ASTROBLEMES IN THE WILLISTON BASIN*†

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Introduction

The Williston Basin is generally described as a rather simple, tectonically quiet, bowl-shaped depression filled with sediments ranging in age from Cambrian to Tertiary. The most pronounced unconformity occurs at the top of the Paleozoic. Glacial drift ranging in thickness from zero to approximately 1000 feet, covers most of the northern half of the region. The Cedar Creek and Nesson anticlines exemplify the larger types of structure present in the Basin.

This rather uniform, "layer-cake" environment facilitates detailed study and correlation of rock units over wide areas as contrasted with the difficulty of such work in more highly disturbed basins.

The concerted exploration effort for hydrocarbons in the Basin during the late 1940's and early 1950's, following the Leduc oil discovery in Alberta, soon convinced explorationists, among them R. L. Milner and R. A. Bishop, that the dominant stencil superimposed on this Basin's sediments was related to Middle Devonian salt tectonics. Many excellent papers have been written on this subject since then.

Most of the structural anomalies encountered are at least partially affected by salt solution-collapse phenomena. One aspect of this process which has been treated rather lightly in the past, is the cause for commencement of local solution activity. The author is sufficiently familiar with a number of sombrero-shaped features resulting from multiple stage solution and collapse that have been adequately mapped with the seismograph and penetrated with the drill to sufficient depth, to rule out any conventional reason for the initiation of the localized solution.

From our knowledge of the extensive impact history of the moon and sister planets, (most recently we saw for the first time the pock-marked surface of Mercury as a result of the Mariner #10 by-pass) intuition tells us that despite the masking effect of the atmosphere and water, plus the various forces of erosion, there must exist both on the surface and within the subsurface of the earth, considerably more evidence of impact scars or astroblemes than has been discovered and documented so far.

The main purpose of this paper is to outline, with the aid of key maps, cross sections and seismic record sections, the basic parameters which allow us to identify three subsurface structures in the Williston Basin as fossil impact craters (Viewfield, Saskatchewan: T. 7, R. 8, W2M; Hartney, Manitoba: T. 5, R. 24, W1M; Red Wing Creek, North Dakota: T148N-101W). It is hoped this will lend further credence to the idea expressed previously (Sawatzky, 1972) that astroblemes may be the primary reason for the existence of at least some of the sombrero features found in the Williston Basin to date.

General

Figure 1 shows the location of known and inferred impact sites in North America, including craters, fossil craters and probable astroblemes. The outline of the Williston Basin is indicated, as well as the location of the three features considered by

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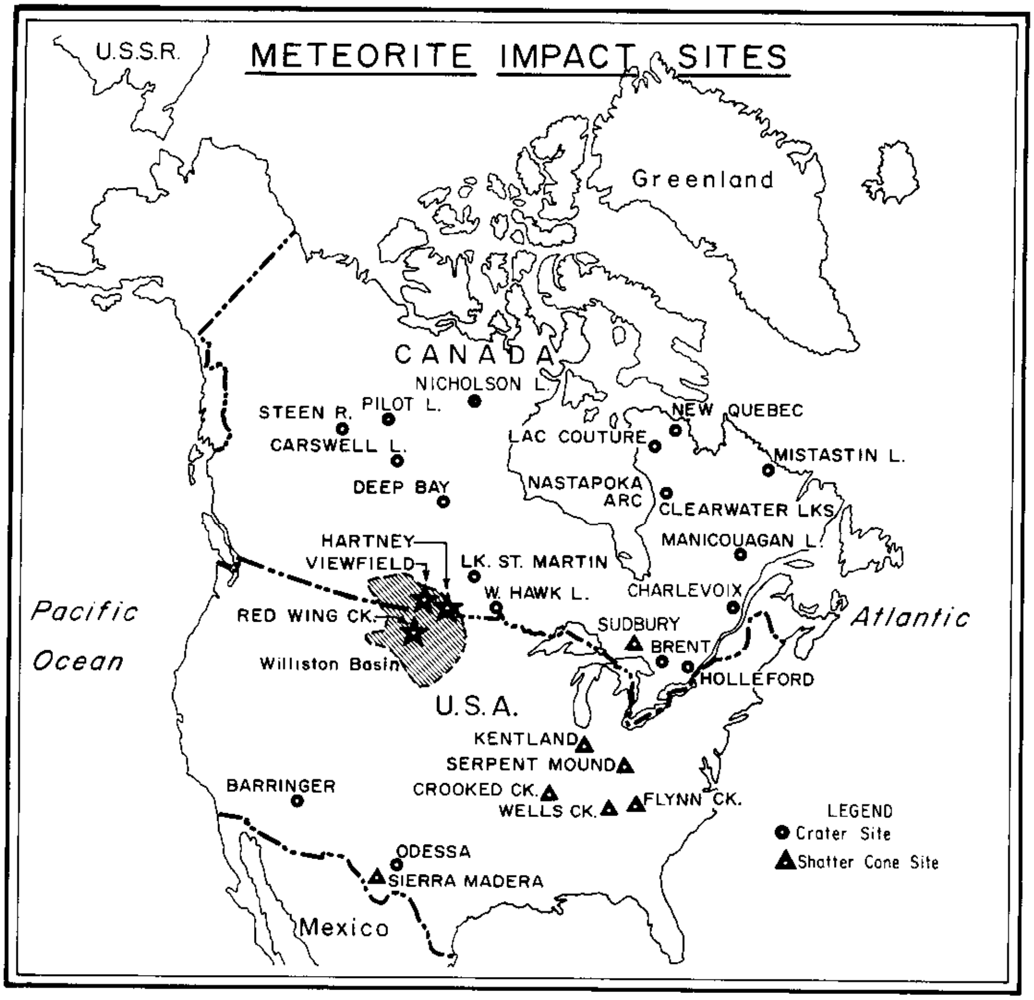
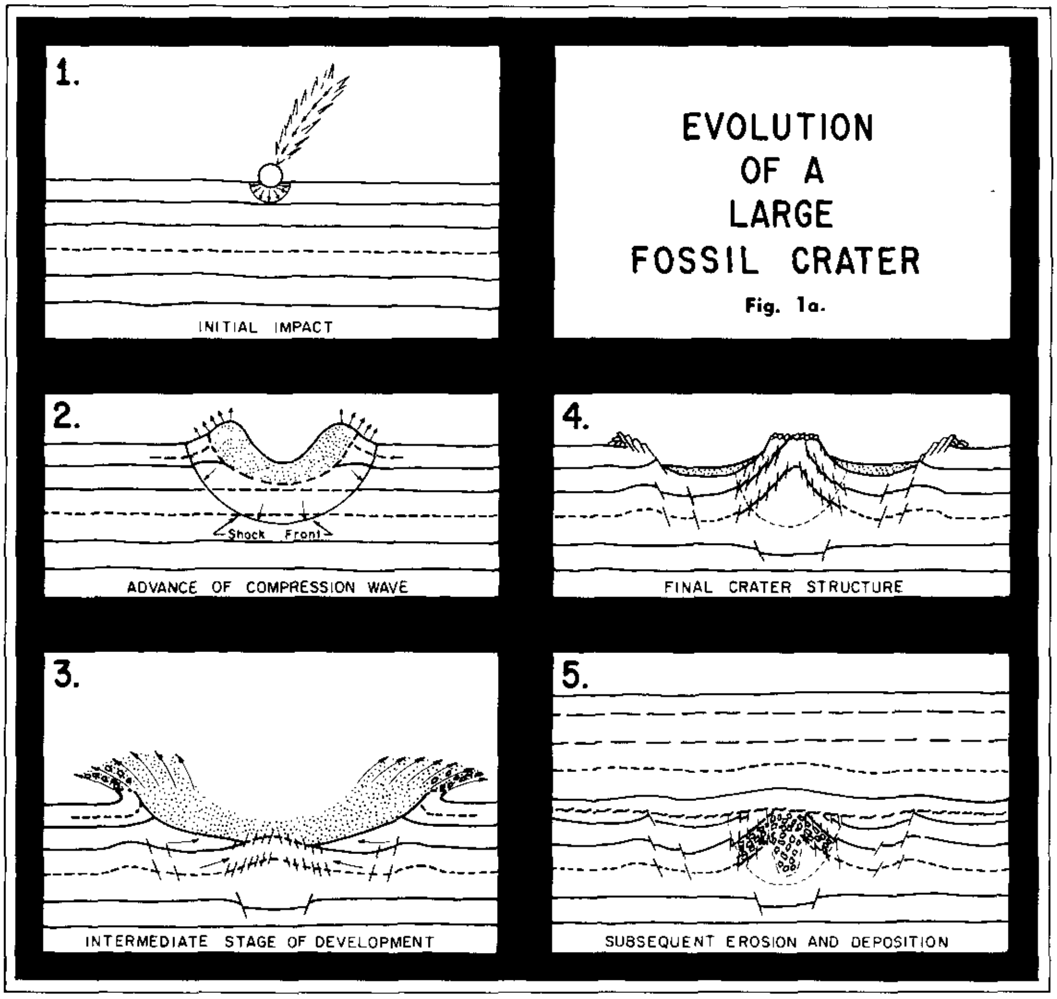

METEORITE IMPACT SITES
U.S.S.R.
Greenland
CANADA
NICHOLSON L.
STEEN R.
PILOT L.
CARSWELL L.
DEEP BAY
NEW QUEBEC
LAC COUTURE
MISTASTIN L.
NASTAPOKA ARC
CLEARWATER LKS
MANICOUAGAN L.
HARTNEY
VIEWFIELD
LK. ST. MARTIN
W. HAWK L.
CHARLEVOIX
Pacific Ocean
RED WING CK.
SUDBURY
BRENT
Atlantic
Williston Basin
HOLLEFORD
U.S.A.
KENTLAND
SERPENT MOUND
BARRINGER
CROOKED CK.
WELLS CK.
FLYNN CK.
LEGEND
Crater Site
Shatter Cone Site
ODESSA
SIERRA MADERA
Mexico

Fig. 1.



the author to be buried fossil craters. The subsurface structures will be discussed in relation to known surface analogues.

The well publicized Barringer Crater in Arizona is an excellent example of the simple bowlshaped crater, displaying an elevated rim, which typifies impact excavations of less than two miles in diameter. The Carswell Lake feature in Northwestern Saskatchewan is a good example of the larger craters which, in addition to the outer rim, invariably display an elevated, highly disturbed central core. Figure 1a shows the evolution of a large fossil crater. A generalized stratigraphic chart representing the regional geology in the study area is shown in Fig. 2.

THE VIEWFIELD (SASKATCHEWAN) CRATER

Figure 3 is a photograph of the Barringer Crater. This feature is approximately 3/4 of a mile in diameter (4150 feet) and 570 feet deep. Its age, estimated at 25,000 years, represents a recent event on the geological time scale.

For comparison, the structure at Viewfield, Saskatchewan, is shown in several illustrations. Figure 4 is a contour map of the top of the Mississippian, based on well control. A rather simple bowl-shaped depression approximately 1½ miles in diameter is indicated. The present elevation of the rim is approximately 200 feet and a minimum crater depth of 600 feet is ex-

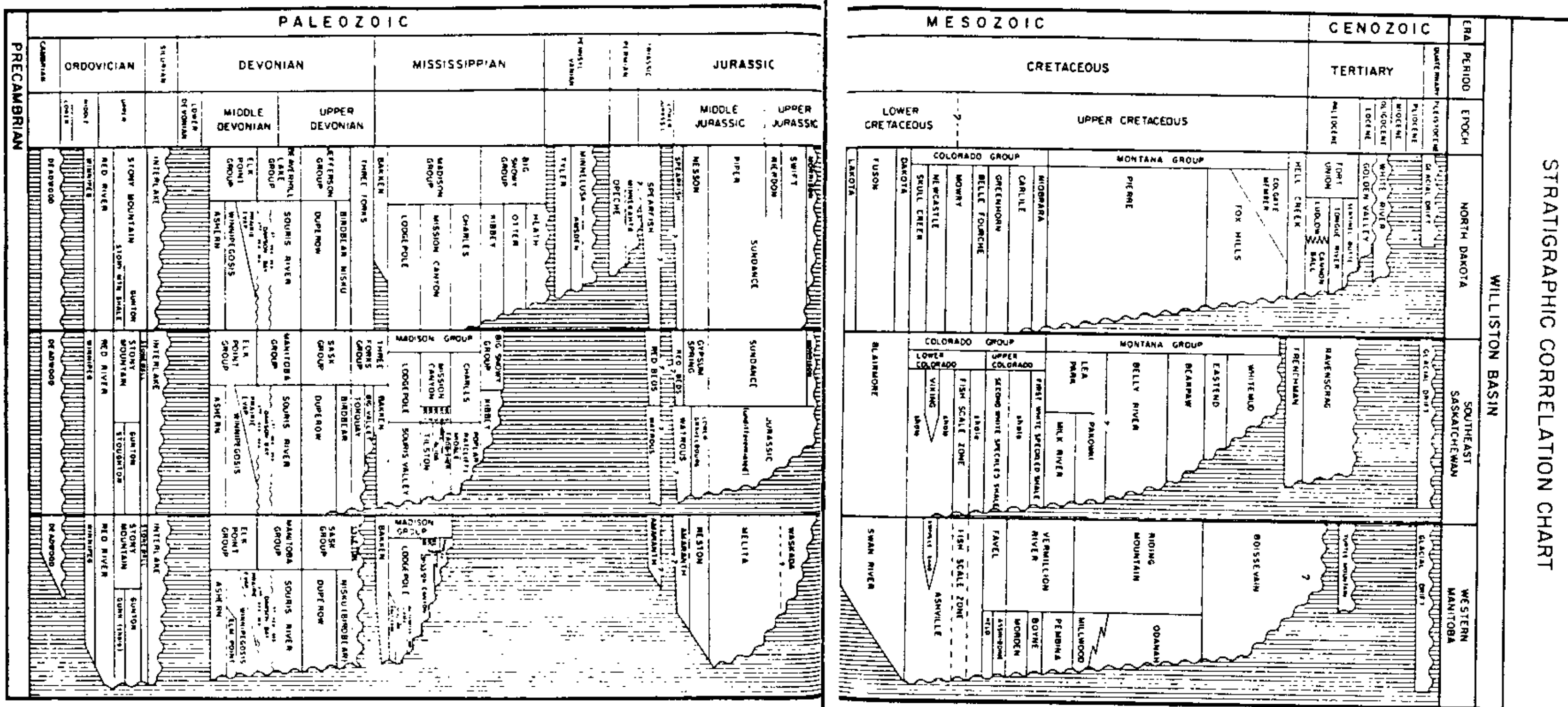

PALEOZOIC
MESOZOIC
CENOZOIC
ERA
PERIOD
EPOCH
PRECAMBRIAN
ORDOVICIAN
DEVONIAN
MISSISSIPPIAN
JURASSIC
CRETACEOUS
TERTIARY
MIDDLE DEVONIAN
UPPER DEVONIAN
MIDDLE JURASSIC
UPPER JURASSIC
LOWER CRETACEOUS
UPPER CRETACEOUS
NORTH DAKOTA
SOUTHEAST SASKATCHEWAN
WESTERN MANITOBA
WILLISTON BASIN
STRATIGRAPHIC CORRELATION CHART

Fig. 2.

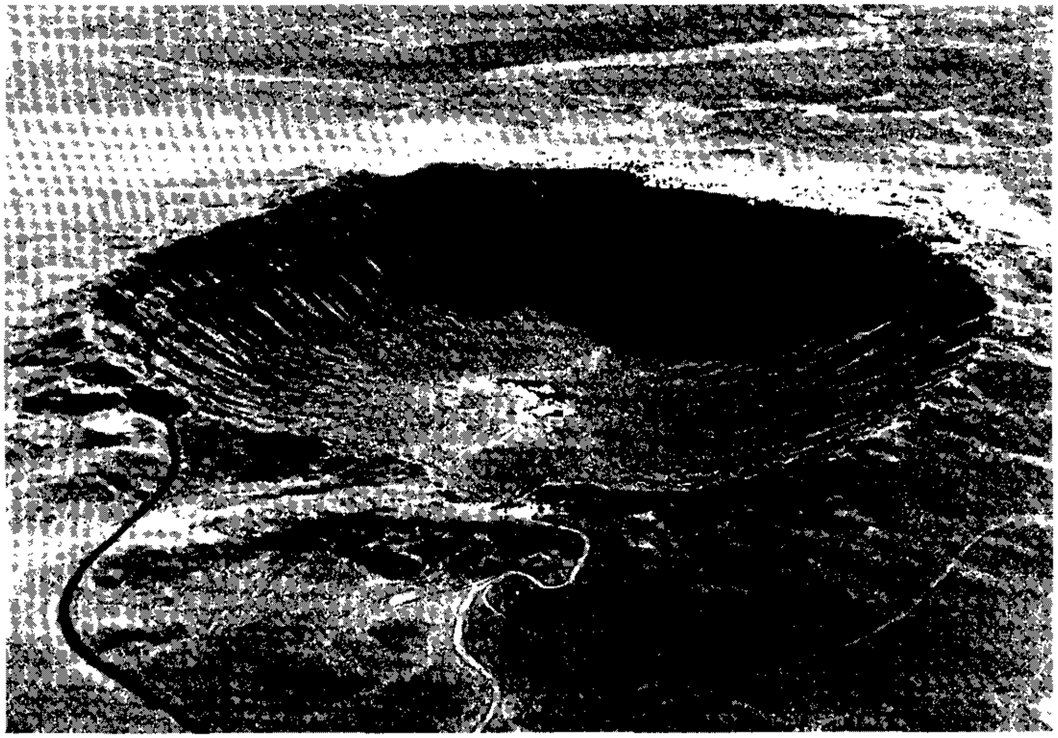


Fig. 3.

pressed. However, neither of the wells near the center of the feature (#13-29 and #15-29) reached the Mississippian, and empirically derived explosion crater equations (Baldwin, 1949) as well as detailed seismic data suggest that they may still be several hundred feet short of this target.

Figure 5 shows a log section across the crater pertaining to the wells highlighted on the previous figure. The impact is considered to be of Jura-Triassic age since disturbed Mississippian limestone and dolomite is found sandwiched between Lower Watrous Red Beds (Triassic) on the periphery of the rim.

Figure 6 is a 300% C.D.P. seismic record section of an east-west line crossing the crater and passing by the wells indicated at the top of figure. The section has been *flattened on the Second White Specks at* 0.650 sec. However, this horizon displays a maximum depression over the crater of approximately 35 feet . The top of the Blairmore is also essentially flat but the basal part of the Blairmore and the Jurassic event show pronounced slumping into the crater. This is attributed to postimpact Middle Devonian salt solution and collapse as well as a certain amount of differential compaction of the clastic section over the crater. The event labelled "Mississippian" and mapped as such, appears to represent the same up-to-the-rim position; however, as one proceeds across the crater it more accurately depicts the top of the Lower Watrous. The precise attitude of the Mississippian is difficult to follow through the crater but appears to be suggested by the strong dips indicated between this horizon and the Devonian Birdbear event. In addition to showing the crater profile, the Birdbear displays several distinct dislocations. These are evident on all of the seismic lines *associated with the impact area. The* Prairie Evaporite event can be carried continuously across the crater and owes its configuration to a certain amount of plastic

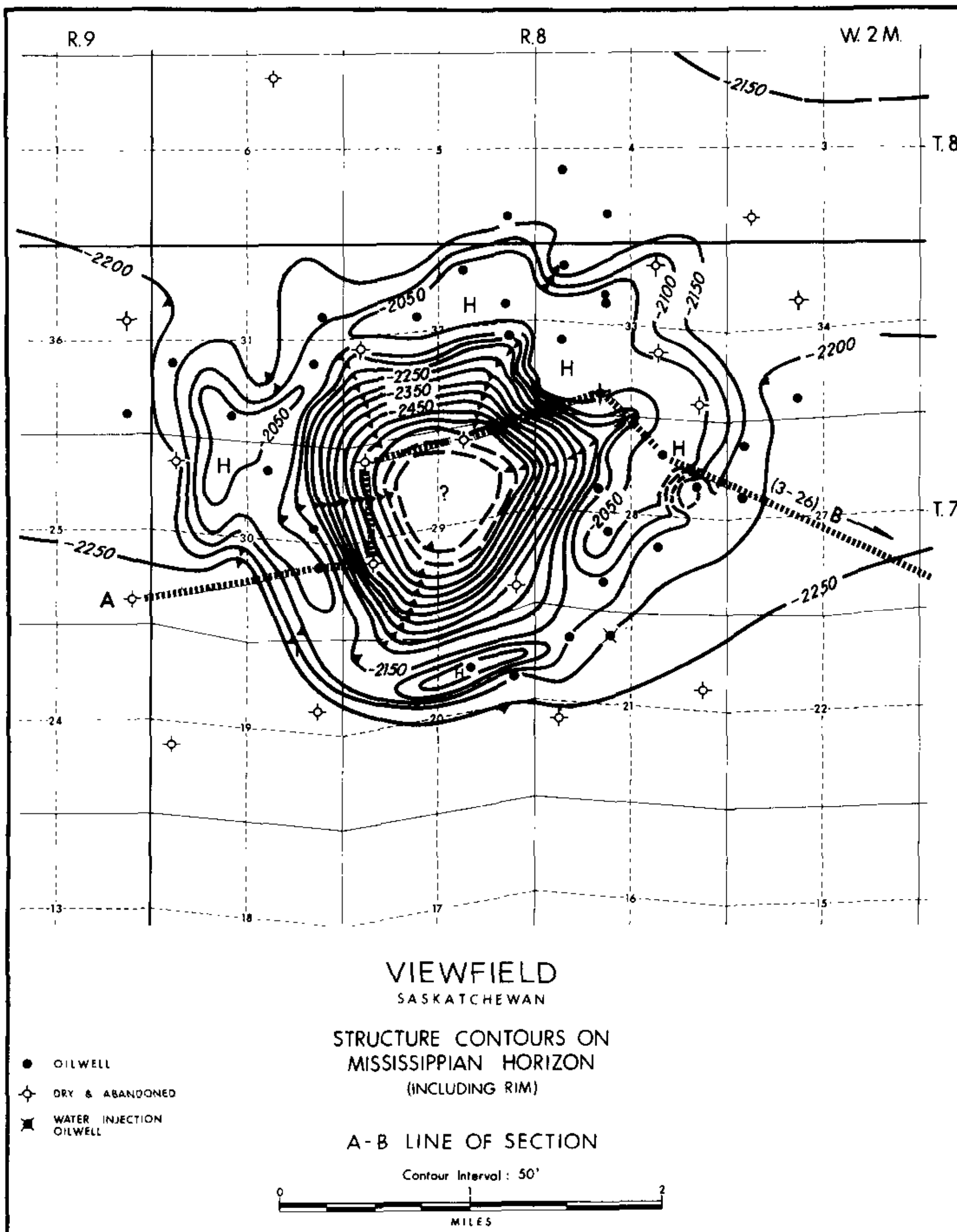
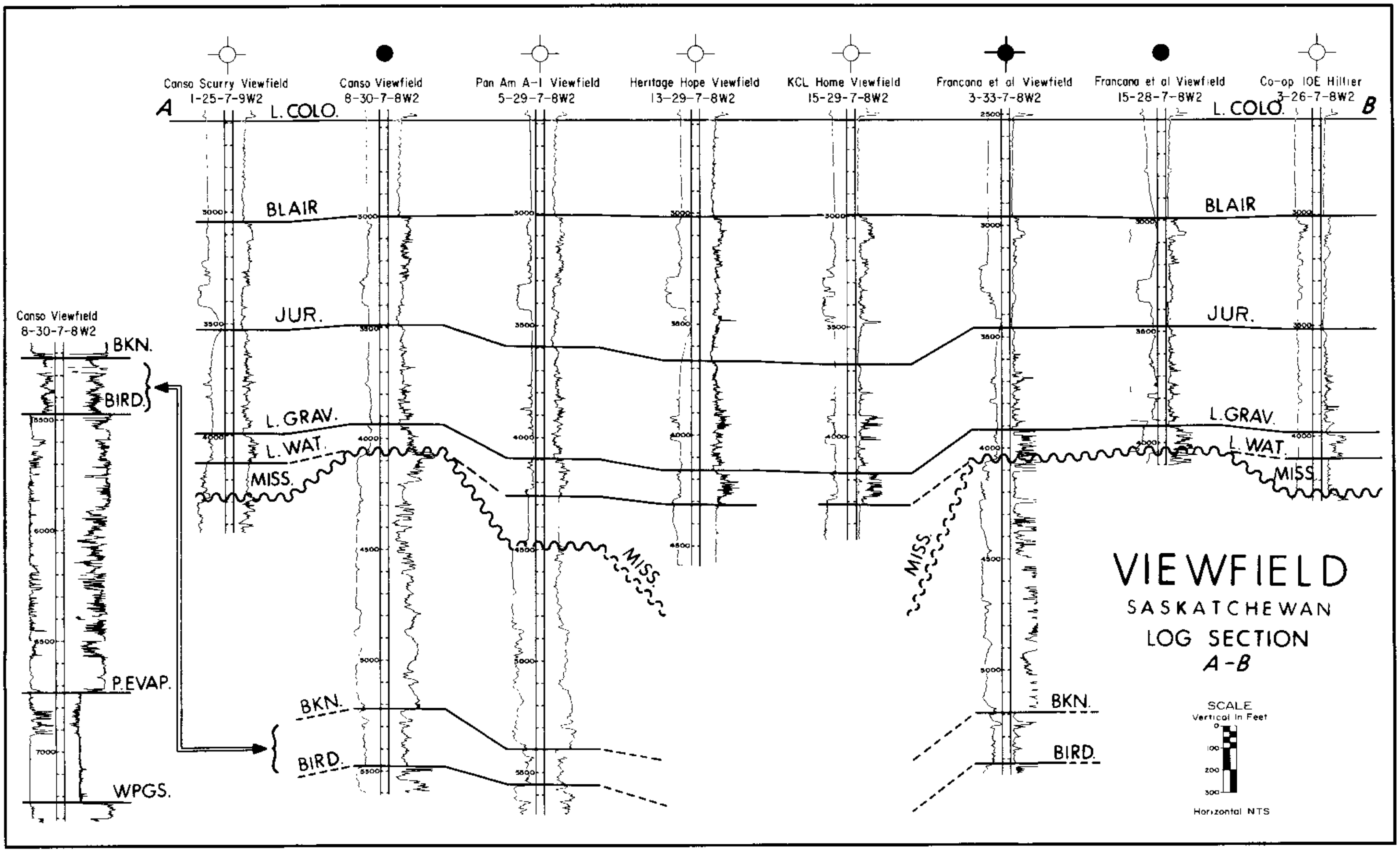

R.9
R.8
W. 2 M.
T. 8
T. 7
-2150
-2200
-2050
-2100
-2250
-2350
-2450
H
?
A
B
(3-26)
VIEWFIELD
SASKATCHEWAN
STRUCTURE CONTOURS ON
MISSISSIPPIAN HORIZON
(INCLUDING RIM)
A-B LINE OF SECTION
Contour Interval: 50'
MILES
OILWELL
DRY & ABANDONED
WATER INJECTION OILWELL

Fig. 4.



VIEWFIELD
SASKATCHEWAN
LOG SECTION
A-B
Canso Scurry Viewfield 1-25-7-9W2
Canso Viewfield 8-30-7-8W2
Pan Am A-1 Viewfield 5-29-7-8W2
Heritage Hope Viewfield 13-29-7-8W2
KCL Home Viewfield 15-29-7-8W2
Francana et al Viewfield 3-33-7-8W2
Francana et al Viewfield 15-28-7-8W2
Co-op IOE Hillier 3-26-7-8W2
A
B
L. COLO.
BLAIR
JUR.
L. GRAV.
L. WAT.
MISS.
BKN.
BIRD.
P. EVAP.
WPGS.
SCALE
Vertical in Feet
Horizontal NTS

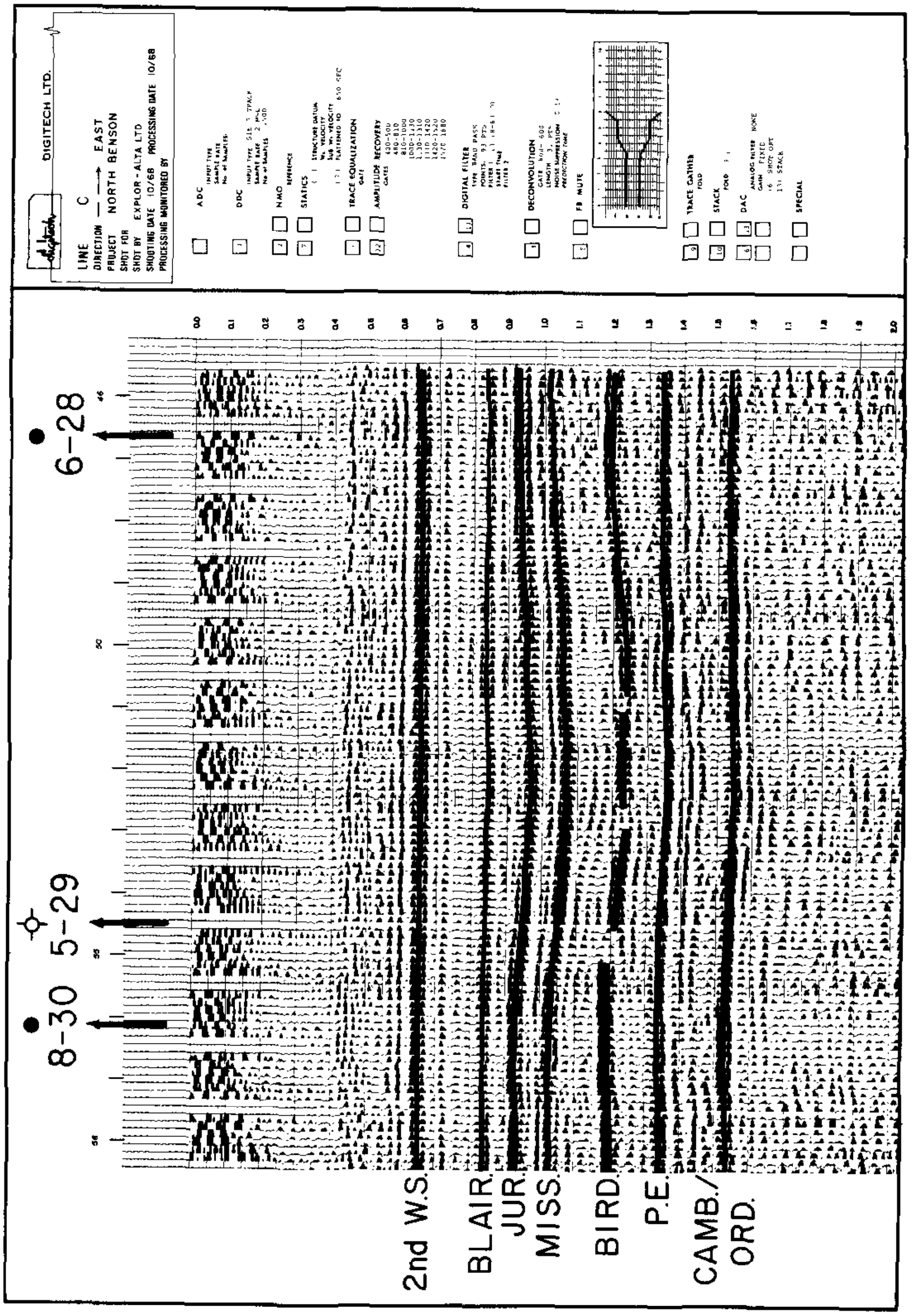

DIGITECH LTD.
LINE C
DIRECTION → EAST
PROJECT NORTH BENSON
SHOT BY EXPLOR-ALTA LTD
SHOOTING DATE 10/68 PROCESSING DATE 10/68
PROCESSING MONITORED BY
6-28
5-29
8-30
2nd W.S.
BLAIR
JUR.
MISS.
BIRD
P.E.
CAMB./
ORD.

Fig. 6.

flow at the time of impact plus post-impact-to-Lower Blairmore solution. Some of the sag is no doubt due to the replacement of high velocity Mississippian sediments in the crater with relatively low velocity fill. The Cambro-Ordovician reflection can be correlated quite continuously and is believed to shows its regional character. Minor local wrinkles are attributed to differential velocity effects.

A more detailed description of the Viewfield anomaly is given in an earlier paper (Sawatzky, 1972). There are presently 30 wells producing oil from the Mississippian horizon along the periphery of the rim at rates as high as 300 barrels per day, from gross pay sections of approximately 200 feet at optimum rim positions. Detailed, multifold seismic data were the key to development of this pool and chief aid in the interpretation.

The Hartney Manitoba Crater

Figure 7 was compiled from the surface geological map of Saskatchewan (Whitaker & Pearson, 1972). It shows the location, size and general configuration of the Carswell Lake structure. It is located in the heart of the Athabasca formation which is predominantly a flat lying fluviatile sandstone, with minor shale and conglomerate, believed to be Late Precambrian (Heilkian) in age. The preserved circular rim of this structure consists of intensely folded, marine stromatolitic dolomite known as the Carswell formation. It is younger than the Athabasca formation and is unique to the entire area. The ring, whose outline can readily be seen on photo mosaics, has an inside diameter of approximately 18 miles, an apparent width of about 3 miles and is expressed as a number of prominent ridges. Brecciated and highly disturbed Athabasca

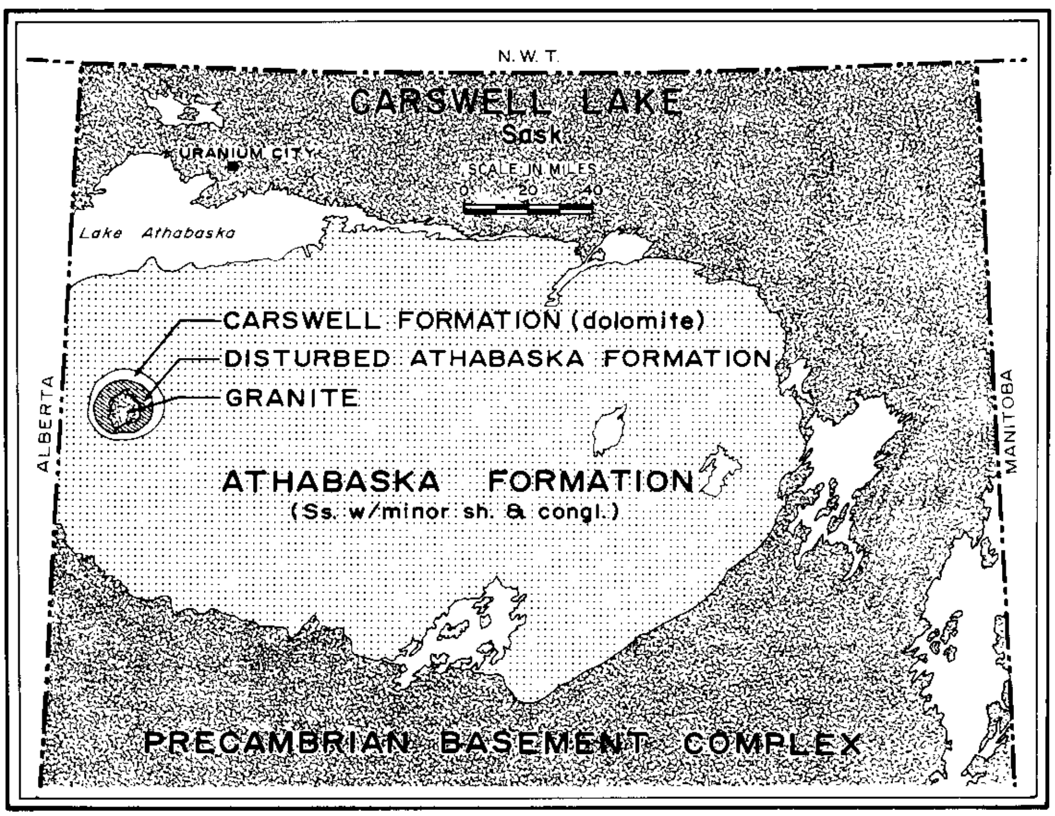


Fig. 7.

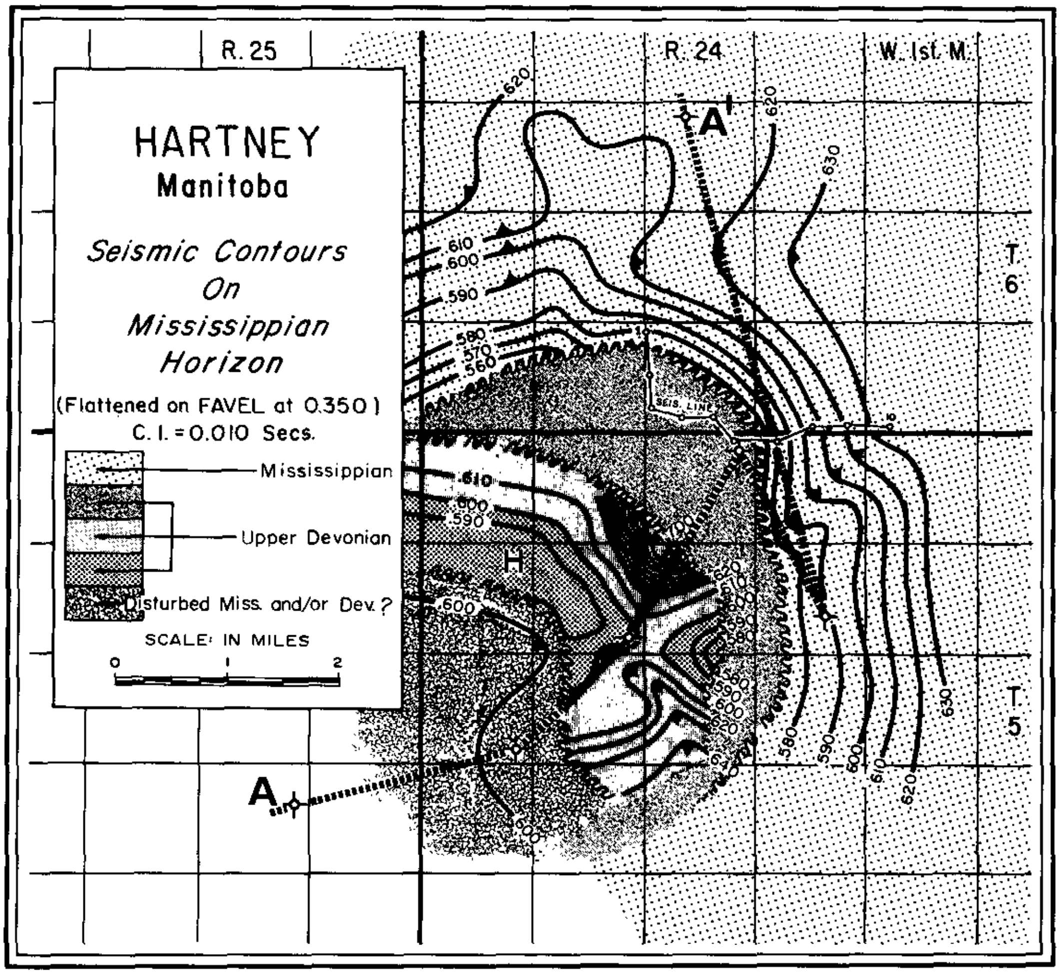


Fig. 8.

strata are located inside the dolomite ring and a core of granite gneiss is exposed at the center of the feature. This structure appears to have distinct similarities to the giant Vredefort Ring in South Africa described in detail by Dietz (1961).

For comparison purposes, the reader is requested to examine Figure 8 which illustrates seismic contours on a horizon near the top of the Mississippian on the Hartney structure in Manitoba (T. 5-R. 24, W1). The Favel (Manitoba equivalent of the Second White Specks or Greenhorn) was used as a datum at 0.350 secs. Due to a lack of diagnostic seismic information only half of the anomaly is shown; however, a good appreciation of its size and configuration is obtained. Note the strong positive outer rim and the highly disturbed central core consisting of fractured and deformed Devonian and/or Mississippian rocks.

Figure 9 shows a log cross-section A-A1 across the crater with respect to the wells highlighted on the previous figure. Datum for this section is the Favel. It illustrates the following pertinent facts:

1. The high rim well at #7-27-5-24.
2. The abrupt and complete excavation of the entire Mississippian plus considerable Upper Devonian section between the #7-27 and #16-33 wells.
3. The pile-up of hundreds of feet of additional Devonian carbonates at the

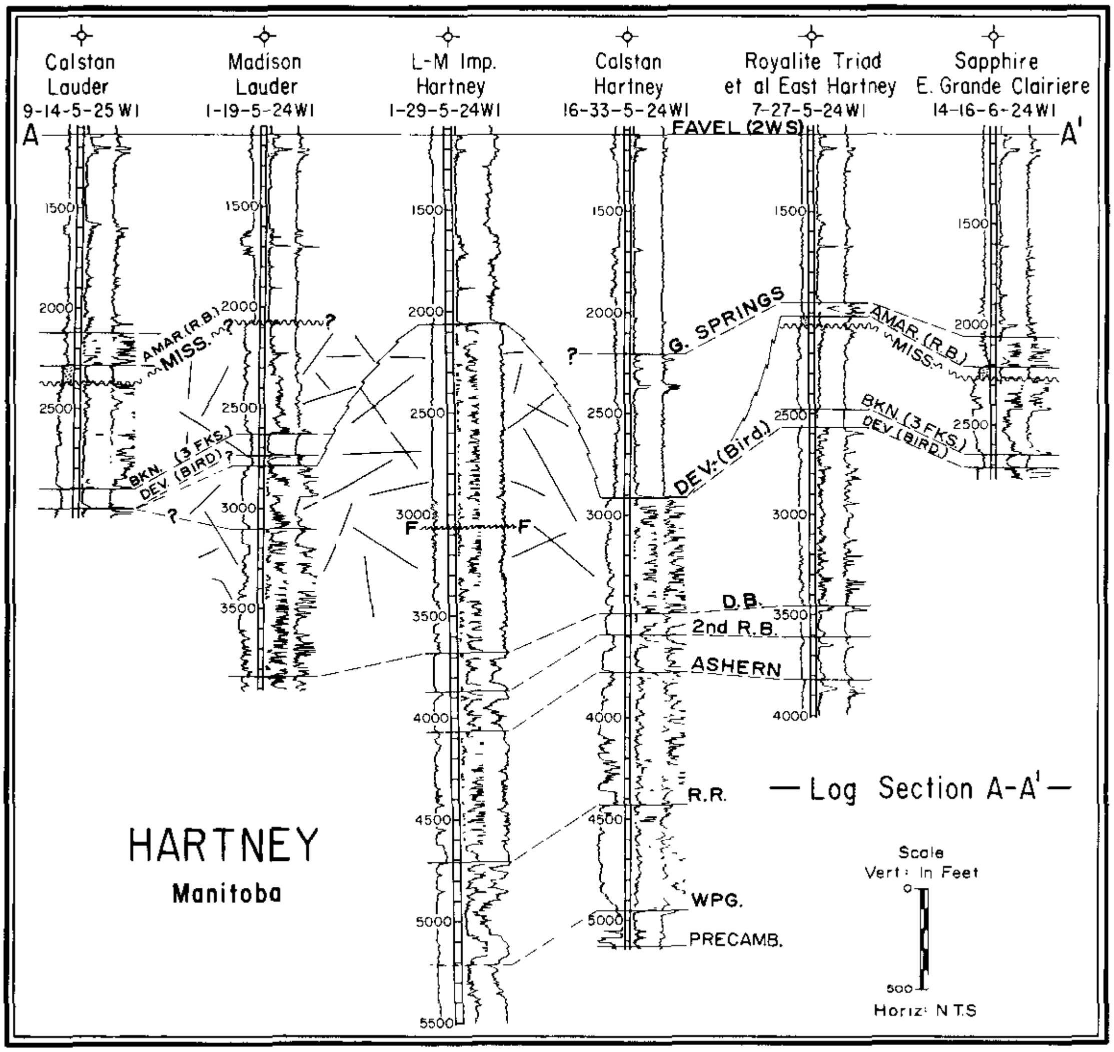


Fig. 9.

#1-29 well. (Note the excellent example of repeated section).

4. The anomalous Mississippian and Devonian section in the #1-19 well.
5. The rather straightforward correlation of the geological section below the Devonian Dawson Bay in all of the wells penetrating this level or deeper.
6. The normal regional Red Beds to Devonian section in the #9-14-5-25 WI well similar to that at #14-16-6-24 W1. The age of this structure also appears to be Jura-Triassic, similar to Viewfield.

Figure 10 is a seismic record section gleaned from conventional 100% subsurface coverage cutting across the extreme northeast corner of the crater. This is a structural section with the datum at 1400 feet A.S.L. Note the slight drape into the crater at the Favel level. The complete cut-out of Mississippian-Three Forks events is also dramatically illustrated. Velocity pull-up is indicated on pre-crater reflections beneath the rim positions.

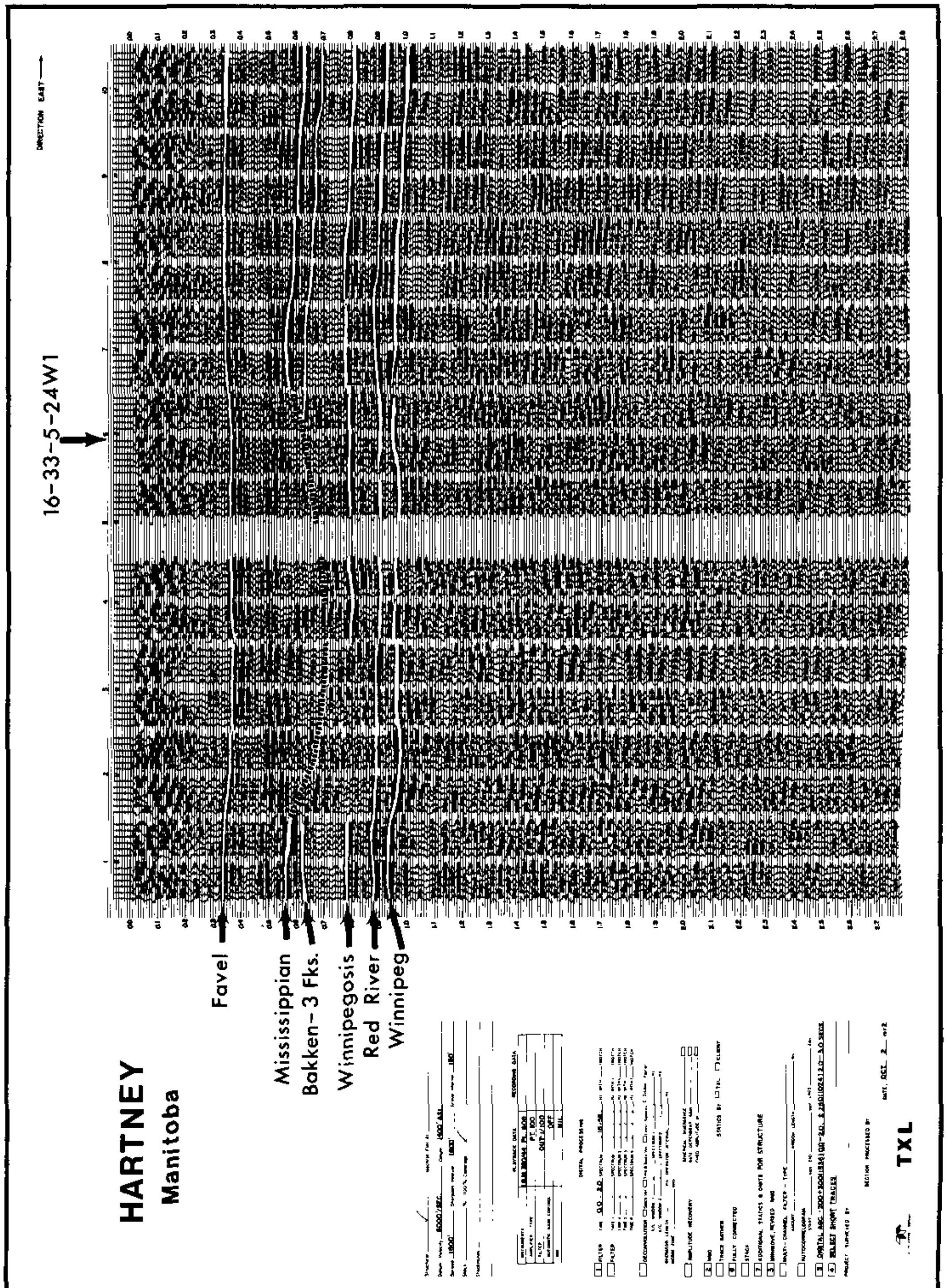

HARTNEY
Manitoba
16-33-5-24W1
DIRECTION EAST
Favel
Mississippian
Bakken-3 Fks.
Winnipegosis
Red River
Winnipeg
TXL

Fig. 10.

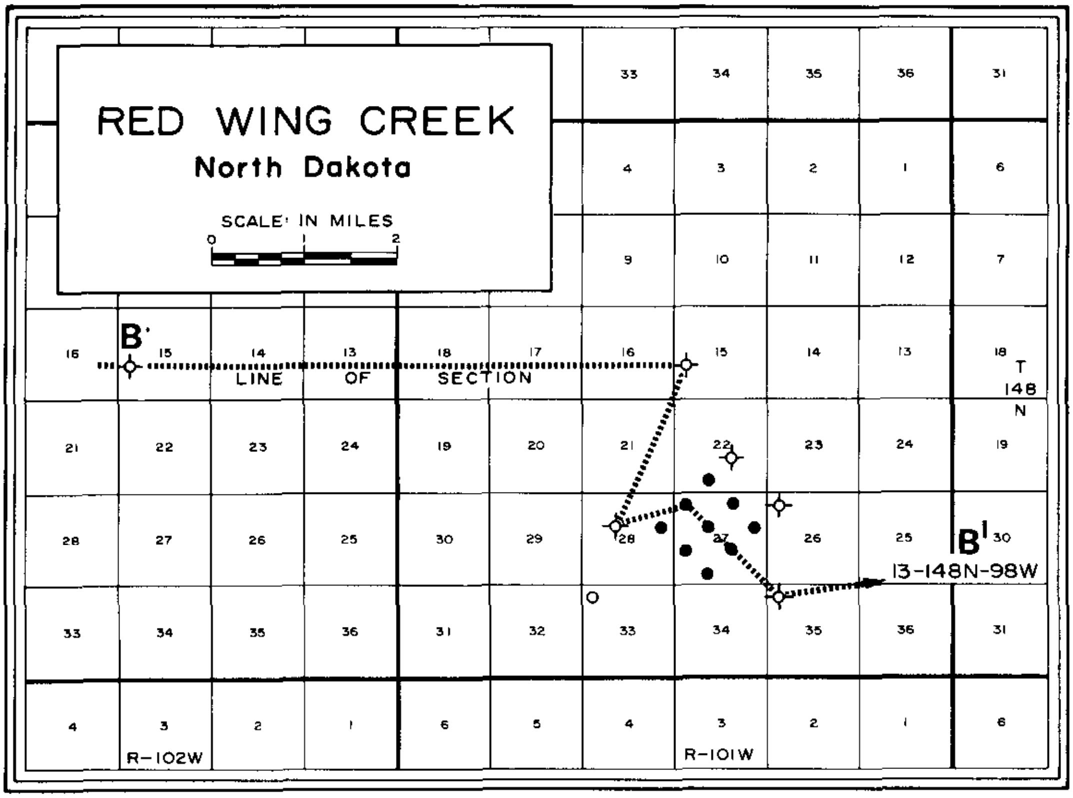


Fig. 11.

The Red Wing Creek, (North Dakota) Crater

Figure 11 shows the location of the wells pertinent to this structure, as well as the line of section B-B1 illustrated in Figure 12. The producing wells are positioned on the highly complex central re-bound area as shown on the log section. The discovery well (True #22-27 Burlington Northern SENW27-148N-101W) contains approximately 3000 feet of gross pay in what has been described as steeply dipping, intensely thrust faulted Mission Canyon? carbonate. The inferred outer rim and crater profile on the left side of Figure 12 are based on seismic information.

The age of this structure appears to be pre-Piper post-Minnekhata which places it in approximately the same time interval as Viewfield and Hartney.

The post-Piper horizons indicate drape over this feature; however, some of the differential relief appears to be related to thickness variations in Charles salts that were no doubt affected at the time of impact as well as during the post-impact period. Although deformation extends into the Pre-Mississippian sediments, correlations can be readily made at and below the Bakken-Three Forks interval. It is interesting to compare the cross-section of this anomaly with that of Hartney and note the structural similarities.

Shatter cones, which according to the experts are essential earmarks of an astrobleme, have been recognized in the cores from Red Wing Creek.

Conclusion

Two of the structures believed to be fossil craters (Viewfield and Red Wing) have resulted in commercial oil production and possibilities at the third (Hartney) in the author's opinion, have not been sufficiently explored. It therefore behooves us to remain on the alert for this type of feature.

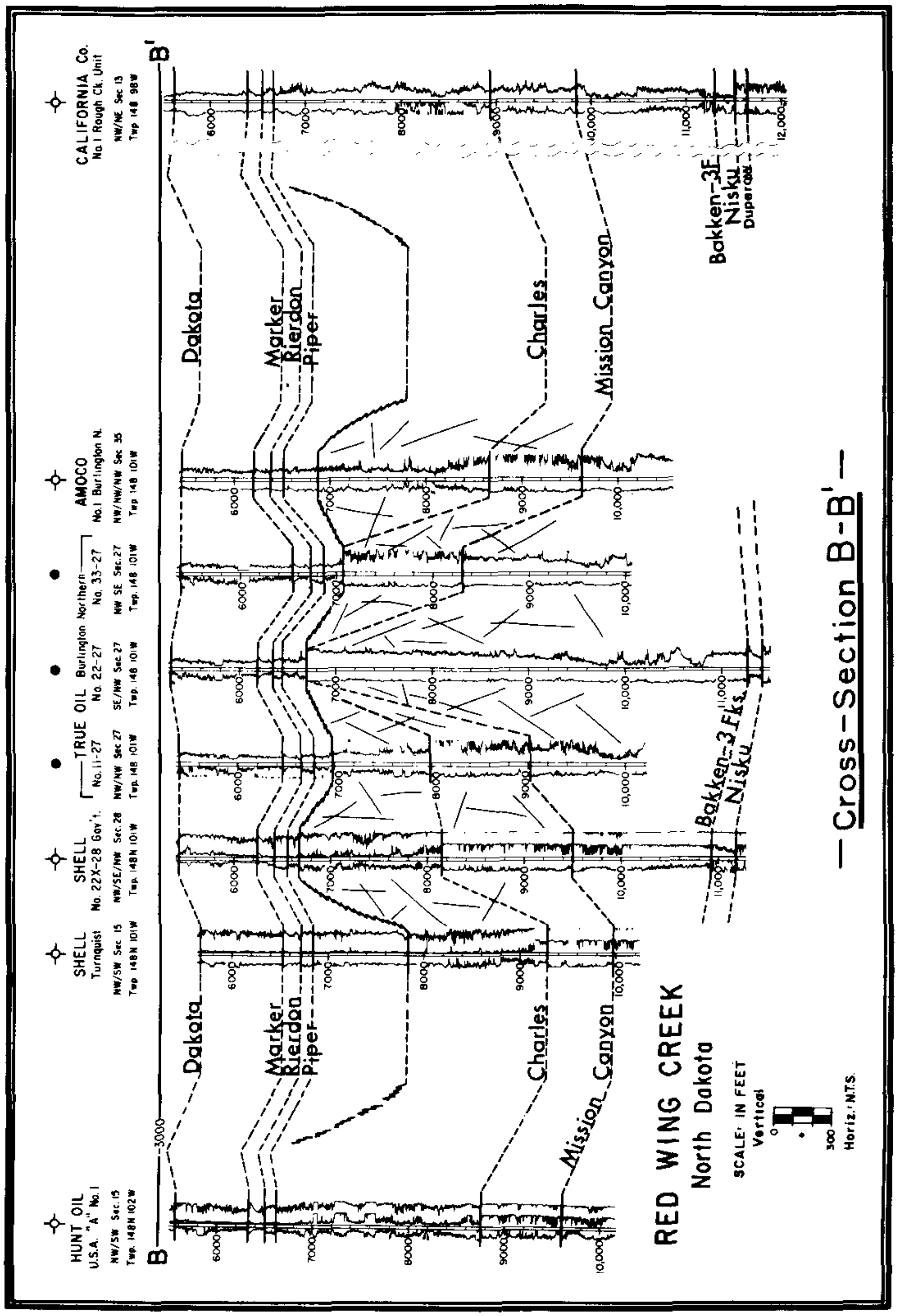

—Cross-Section B-B'—
RED WING CREEK
North Dakota
SCALE: IN FEET
Vertical
Horiz.: N.T.S.
HUNT OIL
U.S.A. "A" No. 1
SHELL
Turnquist
SHELL
No. 22X-28 Gov't.
TRUE OIL
No. 11-27
No. 22-27
Burlington Northern
No. 33-27
AMOCO
No. 1 Burlington N.
CALIFORNIA Co.
No. 1 Rough Ck. Unit
Dakota
Marker
Rierdon
Piper
Charles
Mission Canyon
Bakken-3 Fks.
Nisku
Duperow

Fig. 12.

Astroblemes in the subsurface may be classified as follows: The first, and most obvious, model would be the relatively well preserved fossil craters similar to the three just described.

In a terrestrial environment where major forces of erosion are constantly at work, it is also readily recognized that many actual craters have been completely obliterated to the point where only the much deeper radial fracture patterns remain. The original cause for anomalies of this nature might be very difficult to recognize, particularly if the interpreter is misled by subsequent structures such as solution-collapse features, discussed in more detail in the Viewfield paper.

The third category is perhaps the most elusive. What is the result of an impact in the open sea? Obviously the size of the bolide and water depth would be prime parameters in attempting to predict the effect. However, one can visualize the case where the masking effect of the water would prevent the development of a conventional crater profile in the sea floor, but induce a strong radial fracture pattern which could become the focal point for future structural deformation.

To illustrate this latter situation in the Williston Basin, the writer suggests that some of the radial anomalies resulting from dissolution of salt in the Prairie Evaporite formation have this kind of origin. Examples of known radial solution features dating from the Devonian, Souris River, to relatively recent times have been cited in the references. In many instances no definite reason can be given for the commencement of local solution activity. It is here that we should let our intuition guide us and look to the stars for a possible explanation.

Acknowledgements

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