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A Seismic Analysis of Black Creek and Wabumun Salt Collapse Features, Western Canadian Sedimentary Basin

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ABSTRACT

Two Devonian salts of western Canada, those of the Black Creek member (Upper Elk Point subgroup) in northwest Alberta and those of the Wabamun group in southeastern Alberta, were widely distributed and uniformly deposited within their respective basins. Both of these salts are interbedded within predominantly carbonate sequences and both have been extensively leached. They are now preserved as discontinuous remnants of variable thickness and areal extent.

These salt remnants and their associated collapse features are often associated with structural or stratigraphic traps. Structural traps typically form where reservoir facies are closed across remnant salts, stratigraphic traps often develop where reservoir facies were either preferentially deposited and/or preserved in salt collapse lows. As a result of these relationships between dissolution and hydrocarbon entrapment, the distribution (areal extent and thickness) of these salt remnants is of significant interest to the explorationist.

Both the Black Creek and Wabamun salts have relatively abrupt contacts with the encasing higher velocity, higher density carbonates. Where these salts are sufficiently thick, their top and base typically generate high amplitude reflections, and lateral variations in the salt isopach can be directly determined from the seismic data. Relative salt thicknesses can also be indirectly estimated through analyses of lateral variations in the thicknesses of the encompassing carbonates, time structural drape and velocity pullup. Such seismic information about the thickness and the extent of these salts should be used together with well log control to generate subsurface distribution maps. These maps will facilitate both the delineation of prospective structural and stratigraphic play fairways and the determination of the timing of salt dissolution. In addition, an appreciation of regional salt distribution will decrease the likelihood that remnant salts will be misinterpreted as either reefs and/or faulted structures.

INTRODUCTION

The geographical distribution of the main Devonian salts (Black Creek and Wabamun included) in the western Canadian sedimentary basin is documented by Anderson et al. (1988b), Anderson and Chappell (1988), Bishop (1974), Gorrel and Alderman, (1968), Christiansen (1971), Hamilton (1971), Holter (1969), Meijer Drees (1986), Oliver and Cowper (1983), among others. These authors recognize that each of the salts has been partially dissolved. Such leaching is significant to the explorationist for several reasons:

(1) Structural traps can form where reservoir facies are draped across dissolutional features (Anderson et al., 1988a,b, 1989a,b; Brown et al., 1990).

(2) Stratigraphic traps can form where reservoir facies were either preferentially deposited and/or preserved within dissolutional lows or across positive features associated with salt remnants (Alcock and Benteau, 1976; Anderson et al., 1988a,b, 1989a,b; Brown et al., 1990; Hopkins, 1987).

(3) Relief associated with dissolutional features can be misinterpreted either as drape across reefs or as faulted structures.

We present seismic data acquired over remnants of Black Creek and Wabamun salt. Our interpretation of these data (1) demonstrates that these halites have been extensively dissolved in places; (2) supports the thesis that such leaching occurred more or less continuously from shortly after deposition to the present; (3) illustrates why both structural and

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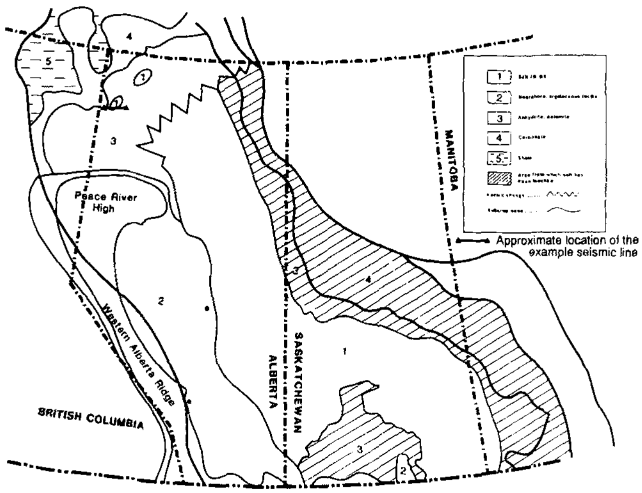

FIG. 1. Facies distribution and paleogeography of the lower part of the Upper Elk Point subgroup and its equivalents, western Interior Plains. The salt facies in the Rainbow Lake area is referred to as the Black Creek member. (Modified after Meijer Drees, 1986).

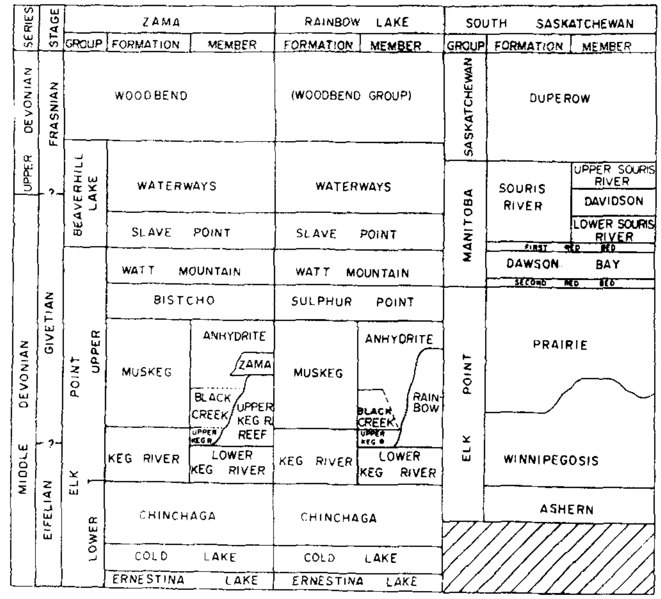

FIG. 2. Stratigraphic correlation chart for part of the Devonian of northern Alberta and southern Saskatchewan, Canada (Anderson et al., 1989a). The example seismic line is from the Rainbow Lake area.

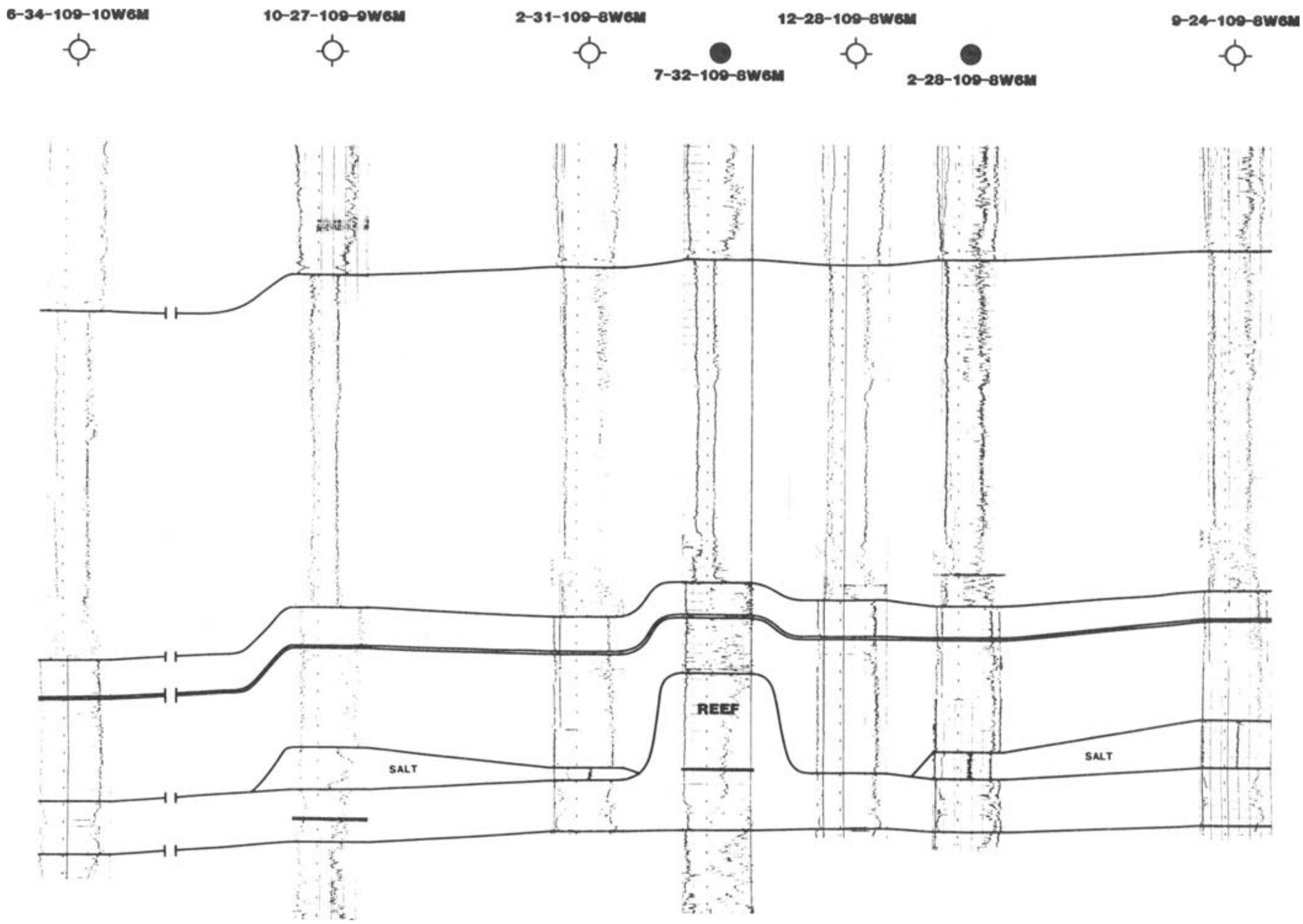

FIG. 3. Cross-section illustrating the log signatures of the reef (Rainbow A pool) and the Black Creek salts crossed by the example seismic line (Figures 4 and 5).

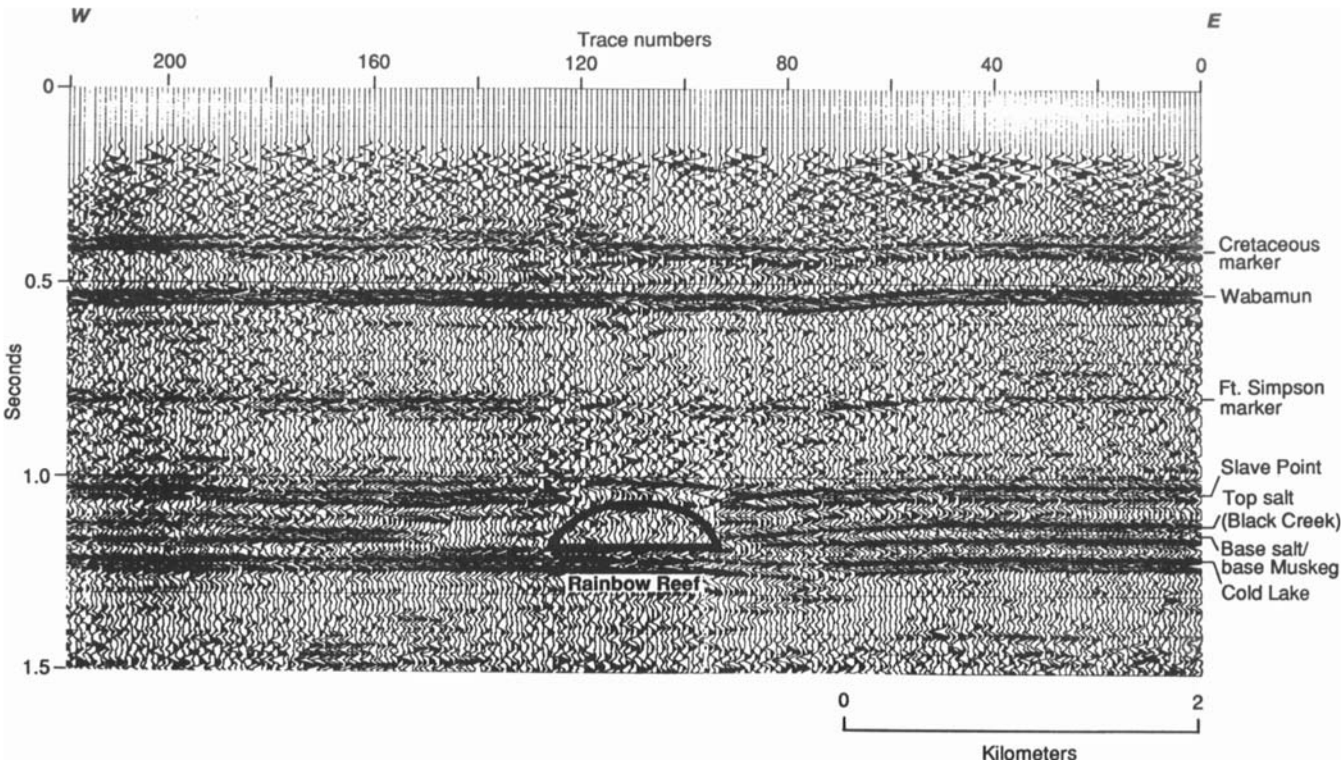

FIG. 4. Reverse-polarity, nonmigrated seismic line, located in Figure 1, depicting the signatures of a Rainbow reef and a remnant of Black Creek salt.

stratigraphic traps are frequently associated with leaching; and (4) demonstrates the potential for misprocessing and misinterpretation.

The basic hypothesis of our analysis, upon which all our estimates of the timing of dissolution rest, is that the dissolution of X vertical meters of salt in post-A time will cause the equivalent vertical collapse of horizon A. This hypothesis is based on the premise that only vertical strain occurs and that no cavities remain. In practice, these assumptions will clearly be violated to some extent, introducing error into any analysis based upon them.

BLACK CREEK MEMBER

Geologic overview

The Upper Elk Point subgroup in the Rainbow Lake area of Alberta (Figure 1) consists of four formations (Figure 2): Keg River, Muskeg, Sulphur Point, and Watt Mountain. The Keg River is subdivided into three members: Lower Keg River, Upper Keg River, and Rainbow; while the Muskeg is subdivided into a lower salt (Black Creek member) and an overlying succession of anhydrites and carbonates (Hriskevich, 1966, 1970).

The Keg River formation in the study area consists of platformal (Lower Keg River), reefal (Rainbow), and interreefal (Upper Keg River) carbonates (Campbell 1987, 1988). The Rainbow reefs tower up to 200 m above the platform facies; the interreef sediments are typically about 50 m thick. These sediments are stratigraphically overlain by the Muskeg formation.

The basal unit of the Muskeg, the Black Creek member salt (Figures 1 and 2), was widely distributed and uniformly deposited in interreef areas, attaining maximum thicknesses of about 80 m (McCamis and Griffith, 1967). Consistent with our cross-sectional interpretation (Figure 3), we find these salts to have been extensively dissolved. We further believe this leaching has been going on since shortly after deposition, at least in places (Anderson et al., 1991). As a result, the Black Creek salt today is preserved as isolated remnants of variable size (Anderson et al., 1986; Brown et al., 1990).

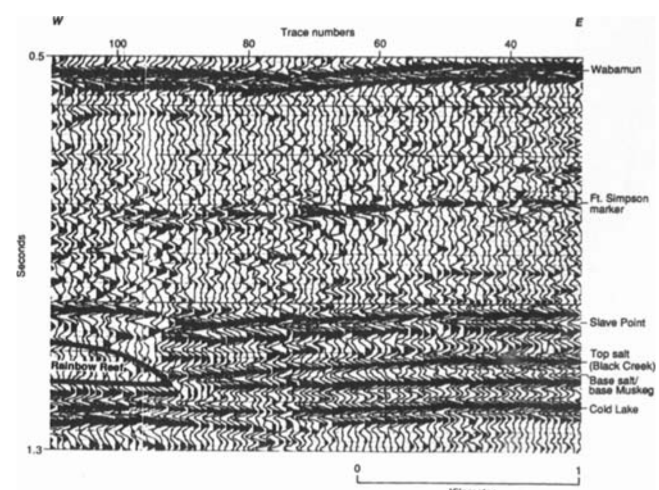

FIG. 5. Enlargement of a portion of the example seismic line (Figure 4).

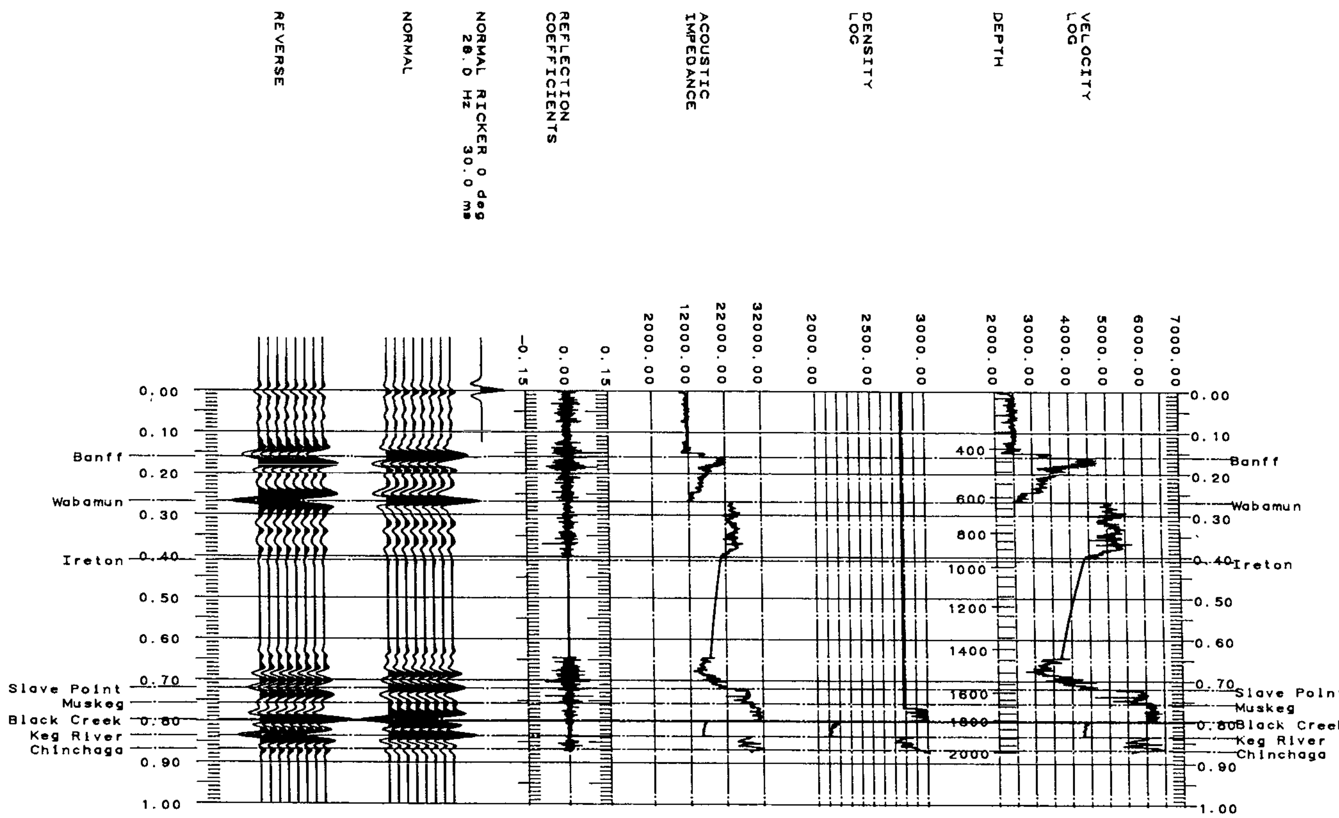

FIG. 6. Synthetic seismogram and related logs for the 9-24-109-8W6M well. This well encountered 82 meters of Black Creek salt. Note that the transit times for the 950 to 1450 meter interval (Ireton shale) were not reliably logged. This log ties the seismic section (Figure 5) reasonably well at trace 210.

Overlying strata drape across both these remnants and the Rainbow reefs (Figures 3 to 5). The magnitude of the drape is primarily a function of the differential compaction of reef and nonreef sediment, and the timing of the dissolution (Anderson and Brown, 1987).

Example seismic line

In Figure 1, the approximate location (Township 109, Ranges 8-9, west of the 6th meridian) of the example seismic line (Figures 4 and 5) is superimposed on a map showing the geographical distribution of the Black Creek salt (Prairie Evaporite equivalent). These are reverse polarity, nonmigrated, six-fold, dynamite data acquired using a 66-m station interval.

The seismic image of the thick Black Creek salt (traces 0–50 and 190–220) is dominated by the high-amplitude reflections originating from the top and base of these salts, respectively; this is confirmed by synthetic seismic modeling (Figure 6). As the Black Creek thins in the proximity of the reef, the upper and lower reflections visually merge and disappear near the flanks of the reef. Note that the upper reflection is structurally low in time near the reef (traces 50–90 and 125–190) from the partial dissolution of the salt.

According to Barss et al. (1970) and Hriskevich (1970), dissolution of the Black Creek salt in the Rainbow area initiated shortly after deposition and continued into the post-Mississippian. Their concept is supported by the seismic data (Figures 4 and 5) in that the amplitude of the salt collapse decreases going upward in the section. For example, compare the Black Creek to Slave Point intervals (inclusive), beneath traces 135, 155, and 205. The interval below trace 135, as calculated from time-thickness values measured on the seismic section and using velocities from the synthetic seismogram (Figure 6), consists of 15 m of salt and 290 m of overlying sediments; at traces 155 and 205 the corresponding thicknesses are 25 and 250 m and 75 and 230 m, respectively. Assuming the Black Creek was uniformly deposited in the study area, then these data imply (1) at least 75 m of salt was initially present, and (2) around 60 and 50 m of salt were dissolved below traces 135 and 155, respectively. Note also that the thicknesses of the Black Creek to Slave Point interval (inclusive) at traces 135, 155, and 205 are 305, 275, and 305 m, respectively. These thicknesses suggest that dissolution beneath trace 135 occurred primarily before the end of Slave Point time, because here the Slave Point top is level with the top at trace 205 where little or no leaching occurred, whereas below trace 155, where the Slave Point is collapsed by 30 m, significant dissolution occurred in post-Slave Point time.

In summary, it appears that (1) extensive dissolution occurred from about traces 125–145 before the end of Slave Point time; (2) extensive dissolution also occurred from traces 50–90 and 145–190 in post-Slave Point time; and (3) little, if any, leaching occurred below traces 0–50 and 190–220.

Structural relief is observed along both the Slave Point and Wabamun horizons in off-reef areas. Assuming these tops to have been relatively flat off-reef prior to salt dissolution, we attribute this structure to the leaching of Black Creek salt in post-Slave Point and post-Wabamun times, respectively. For example, the 30-m difference between the average elevation of the Slave Point horizon above the thick salt remnants and the minimum elevation above the thin salt remnant near trace 80 is attributed to leaching in post-Wabamun time, supporting the thesis that leaching has occurred, in places, more-or-less continuously since deposition.

WABAMUN GROUP SALT

Geologic overview

The Upper Devonian Wabamun group in the Stettler area of Alberta (Figure 7) is subdivided into the Stettler and Big Valley formations (Figure 8). The Stettler consists predominantly of interlayered dolomites, anhydrites, and isolated to contiguous remnants of halite; the Big Valley is composed of green shales and fossiliferous limestones.

The salts of the Wabamun group (Stettler formation) have been mapped in detail by Anderson et al. (1988b) over most of the Stettler area. They conclude that a 40 m thick interval of these halites was uniformly deposited throughout much of southeastern Alberta (Figure 8) and subsequently leached. The discontinuous nature of these salts is illustrated in Figure 9.

Example seismic line

In Figure 7, the approximate location (Township 33, Ranges 20–21, west of the 4th Meridian) of the example seismic line is superimposed on a map showing the geographical distribution of the Wabamun salts (Stettler formation equivalent). These reverse-polarity, nonmigrated data were acquired using a dynamite source and a 40 m group interval. Figures 10 and 11 present interpreted versions of this seismic line.

The reflections from the tops of both the Ireton and Wabamun are high amplitude and laterally continuous across the seismic line, as shown by synthetic seismic modeling (Figure 12). To the east of trace 80 and to the west of trace 240, this interval is consistently about 90 ms thick. In between these two positions, the Ireton-Wabamun interval thins, reaching a minimum of about 75 ms at trace 136. The thickness of the salt interval similarily decreases by about 15 ms. These variations are consistent with the dissolution of 40 m of halite. Inasmuch as the maximum known thickness of salt in the area is about 40 m (Anderson et al., 1988b), the inferences are that about 40 m of salt are present east and west of traces 80 and 240, respectively, and that there is little, if any, salt in the vicinity of trace 136. The 35-ms time-structural low observed along the Wabamun at trace 136, relative to traces 80 and 240, also supports the thesis that about 40 m of salt have been dissolved and replaced by post-Viking clastics (average P-wave velocities on the order of 2500 m/s).

As a consequence of the leaching, time-structural relief is observed along both pre- and post-Wabamun reflections. For example, the Mississippian and Viking events are about 35 ms lower in the vicinity of trace 136 relative to their apparent regional time-depth, indicating that at least some leaching occurred in post-Viking time. Successively less time structure is present along progressively younger strata, suggesting that dissolution occurred over an extended period of time and supporting the conclusion of Anderson et al. (1988b) that leaching has been, and is, an ongoing process.

Structural relief is also observed at pre-Wabamun levels. Note, for example, that the Elk Point reflectors are pushed down by about 10 ms in the vicinity of trace 136. This pattern is consistent with replacing 40 m of salt (P-wave velocity of about 4400 m/s) with 40 m of interlayered mudstones and shales (P-wave velocity of 2500 m/s).

IMPLICATIONS FOR THE EXPLORATIONIST

The dissolution of salts has both positive and negative implications for the explorationist. From a positive perspec-

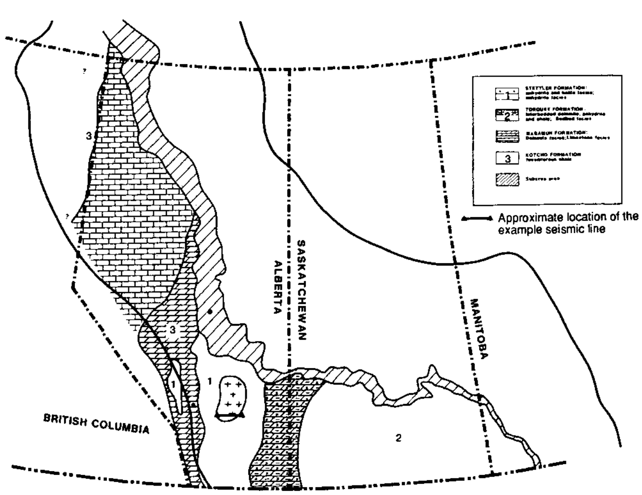

FIG. 7. Facies distribution and paleogeography of the Stettler Formation and its equivalents, western Interior Plains. The halite facies is referred to as the Wabamun salts (modified after Meijer Drees, 1986).

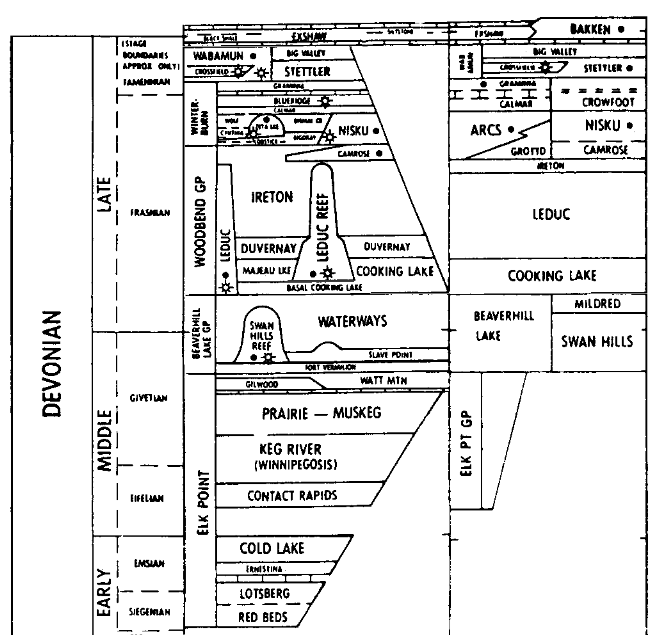

FIG. 8. Stratigraphic correlation chart for part of the Devonian of central and southern plains area, Alberta (after AGAT Laboratories, 1988).

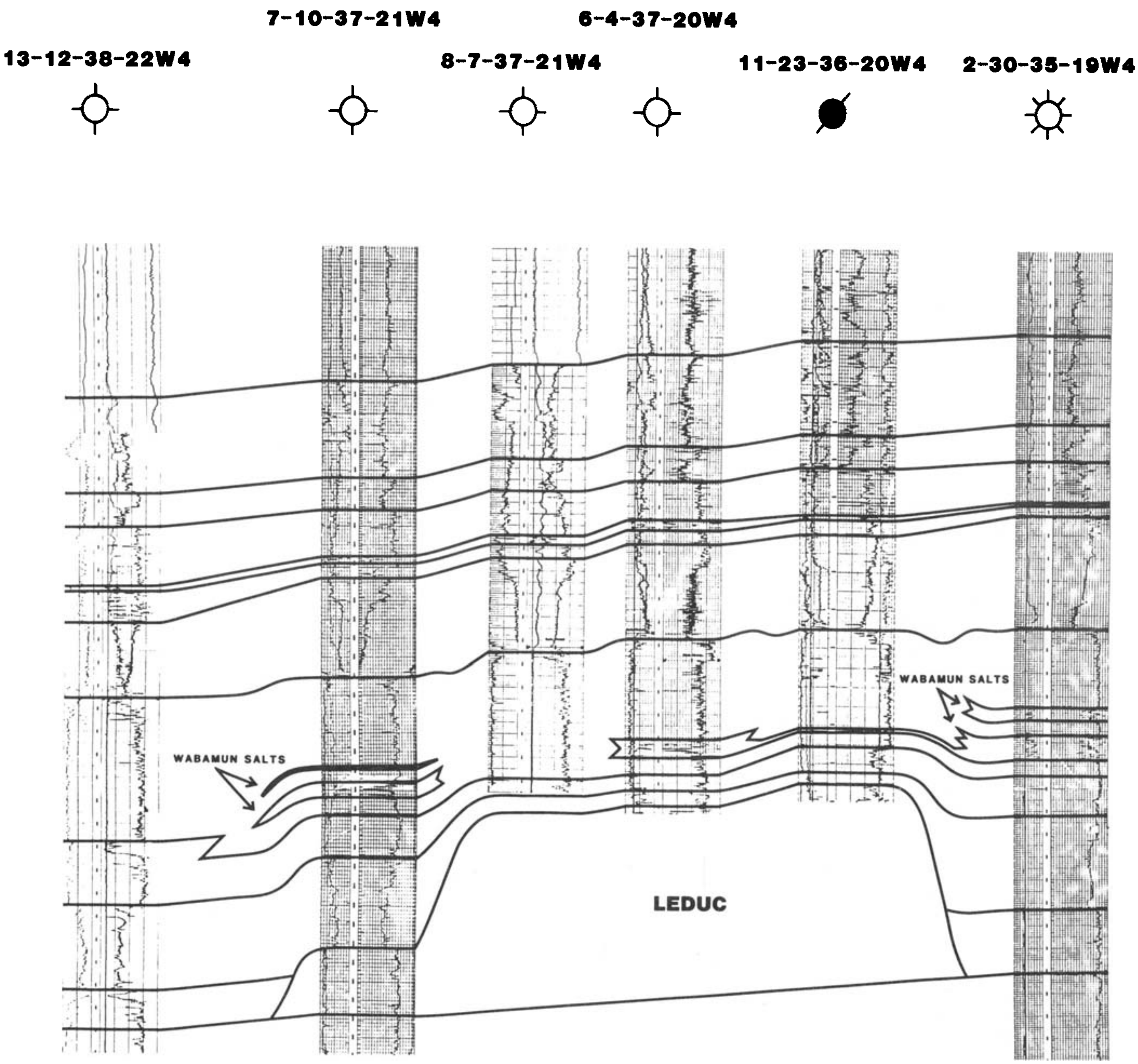

FIG. 9. Cross-section illustrating the log signature of the Wabamun salt.

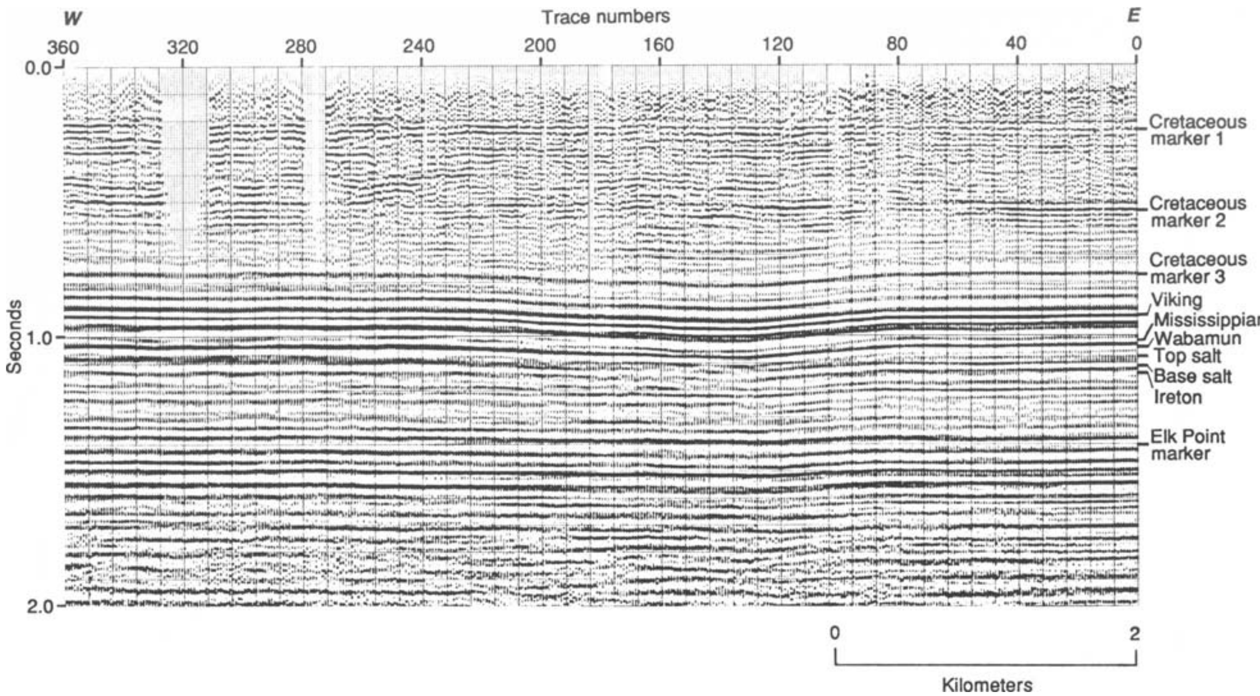

FIG. 10. Reverse-polarity, nonmigrated seismic line, located in Figure 7, depicting the signature of a remnant of Wabamun salt.

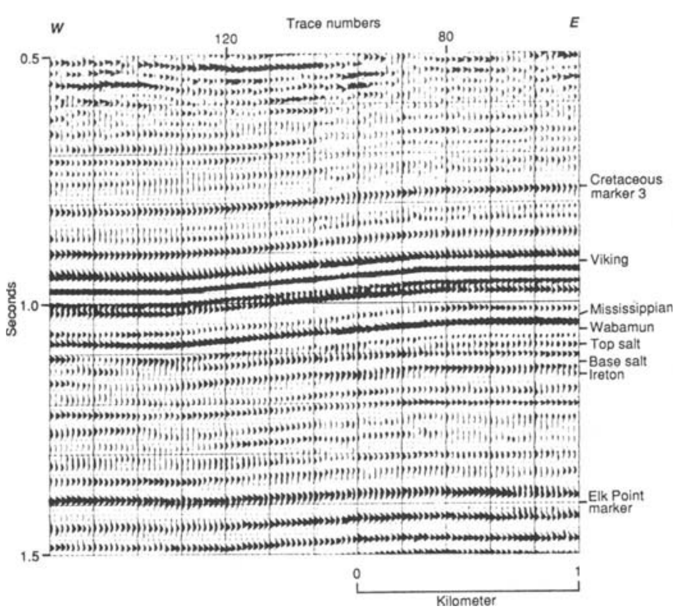

FIG. 11. Enlargement of a portion of the example seismic line (Figure 10).

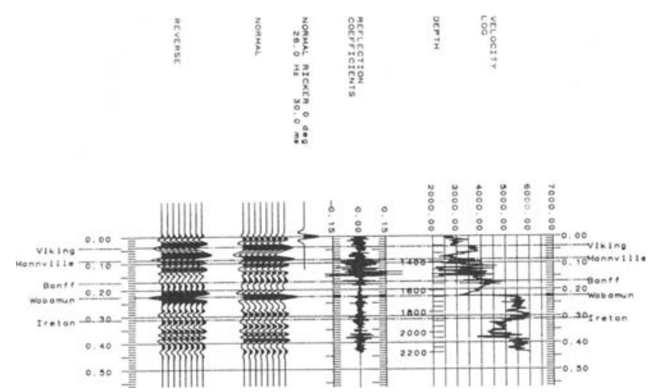

FIG. 12. Synthetic seismogram for the 10-34-32-21W4M well. This well encountered about 25 meters of Wabamun salt. Note that it is about 9 kilometers south of the seismic line and penetrated a thick Banff interval (relative to that seen in the seismic line).

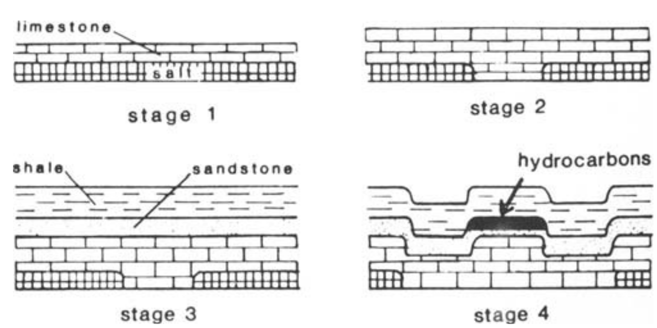

FIG. 13. Schematic diagram showing in four stages how a reservoir facies can be structurally closed over a salt remnant as a result of progressive leaching (Anderson et al., 1988b).

tive, leaching can create both structural traps (Figures 13 and 14) and stratigraphic traps (Figures 15 and 16): from a negative perspective, dissolutional features can be mistaken for either deep-seated structures or reefs.

Structural traps

Structural traps can develop where reservoir facies are draped across collapse features (Figure 13) or the updip edge of remnant salts (Figure 14). The potential for such entrapment is illustrated by both seismic lines (Figures 5 and 11). Note, for example, that postsalt strata drape across the edge of the remnants.

Stratigraphic traps

Stratigraphic traps may develop where reservoir facies are either preferentially deposited or preserved in salt-dissolution lows (Figures 15 and 16). Such traps could have developed within our study area where salts have been extensively leached. Preliminary and ongoing work in the study area (Anderson et al., 1988b) suggests that the progressive leaching of salt influenced paleostructure and drainage patterns. If this thesis is correct, play fairways could be defined on the basis of paleodissolutional patterns.

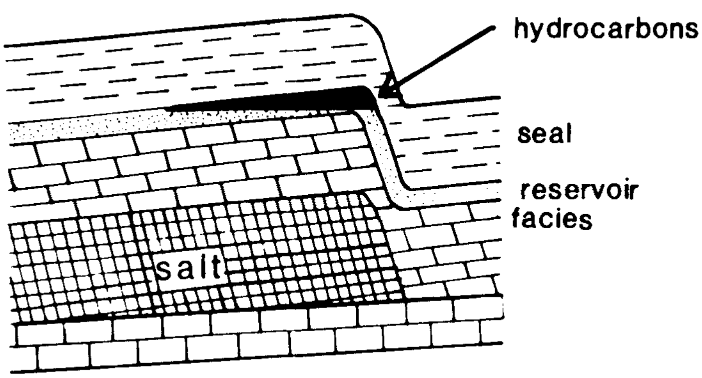

FIG. 14. Schematic diagram showing how a reservoir facies can be structurally closed across the updip edge of a salt remnant (Anderson et al., 1988b).

Misinterpretation

Dissolution can cause time-structural relief along both reflections that are presalt (velocity pullup or pushdown) and on those that are postsalt (collapse structure). As suggested by Figure 17, such relief could be misinterpreted as indicative of reefal buildups or deep-seated structure. When working in an area of salt dissolution, the explorationist must carefully evaluate the seismic data, keeping in mind the several possible interpretations—and testing each—in order to determine the most probable cause of any time-structural relief.

Figure 18 presents a modified version of Figure 10. Manual static corrections were applied to these data by a processor who was not aware that spectacular collapse features occurred in this area. Had it not been for both the anomolous relief at a two-way traveltime of about 20 ms and the discontinuity near trace 102, this processing error might have gone unchallenged. In any case, it is not difficult to conceive of seismic sections that are equally misprocessed but do not display such telltale evidence of it. These data (Figures 17 or 18), on the basis of apparent velocity pullup and the thinning of the Wabamun to Ireton interval, could have been misinterpreted as indicative of reef and/or faults, possibly resulting in the acquisition of additional seismic control, an acreage position, and/or unwarranted drilling.

CONCLUDING SUMMARY

Both the Black Creek and Wabamun salts have been extensively leached in places. As illustrated by the example seismic data and schematic figures, such dissolution can create the potential for structural and/or stratigraphic traps. As shown by these examples, the seismic technique can be a viable exploration tool in the search for such reservoirs, if such salt-related features in the seismic section are recognized by the interpreter.

As a result of the relationships between dissolution and hydrocarbon traps, the presence of leached salts in the subsurface is generally favorable. There are, however, potential pitfalls, the most serious of these being potential misinterpretations when it is not recognized that certain features are salt-related. The possibility of improper proc-

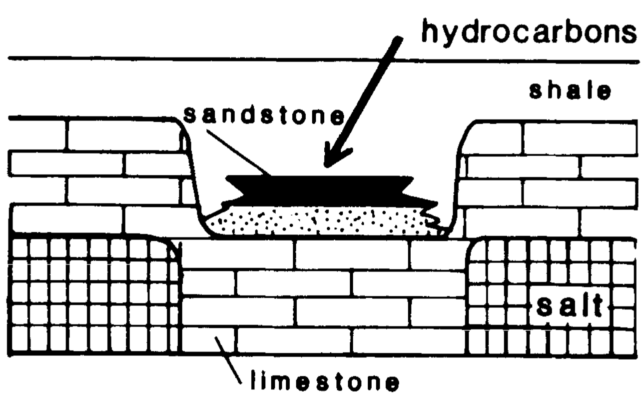

FIG. 15. Schematic diagram showing how a reservoir facies can be preferentially deposited within a salt-dissolution low (Anderson et al., 1988b).

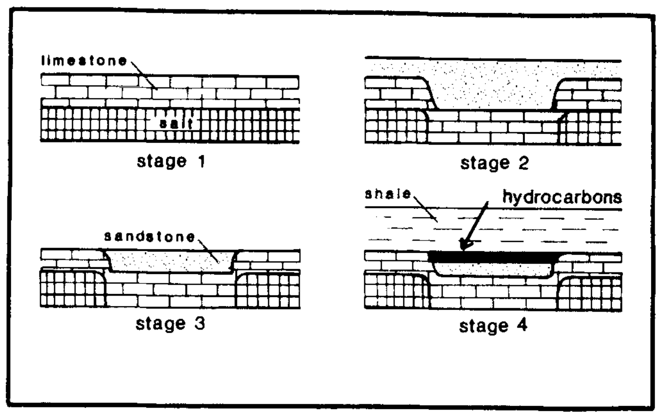

FIG. 16. Schematic diagram showing how a reservoir facies can be preferentially preserved in a salt-dissolution low (Anderson et al., 1988b).

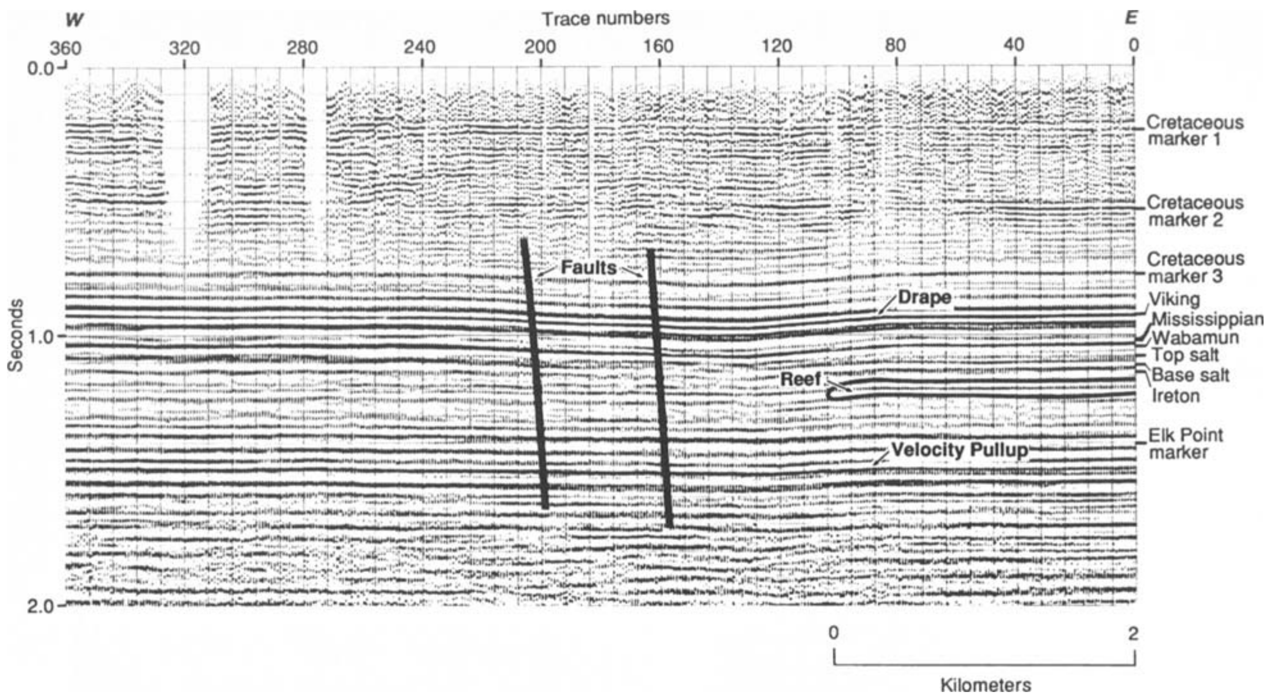

FIG. 17. Intentionally misinterpreted version of the example seismic line (Figure 10), illustrating the similarities among the seismic signatures of salt collapse features, reefs, and faults.

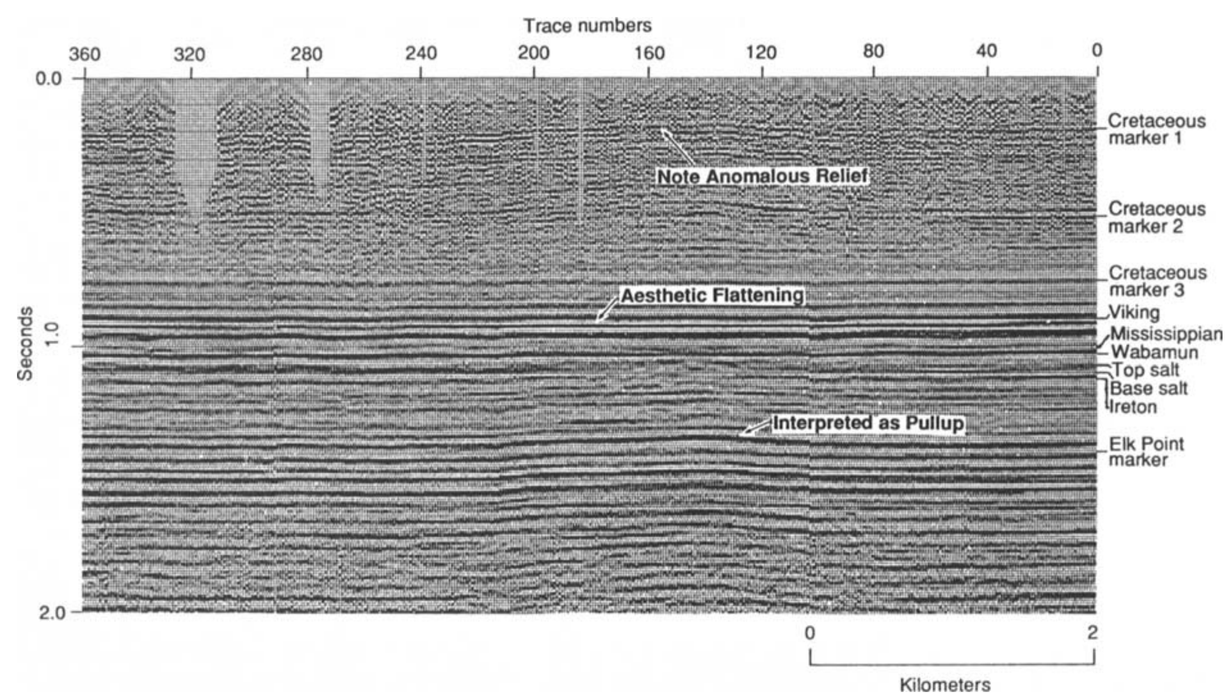

FIG. 18. Improperly processed version of the example seismic section. This line was arbitrarily smoothed at the Viking level by the processor.

essing also exists, as shown in the example above. As illustrated, salt-dissolution features on both properly and improperly processed data may be erroneously attributed to reefs and/or to deep-seated structures.

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