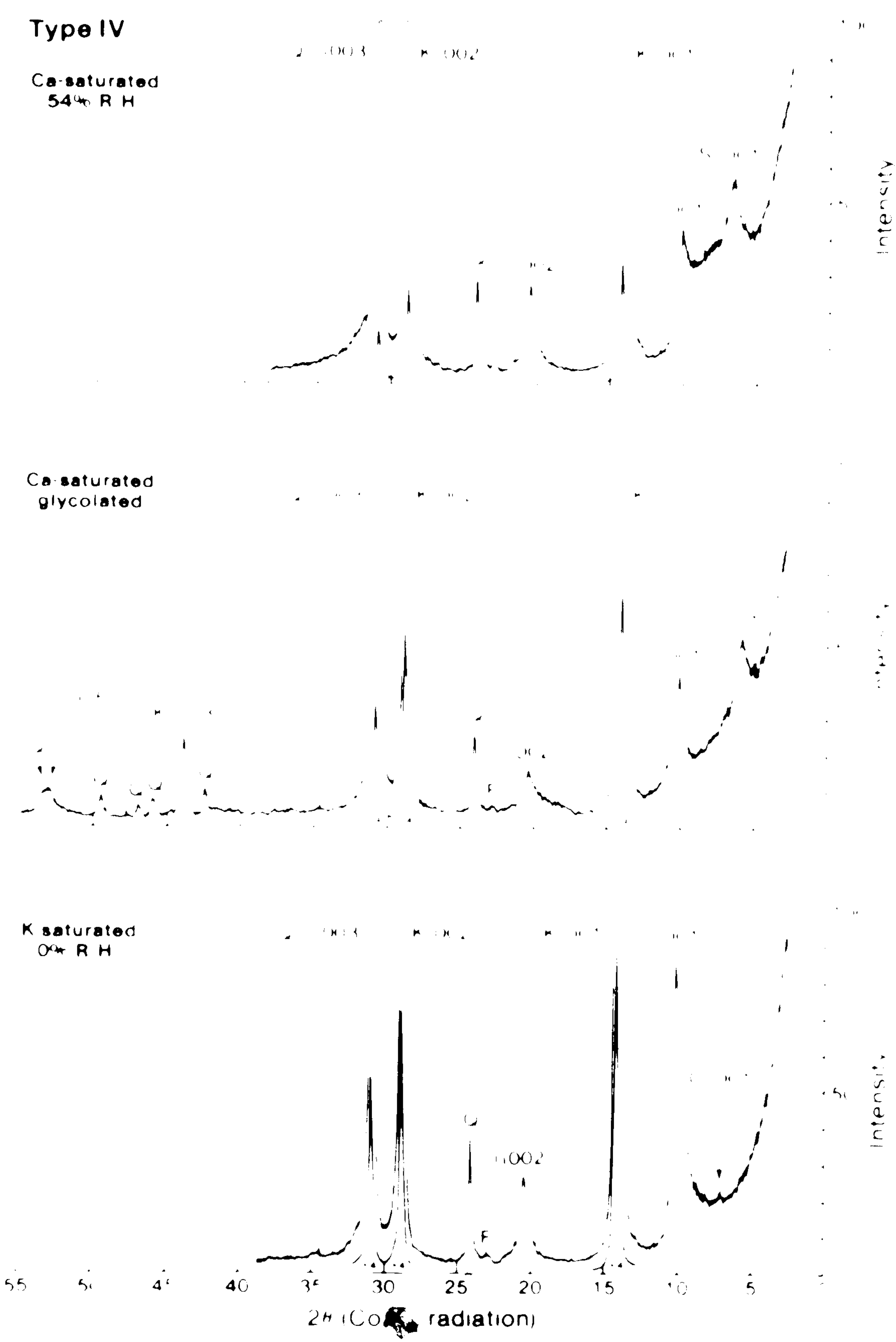

Type III cont.
K-saturated
54% R H
K-saturated
300 C
K saturated
550 C
Q
Intensity
55
50
45
40
35
30
25
20
15
5
2θ (Co Kα radiation)

Figure 25 A and B

X-ray diffractograms representing the <2 micrometre fraction of an oil saturated sandstone of facies 4, type IV clay assemblage. Smectite S content is less than 5 per cent. The smectite (001) peak is relatively sharp on all saturated patterns. Discrete [illegible] occurs in trace amounts.


Type IV
Ca-saturated
54% R H
Ca-saturated
glycolated
K saturated
0% R H
Q
002
F
Intensity
Intensity
55
40
30
25
20
15
5
2θ (Co radiation)

Type IV cont.

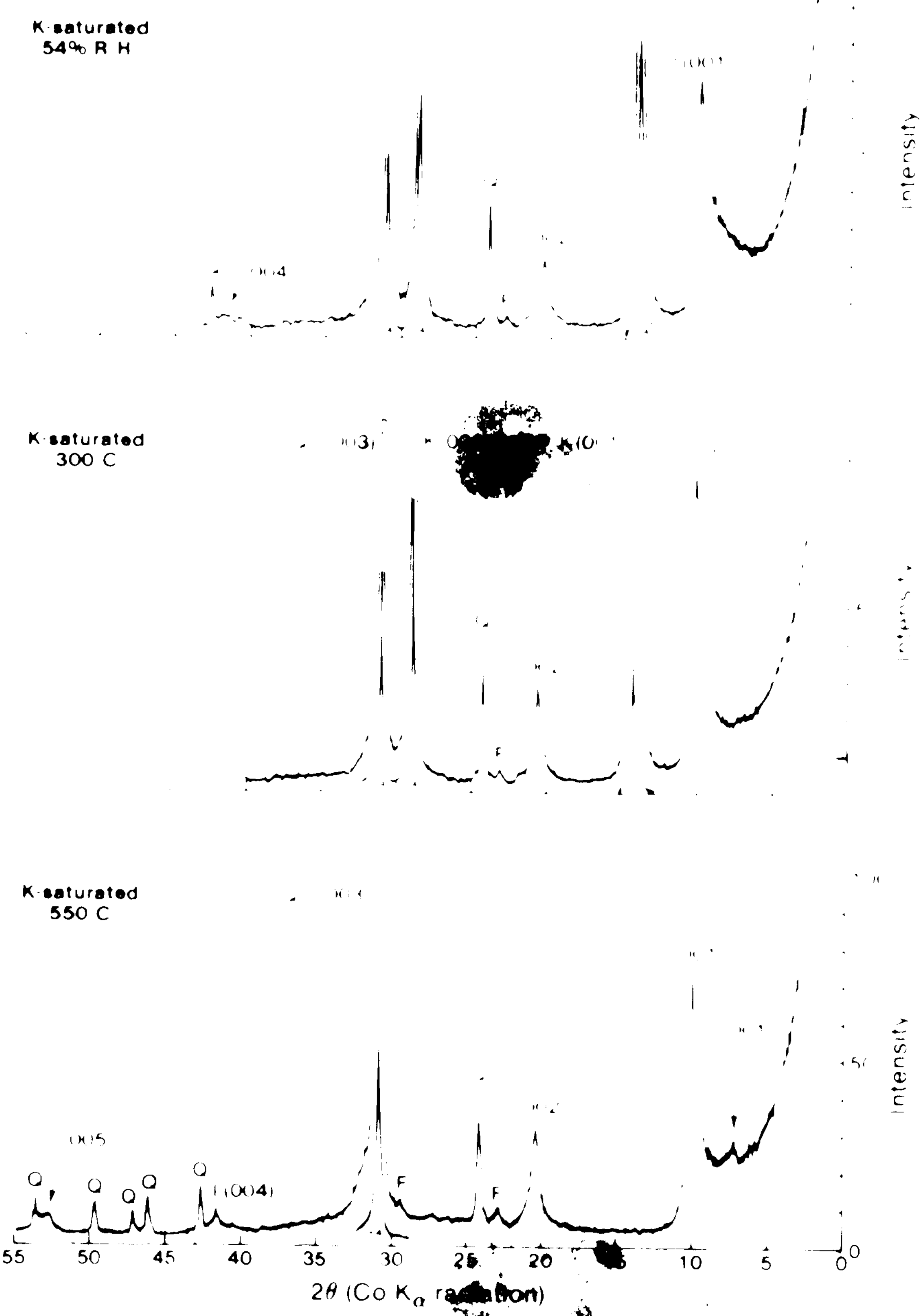
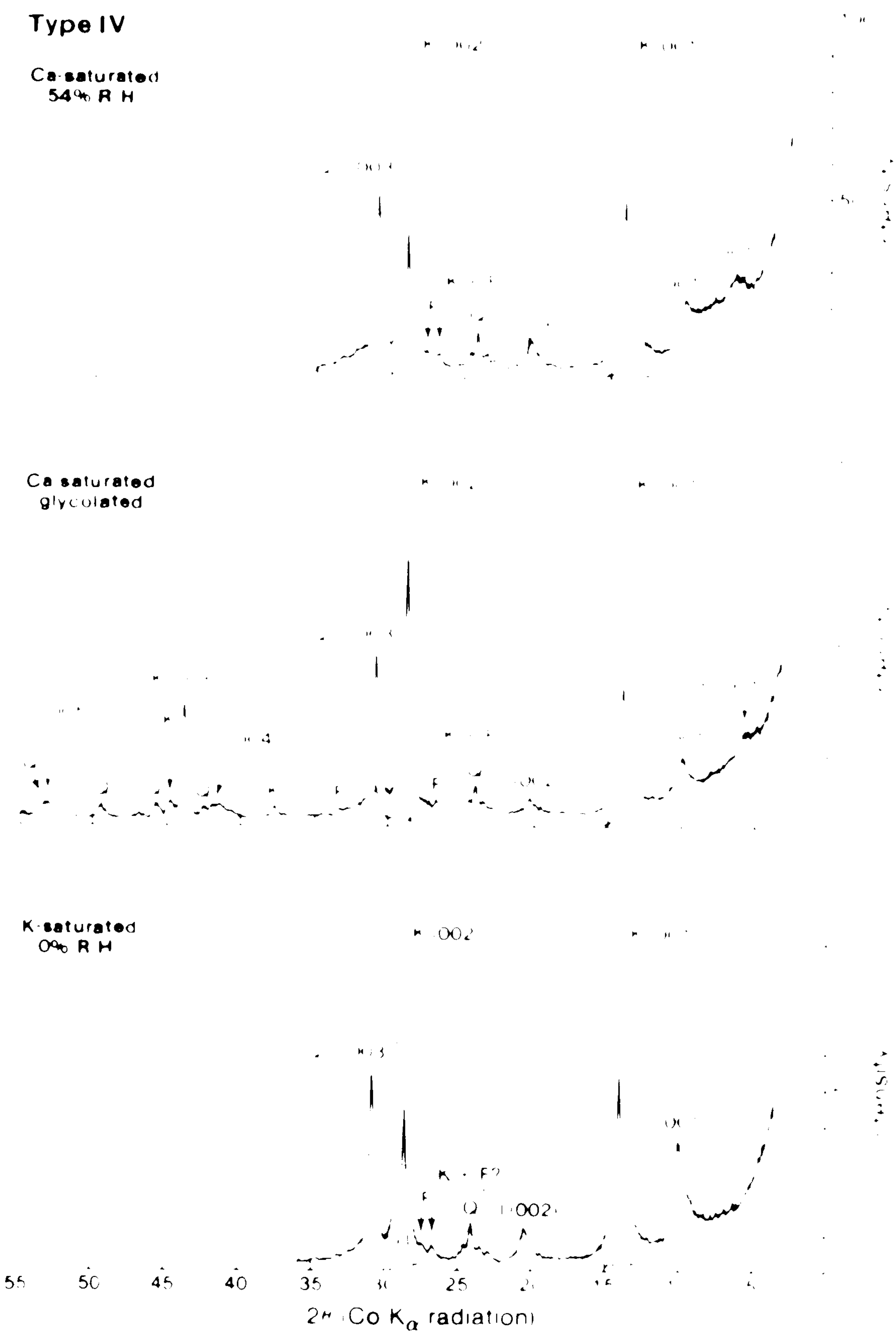
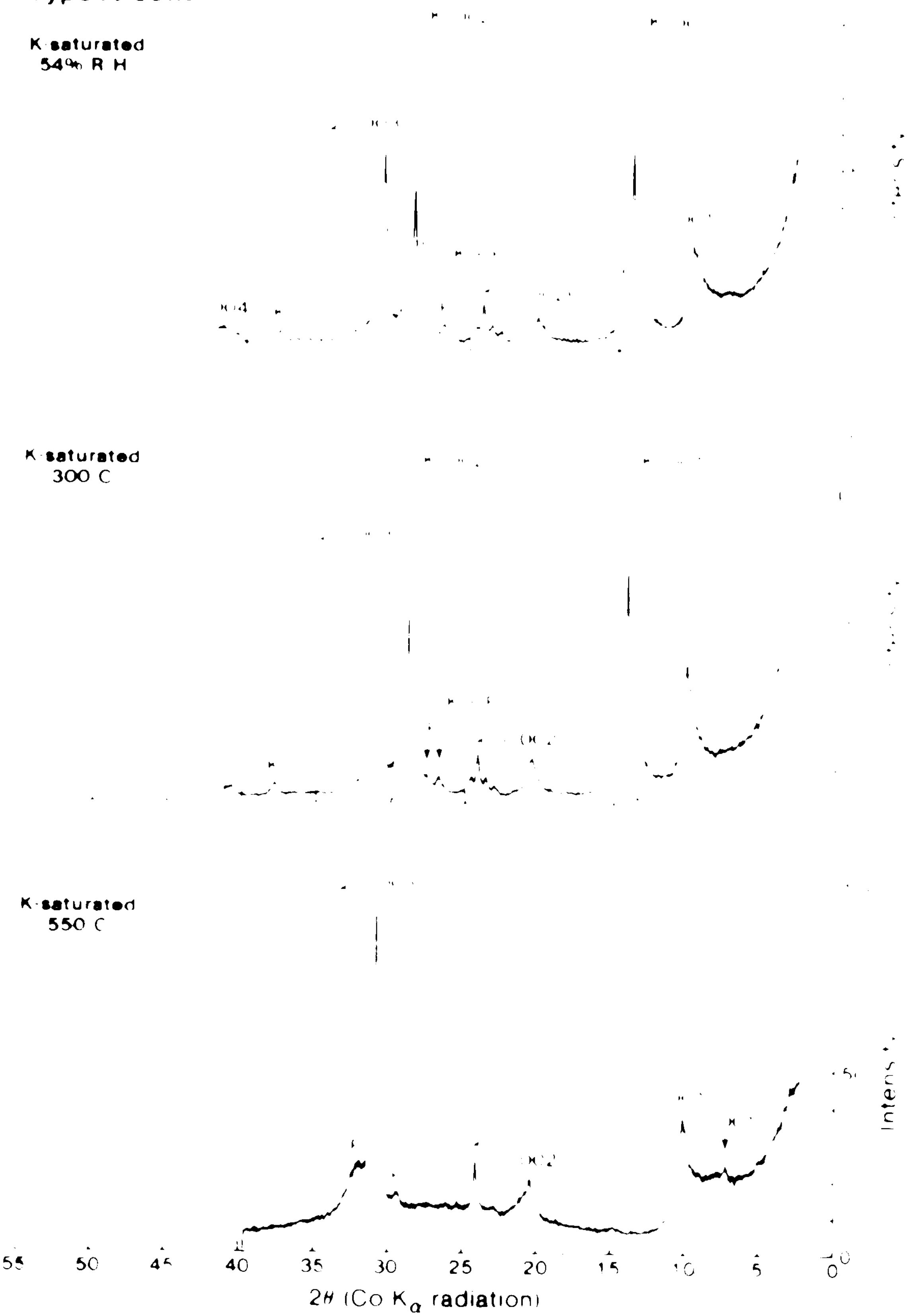

K-saturated
54% R H
K-saturated
300 C
K-saturated
550 C
Q
F
I (004)
Intensity
55
50
45
40
35
30
25
20
10
5
0
2θ (Co Kα radiation)

Figure 24 A and B

X-ray diffractograms representing the < 2 micrometre fraction of an oil saturated sandstone of facies 4, type IV clay assemblage. Smectite content is less than 1 per cent. Smectite (S) is represented by a broad 15 Å reflection which expands to 17Å upon saturation with ethylene glycol. Discrete chlorite occurs in trace amounts. The chlorite (001) peak (14Å) is enhanced upon heating to 550°C (Fig. 24B) and shows as a low intensity broad peak.


Type IV
Ca-saturated
54% R H
Ca saturated
glycolated
K-saturated
0% R H
55
50
45
40
35
25
2θ (Co Kα radiation)

Type IV cont.


K-saturated
54% R.H.
K-saturated
300 C
K-saturated
550 C
55
50
40
35
30
25
20
5
0
2θ (Co Kα radiation)

Paragenetic Sequence

[illegible]

Third Stage Diagenesis

Fourth Stage Diage

VII. RESERVOIR QUALITY

[illegible]

A. Facies 4

[illegible]

B. Permeability and Continuity

[illegible]

Detrital Clay

[illegible]

C. Irreducible Water Saturation

The argillaceous sandstones [illegible] to the abundance of detrital kaolinite. [illegible] high surface area also has high irreducible water saturation [illegible] because of the physical attraction of the [illegible] sandstones, log calculations may indicate that water saturations are too high for a productive interval. However, the reservoir may be capable of essentially water-free production because the water is predominantly irreducible.

E. Fluid Sensitivity

The main concern related to fluid sensitivity in this reservoir pertains to the dispersion of fine kaolinite. Many of these kaolinite plates are only loosely attached to grain surfaces and could easily be dispersed by moving fluids and become lodged in pore throats. Gray and Rex (1966) report that damage caused by migration of fines can drop a very permeable sandstone to less than [illegible] percent of its original permeability within a few hours of flow.

[illegible] containing minerals are sensitive to acidization. These minerals dissolve [illegible] precipitate when conditions change and cause reservoir damage. Although [illegible] very rare [illegible] present [illegible] amounts. Therefore acidization should be avoided.

Effect of the Application of Wet Forward Combustion on the Reservoir

[illegible] laboratory experiments under [illegible] steam [illegible] indicate that [illegible] formed where kaolinite [illegible] a very small amount [illegible] are present [illegible] temperature [illegible] simulate wet forward combustion [illegible] temperature [illegible] suggest that [illegible] reservoir sensitivity.

Another reaction which may occur during the *in situ* recovery of bitumen by wet thermal methods is the dissolution and precipitation of SiO_2 (Boon 1979) Low quartz and amorphous silica may dissolve when temperature and pH are increased and precipitate as the fluid reaches cooler regions Such fluid-rock interactions can lead to a change in reservoir properties such as reduced porosity and permeability and to an undesirable composition of produced fluids suspended clays high dissolved silica and a high degree of hardness (Boon 1979) Chert percentage in the bitumen-saturated portion of the Glauconitic Sandstone in the SHOP project is about 20 per cent (Table 1) This chert may be particularly susceptible to dissolution under raised temperature and pH conditions

VIII. CONCLUSIONS

Three factors control the distribution of hydrocarbons and the reservoir quality in the Glauconitic Sandstone within the Suffield area. They are (1) sedimentology, (2) structure, and (3) mineralogy and diagenesis.

A. Sedimentological Controls

Hydrocarbons are located along a northwest to southeast trending broad arch of thick, vertically continuous sandstone. The sandstone consists of facies representing, in ascending order, the shoreface, foreshore, backshore, marsh and lagoonal or continental zones of a progradational beach or barrier island complex. The facies representing the foreshore zone (laminated sandstone of facies 4) was deposited under high energy conditions and has good reservoir properties: high porosity, low clay content, and good lateral and vertical continuity. Fluctuating energy conditions and bioturbation in the backshore zone created a rock with poor reservoir properties in facies 5 (argillaceous or bioturbated sandstone facies). This unit is characterized by low porosity and high clay content with only isolated porous zones. Tidal inlet and channel deposits occurring along the sandstone trend disrupt the continuity of the reservoir.

B. Structural Controls

Basement faults, possibly related to tectonic activity associated with the North Battleford Arch and active during late Mannville time, have caused downfaulting of a blocks of sandstone such that nondepositional facies changes occur. Thus the hydrocarbon trapping mechanism is stratigraphic with some structural effect.

Movement on basement faults during deposition of the Glauconitic Sandstone is most likely responsible for the locally occurring unusually thick (45 m) progradational beach deposits. Areas with the thickest sandstone accumulations were probably located over downfaulting basement blocks. The rate of subsidence equalled the rate of sediment input such that the shoreline remained in a relatively stable position and facies accumulated vertically.

C. Mineralogical and Diagenetic Controls

The Glauconitic Sandstone is a litharenite composed of quartz, chert, other sedimentary rock fragments, and trace amounts of feldspar. The dominant clay mineral is kaolinite which occurs in both detrital and authigenic forms. It is the abundance of detrital kaolinite present in the rock which determines the reservoir quality. The bioturbated or structureless facies 3 with abundant detrital clay forms a poor reservoir, whereas the clean, nonargillaceous facies 4 has good reservoir qualities. Porosity and permeability is only slightly reduced in the clean sandstones by diagenetic forms such as kaolinite, quartz overgrowths and deformed rock fragments.

The paragenetic sequence is (1) first stage calcite cement and pyrite crystallization (2) quartz cementation and kaolinite growth (3) second stage calcite cementation, feldspar leaching, minor kaolinite illite development, and growth of calcite crystals and (4) smectite chlorite crystallization and the emplacement of hydrocarbons.

The main concern related to fluid sensitivity is the dispersion of kaolinite. Iron containing minerals (pyrite and Fe chlorite) which are sensitive to acidization occur only in trace amounts. When the temperature of the reservoir is raised during the wet combustion process, kaolinite, quartz and dolomite may react to form the swelling clay smectite. Further reduction in permeability may result from dissolution and reprecipitation of SiO_2 (quartz and particularly chert).

D. Recommendations for Future Work

Areas for further study include regional sedimentology and diagenesis. Preliminary examination of core from the eastern sandstone belt centred in range 7, townships 19 and 20, suggest that conglomerates with shale interbeds within this belt represent offshore storm deposits. Further study is necessary to negate or substantiate this idea. The Glauconitic Sandstone in the Suffield area is only a small part of the extensive regional Glauconitic Sandstone for which the entire depositional picture is yet to be understood. Stable isotope analyses are needed to develop a further understanding of water rock interaction during diagenesis. With similar objectives in mind, new cores should be drilled in the SHOP project site after the combustion front has past through the area. Samples from these new cores should be examined in thin section and by SEM to evaluate any reservoir damage due to water-rock interaction during stimulation

PLATE 1: Core Photographs for Facies 6 to Facies 3d.

1. Facies 6b Light grey to light brown very fine to fine grained sandstone with well-defined laminations
   Left Wave-rippled sandstone with a thin shale interbed at the base of the photograph
   Centre Ripple troughs and subhorizontal planar laminations defined by carbonaceous debris
   Right Cross-laminated very fine grained sandstone near the base of the Glauconitic Sandstone

2. Facies 6b Calcite-cemented siltstone or very fine grained sandstone
   Left Calcite-cemented sandstone with low angle planar laminations The circular homogenous patches in the lower right of the photograph are probably burrows
   Right Calcite-cemented sandstone with interbeds of carbonaceous shale The shale has syneresis cracks and the bed is partially bioturbated

3. Facies 6a Bioturbated structureless or indistinctly laminated fine grained sandstone
   Left Generally structureless sandstone poorly defined laminations in lower portion of photograph
   Right Bioturbated zone in upper portion of photograph to structureless in the lower portion

4. Facies 5 Medium grained sandstone interbedded and interlaminated with fine grained sandstone
   Left Thicker medium grained sandstone bed with erosional base The bed fines upward to fine grained sandstone
   Right Low angle planar laminated medium and fine grained sandstone

5. Facies 4 Horizontal laminated to low angle cross laminated fine grained sandstone Low angle cross laminations

6. Facies 4 Low angle planar laminations The black piece of core at the top of the photograph is an uncleaned oil-saturated portion

7. Facies 3d Fine grained sandstone with variable sedimentary structures and argillaceous zones This facies is characterized by patches with good oil saturation interrupted by zones with poor oil-saturation or no saturation
   Left Zone with irregular bedding and patchy oil saturation The upper part of the slab has been cleaned but the lower portion demonstrates an oil saturated lense surrounded by a nonsaturated clay rich sandstone
   Left centre Slightly coarser sandstone interbeds and lenses This slab has been cleaned
   Right centre Relatively high angle laminated nonargillaceous sandstone Both pieces have been cleaned but they probably had good oil saturation originally
   Right Sandstone breccia The laminated breccia blocks are angular and randomly oriented The matrix is a slightly coarser clay rich sandstone

Scale All core in the photographs is 3 inches (7.6 cm) wide

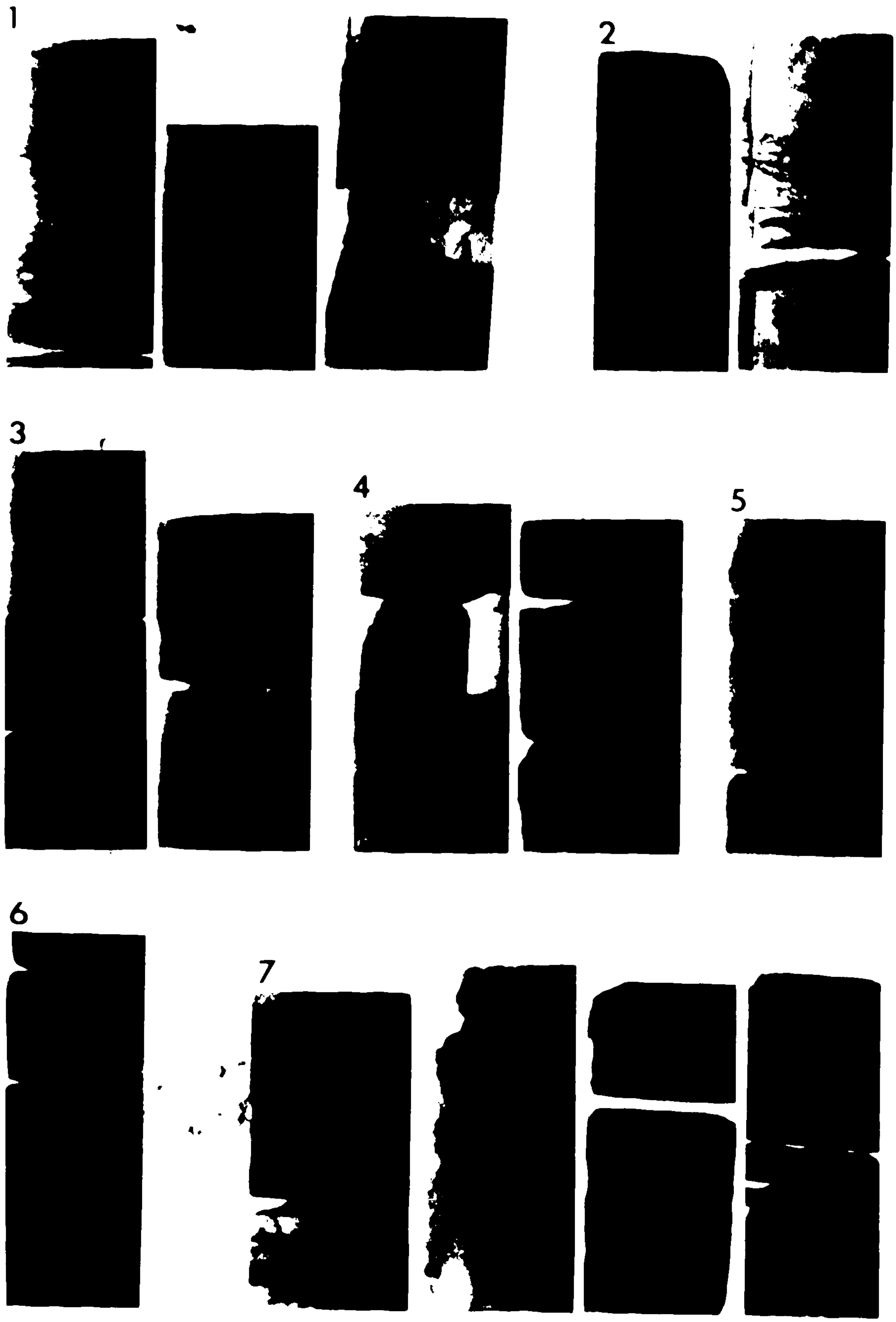

1
2
3
4
5
6
7

PLATE 2 Core Photographs for Facies 3c to Facies 1

1 Facies 3c Facies 3c is more argillaceous than facies 3d and lacks any regular bedding
Left Indistinctly bedded sandstone with patchy oil saturation
Centre Bioturbated sandstone
Right Structureless argillaceous sandstone

2 Facies 3bi Bioturbated argillaceous sandstone
Left Bioturbated to structureless sandstone
Right Bioturbated sandstone with clay streaks

3 Facies 3bii Cross laminated sandstone unit overlain by a breccia
Left Structureless fine-grained sandstone containing coarse grained pyrite overlain by cross-laminated sandstone
Right Breccia Disrupted zone with carbonaceous rootlets and irregularly shaped or subrounded blocks Breccia blocks are finer grained than the matrix

4 Facies 3biii Laminated to low angle cross laminated argillaceous sandstone Laminations are defined by coarse sand sized magnetite grains

5 Facies 3a Light brown rooted argillaceous sandstone

6 Facies 2 Carbonaceous sandstone and shale
Left Dark grey sandy shale The base of the unit is an irregular boundary marked by a colour change from medium or light grey (facies 3) to dark grey (facies 2)
Right Poor quality coal overlain by bioturbated carbonaceous shale

7 Facies 1 Very fine grained sandstone siltstone and shale
Left Structureless to laminated medium grey shale with light grey silt interlaminations and small burrows
Right Interlaminated siltstone and shale rippled to cross laminated with spiated burrows carbonaceous debris along some laminations

Scale All core in the photographs is 3 inches (7.6 cm) wide

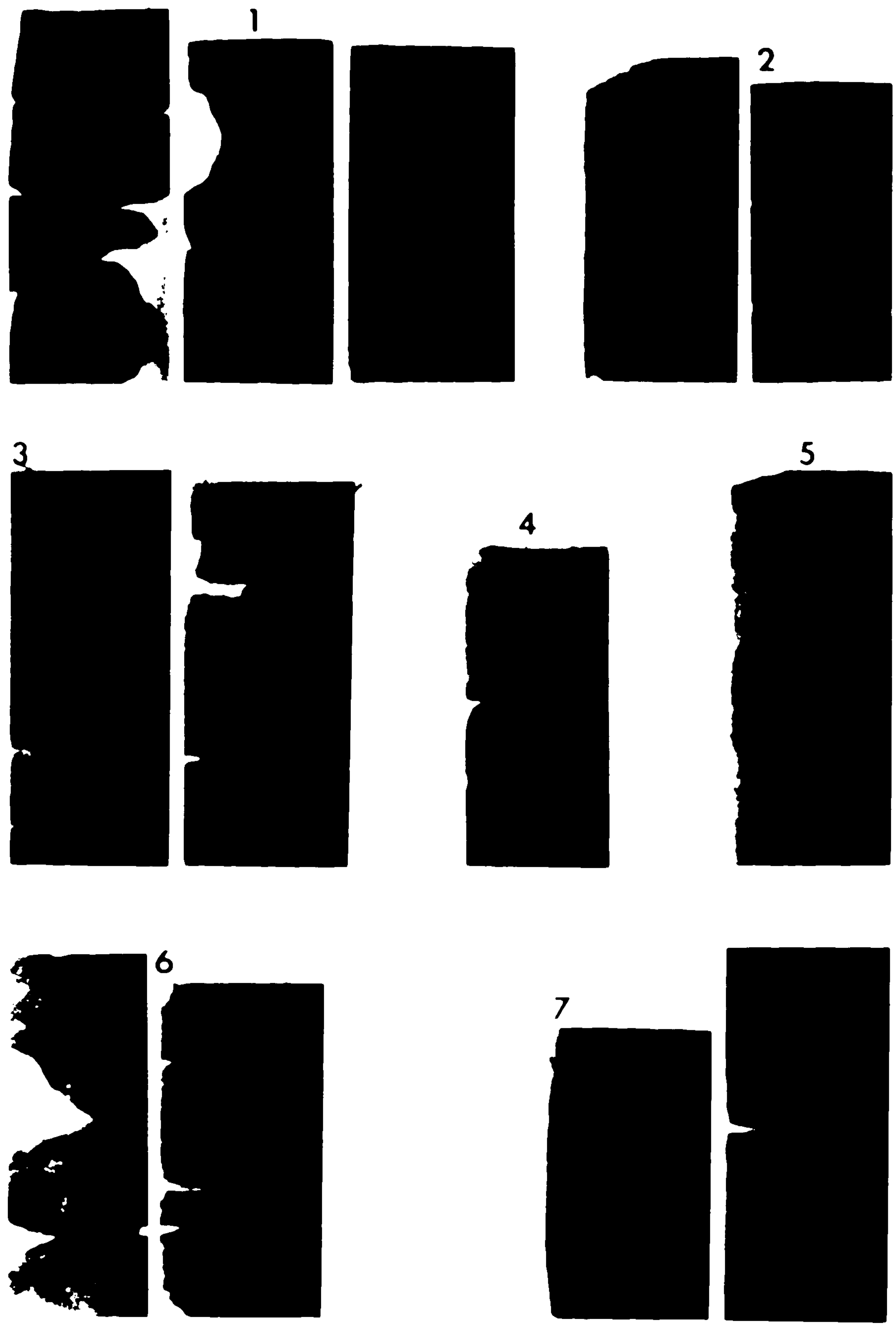
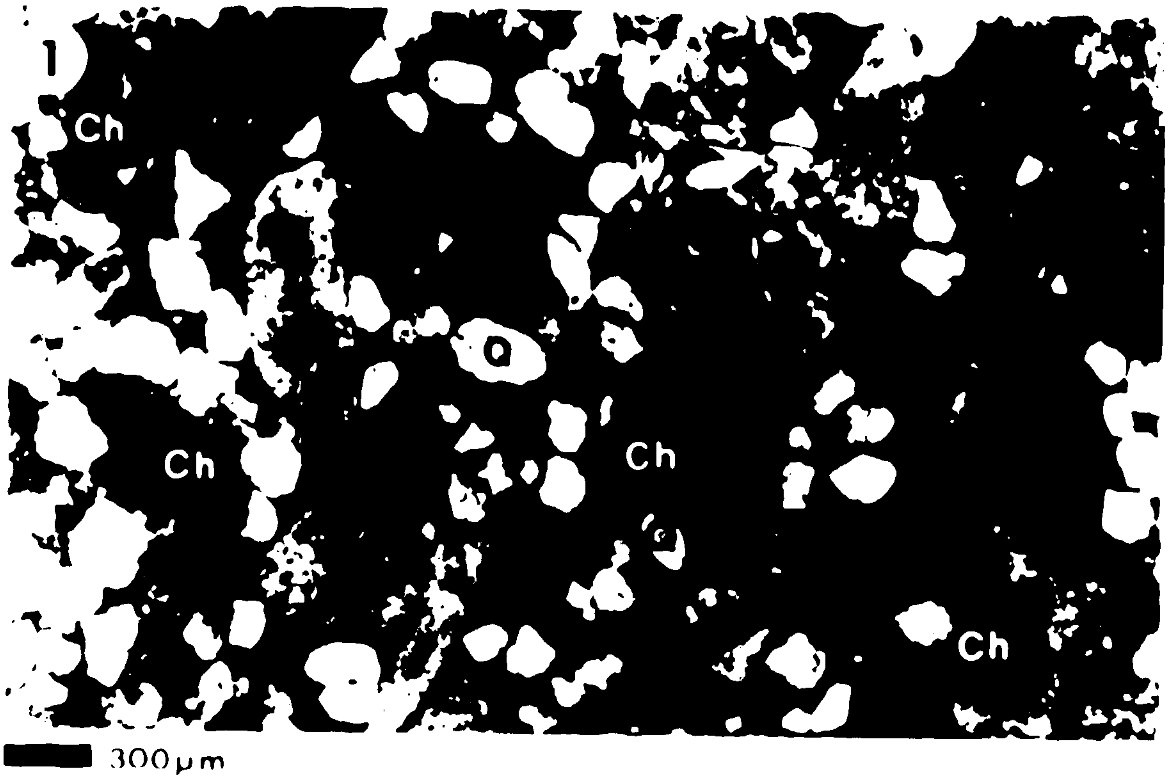

1
2
3
4
5
6
7

PLATE 3 Thin Section Textures for Facies 5 and Facies 3biii

1 Facies 5 Thin section photomicrograph of a sample from facies 5 showing bimodal grain size with coarser chert grains (Ch) and fine quartz (Q) Chert grains have low sphericity and are more angular than the quartz Plane polarized light

2 Facies 3bii Thin section photomicrograph of a sample from facies 3biii showing the preferential horizontal fabric resulting from compaction flattening of soft rock fragments (RF) and orientation of elongate chert grains (Ch) Feldspars (F) (K feldspar and plagioclase) are more abundant than in other facies Plane polarized light


1
Ch
Q
Ch
Ch
Ch
300 μm

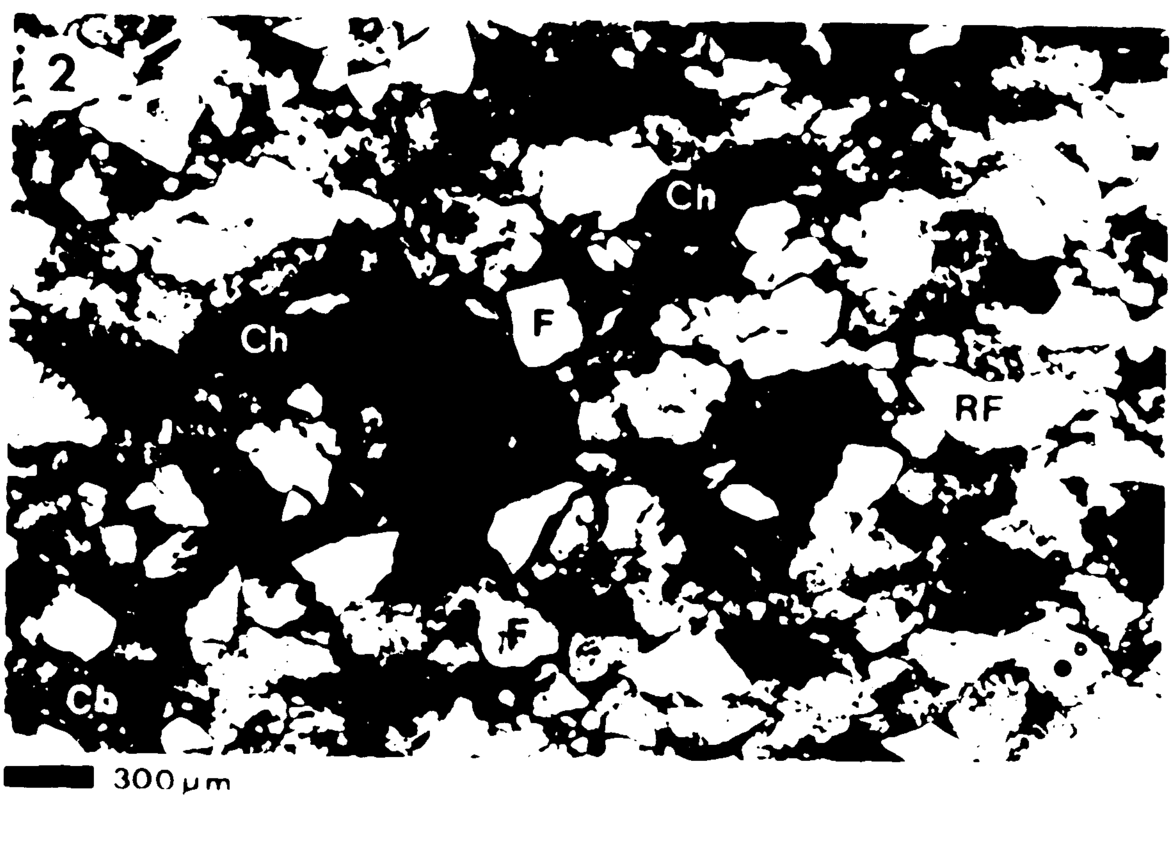

2
Ch
F
Ch
RF
F
Cb
300 μm

PLATE 4 Bulk Mineralogy

1 The detrital shape of some quartz grains is defined by a thin line of abundant inclusions trapped at the boundary between detrital and authigenic quartz (short arrow right side of thin section photomicrograph) Other quartz overgrowths produce an interlocking of quartz grains (long arrows left side of photomicrograph) such that original detrital shape is not obvious Plane polarized light Scale bar is 100 micrometres

2 Thin section photomicrographs showing
(a) microcrystalline chert Plane polarized light
(b) macrocrystalline chert Crossed nicols
(c) chalcedonic chert Crossed nicols
Scale bar is 100 micrometres

3 Thin section photomicrograph showing a deformed siltstone fragment (RF) Plane polarized light Scale bar is 100 micrometres

4 Thin section photomicrograph showing a deformed argillaceous rock fragment (RF) Note the lack of intergranular pore space associated with the rock fragment Plane polarized light Scale bar is 100 micrometres

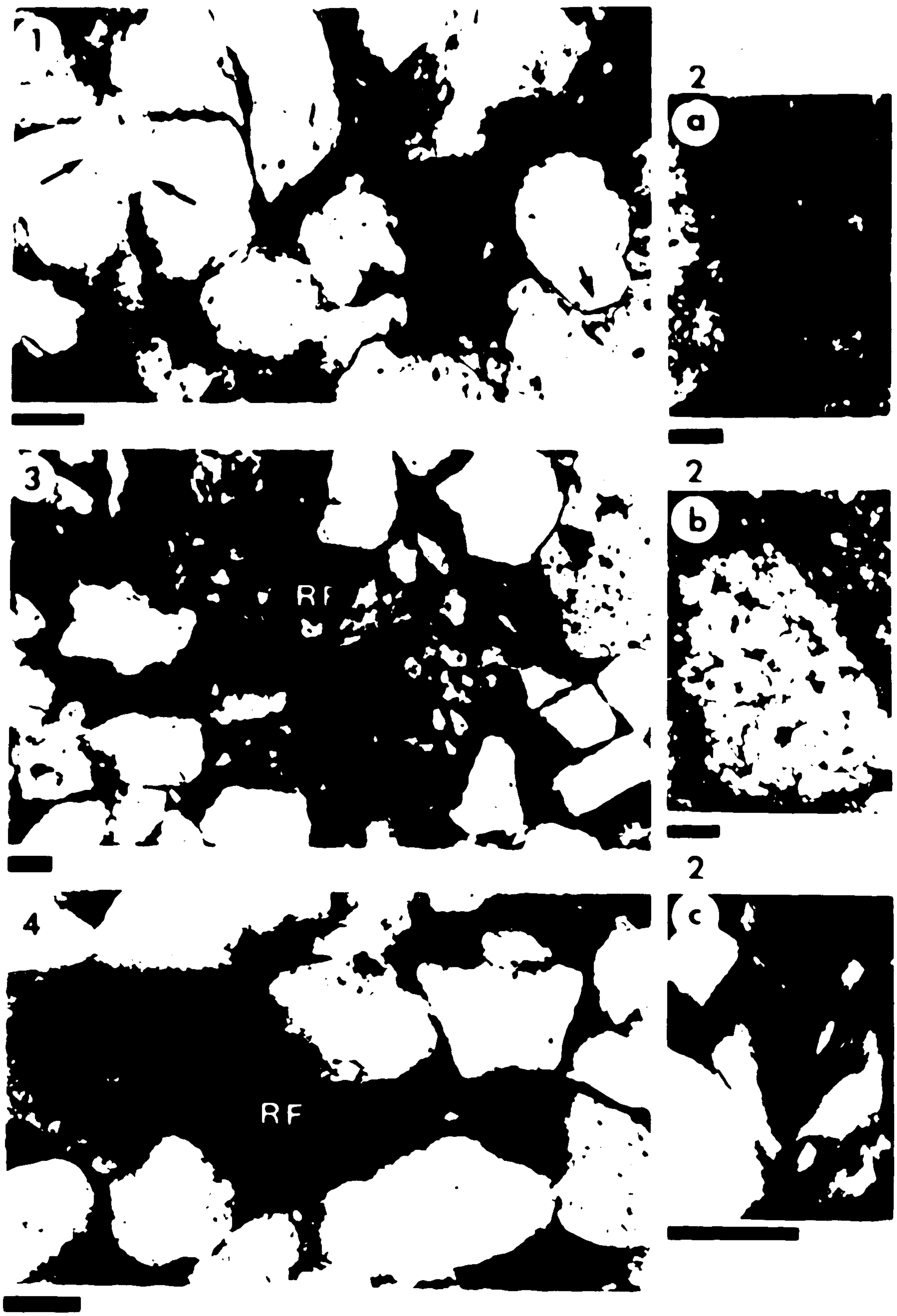

1
2
a
3
RF
2
b
2
c
4
RF

PLATE 5: Bulk Mineralogy and Texture of the Argillaceous Sandstone, Facies 3

1 Thin section photomicrograph showing the skeletal framework of a corroded feldspar (F) Note the secondary porosity (P) created by the corrosion of the grain Plane polarized light

2 Thin section photomicrograph showing carbonate grains (dolomite or siderite) The black arrow (upper left) points to a median grain sized zone of carbonate which has interlocking contacts with adjacent grains The interlocking contacts may be either the result of remobilization of a carbonate grain or due to a combination of both quartz and carbonate overgrowths The white arrows point to a carbonate zone which is a larger than median grain size Contacts with adjacent grains are interlocking and this carbonate probably represents a very local early diagenetic cement Plane polarized light

3 SEM photomicrograph of pyrite (Py) associated with clay on a pore wall

4 SEM photomicrograph of an organic structure replaced by pyrite (Py) subfacies 3a

5 SEM photomicrograph of a very argillaceous sample from facies 3 Masses of very fine kaolinite coat the grains and fill the pores

6 Thin section photomicrograph showing a silt size quartz and clay matrix surrounding sand sized grains quartz (Q) chert (Ch) Plane polarized light

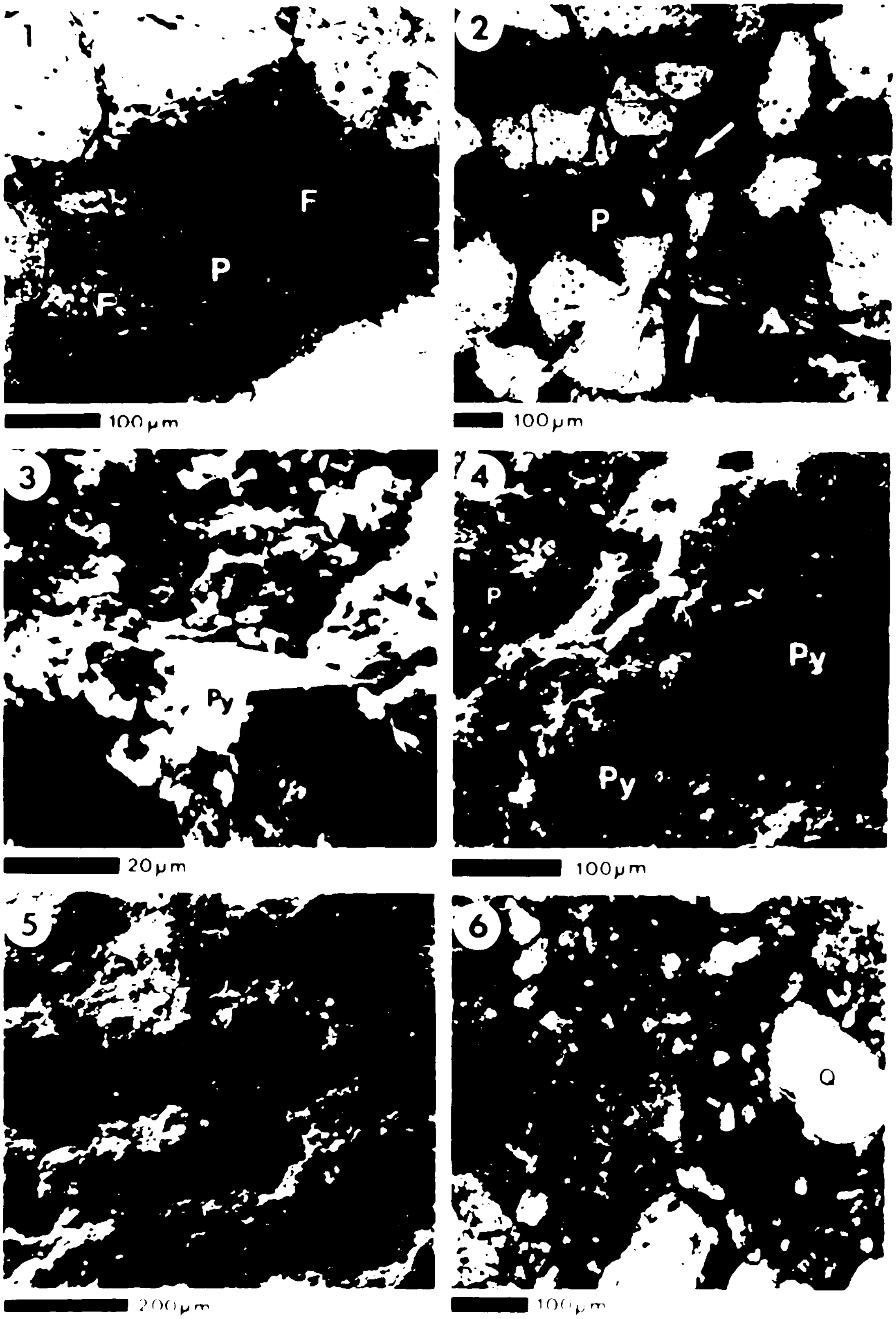

1
F
P
F
100 μm
2
P
100 μm
3
Py
20 μm
4
P
Py
Py
100 μm
5
200 μm
6
Q
100 μm

PLATE 6: **Pore Space Reduction by Kaolinite and Quartz**

1 SEM photomicrograph showing a sheet composed of very fine clay attached to a detrital grain and extending into the pore space

2 SEM photomicrograph showing the majority of pore spce filled by fine detrital kaolinite (dK) Most of the remaining pore space is filled by authigenic kaolinite (aK and quartz overgrowths (Q

3 SEM photomicrograph of large authigenic vermicular kaolinite (vK filling much of the pore space Note the smaller vermicular kaolinite (white arrow on the surface of the large kaolinite

4 SEM photomicrograph showing the occlusion of porosity by vermicular kaolinite vK and quartz overgrowths (Q Note the smaller authigenic kaolinite (arrows) sitting on the larger forms

5 SEM photomicrograph showing a mass of kaolinite booklets (K sitting on quartz overgrowths (Q) and reducing pore space This kaolinite quartz relationship indicates that kaolinite formed after completion of the quartz overgrowth

6 SEM photomicrograph showing a silt sized cluster of authigenic quartz (Q and kaolinite (K reducing the pore size This kaolinite quartz relationship suggests that quartz and kaolinite grew at approximately the same time

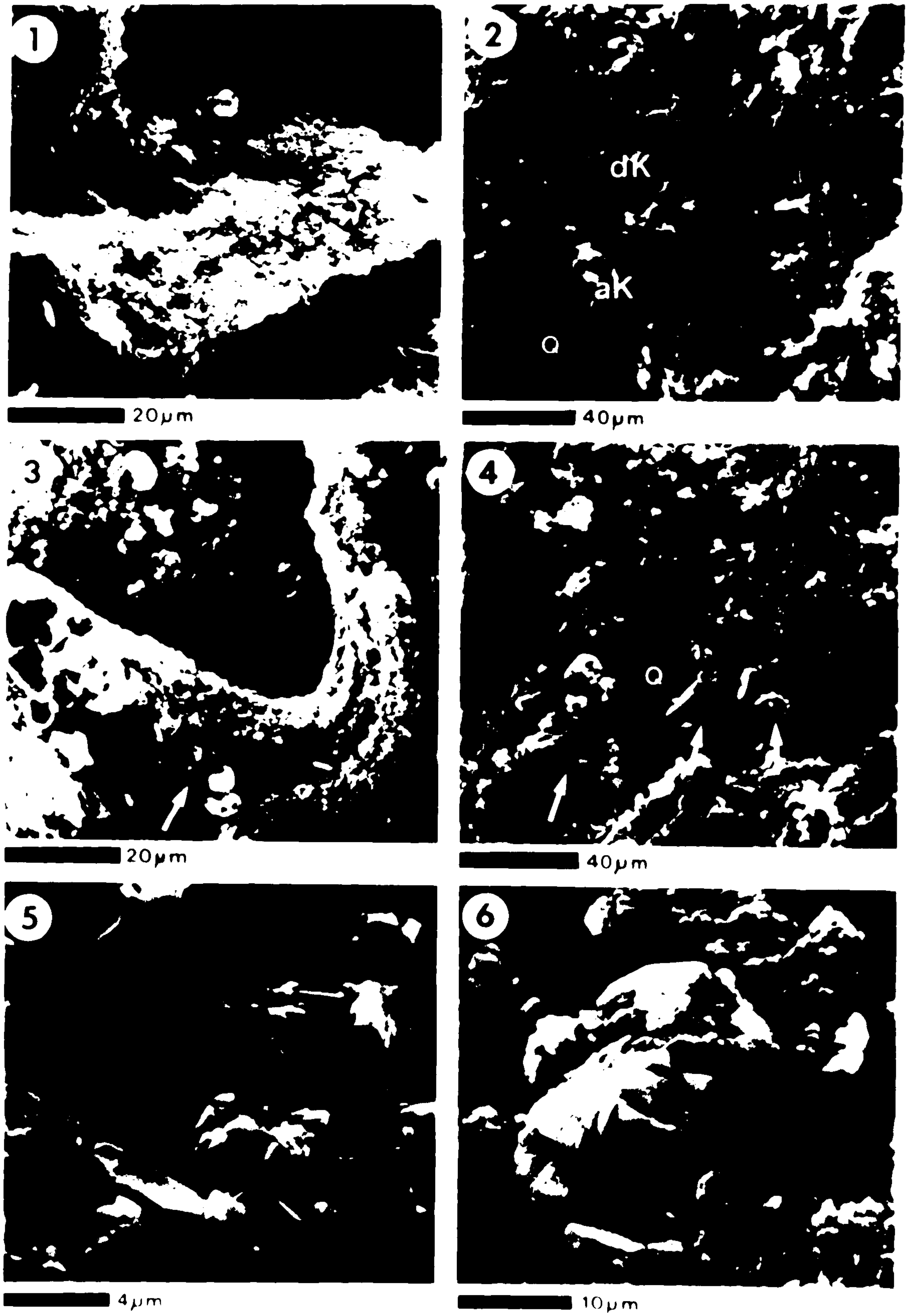

1
20μm
2
dK
aK
Q
40μm
3
20μm
4
Q
40μm
5
4μm
6
10μm

PLATE 7: Morphologies of Illite and Smectite

1 SEM photomicrograph of a clay ridge on a detrital grain This clay ridge has an illitic component but may contain very fine detrital kaolinite or a mixed layer illite-smectite

2 SEM photomicrograph of a very fine grained, delicate clay coating (white arrow) on a kaolinite booklet and extending across a pore space This authigenic clay coating is probably illite or interstratified illite-smectite

3 SEM photomicrograph showing a rare oocurrence of smectite in a honeycomb-like growth habit (white arrow)

4 SEM photomicrograph of a sample with approximately 5 per cent smectite in the clay fraction Note the abundance of clay ridges on the detrital grains

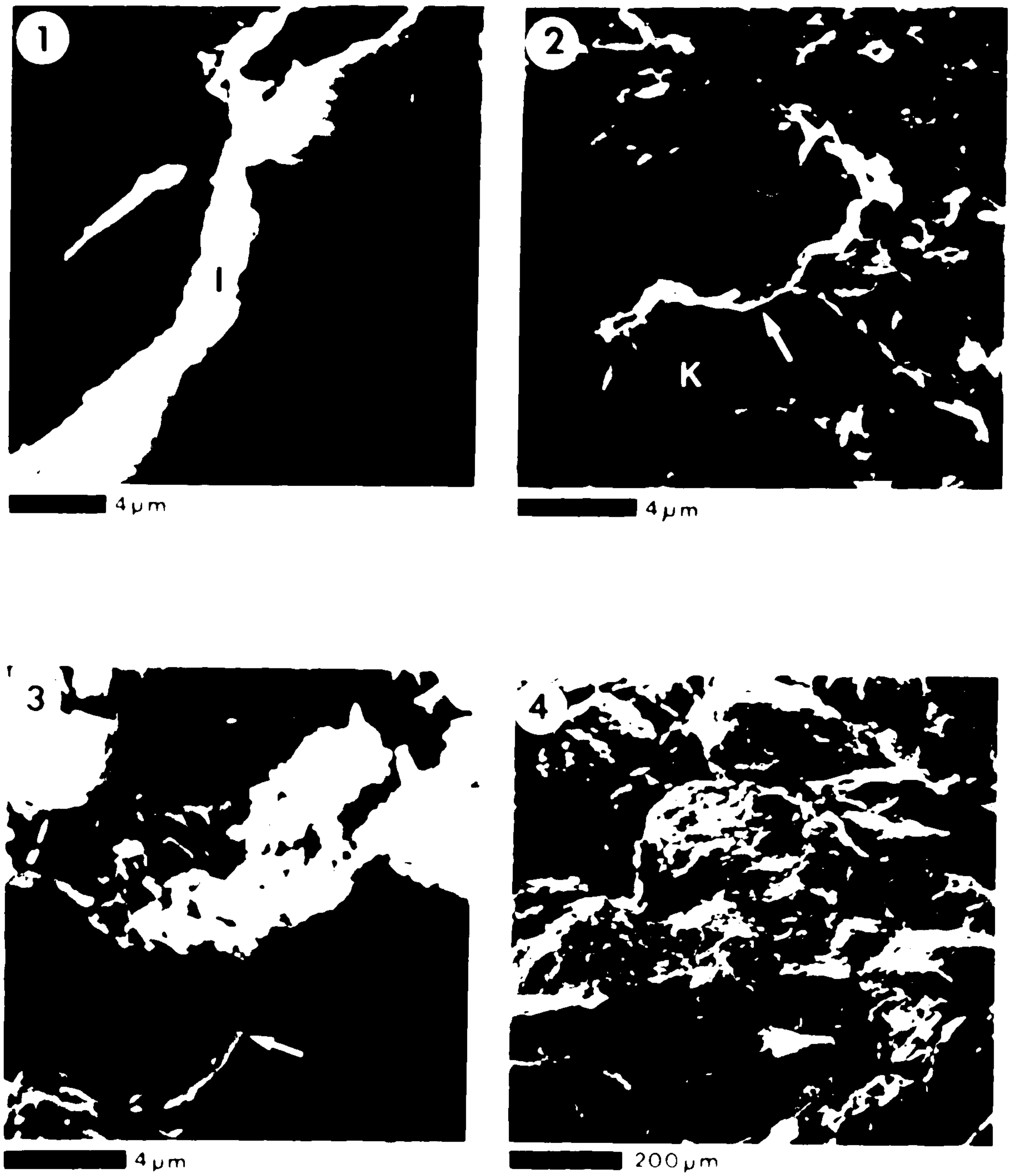

1
I
4 μm
2
K
4 μm
3
4 μm
4
200 μm

PLATE 8: Paragenetic Sequence

1 Thin section photomicrograph of a calcite-cemented sandstone Dark material surrounding grains is calcite cement (C) Note the loose grain packing with few grain-to-grain contacts, and the lack of clay rims around grains This sandstone was probably cemented very soon after sedimentation Plane polarized light

2 Thin section photomicrograph showing a close-up of the calcite cement (C) Note the coarse texture of the cement The dark patches in the cement are zones which have stained a darker pink These zones have fewer impurities than the lighter pink patches and may represent partial recrystallization of the early calcite cement Crossed nicols

3 SEM photomicrograph showing a close association of kaolinite (K) and quartz overgrowths (Q) The arrow points to a zone where the presence of the kaolinite inhibited completion of the quartz overgrowth The quartz overgrowth probably began forming before the kaolinite grew but continued after kaolinite formation

4 SEM photomicrograph showing a kaolinite booklet (K) embedded in calcite cement (C) The kaolinite was present at the time of carbonate cementation

5 SEM photomicrograph showing kaolinite (K) in the pore space created by feldspar (F) dissolution This association of kaolinite with the corroded feldspar grain suggests that kaolinite was formed as a result of the feldspar dissolution An earlier stage kaolinite (black K) grew on the uncorroded feldspar surface

6 SEM photomicrograph of calcite cubes in the pore space created by dissolution of feldspar This association indicates that calcite crystals grew after feldspar dissolution

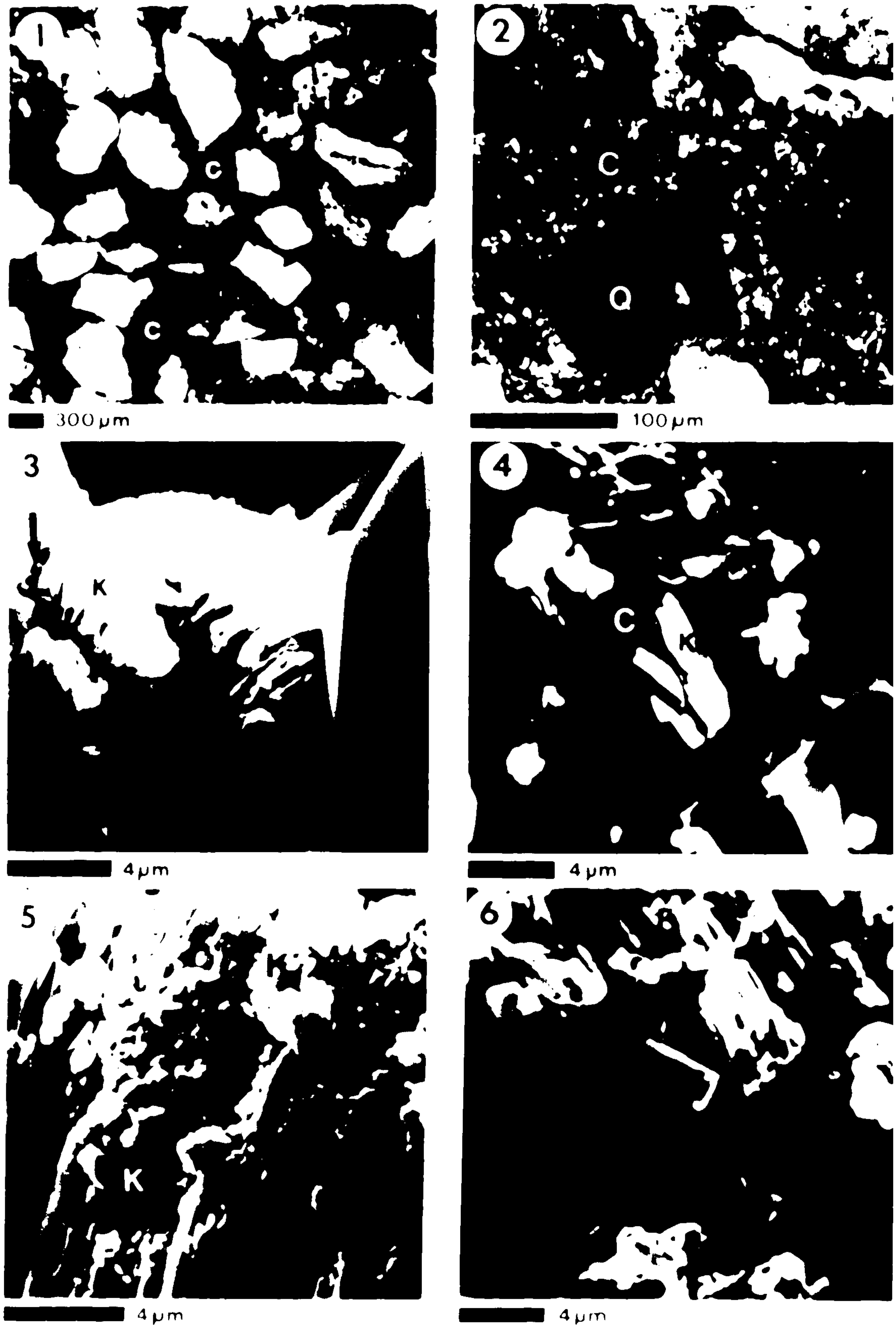

1
C
C
300 µm
2
C
Q
100 µm
3
K
4 µm
4
C
K
4 µm
5
K
K
4 µm
6
4 µm

PLATE 9 Pore Morphology

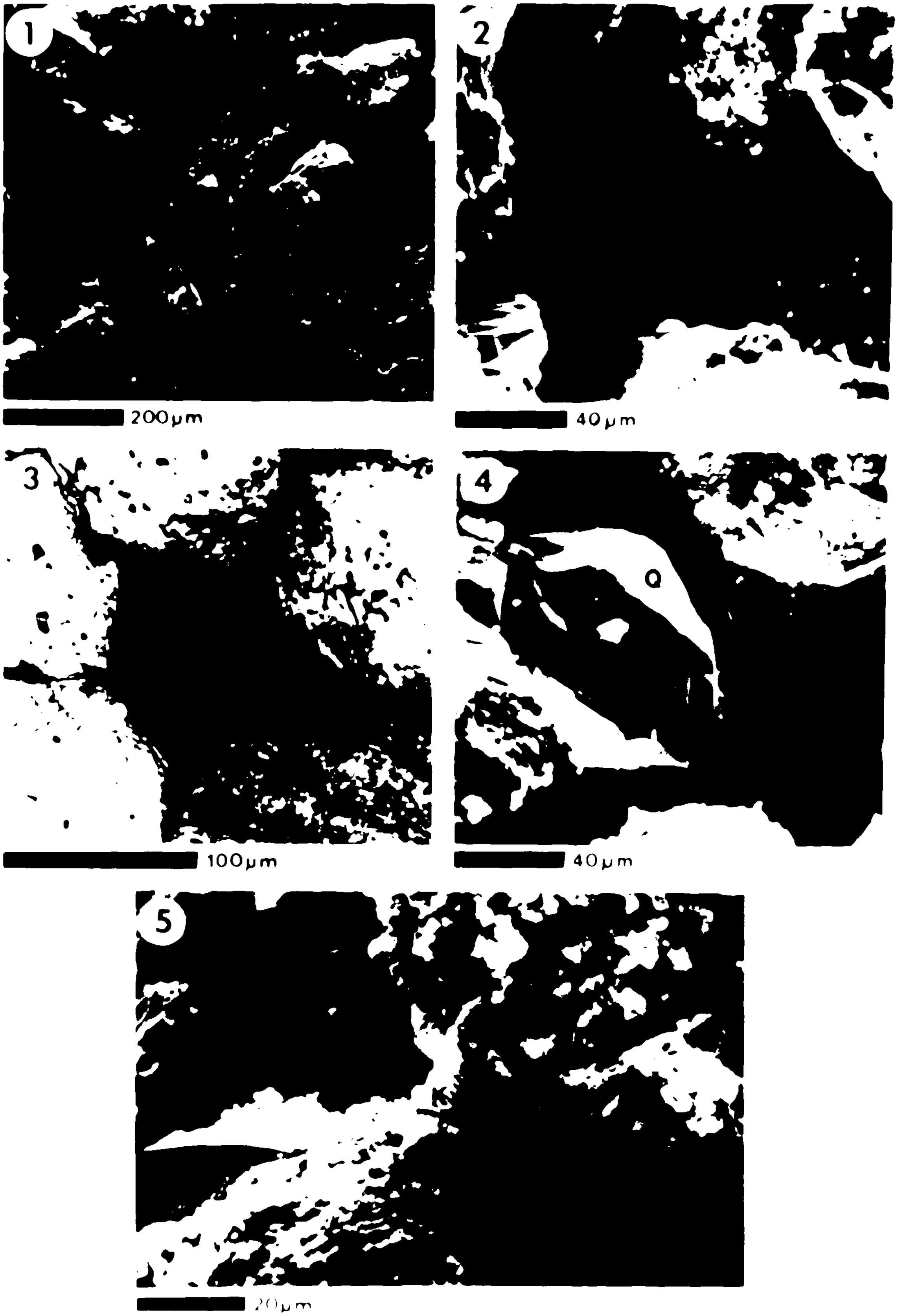
1 SEM photomicrograph of a sample from the laminated facies 4. Note the good porosity slightly reduced by quartz overgrowths and scattered clusters of authigenic clays.

2 SEM photomicrograph showing a typical clean pore from a sample representing facies 4. The pore space has been reduced in size slightly by local clusters of authigenic kaolinite (aK) and quartz overgrowths (Q).

3 Thin section photomicrograph showing a pore space (P) lined by masses of authigenic kaolinite (aK). Plane polarized light.

4 SEM photomicrograph showing the occlusion of pore space by quartz overgrowths (Q).

5 SEM photomicrographs showing a cluster of kaolinite coating the grain and extending across the pore to form a pore bridge and permeability barrier.


1
200μm
2
40μm
3
100μm
4
Q
40μm
5
K
20μm

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X APPENDICES

Appendix A: Core Logs for Wells from the SHOP Project (see attached pocket)

Appendix B Analytical Methods for Detailed XRD Analyses

Samples were gently crushed by hand and treated with a 3 per cent bleach solution (sodium hypochlorite) at 50°C for three days to remove any organic phases. Excess hypochlorite solution was then removed by repeated washings (high speed centrifugation). The mineral material was then dispersed in distilled water using an ultrasonic probe and allowed to settle in columns for the appropriate period of time to extract the particles with an equivalent spherical diameter of < 2 micrometres. The settling procedure was repeated three times for each sample and the < 2 micrometre material collected after each step combined. The < 2 micrometre material was treated with the 3 per cent sodium hypochlorite solution again at 50°C for two days in order to destroy residual organic materials and then repeatedly washed. The sample was split into fractions and separate portions saturated with K and Ca. Once saturated, the < 2 micrometre material was thoroughly washed, freeze dried and then precipitated by [illegible] onto a [illegible] plate [illegible]. The < 2 micrometre Ca and K [illegible] were analyzed on the X-ray diffractometer using the following analytical conditions:

[illegible] alpha radiation obtained by means of a graphite [illegible] monochromator

2. [illegible] degree divergent slit

3. [illegible] degree two theta/minute at [illegible] mm [illegible]

4. Time constant [illegible]

5. [illegible] kV, [illegible] mA

The following X-ray patterns were obtained for the < 2 micrometre samples:

1. Ca [illegible] at 54% relative humidity, 2-35 degrees two theta

2. Ca [illegible] glycolated, 2-35 degrees two theta

3. K [illegible] at [illegible] relative humidity, 2-35 degrees two theta

4. K [illegible] at 54% relative humidity, 2-35 degrees two theta

5. K [illegible] at [illegible], 2-35 degrees two theta

6. K [illegible] at [illegible], 2-35 degrees two theta

[illegible]

Settling time was calculated by means of Stokes' law for streamline [illegible] about a falling spherical body combined with the differential specific gravity and the gravitational constant (Jackson 1979).

The [illegible] spacings and intensities of smectite and vermiculite are decreased by potassium saturation and increased by calcium saturation (Jackson 1979). Thus [illegible] analyses of both Ca and K [illegible] are valuable for the identification of [illegible] the analysis of the sample on the diffractometer The glycolated Ca-disc was prepared by placing the Ca-saturated disc in an enclosed ethylene glycol environment The disc was heated in this environment at 65°C for 14 hours and then left for one day to allow the ethylene glycol to fully penetrate into the clay structures

Relative percentages of kaolinite illite and smectite were estimated using the weighted peak-area method described in Biscaye (1965) The peaks and weighting factors used were the area of the 17A glycolated peak for smectite four time (4X) the 10A peak area (glycolated trace) for illite and twice (2X) the 7A peak area for kaolinite Since kaolinite and chlorite have a common 7A peak the 3 5A peaks for these minerals are used to determine the relative proportion of kaolinite and chlorite The kaolinite peak at 3 58A and the chlorite at 3 54A form a couplet which can sometimes be resolved (Biscaye 1975) In the clay samples from the Glauconitic Sandstone there is generally no indication of a couplet at 3 5A Thus the 7A peak is calculated as 100 per cent kaolinite

NAME AEC et al 01 SUFFIELD

LOCATION 4-10-20-8 W4

KB 755.16 m DATE LOGGED March 1981

LOGGED BY B.J. Tilley

Alberta RESEARCH COUNCIL GEOLOGICAL SURVEY

SYMBOL LEGEND

GRAIN SIZE

- ● Mean
- ○ Median
- × Largest grain

LITHOLOGY

- Conglomerate
- Sandstone c vc m vf f
- Siltstone
- Shale
- Breccia
- Coal
- Calcareous

BEDDING CONTACTS

- — Flat
- ‿ Erosional

SEDIMENTARY STRUCTURES

- H Homogenous, structureless
- Parallel laminated/angle
- Cross bedded/angle
- Trough cross bedded
- Ripple cross laminae
- Ripple troughs
- Oscillation ripples
- Discontinuous laminae
- Flaser bedding
- Contorted laminae
- U Vertical burrows
- ⊂ Horizontal burrows
- BM Burrow mottled
- Scour and fill
- Lenses
- NV Structures not visible due to oil saturation
- Rip up clasts
- Penecontemporaneous faults

ORGANIC MATTER

- Carbonaceous fragments
- Carbonaceous laminae
- Rootlets
- Discontinuous laminae
- ∘∘∘ Carbonaceous grains

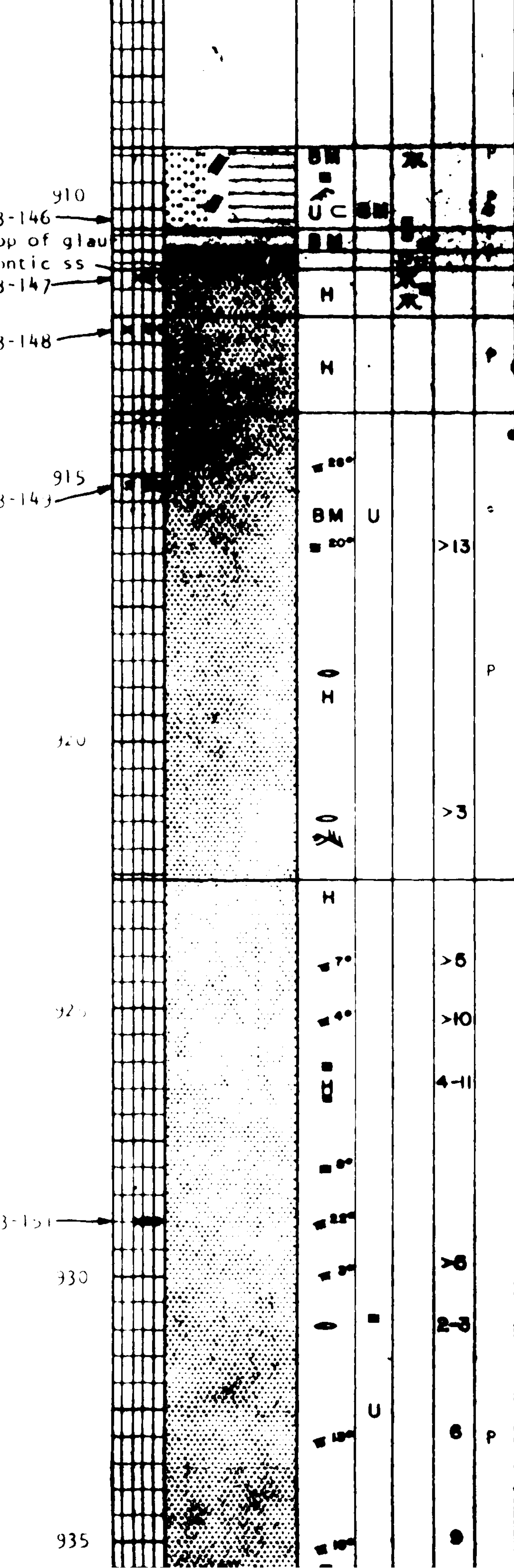
INDURATION

1	Unconsolidated	grains falling apart in dry conditions
2	Friable	grains can be detached using a fingernail
3	Moderately hard	grains can be detached with a knife
4	Hard	sample breaks around most grains

P - Pyrite, G - Glauconite, C - Carbonate Cement

NOTE: All depths have been adjusted so that lithologic log depths correspond to geophysical log depths.

DEPTH – TOPS SAMPLES	GRAIN SIZE	LITHOLOGY	SEDIMENTARY STRUCTURES (main, acc)	ORGANIC MATTER	BEDDING THICKNESS	CEMENT/ACC. MINERALS	DESCRIPTION	INDURATION	SATURATION	CORE/CORE DEPTH (RECOVERY)
905										
			BM			P	908.9-910.4 SHALE, medium grey, interlaminated with light grey SILT and carbonaceous material, parallel laminated to low angle x-bedded, local small scale ripples, pyrite is disseminated along laminations and also occurs as larger nodules			
910			U ⊂ BM							
33-146 → Top of glauconitic ss			BM				910.4-910.7 SHALE, brownish-grey,			
33-147							910.7-911.1 SHALE, black to dark grey, carbonaceous and COAL with some sand grains			(9.00)



908.9-910.4 SHALE, medium grey, interlaminated with light grey SILT and carbonaceous material, parallel laminated to low angle xbedded, local small scale ripples, pyrite is disseminated along laminations and also occurs as larger nodules

910.4-910.7 SHALE, brownish-grey

910.7-911.1 SHALE, black to dark grey, carbonaceous and COAL with some sand grains

911.1-912.0 SAND, fine grained, argillaceous, medium grey, structureless with some lighter grey mottles

912.0-913.8 SAND, less argillaceous, no rootlets, light grey-white with larger chert grain appearing as dark specks, structureless and bioturbated with local hint of bedding, patchy oil saturation

913.8-922.6 SAND, high angled, irregularly laminated beds interbedded with faintly mottled bioturbated zones, irregular laminations disrupted by burrows, patchy oil saturation, non oil saturated clay rich lenses within oil saturated beds

918.9 non oil-saturated sand lenses surrounded by oil saturated sand

921.4 non oil saturated sand lense surrounded by oil saturated sand

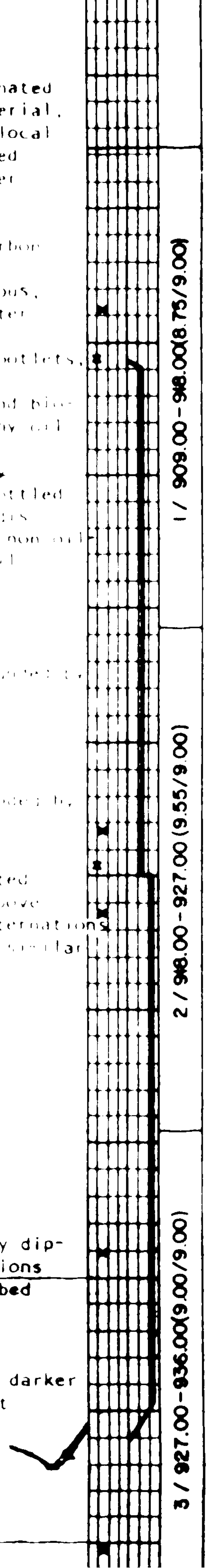
922.6-938.3 SAND, parallel to low angled xlaminated, clean continuously oil saturated with very rare non oil saturated lenses above the oil-water contact, laminations are alternations of dark and light coloured sand layers of similar fine grain size

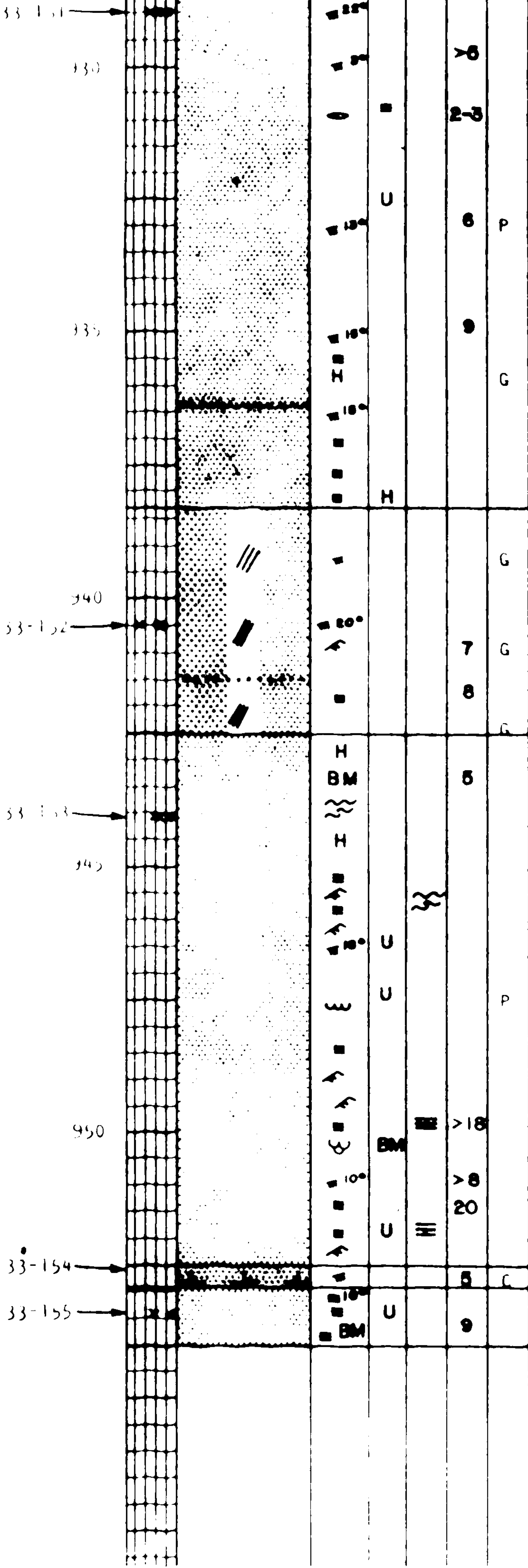
2 of

929.0 Magnetite concentrated along steeply dipping laminations, 3 mm thick dark laminations separated by a 1 cm thick light coloured bed

931.8 non oil-saturated sand lense

932.0 possible escape burrow, subvertical darker band 2 mm wide, pyrite at bottom, at least 7 cm long





929.0 Magnetite concentrated along steeply dipping laminations, 3 mm thick dark laminations separated by a 1 cm thick light coloured bed

931.8 non oil-saturated sand lense
932.0 possible escape burrow, subvertical darker band 2 mm wide, pyrite at bottom, at least 7 cm long

936.4 scour surface, structureless below scour, laminated above

938.0 interbedded parallel laminated and structureless bed
938.3-942.5 SAND, medium and fine grained interlaminated, gradational upper boundary with scattered medium grains becoming more abundant downwards

941.5 coarsest bed, fine sand with scattered medium grains, possible very thin clay drapes at top
942.5-952.5 SAND, medium and fine grained, separated sharply from the overlying unit by a 1 mm thick distinctly darker sand layer, gradually fines downward to very fine grained sand

950.5 1.5-1 mm thick carbonaceous layer

952.5-952.9 SAND, very fine grained, ... cemented
952.9-954.0 SAND, very fine grained
953.6 9 cm thick bioturbated zone, ... carbonaceous material and silt, becomes massive upwards

3 / 927.00-936.00(9.00/9.00)

4 / 936.00-945.00(8.70/9.00)

5 / 945.00-954.00(9.00/9.00)

NAME AEC et al 02 SUFFIELD

LOCATION 4-10-20-8 W4

KB 754.87 m DATE LOGGED March 1981

LOGGED BY B. J. Tilley

ALBERTA RESEARCH COUNCIL
GEOLOGICAL SURVEY

SYMBOL LEGEND

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- Median
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- Erosional

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- Ripple troughs
- Oscillation ripples
- Discontinuous laminae
- Flaser bedding
- Contorted laminae
- Vertical burrows
- Horizontal burrows
- BM Burrow mottled
- Scour and fill
- Lenses
- NV Structures not visible due to oil saturation
- Rip up clasts
- Penecontemporaneous faults

ORGANIC MATTER

- Carbonaceous fragments
- Carbonaceous laminae
- Rootlets
- Discontinuous laminae
- Carbonaceous grains

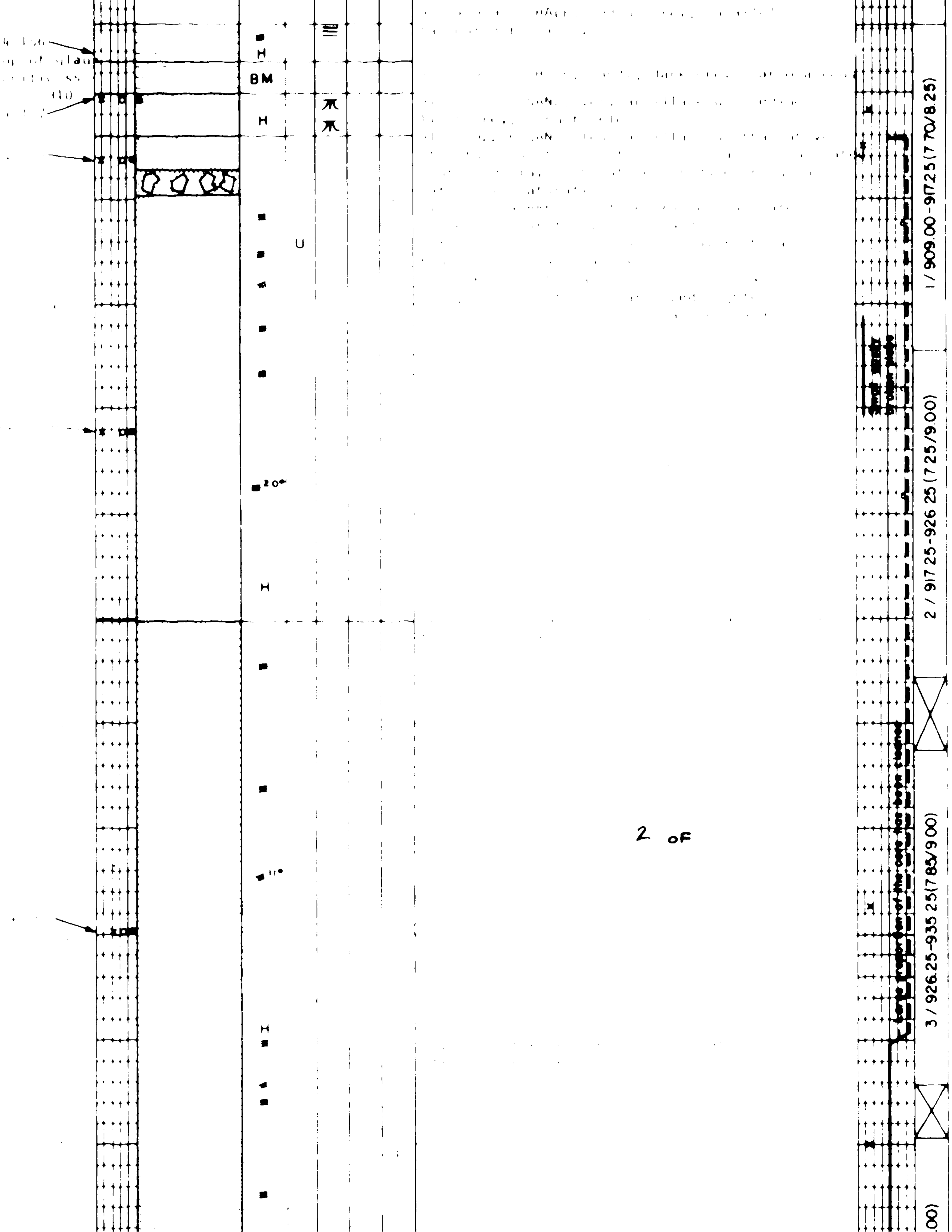
INDURATION

1	Unconsolidated	grains falling apart in dry conditions
2	Friable	grains can be detached using a fingernail
3	Moderately hard	grains can be detached with a knife
4	Hard	sample breaks around most grains

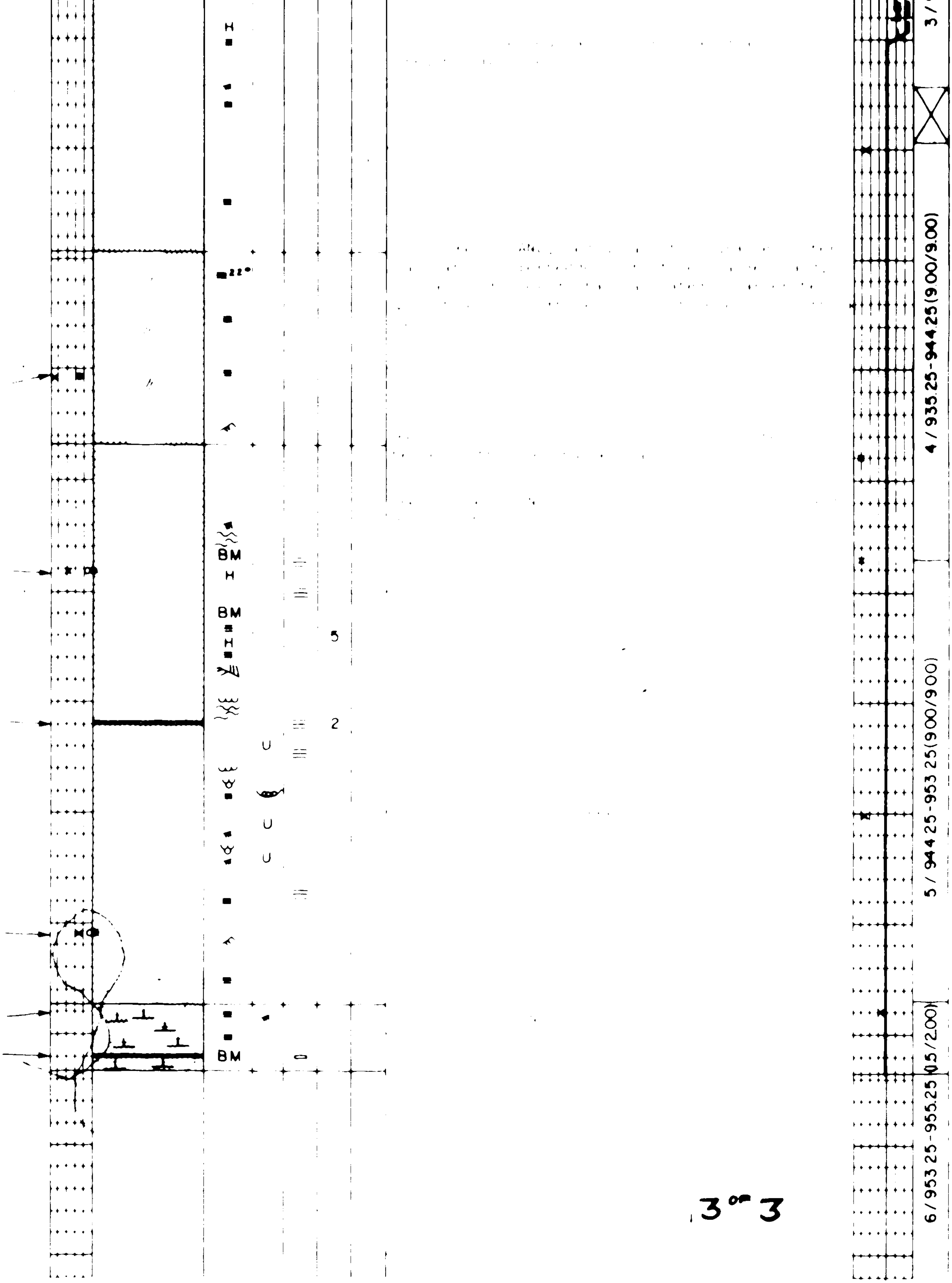
NOTE All depths have been adjusted so that lithologic log depths correspond to geophysical log depths

DEPTH – TOPS SAMPLES	GRAIN SIZE	LITHOLOGY	SEDIMENTARY STRUCTURES (main / acc)	ORGANIC MATTER	BEDDING THICKNESS	CEMENT/ACC MINERALS	DESCRIPTION	INDURATION	SATURATION	CORE/CORE DEPTH (RECOVERY)
			H							
			BM							
310			H							

Grain size scale: 1000–2000, 500–1000, 250–500, 125–250, 62.5–125


H
BM
H
U
H
H
1 / 909.00-917.25 (7.70/8.25)
2 / 917.25-926.25 (7.25/9.00)
3 / 926.25-935.25 (7.85/9.00)

2 OF


4 / 935.25-944.25(9.00/9.00)
5 / 944.25-953.25(9.00/9.00)
6 / 953.25-955.25(0.5/2.00)
BM
BM
BM
5
2
22°

3 of 3

NAME [illegible]

LOCATION [illegible]

KB [illegible]

DATE LOGGED [illegible]

LOGGED BY [illegible]

RESEARCH COUNCIL
GEOLOGICAL SURVEY

SYMBOL LEGEND

GRAIN SIZE

- Mean
- Median
- Largest grain

LITHOLOGY

- Conglomerate
- Sandstone
- Siltstone
- Shale
- Breccia
- Coal
- Calcareous

BEDDING CONTACTS

- Flat
- Erosional

SEDIMENTARY STRUCTURES

- H Homogeneous structureless
- Parallel laminated
- Cross bedded
- Trough cross bedded
- Ripple cross lamination
- Ripple troughs
- [illegible]
- Discontinuous laminae
- [illegible]
- Contorted laminae
- Vertical burrows
- Horizontal burrows
- BM Burrow mottled
- Scour and fill
- Lenses
- Fractures [illegible]
- Rip up clasts
- [illegible]

ORGANIC MATTER

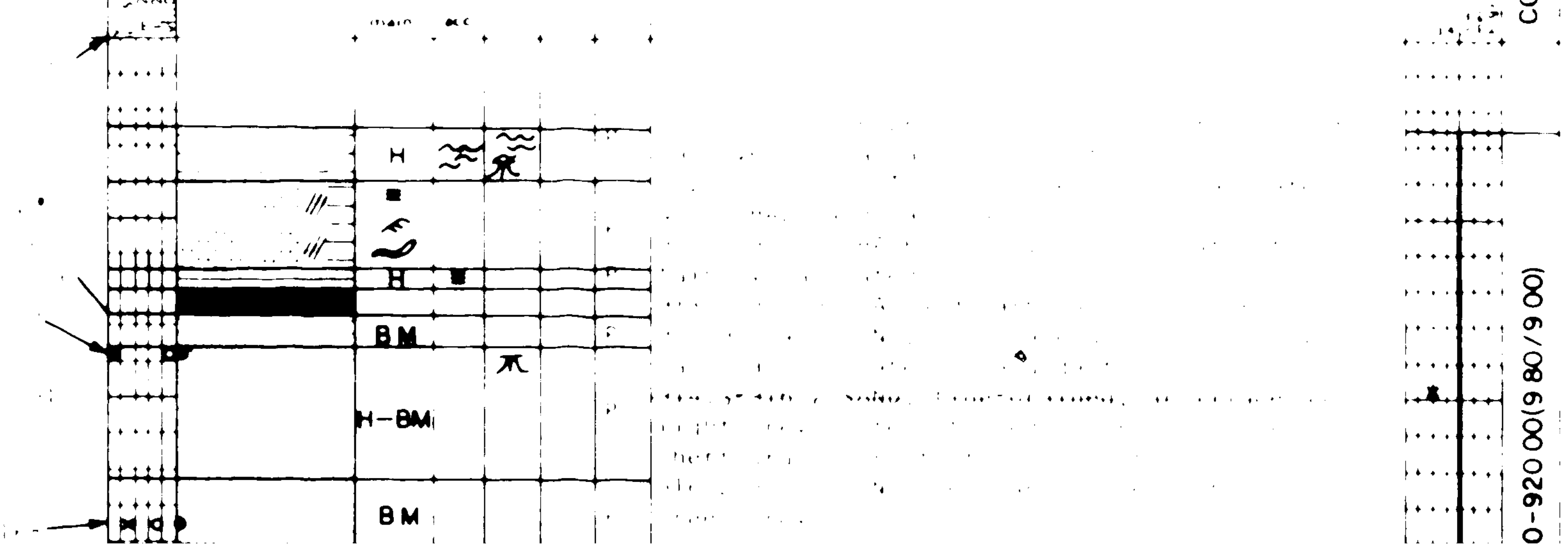
- Carbonaceous fragments
- Carbonaceous laminae
- Rootlets
- Discontinuous laminae
- Carbonaceous grains

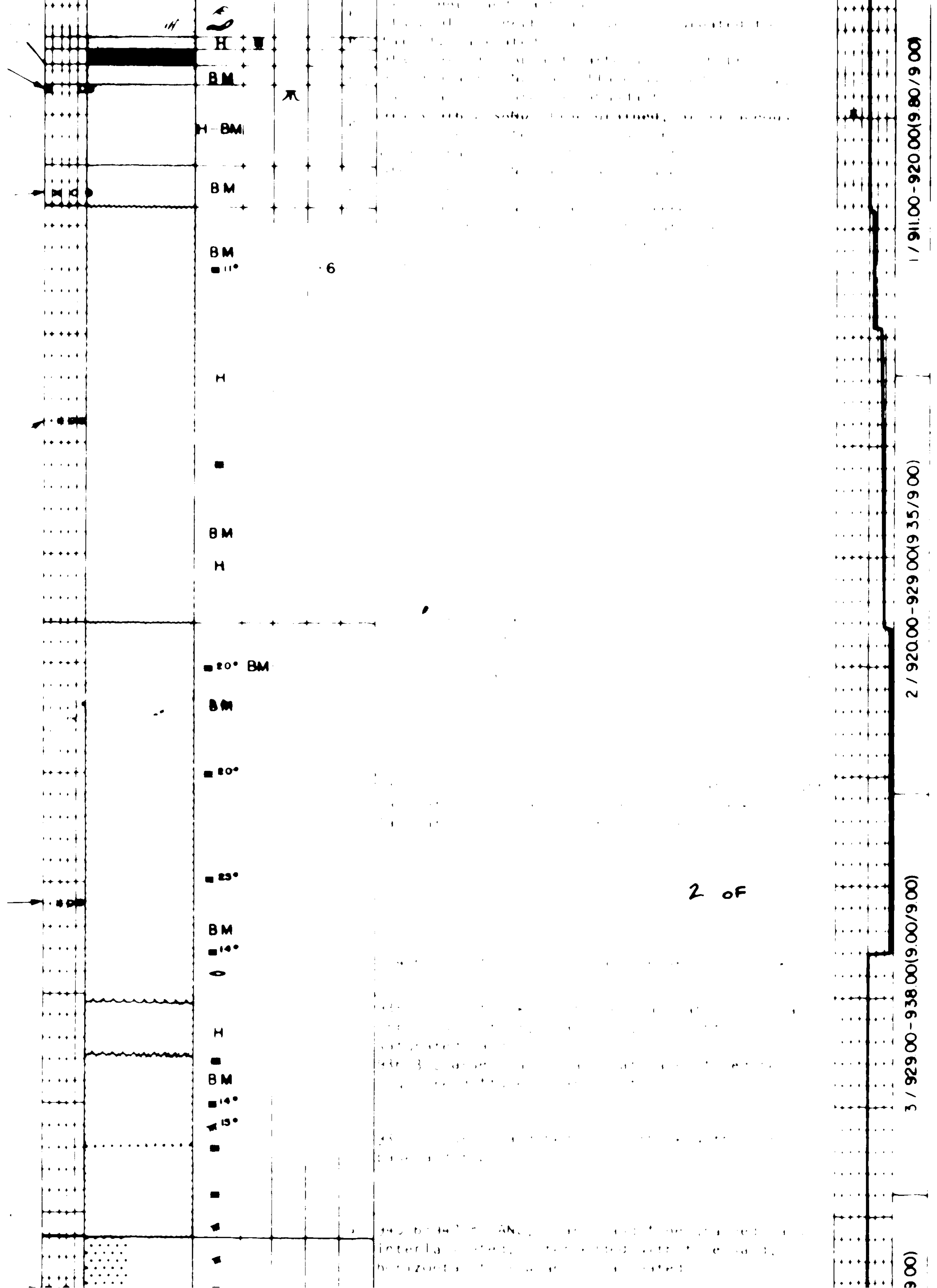
INDURATION

1. [illegible]
2. Friable — grains can be detached using a fingernail
3. Moderately hard — grains can be detached with a knife
4. Hard — sample breaks across grains

NOTE: All depths have been adjusted so that [illegible] depths correspond to geophysical log depths

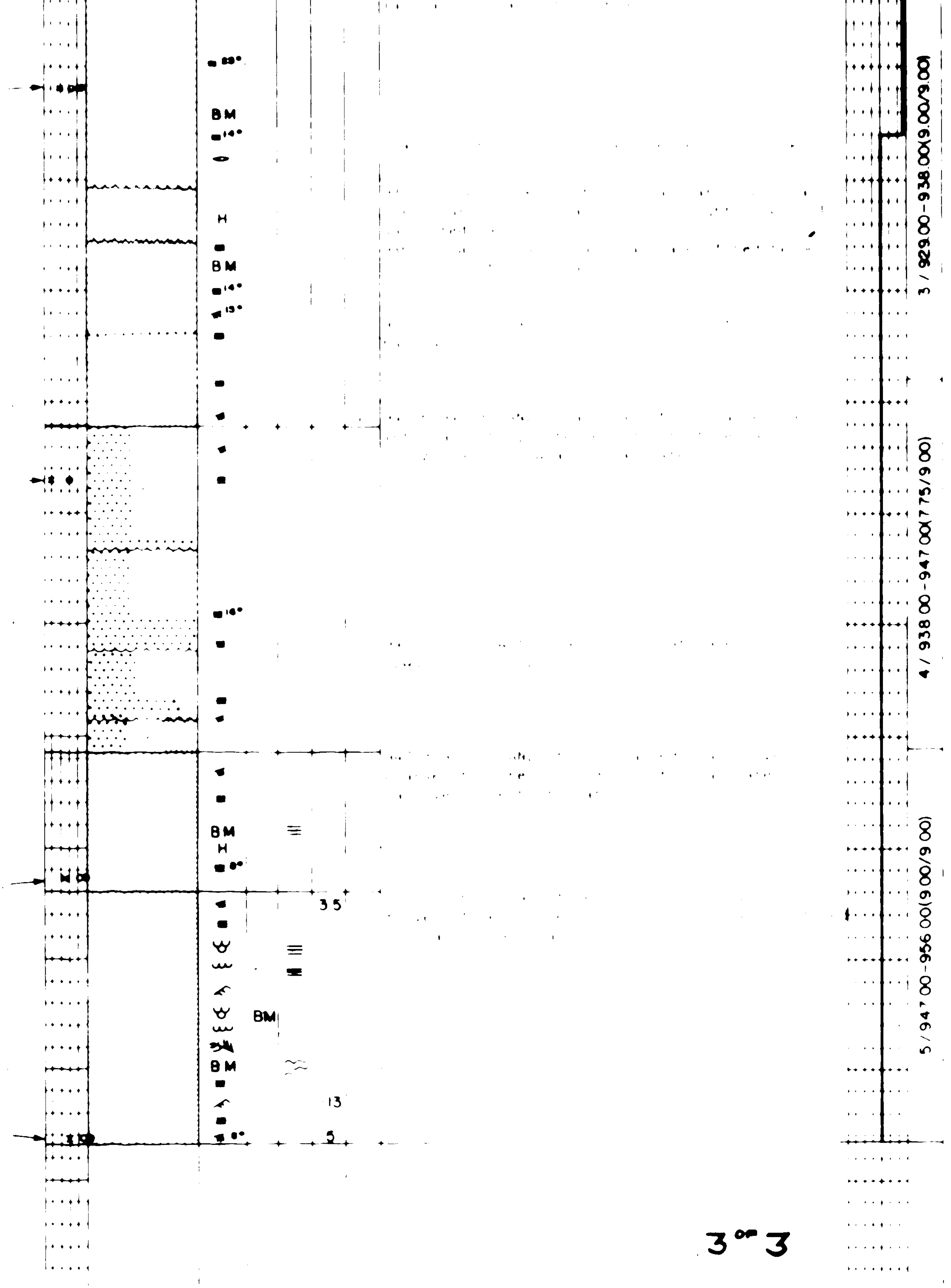
DEPTH | TOPS | SAMPLES | GRAIN SIZE | LITHOLOGY | SEDIMENTARY STRUCTURES (main, acc) | ORGANIC MATTER | BEDDING THICKNESS | CEMENT/ACC MINERALS | DESCRIPTION | INDURATION | SATURATION | CORE/CORE DEPTH (RECOVERY)





BM
H
6
20° BM
20°
25°
14°
13°
1 / 911.00-920.00(9.80/9.00)
2 / 920.00-929.00(9.35/9.00)
3 / 929.00-938.00(9.00/9.00)

2 of


3 / 929.00 - 938.00(9.00/9.00)
4 / 938.00 - 947.00(7.75/9.00)
5 / 947.00 - 956.00(9.00/9.00)

3 of 3

AME ____________

OCATION ____________

B ____________ DATE LOGGED ____________

OGGED BY ____________

RESEARCH COUNCIL
GEOLOGICAL SURVEY

SYMBOL LEGEND

GRAIN SIZE

- Mean
- Median
- Largest grain

LITHOLOGY

- Conglomerate
- Sandstone
- Siltstone
- Shale
- Breccia
- Coal
- Calcareous

EDDING CONTACTS

- Flat
- Erosional

SEDIMENTARY STRUCTURES

- Parallel laminated angle
- Cross bedded angle
- Trough cross bedded
- Ripple cross laminated
- Ripple troughs
- Oscillation ripples
- Oscillation cross laminated
- Flaser bedding
- Vertical burrows
- BM

ORGANIC MATTER

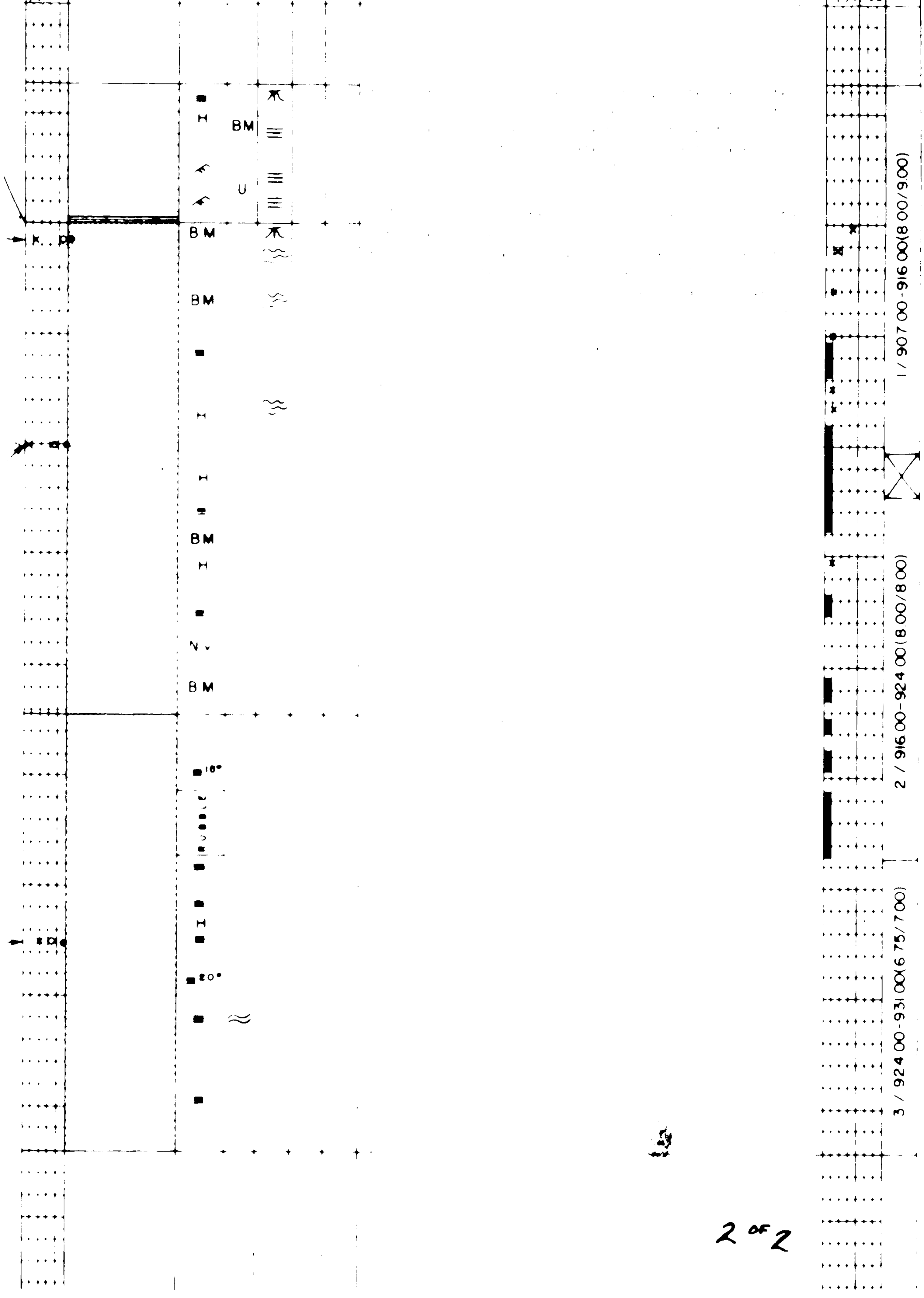
- Carbonaceous
- Carbonaceous

INDURATION

NOTE

DEPTH	TOPS SAMPLES	GRAIN SIZE	LITHOLOGY	SEDIMENTARY STRUCTURES	ORGANIC MATTER	BEDDING THICKNESS	CEMENT ACC MINERALS	DESCRIPTION	INDURATION	SATURATION	CORE CORE DEPTH RECOVERY
				main acc							
				BM							
				U							
				BM							

(08 00/900)



BM
U
BM
BM
BM
BM
16°
RUBBLE
20°
1 / 907.00-916.00(8.00/9.00)
2 / 916.00-924.00(8.00/8.00)
3 / 924.00-931.00(6.75/7.00)

2 of 2

Metric Log Form

NAME AEC et al F2 SUFFIELD

LOCATION 4-10-20-8W4

KB 755.25 m DATE LOGGED March 1981

LOGGED BY

RESEARCH COUNCIL
GEOLOGICAL SURVEY

SYMBOL LEGEND

GRAIN SIZE

● Mean
Median
× Largest grain

LITHOLOGY

Conglomerate
Sandstone
Siltstone
Shale
Breccia
Coal
Calcareous

BEDDING CONTACTS

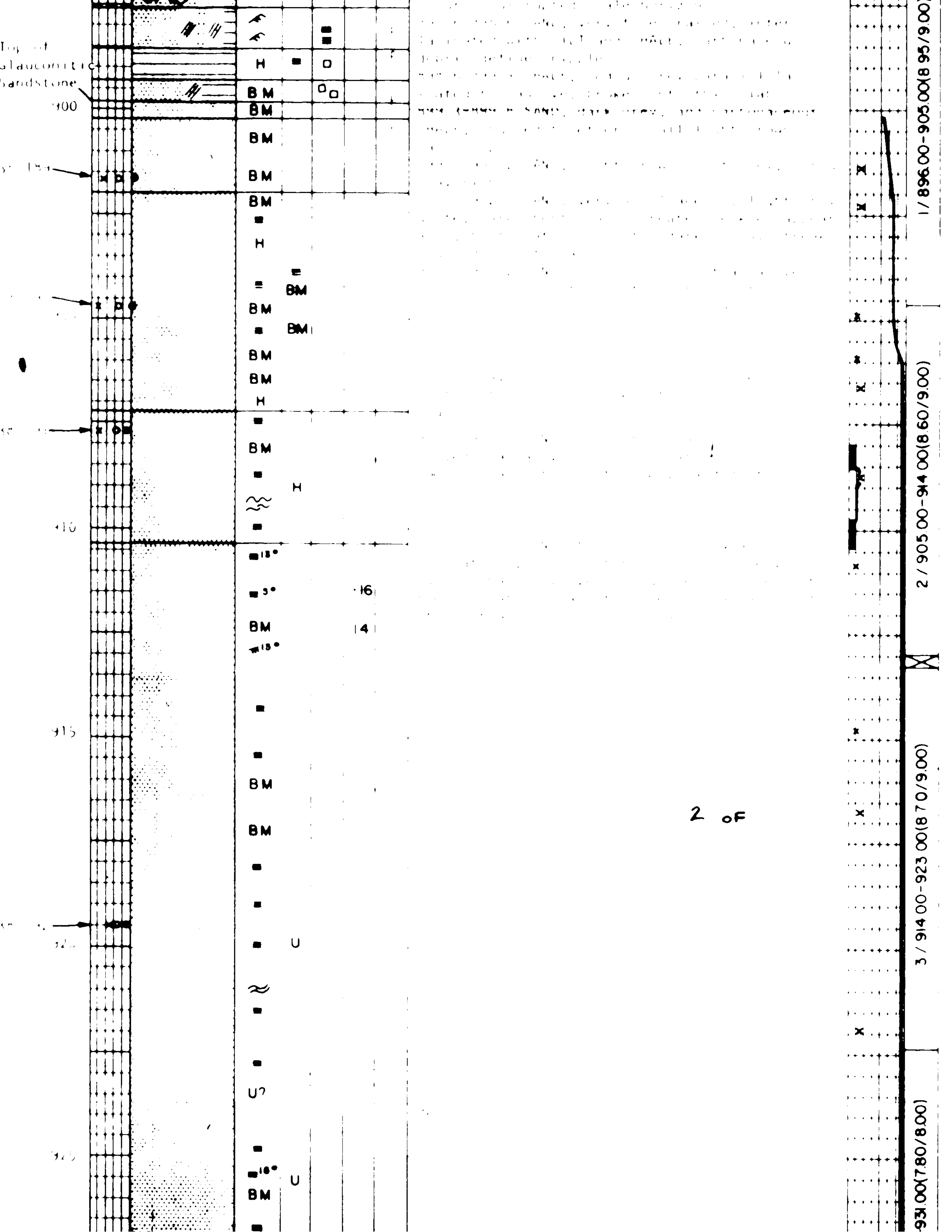
SEDIMENTARY STRUCTURES

BM

ORGANIC MATTER

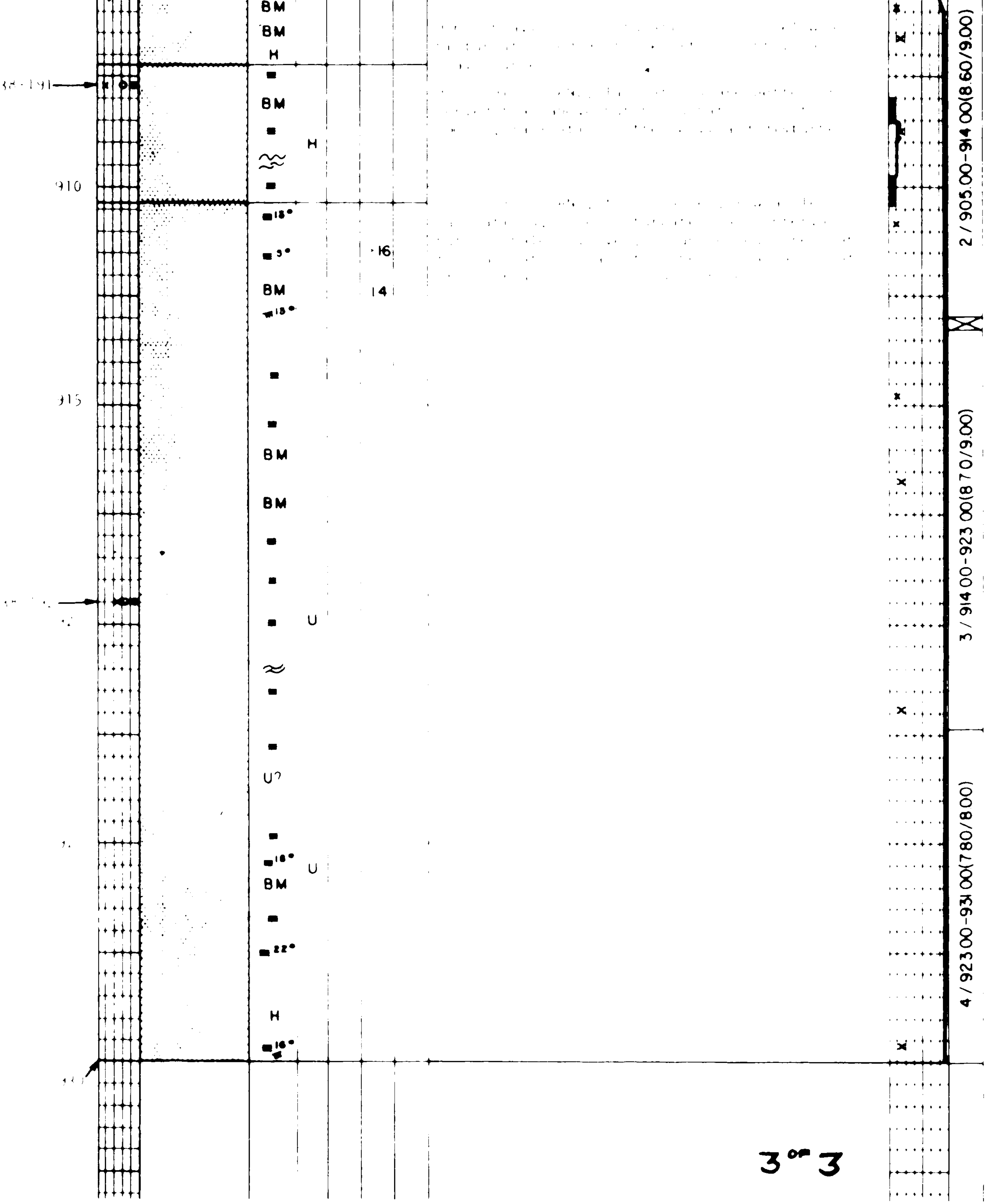
INDURATION

DEPTH	TOPS SAMPLES	GRAIN SIZE	LITHOLOGY	SEDIMENTARY STRUCTURES (main / acc)	ORGANIC MATTER	BEDDING THICKNESS	CEMENT ACC MINERALS	DESCRIPTION	INDURATION	SATURATION	CORE CORE DEPTH RECOVERY
895				U							
				BM							
	Top of Glauconitic Sandstone			H							
900				BM							(895.00-905.00) (8.95/9.00)
				BM				SAND, dark grey, and carbonaceous			
				BM							



Top of glauconitic sandstone
900
910
915
BM
H
U
U?
16
14
1/896.00-905.00(8.95/9.00)
2/905.00-914.00(8.60/9.00)
3/914.00-923.00(8.70/9.00)
931.00(7.80/8.00)

2 of



910
915
BM
H
BM
H
16
14
BM
BM
U
U?
U
BM
H
2 / 905.00-914.00(8.60/9.00)
3 / 914.00-923.00(8.70/9.00)
4 / 923.00-931.00(7.80/8.00)

3 of 3

NAME [illegible]

LOCATION [illegible]

KB [illegible] DATE LOGGED [illegible]

LOGGED BY [illegible]

RESEARCH COUNCIL
GEOLOGICAL SURVEY

SYMBOL LEGEND

GRAIN SIZE

- ● Mean
- ○ Median
- × Largest grain

LITHOLOGY

- Conglomerate
- Sandstone [illegible]
- Siltstone
- Shale
- Breccia
- Coal
- Calcareous

BEDDING CONTACTS

- Flat
- Erosional

SEDIMENTARY STRUCTURES

- H Homogeneous structureless
- Parallel laminated angle
- Cross bedded angle
- Trough cross bedded
- Ripple cross laminae
- Ripple troughs
- Oscillation ripples
- Discontinuous laminae
- Flaser bedding
- Contorted laminae
- Vertical burrows
- Horizontal burrows
- BM Burrow mottled
- Scour and fill
- Lenses
- NV Structures not visible due to oil saturation
- Rip up clasts
- Penecontemporaneous faults

ORGANIC MATTER

- Carbonaceous fragments
- Carbonaceous laminae
- Rootlets
- Discontinuous laminae
- Carbonaceous grains

INDURATION

1	Unconsolidated	grains falling apart in dry conditions
2	Friable	grains can be detached using a fingernail
3	Moderately hard	grains can be detached with a knife
4	Hard	sample breaks around most grains

NOTE: All depths have been adjusted so that lithologic log depths correspond to geophysical log depths

DEPTH TOPS SAMPLES	GRAIN SIZE	LITHOLOGY	SEDIMENTARY STRUCTURES (main / acc)	ORGANIC MATTER	BEDDING THICKNESS	CEMENT ACC MINERALS	DESCRIPTION	INDURATION	SATURATION	CORE/CORE DEPTH (RECOVERY)
			BM				[illegible]			
			BM	≡			[illegible]			
							[illegible] bedded with SHALE [illegible]			
			BM	≡			[illegible]			
30[illegible] Top of [illegible]			U	≡			[illegible] SAND [illegible]			00(8.80/9.00)
			BM				[illegible]			

main acc

BM

BM

BM

U

BM

BM

BM

BM

BM

BM

BM

U

U

U

H

1/ 907.00-916.00(8.80/9.00)

2 / 916.00-925.00(8.70/9.00)

3/925.00-930.50(5.65/5.50)

COR

2 of 2

NAME AEC et al F4 SUFFIELD

LOCATION 4-10-20-8 W4

KB 755.06 m

DATE LOGGED

LOGGED BY B.J. Tilley

ALBERTA RESEARCH COUNCIL
GEOLOGICAL SURVEY

SYMBOL LEGEND

GRAIN SIZE

- ● Mean
- ○ Median
- × Largest grain

LITHOLOGY

- Conglomerate
- Sandstone
- Siltstone
- Shale
- Breccia
- Coal
- Calcareous

BEDDING CONTACTS

- Flat
- Erosional

SEDIMENTARY STRUCTURES

- H Homogenous, structureless
- Parallel laminated, angle
- Cross bedded, angle
- Trough cross bedded
- Ripple cross laminae
- Ripple troughs
- Oscillation ripples
- Discontinuous laminae
- Flaser bedding
- BM Burrowed, Mottled
- Scour and fill
- Lenses
- NV Structures not visible due to oil saturation
- Rip-up clasts
- Penecontemporaneous faults

ORGANIC MATTER

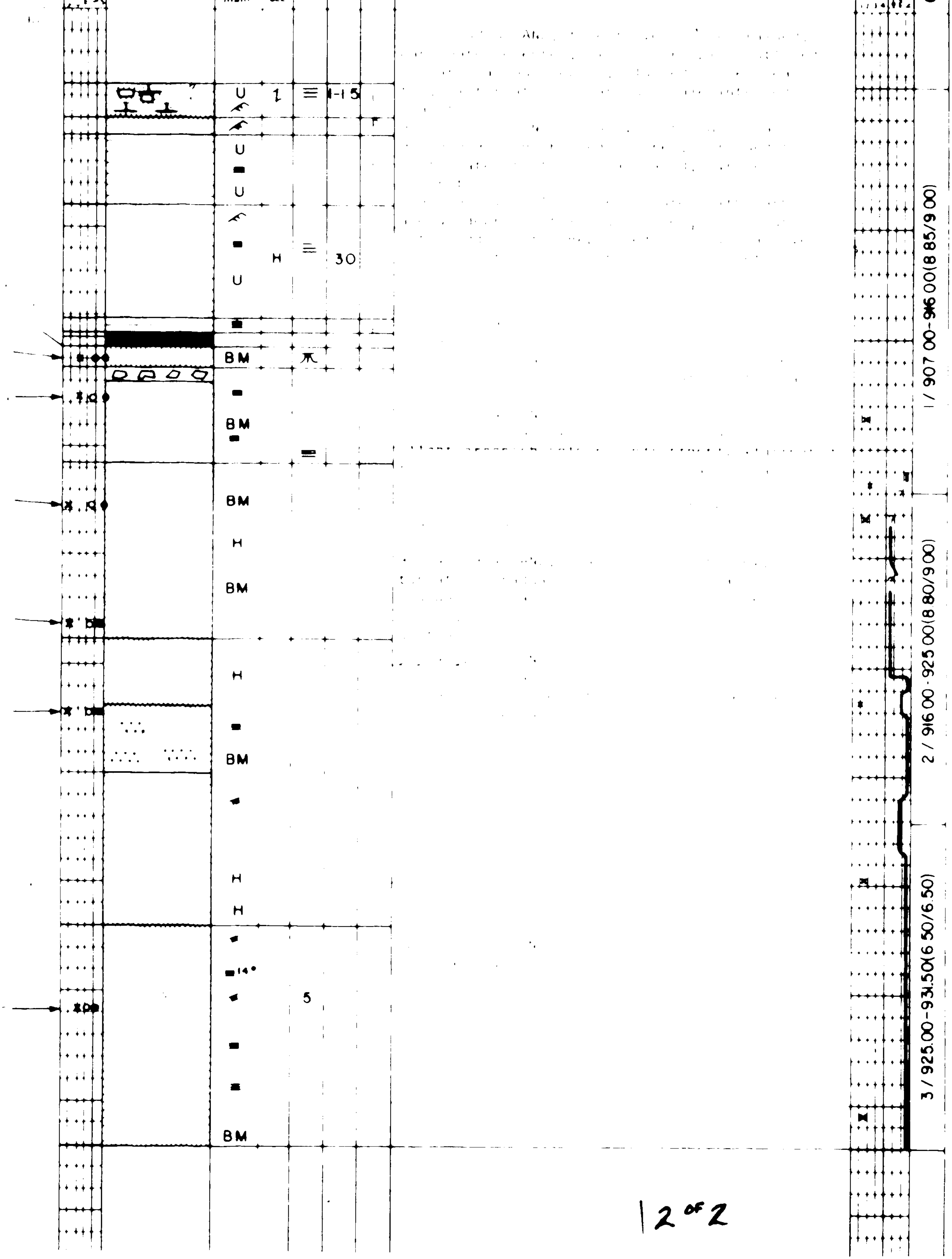
- Carbonaceous fragments
- Carbonaceous laminae
- Rootlets
- Discontinuous laminae
- Carbonaceous grains

INDURATION

	Unconsolidated	grains falling apart in dry conditions
	Friable	grains can be detached using a fingernail
	Moderately hard	grains can be detached with a knife
	Hard	sample breaks around most grains

NOTE: All depths have been adjusted so that lithologic log depths correspond to geophysical log depths

DEPTH	TOPS	SAMPLES	GRAIN SIZE	LITHOLOGY	SEDIMENTARY STRUCTURES (main)	(acc)	ORGANIC MATTER	BEDDING THICKNESS	CEMENT/ACC MINERALS	DESCRIPTION	INDURATION	SATURATION	CORE/CORE DEPTH (RECOVERY)
					U	1	≡	1-1.5					
					U					SHALE			
					U								
							≡			interbedded with SHALE, medium			85/9.00


U
1
1-15
30
BM
H
5
14°
1 / 907.00-916.00(8.85/9.00)
2 / 916.00-925.00(8.80/9.00)
3 / 925.00-931.50(6.50/6.50)

2 OF 2

Metric Log Form

1 OF

NAME

LOCATION

KB

DATE LOGGED

LOGGED BY

RESEARCH COUNCIL
GEOLOGICAL SURVEY

SYMBOL LEGEND

GRAIN SIZE

- Mean
- Median
- Largest grain

LITHOLOGY

- Conglomerate
- Sandstone
- Siltstone
- Shale
- Breccia
- Coal
- Calcareous

BEDDING CONTACTS

- Flat
- Erosional

SEDIMENTARY STRUCTURES

- Homogeneous structureless
- Parallel laminated angle
- Cross bedded angle
- Trough cross bedded
- Ripple cross laminae
- Ripple troughs
- Oscillation ripples
- Discontinuous laminae
- Flaser bedding
- Vertical burrows
- Horizontal burrows
- Lenses
- Microfaults

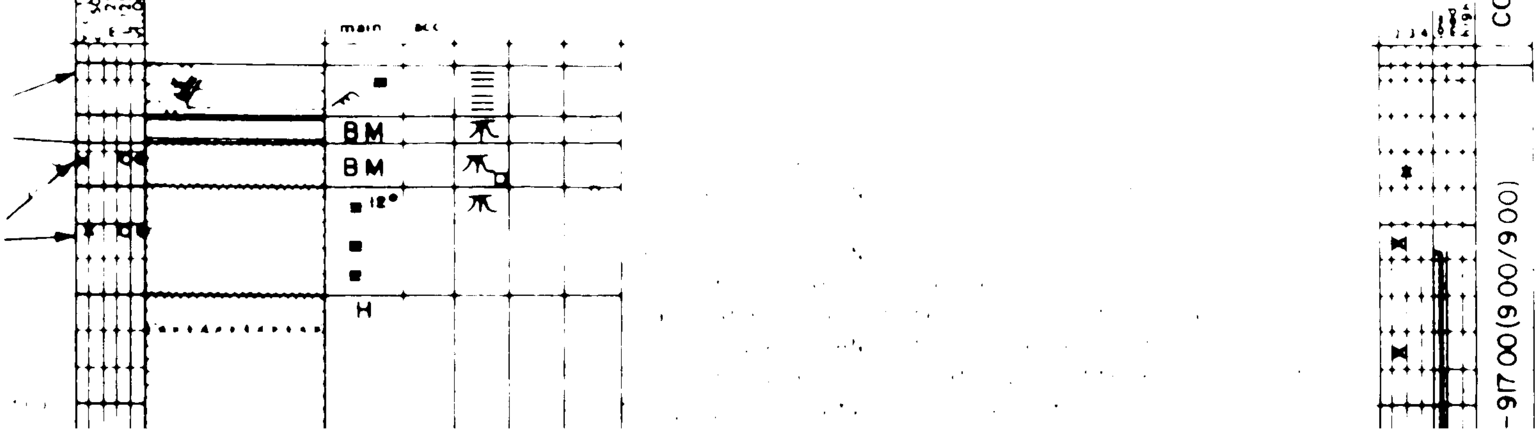
ORGANIC MATTER

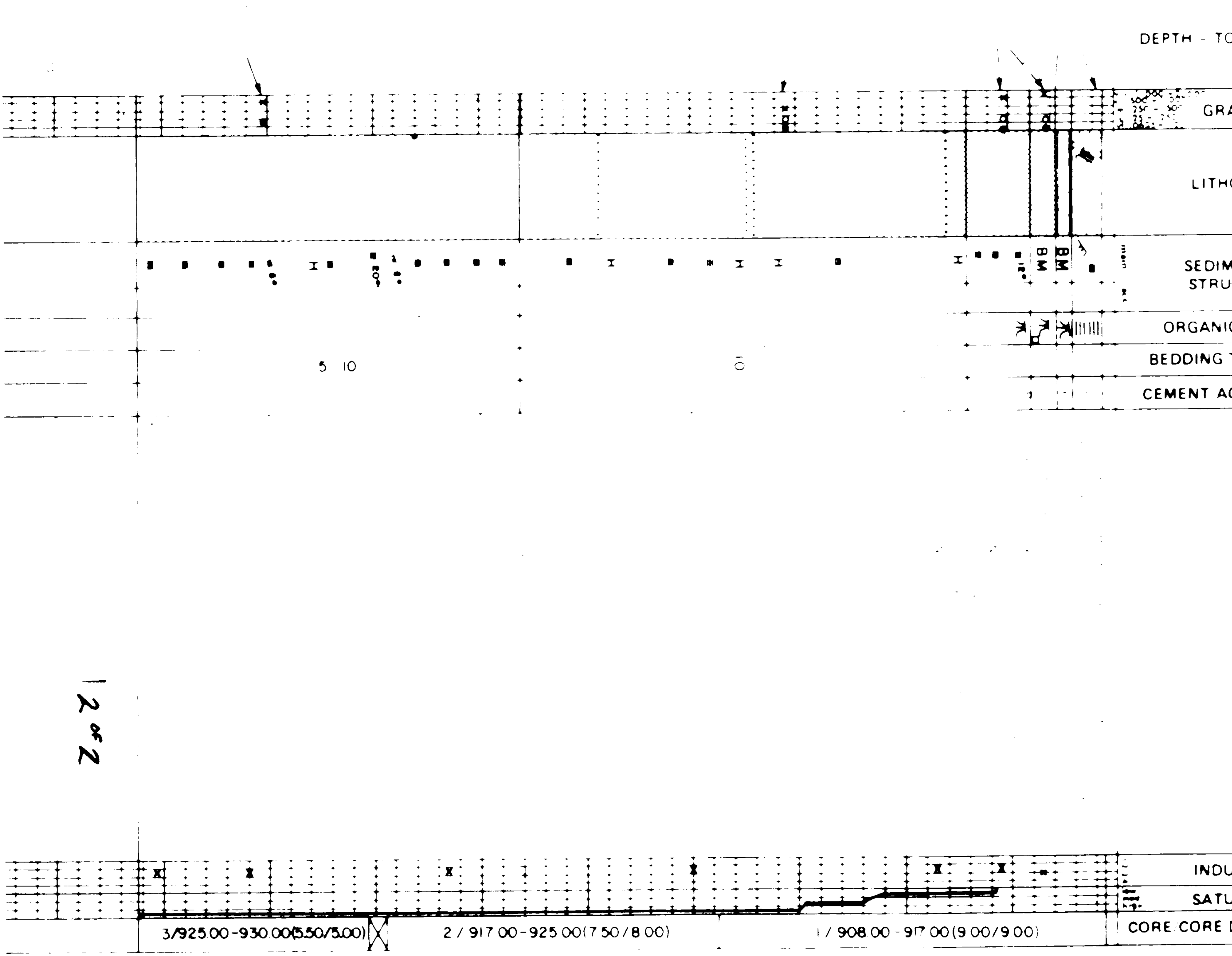
- Carbonaceous fragments
- Carbonaceous laminae
- Rootlets
- Discontinuous laminae
- Carbonaceous grains

INDURATION

- grains falling apart in dry conditions
- grains can be detached using a fingernail
- Moderately hard — grains can be detached with a knife
- Hard — sample breaks around most grains

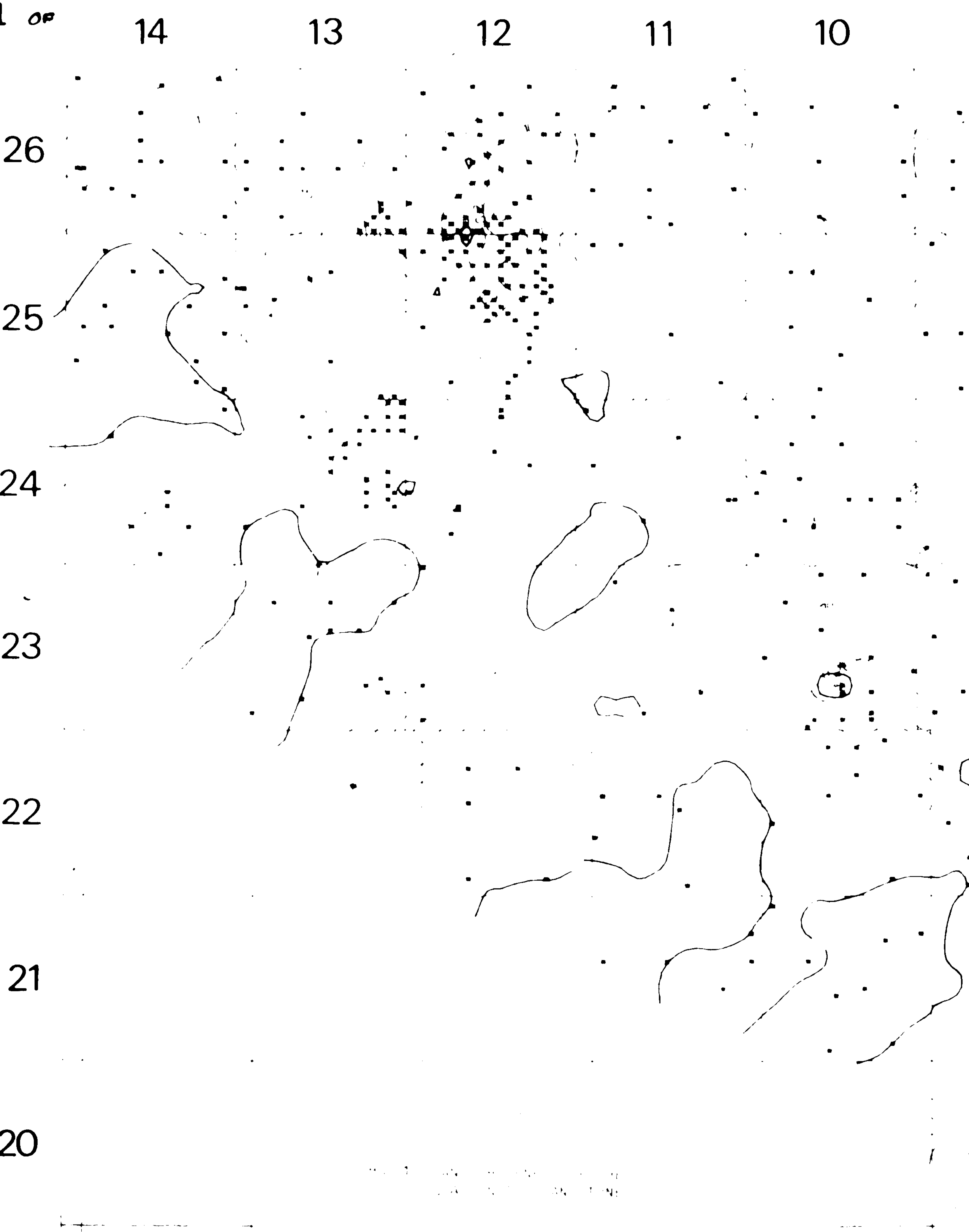
DEPTH	TOPS	SAMPLES	GRAIN SIZE	LITHOLOGY	SEDIMENTARY STRUCTURES	ORGANIC MATTER	BEDDING THICKNESS	CEMENT ACC MINERALS	DESCRIPTION	INDURATION	SATURATION	CORE/CORE DEPTH (RECOVERY)





DEPTH - TO
GRA
LITHO
SEDIM STRU
ORGANIC
BEDDING
CEMENT AC
INDU
SATU
CORE CORE
BM
BM
5 10
10
3/925.00-930.00(5.50/5.00)
2/917.00-925.00(7.50/8.00)
1/908.00-917.00(9.00/9.00)

2 of 2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13
12
11
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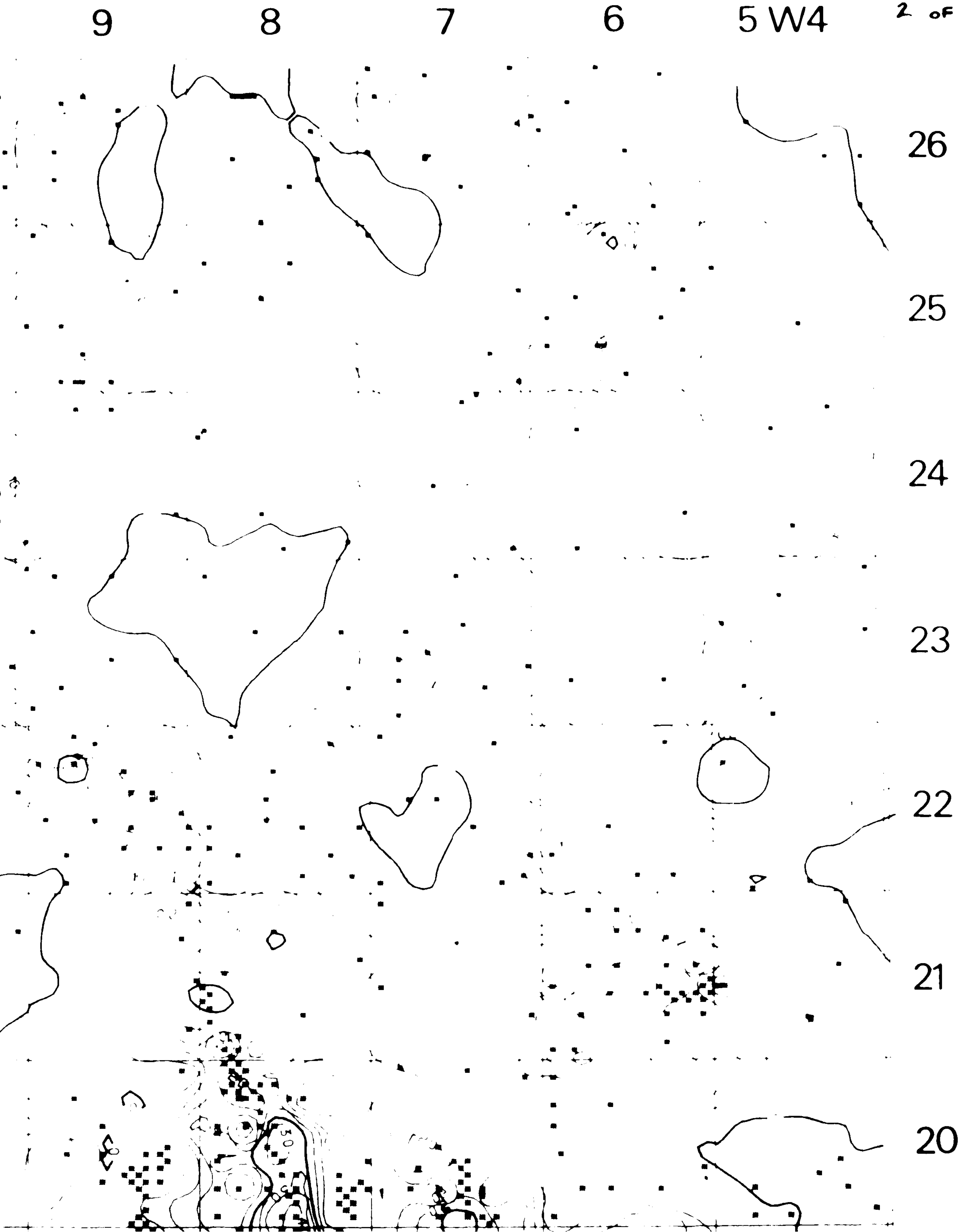
26
25
24
23
22
21
20


9
8
7
6
5 W4
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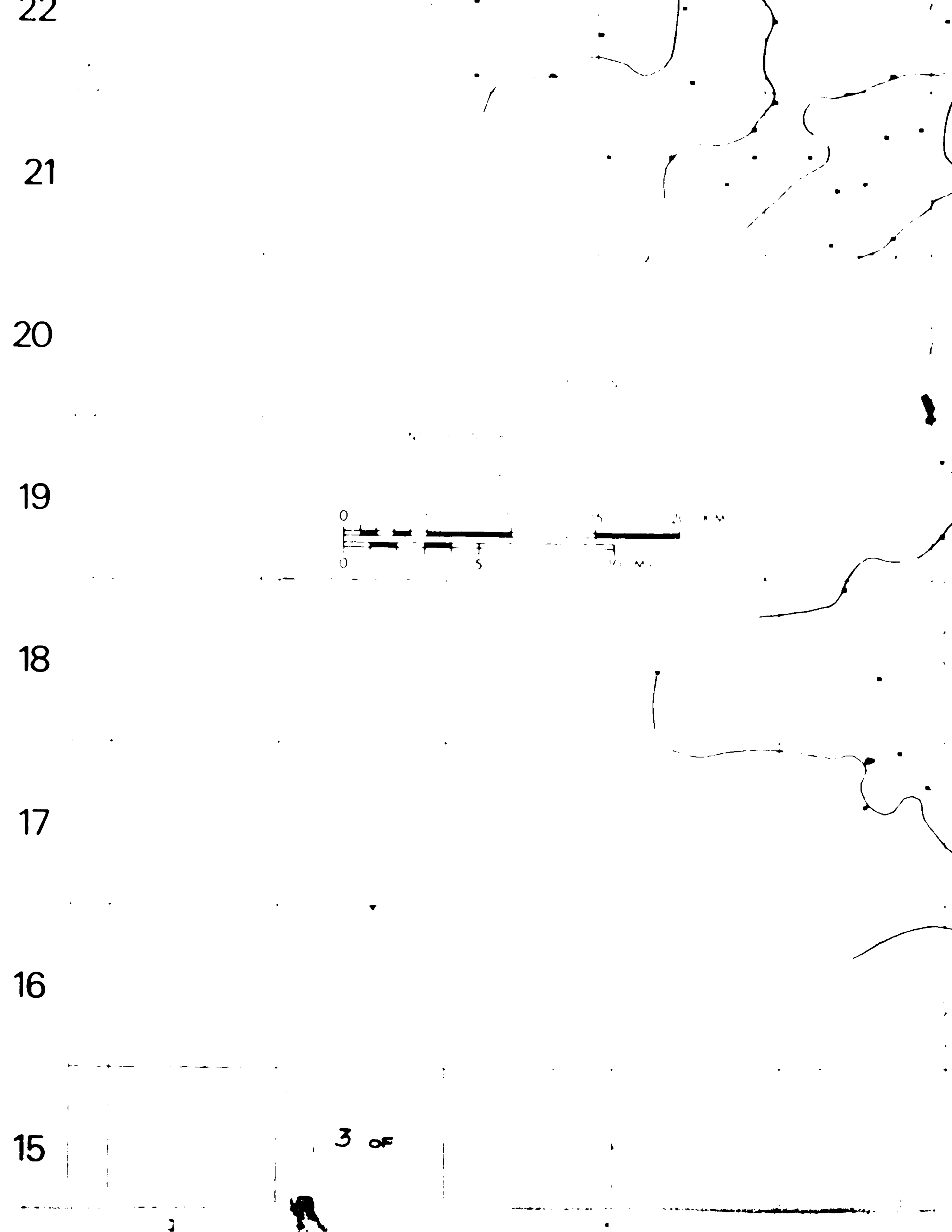
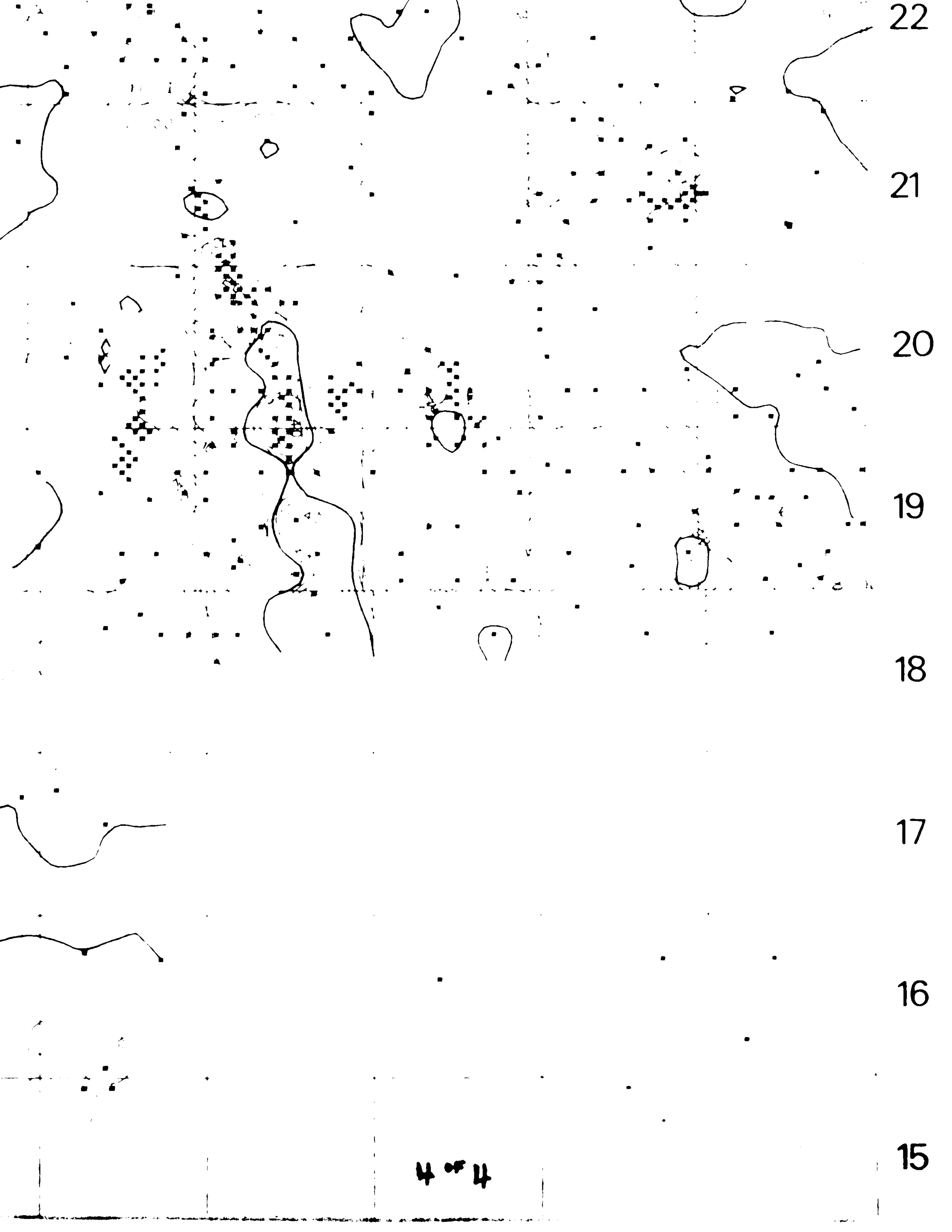
20
30


22
21
20
19
18
17
16
15
0
0
5
3 OF


22
21
20
19
18
17
16
15
4 of 4