THE SWAN RIVER FORMATION IN MANITOBA

by

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ABSTRACT

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This thesis comprises a study of the Swan River formation in Manitoba. The formation is composed predominantly of quartzose sandstone and is of Lower Cretaceous age. The mineralogical and textural characteristics of this formation are described in detail. Structural and stratigraphic features are discussed and are illustrated by means of structure contour and isopach maps and structural cross-sections.

The characteristic lithologies of the Swan River and its underlying and overlying formations, its depositional environment, and its possible source areas are treated in detail.

Results of this study suggest that the Swan River formation in Manitoba can be areally divided into a North Swan River and South Swan River. The two are stratigraphic equivalents but differ mineralogically and texturally, in their type of depositional environment, and in their source areas.

INTRODUCTION

GENERAL STATEMENT

The presence of Cretaceous sands now known as the Swan River (see Table 1, p. 5), was noted by investigators as early as 1892. However, descriptions of these sands were brief and little information has been available concerning their physical and mineralogical characteristics.

The Swan River sands of the north are known from well samples and cores, and from outcrop sections along the Swan and Roaring rivers. In the central and southern parts of the province, however, strata referred to the Swan River are known only in the subsurface, from well samples and cores. The sands of these areas will be treated separately (page 7).

PURPOSE OF INVESTIGATION

At the time this study was begun, little was known about the Swan River. The purpose of this dissertation is to describe and discuss compositional, textural, and structural features of the Swan River formation in Manitoba. Conclusions are reached as to probable correlations and source areas.

The study may have economic applications in that:

(1) the formation almost always contains fresh water and possesses excellent porosity and thus may prove useful as an aquifer;

(2) oil has been found in sands in Saskatchewan which are similar to, and may be correlative to the Swan River;

and, (3) in the northern outcrop area, some sand beds are suitable for the manufacture of various types of glass, including plate glass.

ACKNOWLEDGEMENTS

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The writer is also indebted to Imperial Oil Limited and Anglo-Canadian Oils for use of their electrologs.

Mrs. L. B. Kerr, Manitoba Mines Branch, allowed the writer access to cores and electrologs pertinent to the study.

Mr. L. Flood, Canadian Superior Oils of California, sent the writer photographs and descriptions of outcrops of the Northern Swan River.

Appreciation is expressed to Drs. G. M. Brownell, B. Wilson, and R. Ferguson, Geology Department, University of Manitoba, for their guidance during the study.

The writer thanks Mr. K. S. Wilson for his excellent thin sections.

PREVIOUS GEOLOGICAL WORK

The Swan River in Manitoba has been almost entirely neglected by investigators, and any references to be found in the literature are necessarily short and lacking in detail.

Table 1 (p.5), summarizes the sequence of Mesozoic formations in Manitoba, showing the stratigraphic position of the Swan River.

J. B. Tyrrell (1892, pp.78-215) described glauconitic quartz sands, ferruginous sandstones, silts, sandy shales, and carbonaceous shales lying below the Benton (Ashville) formation, in the Swan River Valley. He assumed them to be of Dakota age because their stratigraphic position and lithology appeared similar to the type Dakota of Meek and Hayden.

W. McInnes (1913) described Cretaceous sands exposed along the south shore of Wapawekka Lake in Saskatchewan as being very pure, white quartz sands. The grains are fairly uniform in size, and are well rounded and frosted. He states that "the exposures seem to be best correlated with similar sands which occur over a wide area further west, where they are known as the tar sands (Dakota)".

W. A. Johnston (1917, pp.37-39) described the refractory characteristics of the fine grained sands and silty clays which Tyrrell had found in exposures along the banks of the Swan River.

J. S. Delury (1924) described Cretaceous sands at Wapawekka and Deschambault Lakes in Saskatchewan as being composed almost entirely of fine to coarse well rounded quartz grains. He suggested

TABLE 1 MESOZOIC FORMATIONS IN MANITOBA

PERIOD AND EPOCH		FORMATION OR MEMBER	TYPICAL LITHOLOGY
CRETACEOUS	UPPER	Boissevain	greenish grey sandstone and sand
		Riding Mountain	greenish grey clay and light grey siliceous shale
		Pembina	dark grey to black, non-calcareous shale with bands of bentonite
		Boyne	calcareous shale with a few beds of bentonite, and some dark grey, non-calcareous shale
		Morden	dark grey, non-calcareous shales and clays
		Favel	grey shale speckled with white calcareous material, also some limestone bands
	LOWER	Ashville	dark grey to black shale with some silt and sand beds
		Swan River	sandstone with interbedded shale
JURASSIC		Amaranth	anhydrite, gypsum, and red shale
TRIASSIC		Spearfish	red to brown shale with some interbedded anhydrite

that the rounding of the grains, as well as the unusual purity of the sandstone, may have been due to the reworking by waves and other erosional agents of an Ordovician basal sand which may have covered the area at one time.

R. C. Wallace (1925, p.24) correlated the sandstone exposed along the banks of the Red Deer, Armitt, Kamatch, Swan and Carrot rivers and at Kettle Hill on Swan Lake, with the Dakota of the south.

S. R. Kirk (1929, p.115) termed beds exposed along the Swan River as "basal beds of the Upper Cretaceous" and described them as approximate time equivalents of the Dakota sandstone.

W. A. Johnston (1934, p.12) introduced the term "Swan River" and described "Swan River" beds (Dakota sandstone) as being composed of quartz sandstone, fine to coarse sand, clay, and shale.

F. H. McLearn (1944, p.4) stated that the Swan River contains marine fossils and coal, and concluded that it is partly marine and partly non-marine.

R. T. D. Wickenden (1945, p.12) designated the Swan River as the "Swan River Group" and described it as being composed of shales, sands, and sandstones of Lower Cretaceous age. He stated that the "Southern" part of the Swan River was partially of marine origin, whereas the "Northern" part was entirely of non-marine origin.

L. Flood (1951) noted a marked similarity between beds outcropping along the Swan River, and Lower Cretaceous beds penetrated by wells in Saskatchewan. He suggested that the Swan River beds were of non-marine origin.

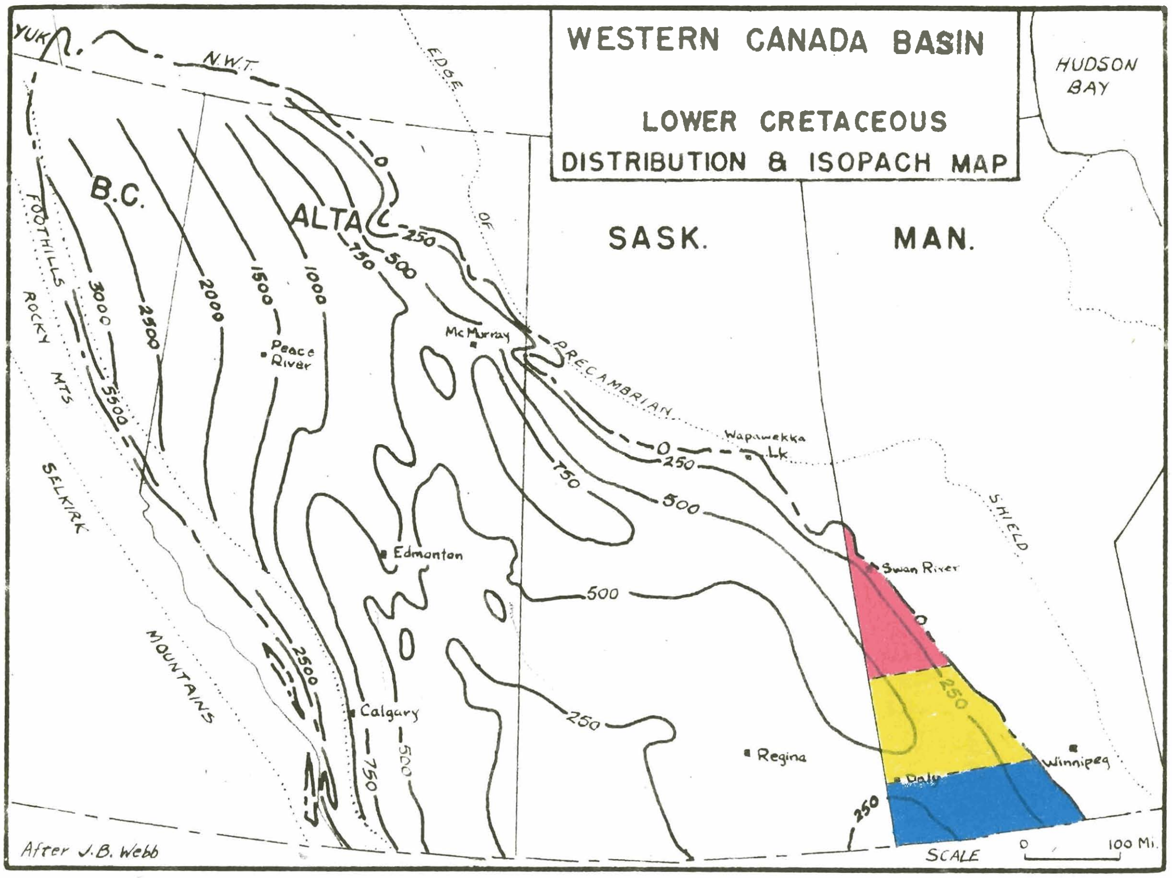
AREAS DISCUSSED

When this study was begun in 1951, only a few wells from which reliable samples and well logs were available had been drilled in that area of Manitoba underlain by Swan River beds. The lithologies of beds tentatively described as Swan River encountered in these wells varied in the different wells and from the outcrop sections of Swan River. Because of this lithological variation and the lack of control wells, correlations were uncertain. For this reason it was decided to divide the region of study into three areas. Each area included several wells and/or outcrop sections which contained Swan River beds of similar lithologic character. These three areas, all of which are bounded on the west by the Second Meridian (West) and on the east by the Manitoba escarpment, are shown in figure 1, (p.8) and are:

1) Northern area - from the northern edge of the Manitoba escarpment, south to the Riding Mountains. This area includes the Swan River and Roaring River valleys which contain the outcrop sections of the Northern Swan River, usually called "Dakota" sands by early investigators.

2) Central area - south of the Northern area, and includes the Imperial Foxwarren No. 1, California Standard Elkhorn 7-8A, and Royalite Triad Et Al Two Creeks No. 1 wells. The central area terminates to the south at a line extending east-west from the Paleozoic erosional high at the Daly oil field where the Swan River is either absent or very thin.

Fig. 1.



Northern area

Central area

Southern area

3) Southern area - south of the Daly field to the International Boundary. Wells in this area include California Standard Ewart Province 4-14, Souris Valley Robert Moore No. 1, and Royalite Triad Et Al Lulu Lake No. 1.

These three areas were studied individually throughout the investigation and are treated individually throughout this report. However, for descriptive purposes, the sands of the northern and central areas will be designated North Swan River and the sands of the southern area will be designated South Swan River.

At the time of commencement of this study, a limited number of samples of Swan River sediments was available. A few outcrop specimens comprised the available material for Swan River sands of the northern area.

Swan River sands of the central and southern areas were represented by core and ditch samples from the relatively few wells which had been drilled at that time.

The sedimentary petrography sections of this thesis thus were based on a relatively small number of samples and consequently the validity of conclusions based on the compositional and textural determinations should be considered relative to the limited amount of available material.

METHOD OF STUDY

GENERAL STATEMENT

Hand specimens, thin sections, heavy mineral slides, and photographs used in this study are on permanent file at the University of Manitoba.

Samples studied consisted of hand specimens collected by Dr. S. R. Kirk (1929) from exposures along the Swan and Roaring Rivers, and core and catch samples from wells drilled in different parts of the province.

Samples of Swan River material were investigated in the laboratory using various qualitative and quantitative methods, as detailed below.

THIN SECTIONS

Almost fifty thin sections were prepared, sections being cut both parallel and perpendicular to bedding.

An impregnating solution was employed for specimens too loosely consolidated to make thin sections in the ordinary way. A slice of material, usually under 1/4 inch thick, was placed in a solution of bakelite (phenolic resin) for twenty-four hours and then heated at 85° Centigrade for twelve hours. The rock was then hard enough to allow a thin section to be made. The desired result might have been achieved with less impregnating and heating time but the above procedure was found to be quite satisfactory.

DISAGGREGATION OF SAMPLES

Difficulty was encountered in disaggregating the majority of sandstone specimens. Samples with siliceous and pyritiferous cements were the most difficult. Disaggregation was accomplished by placing specimens on a soft wooden block and pounding with a second wooden block. Completeness of disaggregation was checked by microscope.

The Swan River sandstones from the northern outcrop areas were almost completely disaggregated by placing them in dilute hydrochloric acid. The more argillaceous types found in the southern part of the province, however, were a little more difficult to work. The argillaceous constituents could generally be washed out but as they were considered as part of the sample, they had to be retained, dried, disaggregated, and sieved along with the more arenaceous constituents. Upon drying, the clay material tended to form small consolidated masses which had to be crushed in order to avoid erroneous sieving data.

Insoluble residues were prepared as follows:
100-150 ccs. of commercial hydrochloric acid ($2H_2O$: 1 HCL) were slowly added to thirty grams of material ground to -4 mesh size (Tyler Standard) in a 250 ml. beaker. Heat was applied if required. After four hours, the liquid was decanted and retained to keep any fines. Fresh acid was then added and when all dissoluable material had gone into solution the mixture was filtered and the solid material retained and weighed.

HISTOGRAMS AND CUMULATIVE CURVES

From data obtained by sieving twenty-eight samples, each weighing about forty grains (Table 6, p.51), histograms and cumulative curves were constructed using the method described by Krumbein (1930, pp.84-90) and Pettijohn (1948, pp.19-45).

HEAVY MINERAL SEPARATIONS

Heavy mineral separations were accomplished using about seven grams of the 200+ mesh sieve size. Tetrabromoethane and bromoform of specific gravity 2.89, were used in the standard method.

Weights and percentages of light and heavy mineral fractions are recorded in Table 6, (p.51).

Permanent slides were prepared by mounting heavy minerals in Canada balsam between a glass slide and cover slip.

Following Krynine's (1946, pp.65-87) method, an attempt at correlation was made by plotting the physical and optical properties of tourmaline grains. However, better results were obtained by plotting all heavy minerals found to be present.

ROUNDNESS, SPHERICITY, FROSTING, and PITTING

Degree of rounding was estimated visually using Krumbein's table, (1941). All sieved portions of Swan River sandstones were examined.

Degrees of sphericity were determined for each sieved fraction using Pye's (1943, pp.28-34) method on the projected images of grains.

Frosting and pitting were estimated visually for each sieved fraction with allowances made for grain size, as will be detailed later.

Samples with considerable argillaceous material usually had the large grains coated with dust, thus concealing frosting and pitting effects. These samples were washed in alcohol. The alcohol removed the dust, was decanted, and the remaining liquid quickly evaporated to leave the quartz grains clean and ready for study.

STRUCTURAL FEATURES

Structural features are illustrated by means of structure contour maps (Plates lX and Xl, in pocket), an isopach map (Plate X, in pocket) and structural cross-sections (Plates Xll, Xlll and XlV, in pocket).

Correlations were based on electric and radio-active logs, as well as sample descriptions.

COMPOSITION OF THE SWAN RIVER FORMATION

GENERAL STATEMENT

The Swan River formation is composed of glauconitic quartz sands, ferruginous sandstones, silts, sandy shales, and carbonaceous shales.

The composition of the Swan River formation is dealt with in detail in the following sections. The nature of the outcrop sections and the mineralogical assemblages of the northern, central, and southern areas are discussed.

NATURE OF OUTCROP SECTIONS

North of the Swan River townsite, several good outcrops expose the upper 30 feet of the Swan River formation and include the contact with the overlying Ashville (Plates 1 and 11, pp. 16, 17). A few isolated exposures of Swan River beds are found south of Swan River Valley but these occur within the section and cannot be correlated. Nowhere in the Swan River Valley is the contact of the Swan River beds with the underlying Paleozoic exposed.

The following is a composite section described by Flood (1951) which he observed along the Swan River from NE$\frac{1}{4}$ of Section 6, Township 37, Range 26 W1 to NW$\frac{1}{4}$ of Section 6, Township 37, Range 26 W1.

Ashville Formation	Feet
Shale, carbonaceous to waxy, silty, dark grey to black, indurated; few sandy stringers at base; coarse quartz sand at base contains chert and fish teeth	2

Swan River Formation	Feet
Sandstone, quartzose, glauconitic, fine grained, with partings of grey, papery shale; secondary gypsum crystals throughout; many rounded ironstone concretions in lower 0.5 feet	5
Shale, dark grey to black; many partings of fine grained sandstone throughout.	5
Sandstone, highly glauconitic, fine grained, bedded	2
Sandstone, quartzose, fine grained; thin bands of ferriginous, fine grained, poorly consolidated sandstone in centre.	10
Shale, silty, carbonaceous, black, interbedded with clay, sandy, grey, plastic; plant remains and lignitic coal fragments throughout.	11
Total	35

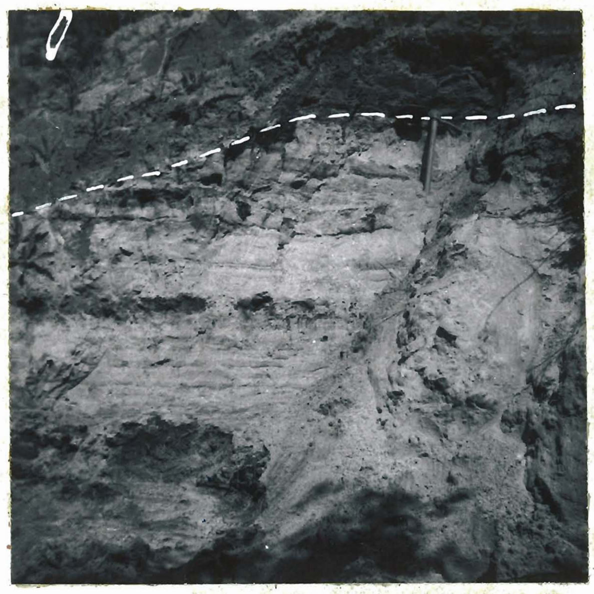
MINERAL STUDY

Light Minerals

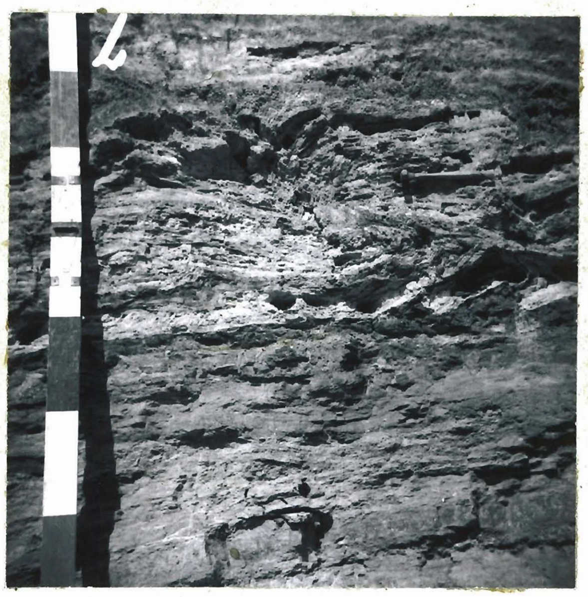
Areal Distribution

Quartz grains are the most common constituents of sands in all three areas.

Light minerals identified in samples of Swan River sand from the northern area are quartz, muscovite, and glauconite. Carbonaceous material, apparently small plant fragments, was noted in some glauconitic sandstone.

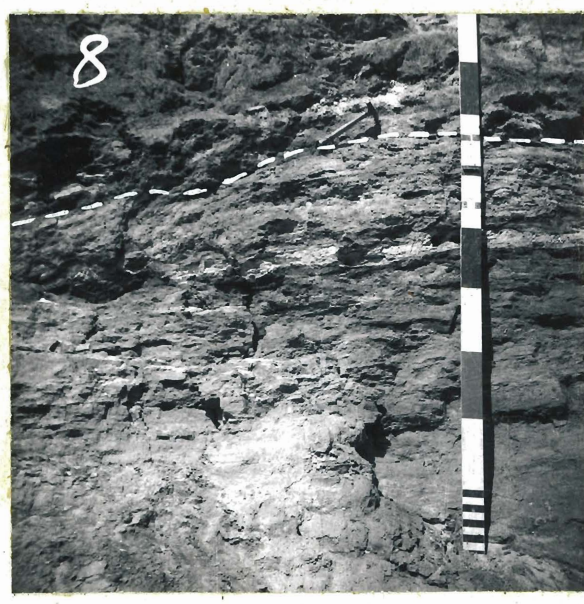


A. Location: SE 1/4 of sec. 8, twp. 37, rge. 26, W 1.
Outcrop of white, fine grained, glauconitic Swan River sand with minor thin black shaly partings. Dashed line represents the Ashville - Swan River contact.



B. Location: NE 1/4 of sec. 6, twp. 37, rge. 26, W 1.
Small shear in Swan River formation.

A. Location: NE 1/4 of sec. 6, twp. 37, rge. 26, W 1.
Dashed line follows Ashville - Swan River contact. Photograph was taken at a distance of 20 feet.



B. Location: Same as above.
Close-up of contact shown in A. Photograph was taken at a distance of 8 feet.

Thin sections of Swan River sand from the central area show muscovite and carbonaceous material, apparently plant fragments, to be present among quartz grains.

In the southern area, samples of Swan River sands, obtained from the Souris Valley Robert Moore #1, and Souris Valley Downey #1 wells, contain traces of microcline and plagioclase.

Conclusions

Light gravity minerals found in samples of Swan River sand taken from the northern, central and southern areas suggest that such factors as type of environment and rate of deposition were not the same in all three areas.

The presence of glauconite indicates that sands in the northern area probably formed, for the most part, during slow deposition in a marine environment under shallow water conditions (Twenhofel, 1950, pp.437-441). The occurence of carbonaceous material in some of the glauconitic sandstone may be due to alternation of marine and non-marine conditions during deposition or to influx of continental organic material.

Carbonaceous material is more common in the central area and glauconite is absent, which suggests at least partially non-marine conditions to have prevailed during deposition of sands in this area.

The presence of microcline and plagioclase, both relatively unstable minerals, in sands of the southern area is indicative of a short distance of transport, little or no re-working, and rapid deposition. This latter may explain the absence of glauconite if the rocks are marine in origin. The presence of strained and re-crystallized quartz grains in samples from the California Standard Hartney 16-18 and Souris Valley Downey #1 wells is indicative that source rocks were in part quartzitic.

Heavy Minerals

Introduction

Heavy minerals identified, and their relative frequencies of occurrence are shown in Table 2 (p.20). Locations of samples from which they were obtained are shown in Table 3 (p.21).

Three methods were employed in the interpretation of heavy mineral data:

(1) direct comparison of the total number of different heavy minerals found in each of the three areas,

(2) comparison of all heavy minerals common to any two areas,

and, (3) comparison of heavy minerals common to any two areas which are not common to the third area.

Method One

The total number of different heavy minerals in each of the three areas is shown below in Table 4.

TABLE 4 - AREAL DISTRIBUTION OF HEAVY MINERALS

AREA	NUMBER OF DIFFERENT HEAVY MINERALS
Northern	15
Central	14
Southern	7

These minerals are those identified and recorded in Table 2 (p.20). There are fifteen different heavy minerals found in samples of

TABLE 2 HEAVY MINERALS IDENTIFIED IN SAMPLES AND THEIR RELATIVE FREQUENCIES OF OCCURENCE

	SAMPLE	CHLORITOID	EPIDOTE	GARNET	HORNBLENDE	ILMENITE	LIMONITE	KYANITE	LEUCOXENE	MAGNETITE	PYRITE	RUTILE	SILLIMANITE	STAUROLITE	TOPAZ	TOURMALINE	ZIRCON
NORTHERN	VKA 1					xxx		xx	xxx	xx		x	x	xxx	xx	xxx	x
	VKA 2		x	x		xx		x	xxx	x	xxx	x	x	xx	xx	xxx	xx
	VKB 1				x	xx	x	xx	xxx	x	xxx		x	xx		xx	x
	VKC 1		x			xx	x	x	xxx	xxx		x		xx		xxx	xx
	VKD 1								xx	xxx					x		
	VKD 2		xx		x	xx	x	xx	xxx	xx	xxx	x		xxx		xxx	xx
CENTRAL	SRB 3						xx	x	xxx		xxx		x	xx	x	xx	xx
	SRB 4					x		x	xxx		xxx		x	xx	x	xxx	x
	SRB 7					xx			xxx	xx	xxx			xx		xx	x
	SRB 8		x					x	xxx	xx	xxx			xx		xx	x
	SRB 11			x					xxx		xxx				xxx	xx	x
	SRF 1		x				xx	xx	xxx	xx	xxx				x		xx
	SRM 1		x				xx	x	xx	x	xxx		x	x		x	x
	SRM 2			x					xx		xxx		x	x	x	x	
	SRM 3	x	x			xx	xx		xx		xxx		x	x		xx	x
	SRM 4		x				xx				xxx						x
	SRM 5										xxx						
	SRM 6	x		x			xxx		xxx		xxx		xx	xx		xx	x
	SRC 1								xx		xxx				x	x	x
SOUTHERN	SRD 1								xxx	x	xxx			xx	x	xx	x
	SRE 1								xxx	xx	xxx			xx		xx	xx
	SRE 2								xx	x	xx			x		xx	xx
	SRG 2								xxx	xx	xxx			x		xx	xx
	SRH 12								xx		xxx			xx	x	xx	x

TABLE 3 LOCATIONS OF SAMPLES

SAMPLE	AREA	LOCATION
VKA 1	Northern	Outcrop on Roaring River
VKA 2	Northern	Outcrop on Roaring River
VKB 1	Northern	Outcrop on Swan River
VKC 1	Northern	Outcrop on Roaring River
VKD 1	Northern	Outcrop on Swan River
VKD 2	Northern	Outcrop on Swan River
SRB 3	Central	Imperial Birtle No. 1 at 1272'
SRB 4	Central	Imperial Birtle No. 1 at 1275'
SRB 7	Central	Imperial Birtle No. 1 at 1280'
SRB 8	Central	Imperial Birtle No. 1 at 1293'
SRB 11	Central	Imperial Birtle No. 1 at 1395'
SRF 1	Central	Imperial Foxwarren No. 1 at 1295'
SRM 1	Central	Imperial Madeline No. 1 at 1187'
SRM 2	Central	Imperial Madeline No. 1 at 1190'
SRM 3	Central	Imperial Madeline No. 1 at 1203'
SRM 4	Central	Imperial Madeline No. 1 at 1217'
SRM 5	Central	Imperial Madeline No. 1 at 1222'
SRM 6	Central	Imperial Madeline No. 1 at 1295'
SRC 1	Central	Brandon Coutts No. 2 at 842'
SRD 1	Southern	Souris Valley Downey No. 1 at 2078'
SRE 1	Southern	Calstan Ewart Prov. 4-14 at 1797'
SRE 2	Southern	Calstan Ewart Prov. 4-14 at 1774'
SRG 2	Southern	Souris Valley Moore No. 1 at 2115'
SRH 12	Southern	Calstan Hartney 16-33 at 1595'

Swan River sands from the northern area, fourteen different heavy minerals in sands of the central area, and seven different heavy minerals found in samples of South Swan River sands.

Method Two

Using Table 2 (p.20), heavy minerals common to the northern and central areas, those common to the northern and southern areas, and those common to the central and southern areas were compared.

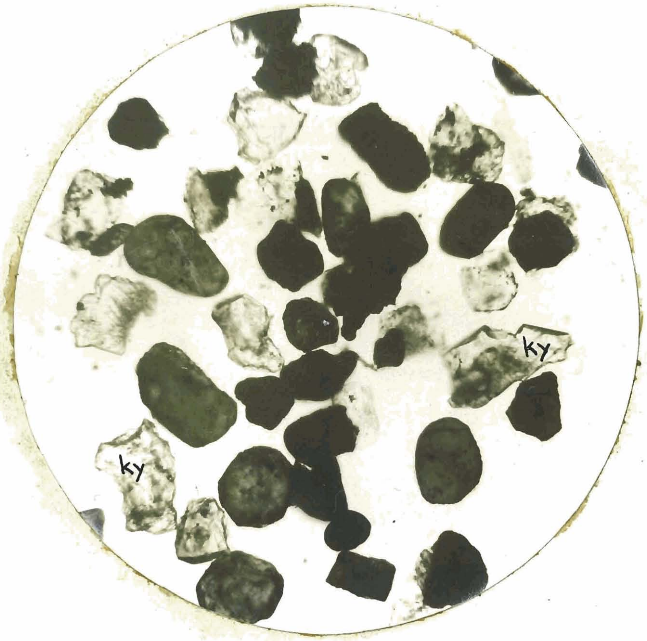
It was found that the northern and central areas have thirteen different minerals in common: epidote, garnet, ilmenite, limonite, kyanite, leucoxene, magnetite, pyrite, sillimanite, staurolite, topaz, tourmaline and zircon (Plate 111, p.23).

The central and southern areas have seven heavy minerals in common: leucoxene, magnetite, pyrite, staurolite, topaz, tourmaline, and zircon. These are the same seven minerals which are common to the northern and central areas. In other words, leucoxene, magnetite, pyrite, staurolite, topaz, tourmaline, and zircon are found in all three areas and so can not be used to illustrate any differences in the mineral assemblage of the areas (Plate lV, p.24).

Method Three

In this method, only those minerals are recorded which are common to any two areas but are not found in the third area.

Again, using Table 2 (p.20), it was found that the northern and central areas have six heavy minerals in common which are not found in the southern area. They are epidote, garnet, ilmenite, limonite, kyanite and sillimanite.

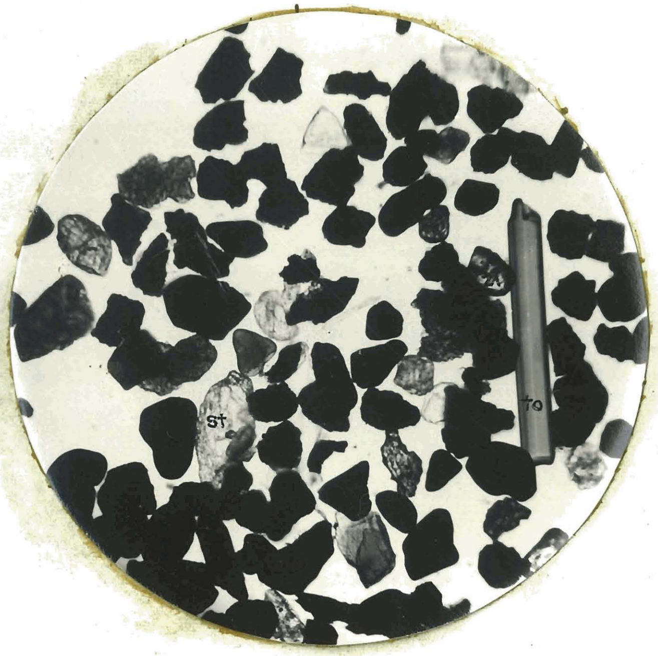


x 75

A. Photomicrograph of heavy minerals found in Swan River sandstone from outcrop along the Roaring River, showing the relative abundance of kyanite (ky).

x 75

B. Photomicrograph of heavy minerals found in Swan River sand of Imperial Madeline No. 1, showing the presence of sillimanite (si), staurolite (st), and tourmaline (to).



x 75

Photomicrograph of heavy minerals found in Swan River sand from Roaring River outcrop, showing presence of tourmaline (to), staurolite (st), and zircon (zi).

There are no heavy minerals common to the central and southern areas that are not found in the northern area, nor are there any heavy minerals found in the northern and southern areas which are not found in the central area.

The only differences in the heavy mineral assemblages in sands of the northern and central areas are that the sands of the northern area contain hornblende and rutile which are not found in sands of the central area, but do not contain chloritoid which is found in sands of the central area.

Conclusions

The heavy mineral assemblages of the North Swan River sands of the northern and central areas appear quite similar both in the number of different heavy minerals found in each area and also in the type of heavy mineral present in each area.

Heavy minerals in the South Swan River sands are less in number and in variety than those of the North Swan River.

The lesser number of heavy minerals in the South Swan River sands is not due to a greater distance of transport of these sands in comparison to North Swan River sands. This is indicated by the presence of such relatively unstable minerals as microcline and plagioclase in the light mineral suites of South Swan River sands indicating a relatively close source with little or no re-working.

The difference between the North and South Swan River sands may be due to a difference in source areas of the two sands.

Tourmaline Investigation

All tourmaline grains observed in heavy mineral studies were carefully described and included in Table 5 (p.27). By using Krynine's (1946, pp.65-87) classification, an attempt was made to interpret the petrology of the source areas or area of the Swan River sands in the three areal divisions.

Introduction

Krynine (1946, pp.65-87) lists five main tourmaline groups. The classification of grains is based on size, shape, colour, and presence and nature of inclusions.

The five groups are:

a) granitic tourmaline

b) pegmatitic tourmaline

c) tourmaline from pegmatized injected metamorphic terranes

d) sedimentary authigenic tourmaline

e) reworked tourmaline

For a detailed description of these groups and a few practical applications of this type of study, the reader is referred to Krynine's publication.

Northern Area

The most common types of tourmaline found in the Swan River sands of the northern area are those of the yellow to brown and pink to green color classes and containing few or no inclusions. Most of the tourmaline grains in these groups are idiomorphic although there are a number of rounded grains.

TABLE 5 DISTRIBUTION OF TOURMALINE TYPES

		COLORLESS--YELLOW						YELLOW--BROWN						PINK--GREEN						PINK--DEEP PINK						BLUE--MAUVE					
		NO INCLUSNS			INCLUSIONS			NO INCLUSNS			INCLUSIONS			NO INCLUSNS			INCLUSIONS			NO INCLUSNS			INCLUSIONS			NO INCLUSNS			INCLUSIONS		
	SAMPLE	ANG	IDI	RND	ANG	IDI	RND	ANG	IDI	RND	ANG	IDI	RND	ANG	IDI	RND	ANG	IDI	RND	ANG	IDI	RND	ANG	IDI	RND	ANG	IDI	RND	ANG	IDI	RND
NORTHERN	VKA 1		x			xx		x	xxx	x			xx	x	x	x	x	x									x	x			
	VKA 2							x	x	x		x		x	x	x										x					
	VKB 1	x						x	x	xx				x	x	x					x					x					
	VKC 1							x	x	x	x		x	x	x									x		x		x	x	x	
	VKD 1																														
	VKD 2							x	x	x	x	x		x	x	x	x											x			
CENTRAL	SRB 3								x	x			x						x												
	SRB 4								x	x					x			x													
	SRB 7							x	x	xxx	x		x	x	x				x												
	SRB 8							x	x	x		x		x			x														
	SRB 11							x	x	x																	x				
	SRC 1														x											x					
	SRF 1								x						x																
	SRM 1							x	x						x											x					
	SRM 2							x	x	x		x	x		x		x	x	x												
	SRM 3							x	x	x	x			x	x	x		x													
	SRM 4														x																
	SRM 5																														
	SRM 6								x	x	x					x															
SOUTHERN	SRD 1								x	x		x	x		x	x															
	SRE 1								x			x						x													
	SRE 2								x	x		x	x		x	x															
	SRG 2							x		x		x	x		x	x															
	SRH 12								x	x	x																				

ANG = ANGULAR IDI = IDIOMORPHIC RND = ROUND x = INCLUSIONS ARE CARBONACEOUS

Tourmaline grains of the yellow to brown and pink to green color groups but containing cavities (empty vacuoles or bubbles) are much less common. The majority of these tourmaline grains are angular or idiomorphic.

Tourmaline grains with blue to mauve color and few or no inclusions are also present. Angular grains of this type are slightly more common than rounded grains.

Grains with carbonaceous inclusions are rare. Both idiomorphic and rounded varieties are observed.

Central Area

The most common types of tourmaline found in Swan River sands of the central area are those of the yellow to brown and pink to green groups with few or no inclusions. Idiomorphic grains predominate over rounded varieties.

Tourmaline grains of the yellow to brown and pink to green color groups, but containing non-carbonaceous inclusions are also present. They are angular, idiomorphic, and rounded.

Idiomorphic tourmaline grains with carbonaceous inclusions are next in order of relative abundance.

Tourmaline grains of blue color and angular and idiomorphic shape are rare.

Southern Area

By far the most common types of tourmaline found in South Swan River sands are those of the yellow to brown and pink to green color groups and containing few or no inclusions. Idiomorphic grains are slightly more common than rounded varieties.

Tourmaline grains containing inclusions and belonging to the yellow to brown and pink to green color groups are also present. Grains containing carbonaceous inclusions are slightly more common than those containing empty vacuoles. Idiomorphic grains are more common than rounded varieties.

Discussion

This study of the types of tourmaline grains found in sands of the North and South Swan River formations shows that the same types of tourmalines are the most common in all three areas. They are the yellow to brown and pink to green color classes, containing few or no inclusions.

According to Krynine, these types of tourmalines are derived from pegmatized injected metamorphic terranes. The rocks forming these terranes would be mainly quartzose in character and would include pegmatized sandstones, metaquartzites, quartz-schists, and quartz-mica-schists.

The next most common types of tourmalines found in North Swan River sands from both the northern and central areas, were of the yellow to brown and pink to green color groups but containing cavities(empty vacuoles or bubbles).

These tourmalines are believed to have been derived from large plutonic igneous bodies.

In South Swan River sands, tourmalines of the yellow to brown and pink to green groups containing carbonaceous inclusions are slightly more common than those of the same color groups but which contain cavities. This relationship is reversed in Swan River sands of the central area. Carbonaceous inclusion - bearing tourmalines are rare in sands of the northern area.

Carbonaceous inclusion - bearing tourmalines are suggested by Krynine to have been derived from a pegmatized injected metamorphic terrane wherein the injected phyllite was originally a dark or black shale.

Blue to mauve tourmalines are present in North Swan River sands from the northern and central areas, but are absent in South Swan River sands.

Krynine believes that this type of tourmaline is characteristic of pegmatites and vein rocks.

Shapes of the tourmaline grains are also shown in Table 5 (p.27). Idiomorphic and angular grains are slightly to considerably more common than rounded grains in all groups.

One inference which can be placed on this fact is that all the grains have not undergone the same amount of abrasion. The reason for this could be that the angular and idiomorphic grains have undergone less distance and time of transport and less reworking than rounded grains. The rounded grains may have gone through more than one cycle of sedimentation and become part of the Swan River sands after derivation from sediments whose source was the same or similar to that which supplied the fresher, less abraided tourmalines found in the North and South Swan River formations.

In summary it may be said that the type of source common to both North and South Swan River formations was a pegmatized injected metamorphic terrane. This terrane probably included pegmatized sandstones, metaquartzites, mica schists, quartz-mica-schists, slates, non-quartzose mica schists, and phyllites, some of which were originally black shales. Large plutonic igneous bodies, pegmatites, and vein rocks were also present.

The main differences in type of source of Swan River sands found in the northern, central, and southern areas as determined by a study of tourmalines, are that the source of sands in the northern area contained a smaller colume of phyllitic rocks than the sources of sands in the central and southern areas, and that the source of the South Swan River contained a smaller volume of pegmatitic rocks than that of the North Swan River. These differences are not significant.

Conclusions

The tourmaline study indicates that the North and South Swan River sands had sources of similar lithologic character.

Complete Mineral Assemblage

Discussion

The complete heavy mineral suites of Swan River sands from the northern, central, and southern areas, are given in Table 2 (p.20). These complete mineral suites were compared in order to determine whether or not they were indicative of any particular types of source areas.

Pettijohn (1948, p.98) lists detrital mineral suites characteristic of different types of source rocks. He classifies these minerals as indicative of derivation from six types of source. They are:

1) re-worked sedimentary source
2) low rank metamorphic source
3) high rank metamorphic source
4) acid igneous source
5) basic igneous source
6) pegmatite source

Areal Characteristics

The three areas, northern, central, and southern, contain one or more minerals from each type of source. However, four of the six minerals common to the northern and central areas, and not present in the southern area, i.e., epidote, garnet, kyanite, and sillimanite, are characteristic of a high rank metamorphic source.

The mineral suite found in Swan River sands of the southern area appears to be more characteristic of an acid igneous source.

Conclusions

Results of the complete mineral assemblage study indicate that Swan River sands in the northern, central, and southern areas were derived from sources containing several types of rocks.

The source or sources of the Swan River sands in the northern and central areas appear to have contained a greater proportion of rocks of the high rank metamorphic type than did the source or sources of sands of the southern area.

Discussion of Results of Mineral Study

Before any definite conclusions based on the study of light and heavy minerals are made, the factors effecting the distribution of these minerals will be discussed.

The factors that control the distribution of heavy minerals in natural sandstones are said by Rubey (1933, pp.3-29) to be:

a) differences in the original size of the various grains in the source rock.

b) the amount of abrasion that all grains have undergone during transportation.

c) the different settling velocities of the various grains at the site of deposition.

d) the degree of sorting to which all grains were subjected there.

Rubey further states that "all these factors seem competent to cause large variations in the relative abundance of various minerals in different samples of deposits that have been derived from exactly the same source and also in different size fractions of each of the samples".

Rubey believes that all variations except those due to differences in the amount of abrasion are eliminated if comparisons are restricted to the heavy minerals taken from "comparable portions of sandstones that have essentially the same grain size and the same degree of sorting". Almost all samples used in this work could be classified as fine grained sands and most appear to have been moderately well sorted.

Cogen (1935, pp.3-8) states that "for quantitative comparison of heavy minerals, materials of the same grade-size should be utilized". In this study, only the 200∤ grade sizes were used. The 200∤ size was the most suitable as, according to Rubey, the processes of sedimentation tend to concentrate the heavy minerals within the finer grained portions of sandstones. Minerals of grain size smaller than 200∤ were found to be too small for identification except by X-ray methods and large screen sizes would have fewer heavy minerals.

In this work, wherein the heavy mineral assemblages of different sandstones are compared, the possible effects of all factors controlling distribution of minerals was borne in mind, and if possible, compensation made for them.

Because all possible precautions were taken, the results of this heavy mineral study are as accurate as was thought possible. However, the preceeding discussion will help to explain variations in the heavy mineral composition of individual or similar samples which might otherwise appear incongruous and tend to nullify or reduce the value of the work done.

Conclusions

The preceding study of the light minerals, the heavy minerals, the tourmaline suites, and the complete mineral assemblages indicates that the sources of the North and South Swan River sands were different geographically and mineralogically.

A common source of the North and South Swan River sands to the north of the outcrop area is contradicted by several facts as follows:

1) There is no uniform gradient in the number of different heavy minerals from the northern area to the southern area. This gradient could be expected if the sands were a single stratigraphic unit as a greater distance of transport would tend to eliminate more of the less stable minerals.

2) The presence of microcline and plagioclase in South Swan River sands is indicative of a relatively short distance of transport, little or no re-working and rapid deposition.

The source of the South Swan River sands was similar in gross lithology but less complex mineralogically than that of the North Swan River sands. Both source areas contained metamorphic and igneous masses, and sediments derived from them. However, the source of the North Swan River sands was mainly of the high-rank metamorphic type whereas that of the southern area was of the low-rank metamorphic and acid igneous type.

The source of the North Swan River sands in the northern and central areas was probably the same.

CEMENTS

The nature and amount of the cementing medium in most samples was determined by means of insoluble residue methods and thin section studies.

Using these two methods, it was observed that samples from the three areas had the following cements:

a) Northern area - mostly calcareous cement (35% - 40%), also some pyritic cement.

b) Central area - mostly argillaceous cement, also some calcareous cement.

c) Southern area - mostly argillaceous cement, also some calcareous and pyritic cement.

FOSSILS

The only fossils identified by the author during this study were found in beds of the Swan River in the Imperial Birtle No. 1 well at a depth of 1319 feet, which is about fifty feet below the top of the Swan River in this well. These fossils are illustrated in Plates V and Vl (pp.38-39).

They include:

Astarte trapezoidales Stanton

Dentalium sp

Arctica occidentales (Whiteaves)

Arcopagella mactroides Meek

Crassatellina oblongata Meek

Callista (*Aphrodina*) *tenuis* (?) Hall and Meek

Nucula percrassa Conrad

Astarte trapezoidales Stanton and *Arctica occidentales* (Whiteaves) are described by Shimer and Shrock as being Lower Cretaceous index fossils.

Tyrrell (1892 p.113), Wallace (1925, p.29), Kirk (1929, p.116), and Wickenden (1945, p.14) identified several fossils found in Swan River outcrop in the northern area. These genera include:

Lingula subspatula Hall and Meek

Ostrea congesta Conrad

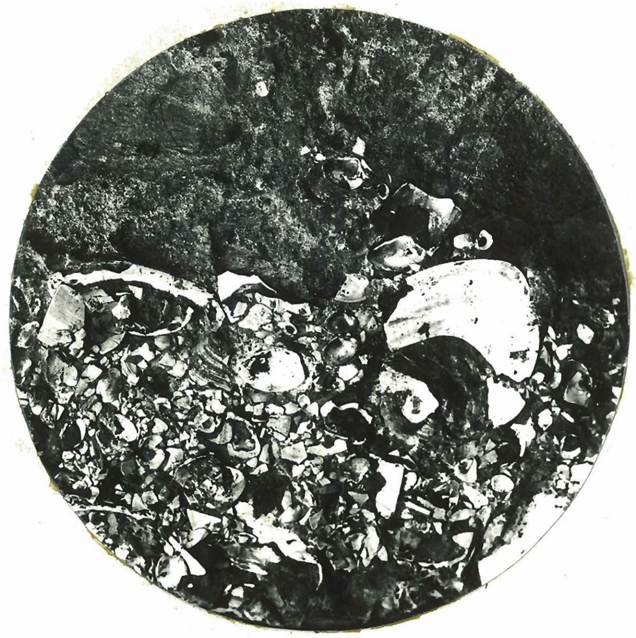
Modiola (Brachidontes) tenuisculpta Dawson

Lamna manitobensis Whiteaves

Gervillia ? sp

Nucula ? sp

None of these appear to be index fossils.



x 2

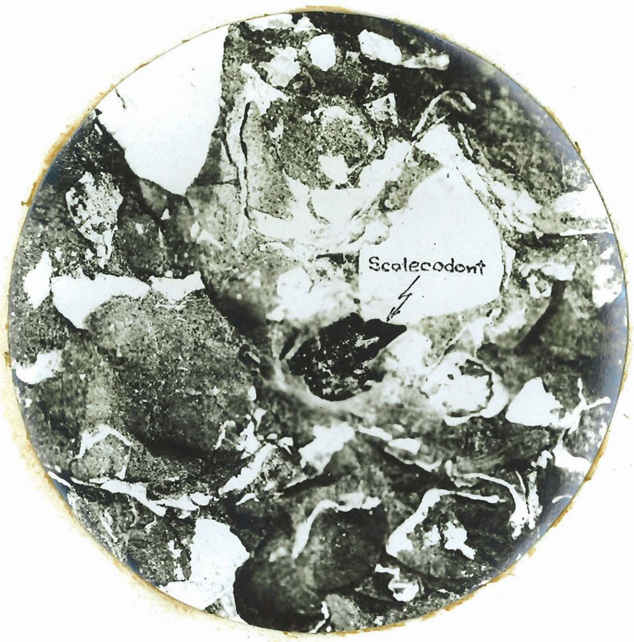
A. Assemblage of pelecypods found in the Swan River of Imperial Birtle No. 1.

x 2

B. Nucula percrassa found in the Swan River of Imperial Birtle No. 1.

x 2

A. Species of Dentalium found in the Swan River of Imperial Birtle No. 1.



x 6

B. Scolecodont found in the Swan River of Imperial Birtle No. 1.

TEXTURAL CHARACTER OF SWAN RIVER FORMATION

HISTOGRAMS AND CUMULATIVE CURVES

Histograms of all samples used in this study were drawn and are included in Plate Vll (p.41). Cumulative curves of these same samples are shown in figures 2-10 (pp.42-50). The histograms and cumulative curves were constructed using sample weights listed on the individual cumulative curve diagrams and in Table 6 (p.51). Significant values and quartile measures derived from the cumulative curves are included in Table 7 (p.52).

Grain size, Sorting, Skewness, and Kurtosis

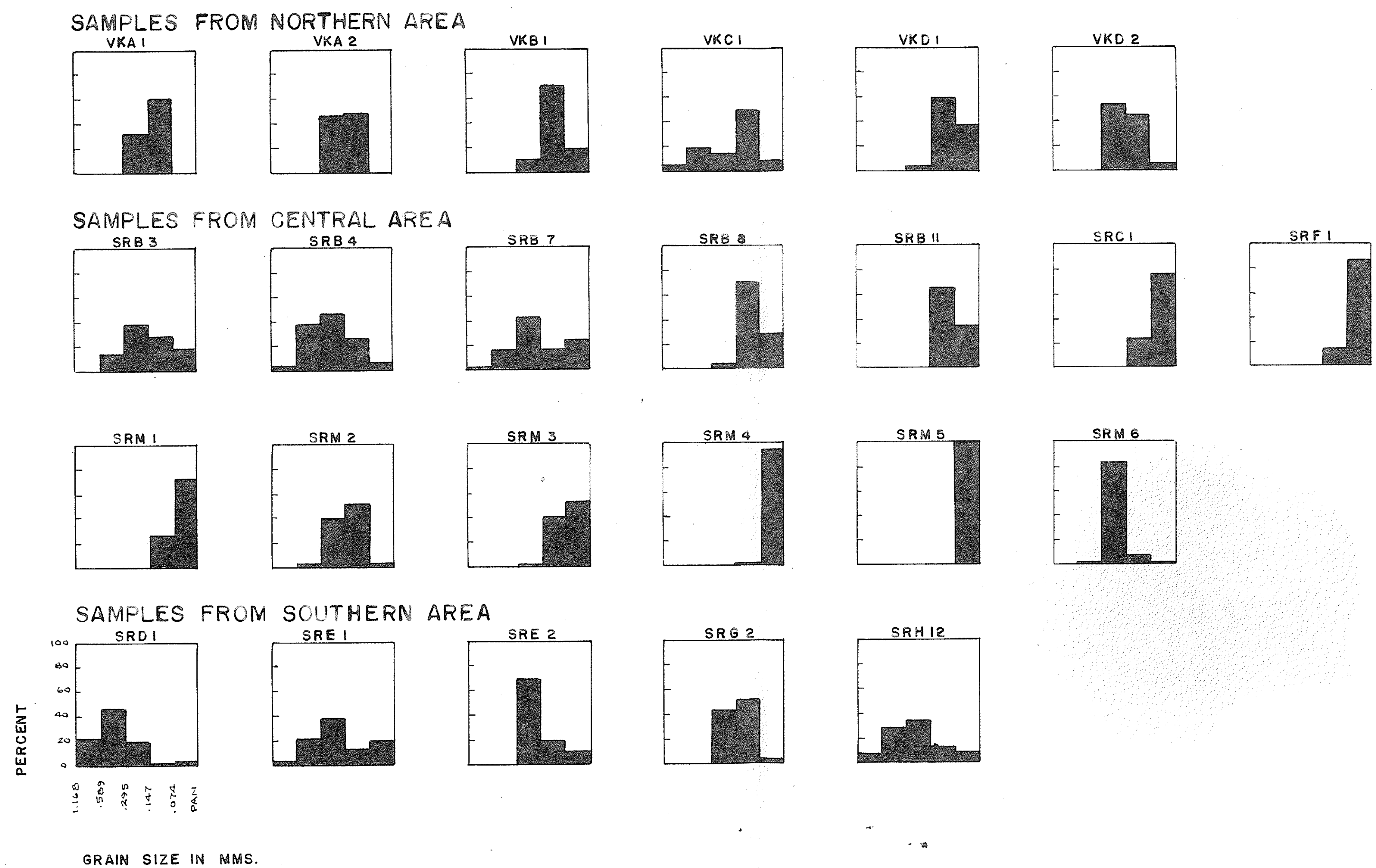
Northern area

The average grain size of Swan River sands from the northern area, as determined from histograms, (Plate Vll, p.41) is 0.074 - 0.147 mms. in diameter. The average "median" as determined from cumulative curves is 0.129 mm. in diameter (Table 7, p.52). Thus, the Swan River sands of the northern area would, according to Wentworth's scale (Pettijohn, 1948, p.16) be classed as "very fine sands". (See Plate V111 A, p.54).

Histograms of Swan River sands from this northern area show them to be well sorted. (Plate Vll, p.41). The average "coefficient of sorting" as determined from cumulative curves is 1.4 which also indicates a fairly well sorted sediment (Pettijohn 1948, p.24).

The average skewness of cumulative curves representing samples of Swan River sands from this area is 0.98 (Table 7, p.52) which according to Pettijohn, would indicate that the average curve for these sands

HISTOGRAMS


SAMPLES FROM NORTHERN AREA
VKA 1
VKA 2
VKB 1
VKC 1
VKD 1
VKD 2
SAMPLES FROM CENTRAL AREA
SRB 3
SRB 4
SRB 7
SRB 8
SRB 11
SRC 1
SRF 1
SRM 1
SRM 2
SRM 3
SRM 4
SRM 5
SRM 6
SAMPLES FROM SOUTHERN AREA
SRD 1
SRE 1
SRE 2
SRG 2
SRH 12
PERCENT
100
80
60
40
20
0
1.168
.589
.295
.147
.074
PAN
GRAIN SIZE IN MMS.

The Tyler Standard Screen Scale

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Name Date

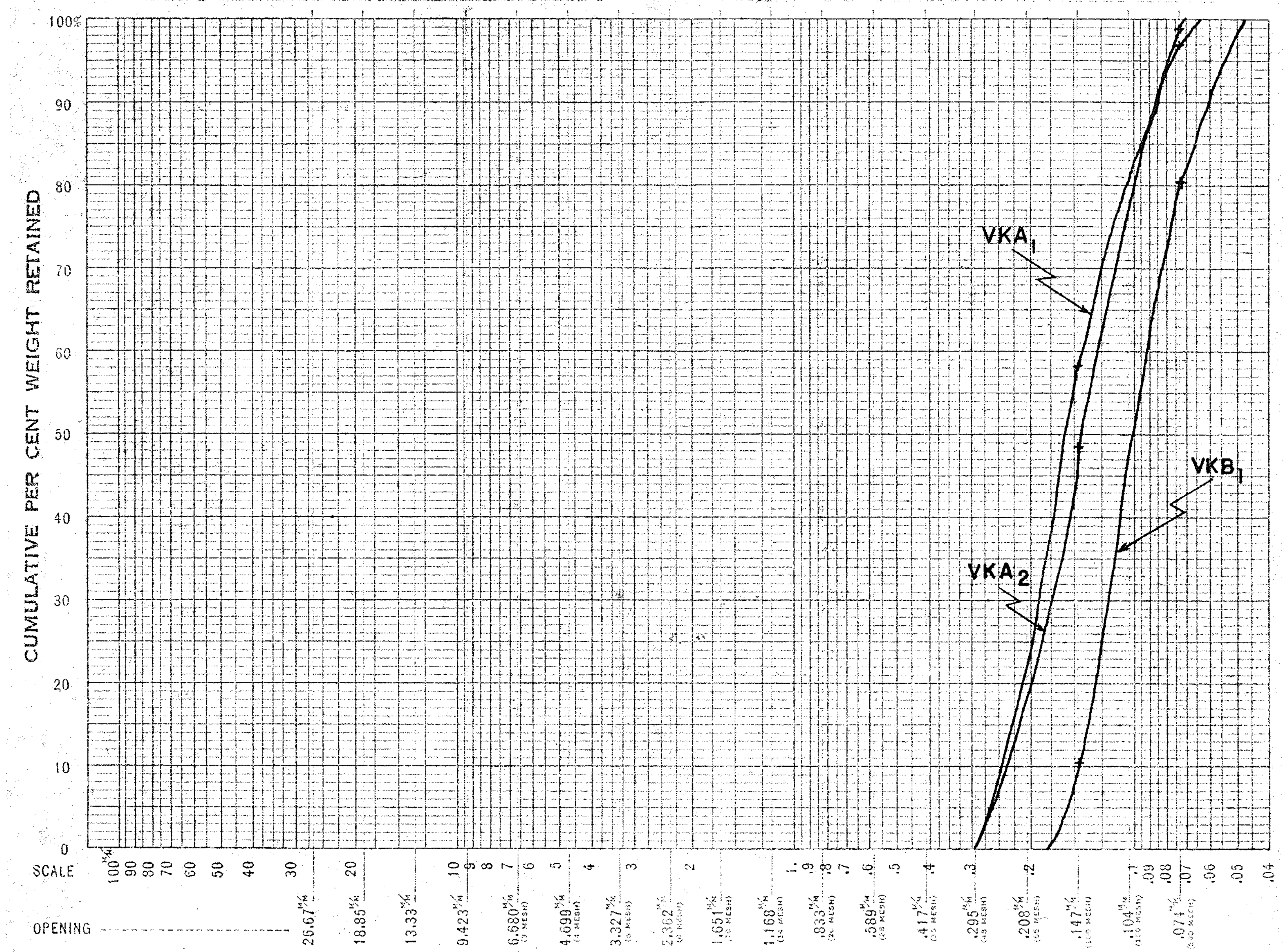

Fig. 2

SCREEN SCALE RATIO 1.414				VKA1			VKA2			VKB1		
Openings		Tyler Mesh	U. S. No.	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights
Milli-meters	Inches											
26.67	1.050											
18.85	.742											
13.33	.525											
9.423	.371											
6.680	.263	3										
4.699	.185	4	4									
3.327	.131	6	6									
2.362	.093	8	8									
1.651	.065	10	12									
1.168	.046	14	16									
.833	.0328	20	20									
.589	.0232	28	30									
.417	.0164	35	40									
.295	.0116	48	50	0.07	0.2	0.2	0.05	0.1	0.1			
.208	.0082	65	70									
.147	.0058	100	100	23.63	58.2	58.4	19.48	48.4	48.5	4.35	10.5	10.5
.104	.0041	150	140									
.074	.0029	200	200	15.70	38.7	97.1	20.31	50.4	98.9	29.04	70.0	80.5
Pass .074	.0029	200	200	1.17	2.9	100.0	0.44	1.1	100.0	8.09	19.5	100.0
			Totals,	40.57	100.0		40.28	100.0		41.48	100.0	

THE W. S. TYLER COMPANY, CLEVELAND 14, OHIO U. S. A. 6-50

Fig. 3

The Tyler Standard Screen Scale

Form No. L-6
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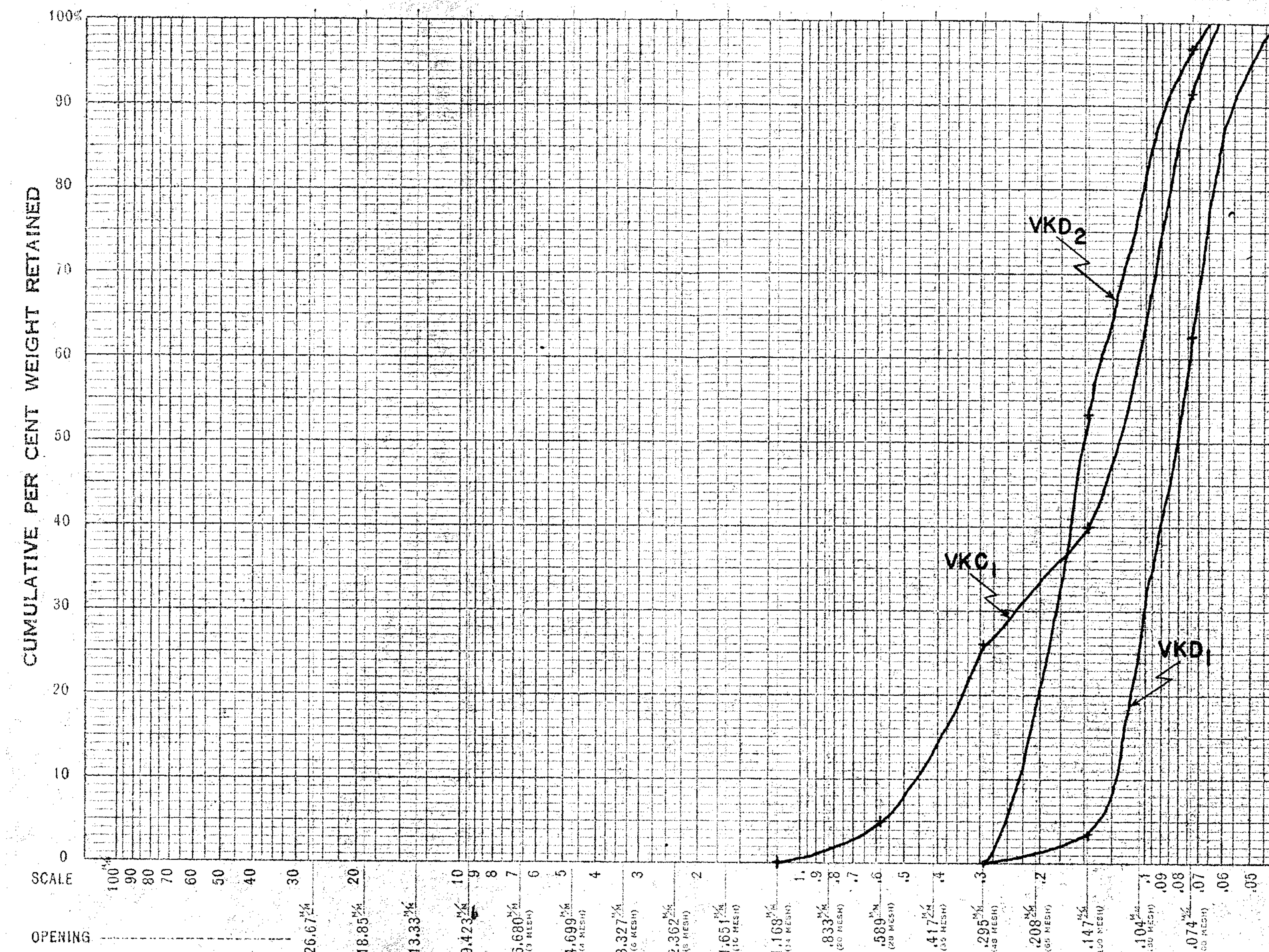
Cumulative Logarithmic Diagram of Screen Analysis on Sample of

Name ______ Date ______



	SCREEN SCALE RATIO 1.414				VKC1			VKD1			VKD2		
	Openings: Milli-meters	Openings: Inches	Tyler Mesh	U. S. No.	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights
	26.67	1.050											
	18.85	.742											
	13.33	.525											
	9.423	.371											
	6.680	.263	3										
	4.699	.185	4	4									
	3.327	.131	6	6									
	2.362	.093	8	8									
	1.651	.065	10	12									
	1.168	.046	14	16	0.10	0.2	0.2						
	.833	.0328	20	20									
	.589	.0232	28	30	2.07	4.9	5.1						
	.417	.0164	35	40									
	.295	.0116	48	50	8.55	20.9	26.0	0.04	0.1	0.1	0.05	0.1	0.1
	.208	.0082	65	70									
	.147	.0058	100	100	5.93	14.0	40.0	1.46	3.6	3.7	21.56	53.2	53.3
	.104	.0041	150	140									
	.074	.0029	200	200	21.96	51.6	91.6	23.63	58.9	62.6	17.71	43.6	96.9
Pass	.074	.0029	200	200	3.58	8.4	100.0	14.98	37.4	100.0	1.26	3.1	100.0
				Totals.	42.19	100.0		40.11	100.0		40.58	100.0	

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Fig. 4

The Tyler Standard Screen Scale

Form No. L-6
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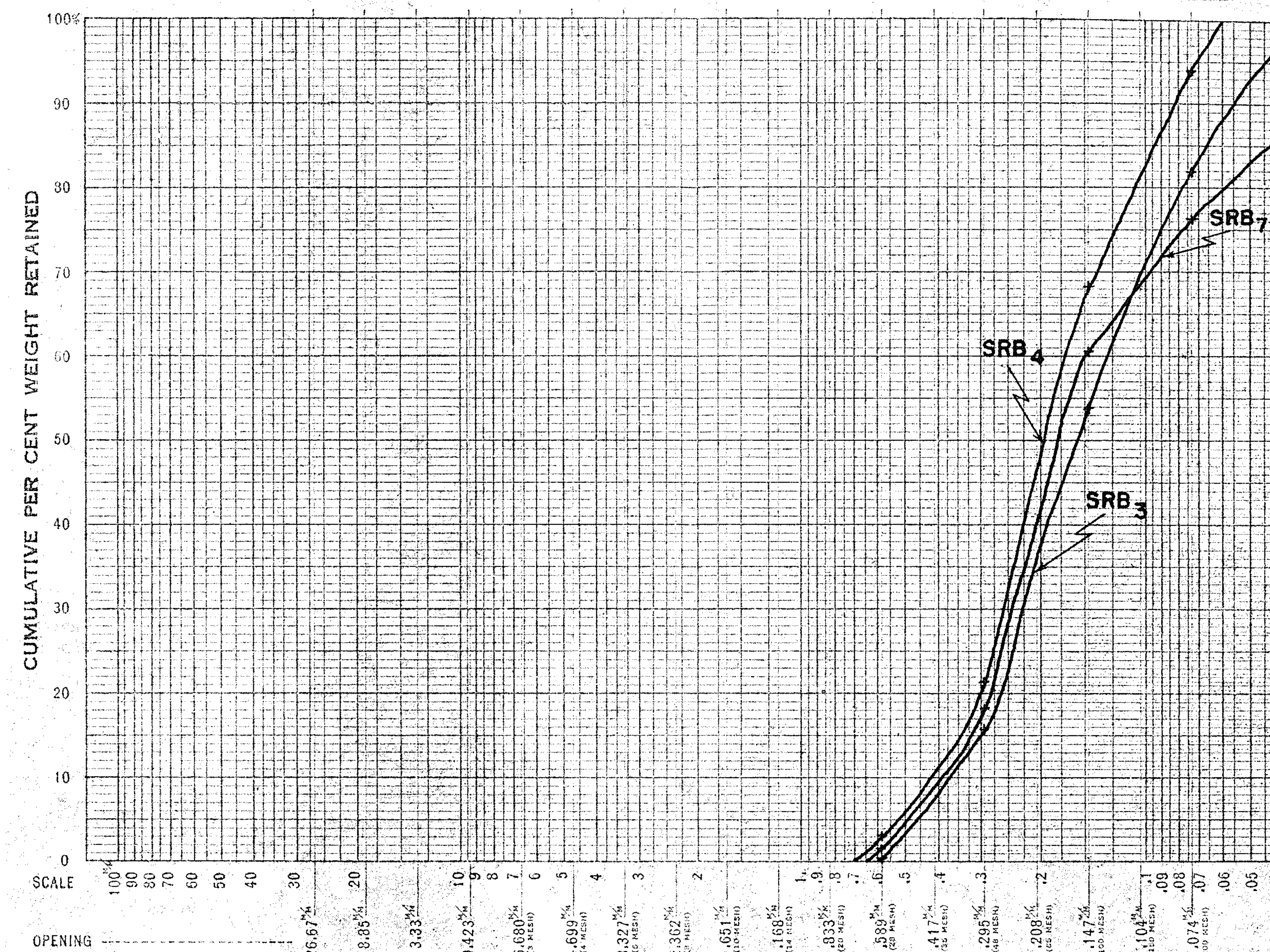
Cumulative Logarithmic Diagram of Screen Analysis on Sample of

Name Date



SCREEN SCALE RATIO 1.414				SRB$_3$			SRB$_4$			SRB$_7$		
Openings Milli-meters	Openings Inches	Tyler Mesh	U. S. No.	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights
26.67	1.050											
18.85	.742											
13.33	.525											
9.423	.371											
6.680	.263	3										
4.699	.185	4	4									
3.327	.131	6	6									
2.362	.093	8	8									
1.651	.065	10	12									
1.168	.046	14	16									
.833	.0328	20	20									
.589	.0232	28	30	0.24	0.6	0.6	1.29	3.2	3.2	0.66	1.5	1.5
.417	.0164	35	40									
.295	.0116	48	50	6.08	15.2	15.8	7.26	18.3	21.5	7.13	16.7	18.2
.208	.0082	65	70									
.147	.0058	100	100	15.21	38.1	53.9	18.95	46.8	68.3	18.08	42.4	60.6
.104	.0041	150	140									
.074	.0029	200	200	11.21	28.1	82.0	10.10	25.5	93.8	6.71	15.8	76.4
Pass .074	.0029	200	200	7.18	18.0	100.0	2.47	6.2	100.0	10.05	23.6	100.0
			Totals.	39.92	100.0		40.07	100.0		42.63	100.0	

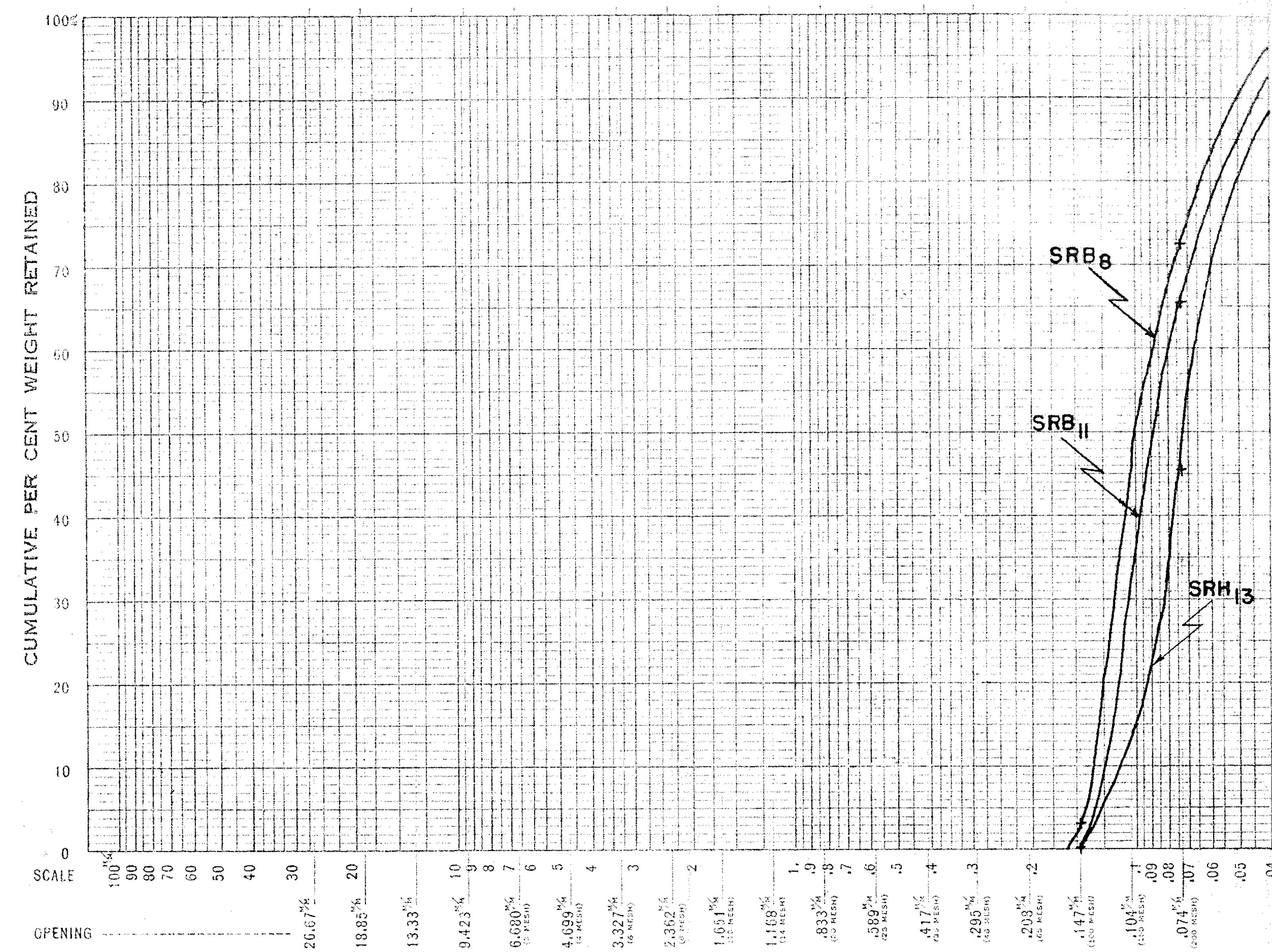
Fig. 5

The Tyler Standard Screen Scale

Form No. 1-5 Please mention above when ordering

Cumulative Logarithmic Diagram of Screen Analysis on Sample of

Name Date



	SCREEN SCALE RATIO 1.414				SRB8			SRB11			SRH13		
	Openings: Millimeters	Openings: Inches	Tyler Mesh	U. S. No.	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights
	26.67	1.050											
	18.85	.742											
	13.33	.525											
	9.423	.371											
	6.680	.263	3										
	4.699	.185	4	4									
	3.327	.131	6	6									
	2.362	.093	8	8									
	1.651	.065	10	12									
	1.168	.046	14	16									
	.833	.0328	20	20									
	.589	.0232	28	30									
	.417	.0164	35	40									
	.295	.0116	48	50							0.03	0.1	0.1
	.208	.0082	65	70									
	.147	.0058	100	100	1.25	3.2	3.2	0.13	0.3	0.3	0.07	0.2	0.3
	.104	.0041	150	140									
	.074	.0029	200	200	27.09	69.4	72.6	24.99	65.2	65.5	18.30	45.3	45.6
Pass	.074	.0029	200	200	10.68	27.4	100.0	13.22	34.5	100.0	21.98	54.4	100.0
				Totals,	39.02	100.0		38.34	100.0		40.38	100.0	

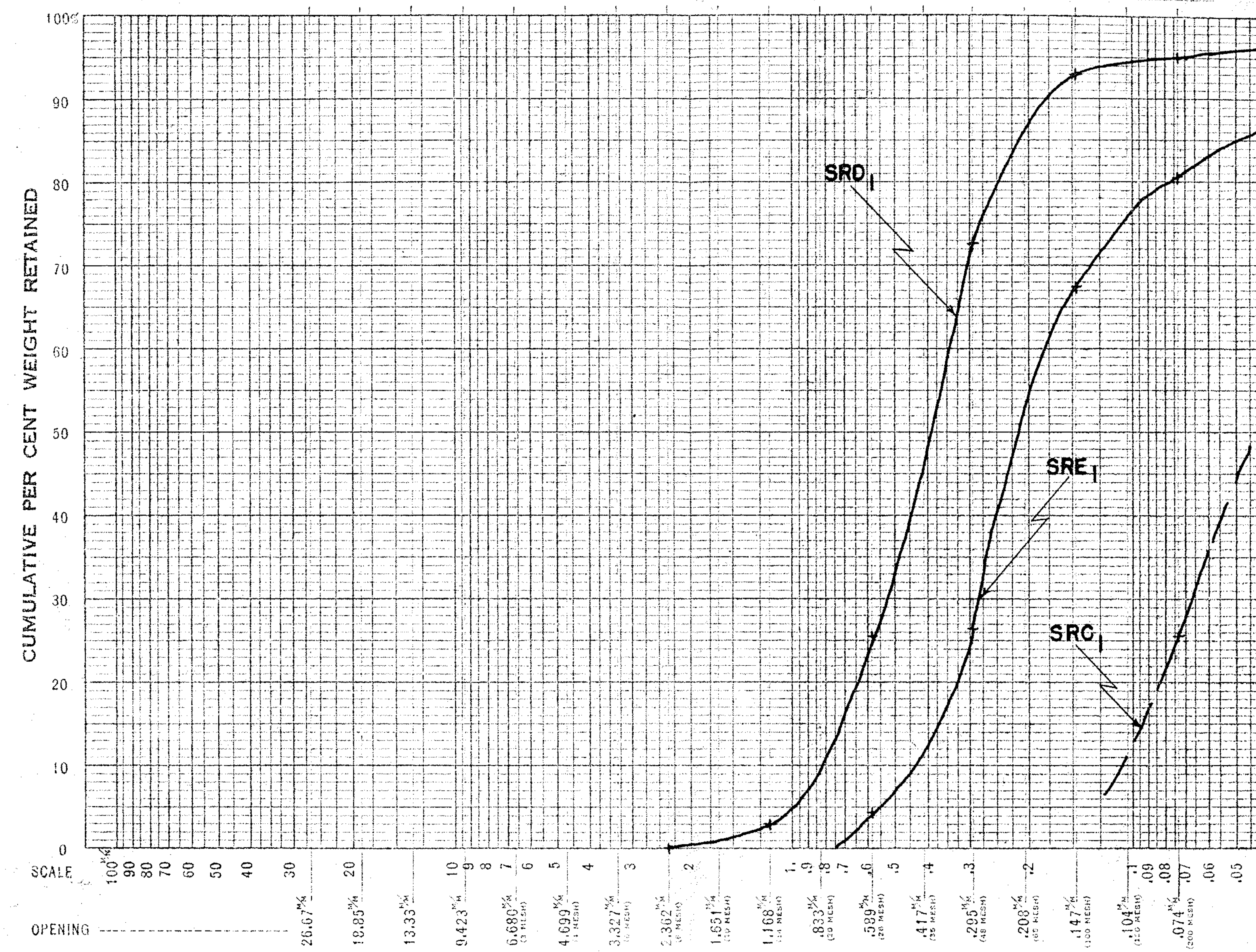
Fig. 6

The Tyler Standard Screen Scale

Form No. L-6
Please mention above when ordering

Cumulative Logarithmic Diagram of Screen Analysis on Sample of

Name Date



	SCREEN SCALE RATIO 1.414				SRC1			SRD1			SRE1		
	Openings: Milli-meters	Openings: Inches	Tyler Mesh	U. S. No.	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights
	26.67	1.050											
	18.85	.742											
	13.33	.525											
	9.423	.371											
	6.680	.263	3										
	4.699	.185	4	4									
	3.327	.131	6	6									
	2.362	.093	8	8				0.06	0.1	0.1			
	1.651	.065	10	12				1.11	2.8	2.9			
	1.168	.046	14	16									
	.833	.0328	20	20				8.74	22.4	25.3	1.67	4.2	4.2
	.589	.0232	28	30									
	.417	.0164	35	40				18.56	47.4	72.7	8.78	22.4	26.6
	.295	.0116	48	50									
	.208	.0082	65	70				7.87	20.2	92.9	16.03	40.8	67.4
	.147	.0058	100	100									
	.104	.0041	150	140									
	.074	.0029	200	200	10.63	25.5	25.5	0.86	2.2	95.1	5.07	13.0	80.4
Pass	.074	.0029	200	200	31.01	74.5	100.0	1.90	4.9	100.0	7.71	19.6	100.0
				Totals.	41.64	100.0		39.10	100.0		39.26	100.0	

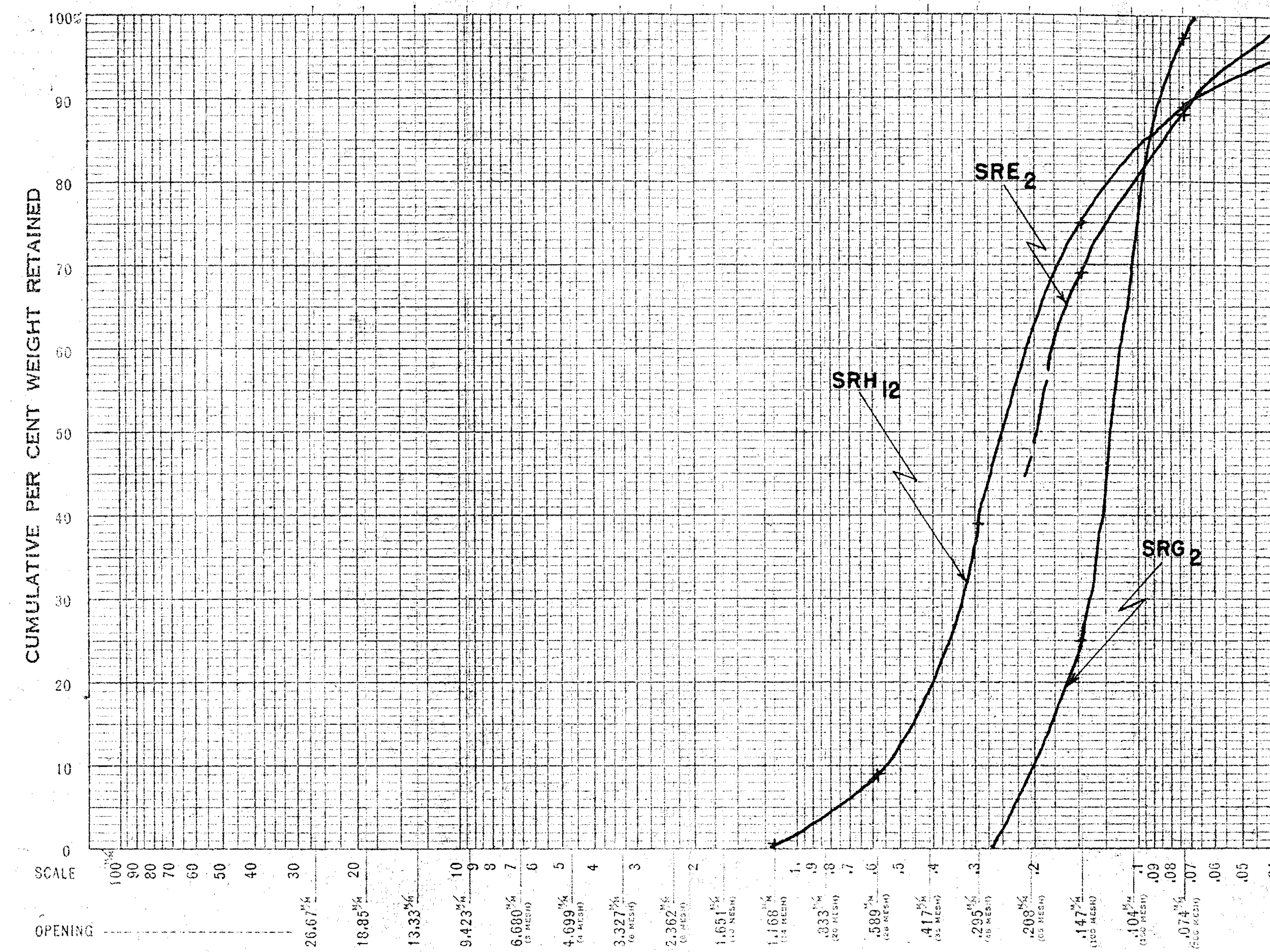
Fig. 7

The Tyler Standard Screen Scale

Form No. L-6
Please mention above when ordering

Cumulative Logarithmic Diagram of Screen Analysis on Sample of

Name Date



SCREEN SCALE RATIO 1.414				SRE2			SRG2			SRH12		
Openings: Milli-meters	Openings: Inches	Tyler Mesh	U. S. No.	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights
26.67	1.050											
18.85	.742											
13.33	.525											
9.423	.371											
6.680	.263	3										
4.699	.185	4	4									
3.327	.131	6	6									
2.362	.093	8	8									
1.651	.065	10	12									
1.168	.046	14	16							0.26	0.7	0.7
.833	.0328	20	20									
.589	.0232	28	30							3.26	8.4	9.1
.417	.0164	35	40									
.295	.0116	48	50							11.92	30.0	39.1
.208	.0082	65	70									
.147	.0058	100	100	27.85	69.0	69.0	10.03	25.0	25.0	14.28	36.0	75.1
.104	.0041	150	140									
.074	.0029	200	200	7.77	19.3	88.3	29.12	72.5	97.5	5.52	14.0	89.1
Pass .074	.0029	200	200	4.76	11.7	100.0	1.01	2.5	100.0	4.28	10.9	100.0
			Totals,	40.38	100.0		40.16	100.0		39.52	100.0	

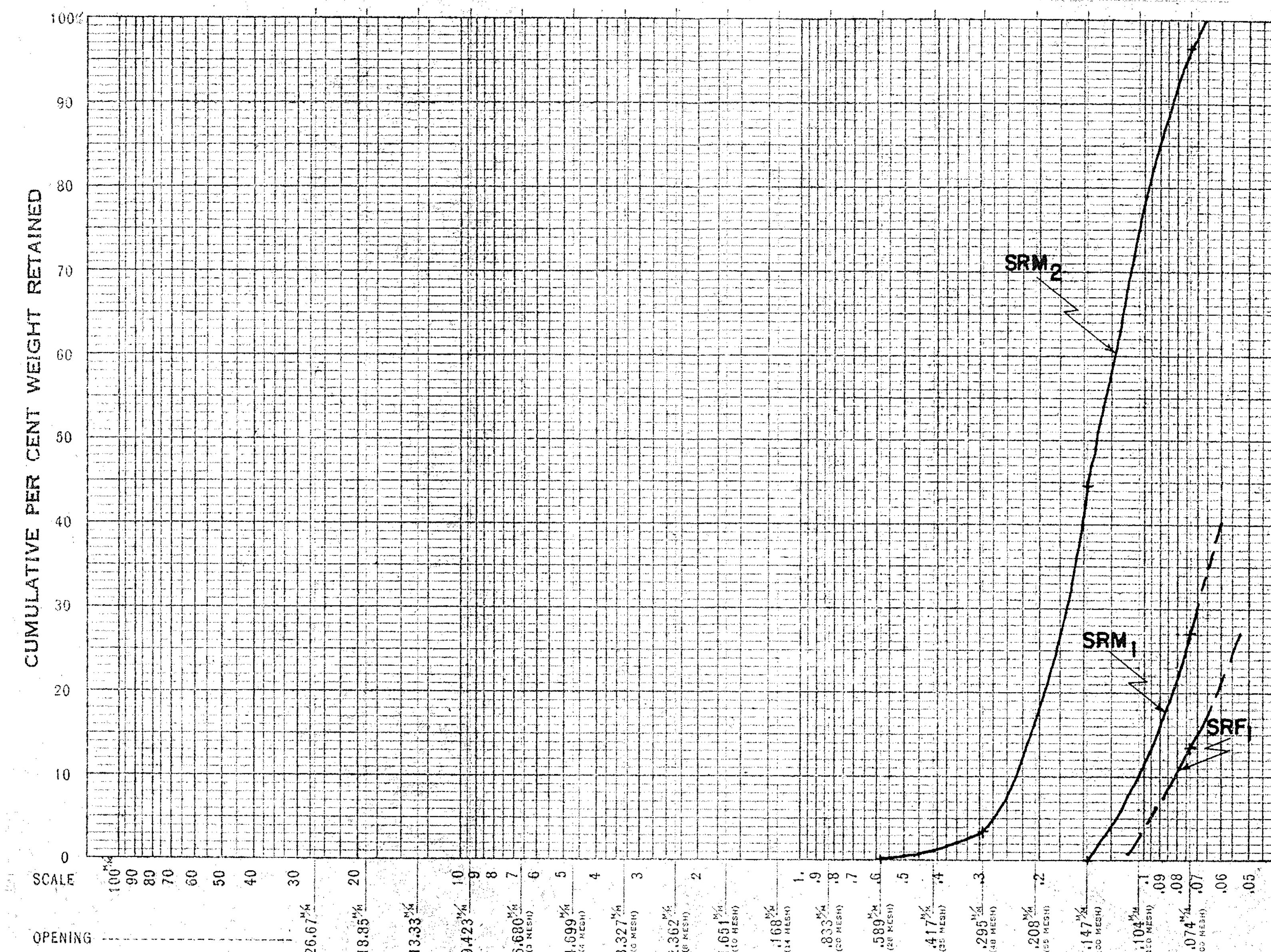
Fig. 8

The Tyler Standard Screen Scale

Form No. L-6 Please mention above when ordering

Cumulative Logarithmic Diagram of Screen Analysis on Sample of ____________

Name ____________ Date ____________



	SCREEN SCALE RATIO 1.414				SRF1			SRM1			SRM2		
	Openings: Milli-meters	Openings: Inches	Tyler Mesh	U. S. No.	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights
	26.67	1.050											
	18.85	.742											
	13.33	.525											
	9.423	.371											
	6.680	.263	3										
	4.699	.185	4	4									
	3.327	.131	6	6									
	2.362	.093	8	8									
	1.651	.065	10	12									
	1.168	.046	14	16									
	.833	.0328	20	20									
	.589	.0232	28	30							0.08	0.2	0.2
	.417	.0164	35	40									
	.295	.0116	48	50							1.28	3.3	3.5
	.208	.0082	65	70									
	.147	.0058	100	100				0.04	0.1	0.1	17.50	41.3	44.8
	.104	.0041	150	140									
	.074	.0029	200	200	5.57	13.4	13.4	11.13	27.1	27.2	21.96	52.0	96.8
Pass	.074	.0029	200	200	35.98	86.6	100.0	29.94	72.8	100.0	1.35	3.2	100.0
				Totals.	41.55	100.0		41.11	100.0		42.17	100.0	

THE W. S. TYLER COMPANY, CLEVELAND 14, OHIO, U. S. A. 6-50

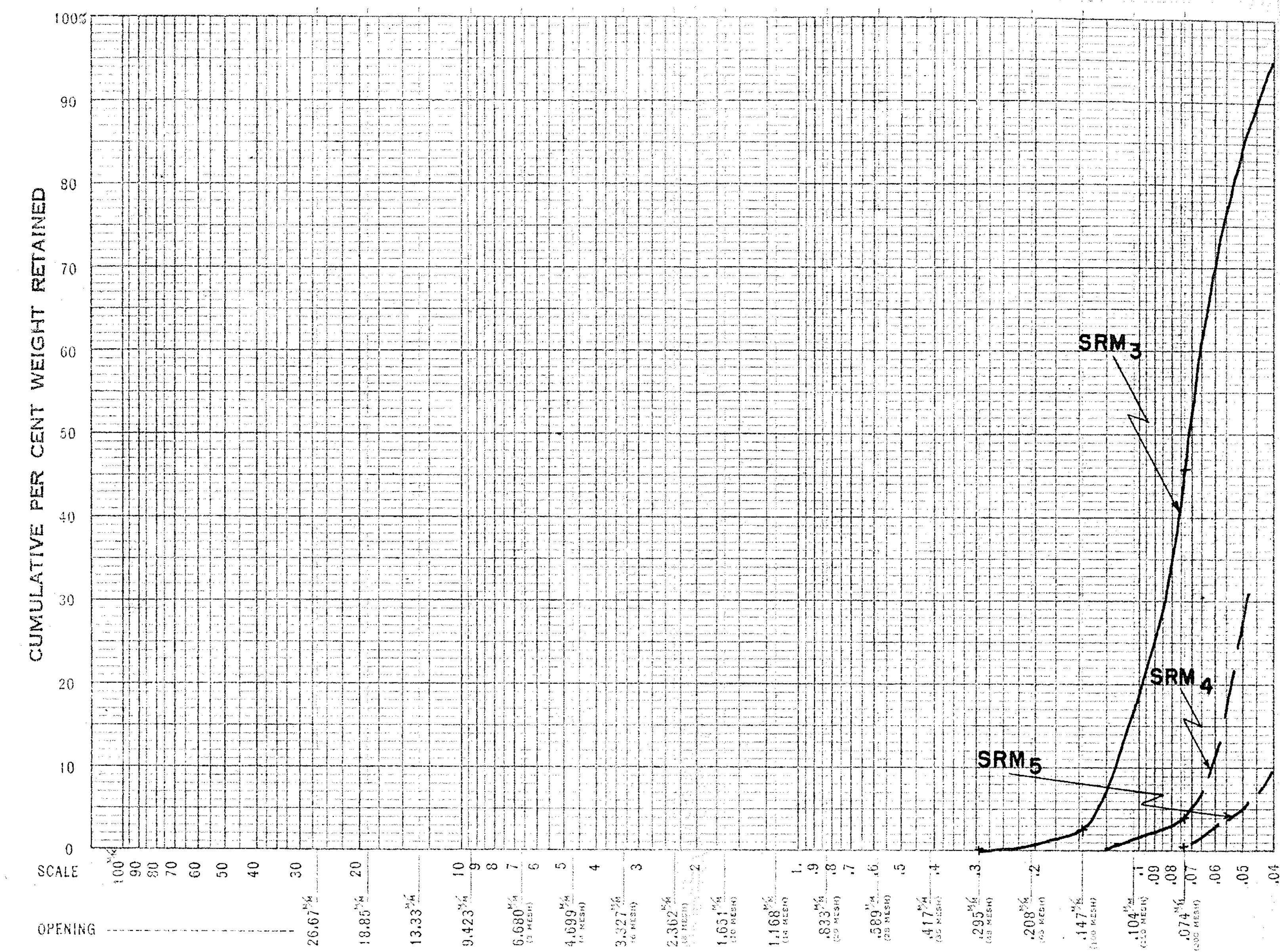
Fig. 9

The Tyler Standard Screen Scale

Form No. L-8
Please mention above when ordering

Cumulative Logarithmic Diagram of Screen Analysis on Sample of

Name — Date



	SCREEN SCALE RATIO 1.414				SRM$_3$			SRM$_4$			SRM$_5$		
	Openings: Milli-meters	Openings: Inches	Tyler Mesh	U. S. No.	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights
	26.67	1.050											
	18.85	.742											
	13.33	.525											
	9.423	.371											
	6.680	.263	3										
	4.699	.185	4	4									
	3.327	.131	6	6									
	2.362	.093	8	8									
	1.651	.065	10	12									
	1.168	.046	14	16									
	.833	.0328	20	20									
	.589	.0232	28	30									
	.417	.0164	35	40									
	.295	.0116	48	50	0.09	0.2	0.2						
	.208	.0082	65	70									
	.147	.0058	100	100	0.97	2.4	2.6	0.02	0.1	0.1			
	.104	.0041	150	140									
	.074	.0029	200	200	17.26	43.2	45.8	1.60	3.9	4.0	0.23	0.6	0.6
Pass	.074	.0029	200	200	21.62	54.2	100.0	39.25	96.0	100.0	40.56	99.4	100.0
				Totals.	39.94	100.0		40.87	100.0		40.79	100.0	

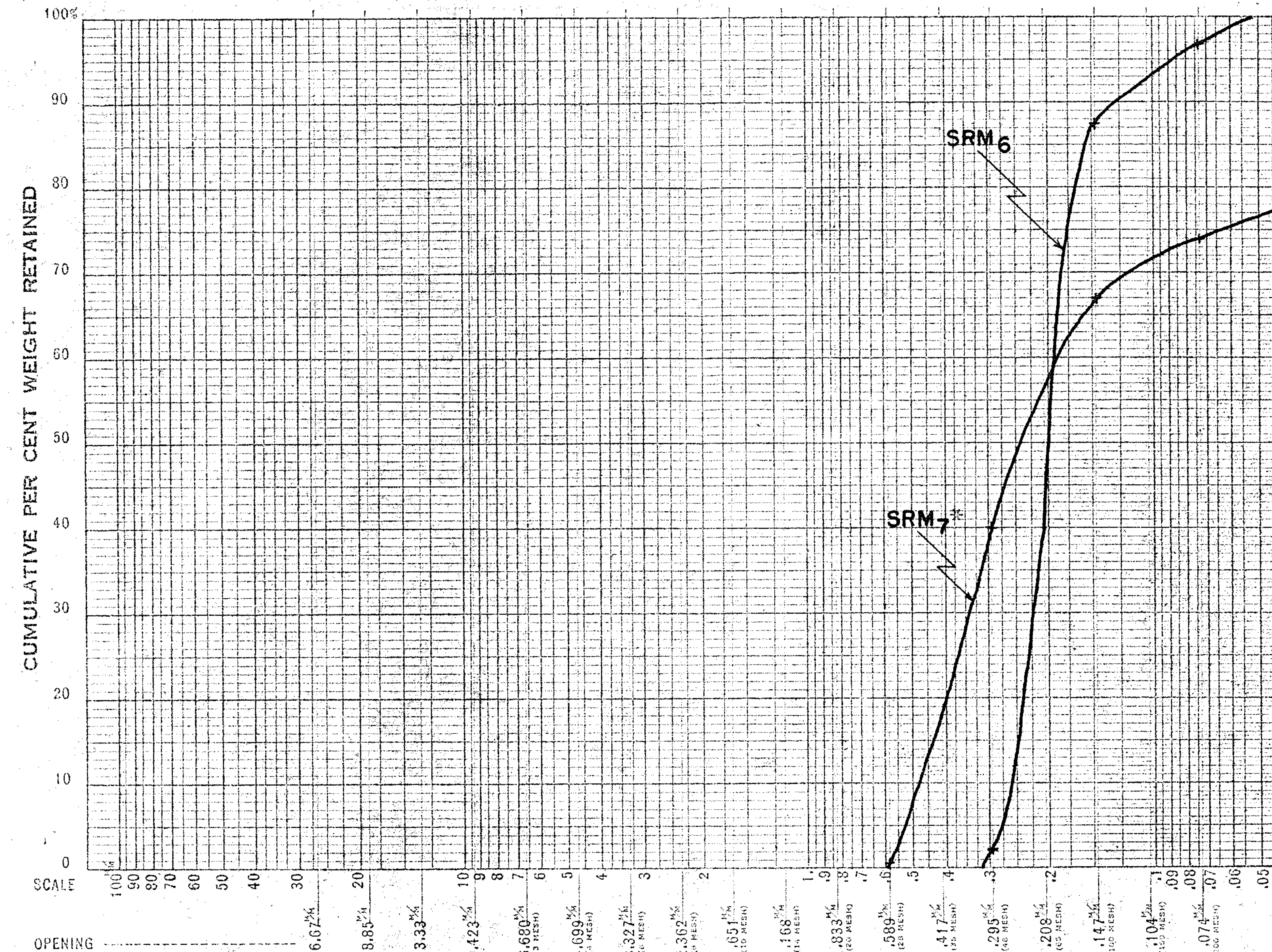
Form No. L-6
Please mention above when ordering

The Tyler Standard Screen Scale

Cumulative Logarithmic Diagram of Screen Analysis on Sample of

Name   Date

Fig. 10



	SCREEN SCALE RATIO 1.414				SRM6			SRM7*					
	Openings		Tyler Mesh	U. S. No.	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights	Sample Weights	Per Cent	Per Cent Cumulative Weights
	Millimeters	Inches											
	26.67	1.050											
	18.85	.742											
	13.33	.525											
	9.423	.371											
	6.680	.263	3										
	4.699	.185	4	4									
	3.327	.131	6	6									
	2.362	.093	8	8									
	1.651	.065	10	12									
	1.168	.046	14	16									
	.833	.0328	20	20									
	.589	.0232	28	30				0.26	0.6	0.6			
	.417	.0164	35	40									
	.295	.0116	48	50	0.92	2.1	2.1	17.45	39.4	40.0			
	.208	.0082	65	70									
	.147	.0058	100	100	36.91	85.3	87.4	11.90	26.9	66.9			
	.104	.0041	150	140									
	.074	.0029	200	200	4.05	9.4	96.8	3.08	7.0	73.9			
Pass	.074	.0029	200	200	1.39	3.2	100.0	11.55	26.1	100.0			
				Totals.	43.27	100.0		43.24	100.0				

* Sample of Jurassic sand.

TABLE 6 DISTRIBUTION OF GRAIN SIZES

			INSOL.		SOLUBLE		14 SIZE		28 SIZE		48 SIZE		100 SIZE		200 SIZE		PAN		LIGHTS		HEAVIES		
	SAMPLE	WT.	WT.	%	WT.	%	WT.	%	WT.	%	WT.	%	WT.	%	WT.	%	WT.	%	WT.	%	WT.	%	SPH
NORTHERN	VKA 1	40.57	31.2	62	19.4	38			neg.	neg.	0.07	0.2	23.63	58.2	15.70	38.7	1.17	2.9	7.85	99.7	0.02	0.3	.80
	VKA 2	40.28	27.3	62	16.8	38			neg.	neg.	0.05	0.1	19.48	48.4	20.31	50.4	0.44	1.1	8.24	99.3	0.05	0.7	.85
	VKB 1	41.48	24.1	65	13.4	35					neg.	neg.	4.35	10.5	29.04	70.0	8.09	19.5	7.63	99.7	0.03	0.3	.75
	VKC 1	42.19	27.6	63	16.2	37	0.10	0.2	2.07	4.9	8.55	20.9	5.93	14.0	21.96	51.6	3.58	8.4	7.47	99.7	0.02	0.3	.80
	VKD 1	40.11	22.3	60	15.1	40					0.04	0.1	1.46	3.6	23.63	58.9	14.98	37.4	8.16	98.4	0.13	1.6	.80
	VKD 2	40.58	27.6	65	15.0	35			neg.	neg.	0.05	0.1	21.56	53.2	17.71	43.6	1.26	3.1	6.75	99.7	0.02	0.3	.80
CENTRAL	SRB 3	39.92	24.0	60	15.9	40			0.24	0.6	6.08	15.2	15.21	38.1	11.21	28.1	7.18	18.0	6.87	98.7	0.09	1.3	.90
	SRB 4	40.07	40.1	100	0.0	0			1.29	3.2	7.26	18.3	18.95	46.8	10.10	25.5	2.47	6.2	6.96	99.0	0.07	1.0	.85
	SRB 7	42.63	42.6	100	0.0	0			0.66	1.5	7.13	16.7	18.08	42.4	6.71	15.8	10.05	23.6	6.52	98.4	0.07	1.6	.85
	SRB 8	39.02	47.0	100	0.0	0							1.25	3.2	27.09	69.4	10.68	27.4	7.03	99.7	0.02	0.3	.85
	SRB 11	38.34	38.3	100	0.0	0					neg.	neg.	0.13	0.3	24.99	65.2	13.22	34.5	6.98	99.8	0.01	0.2	.85
	SRC 1	41.64	32.0	100	0.0	0									10.63	25.5	31.01	74.5	6.98	99.7	0.02	0.3	.85
	SRF 1	41.55	32.1	100	0.0	0									5.57	13.4	35.98	86.6	8.41	99.7	0.02	0.3	.80
	SRM 1	41.11	41.1	100	0.0	0							0.04	0.1	11.13	27.1	29.94	72.8	6.95	99.9	0.01	0.1	.85
	SRM 2	42.17	42.2	100	0.0	0	neg.	neg.	0.08	0.2	1.28	3.3	17.50	41.3	21.96	52.0	1.35	3.2	7.11	99.7	0.02	0.3	.85
	SRM 3	39.94	39.9	100	0.0	0					0.09	0.2	0.97	2.4	17.26	43.2	21.62	54.2	7.05	99.6	0.03	0.4	.85
	SRM 4	40.87	40.9	100	0.0	0					neg.	neg.	0.02	0.1	1.60	3.9	39.25	96.0	7.07	98.1	0.14	1.9	.85
	SRM 5	40.79	40.8	100	0.2	0							neg.	neg.	0.23	0.6	40.56	99.4	7.04	99.0	0.06	1.0	.80
	SRM 6	43.27	43.3	100	0.0	0					0.92	2.1	36.91	85.3	4.05	9.4	1.39	3.2	8.00	98.0	0.16	2.0	.85
SOUTHERN	SRD 1	39.10	30.1	62	17.1	38	1.17	2.9	8.74	22.4	18.56	47.4	7.87	20.2	0.86	2.2	1.90	4.9	6.96	98.4	0.12	1.6	.80
	SRE 1	39.26	39.3	100	0.0	0			1.67	4.2	8.78	22.4	16.03	40.8	5.07	13.0	7.71	19.6	4.99	98.4	0.08	1.6	.80
	SRE 2	40.38	36.7	100	0.0	0					neg.	neg.	27.85	69.0	7.77	19.3	4.76	11.7	6.97	99.0	0.07	1.0	.85
	SRG 2	40.16	33.5	100	0.0	0					neg.	neg.	10.03	25.0	29.12	72.5	1.01	2.5	7.25	99.6	0.04	0.6	.75
	SRH 12	39.52	39.5	100	0.0	0	0.26	0.7	3.26	8.4	11.92	30.0	14.28	36.0	5.52	14.0	4.28	10.9	5.43	98.7	0.07	1.3	.85

TABLE 7 SIGNIFICANT VALUES AND QUARTILE MEASURES

	SAMPLE	Md	Q1	Q3	P10	P90	So	Sk	K
NORTHERN	VKA 1	0.163	0.120	0.200	0.245	0.085	1.3	0.89	0.25
	VKA 2	0.145	0.115	0.190	0.235	0.085	1.3	1.05	0.25
	VKB 1	0.105	0.075	0.125	0.147	0.060	1.3	0.85	0.29
	VKC 1	0.125	0.090	0.300	0.460	0.075	1.8	1.07	0.27
	VKD 1	0.083	0.070	0.105	0.120	0.056	1.2	1.07	0.27
	VKD 2	0.150	0.113	0.190	0.235	0.088	1.3	0.96	0.27
CENTRAL	SRB 3	0.163	0.087	0.247	0.370	0.055	1.7	0.81	0.25
	SRB 4	0.190	0.122	0.280	0.420	0.082	1.5	0.95	0.23
	SRB 7	0.175	0.080	0.267	0.390	-	1.8	0.70	-
	SRB 8	0.096	0.072	0.120	0.135	0.050	1.3	0.94	0.28
	SRB 11	0.087	0.062	0.110	0.125	0.044	1.3	0.90	0.30
	SRC 1	-	0.075	-	-	-	-	-	-
	SRF 1	-	-	-	-	-	-	-	-
	SRM 1	-	-	-	-	-	-	-	-
	SRM 2	0.140	0.100	0.187	0.235	0.083	1.4	0.95	0.25
	SRM 3	0.073	0.055	0.090	0.115	0.045	1.3	0.93	0.25
	SRM 4	-	-	-	-	-	-	-	-
	SRM 5	-	-	-	-	-	-	-	-
	SRM 6	0.215	0.175	0.237	0.260	0.130	1.2	0.90	0.24
SOUTHERN	SRD 1	0.390	0.280	0.590	0.820	0.175	1.5	1.09	0.24
	SRE 1	0.215	0.110	0.300	0.430	-	1.7	0.71	-
	SRE 2	-	0.125	-	-	-	-	-	-
	SRG 2	0.120	0.100	0.147	0.200	0.085	1.2	1.02	0.20
	SRH 12	0.250	0.147	0.360	0.550	0.068	1.6	0.86	0.22

LEGEND

Md = median
Q1 = first quartile
Q3 = third quartile
P10 = 10 percentile
P90 = 90 percentile
So = coefficient of sorting
Sk = skewness
K = kurtosis

very nearly approaches perfect symmetry. However, this curve would have a slightly negative skewness indicating that fine admixtures slightly exceed coarse admixtures in the average sample.

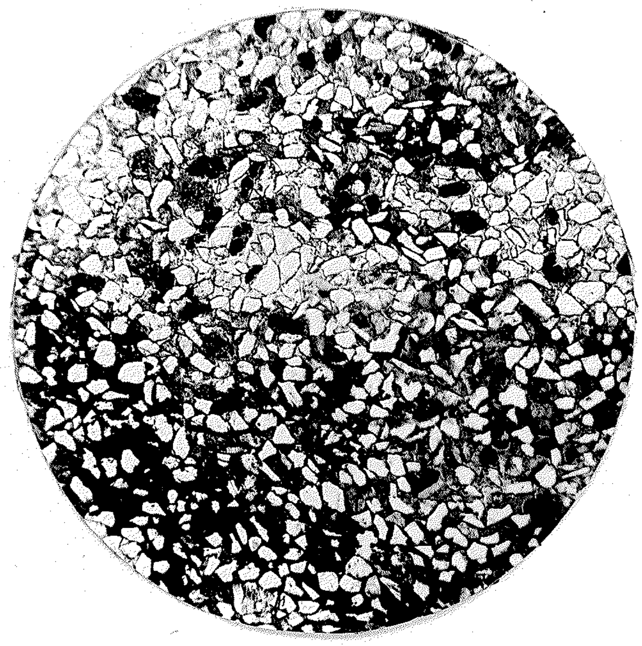
The histograms reflect the same relationship between fine and coarse admixtures as do the cumulative curves, but, because of their non-continuous variation in size, not always as sensitively.

For example, the histogram of sample VKB 1 (Plate V11, p.41) suggests skewness towards the fine sizes. Using the cumulative curve for the same sample, the $\log_{10}$ of the skewness is negative and therefore fine admixtures exceed coarse. Thus, these two determinations agree.

The kurtosis of "peakedness" of the average cumulative curve is 0.27 (Table 7, p.52). None of the curves representing samples of Swan River sands from the northern area depart very much from this value. The individual values (Table 7) derived from the cumulative curves, Figs. 2 and 3) have a direct relationship to the shape of the corresponding histograms.

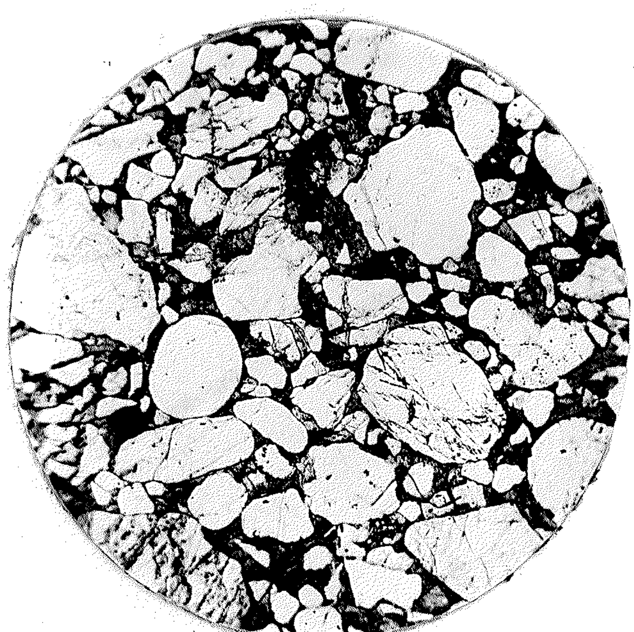
Central Area

Samples of Swan River sands from the central area exhibit some variety in grain size. Samples SRB 3, SRB 4, and SRB 7 from the Imperial Birtle No. 1 well are classified as fine grained sands whereas samples SRB 8 and SRB 11 from the same well are classified as very fine grained sands (Pettijohn, 1948, p.16). An average grain size value for sands from Imperial Madeline No. 1 is 0.142 mms. in diameter (Table 7) which would, according to Wentworth's grade scale (Pettijohn 1948, p.17)



x 20

A. Thin section of Swan River sandstone from outcrop along the Roaring River, showing the fine grained, well sorted, and angular nature of this calcareous sandstone.



x 20

B. Thin section of South Swan River sandstone from Souris Valley Downey No. 1, showing the medium to coarse grained, poorly sorted, and well rounded to subangular nature of this sandstone.

fall into the "fine grained sand" class.

As seen in histograms (Plate Vll) and cumulative curves (Figs. 8, 9 and 10) sands from this area are fairly well sorted. Histograms representing samples SRF 1, SRM 1, and SRM 5 for which median values from cumulative curves could not be obtained, exhibit very good sorting.

Samples SRM 2, SRM 3, and SRM 6 (Table 7) have negative skewness values (using $\log_{10}$SK rather than SK itself) indicating that fine admixtures exceed coarse in these samples.

Swan River samples from this area whose cumulative curves are extensive enough to give significant values, have kurtosis values ranging from 23 to 30. Their corresponding histograms exhibit somewhat the same consistency in their configurations.

Southern Area

The average grain size of Swan River sands of the southern area would appear, from histograms of sands from that area, to fall in the group .147 to .295 mm. in diameter. The average median determined from cumulative curves is .252 which, according to Wentworth's scale, would classify the sands as medium grained. (See Plate V111 B, p.54).

Sands of the southern area are represented by histograms (Plate Vll, p.41) indicative of poorly sorted sediments. This is also indicated by the relatively high average coefficient of sorting of 1.5 as determined from cumulative curve data (Table 7, p.52).

Skewness values (Table 7) of cumulative curves representing sands from this area (Figs. 6 and 7), vary considerably. Both positive and negative values are present. Histograms exhibit the same relationships between coarse and fine admixtures as do the corresponding cumulative curves.

Kurtosis values derived from cumulative curve data shown in Table 7, bear the same relationships to each other as do the "peakedness" characteristics of the corresponding histograms.

Discussion

In this study cumulative curves were drawn as well as histograms as it appears that the former are more suitable for continuous distributions because they emphasize the continuous variation in size, whereas a histogram implies a discrete series in the sharp break between the classes. Also, the proportion of material in any size range may be determined from the frequency curve, whereas, in histograms, the area relations are confined to the particular class interval chosen.

Krumbein (1938, pp.84-90) believes that cumulative curves are more reliable for interpreting the nature of sediments than are histograms.

Conclusions

There is a gradation in grain size of North Swan River sands from very fine sands in the northern area to silts in the central area. This gradation could be the result of greater time and distance of transport and amount of re-working of sands of the same source in the central area as compared to the northern area.

South Swan River sands are essentially medium grained in size. Thus, there is no northern to central to southern areal gradiation. Therefore, the South Swan River sands do not appear to have been derived from the North Swan River sands nor to have been transported from the same direction as those sands.

North Swan River sands are well sorted, whereas South Swan River sands are not. This might be indicative of a shorter time and distance of transport and less reworking of South Swan River sands as compared to North Swan River sands.

ROUNDNESS

Visual roundness values for all sieved fractions of Swan River samples are shown in Table 8 (p.58). A detailed description of the degree of roundness of quartz grains in samples from Swan River sands of the northern, central and southern areas is given below.

Areal Characteristics

Northern Area

In samples of Swan River sand from the northern area, the greatest number of grains of sizes large enough to be effected by rounding factors are dominantly angular. (Table 8, p.58).

Grains larger than .295 mm. are moderately rounded. However, in some samples, the number of grains of this size is negligible.

Central Area

Roundness values of Swan River sands of the central area as recorded in Table 8 indicate that most of the quartz grains which are

TABLE 8 ROUNDNESS, FROSTING, AND PITTING VALUES

	SAMPLE	SIZE	ROUNDNESS			FROSTING			PITTING		
			.1-.3	.4-.6	.7-.9	INT	MOD	CLR	INT	MOD	SL
NORTHERN	VKA 1	28	pres	dom	pres	pres	dom	pres	pres	dom	pres
		48	rare	dom	rare	pres	dom	com	rare	dom	pres
		100	dom	com	pres	pres	dom	abun	rare	abun	dom
		200	dom	abs	rare	abun	abun	abun	rare	com	dom
		Pan	com	dom	pres	dom	pres	abun	rare	com	dom
	VKA 2	28	abs	dom	abs	abs	abs	abs	dom	abs	abs
		48	pres	dom	pres	com	rare	dom	abun	abun	com
		100	dom	rare	rare	com	com	dom	dom	abun	com
		200	dom	pres	rare	pres	com	dom	dom	abun	pres
		Pan	dom	pres	rare	pres	com	dom	dom	abun	pres
	VKB 1	100	dom	pres	rare	pres	com	dom	dom	abun	pres
		200	dom	pres	rare	pres	com	dom	dom	pres	pres
		Pan	dom	pres	rare	abun	com	abun	abun	com	abun
	VKC 1	14	abs	dom	com	abs	abs	dom	dom	com	rare
		28	abs	dom	com	abs	abs	dom	dom	com	rare
		48	pres	dom	com	rare	com	dom	dom	abun	rare
		100	dom	pres	rare	pres	pres	dom	dom	pres	rare
		200	abun	dom	pres	abun	com	dom	dom	com	pres
		Pan	com	dom	pres	abun	com	dom	dom	com	com
	VKD 1	48	pres	dom	com	pres	dom	com	abun	dom	com
		100	pres	dom	pres	dom	com	dom	dom	pres	pres
		200	pres	dom	pres	com	com	dom	dom	pres	pres
		Pan	dom	pres	pres	com	com	dom	pres	pres	dom
	VKD 2	48	abun	dom	com	pres	com	dom	dom	com	pres
		100	dom	pres	rare	pres	com	dom	dom	com	pres
		200	dom	pres	rare	com	pres	dom	dom	com	pres
		Pan	dom	com	rare	pres	abun	abun	com	dom	pres
CENTRAL	SRB 3	28	pres	dom	abun	abs	dom	abs	abun	dom	abs
		48	abun	dom	com	com	dom	rare	com	dom	pres
		100	com	dom	abun	abun	dom	pres	com	dom	pres
		200	com	dom	com	abun	dom	com	com	dom	pres
		Pan	com	dom	com	abun	dom	com	rare	rare	dom
	SRB 4	28	pres	dom	pres	pres	dom	pres	dom	com	pres
		48	rare	dom	pres	pres	dom	rare	pres	dom	pres
		100	abun	abun	com	pres	dom	rare	dom	com	pres
		200	abun	dom	pres	pres	dom	rare	pres	dom	com
		Pan	dom	com	rare	pres	dom	rare	pres	pres	dom
	SRB 7	28	pres	dom	pres	pres	dom	rare	dom	com	rare
		48	pres	dom	pres	pres	dom	rare	dom	com	rare
		100	abun	dom	pres	com	dom	pres	dom	com	pres
		200	abun	dom	com	pres	dom	abun	dom	com	pres
		Pan	dom	com	rare	abun	abun	com	pres	com	dom
	SRB 8	100	dom	abs	abs	abs	dom	abs	abs	dom	abs
		200	dom	pres	rare	pres	dom	abun	rare	com	dom
		Pan	dom	com	rare	pres	abun	abun	rare	rare	dom

TABLE 8 (CONT.)

	SAMPLE	SIZE	ROUNDNESS .1-.3	ROUNDNESS .4-.6	ROUNDNESS .7-.9	FROSTING INT	FROSTING MOD	FROSTING CLR	PITTING INT	PITTING MOD	PITTING SL
CENTRAL	SRB 11	48	dom	pres	pres	pres	dom	abun	dom	rare	pres
		100	pres	dom	pres	com	dom	pres	dom	rare	pres
		200	dom	pres	rare	pres	abun	abun	dom	rare	pres
		Pan	dom	pres	rare	pres	abun	abun	pres	com	dom
	SRC 1	100	dom	abs	abs	abs	rare	dom	dom	pres	rare
		200	dom	pres	abs	rare	pres	dom	abs	pres	dom
		Pan	dom	rare	abs	abs	pres	dom	abs	rare	dom
	SRF 1	200	dom	pres	rare	dom	com	abun	com	dom	pres
		Pan	dom	com	rare	abun	com	abun	com	dom	pres
	SRM 1	100	dom	pres	rare	dom	com	pres	dom	com	pres
		200	dom	pres	rare	dom	com	com	dom	com	com
		Pan	dom	rare	tr	dom	pres	abun	rare	rare	com
	SRM 2	28	pres	dom	pres	pres	dom	abun	dom	pres	rare
		48	com	dom	pres	pres	abun	dom	dom	pres	rare
		100	dom	pres	rare	pres	abun	abun	dom	rare	rare
		200	dom	pres	rare	com	abun	abun	dom	rare	rare
		Pan	dom	rare	rare	com	abun	abun	rare	rare	dom
	SRM 3	48	pres	dom	pres	com	dom	abun	dom	pres	rare
		100	com	dom	rare	com	abun	abun	dom	pres	rare
		200	dom	pres	tr	com	abun	abun	dom	pres	rare
		Pan	dom	rare	tr	com	abun	abun	rare	rare	dom
	SRM 4	100	dom	pres	rare	pres	dom	pres	dom	rare	tr
		200	dom	pres	rare	com	dom	com	dom	rare	tr
		Pan	dom	rare	tr	com	dom	abun	rare	rare	dom
	SRM 5	100	abs	dom	abs	abs	dom	abs	dom	abs	abs
		200	dom	pres	rare	dom	com	pres	dom	pres	rare
		Pan	dom	rare	tr	pres	abun	dom	tr	rare	dom
	SRM 6	48	pres	dom	com	pres	dom	abun	dom	com	pres
		100	com	dom	pres	abun	dom	com	dom	pres	pres
		200	abun	abun	pres	com	dom	com	dom	pres	pres
		Pan	dom	rare	tr	pres	dom	abun	tr	rare	dom
SOUTHERN	SRD 1	14	rare	dom	pres	pres	dom	rare	com	dom	pres
		28	pres	abun	dom	com	dom	pres	com	dom	pres
		48	pres	dom	abun	com	dom	rare	dom	com	com
		100	abun	dom	pres	com	dom	pres	dom	pres	pres
		200	dom	pres	rare	pres	com	dom	dom	pres	pres
		Pan	dom	pres	rare	pres	abun	abun	rare	rare	dom
	SRE 1	28	com	dom	abun	com	dom	rare	dom	abun	rare
		48	com	dom	abun	com	dom	rare	dom	abun	pres
		100	com	dom	abun	com	dom	pres	dom	pres	com
		200	com	dom	pres	com	dom	pres	com	pres	dom
		Pan	com	dom	pres	com	dom	pres	rare	rare	dom

TABLE 8 (CONT.)

	SAMPLE	SIZE	ROUNDNESS			FROSTING			PITTING		
			.1-.3	.4-.6	.7-.9	INT	MOD	CLR	INT	MOD	SL
SOUTHERN	SRE 2	100	rare	dom	pres	rare	pres	dom	rare	pres	dom
		200	abun	dom	rare	rare	pres	dom	abs	rare	dom
		Pan	dom	rare	abs	abs	pres	dom	abs	rare	dom
	SRG 2	48	pres	dom	abs	abs	dom	abs	abs	dom	abs
		100	dom	com	pres	com	dom	com	pres	dom	com
		200	dom	pres	pres	abun	abun	abun	pres	dom	com
		Pan	dom	pres	pres	com	dom	abun	rare	rare	dom
	SRH 12	14	pres	dom	pres	com	dom	rare	dom	pres	rare
		28	pres	dom	pres	com	dom	rare	dom	pres	rare
		48	com	dom	pres	com	dom	rare	dom	com	pres
		100	com	dom	pres	com	dom	rare	dom	com	pres
		200	dom	com	rare	rare	com	dom	dom	pres	rare
		Pan	dom	pres	rare	rare	com	dom	rare	rare	dom

LEGEND

dom = dominant = over 50%
abun = abundant = 25% to 50%
com = common = 10% to 25%
pres = present = 5% to 10%
rare = rare = 1% to 5%
tr = trace = less than 1%
int = intense
mod = moderate
clr = clear = polished
sl = slight

large enough to have been effected by factors tending to change their shape are moderately rounded. Angular or slightly rounded grains are more common than well rounded grains.

Southern Area

In samples of Swan River sands of the southern area, most quartz grains over .1 mm. in diameter are moderately rounded. Angular and well rounded grains appear to be about equally common.

Discussion

Although roundness values were determined for all sizes of quartz grains found in samples of Swan River sands during this study, it was realized that not all grain sizes would exhibit the same degree of roundness, that is, there is a definite relationship between grain size and degree of roundness.

Twenhofel (1950, p.306) states that it is his "considered opinion that rounding of sand grains, particularly of the dimension of 0.5 mm. or less, involves extremely long tractional transportation" and further that "few quartz particles below about 0.1 mm. are much rounded in aqueous transportations".

Thus, rounding will be most noticeable in the 100+ and larger sieve size fractions.

In this study it was found that sands smaller than 0.147 mm. in diameter were almost always angular, which would substantiate Twenhofel's theory. Rounding was most noticeable in the 100+ and larger sieve size fractions. Roundness values of grains smaller than this were not considered as accurate representatives of the sample as a whole.

In Swan River sands of the northern area the moderate roundness of grains larger than 0.295 mm. contrasts with the angularity of most of the remaining grains capable of being rounded. The angularity of most of the grains suggests that re-working after deposition was not the cause of the moderate roundness of the larger grains. A more accurate explanation may be that the larger grains were derived from pre-existing sands containing moderately rounded grains.

Conclusions

North Swan River sands of the central area are more rounded than sands of the northern area.

South Swan River sands are slightly more rounded than Swan River sands of the central area and considerably more rounded than those of the northern area.

As both angular and moderately rounded grains are present in appreciable amounts in Swan River sands of the northern area, it is possible that there were two main sources of the sands in that area. One source could have been a quartzitic body capable of providing angular quartz grains during erosion. The other could have been a pre-existing sedimentary mass composed, in part at least, of moderately rounded quartz grains.

FROSTING

Degrees of frosting were established visually for all sieved samples and are recorded in Table 8 (p.58). Degrees of frosting for the smaller grain sizes were difficult to determine.

Detailed descriptions concerning the degrees of frosting of sand grains in samples of Swan River sands from the northern, central, and southern areas are given below.

Areal Characteristics

Northern Area

Quartz grains making up Swan River sands in the northern area are dominantly clear or very slightly frosted. A much smaller number of grains are moderately frosted, and a few are intensely frosted.

Central Area

Quartz grains in Swan River sands of the central area are dominantly moderately frosted. Clear or very slightly frosted grains are generally abundant and intensely frosted grains are present.

Southern Area

The degree of frosting of quartz grains in different samples of Swan River sands from the southern area is very uniform. Moderately frosted grains are dominant, intensely frosted grains are common, and clear or very slightly frosted grains are generally rare.

Discussion

Pettijohn's (1948, p.55) classification of surface textures was used as the basis for this work. In Table 8 (p.58) the author has substituted the term "clear" for Pettijohn's "polished".

Conclusions

The Swan River sands of the central area are slightly more frosted than the Swan River sands of the northern area but considerably less frosted than the sands of the southern area.

Thus, the southern sands do not appear to bear the same relationship to the sands of the central area as the latter sands do to the northern sands.

The presence of both clear and frosted quartz grains could suggest two different types of sands. Clear grains are most likely to have been derived from relatively nearby quartzose bedrock. Frosted grains were probably derived from pre-existing sediments.

PITTING

The degrees of pitting of all sieved sizes of grains from samples of Swan River sands are recorded in Table 8 (p.58).

Pitting on grains smaller than the 100≠ size was difficult to observe and estimate. It would seem likely that the smaller grains would be too small to be pitted during transportation. For this reason, only sizes larger than .147 mms. in diameter were considered to be of much value.

Areal Characteristics

Northern Area

Although the factors affecting shape and surface textures of grains during erosion, transportation, and deposition, had little effect on degrees of roundness and frosting of grains in this area, they did cause the grains to become pitted.

Quartz grains from samples of Swan River sands from the northern area appear to be dominantly intensely pitted. Moderately pitted grains are generally abundant to common whereas slightly or non-pitted grains are common to rare.

Central Area

Quartz grains making up samples of Swan River sand from the central area are dominantly intensely pitted. Moderately pitted grains are present whereas slightly or non-pitted quartz grains are predominantly rare.

Southern Area

Sands from the southern area are composed of quartz grains which are dominantly moderately pitted. Intensely pitted grains are slightly less numerous. Slightly or non-pitted grains are generally present.

Discussion

The slightly greater degree of pitting of Swan River sand grains of the central area as compared to the northern area could indicate that the central sands are the southward extension of the northern sands and as the distance from the source increases, the degree of pitting increases.

As the sands of the southern area are pitted to a lesser degree than Swan River sands of the other two areas, it would appear likely that the southern sands were not derived from sands of the northern or central areas.

However, degree of pitting as an accurate index of relative distance of transport would be very doubtful as other factors such as amount of authigenic overgrowths could have much more significant effects.

Conclusions

North Swan River sands of the central area appear to be slightly more intensely pitted than those of the northern area.

South Swan River sands exhibit a lesser degree of pitting than Swan River sands from the northern and central areas. Intensely pitted grains are less common and moderately and slightly pitted grains are more common in the southern area than in the other two areas.

SPHERICITY

Sphericity values were obtained by using Pye's (1943, pp.28-34) method on the projected images of grains. These values are recorded in Table 6 (p.51).

The sphericities of quartz grains in samples from the northern, central, and southern areas are detailed below.

Areal Characteristics

Northern Area

The average sphericity value for quartz grains in samples of Swan River sands from the northern area was found to be .80.

Central Area

Quartz grains in samples of Swan River sands from the central area were found to have an average sphericity of .85.

Southern Area

The average sphericity value for quartz grains in sand samples from the southern area was found to be .80.

Discussion

As there is a definite relationship between size and sphericity, (Pettijohn 1948, p.41) only grains of diameters .074 to .147 mm. were used.

According to Krumbein, (1941, p.492) sphericity of grains increases with their distance of transport. Degree of sphericity, like other textural characteristics of sediments, such as grain size, degree of sorting, roundness, frosting, pitting, etc., which have been discussed on the preceding pages, is not by itself an accurate guide of relative distances of transport, degree of re-working, or distance from source. A study of all these textural features of the Swan River, considered with physical properties of the formation, might be used to form one explanation for the particular properties of the sand, and for this reason, a study of these textural characteristics was made.

Conclusions

There is an increase in sphericity of grains of North Swan River sand from the northern to central areas.

The average sphericity of grains from the southern area is less than that of grains from the central area but the same as that of grains from the northern area.

CONCLUSIONS

The following conclusions, based on the preceeding textural determinations, are suggested as being the best assumptions to be made, considering the limited amount of material and control data available.

North Swan River sands as found in the northern and central areas were derived from a source or sources north of the northern outcrop area.

The Swan River sands of the central area are the southern extension of the Swan River sands of the northern area. As the sands were transported south to their final site of deposition in the central area, they became finer grained, better sorted, more rounded, more frosted, more intensely pitted, and more spherical.

The South Swan River sands found in the southern area are not the southward extension of North Swan River sands of the northern or central areas. They were not formed from re-working and re-deposition of North Swan River sands. They are coarser grained, not as well sorted, more rounded, considerably more frosted, less intensely pitted, and less spherical than grains found in samples of Swan River sands from the northern and central areas.

STRUCTURAL FEATURES OF SWAN RIVER FORMATION

REGIONAL

Introduction

Maps and cross-sections used in this study are included in the envelope at the back of this thesis.

Structural features of the Swan River formation in Manitoba are illustrated in this study by the use of maps showing:

a) contours on top of the pre-Cretaceous unconformity (Plate X1).

b) isopachs of the Swan River formation (Plate X).

c) structure contours on top of the Swan River formation (Plate 1X).

Also, three structural cross-sections, using sea level as datum, were constructed, and consisted of:

a) a north-south section (Plate X11) starting from the extreme southwest corner of Manitoba where relatively thick South Swan River sands are present, north through the Daly area where Swan River sands are thin or absent, into the central area described in this report, and terminating in the northern area where the Swan River sands onlap the Paleozoic erosion surface.

b) a north-east south-west section (Plate X111) again starting in the extreme southwest corner of Manitoba in the area of thick South Swan River sands and drawn northeast across the structurally high Spruce Woods area where no Swan River beds were deposited, then southeast where Swan River beds onlap the southern edge of this high, and finally across the depositional edge of the Swan River where the beds are not present.

c) an east-west section (Plate XlV) starting in the Elkhorn area (Twp. 11, Rge. 29 W1) where North and South Swan River beds appear to merge, drawn east across the Scallion field area where North Swan River beds are present in Jurassic structural and erosional lows, and finally south-east and east across the depositional edge of the Swan River caused by the pre-Cretaceous structurally high area extending west from the Spruce Woods area.

These maps and cross-sections were drawn using many wells which had not been drilled at the time this thesis was begun and the sample study completed. Electric logs, radio-active logs, and well samples were used for wells drilled in the central and southern areas and part of the northern area, and outcrop measurements and samples were used for control points in the remainder of the northern area.

Structure Contour and Isopach Maps

The structure contour and isopach maps are located in the envelope at the back of this thesis. The three maps are discussed individually below:

a) Contours on Top of the Pre-Cretaceous Unconformity (Plate lX).

This map shows the present nature of the post-Jurassic erosion surface upon which beds of the Swan River formation were deposited.

The Swan River isopach map (Plate X) was used in conjunction with this structure contour map to determine topographic and structural features which existed on the erosion surface immediately prior to Swan River deposition.

Regional strike over most of the area represented is northwest-southeast. Regional dip is generally to the southwest. Degree of regional dip increases from the northeast to the southwest i.e., in the direction of the centre of the Williston basin which is the depositional basin of the Swan River.

A structurally high area extending from the southwest end of Lake Manitoba through the Spruce Woods-Brandon area is represented by southwesterly flexures of the contour lines and of the outcrop edges of the Jurassic sandstone-shale units. A regionally high area is also suggested in the Daly-Virden-Roselea and Scallion field areas.

Local areas which are structurally high are located in Township 10, Range 27 W1, Township 1, Range 27 W1, and one in Townships 5, 6 and 7, Ranges 22 and 23 W1.

A regionally low area in the vicinity of the Duck Mountain Forest Reserve suggests an embayment in the edge of the major depositional basin.

Low areas of smaller extent are also present. One such area is centered in Township 13, Ranges 25 and 26 W1, north of Scallion field, another is centered in the Hartney area in Township 8, Range 26 W1, another in Townships 1 and 2, Range 25 W1, and another in Township 4, Range 24 W1.

These regional and local highs and lows were probably modified to some extent by Pre-Cretaceous erosion but are probably structurally controlled.

Major structural features were probably initiated by movements in the Precambrian basement. Solution of Middle Devonian salt beds causing collapse of overlying strata is also believed to have influenced deposition of most younger beds, including the Swan River.

b) Isopachs of the Swan River Formation (Plate X).

This map illustrates the manner in which the Swan River thickens and thins as it is influenced by the topography of the Pre-Cretaceous erosion surface and by basining effects.

Three major areas of regionally thin and thick Swan River beds are present. They are:

1. an area of thin Swan River beds extending from the Saskatchewan-Manitoba Boundary, south eastward from the Daly-Virden area to the International Boundary and merging to the east with the eastern area of Swan River non-deposition.

2. an area at the extreme southwest corner of Manitoba wherein the Swan River beds thicken greatly to the southwest in a short lateral distance.

3. an area of thick Swan River sands in the vicinity of the Duck Mountain Forest Reserve.

The first area (1. above) forms the barrier between the North Swan River sands and the South Swan River sands in Manitoba. This barrier is formed by the draping of Jurassic sediments over the escarpment edge of the Mississippian which trends in a general northwest-southeast direction across the province, and the joining of this resultant high trend with the Jurassic erosional high in the Spruce Woods area.

At the western end of this barrier in the Elkhorn area, (Twp. 11, Rge. 29 W1) the North and South Swan River sands appear to coalesce. Between Daly and Virden-Roselea fields a synclinal area is filled with a locally thicker Swan River section. Areas of non-deposition of Swan River sands are located west of Scallion field and over Virden-Roselea and Routledge fields which are structurally high.

The Brandon-Spruce Woods end of the barrier is part of the large regional high seen in the contour map of the Pre-Cretaceous unconformity and described previously. This high area is also the result of differential erosion as the top of the Jurassic in this area is composed of calcareous sandstones and siltstones which would have resisted erosion more effectively than the soft Jurassic shales located at the top of the Jurassic section in areas to the south and southwest.

The second area, (2. above) that of the extreme southwest corner of the province, is located in the deepest part of the Swan River depositional basin in Manitoba and the abrupt thickening of South Swan River sands in this area is the result of the abrupt steepening of slope of the underlying Jurassic beds in the direction of the centre of the basin and to some extent by basining effects. The existance of this relatively steep slope of the Jurassic surface prior to Swan River deposition is indicated by the manner in which the uniformly thick basal Swan River beds abut the Jurassic slope and disappear in a short up-dip distance. This truncation of the basal sand unit can be traced for considerable distances northwesterly into Saskatchewan and southeasterly into North Dakota.

Northeast (updip) of this southwest corner, the South Swan River sands become thinner and onlap the east-west barrier. Small structural or erosional lows on the top of the Jurassic are filled with relatively thick sections of Swan River sand and local areas of higher elevation are overlain by relatively thinner sections of sand.

The third major area, (3. above) in the Duck Mountain Forest Reserve is one of thick North Swan River sands filling in the embayment mentioned in the discussion regarding the contour map of the Pre-Cretaceous unconformity. This area corresponds to the "northern area" of this thesis.

Lack of control wells in the centre of this embayment prevents contouring from being completed.

South of the Duck Mountain area to the Daly-Spruce Woods barrier is the "central area" of this thesis. In it are several localities underlain by thinner or thicker than normal sections of Swan River. One of these localities, in this case, one of thick Swan River sands, is centered in Township 13, Range 25 W1. This local area is underlain by a structural low as seen on the contour map of the Pre-Cretaceous unconformity. This depression infilling, characteristic of the Swan River is also illustrated in a structural cross section drawn through this area (Plate X1V).

c) Structure Contours on Top of the Swan River Formation (Plate X1).

Regional strike of the top of the Swan River as determined from this map is northwest-southeast. Regional dip is to the southwest and increases slightly in the direction of the centre of the basin. This slight increase in dip to twenty feet per mile in the extreme southwest corner of the province from a regional dip of about eight feet per mile in the remainder of the map area suggests that the abrupt steepening of the side of the basin in the southwest corner prior to Swan River deposition was greatly reduced by the thick deposits of basal Swan River sand.

Deviations from regional strike in local areas are due to differential compaction features and to renewed vertical movement originating at depth. An example of each follows:

a) A regional low trending northeast-southwest across the centre of Township 6, Range 28 W1 is located in a small area in which the Swan River formation is unusually thin (Plate X). An adjacent structural high also trending northeast-southwest across the centre of Township 5, Range 28 W1 is situated in a small area in which the Swan River is unusually thick.

As the base of the Swan River is regional in these two areas (Plate lX), it would appear that the area of thin Swan River sand deposition was also the site of considerable Swan River shale deposition. This sandstone-shale section would compact to a greater degree than would the thick sandstone section and so would become a local structurally low area in comparison with the adjacent high area.

b) A small localized area centred in Township 13, Range 26 W1 was structurally low immediately prior to Swan River deposition, as indicated by an unusually thick Swan River section (Plate X), and is represented by a closed low on the top of the Swan River contour map. As will be shown in a structural cross section through this area (Plate XlV), the top of the Favel in this locality is also structurally low. It is apparent that downward movement has occurred in this area in post Swan River time, and in fact, in post Favel time.

In some areas, such as in Township 1, Range 25 W1, and Townships 1 and 2, Range 27 W1, low areas have been infilled by thick sections of Swan River, high areas have had thin sections of Swan River sands deposited over them, no differential compaction has taken place, and as of the end of Swan River time, the topographic anomalies have disappeared.

Structural Cross Sections

Three structural cross sections using electrical and radioactive logs were constructed for inclusion in this thesis (Plates Xll, Xlll and XlV). They are included in the envelope at the back of this thesis, and are discussed individually below:

a) The first structural cross section (Plate X11) is drawn from the Cleary Souris Valley White 5-34 well in the extreme southwest corner of the province, north across the "southern area" of this report, across the Daly portion of the east-west barrier, continuing north through the "central area" and terminating at the Shell Swan River No. 2 well in the "northern area". The Swan River interval can be traced along the entire length of this section, although in the area of the Daly field and the southern end of the central area, correlation becomes difficult.

At the southern end of this section, in the Cleary-Souris Valley White 5-34 and California Standard Pierson 2-29 wells, the South Swan River is seen to be at its thickest, and is composed of a coarse grained basal sand, a median shale unit, and an upper fine to coarse grained sandstone and shale unit. The basal sand and median shale units onlap the relatively steep dipping slope of the Pre-Cretaceous basin and pinch out between the Pierson and Imperial California Standard Eunola 4-28 well. From the Eunola well, through California Standard Tilston Province 5-32 and California Standard Linklater Province 7-20 well, the Swan River continues to thin. A median shale unit present within the upper sandstone and shale unit of the White, Pierson, Eunola, and Tilston wells has pinched out before the area of the Linklater well is reached. From the area of the California Standard Ewart Province 4-14 well, north to the Royalite Triad Two Creeks No. 1 well, the Swan River is very thin and not easily discernable. In the Ewart and Schmelz wells the Swan River interval is occupied by poorly defined beds of fine grained sandstone.

In the Daly 10-1A well and West Hargrave 7-16 well the presence of Swan River in each well is indicated by ten foot thick beds of loose coarse grained sand. Swan River beds in the Two Creeks well are composed of medium grained quartzose sandstone overlying the typical calcareous siltstone of the subcropping Jurassic "A" unit. Thick North Swan River sands of the central area as typified in the California Standard Treat Province 15-29 and Imperial Madeline No. 1 well, onlap the escarpment formed by the subcropping of the Jurassic "A" and "B" units.

The Swan River sands of the Treat well are fine to medium grained and in part unconsolidated. Thus their lithology contrasts markedly with the thinly interbedded calcareous siltstones, shales, and limestones of the Jurassic "A" and "C" units and the variegated calcareous shales of the Jurassic "B" unit in the adjacent Two Creeks well.

As the line of section is traced in a northward direction, it is seen that the Jurassic thins and finally pinches out between the Imperial Bluewing Lake 13-4 well and the Great Sweet Grass Duck Mountain No. 3 well. North of this Jurassic pinchout the Swan River rests directly upon the Paleozoic erosion surface.

The Jurassic "A", "B", and "C" units shown on this and the other two cross sections are respectively, an upper unit composed of thin bedded limestones, calcareous siltstones and fine grained calcareous sandstones, a median argillaceous unit, and a basal unit, similar to the upper unit, composed of thin bedded limestones, calcareous siltstones, and calcareous fine to medium grained sandstones. These subdivisions were made in order to facilitate distinguishing between Swan River sands and Jurassic sands, especially in the area of the east-west (Daly-Spruce Woods) barrier where the Jurassic sands become more massive and the Swan

River sands are poorly defined. The need for this Jurassic correlation will be even more apparent in the third cross section (Plate XlV).

b) The second cross section (Plate Xlll) is confined to the southern area of this thesis. It is drawn in a general east-west direction, from the Cleary Souris Valley White 5-34 well in the extreme southwest corner of Manitoba, and extends across the southern area, across the Spruce Woods structurally high region, off the southern flank of this high, and finally across the depositional edge of the South Swan River sands.

The South Swan River sands thin from west to east, from their thickest section at Cleary Souris Valley White 5-34 to their pinchout between the McCarty Coleman Sands 2-13 well and the California Standard Wawanesa 3-1 well. In the White well, the three major units of the Swan River as detailed in the preceding discussion of the first cross section, are present. The median shale unit and the basal sand have pinched out between the White well and the Anglo et al Souris Valley Sharpe 2-18 well. The upper sandstone and shale unit of the Swan River is present in the Sharpe well and in the Owen North Coulter 5-32 well, but only the uppermost sandstone section is present in Anglo et al McKee 15-1 and Dakota Cassan 5-23.

The South Swan River beds are relatively thin and poorly defined in the Imperial Canadian Superior Argue 15-13, United States Smelting 3-30 Draper, and McCarty Coleman Sands 2-13 wells. The Swan River onlaps the regional high caused by draping of Jurassic beds over the underlying Mississippian escarpment as shown by the log of California Standard Wawanesa 3-1 in which the Swan River is absent, having pinched out down-dip from the location of this well. The Dome St. Alphonse 13-16 well is located off the southern flank of the Spruce Woods structure and penetrated over fifty feet of unconsolidated fine to coarse grained South Swan River sands.

The Sweet Grass Altamont No. 1 well is located east of the depositional edge of the Swan River and so no Swan River beds are present.

c) The third cross section (Plate XlV) is drawn in a general east-west direction beginning in the west at California Standard Elkhorn 7-8A in the area of possible merging of North and South Swan River sands, extending across the Daly and Scallion portions of the Daly-Spruce Woods barrier, into the long westerly extension of the area of non-deposition of the Swan River, easterly across the Spruce Woods area, and terminating at the Canadian Prospect Treherne 13-7 well.

The Swan River at California Standard Elkhorn 7-8A is a fine grained quartzose sandstone, and from the electric log of this well, appears to be typical of the South Swan River sand at the northerly end of the southern area, especially in its position relative to the underlying Jurassic "A" unit.

A thin (ten feet) interval of Swan River beds is present in the Hallis West Hargrave 7-16 well, and in Canadian Superior Dome Carruthers 8-13 which is updip from the Hargrave well, no Swan River beds are present. The Canadian Prospect Scallion 8-5 well has a very thin (three feet) section of Swan River beds present. This section is composed of loose coarse quartz grains, marking the Jurassic-Cretaceous unconformity. The Ashville sand is very prominent in this well. The Jurassic "A" unit is composed of calcareous siltstones and very fine grained sandstones which is the typical lithology of the unit. The top of the Jurassic "A" unit is separated from the Jurassic-Cretaceous unconformity by a fifty foot section of silty shales.

At California Standard Harmsworth 6-24A, the Jurassic "A" unit is at the top of the Jurassic section, directly underlying the unconformity. The presence of loose quartz grains at 1225 feet indicates a thin interval of Swan River to be present. In this well, and the two wells to the east of it, i.e., Sapphire West Blossom 16-20 and Imperial Blossom 3-17, the difficulty of correctly dividing the Swan River from the Jurassic is very apparent. Samples of this part of the section from wells in the area are generally poor, making correlations doubly difficult. The interpretation shown in the above three wells is believed by the author to be the most probable as based on present knowledge and control. In Harmsworth 6-24A the Jurassic "A" unit appears to be composed of typical calcareous siltstones, shales, and very fine grained calcareous sandstones as determined from samples, but sandstone beds within it appear to be thicker bedded and better defined than normal as determined from the electrolog.

The Sapphire West Blossom 16-20 well is located in a structurally low area into which Swan River beds have been deposited, whereas the well to the east, Imperial Blossom 3-17, is comparatively high, and has little or no Swan River present. The California Standard Harmsworth 6-24 A and Imperial Blossom 3-17 wells are good examples of wells in which the Jurassic "A" unit, or part of it, could easily be mistaken for the Swan River when electric logs alone are considered.

The Western Oak River 10-15 well is on regional strike with Canadian Prospect Scallion 8-5, and its Jurassic and Cretaceous sections are very similar to those of the Scallion well. The Ashville Sand is especially well developed in both wells. Also, there is a section of thirty to fifty feet of silty shale which directly overlies the Jurassic "A" unit and whose upper boundary is the Jurassic-Cretaceous unconformity. The Jurassic "A" unit is composed mainly of thin bedded calcareous siltstones and shales with no well defined massive sandstone and siltstone beds included, and the Jurassic "B" unit appears to be devoid of any arenaceous material, in both wells.

From Peacock Kemney No. 1, through Dome Brandon 16-27 and Amerada Crown ME 13-11, all of which are influenced by the Mississippian escarpment and Spruce Woods highs, the Swan River is absent. In the Kemney and Brandon wells, the Jurassic "A" unit is seen to contain thick bedded sandstones with higher than normal spontaneous potential values on the electrolog. This facies change in the Jurassic "A" unit is characteristic of this locality and of the area to the north and northeast of this locality. It is in this area that the Jurassic "A" unit has been often mistaken for Swan River.

In the Amerada Crown ME 13-11 well the Jurassic "A" unit is composed of the thin bedded calcareous siltstones and shales characteristic of this unit in the southern area.

In Great Northern Carbon and Chemical Spruce Woods 1-A the Jurassic "A" unit appears to have thickened at the expense of the underlying Jurassic "B" unit, or else, the Jurassic "B" unit has undergone a facies change to become more arenaceous in its upper portion. Both this Spruce Woods well and Canadian Prospect Treherne 13-7 have unusually thick arenaceous beds within their Jurassic "A" and Jurassic "B" units and the Treherne well and nearby wells have included in their sections loose fine to coarse grained sandstones which resemble, and have been termed, Swan River. Two explanations are possible:

1) The subcrop area of the Jurassic "A" unit is located west of the Treherne area and erosion into the softer Jurassic "B" beds has created a low area into which Swan River beds were deposited as in the Treherne well, or

2) The Treherne well is located near the shore line of the Jurassic sea and the sands are coarser grained because of their position relative to the shore line. This interpretation is the one indicated in the cross section and explains the gradational nature of the Jurassic section in the Amerada Crown ME 13-11, Spruce Woods 1-A, and Treherne 13-7 wells better than does the first interpretation.

LOCAL

Bedding

Graded bedding was noted in two samples from the northern outcrop area. Graded bedding could/ suggest slow deposition and/or reworking.

The possibility of slow deposition was confirmed by the presence of glauconite in the same two samples.

Ripple Marks

Tyrrell (1892, p.113) mentioned ripple marks on surfaces of "Dakota" sandstone outcropping along the Roaring River.

Wickenden (1945, p.16) described indurated layers of red weathering sandstone with ripple-marked surfaces as being common in outcrops along the Red Deer River.

Ripple marked surfaces of a sedimentary rock are indicative of a shallow depositional environment.

CONCLUSIONS

Results of the foregoing study of the structural features of the Swan River formation suggest the following conclusions:

1) An east-west barrier extending east of the Spruce Woods area to the Manitoba-Saskatchewan boundary separates the North Swan River and South Swan River sands in Manitoba. This barrier is structurally controlled but was probably accentuated in part by Pre-Cretaceous erosion.

2) Deposition of the Swan River was influenced by the nature of the Pre-Cretaceous erosion surface. Comparatively thick sections of the Swan River sands were deposited in areas of low elevation and comparatively thin sections of sands, or no sands, were deposited in areas of relatively high elevation.

3) Structural anomalies defined by elevations on the top of the Swan River formation are the result of differential compaction within the Swan River, and of renewal of vertical movement originating in beds underlying the Swan River.

4) Local structural features of ripple marks and possibly graded bedding, observed in beds of the North Swan River, suggest that these beds were deposited at a relatively slow rate in a shallow water environment and that re-working of the sands occurred.

STRATIGRAPHIC AND PALEOGEOGRAPHIC FEATURES OF THE SWAN RIVER FORMATION

STRATIGRAPHIC POSITION AND CHARACTERISTIC LITHOLOGY OF THE SWAN RIVER AND OVERLYING AND UNDERLYING BEDS

The stratigraphy and lithology of the Swan River and its overlying and underlying beds is best illustrated in the north-south cross section (Plate X11) which extends from the northern to the southern area. The North Swan River will be discussed and traced from the northern area, through the central area to its termination at or near the Daly portion of the east-west barrier. The South Swan River will be discussed from its northern termination at the east-west barrier, south to the extreme southwest corner of the province.

North Swan River Sand

The Swan River throughout Manitoba is overlain by the Ashville formation. The Ashville in the northern and central areas is composed of dark grey to black shales with occasional siltstone and sandstone beds. The lower part of the Ashville near the contact with the Swan River contains glauconite. In some outcrop sections this contact appears to be transitional. The Ashville includes beds of both Upper and Lower Cretaceous age (Wickenden, 1945, p.23).

The top of the North Swan River is placed at the first appearance of quartz sands below the dark grey Ashville shales. The North Swan River of the northern area as seen in outcrops and as illustrated in the Swan River No. 2, Duck Mountain No. 3, and Bluewing Lake 13-4 wells (Plate X11), is generally composed of fine to coarse grained quartzose sandstone, often unconsolidated, glauconitic, argillaceous, lignitic, and containing numerous interbeds of shale and silty shale. The North Swan River sands of the central area are finer grained than the sands of the northern area but the lithology of the North Swan River is very similar in the two areas.

The basal beds of the Swan River in the northern area are composed of loose coarse grained quartz sands. They overlap the erosional edges of the Jurassic and Mississippian beds and so overlie beds of Jurassic, Mississippian, and Devonian age. Where Jurassic beds are present, as in Imperial Bluewing Lake 13-4 (Plate X11), the base of the Swan River is placed at the base of the loose coarse grained sands. Where no Jurassic beds are present the Swan River base is placed above the first appearance of Paleozoic carbonates.

Directly underlying the Swan River in parts of the central area are beds of soft calcareous clay. Calcareous clay beds marking the Jurassic-Cretaceous unconformity are also present in some wells in the southern area (e.g. Cal. Stan. Tilston Province 5-32), as well as in wells in the vicinity of the Daly portion of the east-west barrier (e.g. Cal. Stan. Hargrave Province 15-16 and Cal. Stan. Elkhorn 7-8A).

At the southern terminus of the central area the North Swan River onlaps the escarpment formed by the subcropping Jurassic "A" and "B" units and is composed of loose medium to coarse grained quartzose sandstone.

In the western half of the central area, with the exception of its southern terminus, the Jurassic interval is represented by beds of the Jurassic "C" unit (Plate X11). These beds have the typical lithology of the unit, being composed of fine grained calcareous siltstones and calcareous shales. In the eastern half of the central area, the Jurassic "A", "B", and "C" units are present. North of the Spruce Woods area the Jurassic "A" unit becomes more prominent and is often mistakenly termed Swan River.

Thus, in most of the central area, the Jurassic "A", "B", and "C" units, where present, possess their characteristic lithologies. The "A" and "C" units are composed of thinly interbedded calcareous siltstones and calcareous shales, and the "B" unit is composed mainly of calcareous shales. These Jurassic beds are of marine origin. The consistent character of these Jurassic beds makes it possible to establish the presence of the Jurassic escarpment between the Two Creeks and Treat wells (Plate X11) as the partially continental unconsolidated fine to medium grained Swan River sands of the Treat well differ markedly from the marine Jurassic beds in the Two Creeks well.

However, in the northern area, it is possible that the Jurassic "C" unit which corresponds roughly to the Shaunavon formation and the upper part of the Gravelbourg formation, could undergo a facies change to more massive sandstones, and become continental in nature as the Jurassic shoreline is reached. In this case, the separation of Cretaceous beds from Jurassic beds would be an attempt to discriminate between two sandstone sections of very similar, if not identical, character, and would probably be impossible. Thus, it is possible that in the northern area some of the sands which the author has placed in the Swan River formation may be Jurassic in age. In the absence of reliable index fossils this may be neither proved nor disproved.

In this thesis, the author has placed the fine to coarse grained generally unconsolidated quartz sands, as typified in the Bluewing Lake, Duck Mountain, and Swan River wells (Plate X11), in the Swan River formation as they are similar to the North Swan River sands of the central area where the Jurassic-Cretaceous boundary is more obvious. This was believed to be the best solution available as based on present control. However, a Jurassic age for at least the basal beds of the North Swan River in the northern area cannot be disproved at this time.

South Swan River Sand

The South Swan Riwer sand is overlain by beds of the Ashville formation and underlain by beds of the Jurassic "A" unit.

The Ashville formation in the southern area is composed of dark grey to black occasionally silty shale. As in the northern area, the lower part of the Ashville near the contact with the Swan River contains glauconite. The South Swan River-Ashville contact is not gradational. It is placed at first appearance of quartz sandstone below the dark grey Ashville shales.

The South Swan River is composed of fine to coarse poorly sorted generally unconsolidated quartzose sandstones and interbeds of grey shale. The top of the South Swan River is generally marked by the presence of colorless fine grained calcareous and pyritic sandstone. A subdivision of the South Swan River into three units is included in the discussion of Plate X11.

In many areas the lowermost beds of the South Swan River overlie a section about ten feet thick composed of non-calcareous generally variegated shale. In some localities this shale is light grey and has been included in the Swan River by some workers. However, these shales are more properly placed in the top of the Jurassic "A" unit as they are correlated with typically Jurassic variegated shales elsewhere in the area, and as the Swan River is typical transgressive basal sandstone, and consequently would be unlikely to possess argillaceous basal beds. These shales overlie the typical white fine grained calcareous sandstones of the Jurassic.

In the California Standard Hartney 16-33 well, the Jurassic-Cretaceous unconformity is marked by a well defined breccia. Photomicrographs of this breccia and the contact with the underlying Jurassic limestone are shown in Plate XV (p.88).

In the southern area, the Jurassic is composed of fine grained calcareous sandstone, calcareous siltstones, variegated waxy shales, and argillaceous and silty limestones. The Jurassic "A", "B", and "C" unit classification discussed in regard to Plates X11 and X1V are present throughout the southern area. An "Ostracodal limestone" near the top of the Jurassic "A" unit can be correlated over a large part of the area (Plate X111). It is probably this "Ostracodal limestone" which marks the top of the Jurassic "A" unit in the Spruce Woods area, and which is responsible for the erosionally accentuated high in this area.

DEPOSITIONAL ENVIRONMENT

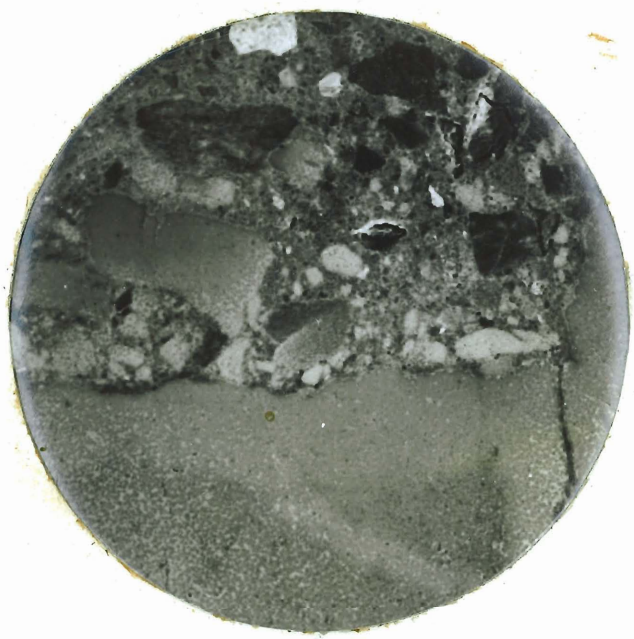
The depositional environments of the North and South Swan River sands are discussed individually below.

North Swan River

Several authors have noted the presence of carbonaceous

x 4

A. Polished section of breccia marking Swan River - Jurassic unconformity at Calstan Hartney 16-33.



x 4

B. Polished section of contact of above breccia with limestone of the underlying Jurassic.

and lignitic material in beds of the North Swan River and related sands. McInnes (1913, p.66) described Cretaceous sands exposed along the south shoreof Wapawekka Lake as containing abundant carbonaceous material. DeLury (1924) also reported the presence of lignitic and carbonaceous material in Cretaceous sands of the Wapawekka and Deschambault Lake areas. Wallace (1925, p.29) noted the presence of pieces of wood and impressions of leaves in the "Dakota sandstone", which is North Swan River sandstone, and cites them as "evidence of coniferous forests in the near vicinity of the advancing sea in which the sandstones were being deposited". Wickenden (1945, p.112) states that "coal occurs at several places and indications are thatthe (Swan River) group is entirely of non-marine origin in the northern part of the area". He does not mark the boundary between the marine and non-marine areas.

Samples used in this study were taken from outcrop sections and from cores from the Imperial Foxwarren No. 1 and Imperial Madeline No. 1 wells and contained appreciable amounts of carbonaceous and lignitic material. As well as containing carbonaceous fragments, samples of Swan River sands from the outcrop area also contained an abundance of glauconite.

The values of average roundness and sphericity of grains of North Swan River sands are comparable to those of known beach sands (Krumbein and Sloss, 1950, p.83). This is especially true for sands in the central area.

The presence of carbonaceous and lignitic fragments in Swan River sands in the outcrop area and in related Cretaceous sands in northeastern Saskatchewan indicate that part of these beds were deposited in a non-marine or brackish water environment. Lignite beds of appreciable thickness such as are present in the Imperial Foxwarren No. 1 well were formed close to the shoreline of the transgressing Cretaceous sea and would be covered by marine sediments as the sea advanced on the land.

The co-existence of lignitic beds and glauconite suggests that the shore line of the Lower Cretaceous sea fluctuated considerably. The presence of glauconite, ripple marks, and graded bedding in sections in the outcrop area of North Swan River indicates that the sea was shallow in that area and that deposition was relatively slow. Slight rises in sea level would cause the incorporation of nearby lignitic beds into the marine beach sands. Carbonaceous fragments were probably derived from nearby coniferous forests and deposited in the glauconitic sands being deposited slowly off-shore.

South Swan River

Unlike the North Swan River, the South Swan River sand does not contain carbonaceous and lignitic material. Quartz grains make up over ninety-eight percent of its mineral composition by weight. Pyrite is common, especially in the uppermost beds of the formation. Glauconite is absent. Plagioclase and microcline, both relatively non-resistant minerals are present although in very limited amounts.

The South Swan River sand is generally poorly sorted (Plate V111, B, p.54).

The values of average roundness and sphericity of quartz grains from South Swan River sands are quite similar to those given by Krumbein and Sloss (1950, p.83) as belonging to known beach sands.

The South Swan River is a typical transgressive marine basal sand. The absence of glauconite indicates that the sands were deposited at a relatively fast rate probably at greater depths than that at which glauconite is formed. This relatively fast rate of deposition is also indicated by the poorly sorted nature of the sand and by the presence of unstable minerals such as plagioclase and microcline.

The presence of pyrite in the uppermost South Swan River beds suggests that the Cretaceous sea in the southern area at the end of Swan River deposition became partially restricted.

Pre-Cretaceous erosion formed local depressions in the Jurassic land surface. As theCretaceous seas advanced over this land surface, Swan River sands were dumped first in these depressions and in the lower portions of the depositional basin and then were laid down across the entire southern area. Intermittent deepening of the seas into which the sands were being deposited caused the deposition of thin beds of shale. The end of Swan River deposition was marked by a sudden increase in the depth of the seas which ended the partially restricted basinal environment of the uppermost Swan River sands, and caused deposition of shales of the Ashville formation.

SOURCES

Results of the compositional, textural, and structural studies discussed previously suggest that the respective sources of the North and South Swan River differed in their geographical locations and, to a limited degree, in their lithologic characters. For this reason, the North and South Swan River sands are discussed separately.

North Swan River

The heavy mineral investigation indicated that the North Swan River sands had been derived mainly from a pegmatized injected terrane which had undergone high-rank metamorphism, a granitic mass, and sediments derived from these types of sources.

The most obvious area of this description is that of the Precambrian Shield which is located along the northeast rim of the depositional basin of the Swan River in Manitoba. Although the Swan River in Manitoba does not directly overlie the Precambrian, Cretaceous sands correlative with the Swan River, and located in the Wapawekka Lake area of northeastern Saskatchewan, do overlap the Paleozoic and rest directly upon the rocks of the Precambrian complex. This would indicate that prior to deposition of Cretaceous sediments, the northeastern region of Saskatchewan, and probably the northern and eastern areas of Manitoba were eroded down so as to expose the Precambrian. An alternative, but rather unlikely conclusion would be that the Precambrian in this region was never covered by Paleozoic or early Mesozoic sediments. In either case, the Precambrian bedrock was in a position to act as a source for Cretaceous sediments, including the Swan River. McInnes described a sandstone at Wapawekka Lake as being "very soft and quartzose. In places the sandstone becomes a fine conglomerate, in certain layers with pebbles of gneiss andother rocks, and in places it contains carbonaceous material resembling the comminuted remains of plants". He termed these sands "Dakota". The presence of pebbles of gneiss indicates that the sandstone has been derived from the adjacent Precambrian rocks. Even these sands which are described generally as being very pure and greatly reworked, could form a sandstone with the variety of heavy minerals seen in the Swan River sands.

A possible sedimentary source of Cretaceous sands, including the Swan River, in Saskatchewan and Manitoba is the Athabasca sandstone of presumed Precambrian age. Both the Cretaceous sandstone at Wapawekka Lake and the Athabasca sandstone are described as being well rounded pure quartz sands. In places they are very loosely cemented and in other places are indurated to form hard sandstone and quartzite. One thin section of a rock sample taken from the northeast end of Lake Athabasca was found to be composed of a sandstone with quartz grains poorly sorted, very fine to medium grained, moderately rounded, and exhibiting some authigenic growth of quartz.

It would seem that the sand at Wapawekka Lake could have been derived from the Athabasca sandstone. The formation of quartzites from the originally moderately to well rounded grains would, by recrystallization of the quartz grains, destroy their original textural features such as roundness, frosting, pitting, and sphericity. Erosion of the quartzites and loose sands would produce quartz grains of variable roundness values. This variety in degree of roundness of grains is evident in North Swan River sands which are dominantly moderately rounded but have abundant angular types as well as appreciable amounts of well rounded grains.

If, as many authors believe, the Paleozoic sediments of the west side of Hudson Bay were connected with the sediments of the same age further west, there would have been a great thickness of sediments which was eroded and could have contributed to the formation of the North Swan River. The Winnipeg sandstone of Ordovician age, for example, could have furnished a sand of the nature of the Swan River.

McInnes states that "There seems to be a great probability that rock of about the age of the Athabasca sandstone or of Animikie and Keweenawan age occur under the Paleozoic sediments near the shores of Hudson Bay".

This would suggest a continuous section of Precambrian material, with or without overlying Paleozoic sediments, to have extended from Lake Athabasca to Hudson Bay. The erosion of most of this section could have contributed to the formation of Cretaceous sediments, including the North Swan River, in the northern areas of Manitoba and Saskatchewan.

Erosion and re-deposition of beds of the Jurassic "A" and "C" units could have resulted in the formation of Swan River beds, especially in areas adjacent to Jurassic topographic highs, including escarpment edges of the "A" and "C" units.

South Swan River

The heavy mineral study of the South Swan River sands indicated that the main sources of the sands were a pegmatized injected metamorphic terrane, a granitic mass, and related sediments.

The east-west barrier which extends from the Saskatchewan-

Manitoba boundary to the southwest shore of Lake Manitoba prevented sands derived from sources in northern Saskatchewan and northern Manitoba from being included in South Swan River beds in Manitoba.

It would appear that the main sources of the South Swan River sands were the adjacent Precambrian Shield and sediments derived from it, situated to the east of the "southern area" of this thesis.

This relative nearness of source is also suggested by the large grain size, poor sorting, and presence of such unstable, non-resistant minerals as microcline and plagioclase in South Swan River sands.

CONCLUSIONS

The North Swan River sands and the South Swan River sands occupy the same stratigraphic interval.

The North Swan River sands were deposited slowly in a partially marine and partially non-marine or brackish water environment, whereas the South Swan River sands were deposited relatively rapidly in a marine environment.

The sources of the North Swan River sands were the Precambrian complex and derived sediments situated in northwest, north and northeast directions from the depositional basin of the North Swan River. The sources of the South Swan River sands were thePrecambrian complex and derived sediments located east of the depositional basin of the South Swan River.

CONCLUSIONS

Results of this study of the Swan River beds in Manitoba have suggested the following conclusions.

Those beds underlying the Ashville formation and overlying beds of Jurassic, and in certain areas, of Mississippian and Devonian age, previously termed "Dakota" and "Swan River Group", comprise a mappable unit and so may be properly termed the "Swan River Formation".

In Manitoba the Swan River formation is areally divided by an east-west barrier extending from the Spruce Woods area to the Saskatchewan-Manitoba boundary, into a North Swan River and South Swan River.

The North and South Swan River are stratigraphic equivalents but differ in their respective mineralogical content, textural characteristics, sources, and depositional environment.

BIBLIOGRAPHY

Alcock, F. J. (1936): Geology of Lake Athabaska Region, Sask., Geol. Surv., Canada, Mem. 196, pp.21-24.

Allan, J. D. (1951): Exploration for Oil and Gas in Manitoba, Can. Oil and Gas Indust., vol. 4, No. 6, pp.33-36.

Allen, P. (1947): Correlation Between Allogenic Grade Size and Allogenic Frequency in Sediments, Jour. Sed. Petrol., vol. 17, No. 1, pp.3-7.

Allen, V. T. (1948): Weathering and Heavy Minerals, Jour. Sed. Petrol., vol. 18, No. 1, pp.38-42.

Bramlette, M. N. (1941): The Stability of Minerals in Sandstone, Jour. Sed. Petrol., vol. 11, No. 1, pp.32-36.

Carroll, D. (1938): Recording the Results of Heavy Mineral Analyses, Jour. Sed. Petrol., vol. 8, No. 1, pp.3-9.

Cogen, W. M. (1935): Some Suggestions for Heavy Mineral Investigations of Sediments, Jour. Sed. Petrol., vol. 5, No. 1, pp. 3-8.

Cole, H. (1928): Silica in Canada, Its Occurrence, Exploitation, and Uses, Geol. Survey, Canada, Mem. 686.

Crowley, A. J. (1951): Possible Lower Cretaceous Uplifting of Black Hills, Wyoming and South Dakota, Bull. Amer. Assoc. of Pet. Geol., vol. 35, No. 1, pp.83-90.

Dana, E. S. (1947): A Textbook of Mineralogy, 4th Ed.

Dapples, E. C. (1947): Sandstone Types and Their Associated Depositional Environments, Jour. Sed. Petrol. vol. 17, pp.91-100.

Delury, J. S. (1924): Wapawekka and Deschambault Lakes Area, Saskatchewan, Geol. Surv., Canada, Sum. Rept., pt. B.

Doeglas, D. J. (1946): Interpretation of the Results of Mechanical Analyses, Jour. Sed. Petrol., vol. 16, No. 1, pp.19-40.

Dowling, D. B., Slipper, S. E., and McLearn, F. H. (1919): Investigations in the Gas and Oil Fields of Alberta, Sask., and Man., Geol. Surv., Canada, Mem. 116, pp.2-9, 27-38.

Dryden, L., and Dryden, C. (1946): Comparative Rates of Weathering of Some Common Heavy Minerals, Jour. Sed. Petrol., vol. 16, No. 3, pp. 91-96.

Eardley, A. J. (1951): Structural Geology of North America, 1st Ed.

Eisenhart, C. (1935): A Test for the Significance of Lithological Variations, Jour. Sed. Petrol., vol. 5, No. 3, pp.137-145.

Emery, K. O. (1938): Rapid Method of Mechanical Analysis of Sands, Jour. Sed. Petrol., vol. 8, No. 3, pp.105-111.

__________ (1945): Transportation of Marine Beach Sand by Flotation, Jour. Sed. Petrol., vol. 15, No. 3, pp.84-87.

Gilbert, C. M. (1947): Cleaning Heavy Minerals for Petrographic Study, Jour. Sed. Petrol., vol. 17, No. 2, pp.83-85.

Goldstein, A. (1948): Cementation of Dakota Sandstones of the Colorado Front Range, Jour. Sed. Petrol., vol. 18, No. 3, pp.108-125.

Grabau, A. W. and Shimer, H. W. (1909): North American Index Fossils, vol. 1.

Herbert, P. Jr. (1942): Petrographic Microscope Slides of Detrital Mineral Grains, Jour. Sed. Petrol., vol. 12, No. 2, pp.90-91.

Hume, G. S. (1947): The Interior Plains, Geology and Economic Minerals of Canada, Econ. Geol. Series, No. 1, Geol. Surv., Canada, 3rd. Ed.

Hunt, C. W. (1951): Significance of Cretaceous Oil Discoveries on the Central Plains, Can. Oil and Gas Indust., vol. 4, No. 11, pp. 50-51.

Johnston, W. A. (1918): Semi-Refractory Clay and Pure Quartz Sand of Swan River Valley, Geol. Surv., Canada, Sum. Rept. pt. D, pp. 22-36.

__________ (1934): Surface Deposits and Ground-water Supply of Winnipeg Map-area, Manitoba, Geol. Surv., Canada, Mem. 174, pp. 12-13.

Kindle, E. M. (1936): Dominant Factors in theFormation of Firm and Soft Sand Beaches, Jour. Sed. Petrol., vol. 6, No. 1, pp. 16-22.

Kirk, S. R. (1929): Cretaceous Stratigraphy of the Manitoba Escarpment, Geol. Surv., Canada, Sum. Rept., pt. B, pp.112-136.

Krumbein, W. C. (1934): Size Frequency Distribution of Sediments, Jour. Sed. Petrol., vol. 4, No. 2, pp.65-77.

__________ (1938): Size Frequency Distribution of Sediments and the Normal Phi Curve, Jour, Sed. Petrol., vol. 8, No. 3, pp.84-90.

Krumbein, W. C. (1941): Measurement and Geological Significance of Shape and Roundness of Sedimentary Particles, Jour. Sed. Petrol., vol. 11, No. 2, pp.64-72.

_______________(1947): Shales and Their Environmental Significance, Jour. Sed. Petrol., vol. 17, No. 3, pp.101-108.

_______________and Rasmussen, W. C. (1941): The Probable Error of Sampling Beach Sand for Heavy Mineral Analysis, Jour. Sed. Petrol., vol. 11, No. 1, pp.10-20.

_______________and Sloss, L. L. (1951): Stratigraphy and Sedimentation, 1st. Ed.

Krynine, P. D. (1946): The Tourmaline Group in Sediments, Jour. Geol., pp.65-87.

LeRoy, L. W. (1951): Subsurface Geologic Methods, 2nd Ed.

Lindberg, M. L. (1944): Heavy Mineral Correlation of the Fox Hills, Hell Creek, and Cannonball Sediments, Morton and Sioux Counties, North Dakota, Jour. Sed. Petrol., vol. 14, No. 3, pp.131-143.

Link, T. A. (1950): The Western Canada Sedimentary Basin Area, Can. Min. and Met. Bull., vol. 43, No. 459.

Longwell, C. R. et al (1941): Outlines of Geology, 2nd Ed.

Manger, G. E. (1934): A Mineral Analysis of Some Common Sands and Their Silica Content, Jour. Sed. Petrol., vol. 4, No. 3, pp.141-151.

Marsland, P. S. and Woodruff, J. G. (1937): A Study of the Effects of Wind Transportation on Grains of Several Minerals, Jour. Sed. Petrol., vol. 7, No. 1, pp.18-30.

Meek, F. B. and Hayden, F. V. (1876): Report of the U. S. Geology of the Territories, vol. 1X.

McInnes, W. (1913): Basins of Nelson and Churchill Rivers, Geol. Surv., Canada, Mem. 30, p.66.

McLearn, E. H. (1944): Revision of the Lower Cretaceous of the Western Interior of Canada, Geol. Surv., Canada, Prof. Pap.44-17, p.5.

_____________(1944): Revision of the Paleogeography of the Lower Cretaceous of the Western Interior of Canada, Geol. Surv., Canada, Prof. Pap.44-32, p.2.

Otto, G. H. (1933): Comparative Tests of Several Methods of Sampling Heavy Mineral Concentrates, Jour. Sed. Petrol., vol. 3, No. 1, pp.30-39.

Pettijohn, F. J. (1948): Sedimentary Rocks, 1st. Ed.

____________and Lundahl, A. C. (1943): Shape and Roundness of Lake Erie Beach Sands, Jour. Petrol., vol. 13, No. 2, pp.69-78.

Pye, W. D. (1943): Rapid Methods of Making Sedimentational Analyses of Arenaceous Sediments, Jour. Sed. Petrol., vol. 13, No. 3, pp.85-104.

____________and Pye, M. H. (1943): Sphericity Determination of Pebbles, Jour. Sed. Petrol., vol. 13, No. 1, pp.28-34.

Rasmussen, W. C. (1941): Local Areal Variation of Heavy Minerals in Beach Sand, Jour. Sed. Petrol., vol. 11, No. 2, pp.98-101.

Riley, N. A. (1941): Projection Sphericity, Jour. Sed. Petrol., vol. 11, No. 2, pp.94-97.

Rittenhouse, G. (1943): A visual Method of Estimating Two Dimensional Sphericity, Jour. Sed. Petrol., vol. 13, No. 2, pp.79-81.

____________and Connaughton, M. P. (1944): Errors of Sampling Sands for Mechanical Analysis, Jour. Sed. Petrol., vol. 14, No. 1, pp.20-25.

Rubey, W. W. (1933): The Size Distribution of Heavy Minerals Within a Water-lain Sandstone, Jour. Sed. Petrol., vol. 3, No. 1, pp. 3-29.

Russell, R. D. (1935): Frequency Percentage Determinations of Detrital Quartz and Feldspar, Jour. Sed. Petrol., vol. 5, No. 3, pp. 109-114.

Schalk, M. (1946): A Study of Textural Changes in a Beach by Repeated Samplings, Jour. Sed. Petrol., vol. 16, No. 2, pp.43-51.

Shillaber, C. P. (1944): Photomicrography in Theory and Practise, 1st. Ed.

Shimer, H. W. and Shrock, R. R. (1944): Index Fossils of North America, 1st Ed.

St. Clair, D. W. (1935): The Use of Acetic Acid to Obtain Insoluble Residues, Jour. Sed. Petrol., vol. 5, No. 3, pp.146-149.

Taylor, J. M. (1950): Pore-space Reduction in Sandstones, Bull. Amer. Assoc. of Pet. Geol., vol. 34, pt. 1, pp.701-717.

Tester, A. C. (1931): The Measurement of the Shapes of Rock Particles, Jour. Sed. Petrol., vol. 1, No. 1, pp.1-5.

Theil, G. A. (1940): The Relative Resistance to Abrasion of Mineral Grains of Sand Size, vol. 10, No. 3, pp.103-124.

Twenhofel, W. H. (1941): The Frontiers of Sedimentary Mineralogy and Petrology, Jour. Sed. Petrol., vol. 11, No. 2, pp.53-63.

_________________(1945): The Rounding of Sand Grains, Jour. Sed. Petrol. vol. 15, No. 2, pp.59-71.

_________________(1950): Principles of Sedimentation, 2nd. Ed.

Tyler, S. A. (1936): Heavy Minerals of the St. Peter Sandstone in Wisconsin, Jour. Sed. Petrol., vol. 6, No. 2, pp.55-84.

_____________and Marsden, R. W. (1938): The Nature of Leucoxene, Jour. Sed. Petrol., vol. 8, No. 2, pp.55-58.

Tyrrell, J. B. (1892): Report on North-western Manitoba, Geol. Surv., Canada, Ann. Rept., pp.5-231.

Wahlstrom, E. E. (1948): Igneous Minerals and Rocks, 1st. Ed.

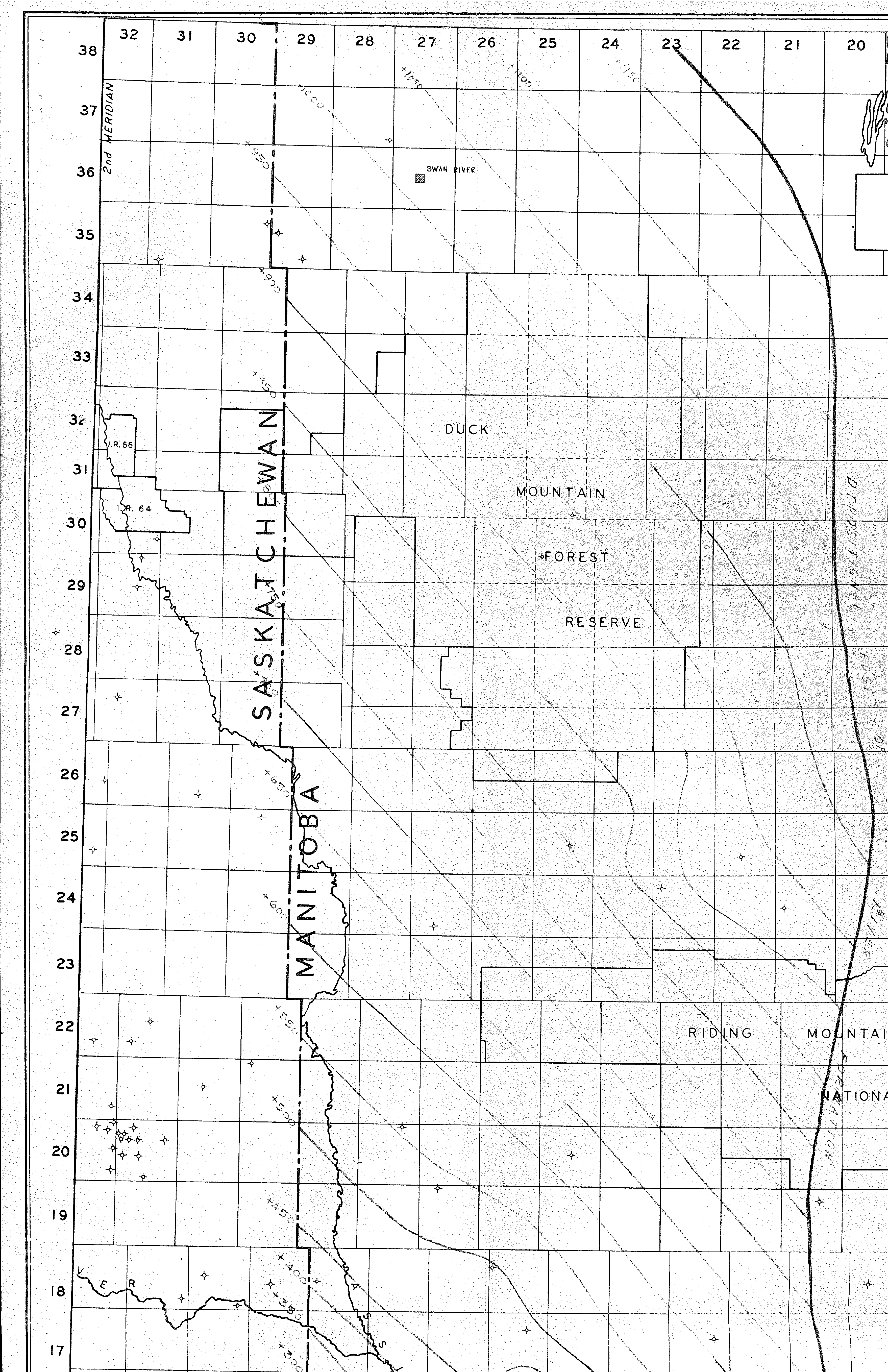
Wallace, R. C. (1925): The Geological Formations of Manitoba, 1st. Ed.

Webb, J. B. (1951): Geological History of Plains of Western Canada, Bull. Amer. Assoc. of Pet. Geol., vol. 35, pp.2291-2316.

Whiteaves, J. F. (1876): Mesozoic Fossils, Geol. Surv., Canada, Mem. 116, v ol. 1.

Wickenden, R. T. D. (1945): Mesozoic Stratigraphy of the Eastern Plains, Manitoba and Saskatchewan, Geol. Surv., Canada, Mem. 239, pp.12-17.

Workman, L. E. et al (1952): Lower Cretaceous of the Peace River Region, Can. Oil and Gas Indust., vol. 5, No. 3, pp.56-57.



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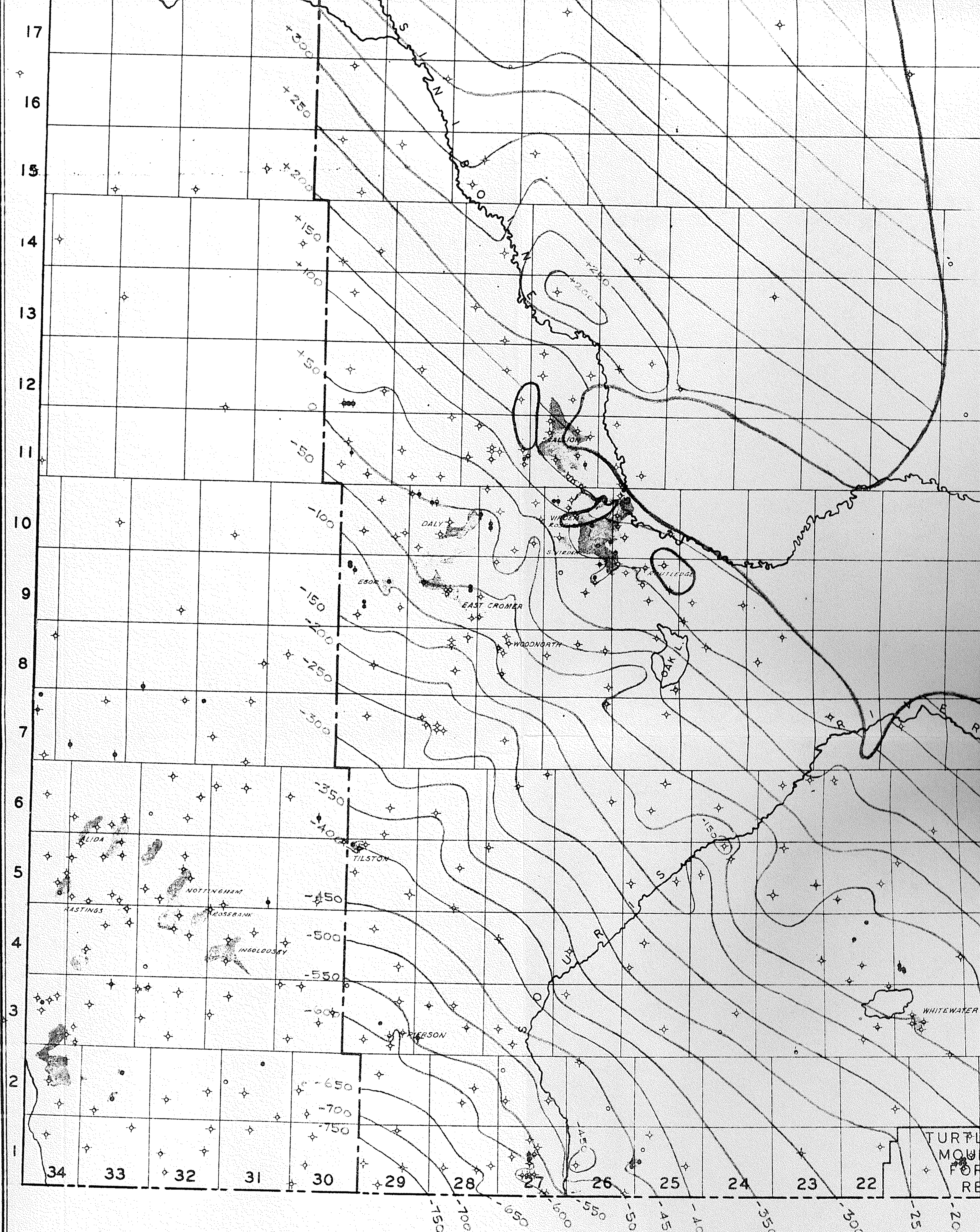
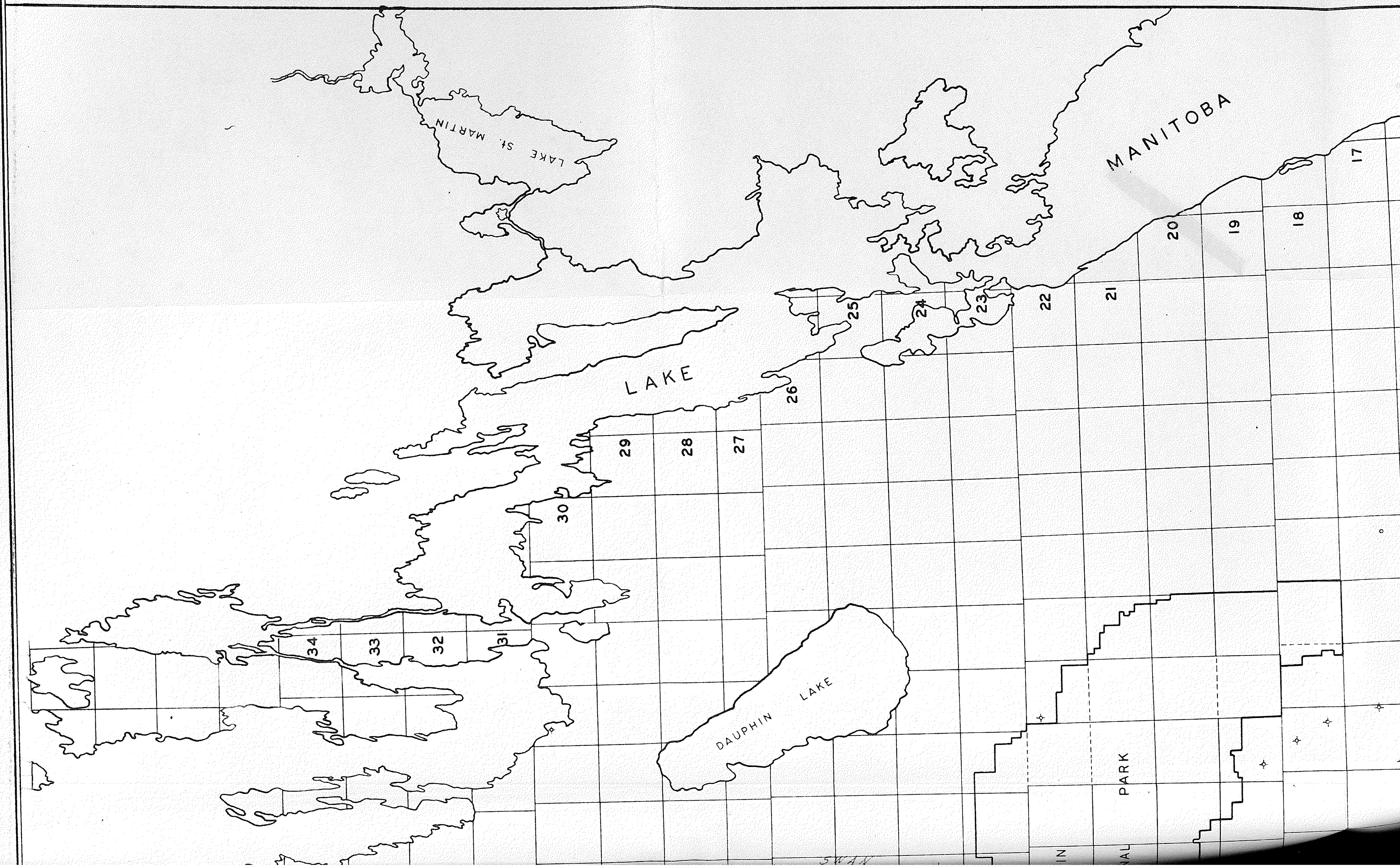
18
17
2nd MERIDIAN
SWAN RIVER
+1050
+1100
+1150
+1000
+950
+900
+850
+750
+650
+600
+550
+500
+450
+400
+350
+300
I.R. 66
I.R. 64
SASKATCHEWAN
MANITOBA
DUCK
MOUNTAIN
FOREST
RESERVE
RIDING
MOUNTAIN
NATIONAL
DEPOSITIONAL
EDGE
FORMATION
RIVER



STRUCTUR

ON TOP OF SWAN

SCALE: 1 INCH = 8 MILES



LAKE St. MARTIN
MANITOBA
LAKE
DAUPHIN LAKE
PARK
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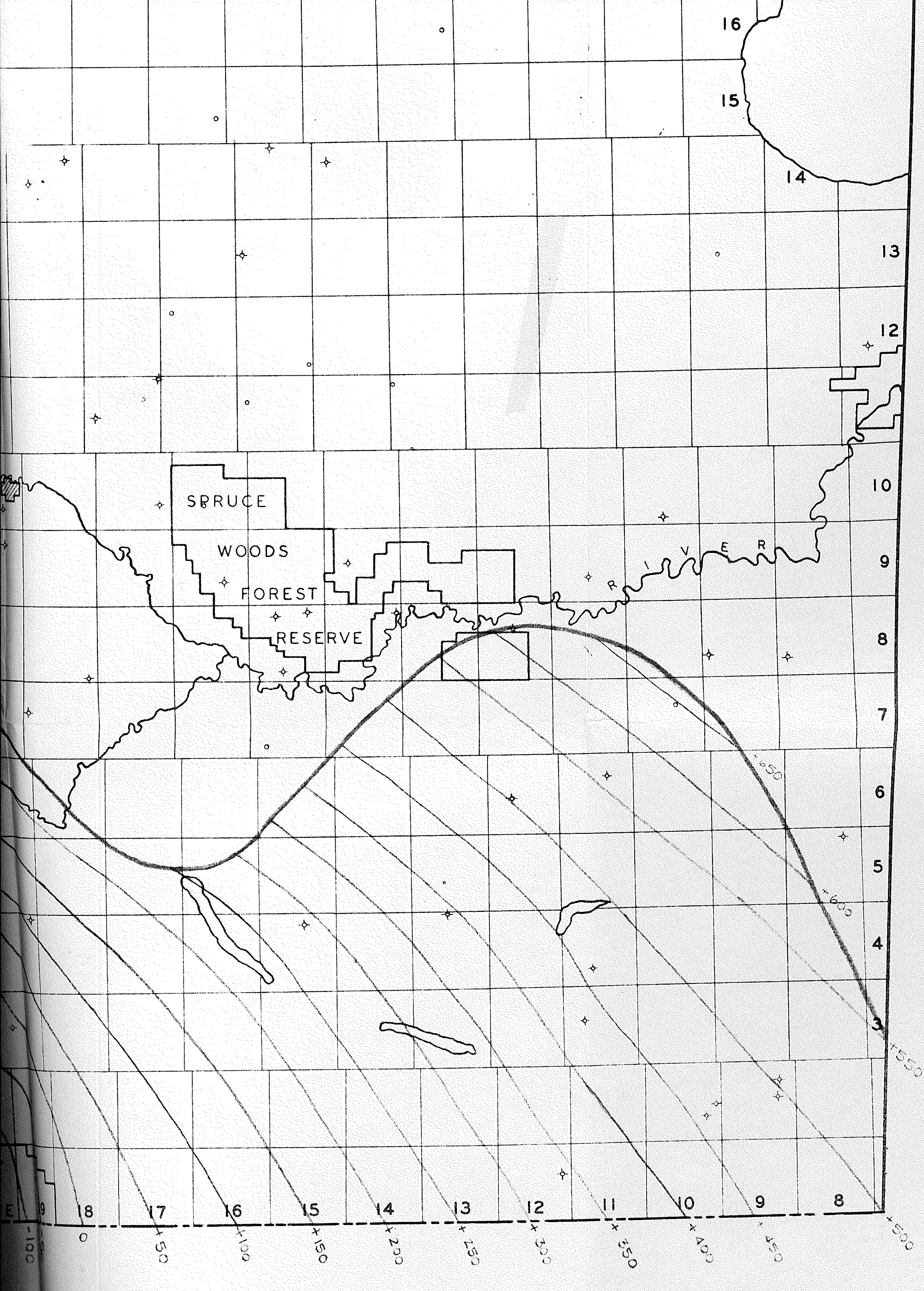
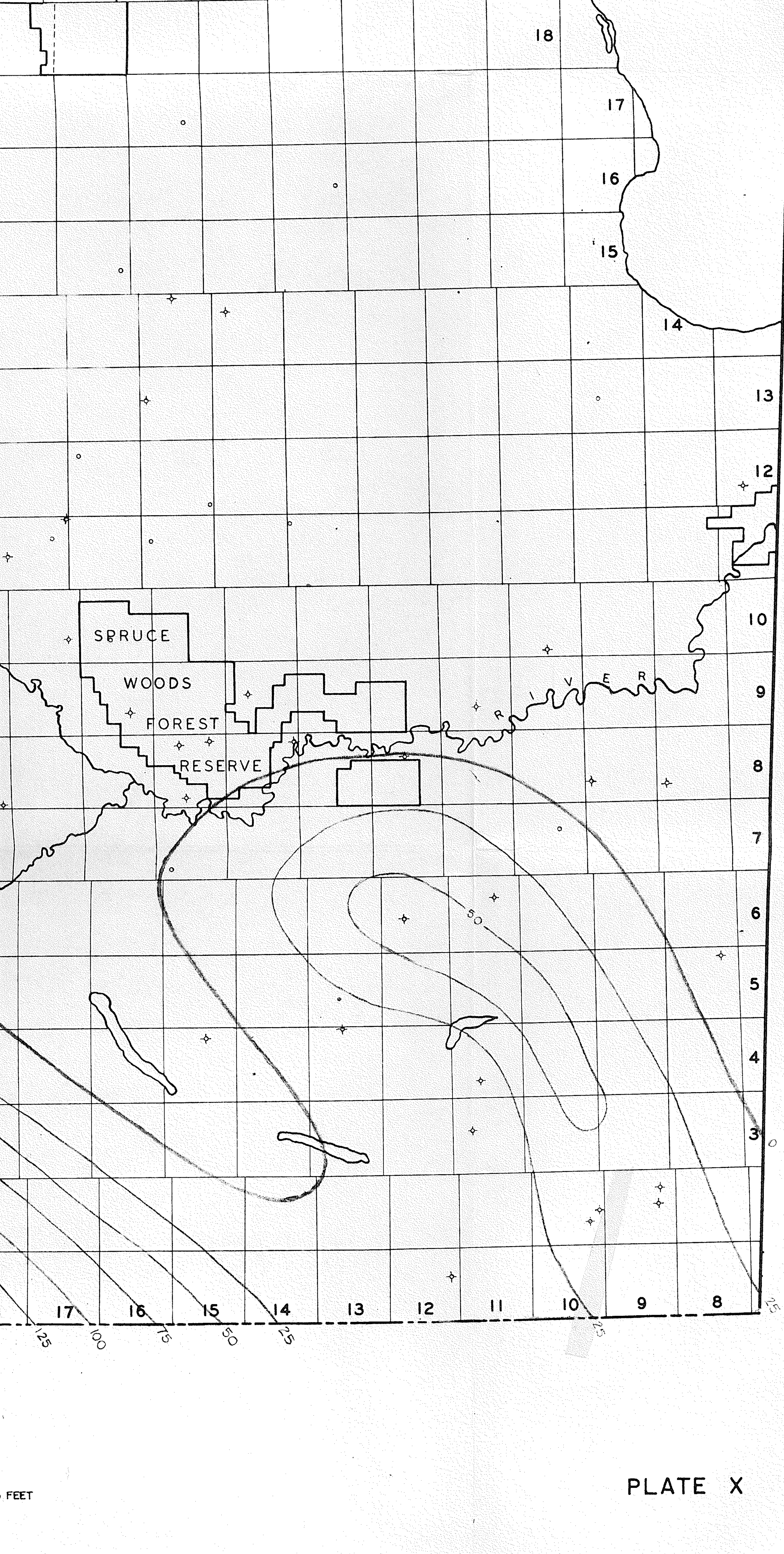


ONTORS

VER FORMATION

CONTO INTERVAL = 50 FEET

PLATE XI



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SPRUCE
WOODS
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RESERVE
R I V E R
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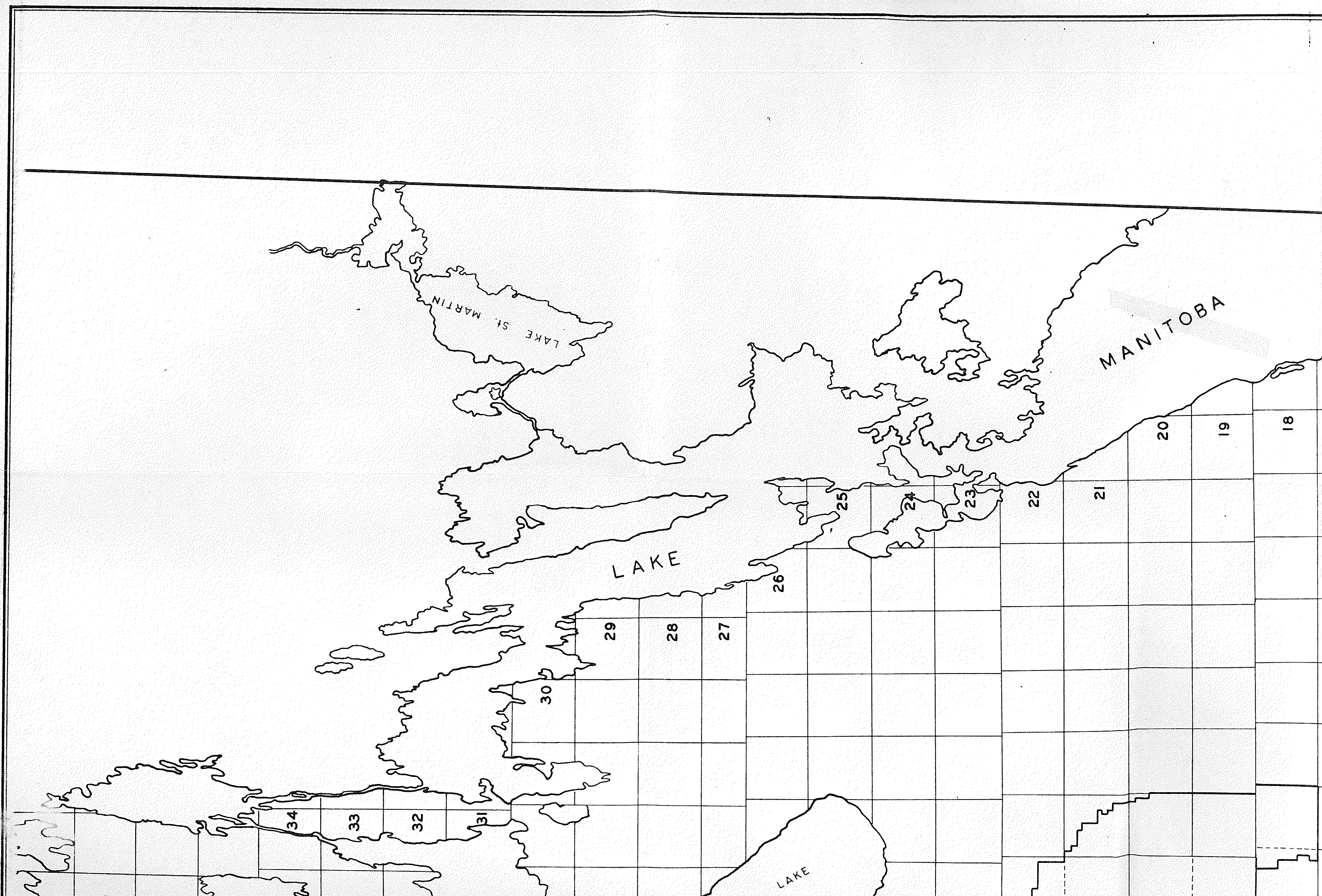
FEET

PLATE X



LAKE St. MARTIN
MANITOBA
LAKE
LAKE
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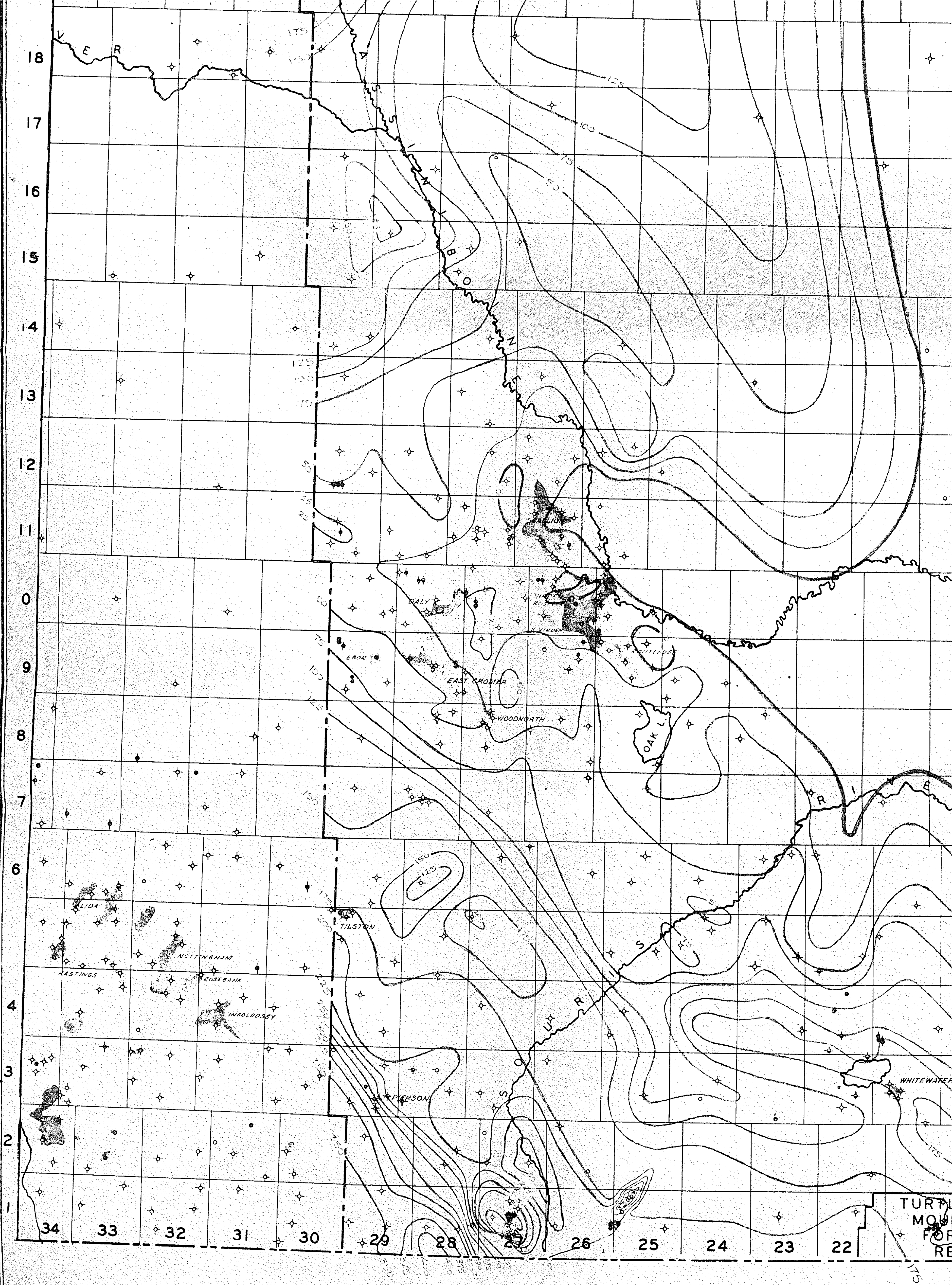
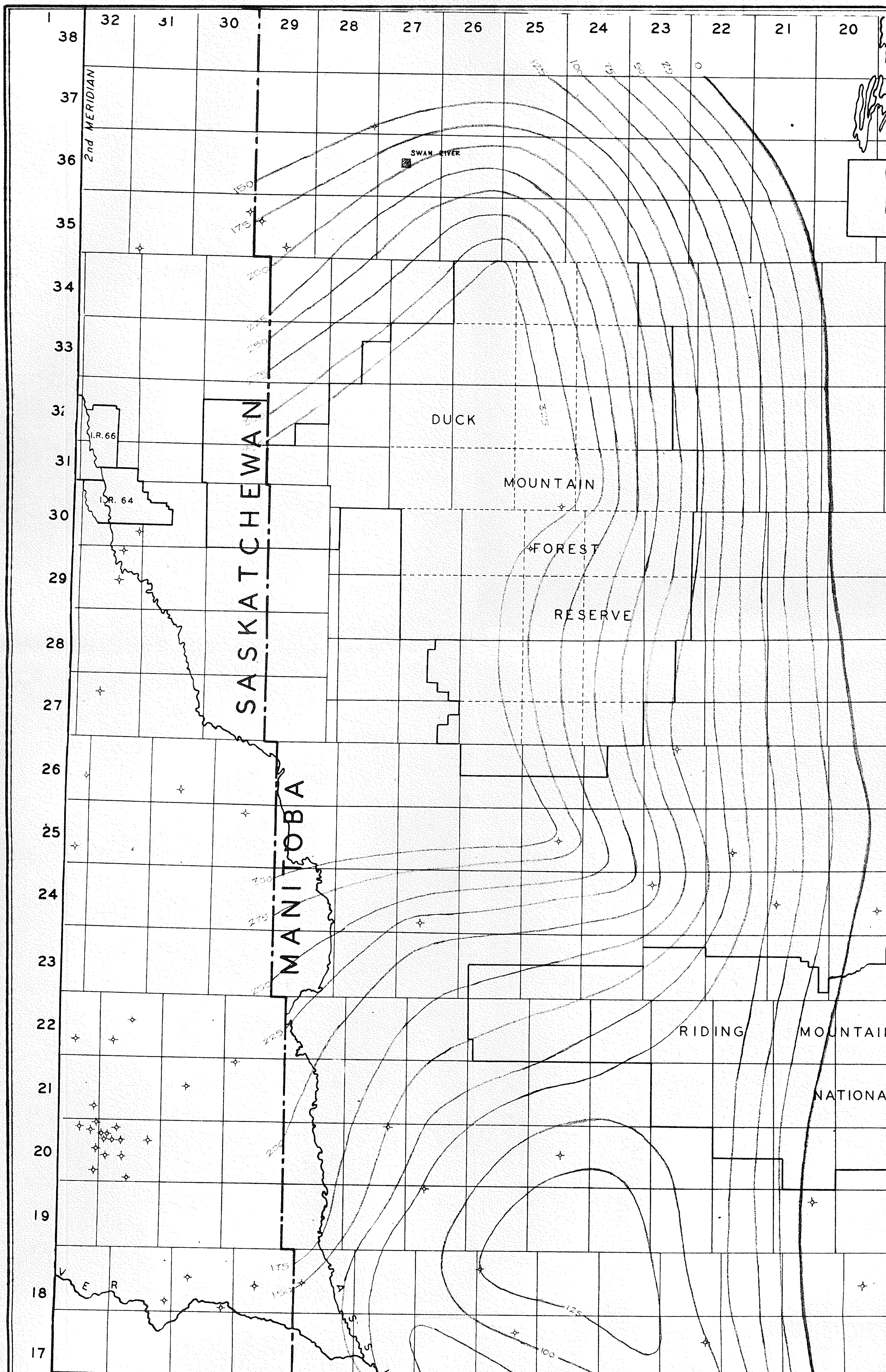


ISOPACH
SWAN RIVE

SCALE : 1 INCH = 8 MILES



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19
18
17
2nd MERIDIAN
SWAN RIVER
DUCK
MOUNTAIN
FOREST
RESERVE
SASKATCHEWAN
MANITOBA
I.R. 66
I.R. 64
RIDING
MOUNTAIN
NATIONA
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75
50
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0
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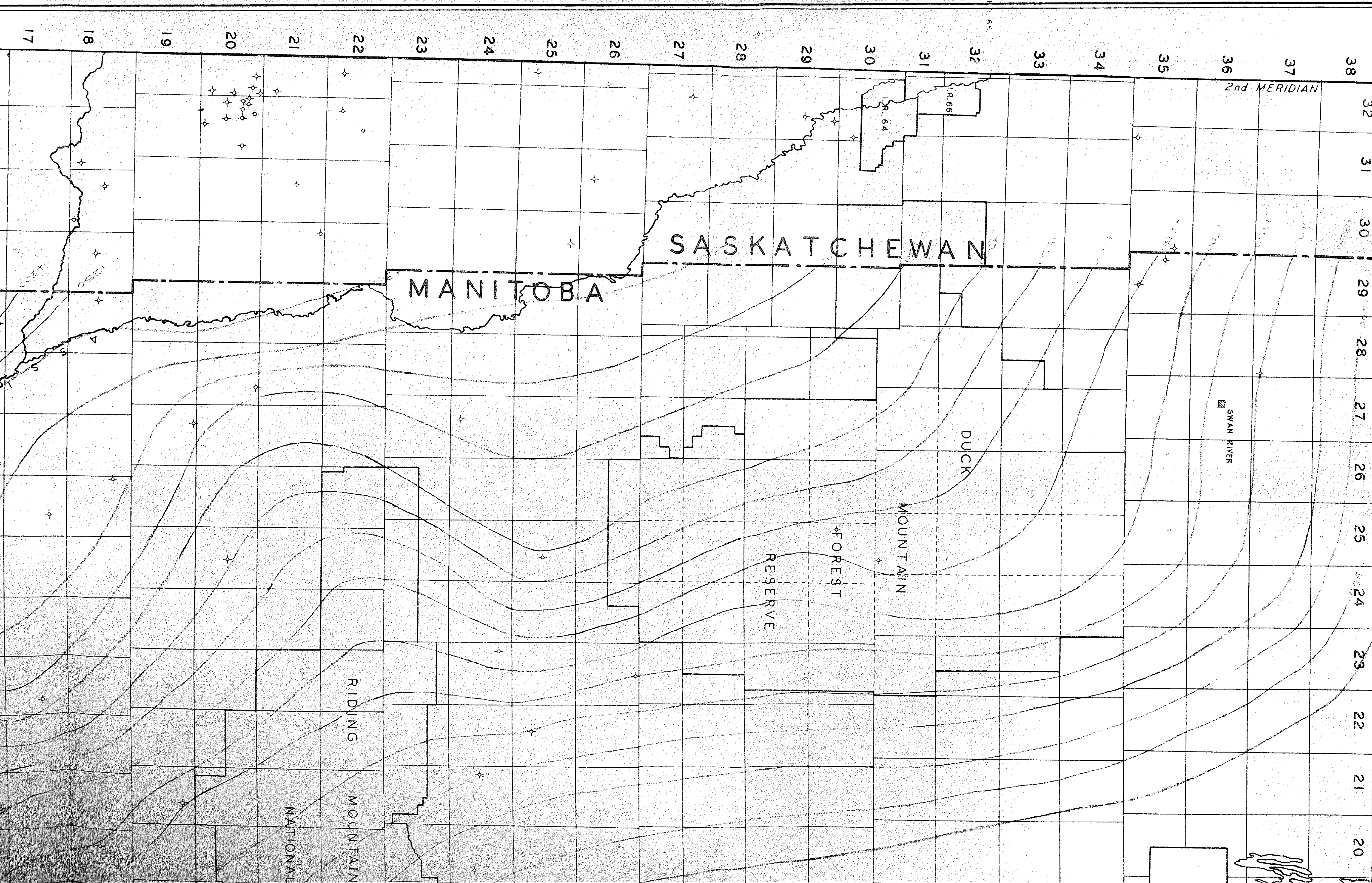
275
300
325



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38
2nd MERIDIAN
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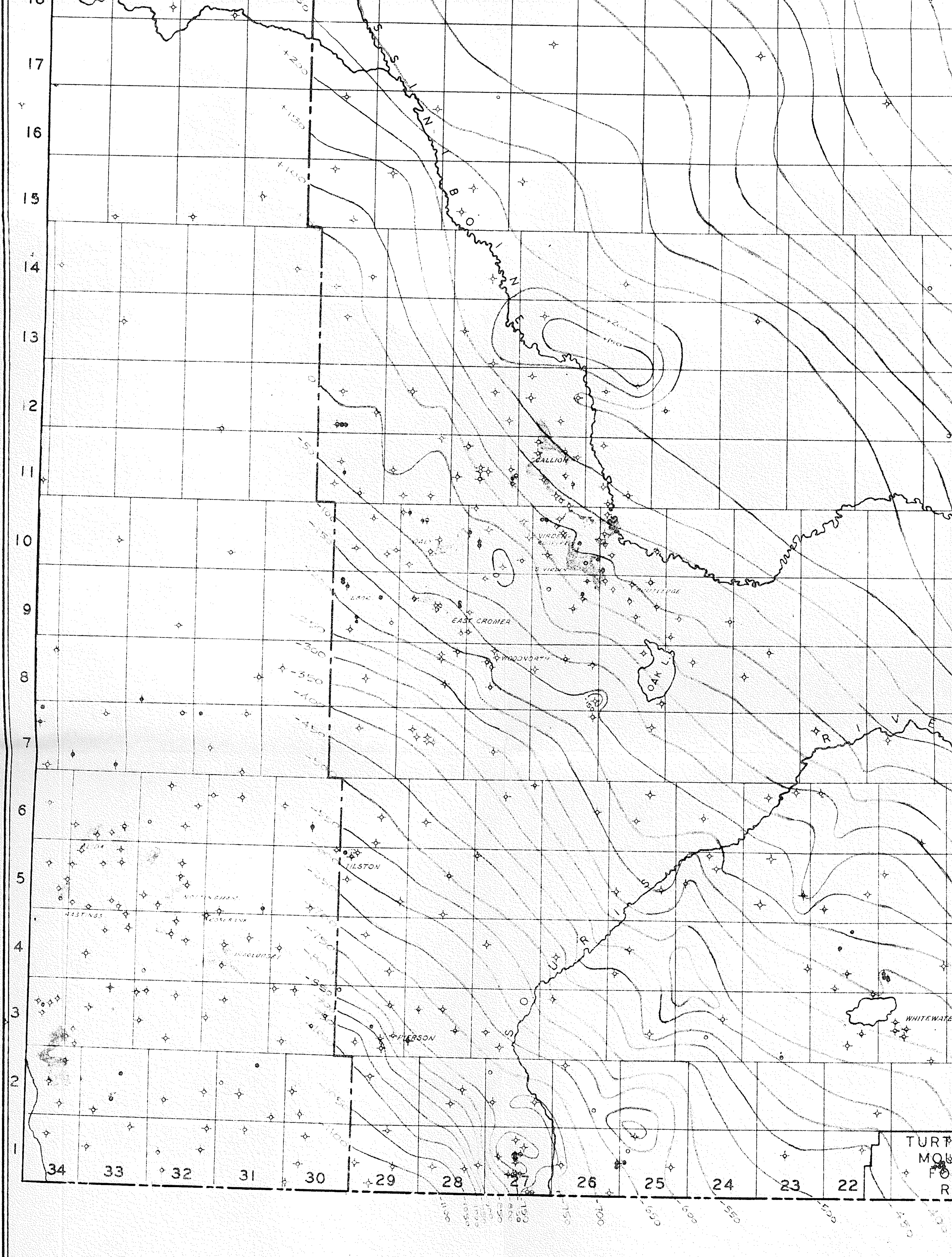
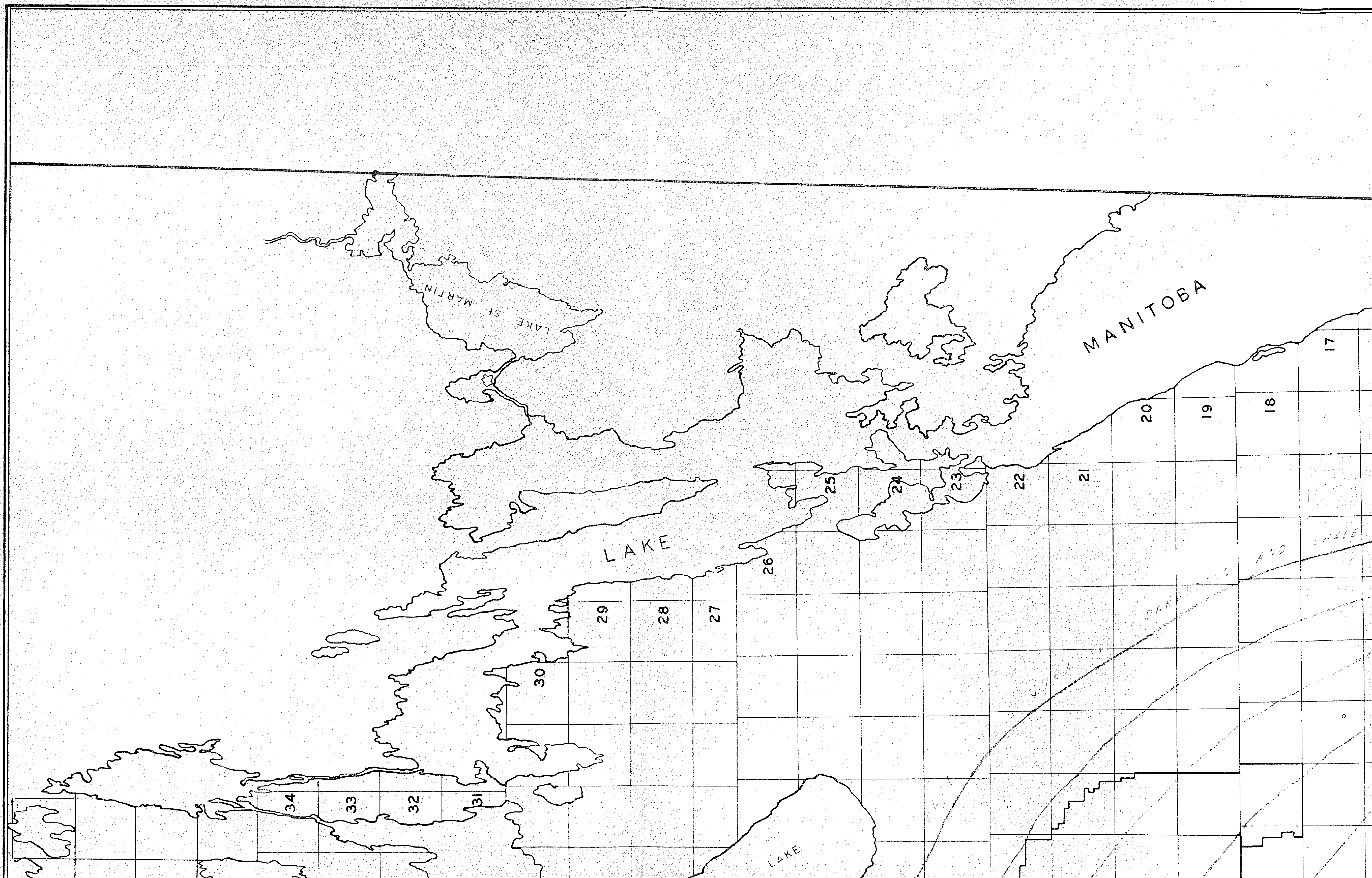
26
25
24
23
22
21
20
I.R. 64
I.R. 66
SASKATCHEWAN
MANITOBA
DUCK
MOUNTAIN
FOREST
RESERVE
SWAN RIVER
RIDING
MOUNTAIN
NATIONAL



CONTOUR

PRE - CRETACE

SCALE : 1 INCH = 8MILES



LAKE ST. MARTIN
MANITOBA
LAKE
LAKE
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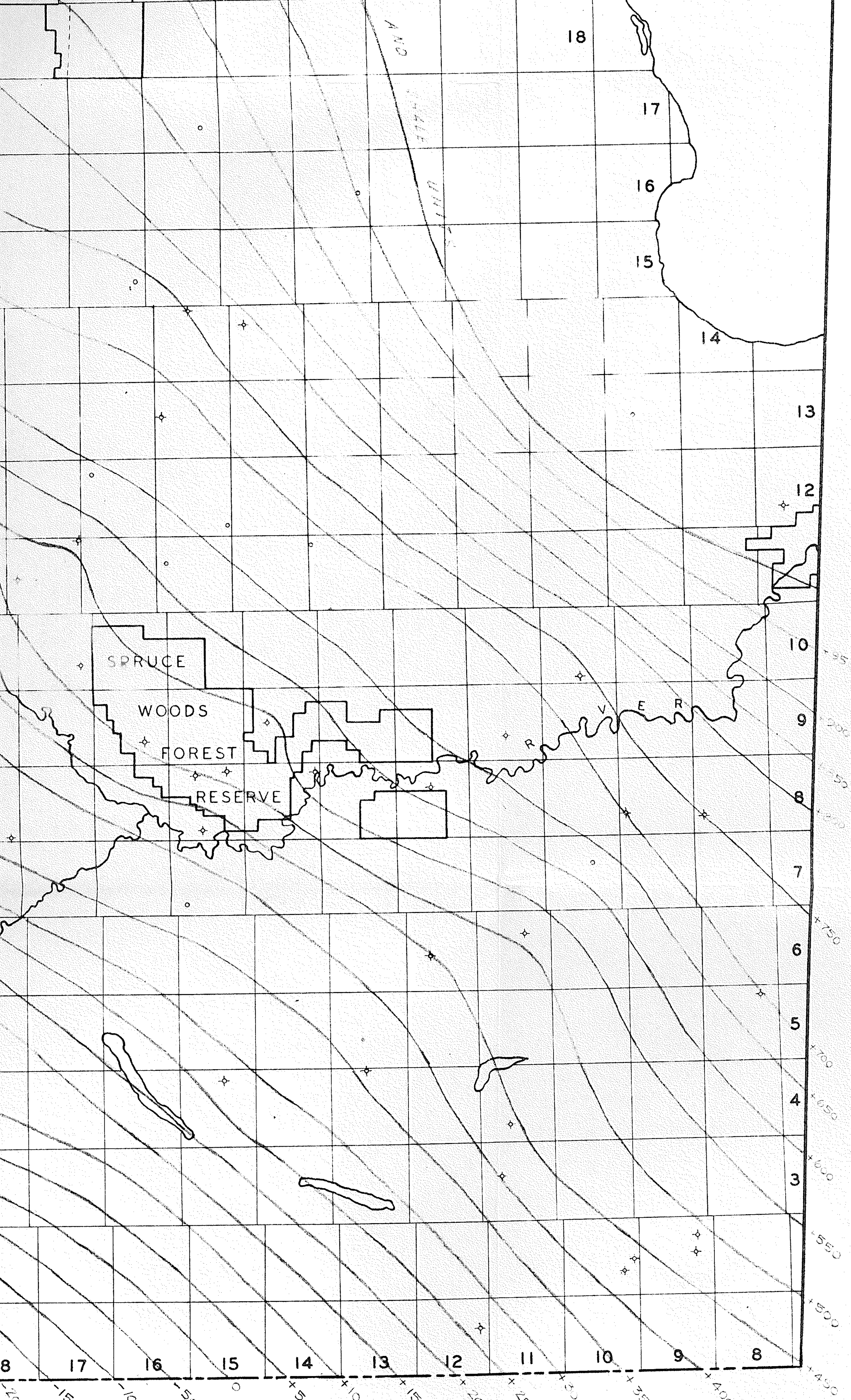
JURASSIC SANDSTONE AND SHALE



MITY

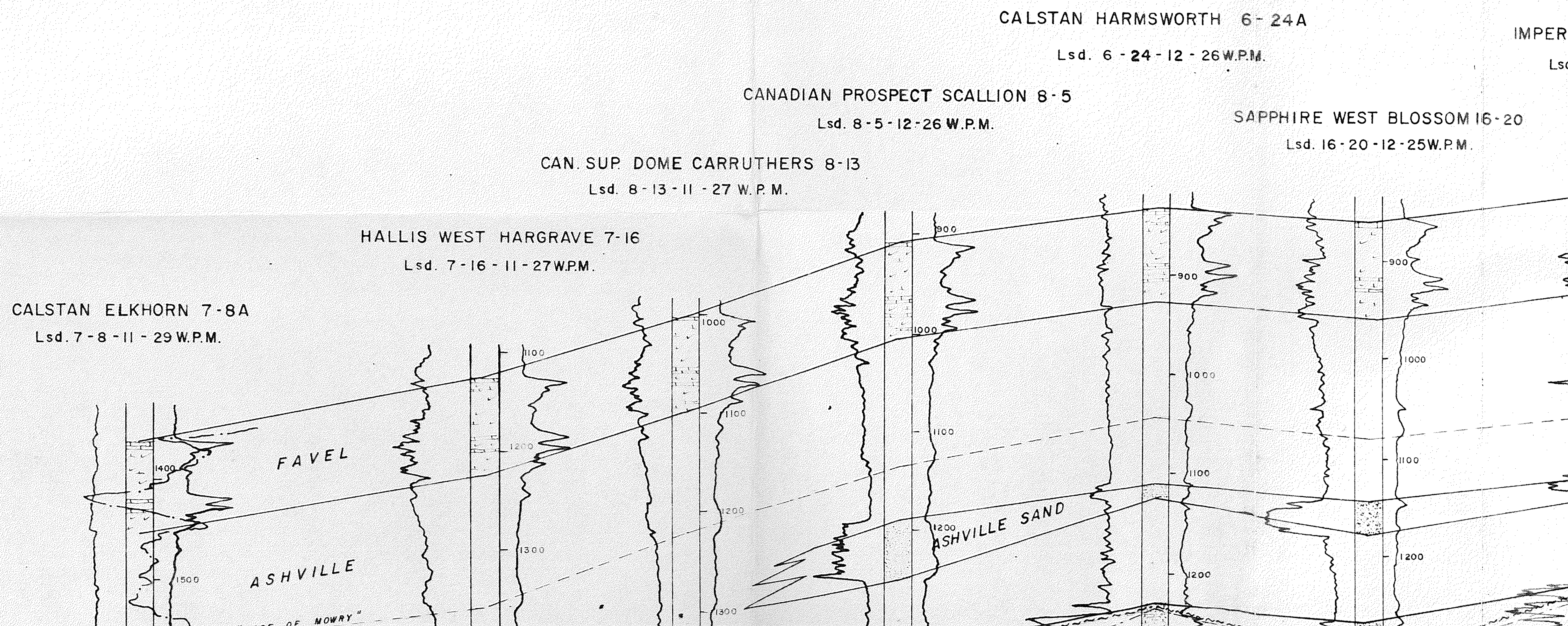
VAL = 50 FEET

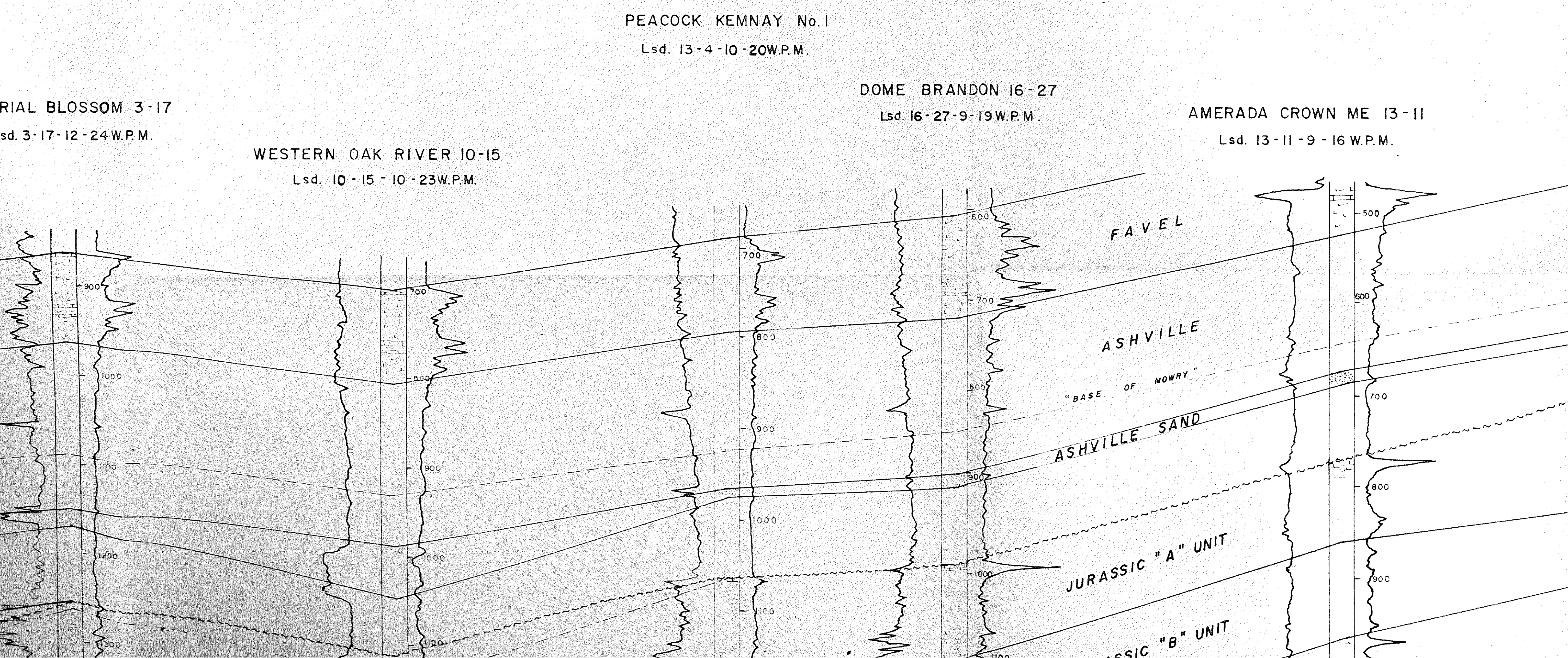
PLATE IX

PLATE XIV

STRUCTURAL CROSS SECTION
from
CALSTAN ELKHORN 7-8A
to
CANADIAN PROSPECT TREHERNE 13-7

SCALE: Vertical : 1 inch = 100 feet
Horizontal : 1 inch = 8 miles





PEACOCK KEMNAY No. I
Lsd. 13-4-10-20W.P.M.
RIAL BLOSSOM 3-17
sd. 3-17-12-24W.P.M.
WESTERN OAK RIVER 10-15
Lsd. 10-15-10-23W.P.M.
DOME BRANDON 16-27
Lsd. 16-27-9-19W.P.M.
AMERADA CROWN ME 13-11
Lsd. 13-11-9-16W.P.M.
FAVEL
ASHVILLE
"BASE OF NOWRY"
ASHVILLE SAND
JURASSIC "A" UNIT
ASSIC "B" UNIT
900
1000
1100
1200
1300
700
800
900
1000
1100
700
800
900
1000
1100
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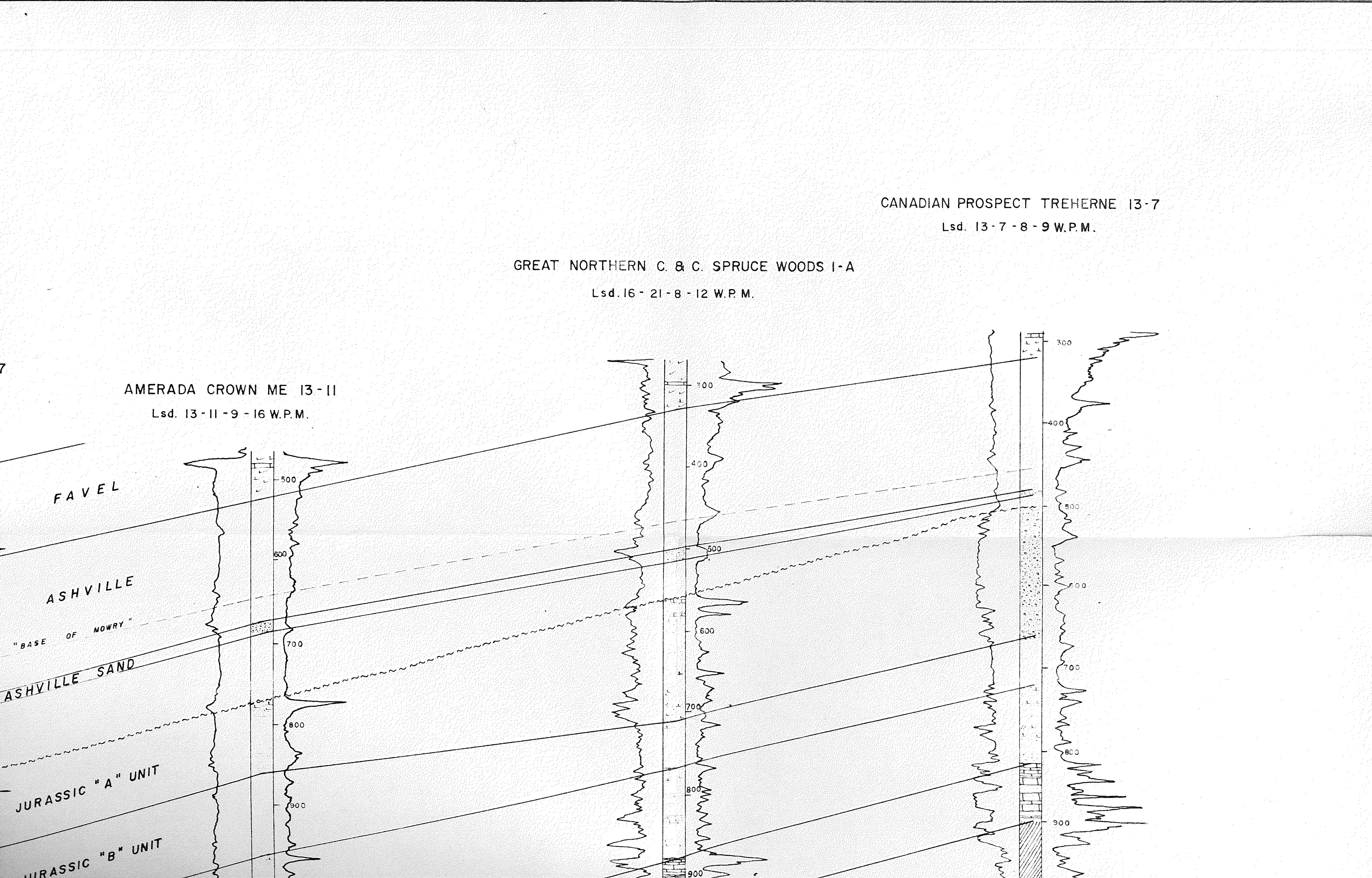
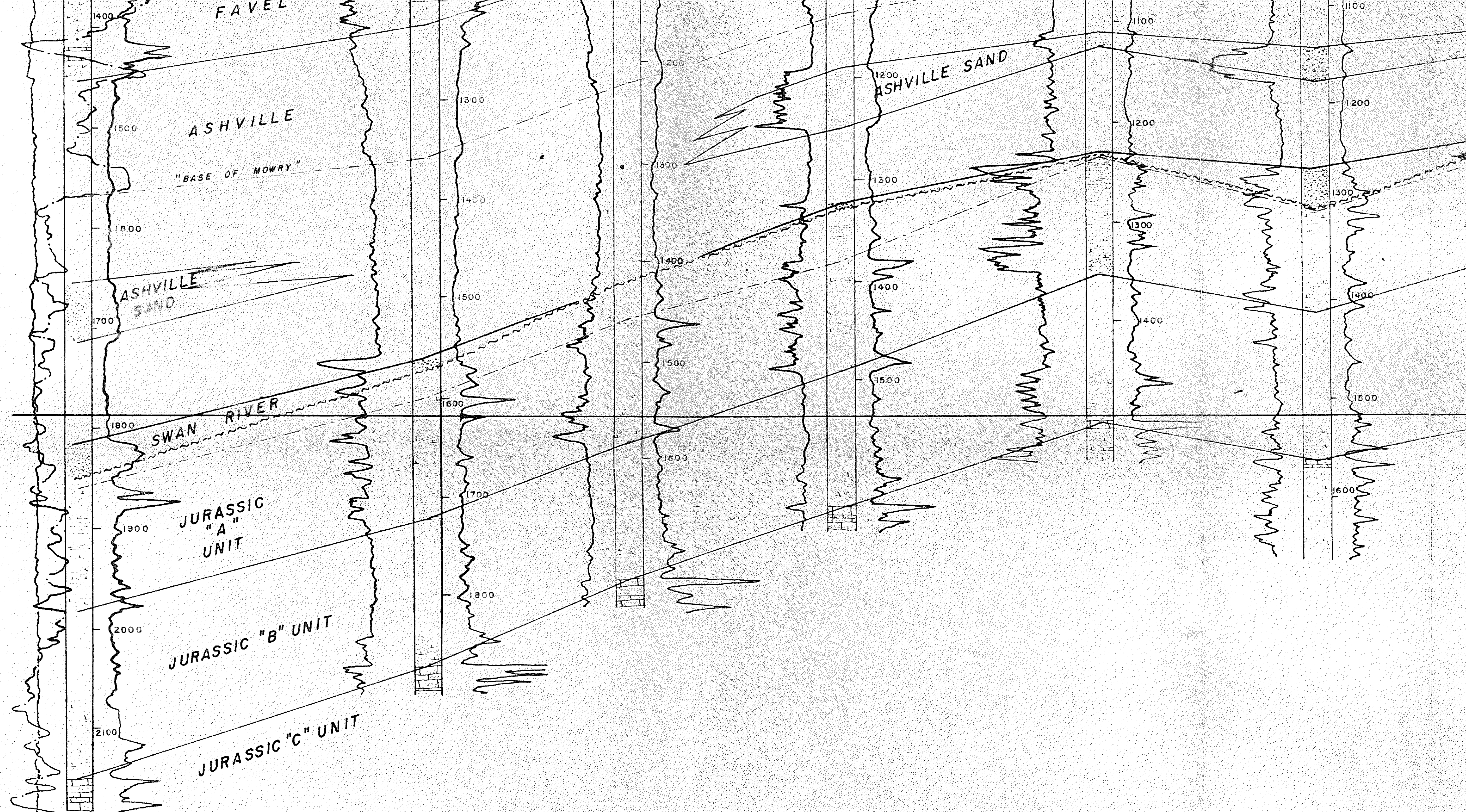
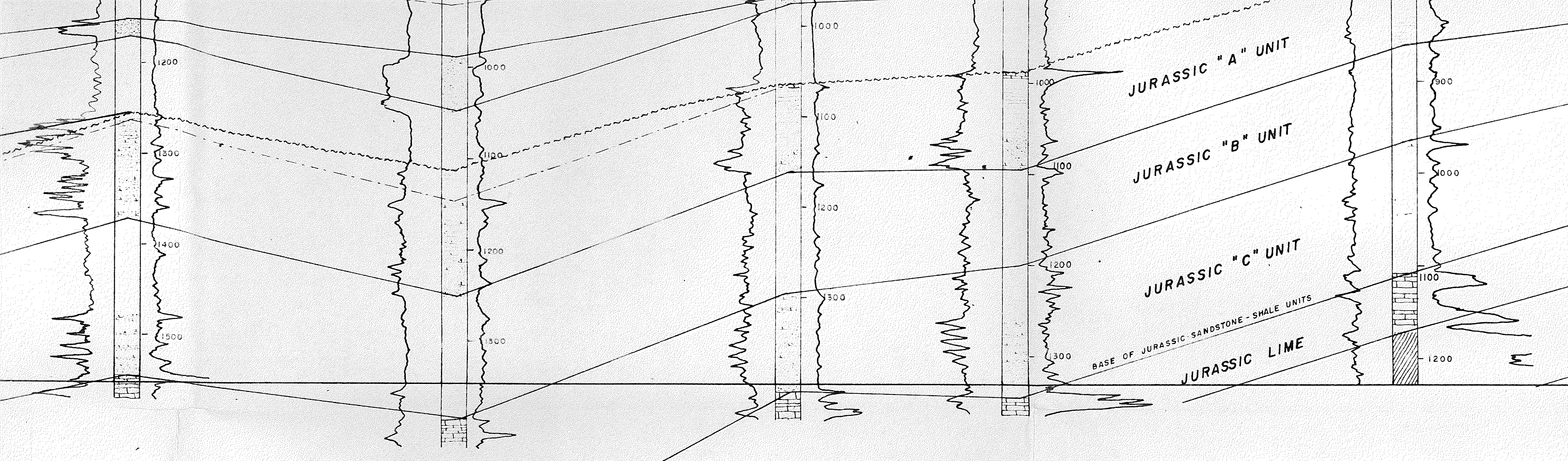
900

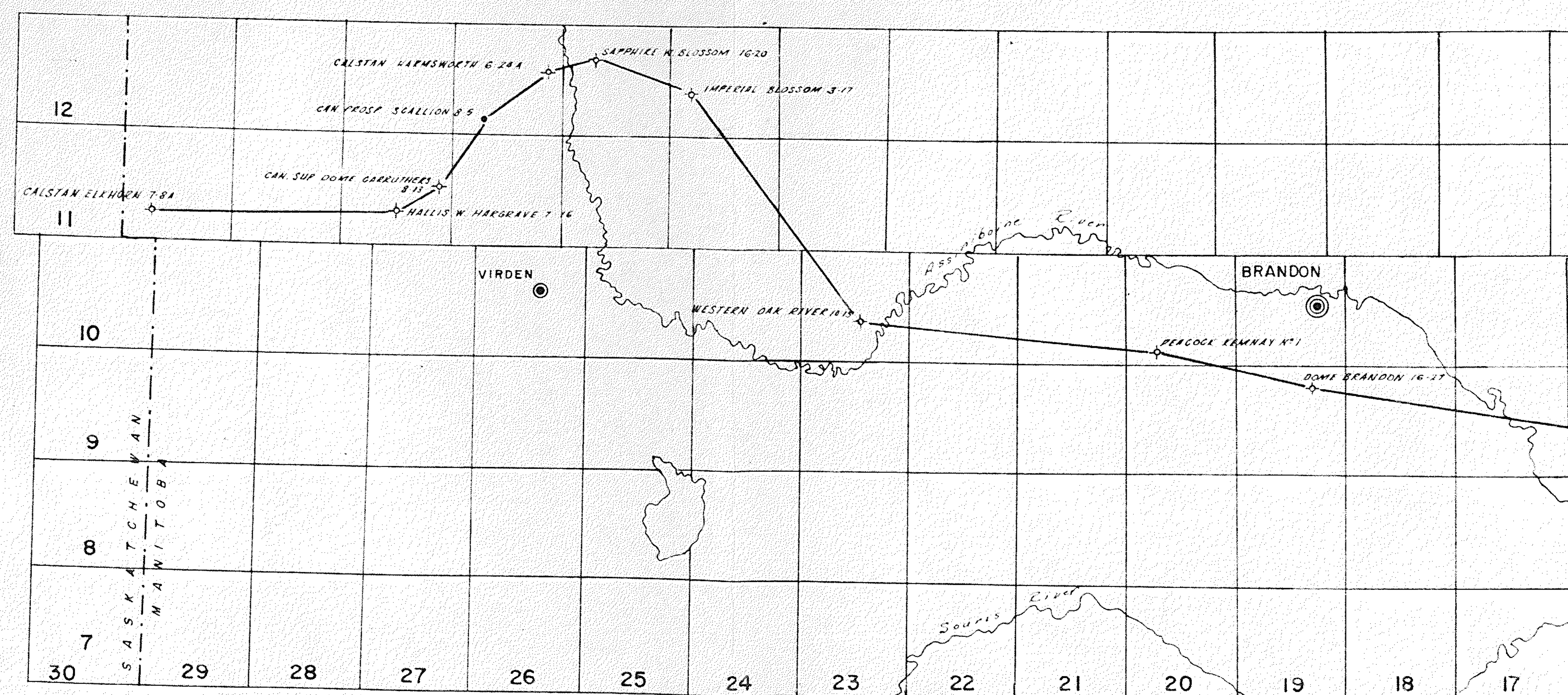

CANADIAN PROSPECT TREHERNE 13-7
Lsd. 13-7-8-9 W.P.M.
GREAT NORTHERN C. & C. SPRUCE WOODS 1-A
Lsd. 16-21-8-12 W.P.M.
AMERADA CROWN ME 13-11
Lsd. 13-11-9-16 W.P.M.
FAVEL
ASHVILLE
"BASE OF NOWRY"
ASHVILLE SAND
JURASSIC "A" UNIT
JURASSIC "B" UNIT
300
400
500
600
700
800
900


FAVEL
ASHVILLE
"BASE OF MOWRY"
ASHVILLE SAND
ASHVILLE SAND
SWAN RIVER
JURASSIC "A" UNIT
JURASSIC "B" UNIT
JURASSIC "C" UNIT



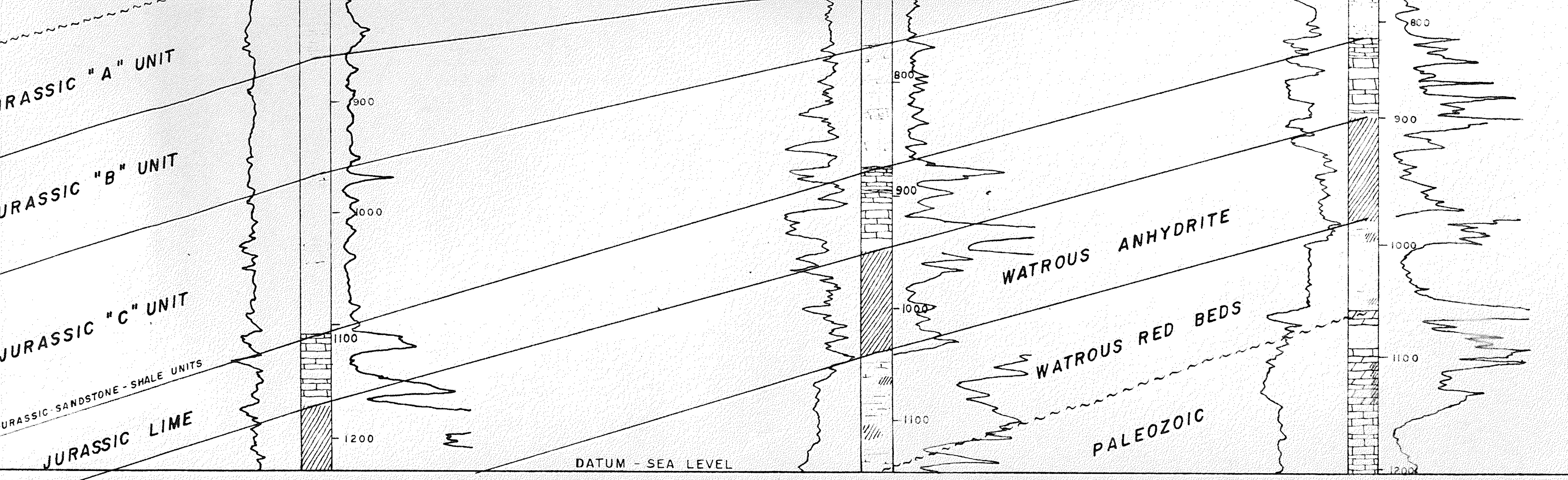
LEGEND

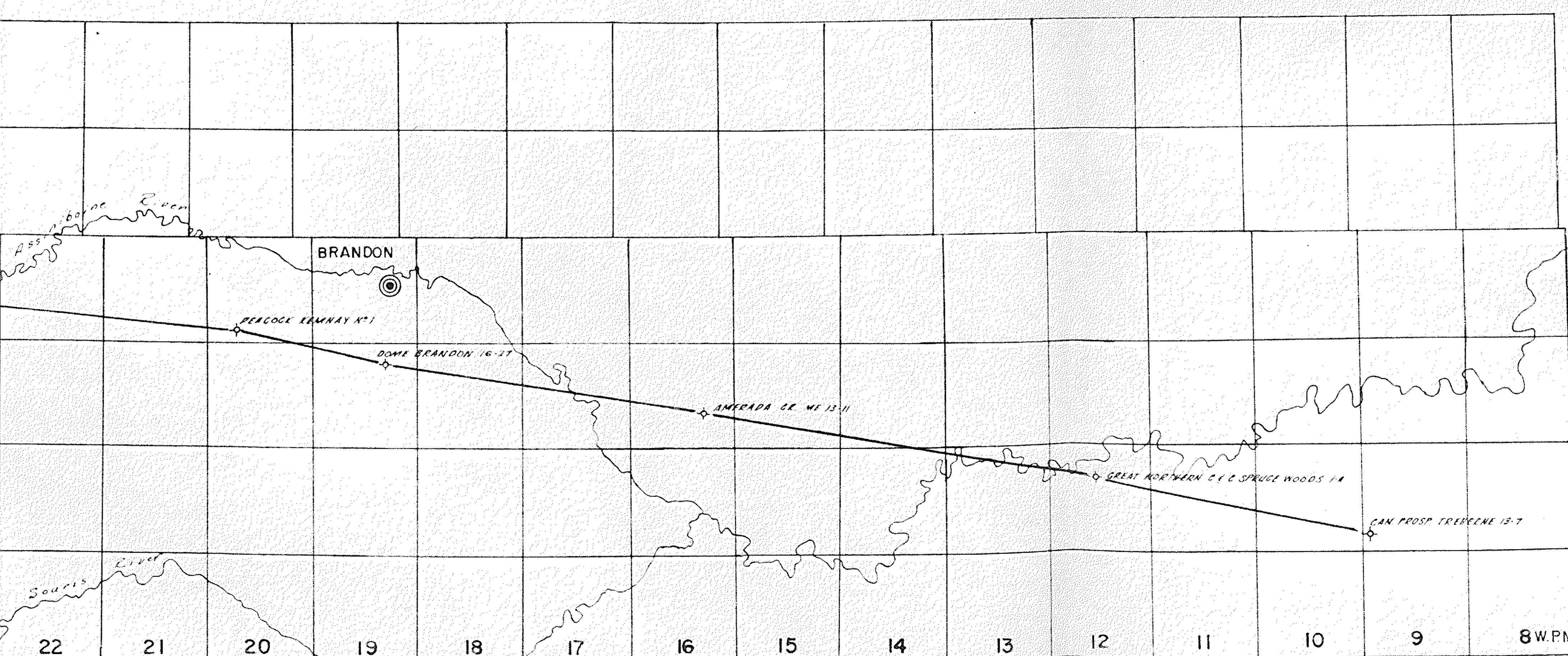
- COARSE GRAINED SANDSTONE
- MEDIUM GRAINED SANDSTONE
- FINE GRAINED SANDSTONE
- SILTSTONE
- LIMESTONE
- DOLOMITE
- ANHYDRITE
- SHALE
- SPECKLED SHALE
- CALCAREOUS SHALE, SILTSTONE, SANDSTONE



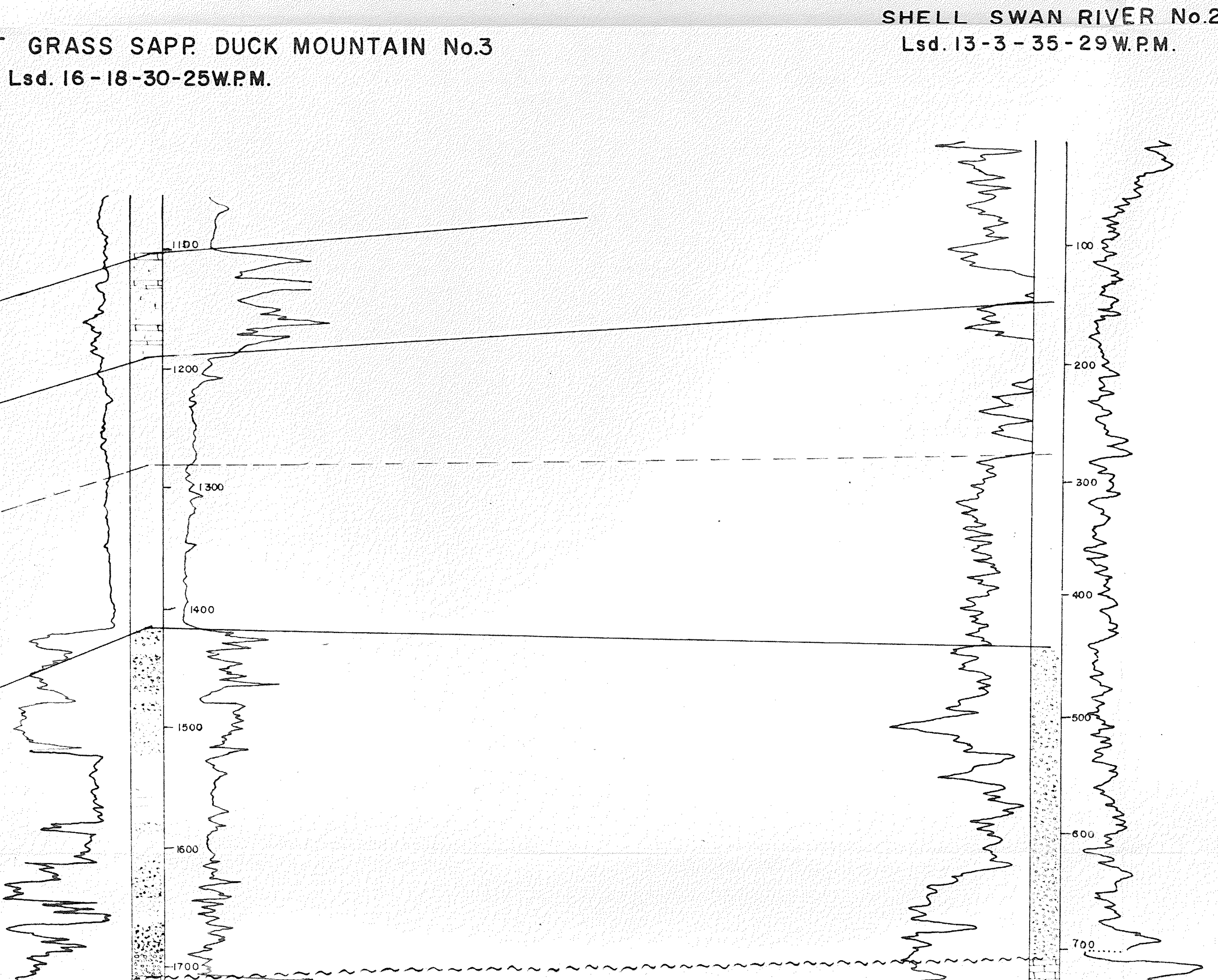
INDEX MAP

Scale : 1 inch = 8 miles





INDEX MAP
Scale: 1 inch = 8 miles


GRASS SAPP. DUCK MOUNTAIN No.3
Lsd. 16-18-30-25W.P.M.
SHELL SWAN RIVER No.2
Lsd. 13-3-35-29W.P.M.
1100
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1300
1400
1500
1600
1700
100
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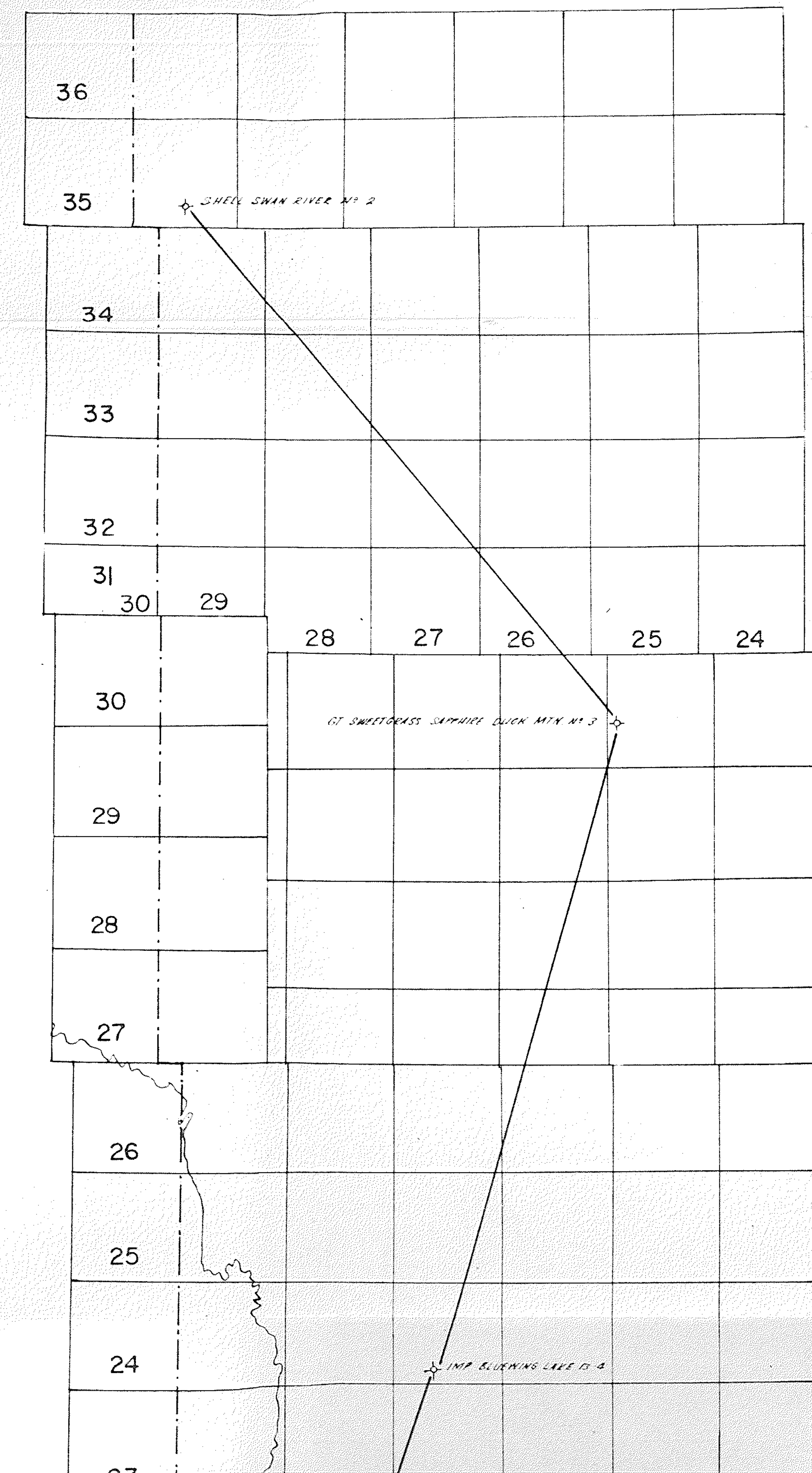
300
400
500
600
700


SHELL SWAN RIVER No 2
GT. SWEETGRASS SAPPHIRE DUCK MTN. No 3
IMP. BLUEWING LAKE 13-4
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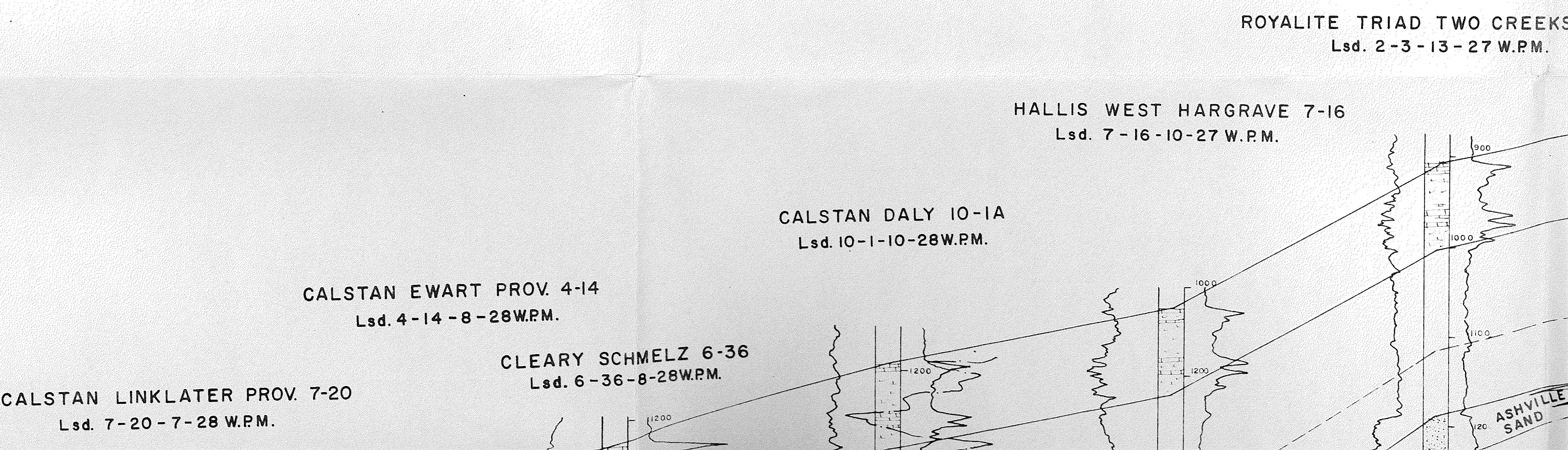
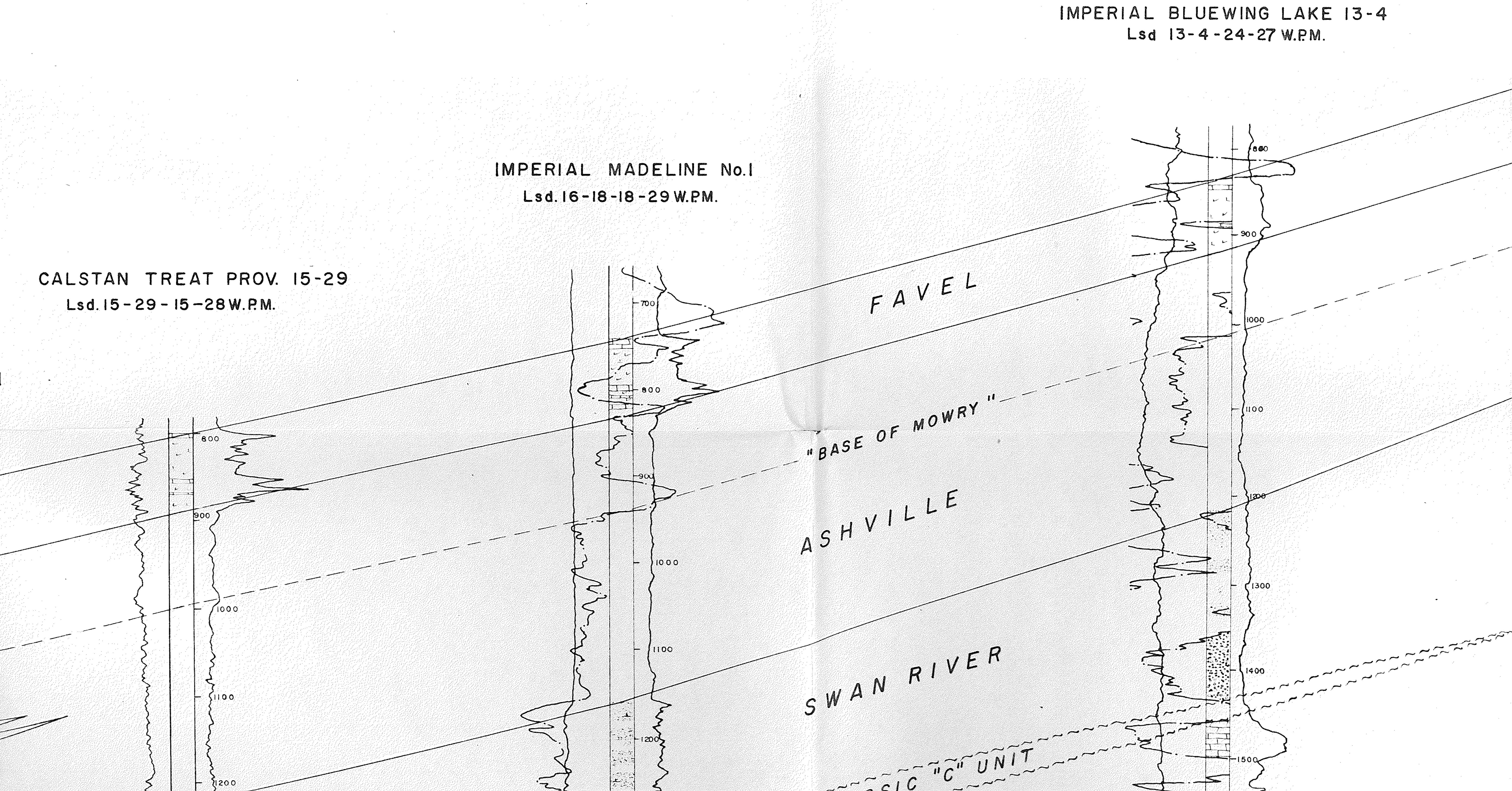
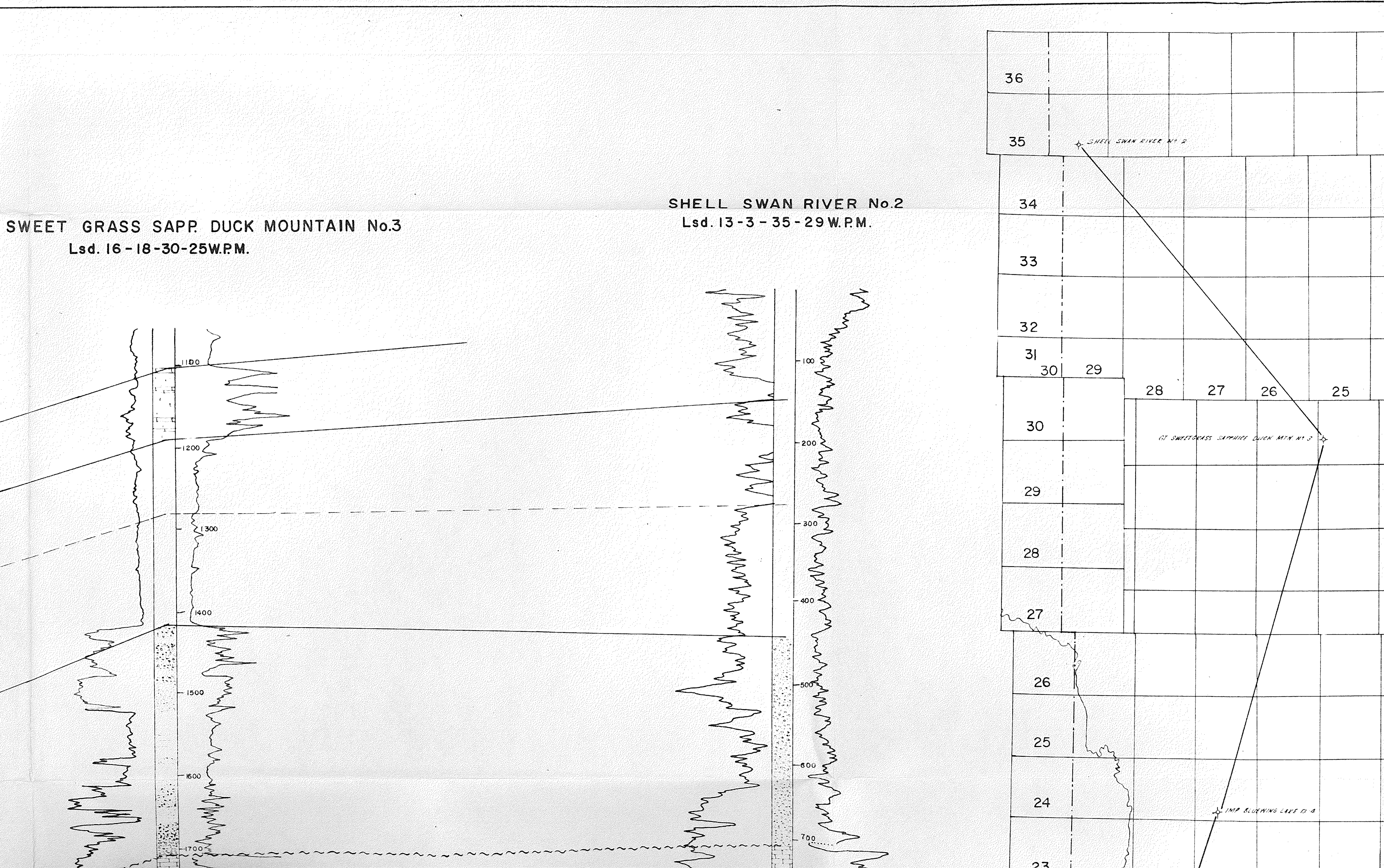

ROYALITE TRIAD TWO CREEKS
Lsd. 2-3-13-27 W.P.M.
HALLIS WEST HARGRAVE 7-16
Lsd. 7-16-10-27 W.P.M.
CALSTAN DALY 10-1A
Lsd. 10-1-10-28W.P.M.
CALSTAN EWART PROV. 4-14
Lsd. 4-14-8-28W.P.M.
CLEARY SCHMELZ 6-36
Lsd. 6-36-8-28W.P.M.
CALSTAN LINKLATER PROV. 7-20
Lsd. 7-20-7-28 W.P.M.
900
1000
1100
1200
ASHVILLE SAND


IMPERIAL BLUEWING LAKE 13-4
Lsd 13-4-24-27 W.P.M.
IMPERIAL MADELINE No.1
Lsd.16-18-18-29 W.P.M.
CALSTAN TREAT PROV. 15-29
Lsd.15-29-15-28 W.P.M.
FAVEL
"BASE OF MOWRY"
ASHVILLE
SWAN RIVER
"C" UNIT


SWEET GRASS SAPP. DUCK MOUNTAIN No.3
Lsd. 16-18-30-25W.P.M.
SHELL SWAN RIVER No.2
Lsd. 13-3-35-29W.P.M.
1100
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1600
1700
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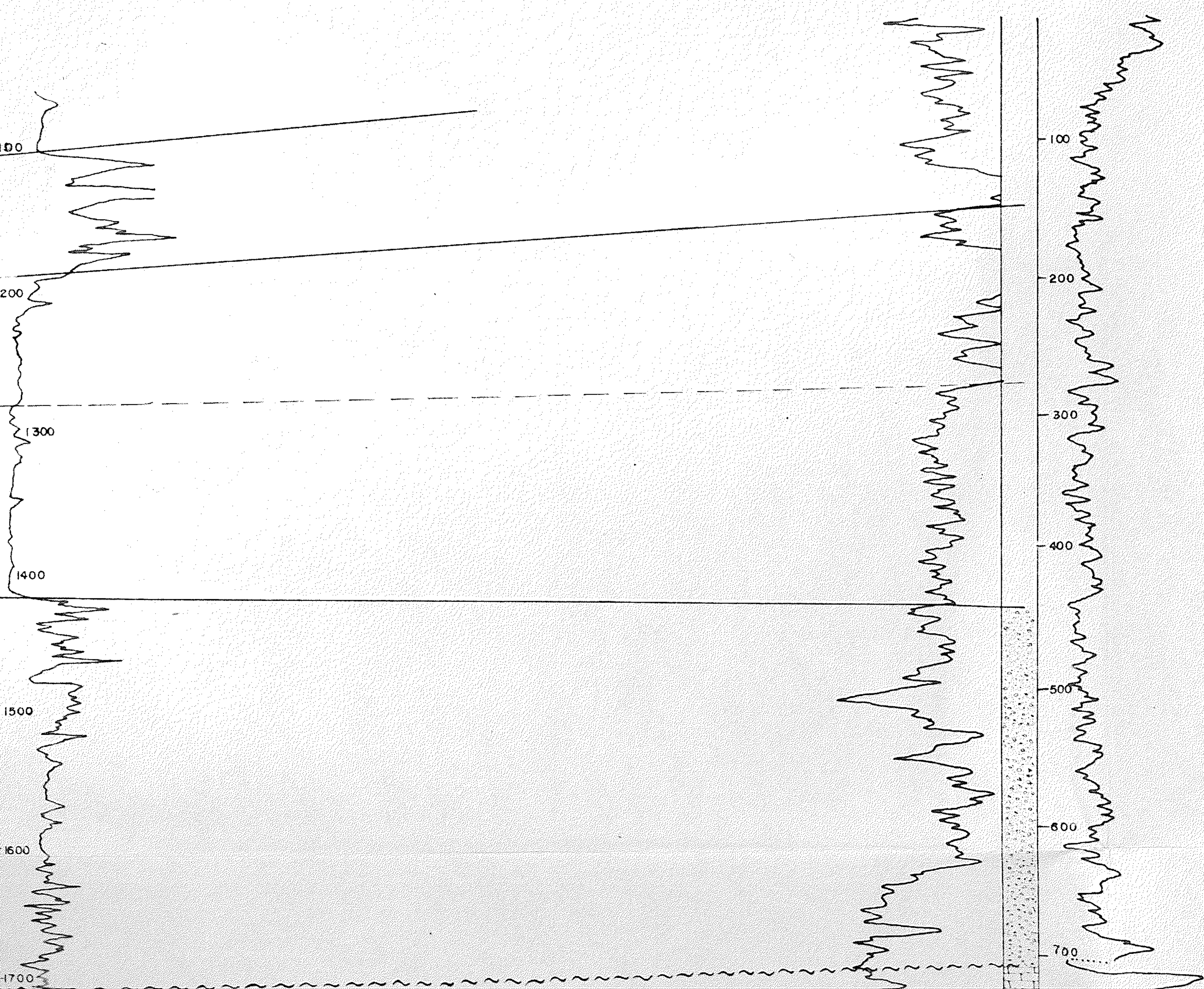
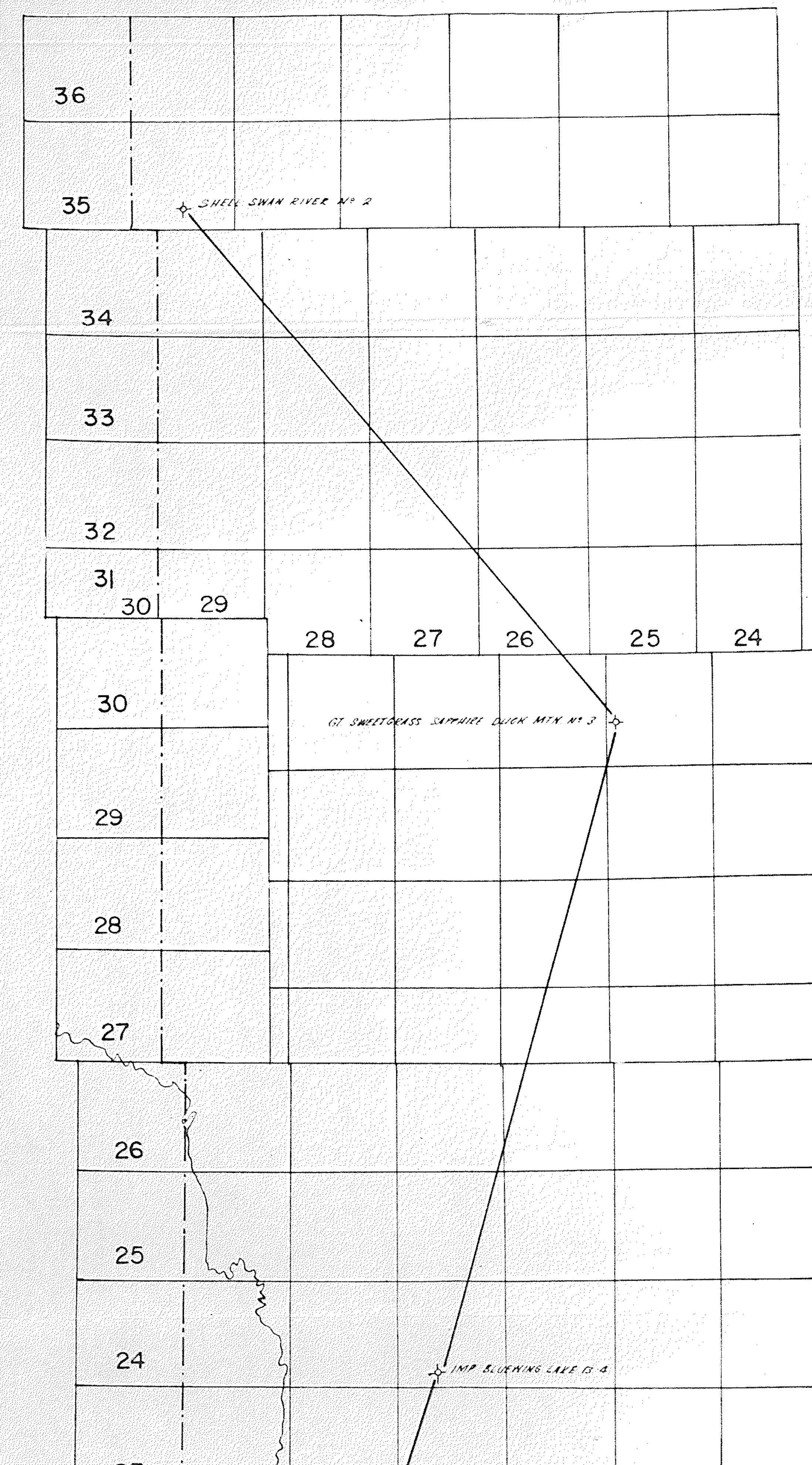
P. DUCK MOUNTAIN No.3
25W.P.M.

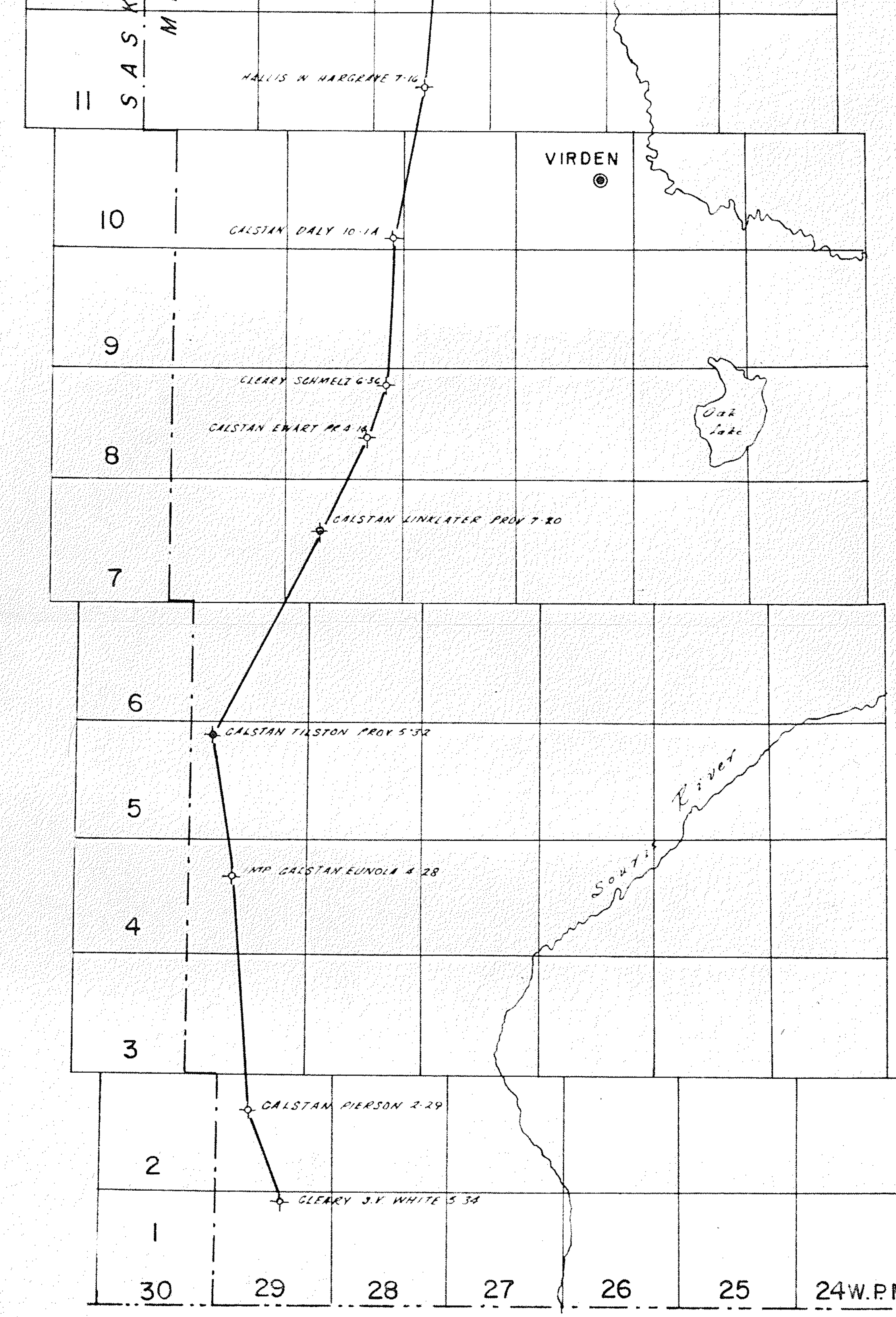
SHELL SWAN RIVER No.2
Lsd. 13-3-35-29 W.P.M.





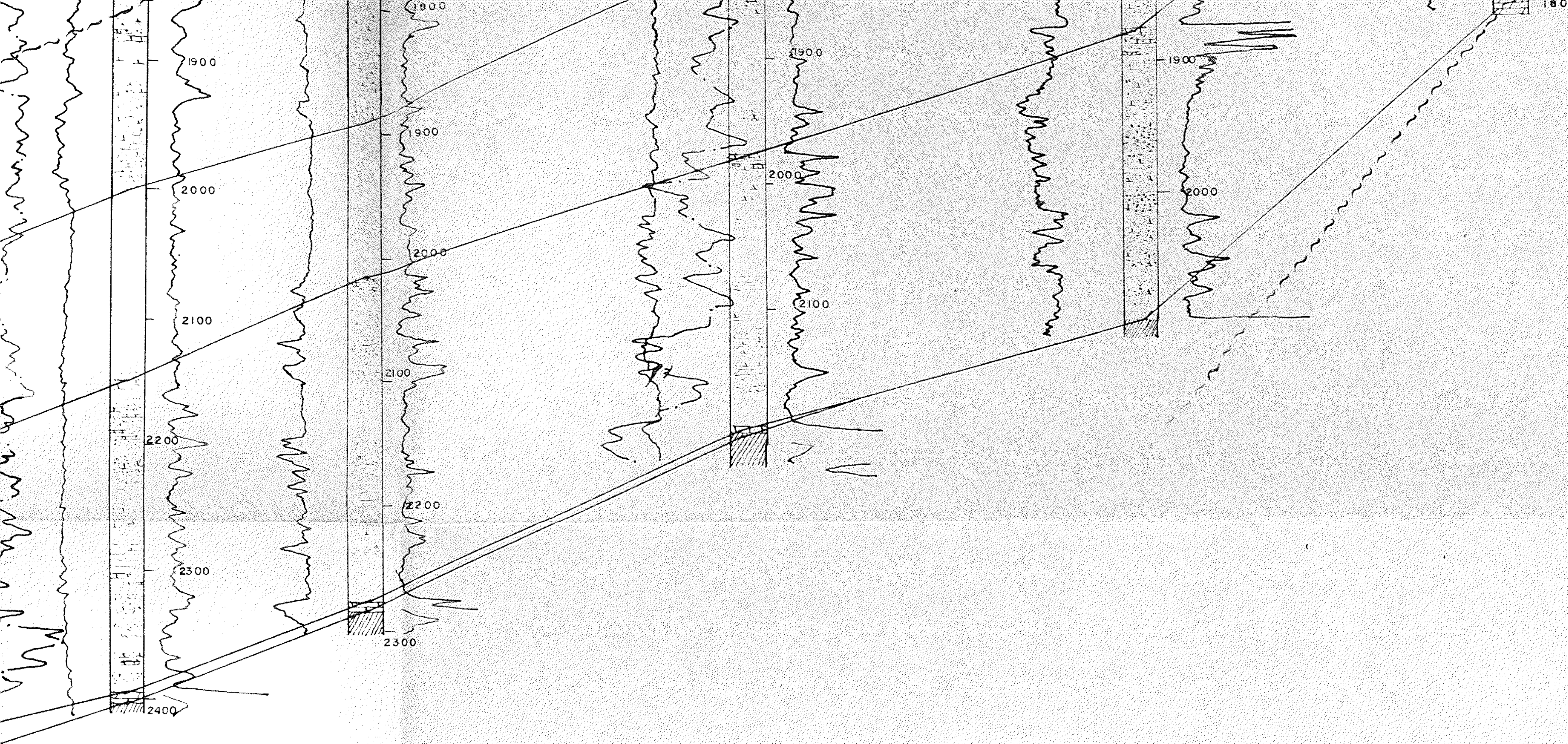
LEGEND

- COARSE GRAINED SANDSTONE
- MEDIUM GRAINED SANDSTONE
- FINE GRAINED SANDSTONE
- SILTSTONE
- LIMESTONE
- DOLOMITE
- ANHYDRITE
- SHALE
- SPECKLED SHALE
- CALCAREOUS SHALE, SILTSTONE, SANDSTONE



INDEX MAP

I inch = 8 miles



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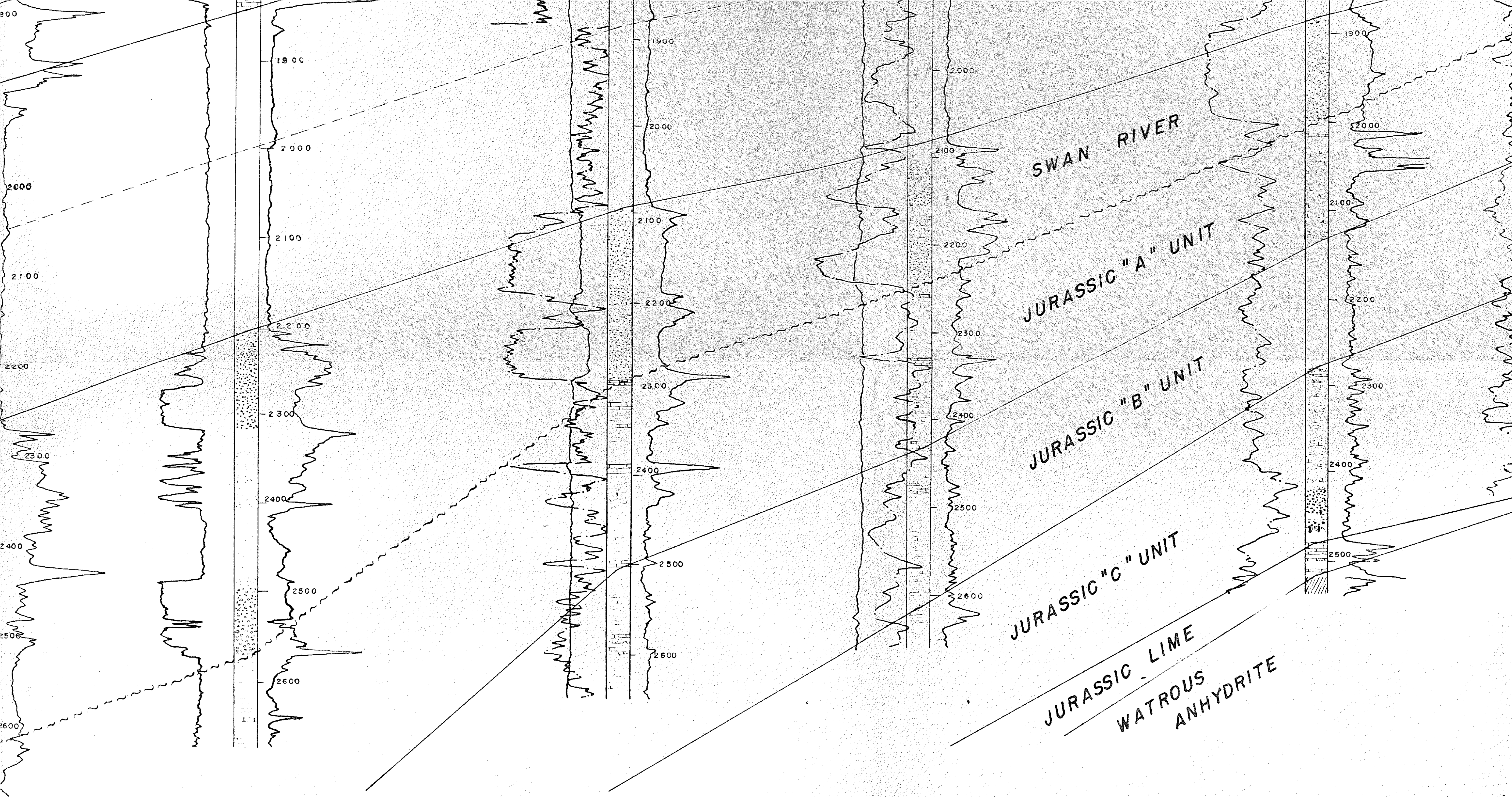
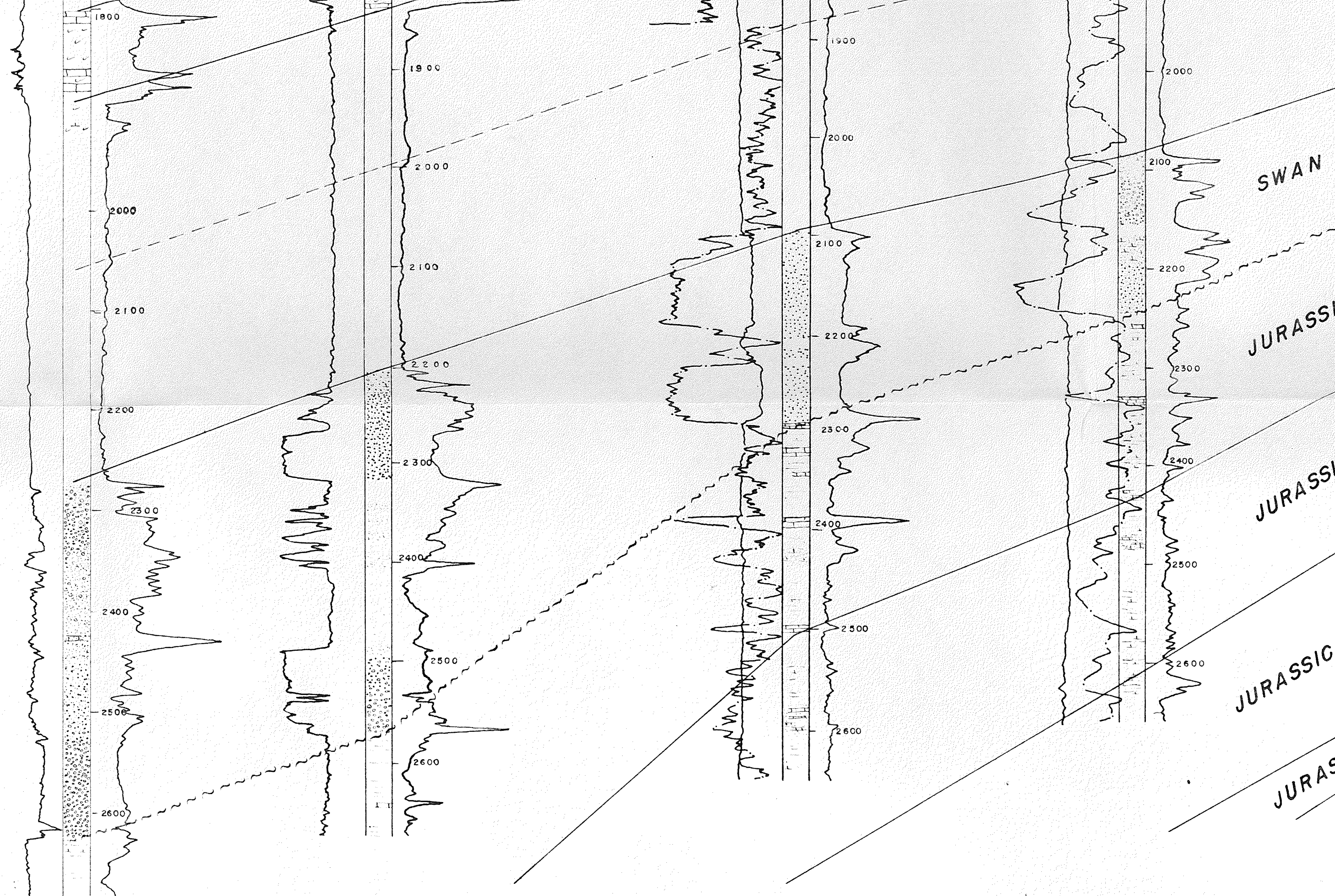

SWAN RIVER
JURASSIC "A" UNIT
JURASSIC "B" UNIT
JURASSIC "C" UNIT
JURASSIC LIME
WATROUS
ANHYDRITE


1800
1900
2000
2100
2200
2300
2400
2500
2600
SWAN
JURASSIC

CLE

PLATE XIII

STRUCTURAL CROSS SECTION
from
LEARY SOURIS VALLEY WHITE 5-34
to
SWEETGRASS ALTAMONT No. 1

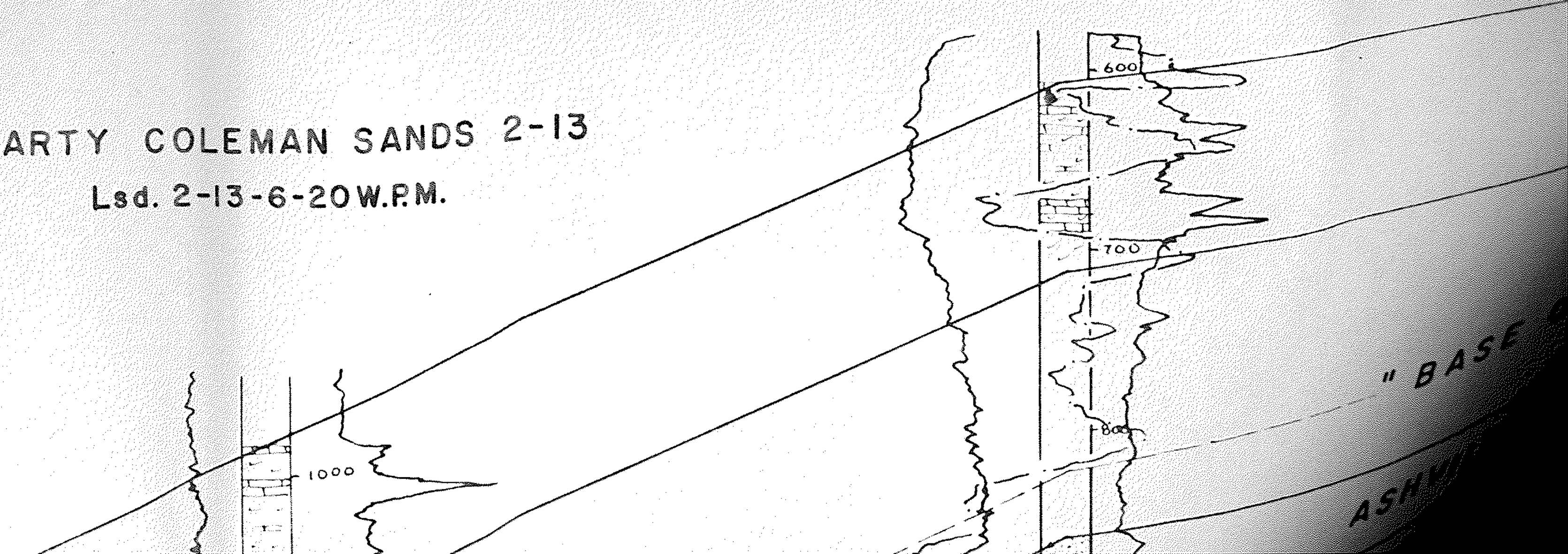
SCALE: Vertical: 1 inch = 100 feet.
Horizontal: 1 inch = 8 miles.

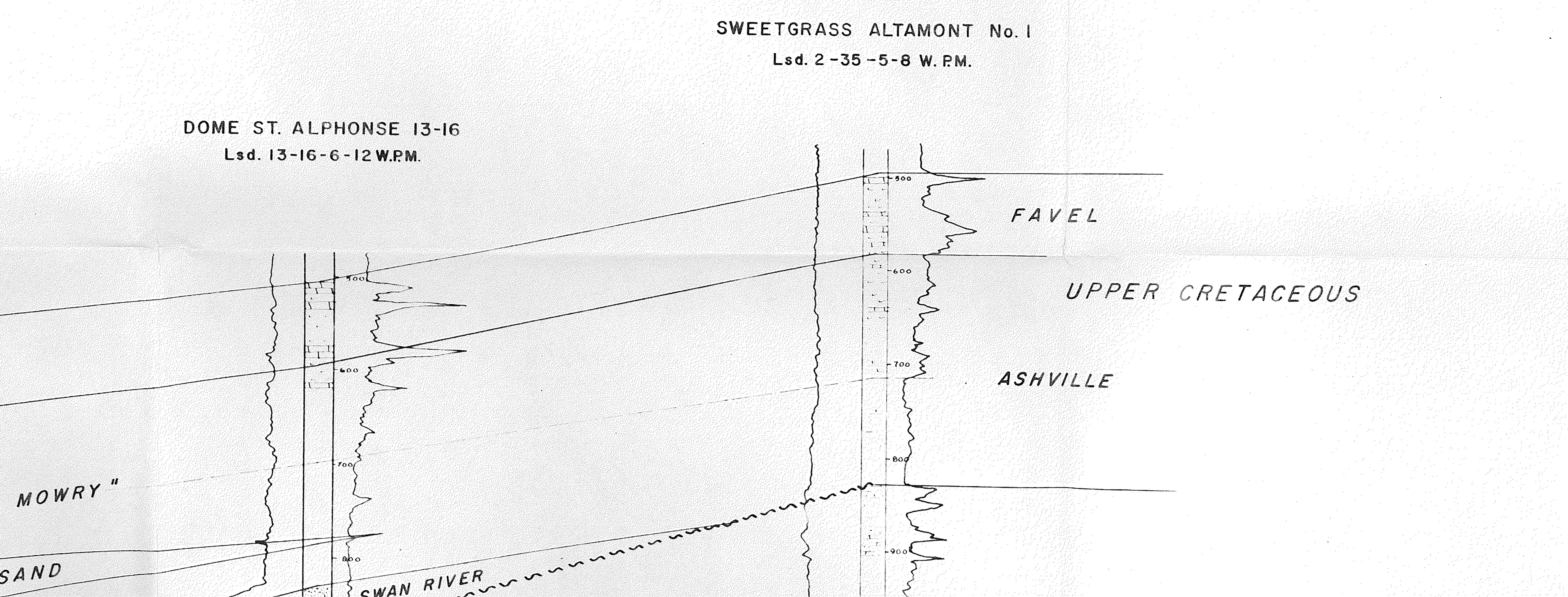
CALSTAN WAWANESA 3-1
Lsd. 3-1-8-18W.P.M.

McCARTY COLEMAN SANDS 2-13
Lsd. 2-13-6-20W.P.M.

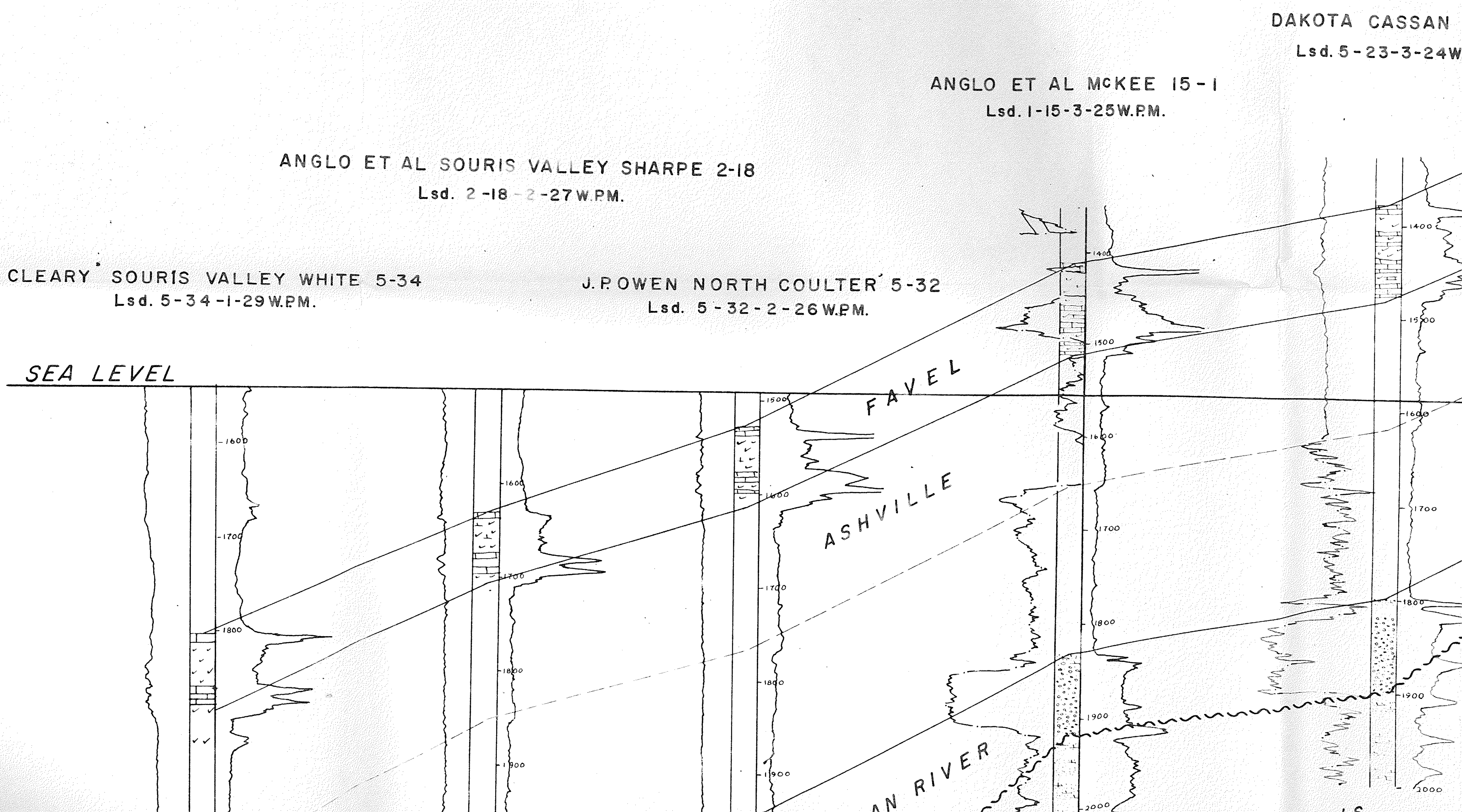
U.S.S. 3-30 DRAPER
Lsd. 3-30-5-21W.P.M.

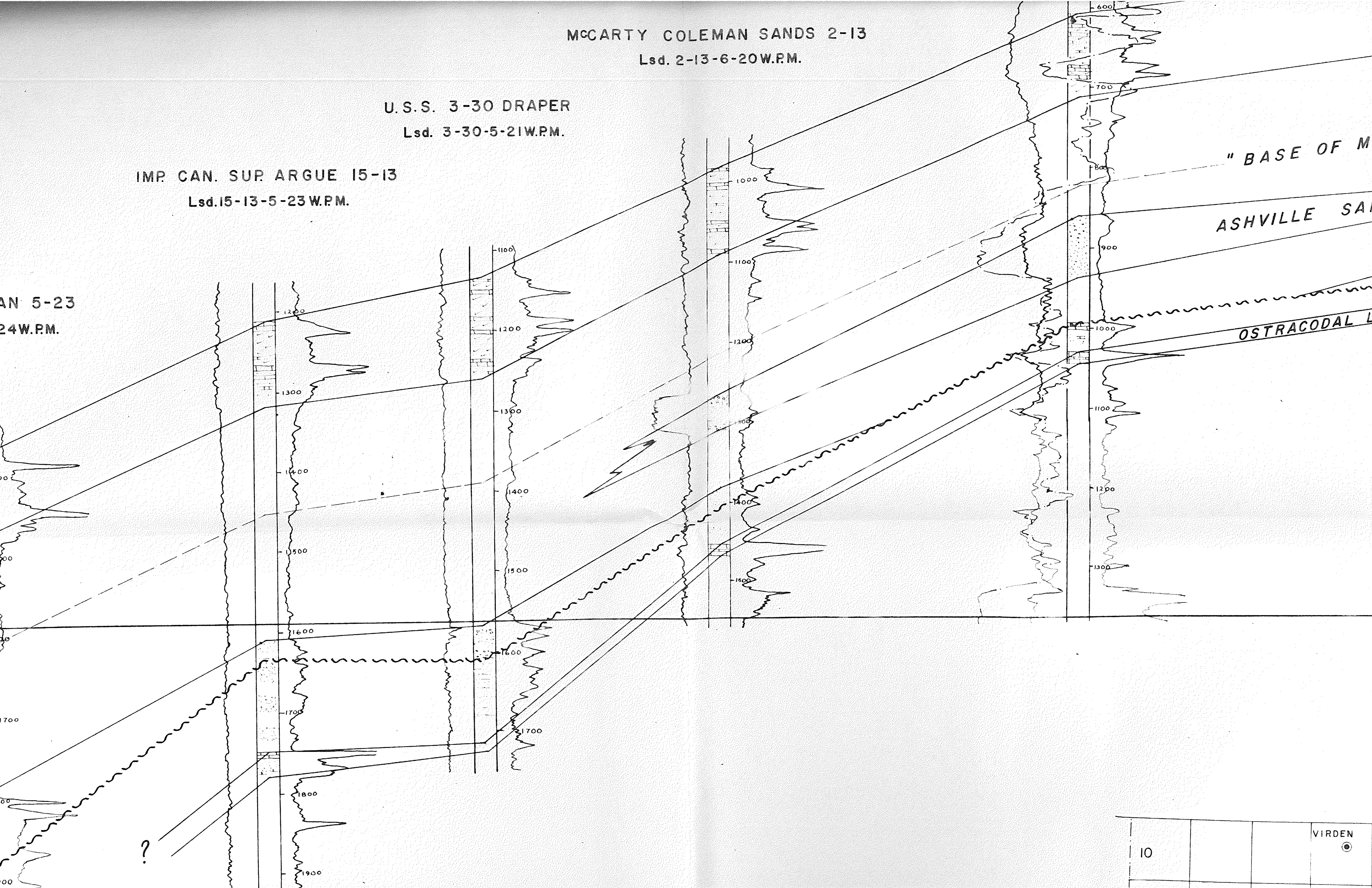
IMP. CAN. SUP. ARGUE 15-13
Lsd. 15-13-5-23 W.P.M.

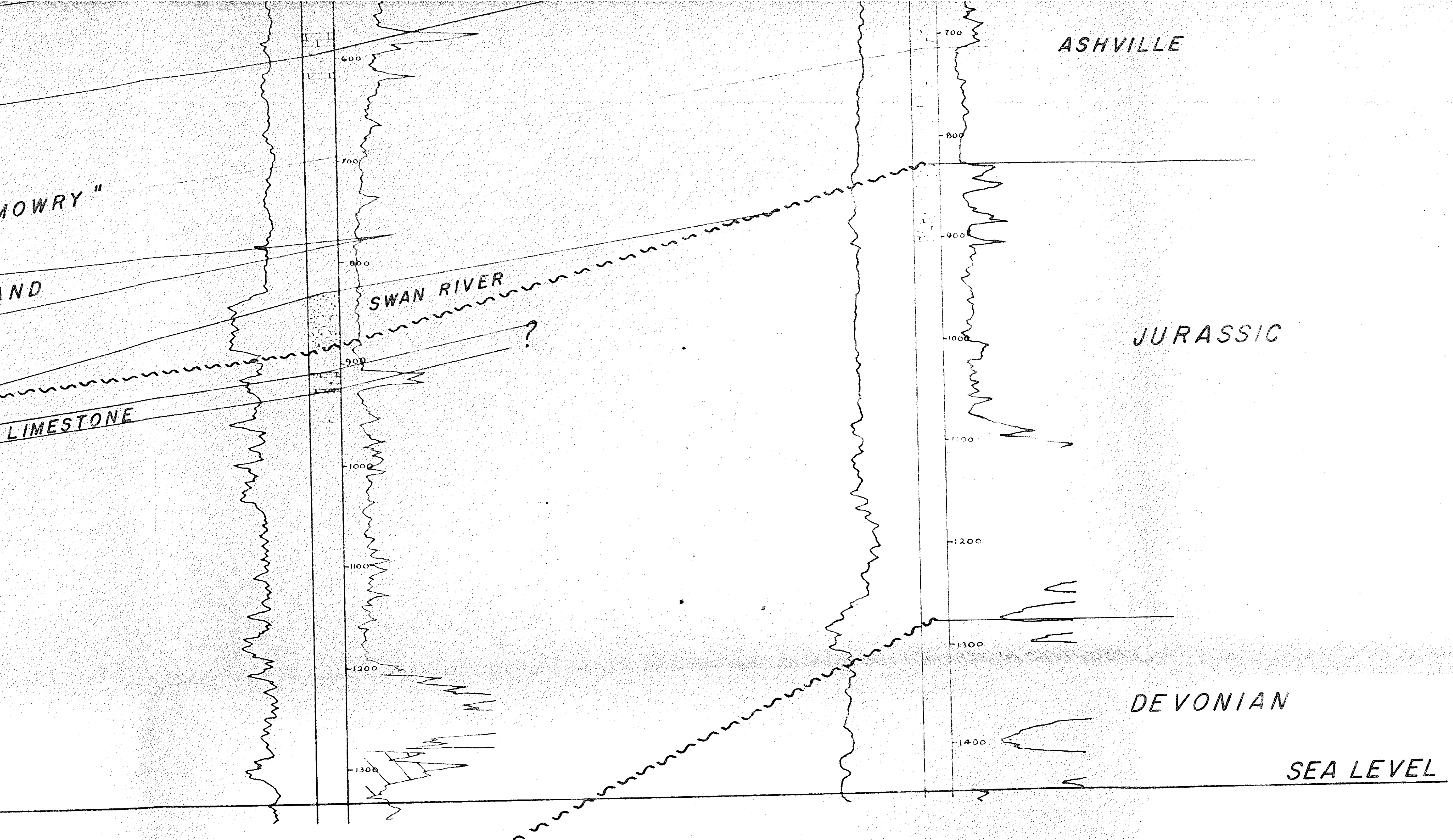


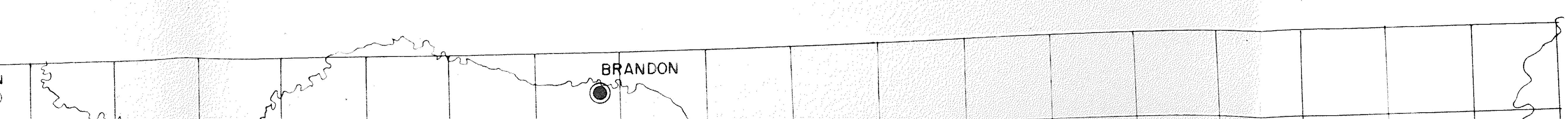


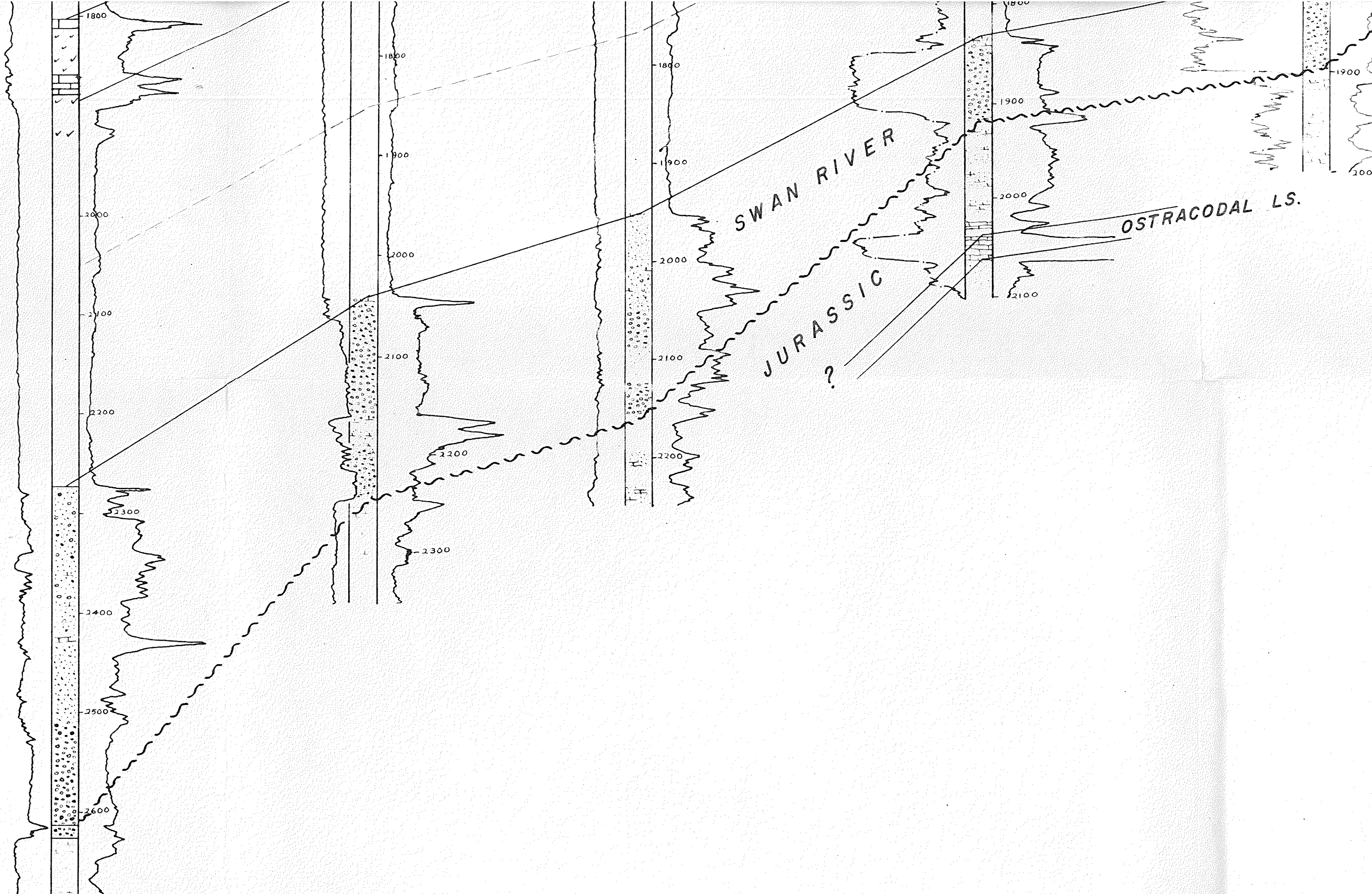
SWEETGRASS ALTAMONT No. 1
Lsd. 2-35-5-8 W. P.M.
DOME ST. ALPHONSE 13-16
Lsd. 13-16-6-12 W.P.M.
FAVEL
UPPER CRETACEOUS
ASHVILLE
MOWRY"
SAND
SWAN RIVER

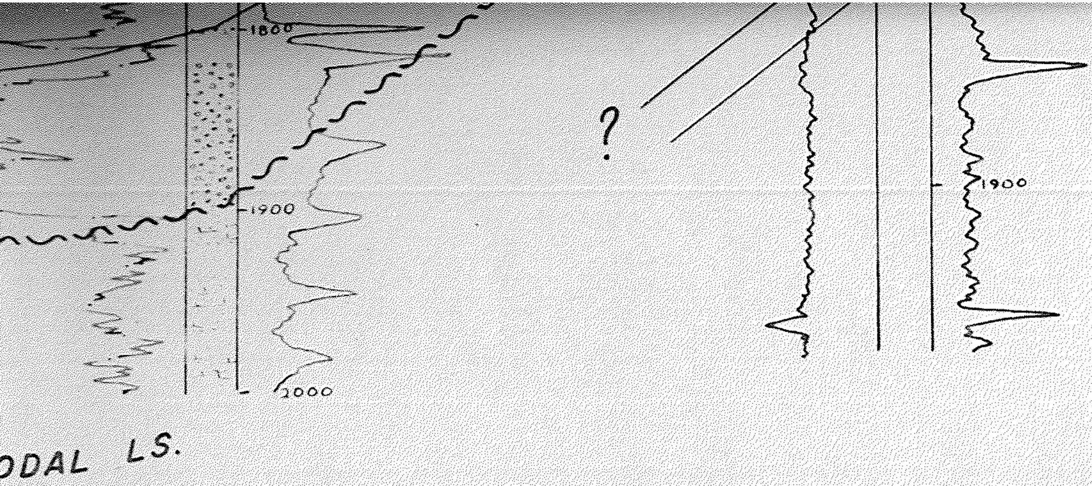

DAKOTA CASSAN
Lsd. 5-23-3-24W
ANGLO ET AL McKEE 15-1
Lsd. 1-15-3-25W.P.M.
ANGLO ET AL SOURIS VALLEY SHARPE 2-18
Lsd. 2-18-2-27W.P.M.
CLEARY SOURIS VALLEY WHITE 5-34
Lsd. 5-34-1-29W.P.M.
J.P. OWEN NORTH COULTER 5-32
Lsd. 5-32-2-26W.P.M.
SEA LEVEL
FAVEL
ASHVILLE
RIVER


McCARTY COLEMAN SANDS 2-13
Lsd. 2-13-6-20W.P.M.
U.S.S. 3-30 DRAPER
Lsd. 3-30-5-21W.P.M.
IMP. CAN. SUP. ARGUE 15-13
Lsd.15-13-5-23 W.P.M.
AN 5-23
24W.P.M.
"BASE OF M
ASHVILLE SA
OSTRACODAL L
?
VIRDEN
10


ASHVILLE
"MOWRY"
ND
SWAN RIVER
LIMESTONE
JURASSIC
DEVONIAN
SEA LEVEL
600
700
800
900
1000
1100
1200
1300
1400

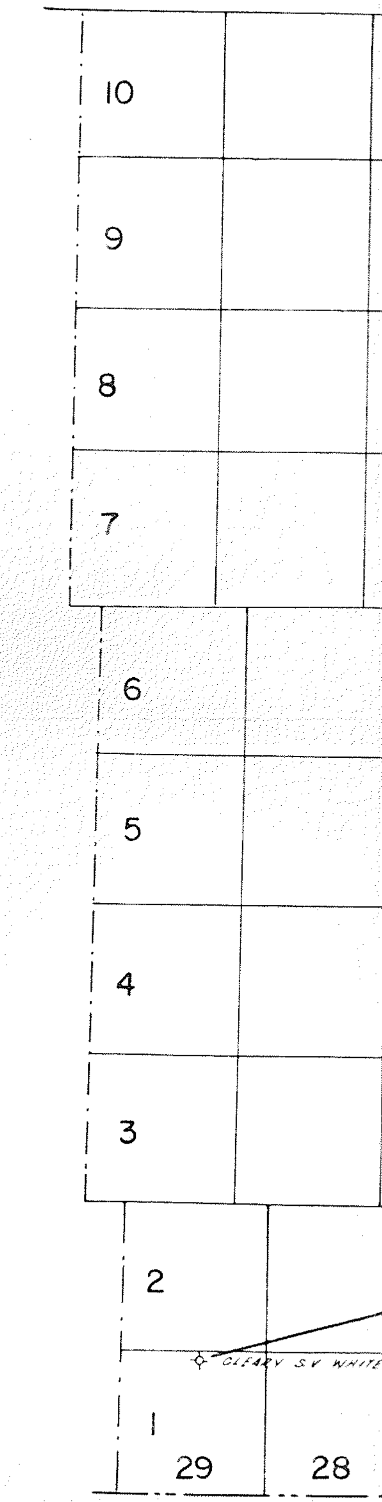

BRANDON

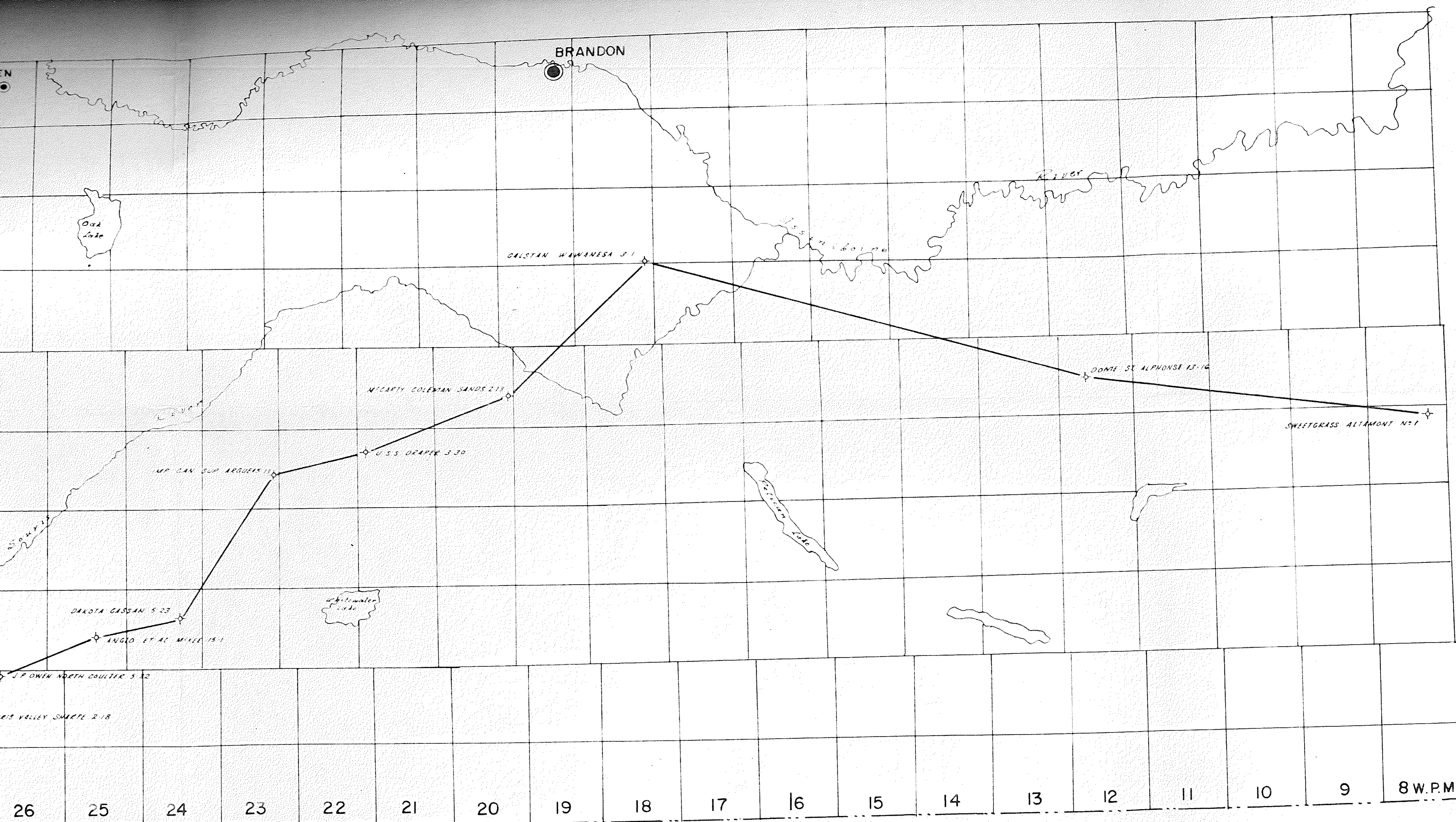

SWAN RIVER
OSTRACODAL LS.
JURASSIC
?
1800
1900
2000
2100
2200
2300
2400
2500
2600



LEGEND

- COARSE GRAINED SANDSTONE
- MEDIUM GRAINED SANDSTONE
- FINE GRAINED SANDSTONE
- SILTSTONE
- LIMESTONE
- DOLOMITE
- ANHYDRITE
- SHALE
- SPECKLED SHALE
- CALCAREOUS SHALE, SILTSTONE, SANDSTONE





INDEX MAP

1 inch = 8 miles