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DELINEATION OF THE NORTHERN EXTENSION OF THE RIMBEY-MEADOWBROOK REEF TRACT, UPPER DEVONIAN NORTHEASTERN ALBERTA

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Abstract

The Rimbey-Meadowbrook-Leduc reef chain is a well-defined SSW-NNE linear trend which is made up of individual Upper Devonian Leduc Formation reefs. This linear trend can be recognized from Township 35 to Township 95 and is located in the subsurface of central Alberta.

The reefs are localized on topographic highs along the western margin of the Cooking Lake Formation platform and are surrounded by argillaceous limestones and calcareous shales of the Duvernay and Ireton Formations. The buildups are directly overlain by Ireton shales but in one case, appears to be directly overlain by Grosmont Formation platform carbonates.

The thickness of the reefs varies from 90 meters in the north to 200 meters in the south. One factor which restricted the vertical development of the Leduc reefs in the northern portion of the reef tract was the westward progradation of the Grosmont Formation. The prograding Grosmont front encroached on the Leduc reefs and inhibited further reef development earlier in the north than in the south. As a result, the reefs are thinnest towards the north, thicken gradually southward, and are the thickest beyond the southern depositional edge of the Grosmont Formation.

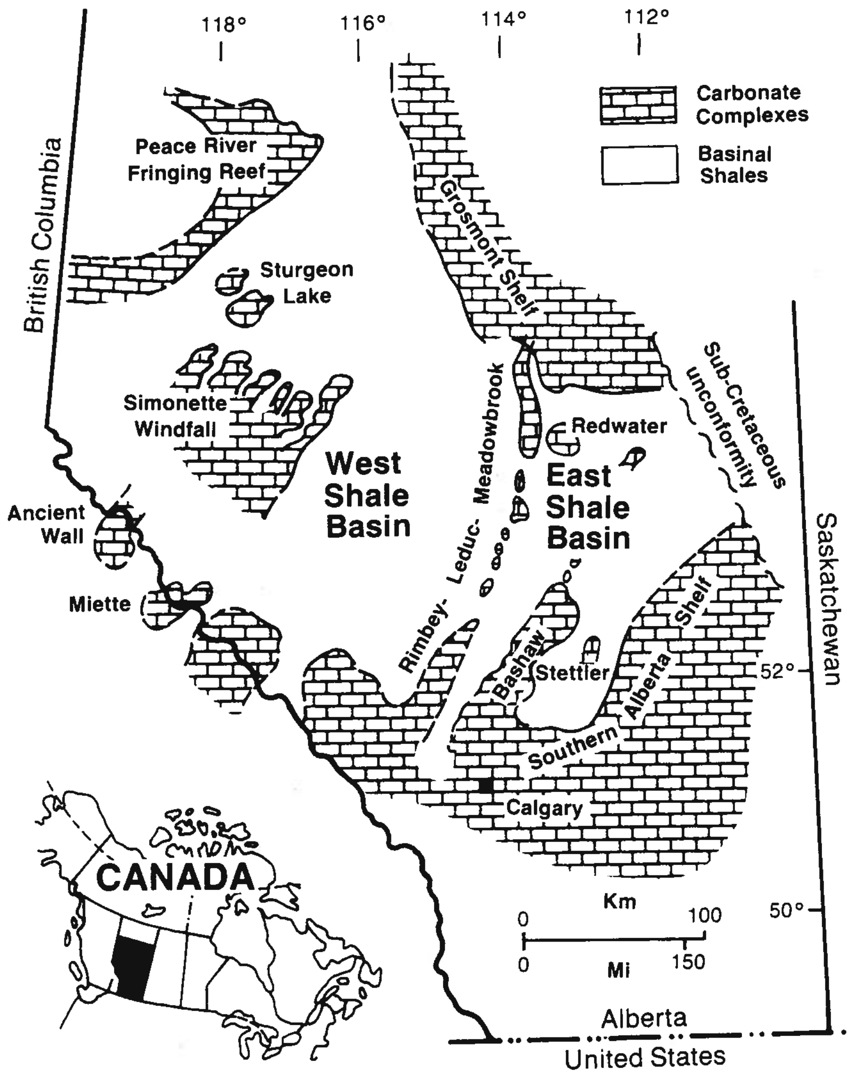

Figure 1. Distribution of Upper Devonian Carbonate Complexes (Stoakes, 1980).

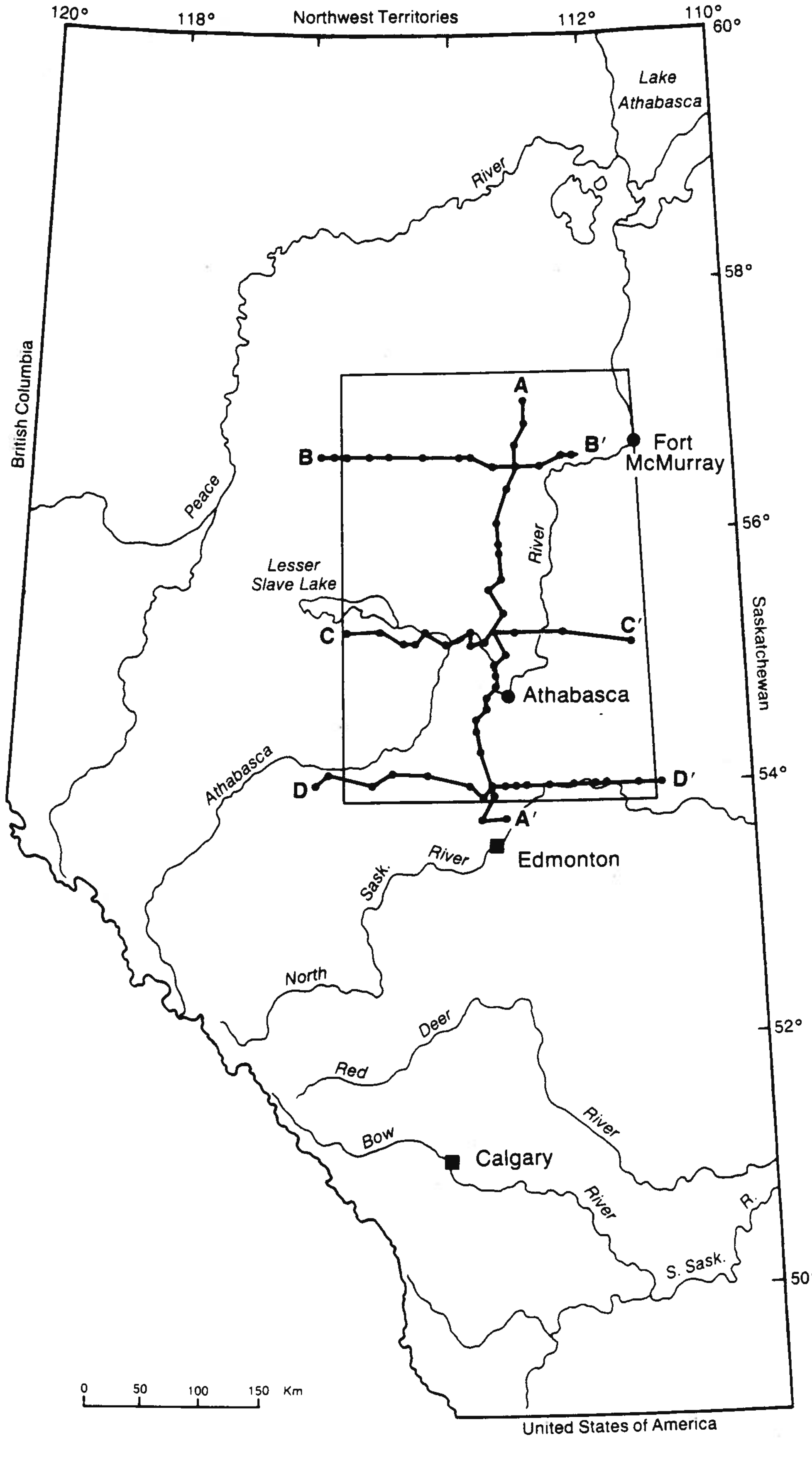

Figure 2. Location of study area and cross-sections.

Introduction

The Rimbey-Leduc-Meadowbrook reef tract is one of the more prominent Upper Devonian carbonate complexes in the Alberta basin (Fig. 1). There have been numerous petroleum discoveries in the carbonate buildups which make up the southern portion of the reef trend and as a result, the individual reefs have been studied in considerable detail in terms of local stratigraphic relationships, depositional facies, diagenetic history, and reservoir properties. The Leduc trend continues northward beneath the Grosmont Formation, a platform carbonate unit, and extends at least as far north as Township 95 but little has been published on this extension as it has not been proven economically significant. There are, however, a number of shut-in gaswells north of Township 90 where gas is present in the Leduc Formation. In virtually all of the present literature (e.g, Belyea, 1960; Klovan, 1974; Mountjoy, 1980), delineation of the Rimbey-Meadowbrook reef chain ends near the depositional edge of the Grosmont platform around Township 68.

Objectives

The purpose of this study is to map the northern extension of the Rimbey-Leduc-Meadowbrook reef tract between Townships 58 and 95, and from Ranges 10, west of the 4th meridian to 10, west of the 5th meridian (Fig. 2). The stratigraphic interval of interest is the Upper Devonian Frasnian Woodbend Group (Fig. 3). The main objectives of this study are as follows:

1 Show the geographic position, dimensions (width, areal distribution) and thickness variations of the Leduc reefs.

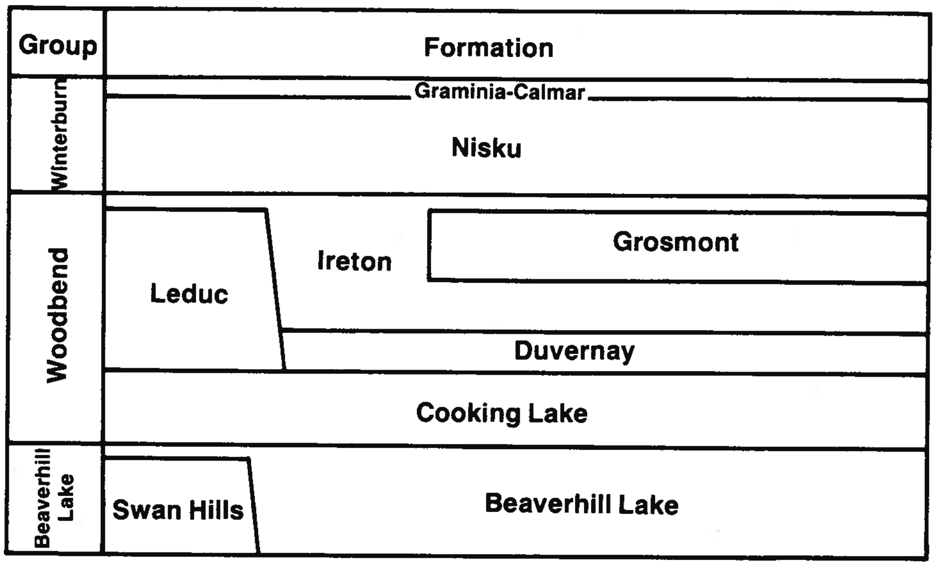

Figure 3. Stratigraphic nomenclature of the Upper Devonian in central-northeastern Alberta.

2 Show the geographic limits and thickness variations of the underlying Cooking Lake platform with respect to the localization of the Leduc buildups.

3 Examine the time stratigraphic relationships between the Leduc reefs, the Ireton basin fill, and the overlying Grosmont platform.

Method of Study

The study was based almost exclusively on correlation of geophysical logs, with only very minor reconnaissance core examination. Well control in the study area consists of 577 wells which penetrate part or all of the Woodbend Group. Four key stratigraphic cross-sections, one along the reef trend and three perpendicular to it (Fig. 2), were constructed using the top of the Beaverhill Lake Formation as the datum. Gamma ray logs were used for most of the correlations but electric (resistivity) logs were substituted when gamma ray logs were not available. Figures 4a and 4b illustrate typical log responses of the various lithologies within the Woodbend Group.

The Surface II Contouring package, a commercial product developed by the Kansas Geological Survey and used extensively by the Alberta Geological Survey, was used to generate structure and isopach contour maps which required very little hand adjustment of the formation tops picked from the 577 wells. The map command parameters used in the Surface II program are given in Appendix I along with a brief description of the graphics system.

A number of correlation problems were encountered in this study: 1) many of the deep wells date back to the early 1950°s when geophysical logging methods were still very crude and resulted in poor quality logs; 2)

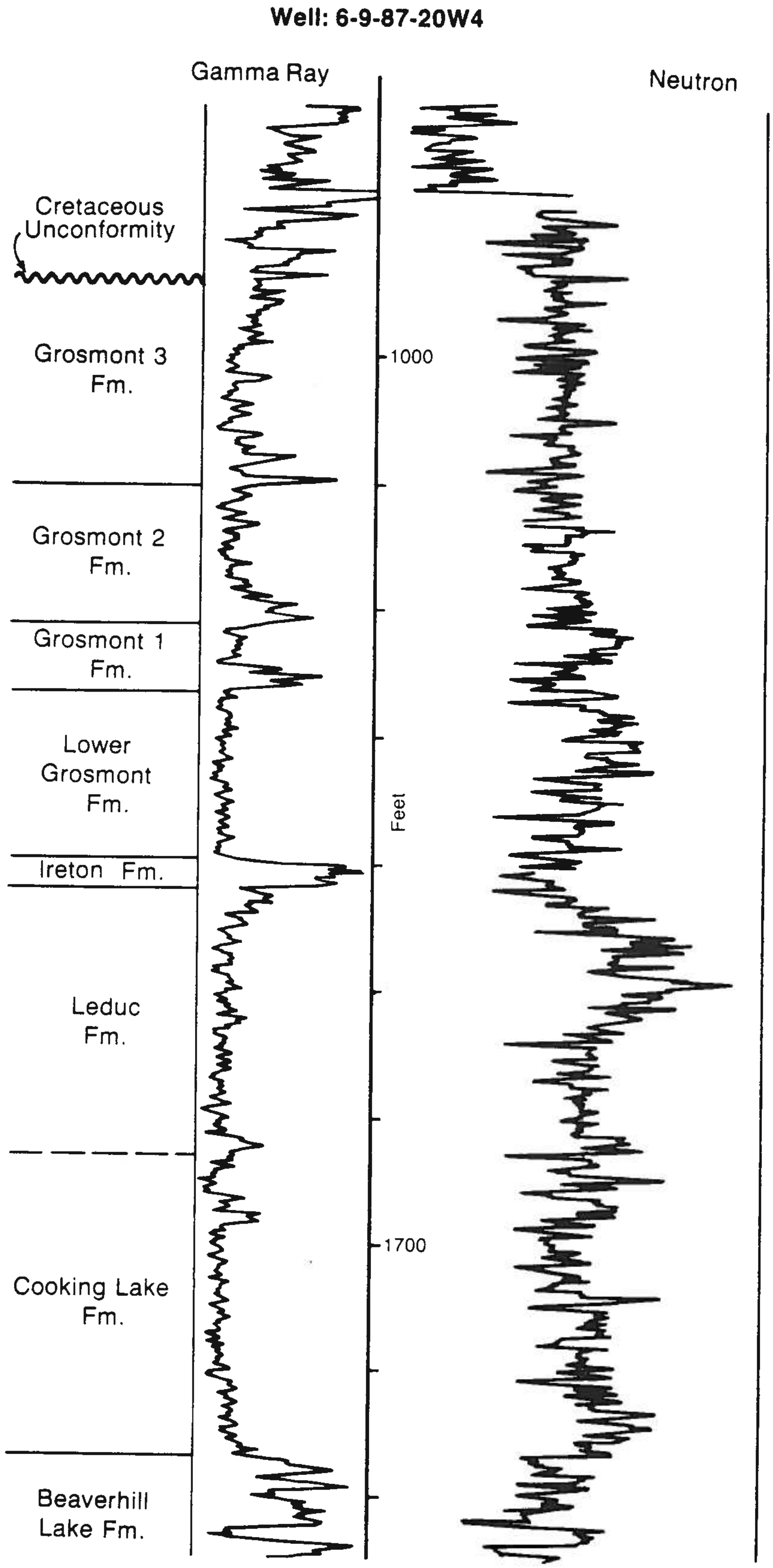

Figure 4(a). Reefal section showing log response and stratigraphic units.

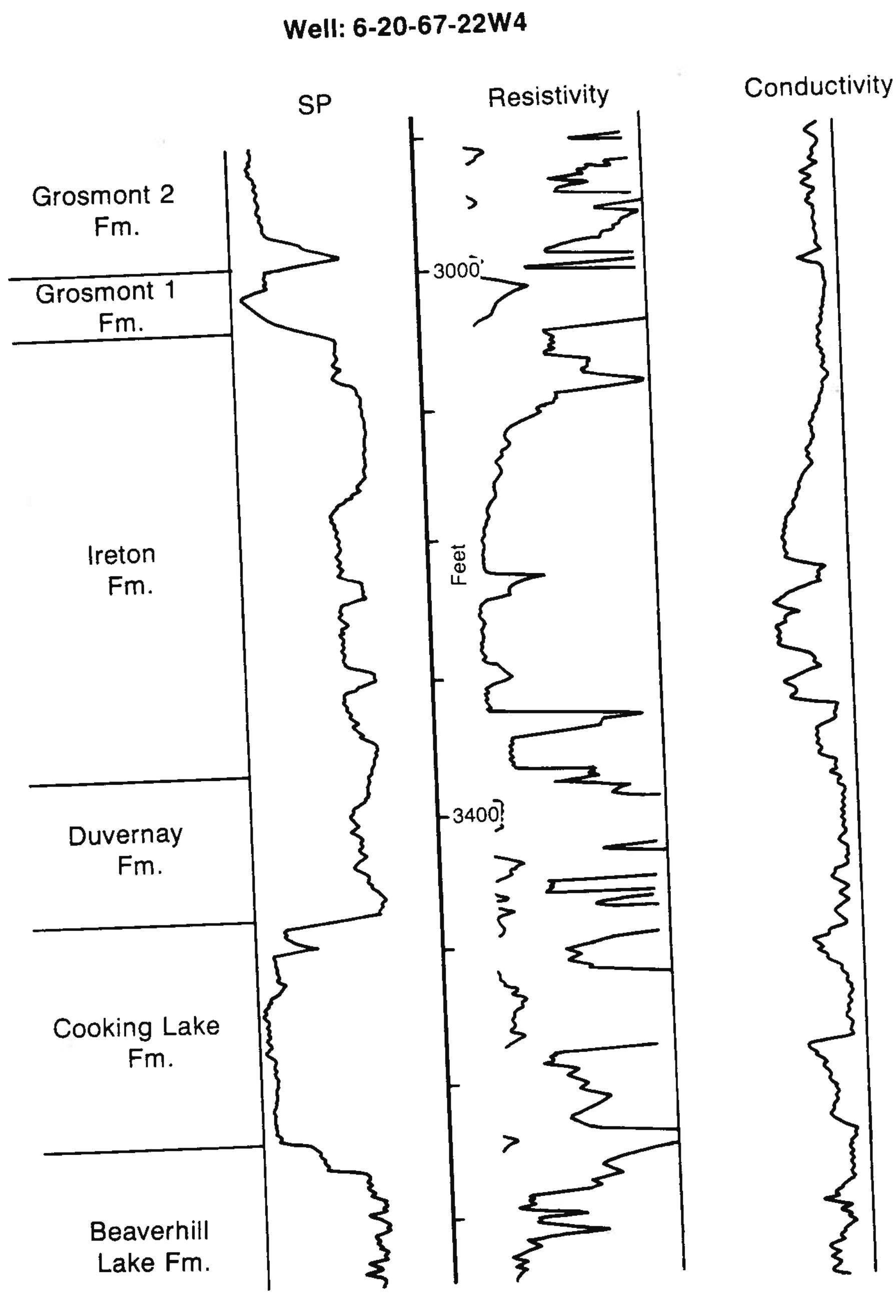

Figure 4(b). Off-reef section showing log response and stratigraphic units.

detailed delineation of reef morphology, particularly in the northern portion of the study area was not possible due to the lack of well control; 3) correlation of marker beds became difficult when the wells were 10°s of kilometers apart; 4) differentiation of massive carbonate units (such as the Grosmont subdivision, or the Cooking Lake/Leduc carbonate package) was speculative when shale breaks were not present.

Description of Major Stratigraphic Units

The basal platform carbonate unit of the Woodbend Group is known as the Cooking Lake (CKL) Formation and conformably overlies interbedded limestones and shales of the Beaverhill Lake (BHL) Formation. The Cooking Lake Formation is a broad, extensive platform which consist of a series of upward shallowing cycles. Wendte (1974) recognized 3 major cycles, some which are marked by submarine hardground surfaces in the Cooking Lake Formation at Redwater. There are smaller scale 2nd and 3rd order cycles within these major shoaling upward cycles. An idealized upward shoaling cycle consists of nodular lime mudstones at the base, grading upward into an *Amphipora* or stromatoporoid mudstone and floatstone facies, and finally into lime grainstones and fenestral limestones at the top of the cycle. At Redwater, the bulbous stromatoporoid and coral mudstone/floatstone facies were localized along the western edge of an open marine embayment which existed during upper Cooking Lake time. The high growth rates of the stromatoporoid facies gradually created and accentuated a topographic high, forming the Cooking Lake platform edge.

West of the Rimbey-Meadowbrook reef chain, the Cooking Lake Formation goes through a lateral facies change into calcareous shales with the exception of a thin basal carbonate unit which ranges between 5-10 meters in thickness.

The Cooking Lake Formation is overlain by the Leduc reefs, many of which have been dolomitized. The reefs are tabular stratified bodies although they usually appear to be large pinnacles as a result of vertical exaggeration on cross-sections. The Golden Spike Leduc reef, which has dimensions of 3.6 km (length) x 2.4 km (width) x 175 m (thickness), illustrates this point in Fig. 5 (McGillivray and Mountjoy, 1975). The reefs are composed primarily of shallow water lagoonal sediments surrounded by massive stromatoporoids and organic detritus (Mountjoy, 1980). Shale breaks (or more argillaceous carbonates) within the Leduc reefs (Fig. 6) represent disruptions in carbonate production and indicate that vertical development of the buildups occurred in incremental (cyclic) stages rather than continuously (Stoakes, 1980).

It is difficult to distinguish the top of the Cooking Lake from the base of the Leduc on the basis of geophysical logs alone because of the similarity of log responses between the 2 carbonate units. Carbonate sedimentation often appeared to be continuous on the geophysical logs, however Wendte (1974), provided evidence that submarine-cemented hardground surfaces were developed at the top of the Cooking Lake platform beneath and away from the Redwater (Leduc Formation) reef. Such surfaces indicate an interruption in sedimentation between the platform and overlying reef caused by the initial transgression of open-marine water (Wendte, 1974).

The off-reef areas are infilled with the shales of the Duvernay and Ireton Formations. The basin fill can be divided into two components: the intrabasinal carbonate component derived from the reefs and the extra-

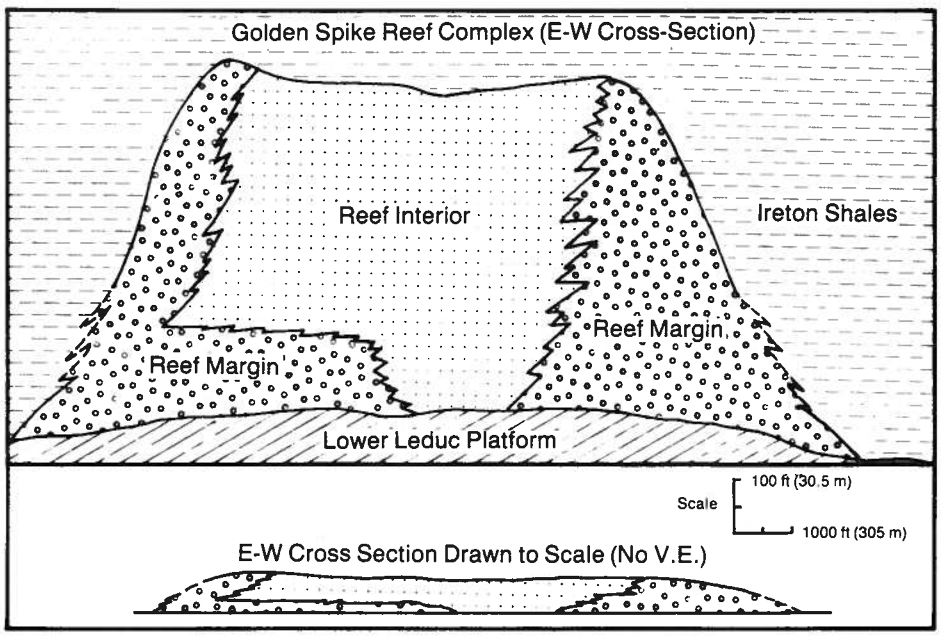

Figure 5. East-west cross-sections of the Golden Spike reef with and without vertical exaggeration. (modified Mountjoy, 1980).

basinal terrigenous component derived from a distant eastward landmass (Oliver and Cowper, 1963) and/or from the north by longshore currents (Stoakes, 1980).

The Duvernay Formation directly overlies the Cooking Lake Formation wherever Leduc reef development did not occur. The fact that the unit is not present beneath the Leduc reefs indicates that Duvernay deposition occurred after reef inception. The Duvernay Formation consists of argillaceous limestones and black bituminous shales which can be distinguished from the overlying Ireton shales on the basis of increased resistivity values on electric logs. Fine, undisturbed laminations, high preservation of organics and the lack of organisms all tend to suggest oxygen-deficient conditions during the time of Duvernay accumulation. The mechanisms causing the semi-starved basin conditions are not well understood but Mountjoy (1980) suggests the possibility that a sill located somewhere to the west or northwest restricted the water circulation within portions of the Alberta Basin. Stoakes (1980) concluded that the buildups of the Rimbey-Meadowbrook trend were partially responsible for the restricted circulation within the East Shale Basin (Fig. 1).

The Ireton Formation conformably overlies the Duvernay Formation. The Ireton Formation is a thick unit consisting of irregularly laminated, green calcareous shales, and nodular limestones. The colour and nature of the rocks indicate improved water circulation during Ireton deposition although the cause of the improvement, like the cause of the restriction during Duvernay time, is unknown. The Ireton Formation thickens westward, particularly to the west of the reef chain, as a result of thinning of the underlying Duvernay and deeper basin conditions in the West Shale Basin (Fig. 1). Oliver and Cowper (1963) and Stoakes (1980) recognized marker

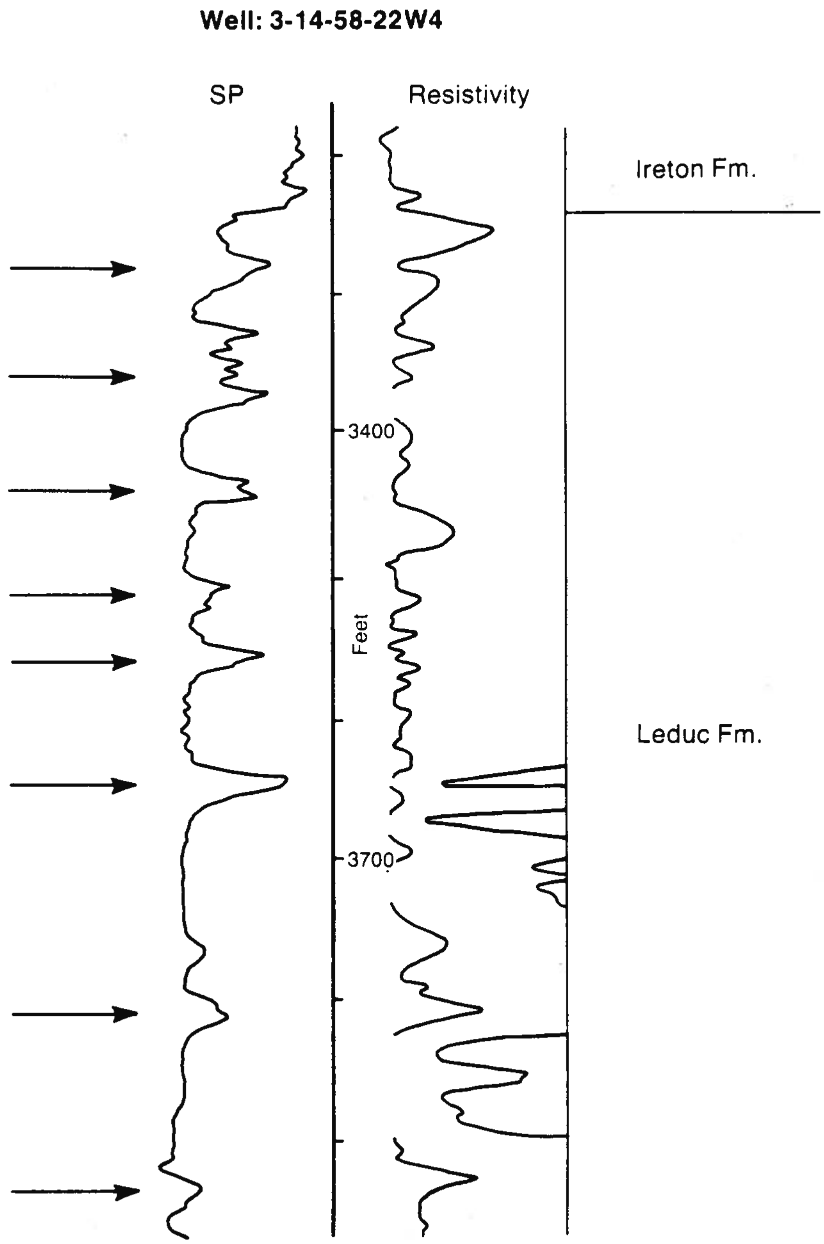

Figure 6. Argillaceous beds (indicated by arrows) within the Leduc Formation indicate that reef growth was incremental rather than continuous.

horizons within the Ireton which demonstrated a general westward progradation of the basinal Ireton sediments. The Ireton marker beds are believed to represent the topographic profile of the basin at various stages of basin infilling and thus represent time lines.

Associated with the formation of Leduc reefs and Ireton basin fill was the formation of the Grosmont platform. It is a thick, extensive platform which covers much of northeastern Alberta. The complex can be subdivided into 4 units, the Lower Grosmont (LG), Grosmont 1 (G1), Grosmont 2 (G2), and Grosmont 3 (G3), (Harrison, 1982, 1884; Cutler, 1983, Walker and Harrison, in press), based on argillaceous carbonate or calcareous shale breaks which are recognizable throughout the platform. Each subdivision prograded farther westward than the preceding one while erosion at the sub-Cretaceous unconformity obliterated the eastern extent of the Grosmont Formation.

Study Results

The extension of the Rimbey-Leduc-Meadowbrook reef trend is a well-defined linear reef chain located along the edge of the Cooking Lake platform and oriented from SSW to NNE. The reef trend is present south of Township 40 and extends north of Township 95 although its lateral extent is confined within two townships. The stratigraphic cross-sections and contour maps illustrate these points and are discussed below.

Cross-sections

The stratigraphic cross-sections include one section along the trend of the reef and three at right angles to it. Section A-A° was constructed along the Rimbey-Meadowbrook reef trend from Township 58 to 95. The reef chain consists of individual build-ups ranging from approximately 90 meters in thickness in the northeastern portion of the reef tract to 200 meters in the southwest. In many areas, the Leduc Formation cannot be differentiated from the underlying Cooking Lake on the basis of geophysical logs alone. Shales of the Ireton and Duvernay (which were not differentiated in this study) surround the Leduc reefs while the Ireton also caps the Leduc and Grosmont Formations.

Possible time-stratigraphic correlations are shown between the Leduc, Grosmont and Ireton Formations in section A-A°. For example, the argillaceous unit between the Lower Grosmont and Grosmont I subdivisions has been traced out into the Ireton basin sequence and correlated with horizons within the Leduc reefs. Although the correlations are tentative they represent relative time relationships between the accumulation of carbonates and the accumulation of shales. Such correlations provide a better understanding of depositional histories than correlations based solely on lithostratigraphic units.

Stoakes (1980) correlated synchronous marker horizons within the Ireton Formation to gain insight into the style of basin infilling and its effect on reef growth. In the present study area however, marker beds were very difficult to recognize. The southernmost cross-section (D-D°) does show subtle clinoforms of Ireton beds which can be traced into the shale basin but generally the lack of good marker beds may be attributed to insufficient well control.

Comparison of the 3 dip sections (B, C, and D) also shows the relationship between the Leduc and Grosmont Formations. In the northeastern portion of the study area, encroachment by the prograding

Grosmont front occurred during early stages of reef development and inhibited vertical accretion of the Leduc much sooner than in the south (Fig. 7). As a result, the reefs are thinnest towards the north, thicken gradually southward, and are the thickest beyond the Grosmont front.

Structural Contour and Isopach Maps

Accompanying the cross-sections are computer-generated structure contour and isopach maps. The Beaverhill Lake structure contour map shows the present regional dip trending in a southwesterly direction. The Cooking Lake and Leduc Formations were combined in the structure-contour and isopach maps because of the inability, in many wells, to separate the massive carbonate packages.

From the Leduc/Cooking Lake structure contour map, it may be possible to recognize a number of topographic lows which cut across the Cooking Lake platform and into the basin in a direction approximating that of the regional dip (NE-SW). The area enclosed by Townships 20-23 and Ranges 70-73, west of the 4th meridian has sufficient data to illustrate this point. It is worthwhile noting that the Leduc reefs do not form in these depressions but on the topographic highs beside them. The contour maps also show the Cooking Lake Formation as a broad platform covering most of the eastern portion of the study area. The Cooking Lake Formation gradually thickens westward from 30 to 60 meters with a pronounced thickening at the platform margin to 90 to 100 meters. The western edge of the platform is relatively steep and well defined. West of the platform, the remaining basal carbonate unit of the Cooking Lake Formation thins to 2 meters.

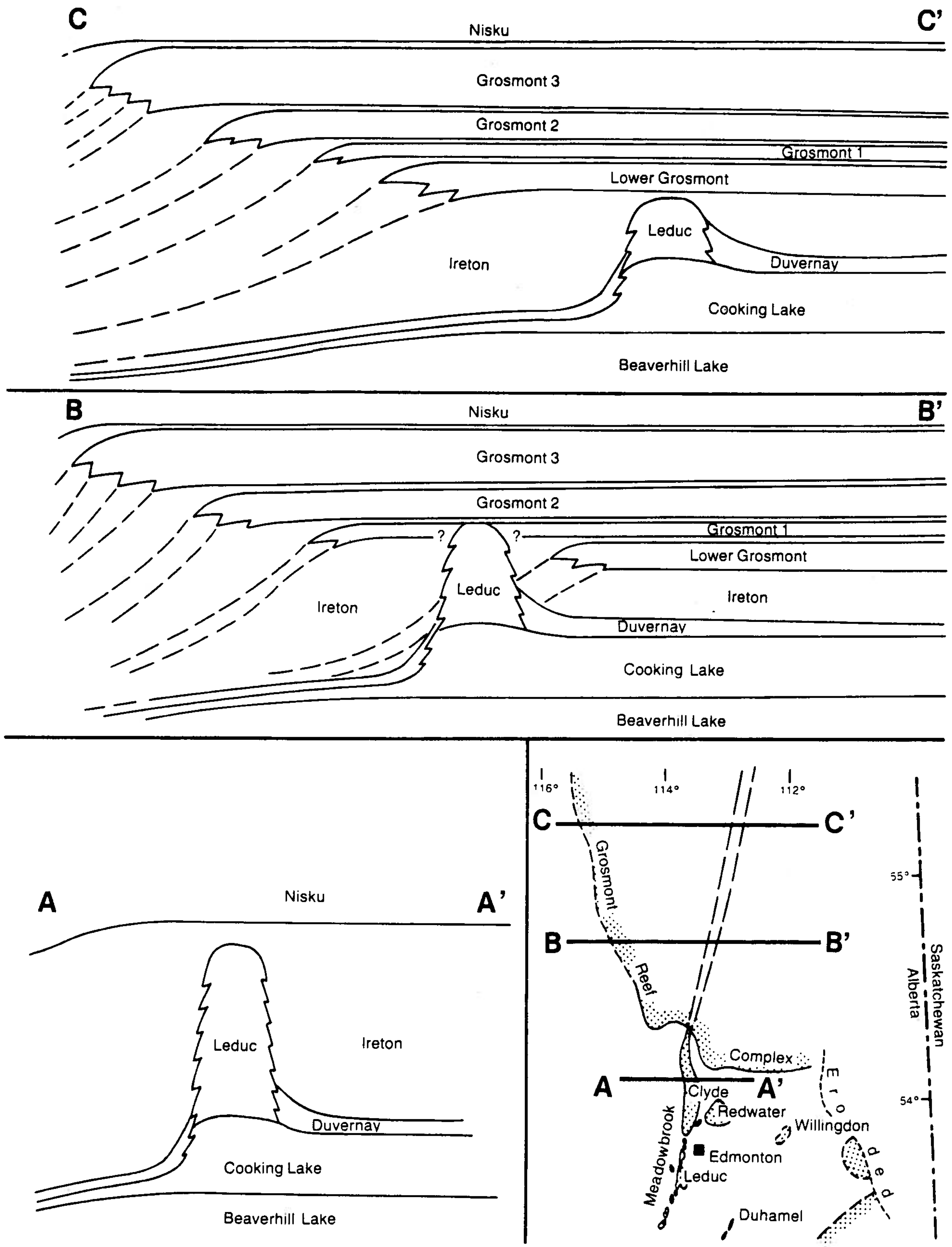

Figure 7. Simplified schematic diagrams showing the relationship of the Leduc reef tract and the Grosmont platform. The reefs along the Rimbey-Leduc-Meadowbrook reef chain increase in thickness southward and are thickest beyond the Grosmont front.

Discussion

Shallowing upward cycles have been recognized in the Cooking Lake (Wendte, 1974), Ireton (Stoakes, 1980), and Grosmont (Harrison, 1982; Cutler, 1983) Formations. They may be a result of relative sea level changes, eustatic sea level changes, environmental stresses or variability in terrigenous sediment supply. Of these, relative sea level changes probably played the most important role. Kendall and Schlager (1981) recognized three major responses of carbonate platforms to a relative rise in sea level: (1) completely drowned platforms which occur when the rate of sea level rise exceeds the rate of carbonate production; (2) platforms where only the rim and patch reefs could keep pace with the change in sea level while the interior drowned; (3) platforms which kept pace with the rising sea and maintained a flat surface at sea level.

The initial stages of Leduc growth may have developed according to (2) above, where the margin of the Cooking Lake platform (on which the reefs grew) could keep pace with the rising sea while the platform interior drowned. The calcareous shales of the Ireton were deposited across the drowned interior of the Cooking Lake platform during adverse water conditions or periods of increased terrigenous influx. During later relative sea level rises (Grosmont/Upper Leduc time), carbonate growth on the Leduc reefs and Grosmont platform matched or outpaced the rise in sea level. As a result, the platform prograded westward and eventually engulfed the Leduc buildups. The argillaceous beds separating the Grosmont subdivisions represent the lag time incurred before carbonate deposition could be re-established after sea level rises have taken place (Kendall and Schlager, 1981).

Summary

(1) The Cooking Lake Formation is a relatively flat, extensive platform which gradually thickens from 30 to 60 meters in a westerly direction with a pronounced thickening at the platform margin to 90-100 meters. Beyond the platform margin, there is a lateral facies change from carbonates to shales except for a thin basal carbonate unit of the Cooking Lake Formation.

(2) The Leduc reefs are isolated buildups localized on topographic highs along the margin of the Cooking Lake platform. The localization of these reefs produced a narrow (less than 2 townships across) SSW-NNE linear trend, an extension of the Rimbey-Leduc-Meadowbrook reef tract, which can be recognized as far north as Township 95. The reefs range in thickness from 90 meters in the north to 200 meters in the south.

(3) Progradation of the Grosmont Formation restricted the vertical development of the Leduc reefs beneath it. The Leduc reefs located north of Township 78 were engulfed by the prograding Grosmont front during Lower Grosmont time whereas the reefs near the southern depositional edge of the Grosmont platform were not inhibited until Grosmont 3 time. As a result, the reefs along this trend tend to increase in thickness southward and are thickest beyond the Grosmont front.

Acknowledgements

I would like to thank R.S. Harrison and P.D. Flach for their critical reviews of the manuscript. Lenco Drafting and the Alberta Research Council Graphic Services drafted the maps and diagrams.

Appendix I: Surface II Graphics Package

The Surface II Graphics system is a computer mapping package developed by the Kansas Geological Survey, which graphically displays data in three basic forms; contour map, block diagram, and posting (the plotting of symbols or Z values at the appropriate data points). All Surface II operations require a "grid of values which is a numerical representation of the surface to be displayed" (Sampson, 1978, p. 5). A value is assigned to each grid node through extrapolation (using various methods) of the surrounding data points. Contour lines can then be generated by interpolation along the edges of the grid matrix between grid nodes as in Fig. A-1, or the grid nodes can be vertically offset to an amount proportional to the assigned value for the creation of block diagrams (Fig. A-2). The contour maps produced for the present study area were superimposed with maps generated by ALPLOT, an Alberta Research Council developed software package which plots land locations, e.g., township and range, longitude and latitude.

The following section briefly describes the Surface I parameters used to generate contour maps in this study (taken from Sampson, 1978).

TITLE	A phrase used to label output generated by Surface II.
DEVICE	Initializes the plotting device.
IDXY	Reads and stores the input data.
GRID	Creates a grid matrix of values extrapolated from the input data.

NEAR	Uses the nearest neighbour search method to estimate Z values for the grid nodes.
EXTREMES	Specifies the boundaries of a grid matrix.
SAVE	Stores the grid matrix onto a file.
PERFORM	Executes Surface II commands.
ROUT	Reads the X and Y coordinates which forms an outline within the map area.
BLANK	Blanks out the contour lines outside of the area defined by ROUT.
CONTOUR	Contours the grid matrix.
CINTERVAL	Specifies contour interval, labeling, etc.
LEVEL	Specifies the contour intervals to be plotted.
SIZCON	Specifies the size of a map to be generated on a plotting device.

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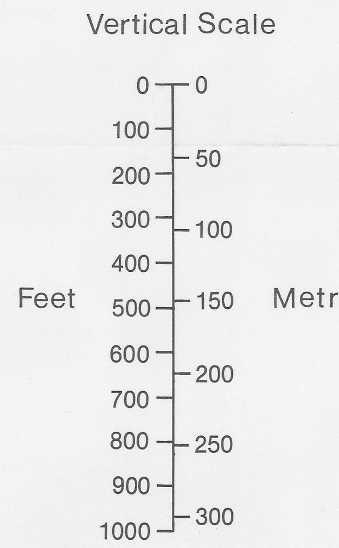

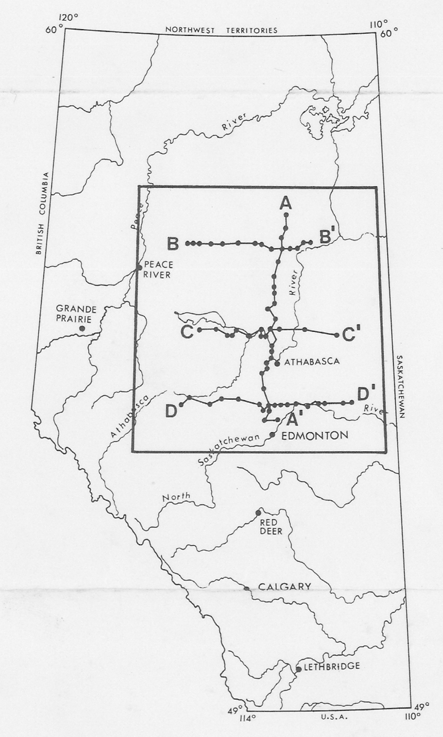

Leduc Formation

Cooking Lake Formation

Upper Devonian Woodbend Group North-South Strike Cross Section Northern Alberta

Anne Ing

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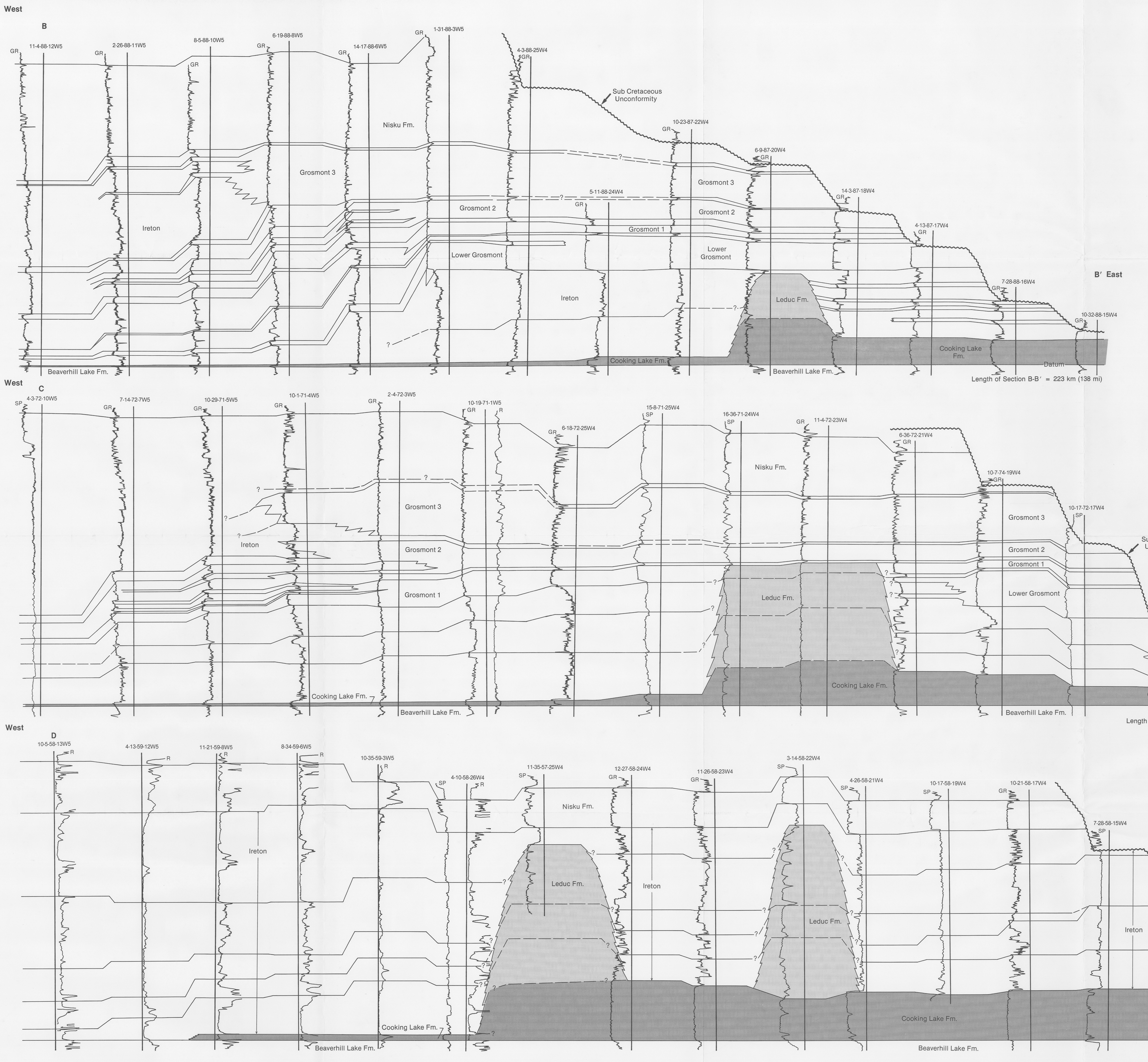

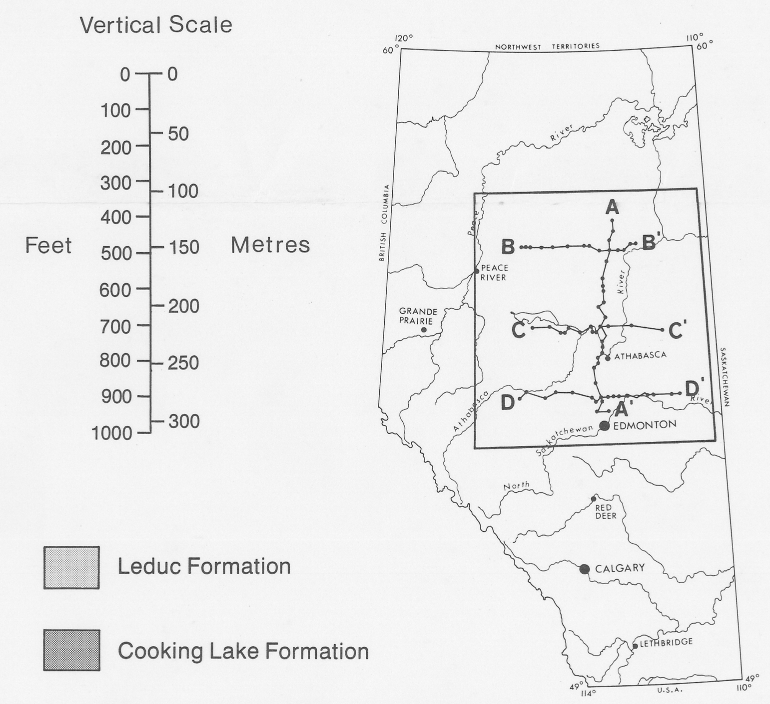

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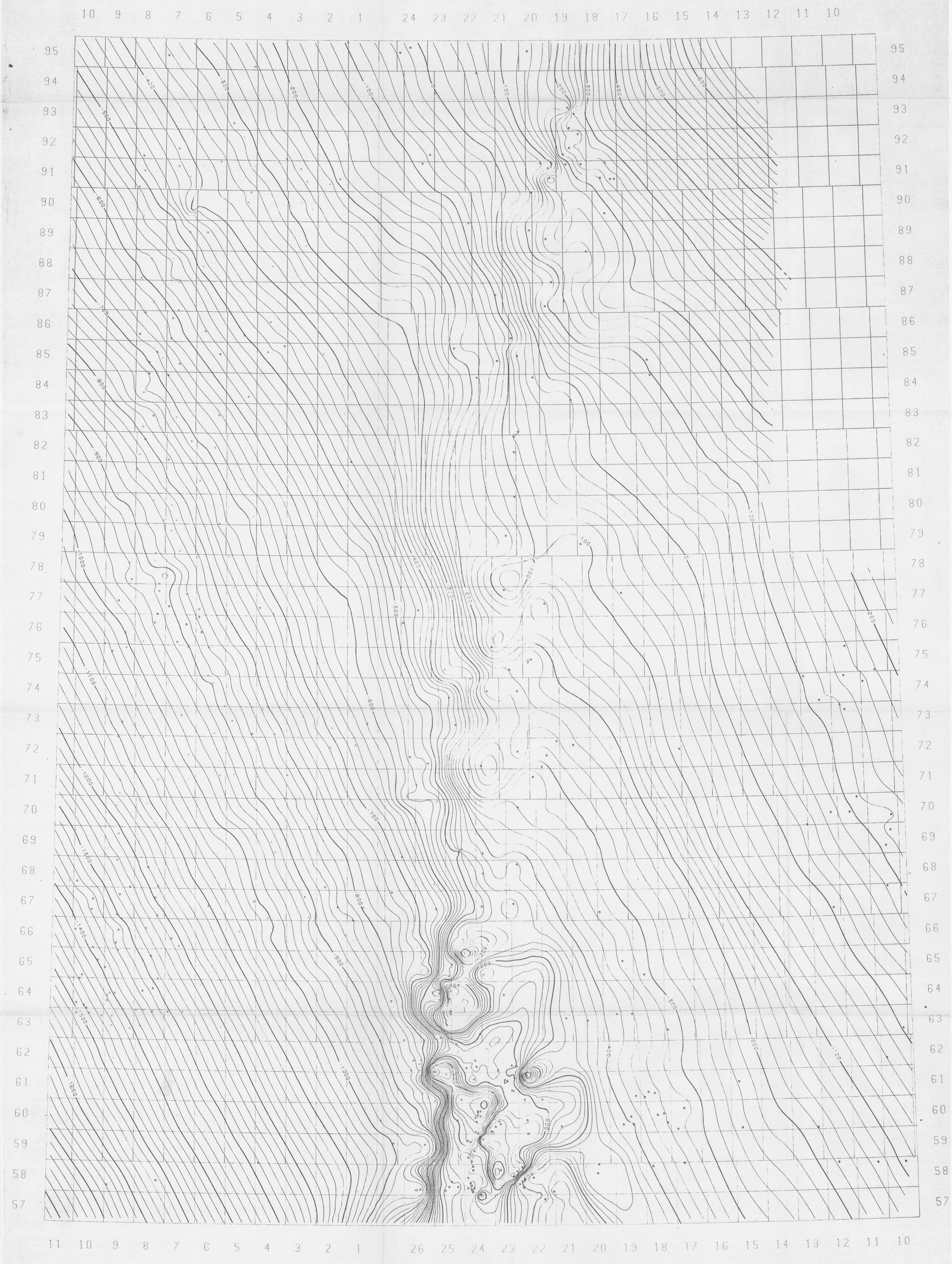

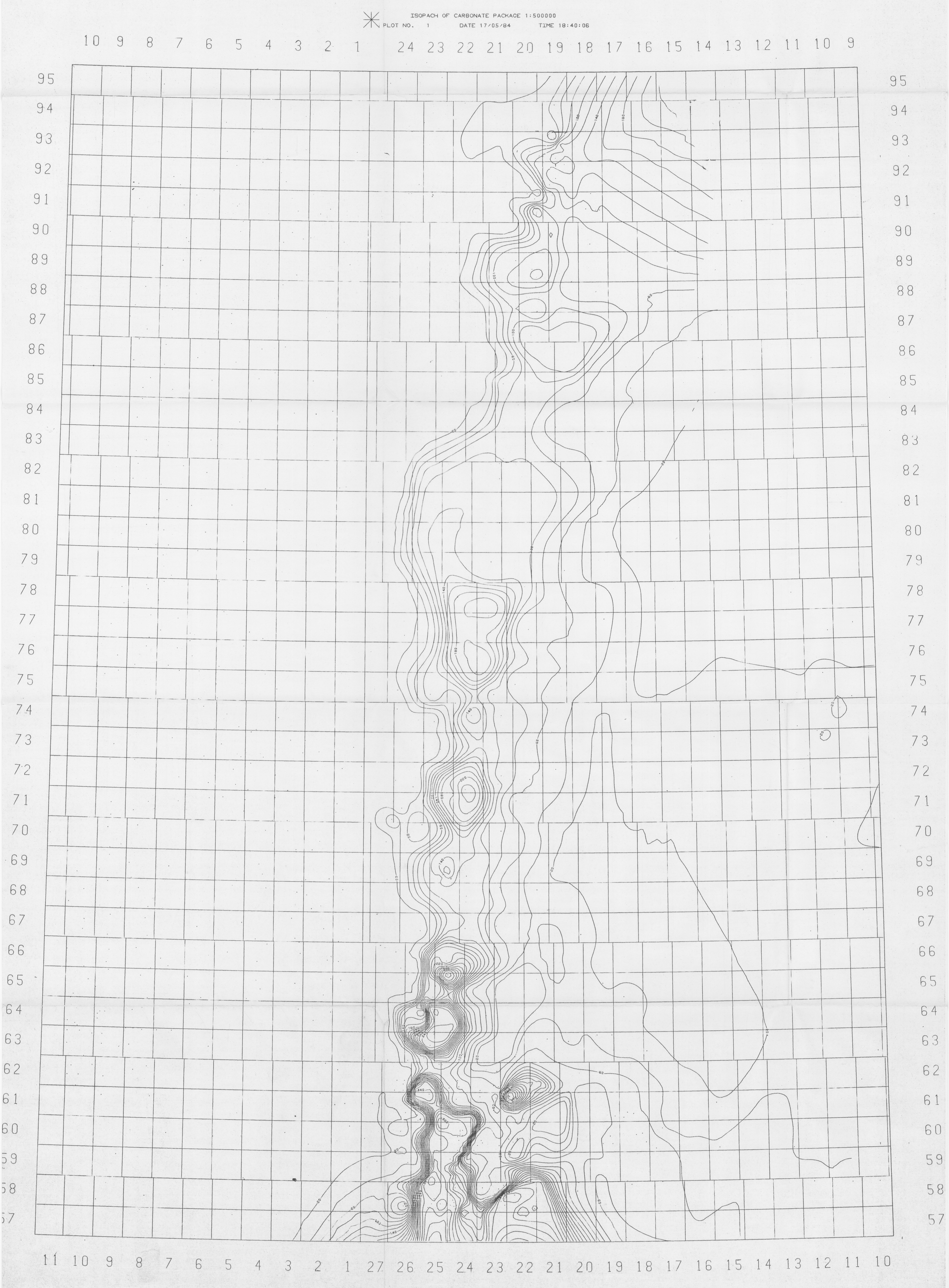
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