A SEISMIC ANALYSIS OF DIFFERENTIAL COMPACTION WITHIN A LEDUC REEF, ALBERTA, CANADA

by

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ABSTRACT

The Duhammel Leduc Formation atoll exhibits a seismically visible raised rim, a secondary feature attributed to differential compaction within the reef. Such raised rims are generally more porous than the encircled and structurally lower lagoon, and constitute a preferred well completion site. As evidenced by the Duhammel example, reflection seismic data should be acquired across such atolls with a view to ensuring that the raised rim is penetrated by the drill.

INTRODUCTION

The Leduc Formation of Alberta (Figure 1) developed as fringing reef complexes, linear chains of reefs, isolated atolls and isolated pinnacles (Anderson et al., 1989a, 1989b: Klovan, 1964; Mountjoy, 1980; Stoakes, 1980; Stoakes and Wendte, 1987;). As used herein, the term atoll refers to a reef which exhibits a raised rim; the term pinnacle refers to a buildup which does not. Typically, the larger Leduc reefs, such as Redwater (basal diameter of 20 kilometers) are classified as atolls (Mossop, 1972); the smaller buildups such as Morinville (basal diameter of 1 kilometer) are usually described as pinnacles (Anderson et al., 1989a).

In central Alberta, the Leduc overlies a regional platform facies, the Cooking Lake Formation, and is encased in the impermeable shales of the Duvernay and Ireton formations (Figures 2 and 3). As a result of differential compaction between the reefal carbonates and these offreef shales (Mossop, 1972; O'Connor and Gretener, 1974; Wirnkar and Anderson, 1989), overlying strata typically drape across Leduc buildups. Drape is a function of the thickness of the overlying sedimentary section and of the relative compactabilities of these reef and offreef facies through all postdepositional volume changes, whether chemical or physical in origin.

The seismic data described in this paper extend across the Duhammel Leduc atoll and illustrate two classic compactional features: 1) relief along post-reef strata as a result of the differential compaction of reef and offreef facies; and 2) a raised reef rim, a post-depositional feature attributed to the differential compaction of the rim and lagoonal facies.

DUHAMMEL LEDUC REEF

Duhammel is an isolated Leduc atoll, located immediately to the north of the Bashaw complex within the confines of the East Ireton Shale Basin (Figure 3). The reef is roughly elliptical in plan view (2 by 6 kilometers) and towers some 290 meters above the regionally planar platformal carbonates (Figures 4, 5 and 6).

On the basis of morphology, Duhammel can be subdivided into rim and lagoonal facies (Figure 4). The rim facies, as described by Klovan (1964) for the analogous Redwater Leduc reef, consists primarily of sediments deposited in a high energy environment about the seaward edge of the complex and effectively encircle the interior lagoon. These lagoonal sediments were deposited in a sheltered, relatively low energy environment (Klovan, 1964). At the time of deposition, the interior (lagoon) of Duhammel was probaby as high or higher than the encircling rim (Mossop, 1972). However as a result of post depositional, differential compaction, the rim is now structurally elevated by some 25 meters.

Mossop (1972), estimated that the interior of the Redwater reef was about 12 meters higher than the rim at the time of deposition, and noted that the rim is now 34 meters higher than the interior. He concluded that the rim and interior facies were compacted by a minimum of 13 and 24 percent, respectively. Anderson and Franseen (1990), in a seismic study of a western Canadian, Winnipegosis atoll reported higher rim and interior compaction values: 30 and 44 percent, respectively. Although the Winnipegosis is older than the Leduc (Givetian as opposed to Frasnian), these and Mossop's minimum estimates support the thesis that significant differential compaction occurred within the Duhammel atoll, and that the rim is primarily a secondary feature.

Principally as a consequence of differential compaction between reef and offreef facies, overlying strata are draped. In Figure 5, the Ireton, Calmar, Wabamun, Viking and Lea Park are shown to be up to 90, 70, 30, 20 and 10 meters respectively, higher onreef than offreef. In Figure 7 the Ireton, as contoured, is up to 25 meters higher across the rim than above the reef interior. The fact that 25 meters estimates were calculated for both the Ireton and Leduc, suggests that the top of the Duhammel reef was relatively planar at the time of formation. Structural relief, due to differential compaction within the reef cannot be confidently mapped at the Viking level on the basis of available well control (Figure 8).

SEISMIC DATA

The approximate location of the normal-to-field polarity seismic line (Figure 9) is shown in Figure 4. These 12-fold, non-migrated, dynamite data were recorded using a 35 meter group interval and conventionally processed. In Figure 10, a segment of these data are correlated to the 8-30-45-21W4M synthetic seismogram in support of our interpretation.

The seismic image of the reef (traces 71 to 151), as shown on Figure

9, is bounded by the Cooking Lake (base reef) and Leduc events. Of particular interest, are the patterns of relief along these two reflections. More specifically, note that the Leduc is about 13 ms (25 meters) higher above the rim (traces 85 and 135) than above the reef interior (trace 110). It is interesting to note that the Beaverhill Lake reflections are pulled up to a greater degree beneath the interior of the reef (15 ms at trace 110) than beneath the structurally elevated rim (8 ms at trace 135). This could be due to the fact that the rim facies are generally more porous than the interior facies and typically have a lower seismic velocity. A similar pattern of time-structural relief is observed along the underlying reflections supporting the thesis that the Cooking Lake is relatively planar in the study area.

Relief is similarily present along post-reef horizons. For example, the Ireton, Wabamun and Viking events are up to 40 ms (90 meters), 18 ms (30 meters) and 12 ms (20 meters) respectively, higher onreef than offreef. These same reflections are interpreted as 13 ms (25 meters), 10 ms (15 meters) and 4 ms (6 meters) respectively, higher above the rim than above the reef interior.

SIGNIFICANCE

Both the well log and seismic control indicate that the Duhammel Leduc atoll exhibits a raised rim. The seismic data suggests that the rim facies have a lower velocity than the interior facies and are therofor probably more porous. These data would suggest that optimal hydrocarbon recovery would be realized if all producing wells were drilled into the raised rim.

An examination of the well locations (Figure 4) suggests that several of these were drilled into the reef interior. Very probably, the explorationists were not aware that Duhammel has a raised rim, and were attempting to drill into a central apex.

SUMMARY

On seismic data, the Duhammel Leduc atoll exhibits a raised rim, a secondary feature, characteristic of Leduc reefs, which results from the differential compaction of the rim and interior facies. Our data shows that these rims can be seismically visible and suggests that they may be more porous than the encicled lagoon. The explorer/developer must be aware that even relatively small reefs, such as Duhammel, can exhibit raised rims, and should drill with the intention of maximizing production as opposed to merely penetrating the centre of the reef.

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Figure 1. Distribution of Upper Devonian carbonate complexes (Leduc Formation and equivalents) and intervening shale basins (after Belyea, 1964).

Figure 2. Stratigraphic chart for the Upper Devonian of southern and central Alberta (modified after AGAT Laboratories, 1988): a) central plains; b) south-central mountains and foothills; c) southern plains.

Figure 3. Stratigraphic terminology of the Woodbend Group in the subsurface of central Alberta (after Stoakes, 1980).

Figure 4. Map of the study area and contour map (in meters subsea) of the Leduc Formation top (or, in its absence, the Cooking Lake Formation) showing the seismic line (dashed) and the wells used in the geologic cross-section (solid lines). (For an explanation of well symbols, see Sheriff, 1984, p. 229).

Figure 5. Contour map of the Ireton Formation top (in meters subsea).

Figure 6. Contour map of the Viking Formation top (in meters subsea).

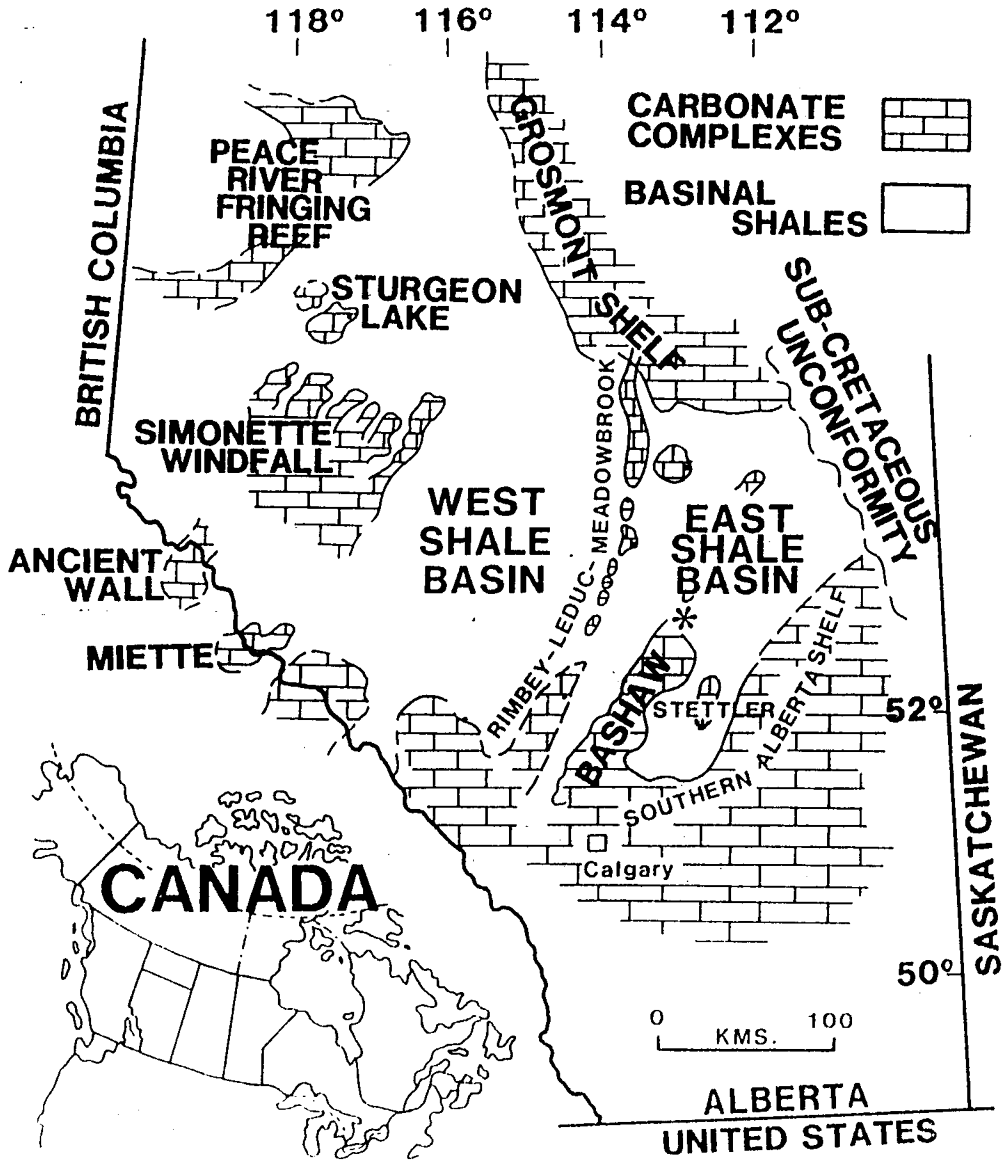
Figure 7. Geological cross-section A-A', illustrating the structural relationships between the platform, reef, offreef and post-reef strata. (well locations are shown in Figure 4).

Figure 8. Geological cross-section B-B', illustrating the structural relationships between rim of the reef and the reef interior. (well locations are shown in Figure 4).

Figure 9. A comparison of the field data and a 1-D synthetic seismogram for the 8-30-45-21W4M offreef well. (Courtesy of Geophysical Microcomputer Applications Ltd., Calgary).

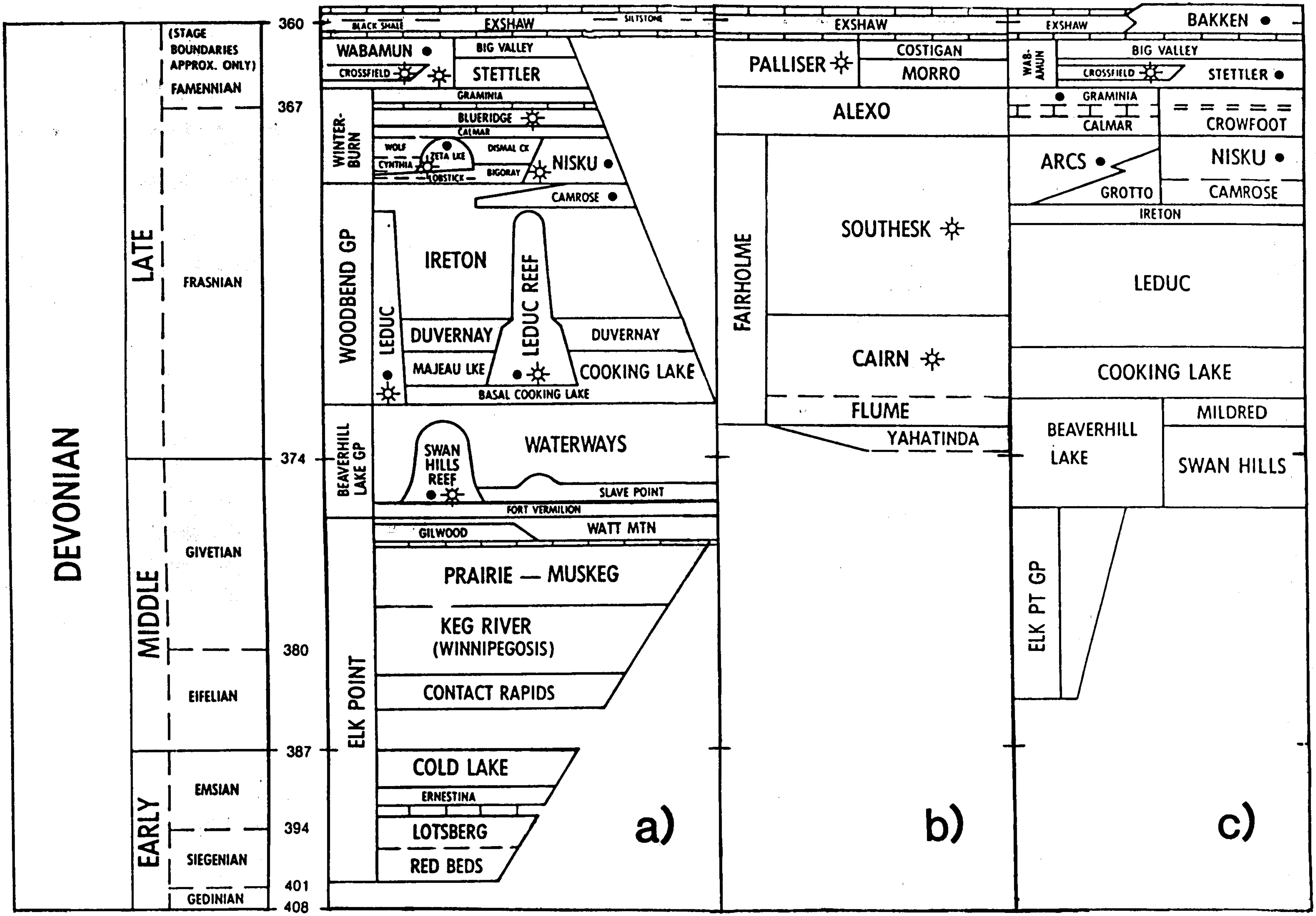
Figure 10. Normal-polarity seismic section, Duhammel study area.

Figure 11. Blow-up of a portion of the normal-polarity seismic section, Duhammel study area.



118°
116°
114°
112°
CARBONATE COMPLEXES
BASINAL SHALES
BRITISH COLUMBIA
PEACE RIVER FRINGING REEF
STURGEON LAKE
GROSMONT SHELF
SUB-CRETACEOUS UNCONFORMITY
SIMONETTE WINDFALL
WEST SHALE BASIN
RIMBEY-LEDUC-MEADOWBROOK
EAST SHALE BASIN
ANCIENT WALL
MIETTE
BASHAW
STETTLER
SOUTHERN ALBERTA SHELF
52°
SASKATCHEWAN
CANADA
Calgary
50°
0 KMS. 100
ALBERTA
UNITED STATES

* Duhammel



DEVONIAN
LATE
MIDDLE
EARLY
(STAGE BOUNDARIES APPROX. ONLY)
FAMENNIAN
FRASNIAN
GIVETIAN
EIFELIAN
EMSIAN
SIEGENIAN
GEDINIAN
360
367
374
380
387
394
401
408
BLACK SHALE
EXSHAW
SILTSTONE
WABAMUN
BIG VALLEY
CROSSFIELD
STETTLER
GRAMINIA
BLUERIDGE
CALMAR
WINTER-BURN
WOLF
ZETA LKE
DISMAL CK
CYNTHIA
LOBSTICK
BIGORAY
NISKU
CAMROSE
WOODBEND GP
LEDUC
IRETON
LEDUC REEF
DUVERNAY
MAJEAU LKE
COOKING LAKE
BASAL COOKING LAKE
BEAVERHILL LAKE GP
SWAN HILLS REEF
WATERWAYS
SLAVE POINT
FORT VERMILION
GILWOOD
WATT MTN
PRAIRIE — MUSKEG
KEG RIVER (WINNIPEGOSIS)
CONTACT RAPIDS
ELK POINT
COLD LAKE
ERNESTINA
LOTSBERG
RED BEDS
a)
EXSHAW
PALLISER
COSTIGAN
MORRO
ALEXO
FAIRHOLME
SOUTHESK
CAIRN
FLUME
YAHATINDA
b)
EXSHAW
BAKKEN
WAB-AMUN
BIG VALLEY
CROSSFIELD
STETTLER
GRAMINIA
CALMAR
CROWFOOT
ARCS
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IRETON
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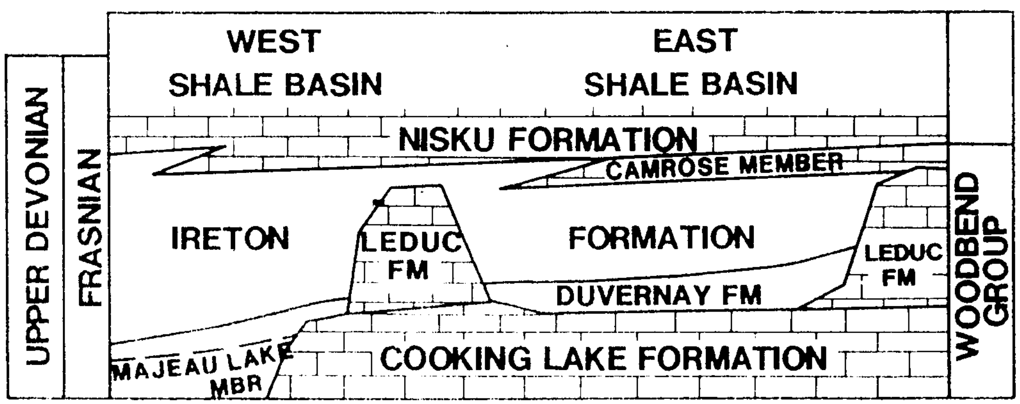
BEAVERHILL LAKE
MILDRED
SWAN HILLS
ELK PT GP
c)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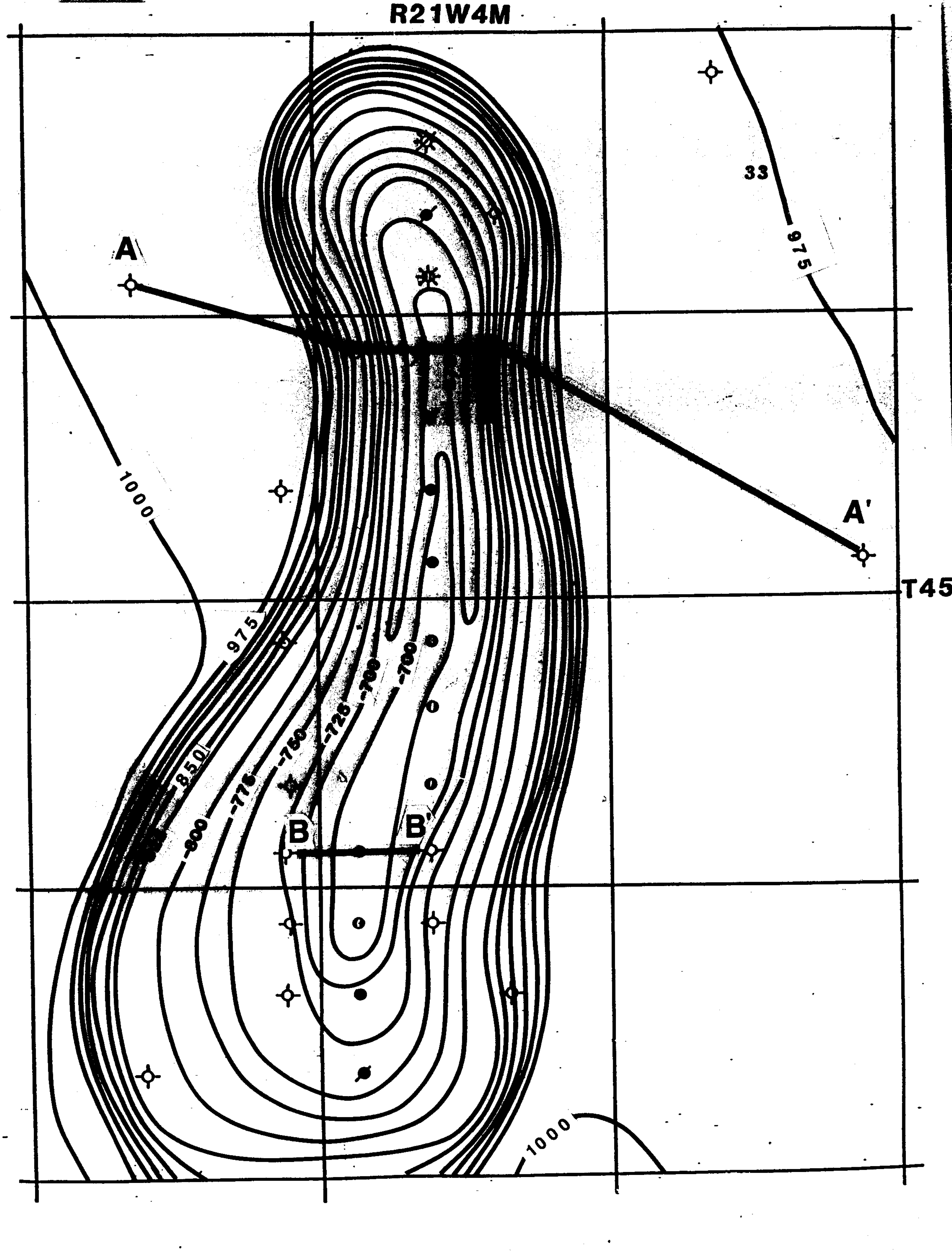
SHALE BASIN
EAST
SHALE BASIN
NISKU FORMATION
CAMROSE MEMBER
IRETON
LEDUC FM
FORMATION
LEDUC FM
DUVERNAY FM
COOKING LAKE FORMATION
MAJEAU LAKE MBR
UPPER DEVONIAN
FRASNIAN
WOODBEND GROUP



R21W4M
T45
33
A
A'
B
B'
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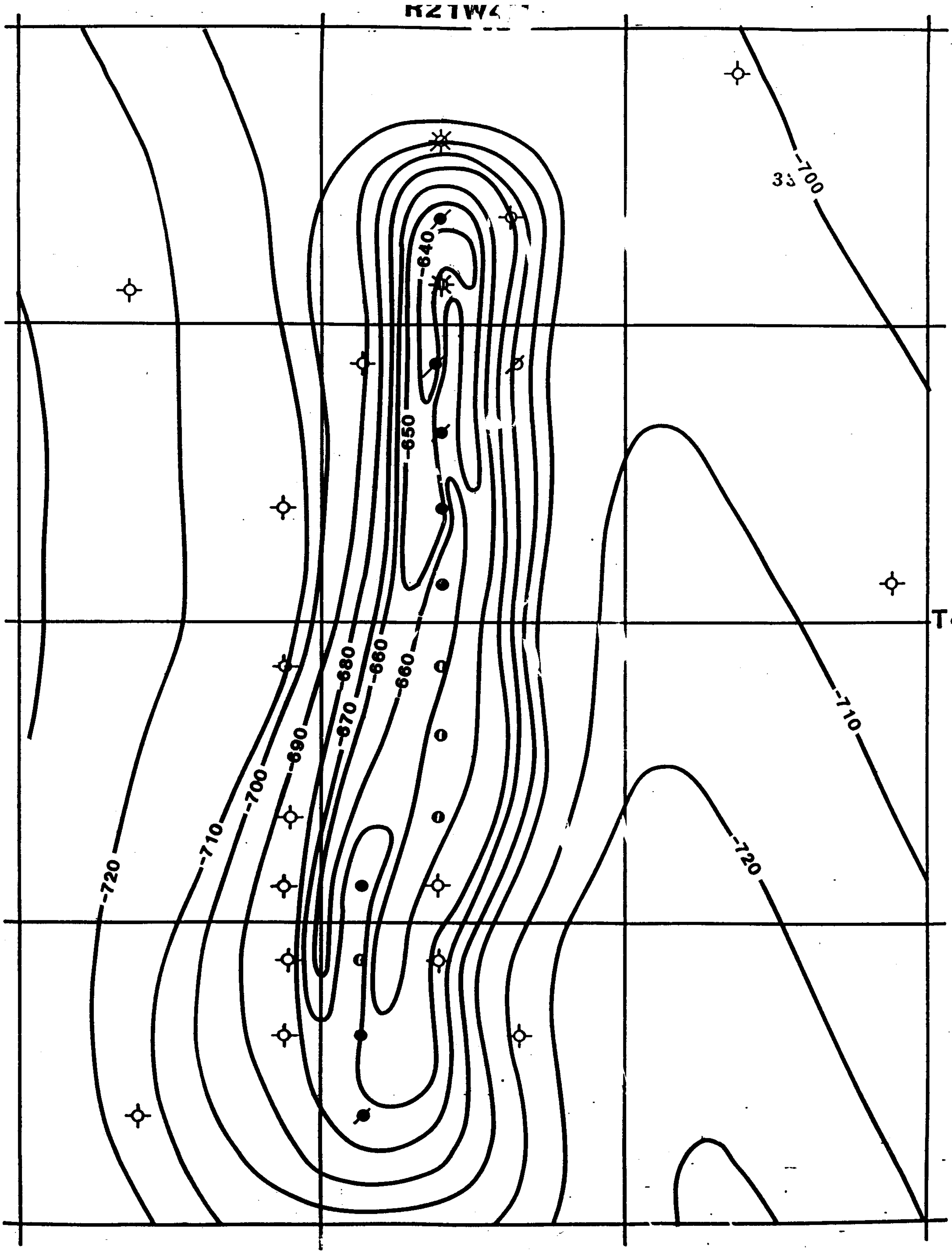
R21W4
T4
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-660
-660
-670
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-710
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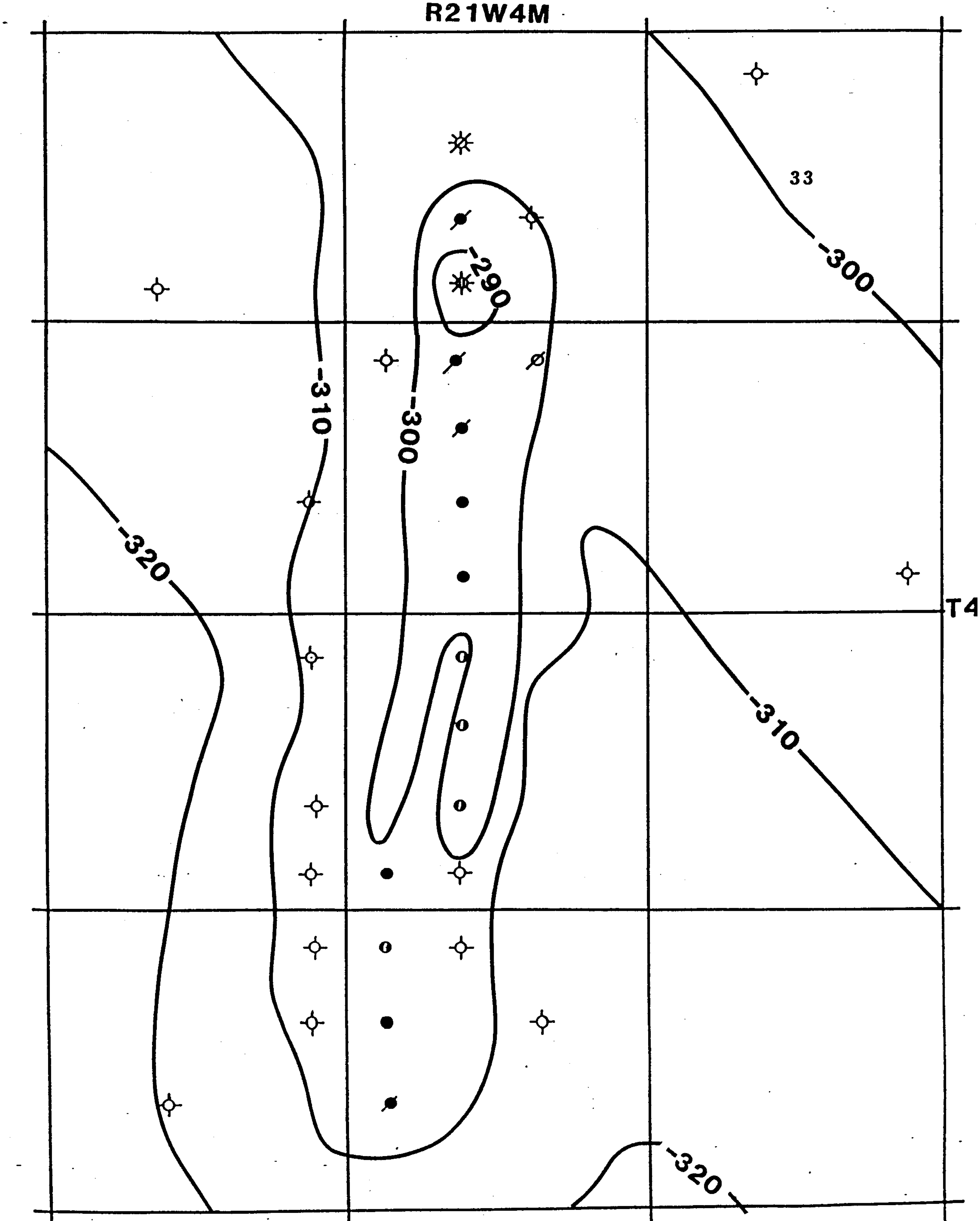
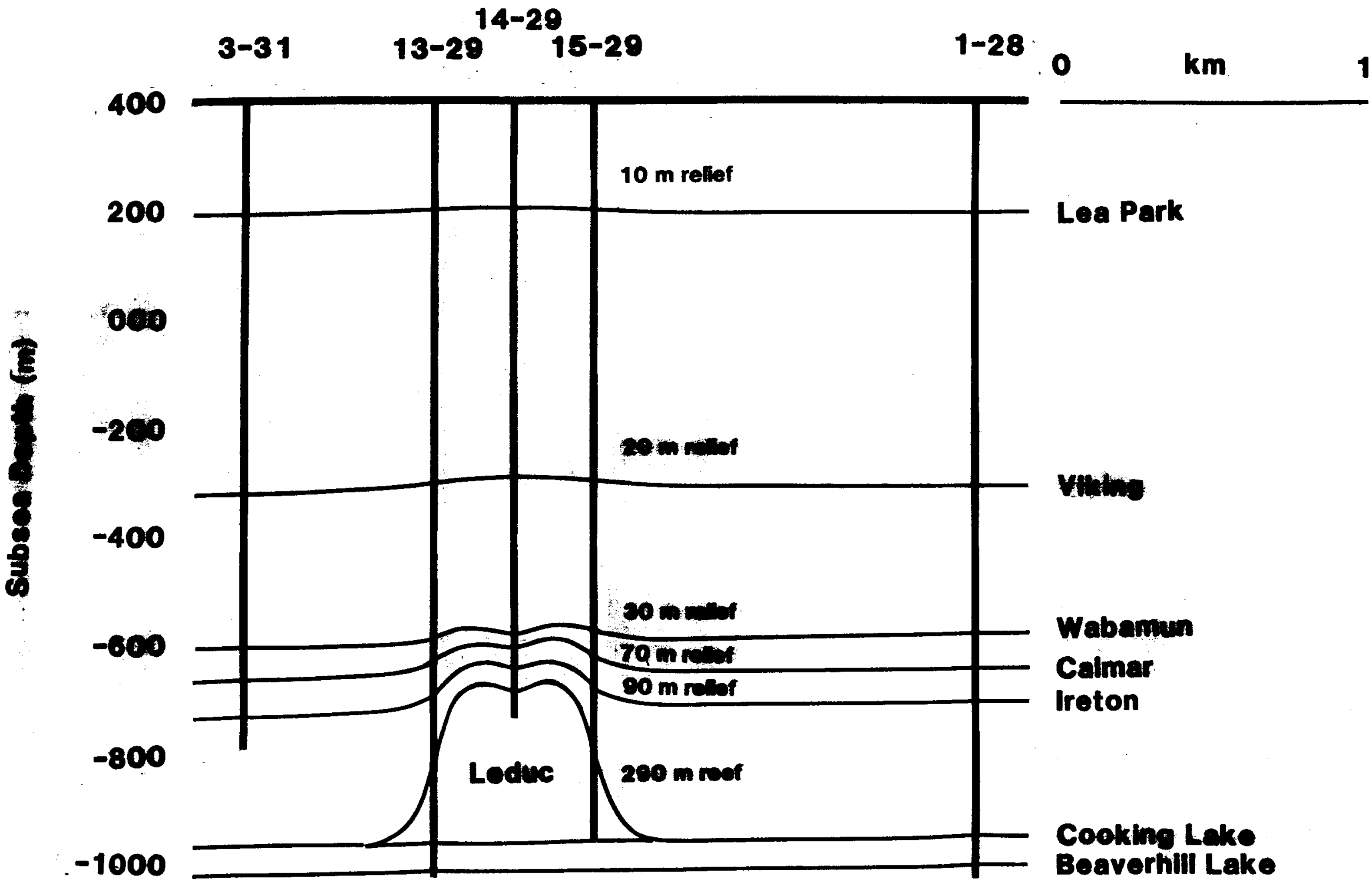
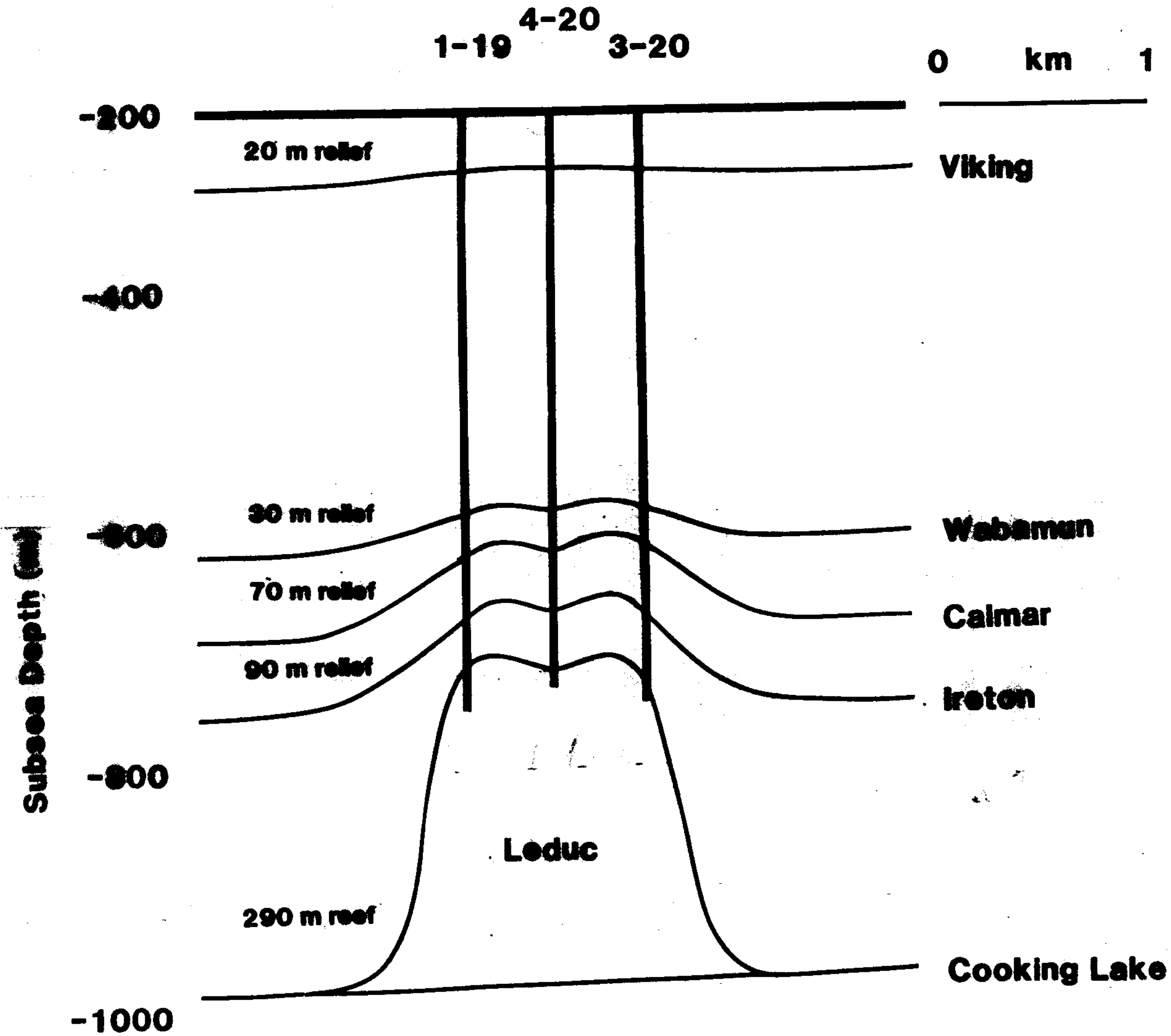


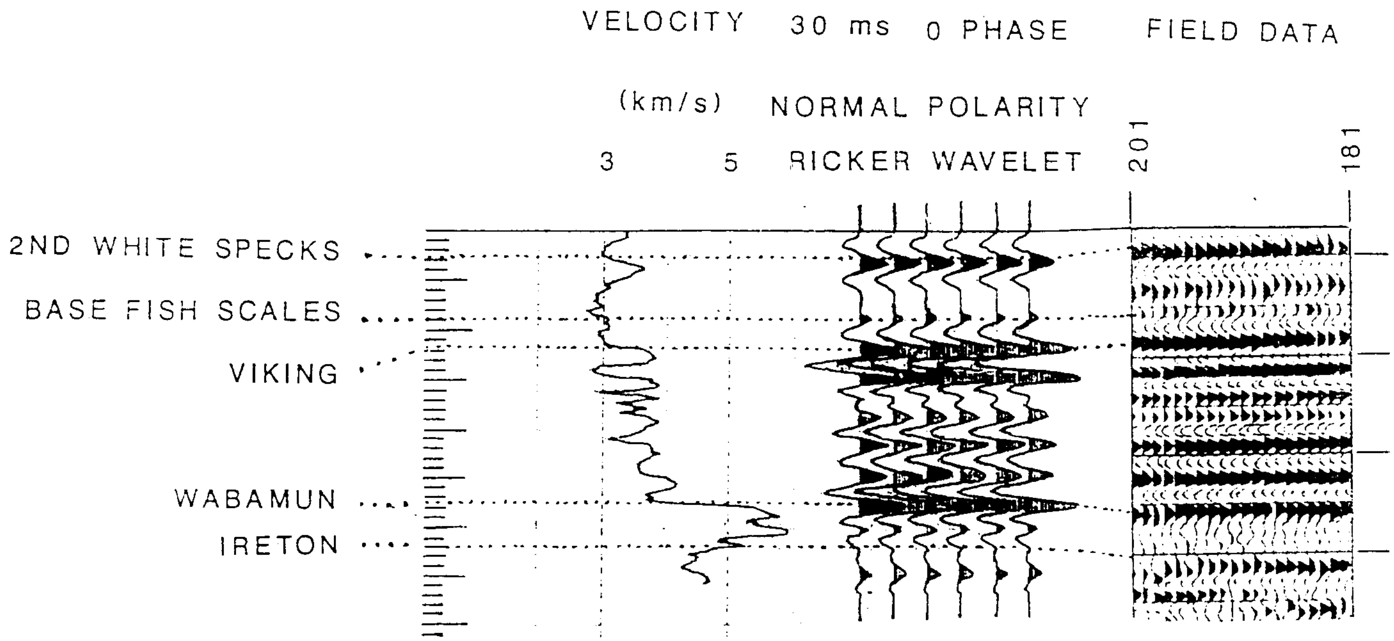
Viking Structure Map (m)

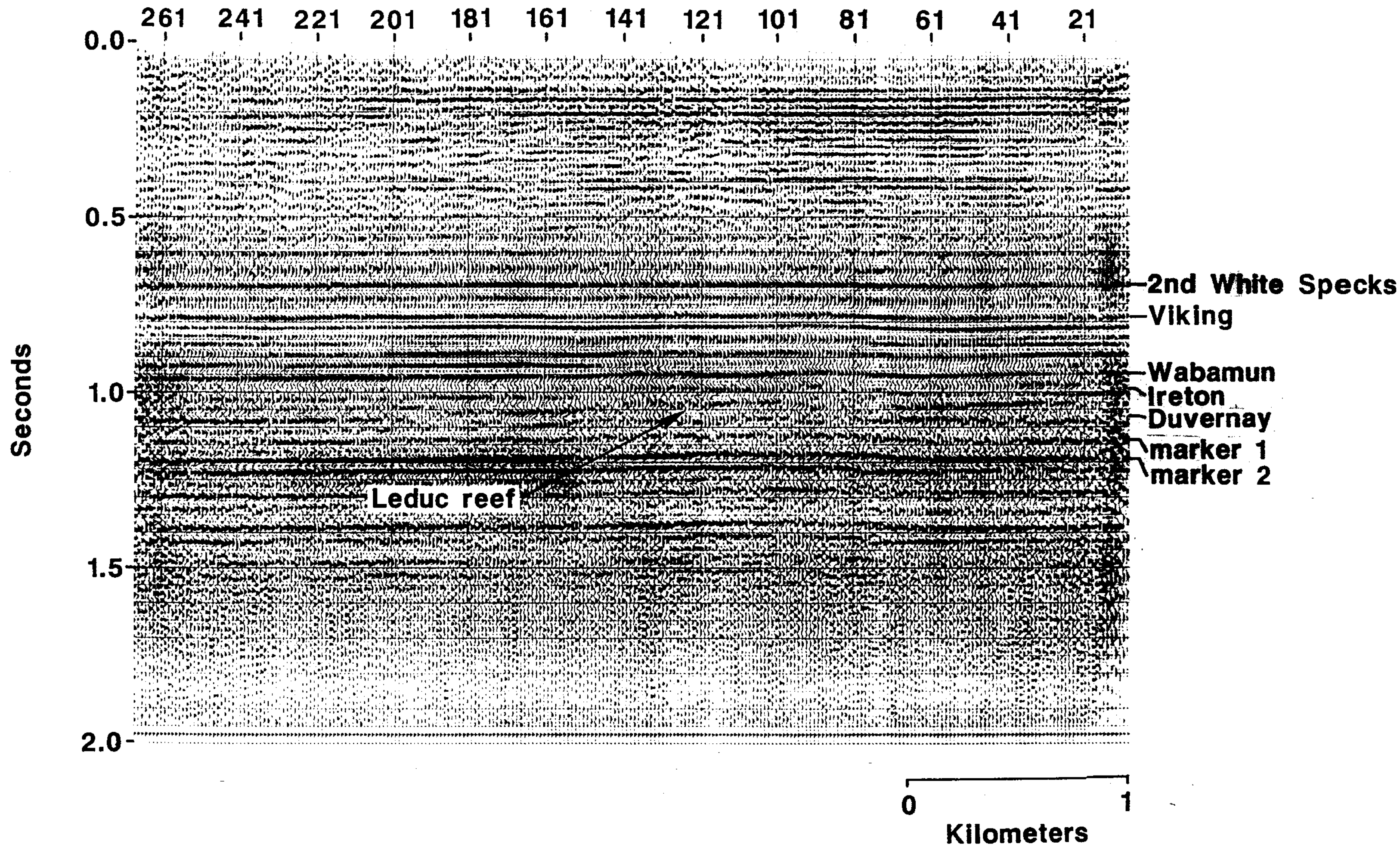


Leduc Cross-section A-A



Leduc Cross-section B-B


VELOCITY
(km/s)
3
5
30 ms 0 PHASE
NORMAL POLARITY
RICKER WAVELET
FIELD DATA
201
181
2ND WHITE SPECKS
BASE FISH SCALES
VIKING
WABAMUN
IRETON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221
201
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121
101
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41
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0.0
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Seconds
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Viking
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Leduc reef
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1
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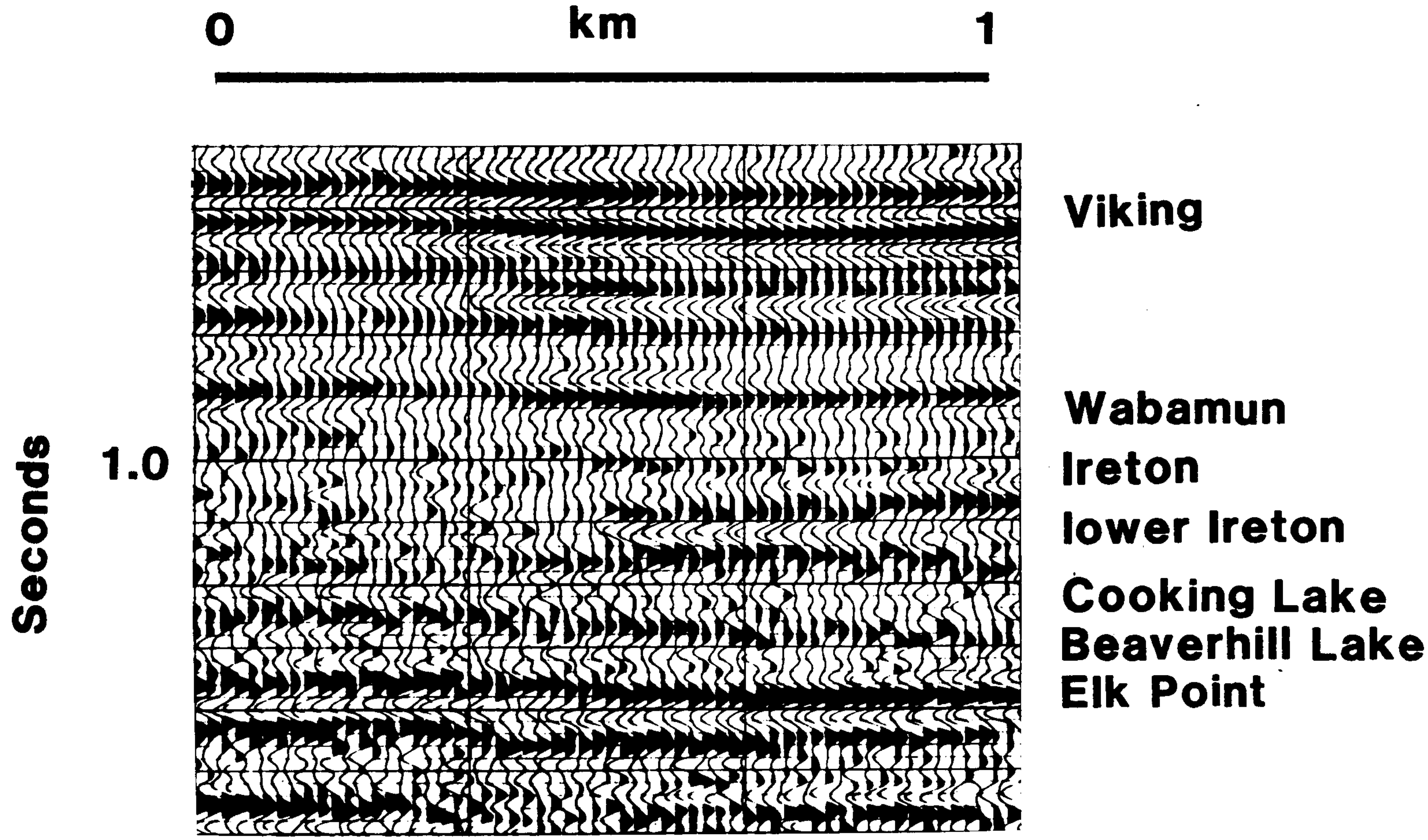

Leduc Reef Example