PETRO-CANADA

CAMERON HILLS
NORTHWEST TERRITORIES
E.A. 164

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REPORT ON THE
SEISMIC EXPLORATION SURVEY

PROGRAM NO.: 9229-P28-16E

IN

CAMERON HILLS
NORTHWEST TERRITORIES
EXPLORATION AGREEMENT NO. 164

Operator and Interest Holder: Petro-Canada Inc.

Date of Field Work: January-February 1986

Data Acquisition: Sonics Exploration Ltd.

Location: Latitude 60° 00' - 60° 12' North
Longitude 116° 10' - 117° 00' West

Land Use Permit No.: N85-B466

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LIST OF DATA TRANSMITTED UNDER SEPARATE COVER

1. 1986 DATA: Migrated, Normal Polarity, 36 traces/inch, 7.5 inches/second

   8010, 8012, 8014, 8022, 8024, 8065, 8067, 8069, 8071, 8073, 8075, 8077, 8079, 8081, 8083, 8085, 8087, 8089, 8091, 8093, 8095.

2. 1968/69 DATA: Structural Sections, Normal Polarity, 24 traces/inch, 7.5 inches/second

   JAL-1, -2, -3, -4, -5, -6, -7, -8, -10, -12, -14, -16, -18, -103, -111, -112, -113, -114.

3. Seismic Base Map: 1 to 50,000

ACKNOWLEDGEMENTS

Many thanks to K. Collings, P. Hurst, and P. Proverbs of Petro-Canada for their invaluable contributions to the understanding of the Cameron Hills acreage.

SECTION ONE

INTRODUCTION

1.1 Location

Petro-Canada Inc. conducted a seismic survey during the 1985-86 winter season in the southeast portion of E.A. 164 in the Northwest Territories. Figure 1.1 shows the current land status (as of September 1, 1986) for the Cameron Hills Exploration Agreement 164 and Figure 1.2 shows the 1986 survey area, and the E.A. boundary prior to the relinquishments of September 1. The map area is on the NWT-Alberta border between longitudes 116° 10' W and 117° 00' W and latitudes 60° 00' N and 60° 12' N (as shown in Figure 1.2). The study area is interpreted to be on a northern extension of the Meander Basin of northern Alberta. This concept (illustrated in Figure 3.2) will be dealt with in more detail in Section 3.

1.2 1986 Exploration Objectives

Prior to the 1986 seismic survey, the data coverage of E.A. 164 was sparse. On one 1985 seismic line (85-8011), however, two anomalies were identified as potential carbonate build-ups, similar to the oil-prone reefs found in the Devonian subbasins of Northern Alberta. Thus, the 1986 survey was designed to provide detailed coverage (star patterns) over the anomalies and moderate coverage in the surrounding area (see Seismic Data Base, Figure 1.3). As a supplement to the 1986 survey, some data from 1968-69 was purchased and reprocessed.

The mapping project utilized all available data and the objective was to delineate the two anomalies identified on 85-8011 and to identify any other similar anomalies in the area.

1.3 Data Base

The data base is located in the southeast block of E.A. 164 and consists of 140 km of 1985 data, 198 km of 1986 data, and 157 km of 1968/69 purchased data for a total of 495 km of seismic data. This is shown in Figure 1.3.

Three wells tie into the seismic data base, namely: Cameron Hills H-34, Cameron Hills E-69, and Cameron D-16. Other wells in the area were used for regional studies.

SECTION TWO

1986 SEISMIC OPERATIONS

2.1 Field Operations and Statistics

The Cameron Hills Vibroseis seismic survey was carried out in the southeast portion of E.A. 164 (see Figures 1.2 and 1.3) from January 2 to February 19, 1986 by Sonics Exploration Ltd. who subcontracted the surveying, bulldozing, drilling (for refraction survey), and catering.

The terrain was fairly flat muskeg over the entire survey area with elevations ranging from 285 to 320 metres. The Mackenzie Highway runs alongside the Hay River (NE-SW) and bisects the southeast block of E.A. 164 which is the map area discussed in this report.

The survey employed 57 people, 26 (or 45.6%) being residents of the Northwest Territories.

Table 2.1 summarizes the project chronology and Table 2.2 gives a statistical summary of the seismic production. Table 2.3 outlines the project organization of personnel.

Mobilization	- cat camp	January 2
	- main camp	January 7
	- recording crews	January 10
Commencement	- surveying and cutting	January 3
	- refraction	January 12
	- Vibroseis reflection	January 12
Completion	- surveying	February 19
	- refraction	February 19
	- Vibroseis reflection	February 26
Demobilization		February 28

TABLE 2.1 SEISMIC PROJECT CHRONOLOGY

Total Test Days	1
Total Recording Days	46
Total Down Days	nil
Total Mob/Demob Days	3
Total Crew Days in Field	59
Total Production Profiles Shot	3965
Total Kilometres Shot	198
Average Shot Points/Day	86
Average Kilometres/Production Day	4.3

TABLE 2.2 STATISTICAL SUMMARY OF SEISMIC OPERATIONS

<u>SONICS EXPLORATION LTD.</u>	
Party Manager	1
Assistant Party Manager	1
Vibroseis Technician	1
Vibroseis Operators	5
Mechanic	1
Observers	2
Junior Observer	1
Shooter	1
Line Truck Drivers	6
Recording Helpers	10
<u>PEARSON CONSTRUCTION</u>	
Cat Foreman	1
Cat Push	1
Cat Skinners	4
<u>RAYMAC (SURVEYING)</u>	
Surveyors	2
Rodmen	2
<u>DRILLS (R. Garry and T. Sloan)</u>	
Driller	1
Drillers Helpers	3
<u>HOFAM CATERING</u>	
Cooks	2
Camp Staff	2
<u>OTHER STAFF</u>	
Slashers	5
Hand Cut Sawmen	2
Skidder Operator	1
Ice Builders	2

TABLE 2.3 PROJECT ORGANIZATION OF PERSONNEL

2.2 Instruments

Table 2.4 summarizes the field equipment used for Vibroseis, detection, and recording.

VIBROSEIS	
Vibrators (3)	Litton International LRS-315 Series
DETECTION	
Vibrator Electronics	Pelco Advance 1 Model 5 System
Geophones	OYO McSeis-111 14 Hz
RECORDING	
Amplification, Filtering	
Multiplexing, A/D Conversion	DFS V (Texas Instruments)
Cameras	OYO Fieldgraph 140 Digital Camera
	S.I.E. ERC-10 Electrostaic Camera
Data Processor	FTI/DFSV Seismic Exploration System

TABLE 2.4 SEISMIC FIELD EQUIPMENT

2.3 Field Parameters

The field recording parameters for the Vibroseis reflection survey and the refraction survey are given in Tables 2.5 and 2.6 respectively.

Receiver Group Interval	10 m
Vibroseis Source Interval	50 m
Geophones	14 Hz, 9/group
Spread Length	630 m - 40 m * 40 m - 630 m
No. of Channels	120
Sub-surface Coverage	1200%
Sample Rate	2 ms
Record Length	3 s
Recording Filter	out - 128 Hz, notch:out
Sweep Length	12 s
Sweep Frequency	14-96 Hz, + 3 db/oct
Number of Sweeps	6

TABLE 2.5 VIBROSEIS RECORDING PARAMETERS

Receiver Group Interval	10 m
Shot Point Interval	480 m
Geophones	30 Hz, single
No. of Channels	48
Record Length	3 s
Recording Filter	out - 128 Hz
Charge Size	2 kg
Hole Depth	10 m, single

TABLE 2.6 REFRACTION RECORDING PARAMETERS

2.4 Seismic Data Processing

The seismic data were processed by Geo-X Systems Ltd. in March 1986 using the following processing sequence.

1. Digital Conversion

2. Amplitude Recovery
   (AT) exp (BT)

3. Deconvolution
   Type: zero-phase, spiking
   Operator Length: 60 ms
   Prewhitening: 1%
   Gate: 200-1100 ms at 0 offset
   450-1030 ms at 630 m offset

4. Structural Corrections
   Datum Elevation: 300m
   Datum Velocity: 4500 m/s
   Processing Datum: -100 ms
   Elevation, Weathering, and Drift (Refraction Survey)

5. Preliminary Velocity Analysis and Statics

6. Statics
   Surface Stack Residual

7. Trace Kills

8. Velocity Analysis
   Interval: 600 m

9. Final Normal Moveout

10. Mean Scaling
    100-850 ms

11. Mute

Distance	140	1260
Time	210	1000

12. Statics
    Surface Consistent Residual

13. C.D.P. Stack

14. Predictive Deconvolution
    Operator Length: 60 ms
    Prediction Distance: 30 ms
    Window: 50-850 ms

15. Migration
    K-K Migration
    80% Stacking Velocities

16. Filter
    14/18 - 80/90 Hz

17. Equalization
    Mean Window: 100-850 ms

18. Display
    Horizontal Scale: 36 traces/inch
    Vertical Scale: 7.5 in./sec

SECTION THREE

GEOLOGY

3.1 Regional Setting

Geological and geophysical evidence indicate that the Cameron Hills area lies on a northern extension of the Middle Devonian Meander Basin of Alberta. This basin lies west of the Hay River fault and southeast of the Tathlina Arch. The Meander Basin is a subbasin located in a transition zone between the Presqu'ile Barrier Reef in the northwest and the Elk Point Evaporite Basin in the southeast, the axis of which trends southeast-northwest through the three prairie provinces and into the Northwest Territories (see Figure 3.1).

Oil and gas bearing Keg River reefs of Middle Devonian age occur in the Rainbow, Zama and Shekilie basins of northwestern Alberta (see Figure 3.2). These prolific subbasins are also located in the same geological setting in which the Meander Basin lies: the transition zone between the Presqu'ile Barrier and the Elk Point Evaporite Basin. Consequently, Middle Devonian Keg River reefs, similar to those found in northern Alberta, have been the primary exploration target for this mapping project.

The regional stratigraphy is illustrated in a schematic cross-section shown in Figure 3.3. Initially, the Lower Elk Point Basin was situated in an open marine environment as Paleozoic seas transgressed from the northwest. Carbonate or shale deposition prevailed over most of the area with sands and silts being deposited along the basin margins (shorelines). These sediments onlapped the Tathlina Arch which was a topographic high during Elk Point time. In the Cameron Hills area, these clastics are known as Basal Red Beds or the Ebbutt Clastics. Carbonate banks built up across the basin (in the northwest) eventually restricting circulation of marine waters. As a result, Middle Devonian salt of the Cold Lake Formation precipitated in the central portion of the basin. The deposition of the Chinchaga anhydrite and dolomite followed and brought Lower Elk Point time to a close.

During Upper Elk Point time the sea once again transgressed the carbonate barrier and extended across the entire Elk Point Basin. The resulting open marine conditions allowed for the deposition of shallow subtidal carbonates resulting in the accumulation of the laterally extensive Lower Keg River carbonate platform. (By this time, onlapping sediments covered the Tathlina Arch.)

Upper Keg River time is thought to have been characterized by variability in relative subsidence rates. Subbasins developed in areas of local rapid subsidence while banks were established on the surrounding, more slowly subsiding areas. The growth of pinnacle and patch reefs in the subbasins was concurrent with the development of the intervening banks. These reefs are the main exploration target in northern Alberta and southern N.W.T. The Upper Keg River facies are discussed in more detail in Section 3.2. The Upper Keg River barrier facies represents the reactivation of the carbonate barrier across the mouth of the basin and is part of the Presqu'ile Barrier Reef Complex. The coalescing and lateral development of this barrier reef complex again restricted the entry of normal marine water and resulted in the precipitation of evaporites, including salt (Black Creek Member) and anhydrite and dolomite of the Muskeg Formation, thus bringing reef growth to an end. It has been suggested by Maiklam (1971) that evaporative drawdown across the barrier may have been the mechanism responsible for the lowering of sea level and development of the Muskeg evaporite.

Subsequently, another transgression resulted in better water circulation and the deposition of the Bistcho and Sulphur Point carbonates. These were then covered by the Watt Mountain Shale. A major drop in sea level resulted in the Watt Mountain Unconformity which marks the top of the Upper Elk Point Group. Evaporites and carbonates of the Fort Vermilion Member of the Slave Point Formation accumlated in very shallow (subaerial) restricted conditions and were followed by the open marine carbonates of the Slave Point Formation.

After deposition of the Slave Point, subsidence (or, perhaps, eustatic changes) occurred and Upper Devonian shales became the dominant sediment reaching considerable thickness over the area. Upper Devonian carbonates (with some shaly members) were then deposited. These were covered with a Cretaceous shale and a thin layer of drift.

3.2 Stratigraphy

The majority of the sediments present in the Cameron Hills area are of Middle and Upper Devonian age. These rocks consist of shallow shelf and basinal marine sediments; carbonates and evaporites being the predominant lithology in the Middle Devonian, and shales and carbonates in the Upper Devonian. Triassic, Jurassic, and Tertiary rocks are absent.

The stratigraphy, thicknesses, velocities, and densities of the formations are shown in Figure 3.4. The formations are described here from oldest to youngest.

Precambrian: The Precambrian basement consists of pink to light red granite.

Ebbutt Clastics (Basal Red Beds): The Basal Red Beds are well known in northern Alberta as pink to reddish brown anhydrite, marl, shale, silstone or sandstone which represent a transgressive near-shore facies of the Elk Point. However, in the Cameron Hills area they are referred to as the Ebbutt Clastics because they resemble a weathering product (granite wash) of the Precambrian (probably from the Tathlina Arch) which is probably an equivalent of the Red Beds. Thus, the two terms are used interchangeably. The age of this unit is not precisely known and may vary from place to place. They have been tentatively assigned to Cambrian, however, data from some wells in northern Alberta indicate that they may be Ordovician, Silurian, or even a basal unit of the Middle Devonian.

The Cold Lake Salt, which overlies the Red Beds in northern Alberta, is not present in the Cameron Hills area. The absence of salt may be depositional and due to the proximity of the mouth of the Elk Point Basin (providing better circulation of normal marine waters), or may be a result of early removal of salt by solution.

Chinchaga: The Chinchaga Formation is Middle Devonian in age and, in northwestern Alberta, this unit consists of anhydrite with minor amounts of dolomite. However, in southern Northwest Territories this unit consists mainly of dolomite with 10 to 30% anhydrite and appears to be an asymmetric dolomite-anhydrite cyclic sequence.

Keg River: The Keg River Formation is divided into the upper and lower members. The Lower Keg River is an open marine carbonate platform which is locally dolomitized. The Upper Keg River is generally dolomite. The precursor limestones of the Upper Keg River accumulated in four dominant facies: reef, bank, basinal, and barrier.

In the Cameron Hills area, reef facies of the Upper Keg River have not been penetrated by the existing wells because the majority of these wells were drilled on basement highs that were probably too high to initiate reef growth. It is possible that patch reefs, pinnacle reefs, and fringing reef banks along the shorelines, similar to those found at Rainbow, Zama, and Shekilie, may be present in the Cameron Hills area. These reefs would be encased by evaporitic sediments of the overlying Muskeg Formation.

The main criteria used for distinguishing bank facies from basinal facies is the Lower Keg River lithology and the isopach of the Upper Keg River. A dolomitized Lower Keg River platform has been associated with an Upper Keg River bank facies; a Lower Keg River consisting of limestone is evidence that an Upper Keg River basinal facies was deposited, in which Upper Keg River reefs are expected. The Upper Keg River sediments are thicker in the bank facies; the interreef basinal facies being thinner or absent. Within the basins, carbonate deposition was limited to local patches (reefs) that were able to keep pace with subsidence. The areas between the reefs were essentially starved of sediment. Meanwhile, on the surrounding bank, active sediment accumulation was taking place. The full development of the Presqu'ile Barrier across the northwest end of the basin brought reef and bank sedimentation to an end.

The transition zone between the bank and basin is often referred to as the "shelf", however, a true shelf as found in modern analogues did not exist in the Middle Devonian. This transition zone is called the bank-edge facies. It is thought that reef growth is also possible in these transition zones, however, the buildups would not be as thick as those in the basins.

The barrier facies of the Upper Keg River (forming part of the Presqu'ile/Shekilie Barrier) represents the reactivation of the carbonate barrier across the northwest end of the Elk Point Basin. This barrier lies north and west of the Cameron Hills study area and cuts through the north part of the E.A.. The barrier consists of light to dark brown, fine- to medium-grained, porous (10% on average) dolostone. Locally, the barrier is medium-to coarse-grained, white dolostone as a result of hydrothermal dolomitization (Presqu'ile dolomite). By restricting the Elk Point Basin environment, the barrier is responsible for cessation of reef growth and the onset of the evaporitic conditions (Muskeg Formation).

Muskeg: This evaporitic unit is the thickest unit of the Elk Point group of northern Alberta and N.W.T. and is the effective seal for any Keg River reefs. It has been suggested that the Muskeg may have source potential, however, little work on this has been achieved. The formation consists of cyclic deposits of anhydrite and dolomite and, locally, salt.

In northern Alberta, the unit is divided, informally, into lower, middle, and upper members.

The lower Muskeg, known as the Black Creek Salt, is not present in the Cameron Hills area. The lower member may never have been deposited here, or may be present as the anhydrite facies equivalent of the Black Creek Salt. In the Rainbow Basin of northern Alberta, the solutioning of the Black Creek Salt produced pronounced drape over the Keg River reefs. This drape makes the recognition of such reefs on seismic data relatively easy. In the Cameron Hills area, however, there is no pronounced drape over interpreted reefs, and no other geological or geophysical evidence for the presence of salt. This makes recognition of reefs on seismic difficult. This may either be because the salt solutioning took place earlier or because the Black Creek Salt was never deposited that far north in the Elk Point Basin (due, perhaps, to the proximity of normal marine waters on the north side of the Presqu'ile Barrier).

The middle Muskeg is the stratigraphic equivalent of the Upper Keg River and the upper Muskeg is that portion of the Muskeg which overlaps the Keg River. These two members consist of cyclic anhydrite-dolomite and minor amounts of shale. The contact between these two members varies with the thickness of the Upper Keg River. That is, where the Keg River is thin (no reefal build-up in the basin), the middle Muskeg would also be thin or absent.

The Upper Keg River basins, reefs, and banks are covered by the Muskeg formation, however, Muskeg beds are absent from the top of the Presqu'ile/Shekilie Barrier; the evaporites lap out against it (Hriskevich, 1979).

Sulphur Point: The Sulphur Point (known as the Bistcho in Alberta) is a carbonate unit which was deposited in normal marine waters above the Muskeg Formation. In addition to limestone (the main component of this formation), shale and dolomite are also present. The formation is a potential hydrocarbon reservoir where it is part of a structural trap. This is apparent in the basins of northern Alberta where there is draping over Keg River reefs and in the Cameron Hills area where the Sulphur Point drapes over basement highs. It also has potential for shoaling over structures and for growth of patch reefs in some areas.

Watt Mountain: The Watt Mountain accumulated in shallow water and is the uppermost formation of the Elk Point Group. It consists of shale with minor siltstone, arkose, limestone breccia, anhydrite, and dolomite (Law, 1955). An unconformity is present at the top of the Watt Mountain and marks the end of the Elk Point Group.

Slave Point: The Slave Point is the first major carbonate formation below approximately 400 metres of Upper Devonian shale and is therefore a prominent seismic reflector. The lower member of the Slave Point is called the Fort Vermilion Member and consists of mainly anhydrite, limestone and minor shale. The upper member (presently unnamed) of the Slave Point is a marine limestone unit. Some Slave Point reefs are present along a "carbonate front" where the Slave Point overlies the crest of Presqu'ile/Shekilie Barrier. Southeast of the carbonate front there are a few patch reefs of less than 30 metres thick.

Upper Devonian: The Upper Devonian overlies the Middle Devonian with no apparent unconformity. In the Cameron Hills area, it is approximately 660 m thick and consists of shales in the lower third, namely, the Muskwa and Hay River shales; and shaly limestones and carbonates in the upper two-thirds, namely, the Twin Falls shaly limestone, the Fort Simpson shale, the Jean-Marie and Redknife silty limestones, the Kakisa limestone, and the Trout River shaly limestone. The final two Upper Devonian formations are equivalents of the Wabamun formation in Alberta and are the Tetcho and Kotcho limestones. In the Cameron Hills map area, the top of the Kotcho is very close to the present surface and is considered the "base of weathering" for the static corrections on the 1986 seismic data. This surface is also a major unconformity which is overlain by Cretaceous sediments.

Cretaceous: There are approximately 60 metres of Cretaceous sediment overlying the Upper Devonian. These sediments consist of both consolidated and unconsolidated shales, sands, and silts. The Cretaceous unit is overlain by a thin layer (4-8 m) of unconsolidated drift at the surface.

3.3 Structure

The Alberta Basin trends northwesterly and extends up into the southern portion of the Northwest Territories. Regionally, the strata thicken and dip gradually to the southwest and thin both erosionally and depositionally to the northeast where the zero edge meets the Precambrian Shield.

In the Cameron Hills area, the major features which controlled sedimentation during Paleozoic time were the Tathlina Arch to the northwest of the Presqu'ile Barrier and the rising surface of the Precambrian Shield to the east. The Tathlina Arch persisted as a topographic high through much of the early Paleozoic. Due to the influence of the Tathlina Arch, the Middle Devonian isopach actually thins to the northwest.

The overlying sediments, however, thicken and tilt to the west and south. The Cameron Hills map area is located such that the interval of Middle Devonian sediments is thick enough for appreciable reef growth and, although the entire Upper Devonian section is thicker to the west, the zone of interest (Middle Devonian) was deep enough (approximately 850-900 m) to yield some oil-prone carbonate buildups.

Precambrian: In the Cameron Hills area many of the structures drilled have been Precambrian basement highs. The Cameron Hills gas field to the southwest (on the Dome land adjacent to PCI's E.A. 164) consists of gas-bearing Sulphur Point (and often Keg River and Muskeg) along NW-SE linear trends of basement highs (see Summary Map, Figure 3.5). The Sulphur Point Formation is thicker on these highs and this has been attributed to shoaling of the carbonate over the structures. Similar structures have been identified seismically within the southeast block of E.A. 164.

There are also several isolated positive structures ("Precambrian Knolls") present in the area (also shown on Figure 3.5). The Red Beds and Chinchaga formations are usually missing from the tops of these structures. These isolated knolls give prominent seismic anomalies (significant drape on the Slave Point), however, they should be avoided because they have not yet provided Sulphur Point gas, Keg River reefs, or hydrocarbons from other formations.

All basement structures appear to have been controlled by faulting and, although some may contain Sulphur Point gas, they are not considered prospective for Keg River carbonate buildups. Smaller more subtle Precambrian highs are more likely to have initiated reef growth; the larger knolls and linear highs were probably entirely exposed at Keg River time and consequently not suitable locales for reef growth.

Faults: At the Precambrian level there are numerous normal faults which have been recognized on seismic. Thrust faults and reverse faults are not believed to be present. The faults appear to penetrate the overlying Red Beds in most cases. This regional normal faulting of Precambrian age may have influenced deposition during lower Elk Point time. The faulting may also have been rejuvenated at later times though evidence for this is limited. The Presqu'ile/Shekilie barrier may have been localized on regional positive tectonic features produced by faulting (Hriskevich, 1976). According to Budwill (1967), there is probably no connection between faulting and Middle Devonian reef development although faulting may have enhanced reef porosity through fracturing. However, this author feels it is possible to have reef growth on subtle positive structures induced by faulting.

A set of NW-SE trending faults has been identified in the Cameron Hills map area. These faults do not continue over large distances (they are 1 to 4 km long). Further to the east there is the NE-SW trending Hay River Fault zone which is best recognized from aeromagnetic maps. This fault zone goes through the S.E. corner of E.A. 164 and extends southwest, through the Dizzy Creek area, and to the southeast side of Rainbow Basin.

Keg River Paleogeography: The Middle Devonian paleogeography for northern Alberta and southern N.W.T. is illustrated in Figure 3.2. The Meander Basin is thought to extend north into the Cameron Hills acreage. Previous work by Petro-Canada has provided evidence for the presence of a basinal facies extending from northern Alberta (6-25-125-18 W5) into the S.E. block of Cameron Hills E.A. 164 as illustrated on the Summary Map (Figure 3.5). The well control for this geologic study was limited and therefore the area defined as a possible basin is based partially on extrapolation of trends from northern Alberta. The closest basin well to the Cameron Hills area is 12 km to the south of the border at 6-25-125-18 W5.

Slave Point: In the subbasins of northern Alberta, especially Rainbow Basin, there is considerable drape of the Slave Point (and older beds) over the reefs. For the Rainbow Basin, it is generally agreed that the drape was caused by removal of the Black Creek Salt and that this removal was caused by solutioning of the salt around the reefs. However, if little or no Black Creek Salt was deposited or if salt removal occurred prior to Slave Point time, there would be very little structure, if any, on the Slave Point Formation over reefs. This is probably the environment in which the Meander Basin existed (and possibly Shekilie and Jackfish Basins as well) and, thus, there would be a lack of Slave Point drape over possible reefs. This is supported by lack of seismic evidence for the presence of salt; in Rainbow Basin, the acoustic response of the Black Creek Salt can be seen on seismic in the interreef areas. Therefore, the reefs are more difficult to detect on seismic due to the subtle, or lack of, Slave Point structure over them. This is significant because there may be reefs in the Cameron Hills area where no Slave Point drape occurs.

3.4 Prospectivity

The Cameron Hills area has several types of prospects, namely:

(i) Keg River oil in carbonate buildups;
(ii) Sulphur Point gas on positive basement structures; and
(iii) dolomitized Devonian fracture systems along the Hay River fault zone.

The major hydrocarbon occurrences in the Cameron Hills area are noted on the stratigraphic column shown in Figure 3.4.

Keg River: Upper Keg River carbonate buildups are the main exploration target in the Cameron Hills area and are modelled to be in a geological setting similar to those found in northwestern Alberta. The Upper Keg River Formation has numerous hydrocarbon shows within the study area and, although most of the successful tests have been gas (see Figure 3.4), live oil staining is common especially in the map area. No wells have penetrated Keg River carbonate buildups in the Cameron Hills area and, therefore, the Cameron Hills play concept is untested. Considering the previous lack of focus on reef exploration in the area, the large distances between existing wells, and the encouraging results from DST's, there is ample potential for oil-bearing carbonate buildups in the Cameron Hills area.

Further support for this play was given in Section 3.3 where it was demonstrated that the Middle Devonian basin facies (identified at 6-25-125-18 W5) extends north into the Cameron Hills acreage. The outline of the basin facies could easily include the Cameron Hills Anomaly shown on the Prospect Map, Enclosure 4.e) and other seismically identified anomalies. Some geophysical modelling (to be discussed in Section 4.5) verified that the observed anomalies could be Keg River carbonate buildups.

Sulphur Point: The Sulphur Point formation is a secondary target and is prospective for gas (and possibly oil) when it overlies basement highs. This has been recognized on the adjacent Dome acreage in the southwest where there are at least two NW-SE trending Sulphur Point gas fields (illustrated on Figure 3.5). These prospects may extend onto the southwest portion of the Cameron Hills acreage. Similar structures have been identified seismically within the southeast block of E.A. 164.

Although most of the Sulphur Point hydrocarbon occurrences are gas (see Figure 3.4), oil staining is fairly common. In addition, Keg River oil and gas and Slave Point gas are often associated with the Sulphur Point gas trends.

Hay River Fault: A third potential play is related to dolomitization of the Keg River Formation caused by adjustments along the Hay River fault zone which extends up into the southeast corner of E.A. 164. However, seismic and well data are limited in this corner of the acreage and therefore the Cameron Hills area has not yet been evaluated for this type of prospect.

SECTION FOUR

GEOPHYSICAL INTERPRETATION

4.1 Data Base

A moderate grid density (see Figure 1.3) of 495 km of good quality seismic data were interpreted for the Slave Point (blue) and Basal Red Beds (red) horizons. It is within this interval that detection of carbonate buildups is possible. A third horizon, the Mid Hay River reflector (yellow), was also interpreted, however, mapping of this reflector did not prove useful in identification of buildups.

The 1985 (12-fold, dynamite) and 1986 (12-fold, Vibroseis) data were migrated; the 1968 data (3-fold) and the 1969 data (6-fold), were not migrated, and were acquired with a dynamite source. Both the structural stack and migrated sections of the 1986 and 1985 data were used in the interpretation. All of the records are 1 second in length. Misties of 15 ms to 41 ms were present between the 1986 Vibroseis data and the 1968-69 dynamite data. A list of the seismic data is given in Appendix A.

Correlation of geology to geophysics was achieved with synthetic seismograms from Cameron Hills H-34, Cameron D-16, and Cameron Hills E-69 included in this report as Enclosures 4.a, 4.b and 4.c respectively.

Prior to acquisition of the 1986 data, two anomalies (within the Slave Point - Red Beds interval) were identified on line 85-8011 as potential carbonate buildups. As a result, the 1986 seismic data base includes a star pattern over each anomaly (see Figure 1.3). Interpretation of these data indicated that only the south anomaly ("Cameron Hills Anomaly") was prospective as a carbonate buildup. Some seismic modelling of carbonate buildups was also done in order to further resolve the Cameron Hills Anomaly.

4.2 Reflection Identification

Reflection identification was achieved for the tops of both the Slave Point and Basal Red Beds reflectors. The top of the Slave Point is characterized on the sonic log by a large and abrupt increase of interval transit time from about 101 ms/ft. (3000 m/s) to 52 ms/ft. (5862 m/s) on average. This is explained by the immediate lithology change from the younger Hay River and Muskwa shales to the Slave Point carbonate. The resulting seismic response is a high amplitude, positive acoustic impedance contrast. There is, however, no corresponding density contrast at this interface.

The Red Beds Formation has not always been penetrated by the wells in the area. From the available sonic log data, it appears that the top of this formation has a small but sharp transit time response which shows a decrease from about 52 ms/ft. (5862 m/s) to 56 ms/ft. (5443 m/s) on average. The resulting convolved acoustic impedance response is complicated by the gradual decrease in sonic velocity within the Chinchaga Formation. This often creates a broadening of the reflector. A corresponding density contrast at the Red Beds-Chinchaga interface shows an abrupt decrease in density from about 2.9 g/cm^3 to 2.6 g/cm^3. The convolved response is, thus, usually a high negative acoustic impedance response.

4.3 Seismic Reflection Characteristics

The Red Beds to Slave Point time interval map was generated at a scale of 1:25,000 and the mapped horizons are described below.

Basal Red Beds (Ebbutt Clastics): Although this seismic reflector typically has a strong negative acoustic impedance contrast, it can also be discontinuous or exhibit a laterally varying acoustic response. It appears that, in most cases, the reflector is actually a tuning of both the top of the Red Beds and the top of the Chinchaga reflectors since both have negative reflection coefficients. Usually, a loss of amplitude at this reflector is interpreted as a thinning or absence of the Red Beds Formation. However, this may also indicate a lack of acoustic impedance contrast above due perhaps to a more porous Lower Keg River platform. A loss of amplitude that is associated with a broadening of the reflector has also often been identified in places. Previous interpretations have attributed this to a lack of Red Beds, however, it may indicate a thickening of the Chinchaga Formation. A doublet at this level probably represents an even thicker Chinchaga, that is, the top of which is separated from the top of the Red Beds at a distance that is beyond the temporal resolution.

The Red Beds reflector exhibits faulting which was apparently initiated in the Precambrian. The faults shown on the isochron map are at the Precambrian-Red Beds level and, with few exceptions, do not appear to have been reactivated at later times. The faults created a subtle horst-graben terrain, especially in the north part of the map area. Many of the fault blocks appear to have been tilted and/or differentially eroded.

In the southern part of the map area, the reflector is laterally more continuous. This may further support the thesis that a subbasin extends up into the southern portion of the acreage as discussed previously.

The Red Beds event often exhibits a loss of amplitude under anomalies interpreted to be Keg River carbonate buildups. This can be attributed to: (i) a small basement high (causing thinning or absence of the Red Beds) which may or may not have been a site for reef growth, (ii) the defocussing (refraction) of the ray paths under the carbonate buildups, or (iii) a change in the Chinchaga-Red Beds lithological relationship (such as, thickness or velocity). The Red Beds reflector also exhibits a "pull-up" effect under a few of the observed anomalies. This may be due to either: (i) a small basement high, or (ii) a lateral change in velocity. This will be addressed in more detail in Section 4.5.

Slave Point: The Slave Point reflector exhibits a very strong and laterally continuous positive acoustic impedance contrast because it is the first carbonate formation below 400 m or more of lower velocity shale. In a few locations over significant structures the event exhibits a loss of amplitude at the crest and a brightening of amplitude at the edges as a consequence of structural drape. This can be attributed to defocussing (and focussing) of the raypath over the convex (and concave) portions of the reflector. The reflector dips to the southwest and is a relatively undisturbed unit.

4.4 Maps

Two maps were generated for the Cameron Hills area, both at a scale of 1:25,000: a time interval map of the Basal Red Beds to Slave Point (Enclosure 4.d) and a Prospect Map showing potential carbonate buildups and other prospects (Enclosure 4.e). No time structure maps were generated because: (i) there were inconsistent misties between the three data vintages; and (ii) a constant but incorrect replacement velocity for static corrections was used throughout the area.

The misties (ranging from 15 ms to 41 ms) changed significantly from tie point to tie point and thus corrections between tie points would require approximations. Assuming the use of a linear extrapolation between tie points, any variance of the required correction data from the assumed linear trend would have generated a false structural anomaly. Thus time structure maps are meaningless, especially in the Cameron Hills area where structural anomalies are very subtle (2-8 ms) and are of the same order of magnitude as the error margin of the correction data.

The use of a constant replacement velocity (4500 m/s) for static corrections has probably also induced false structure which would be evident on a time structure map wherever the velocity of the formation below the "base of weathering" (i.e.: top of the Devonian) deviated from the chosen replacement velocity. The refraction survey data have confirmed that the Upper Devonian velocity does in fact deviate frequently from 4500 m/s (up to 4800 m/s). Thus, for this reason also, time structure maps are meaningless to the Cameron Hills area.

Basal Red Beds to Slave Point Isochron Map: This time interval map (Enclosure 4.d) is contoured at an interval of 4 msec. A thickness anomaly on this isochron is usually interpreted to represent a potential carbonate buildup except where it is due to a basement low. However, as seen in a few wells in northern Alberta, thickness anomalies on seismic may also be a result of two stage salt removal. Early removal of the Black Creek Salt creates a depression where an additional thickness of younger Muskeg could be deposited. Subsequent removal of the remaining salt would then produce drape of the younger beds over the anomalously thick portion of the Muskeg, thus, giving a seismic signature similar to that of a reef. This type of anomaly is rare and therefore all thickness anomalies are initially considered prospective, especially in Cameron Hills where the Black Creek Salt may never have been deposited. The isochron map shows several prospective thickness anomalies in the area (see "Prospect Map").

There are several areas delineated on the map which exhibit a loss of the Red Beds reflector on seismic. These are recognized as paleohighs at the Precambrian level, many of which show structure on the Slave Point as well. One of these zones is a long linear NW-SE trending basement high which has a similar seismic character to that of the basement highs over which the Cameron Hills gas-bearing structures lie. These and other basement highs are considered prospective for Sulphur Point gas and therefore shown on the Prospect Map.

The faulting shown on the isochron map is interpreted to be of Precambrian age and appears to only penetrate up to the Red Beds.

Prospect Map: The purpose of this map (Enclosure 4.e) is to show all potential prospects in the Cameron Hills area. The majority of these anomalies are potential Keg River carbonate buildups, many of which correspond to Red Beds-Slave Point thickness anomalies.

The Cameron Hills thickness anomalies have been looked at in detail on seismic and only the ones which look like possible carbonate buildups were delineated on the map. Other thickness anomalies are either topographic lows in the basement or do not show any evidence of reefal buildup. One anomaly in particular, called the Cameron Hills Anomaly has been modelled as will be discussed in Section 4.5 of this report. Other anomalies in the area are essentially one-line anomalies and require further seismic detection. Some examples of these leads are given in Figures 4.7 to 4.9.

All of the anomalies are very subtle and exhibit a lack of pronounced drape. This is probably because little or no Black Creek Salt was deposited in the Cameron Hills area thereby eliminating the possibility of drape as discussed in Section 3.2. Thus, other carbonate buildups may exist which do not exhibit a corresponding thickness anomaly. Some leads of this type are also delineated on the Prospect Map as potential buildups. These leads do not exhibit an appreciable (greater than 3 ms) thickening in the Red Beds - Slave Point interval but are recognized by lateral changes in seismic character or by draping of the Muskeg-Sulphur Point reflector. Figures 4.8 and 4.9 show seismic examples of this subtle type of prospect. Due to their subtle character, there may be other undetected prospects of this type in the map area.

By overlaying the Prospect and Isochron maps, the two types of potential Keg River buildups (that is, with and without thickness anomalies) can be distinguished. There are also a few anomalies which have been identified as possible Sulphur Point carbonate buildups because they exhibit a thickening of the Slave Point - Muskeg interval. These anomalies exhibit small thicknesses and would not be worth pursuing at this time.

A second type of prospect in the map area is a potential Sulphur Point gas play similar to the Cameron Hills gas field located on the adjacent Dome acreage to the west. In particular, the one in the central part of the map area exhibits the same type of long linear NW-SE trending Precambrian high and associated Slave Point - Sulphur Point drape. This can be seen on line 86-8075, Figure 4.10. (In addition, Sulphur Point gas-bearing structures may extend from the Dome acreage in the south onto the west portion of E.A. 164, outside of the map area.)

Many of these potential Sulphur Point gas plays over basement highs are associated with an increase in, or brightening of, the negative amplitude at the Watt Mountain - Sulphur Point level. The "trough" (i.e., representing a decrease in velocity) between the Slave Point "peak" and the Muskeg "peak" is probably a tuning of both the negative acoustic impedance response of the top of the Watt Mountain, and the slightly positive response of the Sulphur Point. When the velocity of the Sulphur Point is lowered (due, perhaps, to the presence of gas or to higher porosity), the trough would exhibit a brightening of amplitude (and, of course, a change in the shape of the wavelet). Thus, these acoustic anomalies have also been delineated on the Prospect Map as potential Sulphur Point gas plays.

There is a possibility of a Hay River fault-related play in the area, however, this would be present to the west of the map area where there are no seismic data.

4.5 Geophysical Modelling

The purpose of this modelling study was to demonstrate that the seismic phenomena observed at the Cameron Hills Anomaly can be attributed to the presence of an Upper Keg River carbonate buildup (and not to a basement high). Geophysical models of carbonate buildups were generated using the AIMS modelling package. Two of these models are shown in Enclosures 4.f and 4.g and Figures 4.11 to 4.18. The velocity and density data were taken from the Cameron Hills H-34 and Cameron River J-12 wells, H-34 being the key well.

The first model (KHMODEL 1) is shown in Enclosure 4.f and Figures 4.11 to 4.14. This model represents the Cameron Hills Anomaly as seen on seismic line 86-8012 (Figure 4.1) where there appear to be either two adjacent carbonate buildups or one long buildup with a depression in the middle. This model was given the following characteristics:

(i) the thickness of the Upper Keg River Formation goes from 55 m (off-reef) to 90 m (at the east crest of the anomaly);

(ii) the top of the Muskwa was not given a velocity contrast (and is therefore not a reflector);

(iii) there is a reflector within the Hay River where the velocity changes from 2903 to 3048 m/s;

This model was refined and a final model KHMODEL 3, was generated. The model is shown in Enclosure 4.g and Figures 4.15 to 4.18. This revised model represents the same anomaly, but as seen on lines 86-8093 (Figure 4.3) and 86-8089 (Figure 4.5). In these views the anomaly appears to have a single crest and was modelled using the following features:

(i) at the anomaly, the thickness of the Upper Keg River Formation goes from 11 m (off-reef) to 90 m (crest) (the thinner UKR is based on the assumption that an interreef basinal facies exists);

(ii) away from the anomaly, the modelled Upper Keg River goes from 11 m (basinal facies) to 55 m (possible bank facies);

(iii) lateral changes in velocity (6555 to 6107 m/s) and density (2.83 to 2.70) were assigned assuming a change of porosity from 4% (in the off-reef location) to 7% (at the reef). The lower, reef velocity was calculated using the Wyllie time average equation as shown in Appendix B;

(iv) the top of the Muskwa was given a velocity contrast (3000 m/s in Hay River to 3048 m/s in Muskwa);

(v) the Hay River velocity was averaged and no reflector was placed within it;

(vi) all of the depths were refined from KHMODEL 1 including the thickness of the low velocity layers (calculated from the refraction data as shown in Appendix C). These depths are listed in Table 4.1.

Both models demonstrate a "pull-up" effect on the flat Red Beds reflector below the anomalies. A "pull-up" of similar magnitude is seen on the seismic over the anomaly. Prior to this modelling study, it was generally agreed that the "pull-up" under the anomaly could be due to:

a) an actual basement high; or

b) laterally varying velocity within the Slave Point-Red Beds interval; or

c) a thicker portion of a high velocity formation such as Muskeg or Keg River.

It is now evident that the last two phenomena (b and c) could not create pull-up on the Red Beds of the observed magnitude since: an increase in velocity could only be marginal in these already high velocity carbonates; and an increase in thickness would have a negligible effect. (Calculations demonstrate that the pull-up effect of a velocity and/or thickness contrast within the Slave Point-Red Beds interval would only be 1 to 2 milliseconds.) Even KHMODEL 3 exhibits significant pull-up under a reef which was given a <u>lower</u> velocity than the surrounding sediments. Thus, the pull-up effect on the Red Beds reflector can be attributed to the formations <u>above</u> the Slave Point: structure on the Slave Point results in a smaller thickness of the lower velocity formations above it thereby creating a lateral change in average velocity. No pull-down is observed because the <u>net</u> velocity effects are such that a pull-up is generated. (The velocity variation at the reef generates a two-way time lag of 6 ms which is displaced by 10 ms of pull-up due to Slave Point structure; the net effect is 4 ms of pull-up on the Red Beds.)

Although the Cameron Hills Anomaly could still be associated with a basement high, this modelling verifies that the apparent "structure" on the Red Beds under the anomaly is not necessarily due to a positive basement structure but can instead be attributed to a velocity pull-up effect generated by a Slave Point structure. Furthermore, the Slave Point structure at the Cameron Hills Anomaly may be due to the presence of a carbonate buildup.

The modelling demonstrates that it is difficult to use seismic data to detect small variations in Keg River porosity because, as previously demonstrated, velocity variations within the Slave Point - Red Beds interval have a negligible effect. Even lateral changes in amplitude can not be a reliable indication of velocity variations because the absolute values of reflection coefficients are very small (in the order of 0.01) in the Muskeg-Red Beds interval. This makes the reflections extremely susceptible to the effects of noise (which can also have an amplitude that is of the same order of magnitude as the reflections within this interval), and to the constructive and destructive interference of multiples. Thus, for velocity-porosity variations of the magnitude discussed here, structure on the Slave Point is the only reliable indication of possible carbonate buildups. However, if the velocity of the reef were much lower than the 6107 m/s used, there would be a larger amount of time-lag and the net effect could be one of pull-down on the Red Beds. There is no indication that Cameron Hills reefs would be this porous but the possibility cannot be ignored.

The modelling also shows the brightening of the Slave Point amplitude at the edges of the structural drape as seen on seismic. The ray tracing diagrams (Figures 4.13, 4.14, 4.17, and 4.18) indicate that this is a result of the focussing of the rays (refraction). There is no associated defocussing (loss of amplitude) at the crest of the structure (on seismic or the model). This can be attributed to its broad, subtle character.

The AIMS modelling package is very crude and is based on a multitude of simplistic assumptions. The given model is also a largely simplified version of the real world. Consequently, this modelling exercise cannot provide solid evidence for the presence of a reef but it does provide some support for the existence of a carbonate buildup.

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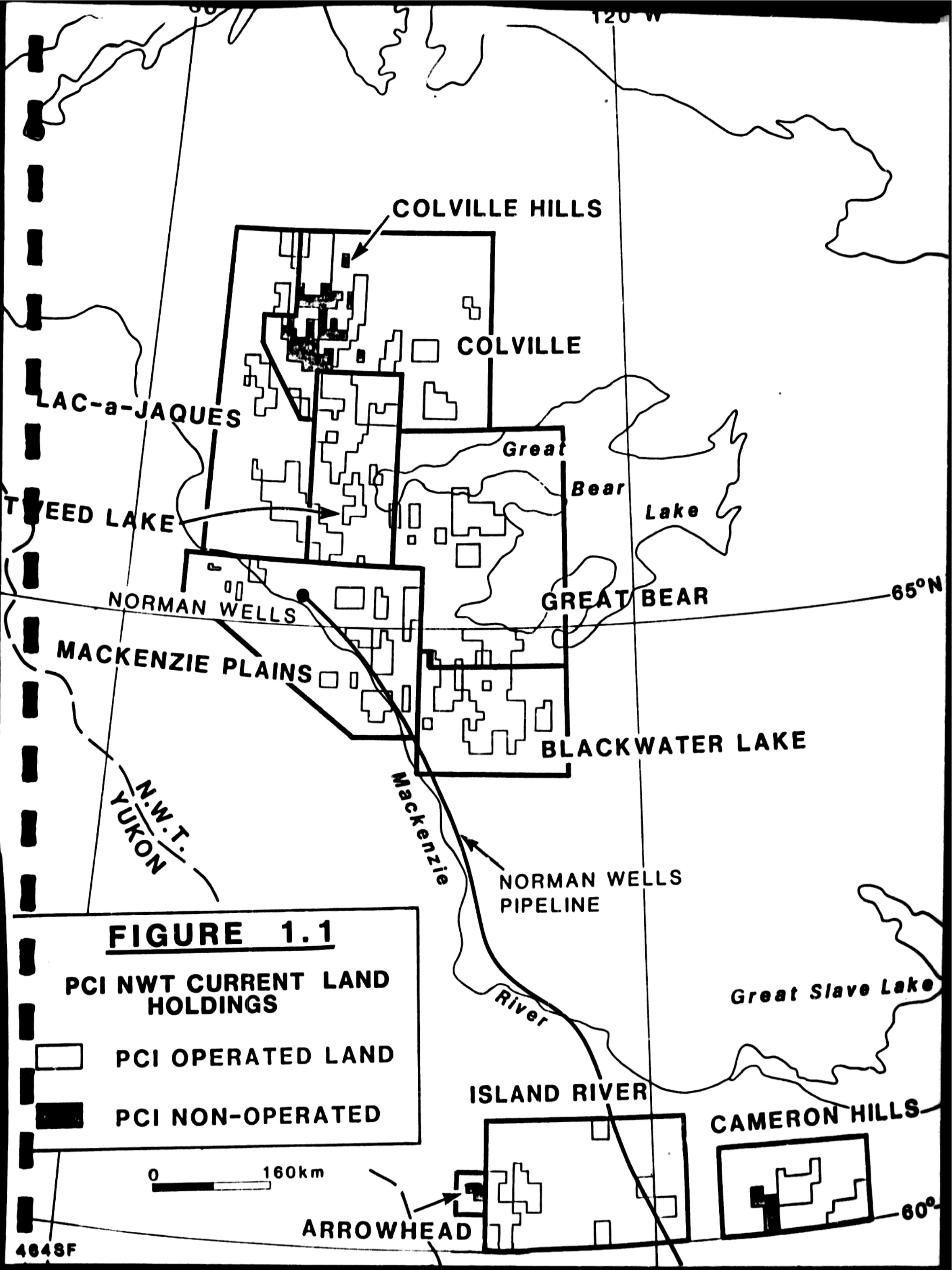
FIGURES


120° W
COLVILLE HILLS
COLVILLE
LAC-a-JAQUES
Great
Bear
Lake
TWEED LAKE
NORMAN WELLS
GREAT BEAR
65°N
MACKENZIE PLAINS
BLACKWATER LAKE
N.W.T.
YUKON
Mackenzie
River
NORMAN WELLS
PIPELINE
FIGURE 1.1
PCI NWT CURRENT LAND
HOLDINGS
PCI OPERATED LAND
PCI NON-OPERATED
0
160km
Great Slave Lake
ISLAND RIVER
CAMERON HILLS
ARROWHEAD
60°
464SF

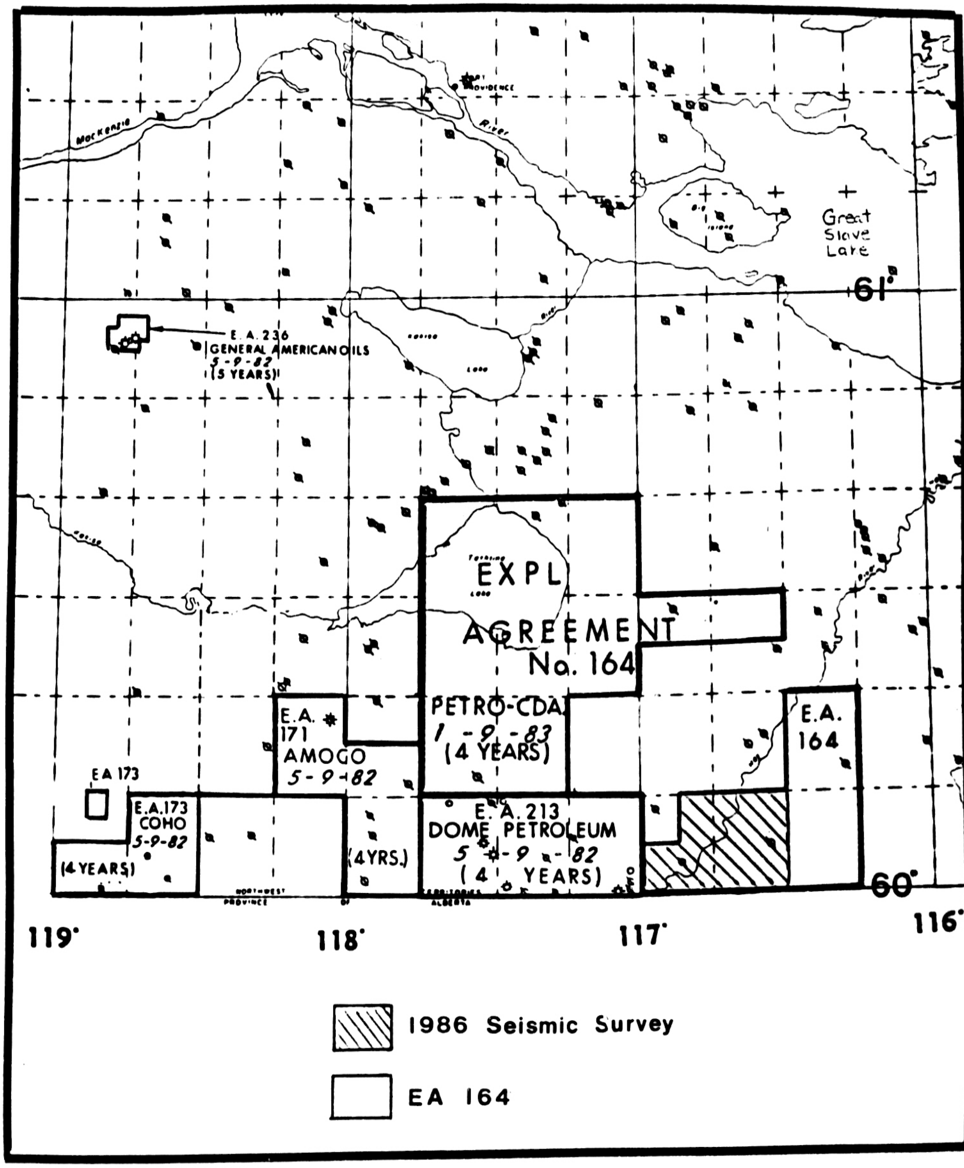
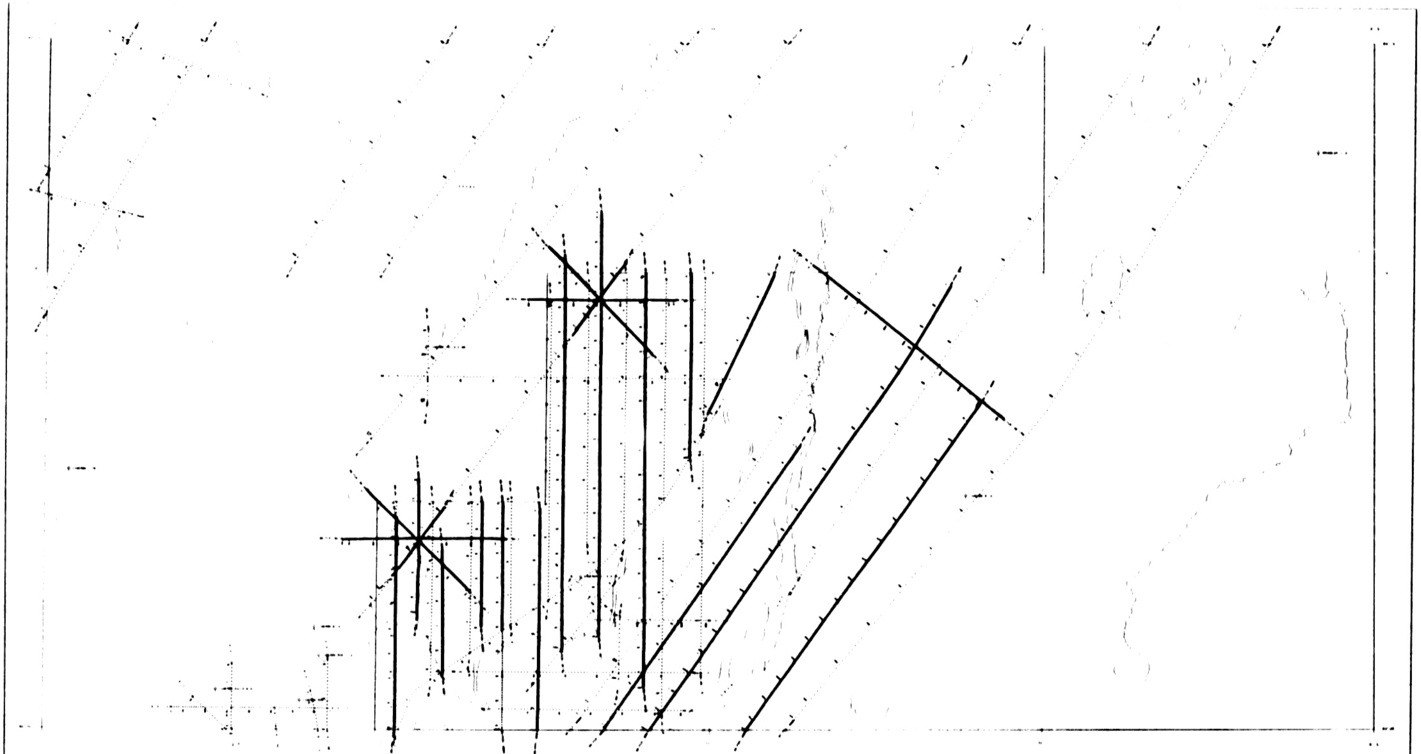


FIGURE 1.2

EA 164 Location Map



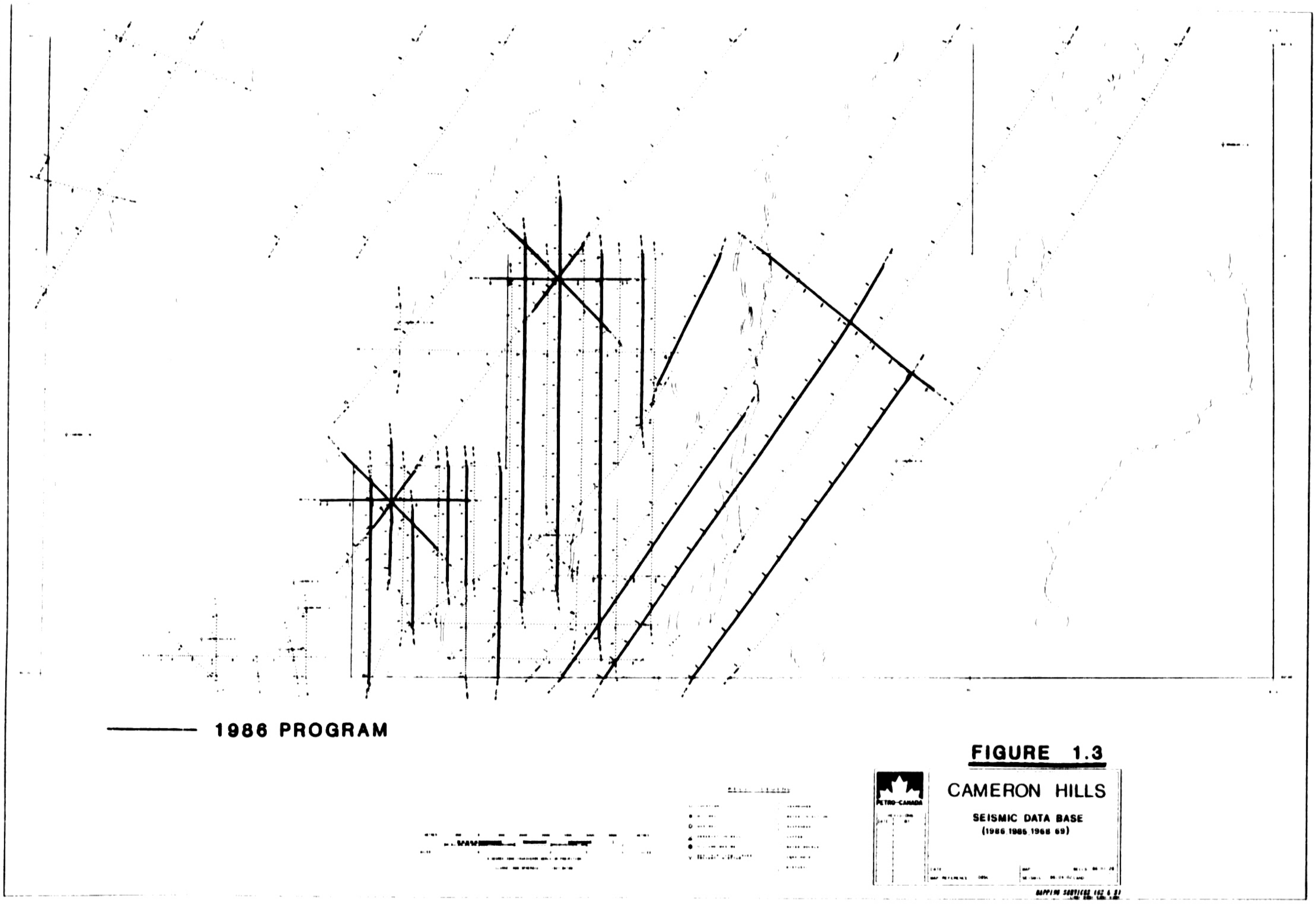
——— 1986 PROGRAM

FIGURE 1.3

PETRO-CANADA

CAMERON HILLS

SEISMIC DATA BASE
(1986 1985 1968 69)



1986 PROGRAM
CAMERON HILLS
SEISMIC DATA BASE
(1986 1985 1968 69)
PETRO-CANADA

FIGURE 1.3

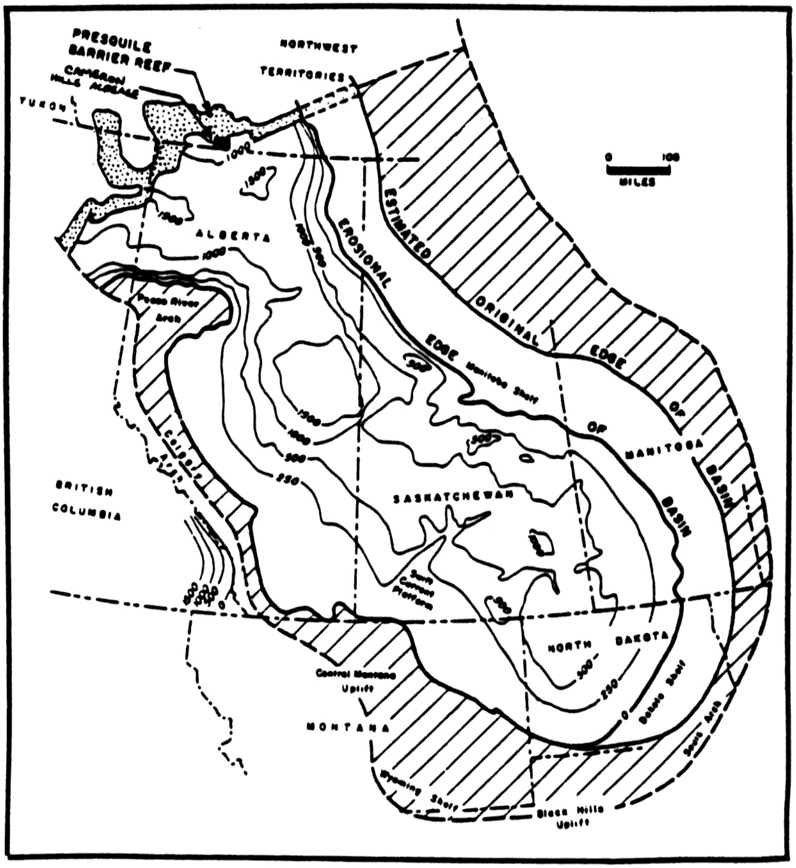
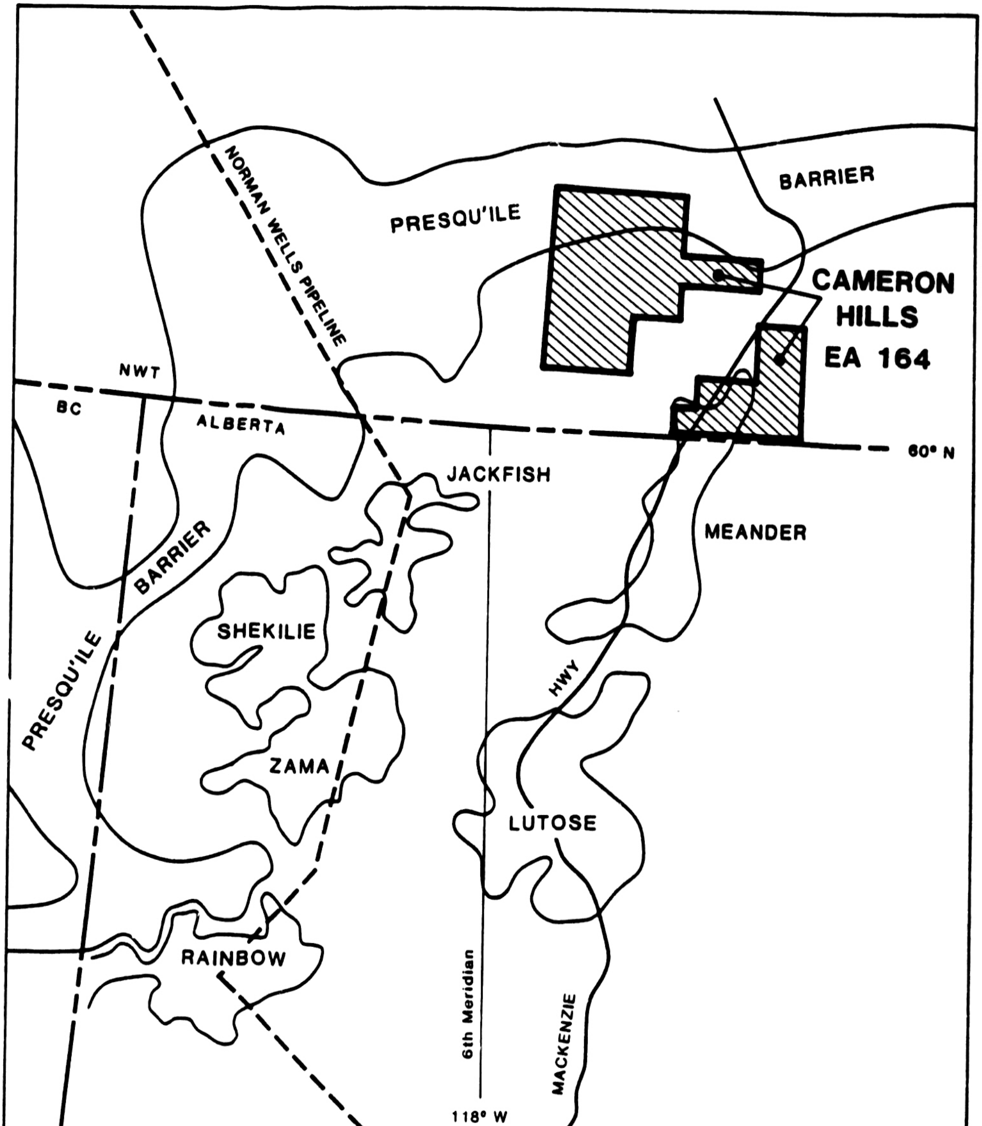


FIGURE 3.1

Map of middle devonian Elk Point Basin showing:
(i) thickness and erosional edge of the basin
(ii) the Presqu'ile Barrier, and
(iii) the location of the Cameron Hills acreage.

(from Maiklem, 1971)

FIGURE 3.2



LOCATION MAP
SHOWING CAMERON HILLS EA 164
IN RELATION TO
THE MIDDLE DEVONIAN SUB-BASINS
OF NORTHERN ALBERTA

0 50 100 km

5455 SF

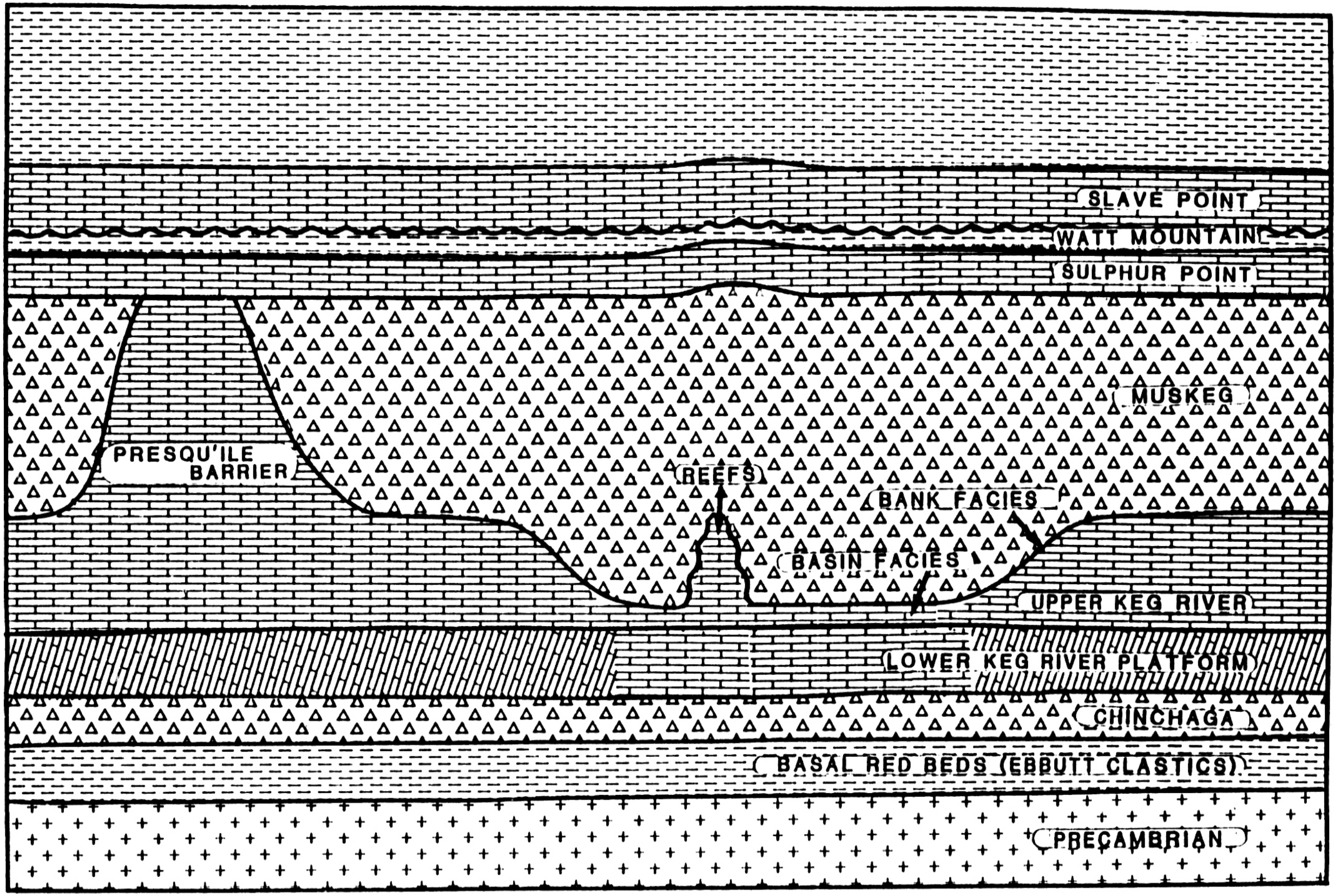
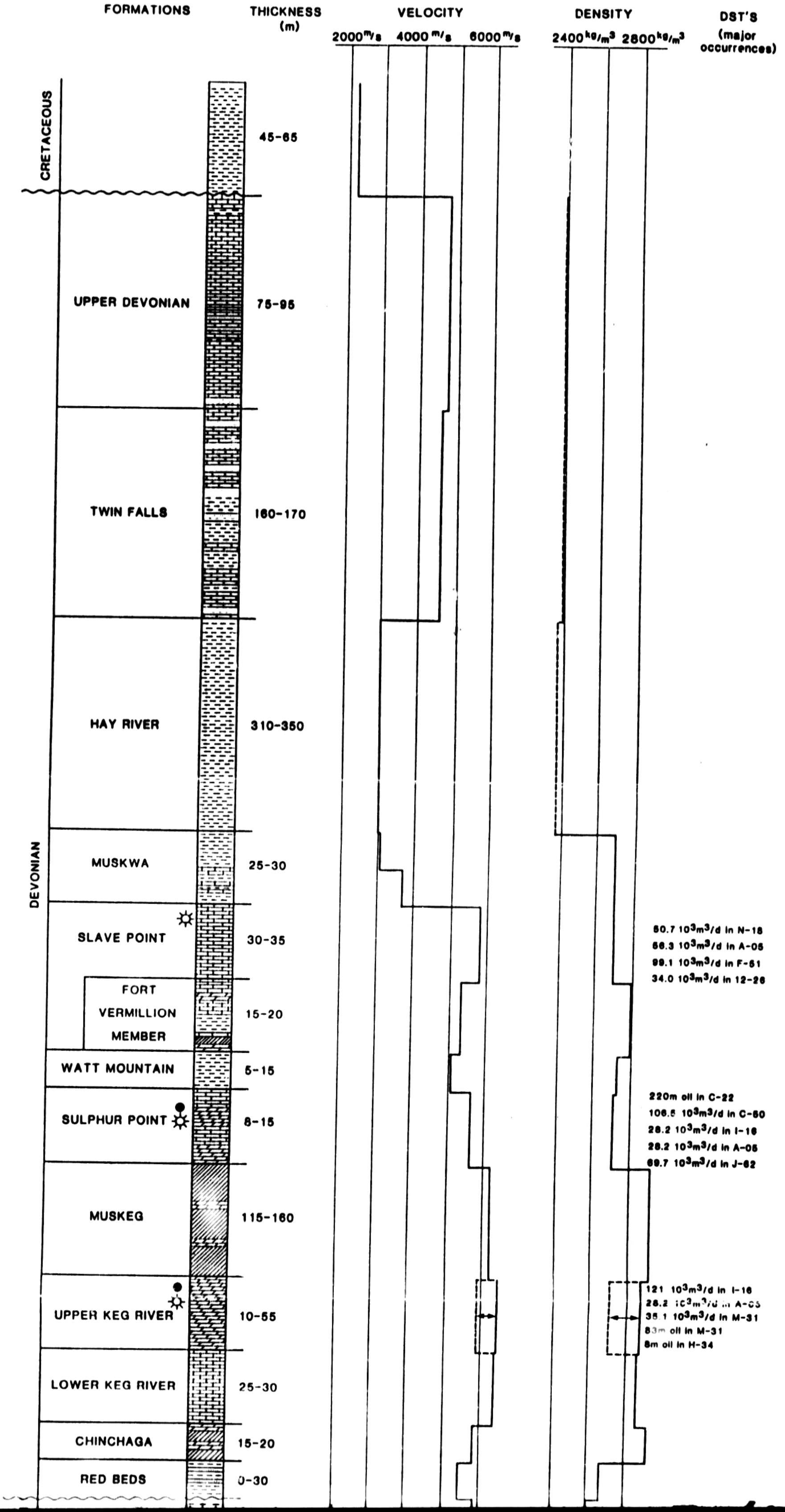
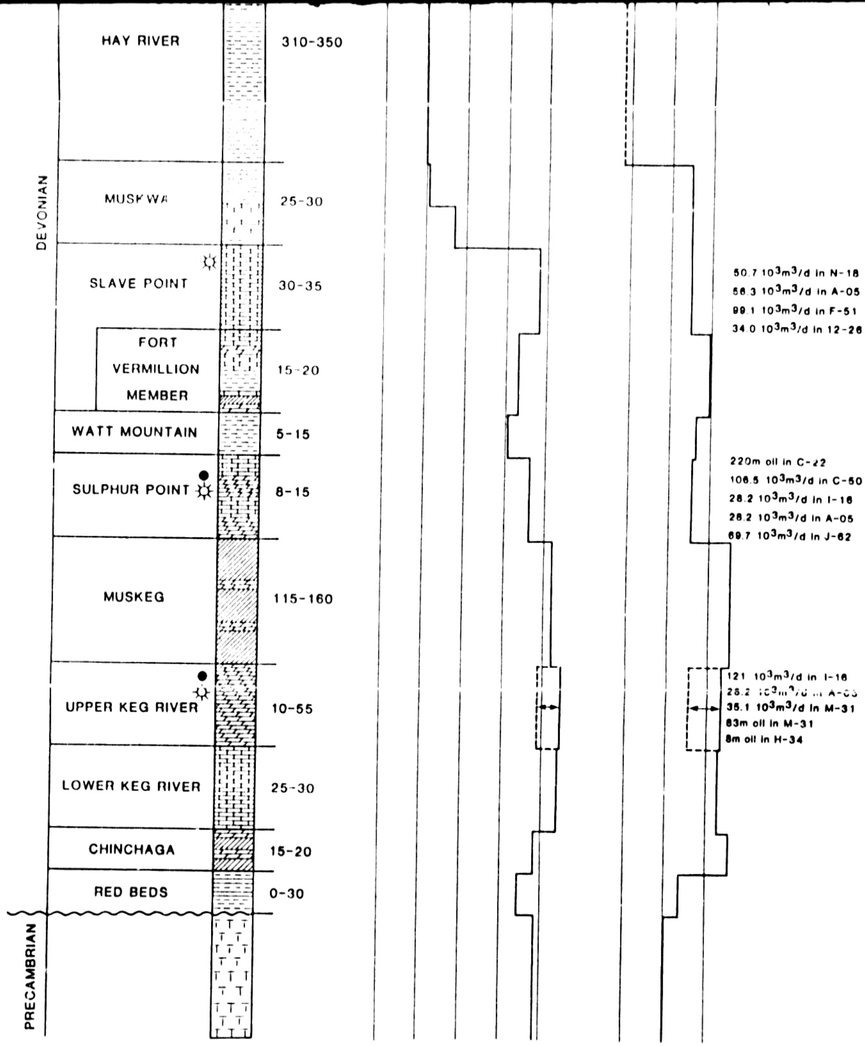


FIGURE 3.3 Schematic Cross-Section Regional Middle Devonian Stratigraphy.

FIGURE 3.4

CAMERON HILLS
STRATIGRAPHIC COLUMN, VELOCITY AND DENSITY INFORMATION





Velocity and Thickness Information from Wells: H-34 and J-12

(Note: These thicknesses do not consider draping over a carbonate buildup.)

Originally compiled by: Charles Boyer, July 85

Revised by: K. Brawley-Hogg, September 86

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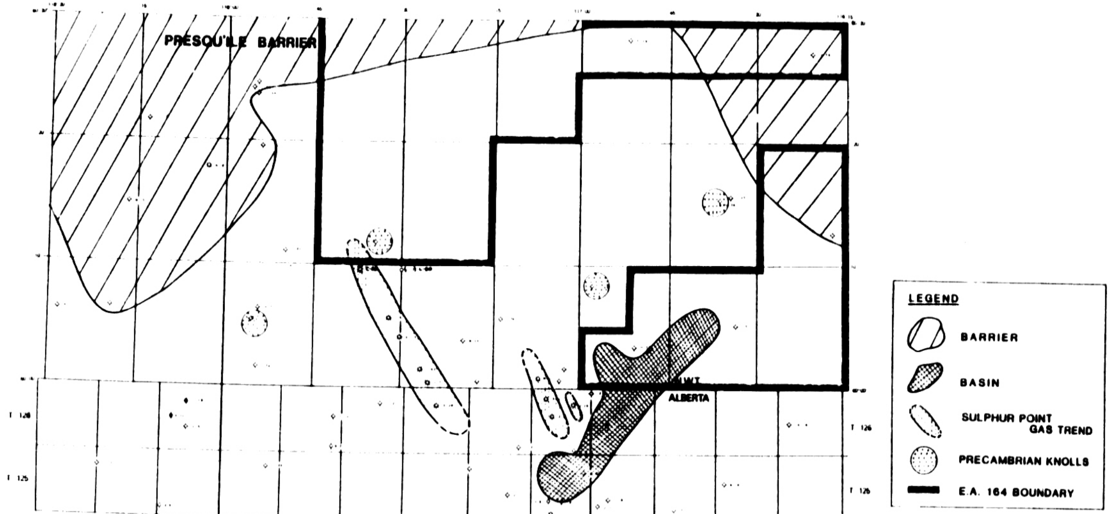

FIGURE 3.5

CAMERON HILLS
E.A. 164 AND AREA
SUMMARY MAP

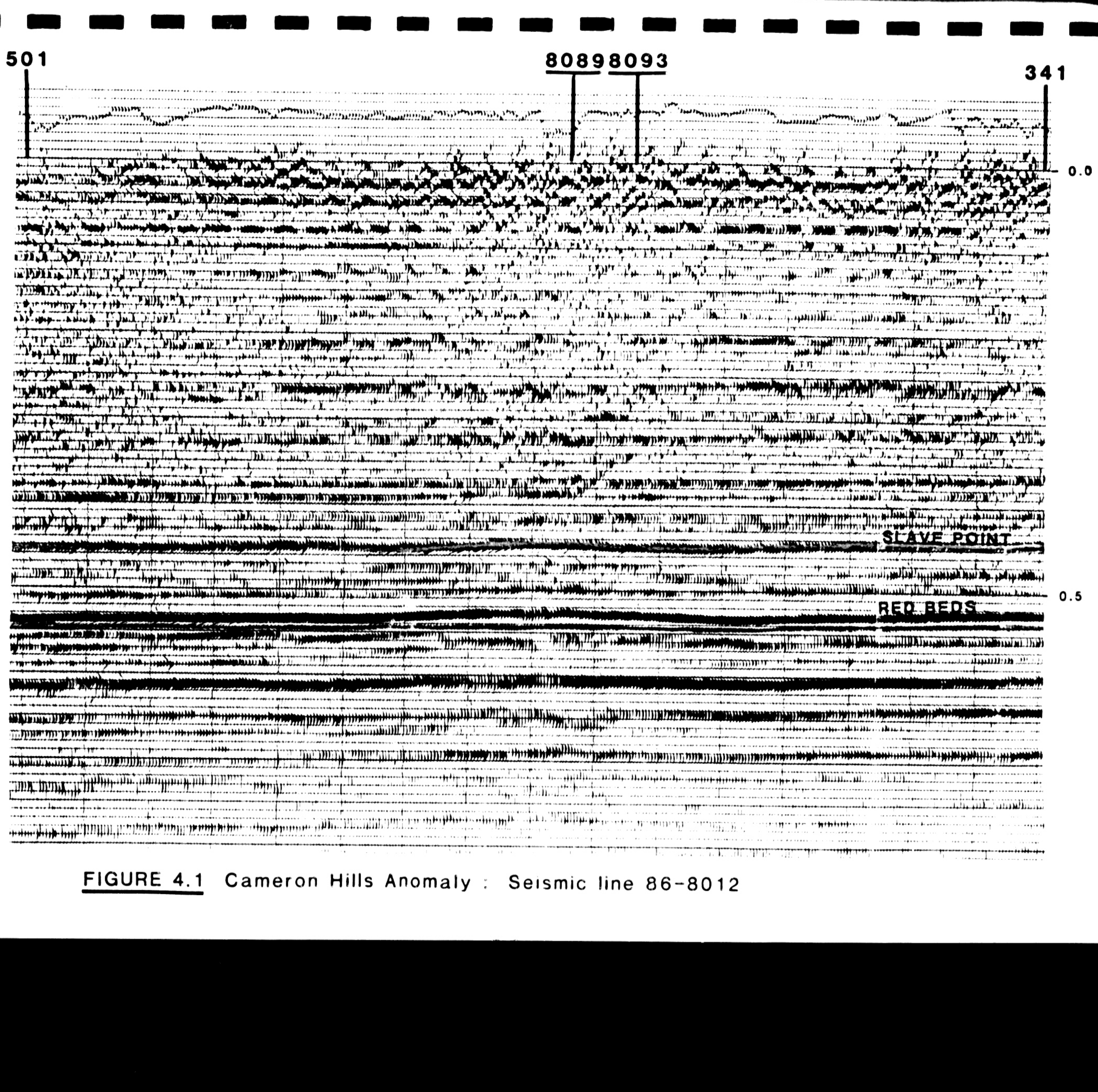

FIGURE 4.1 Cameron Hills Anomaly : Seismic line 86-8012

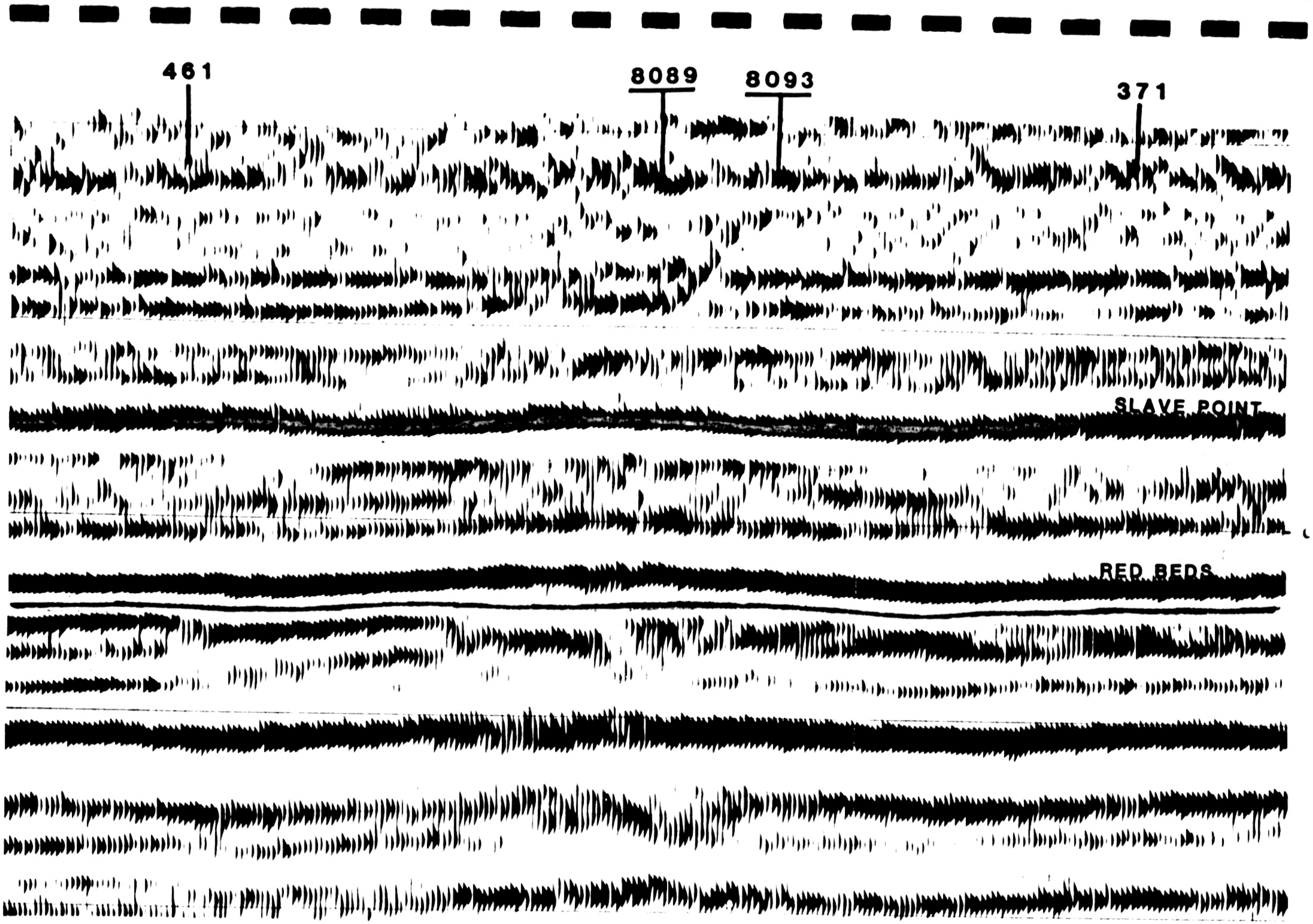

FIGURE 4.2 Cameron Hills Anomaly : Seismic line 86-1012

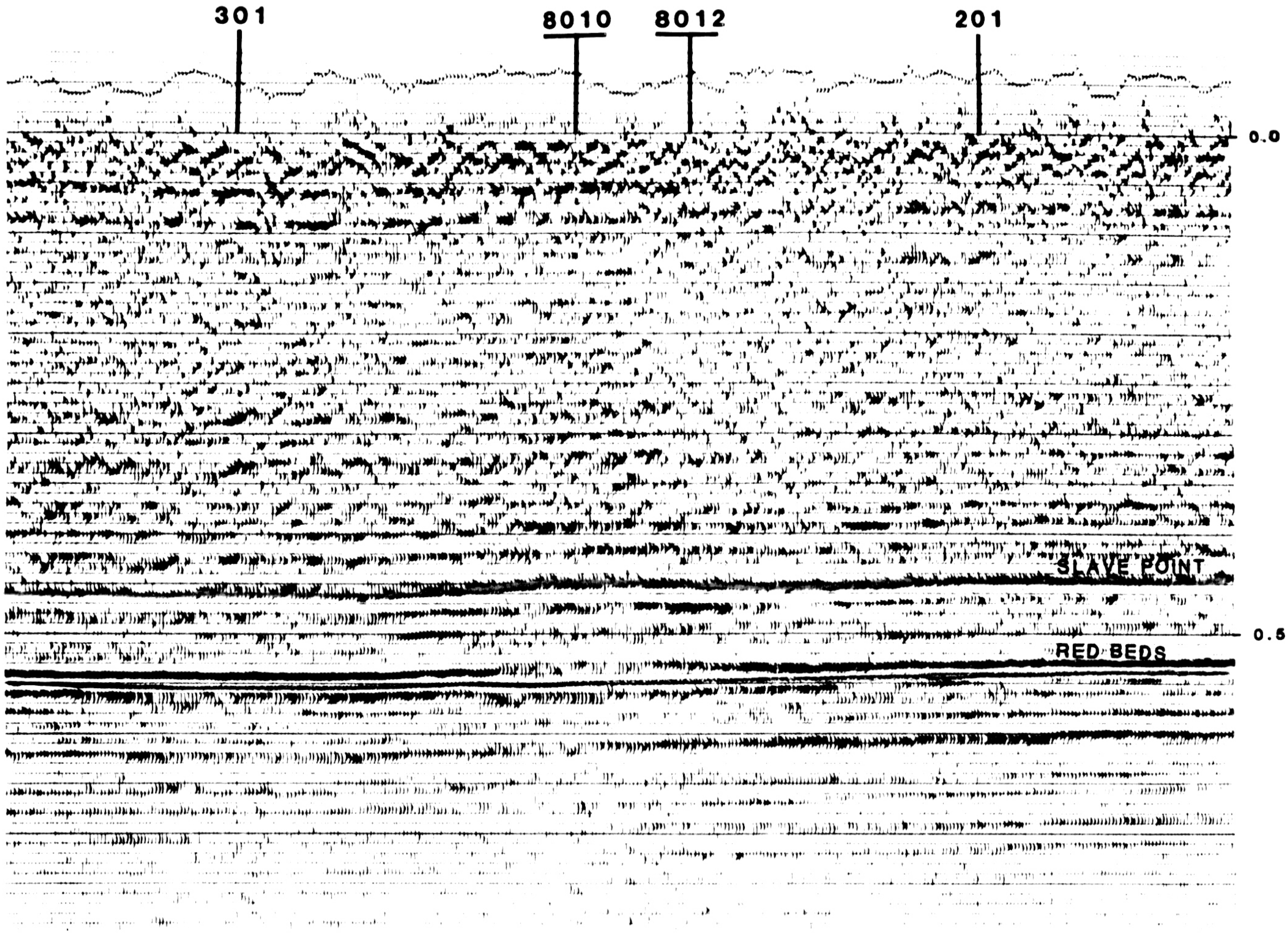

FIGURE 4.3 Cameron Hills Anomaly : Seismic line 86-8093

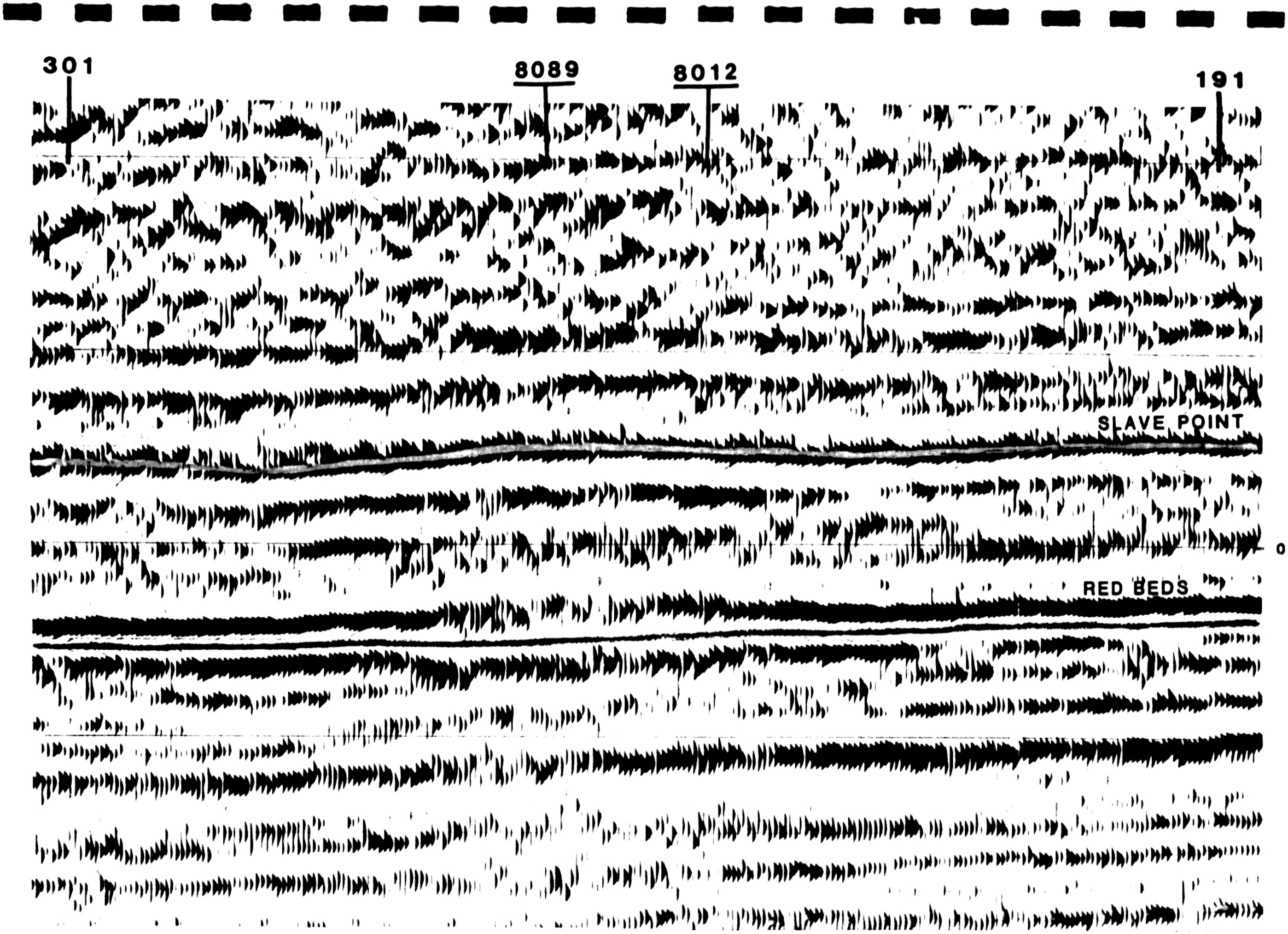

FIGURE 4.4 Cameron Hills Anomaly : Seismic line 86-8093

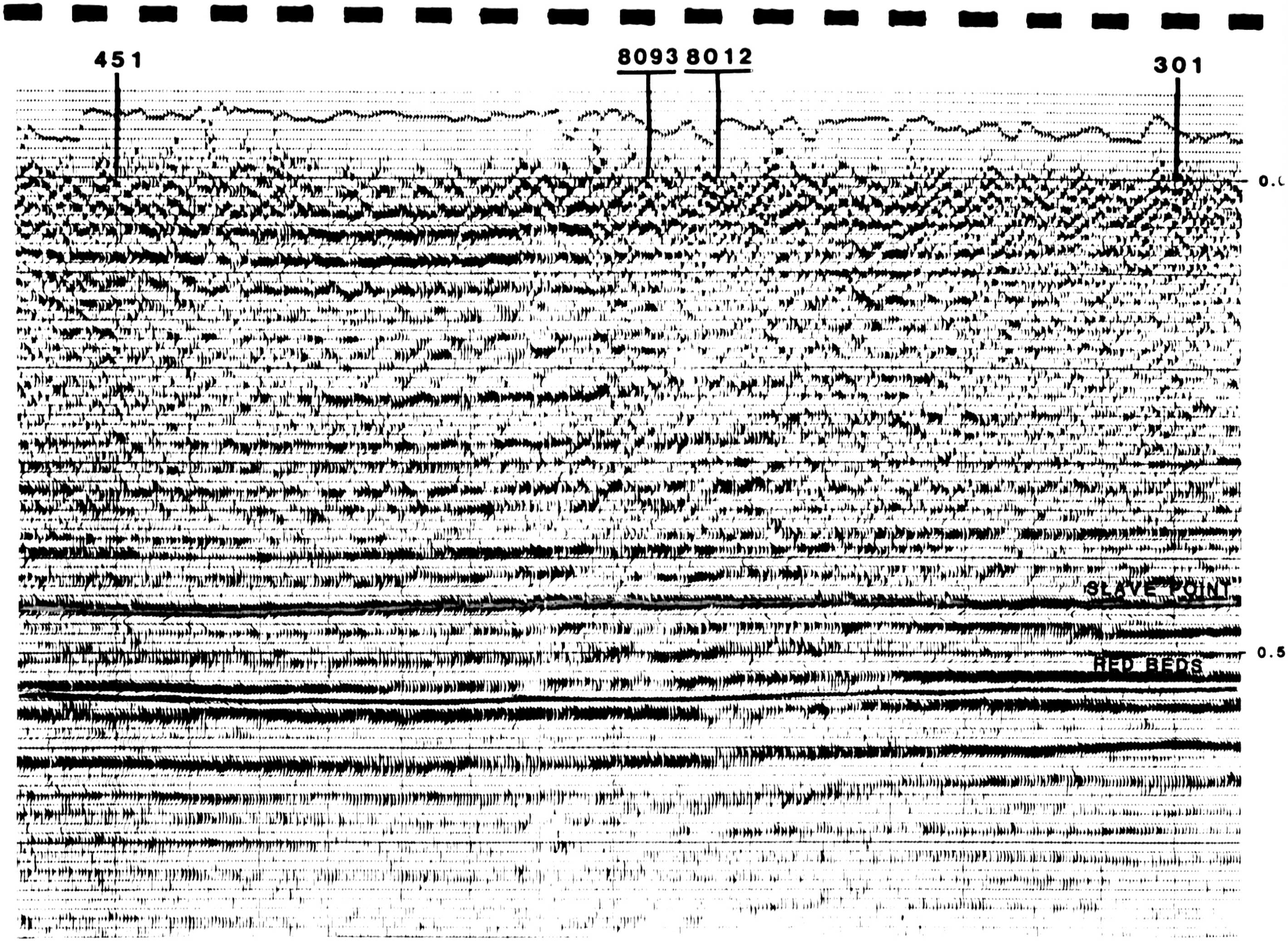

FIGURE 4.5 Cameron Hills Anomaly : Seismic line 86-8089

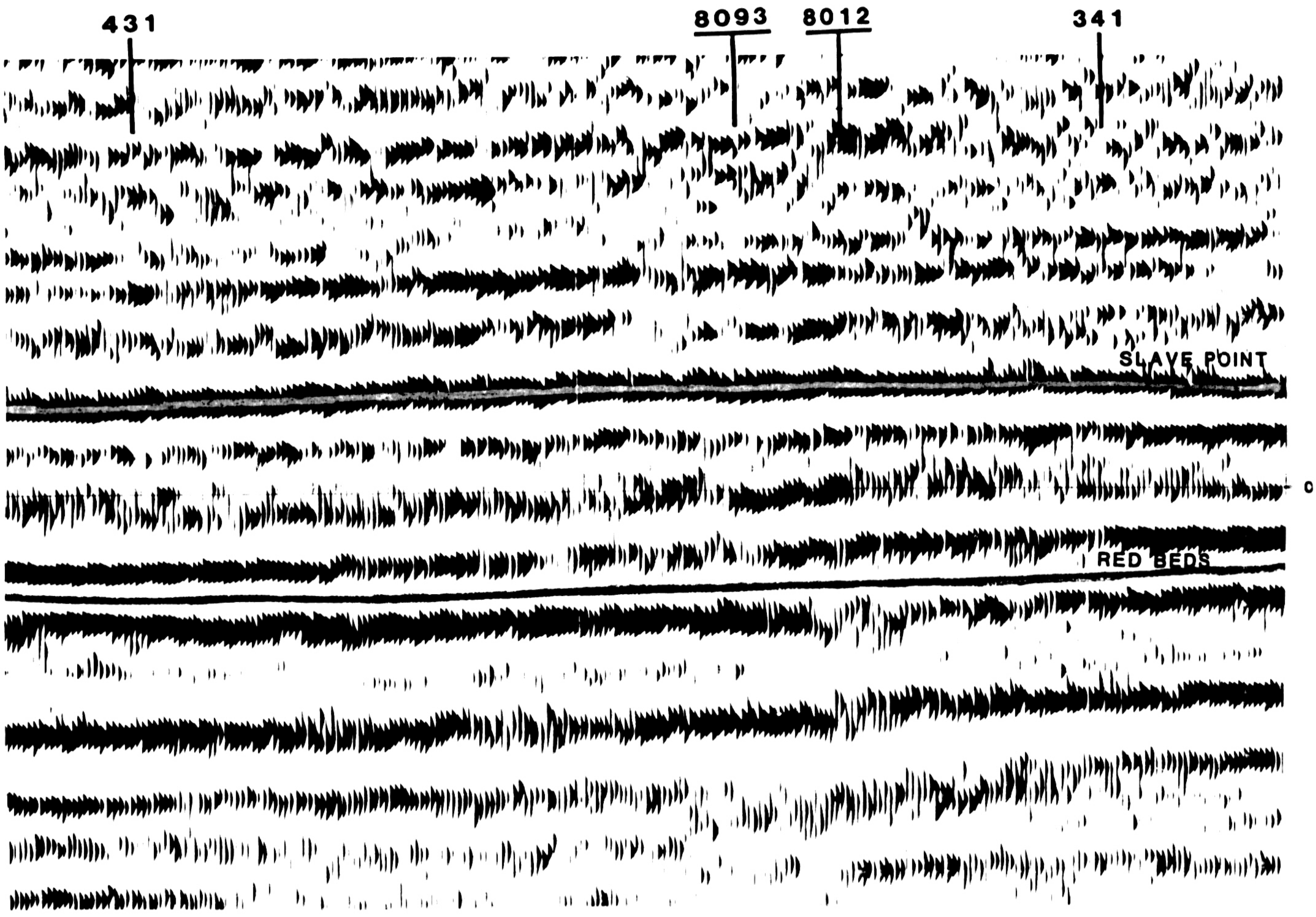

FIGURE 4.6 Cameron Hills Anomaly : Seismic line 86-8089

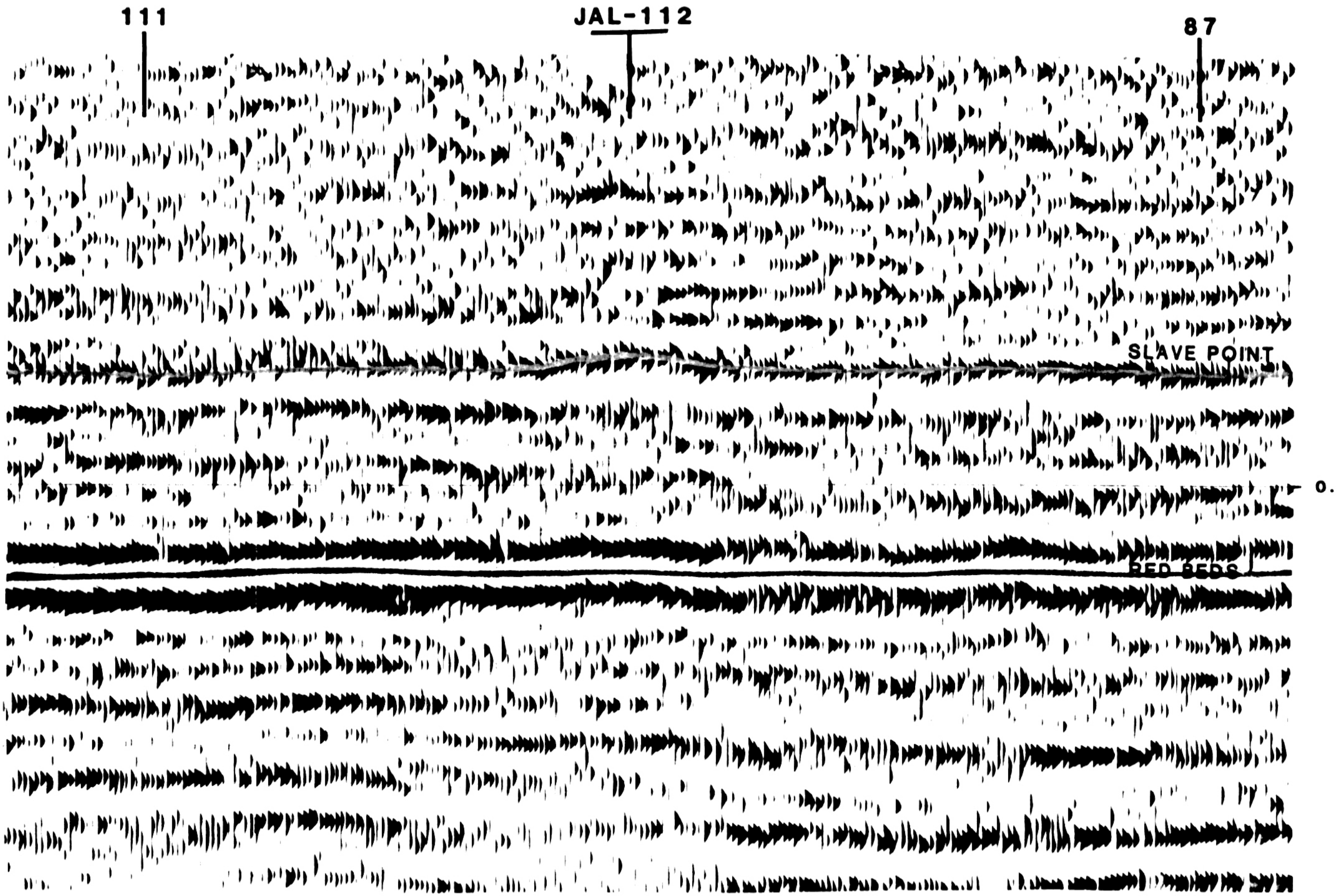

FIGURE 4.7 Possible Keg River Carbonate Buildup - Seismic line JAL - 18

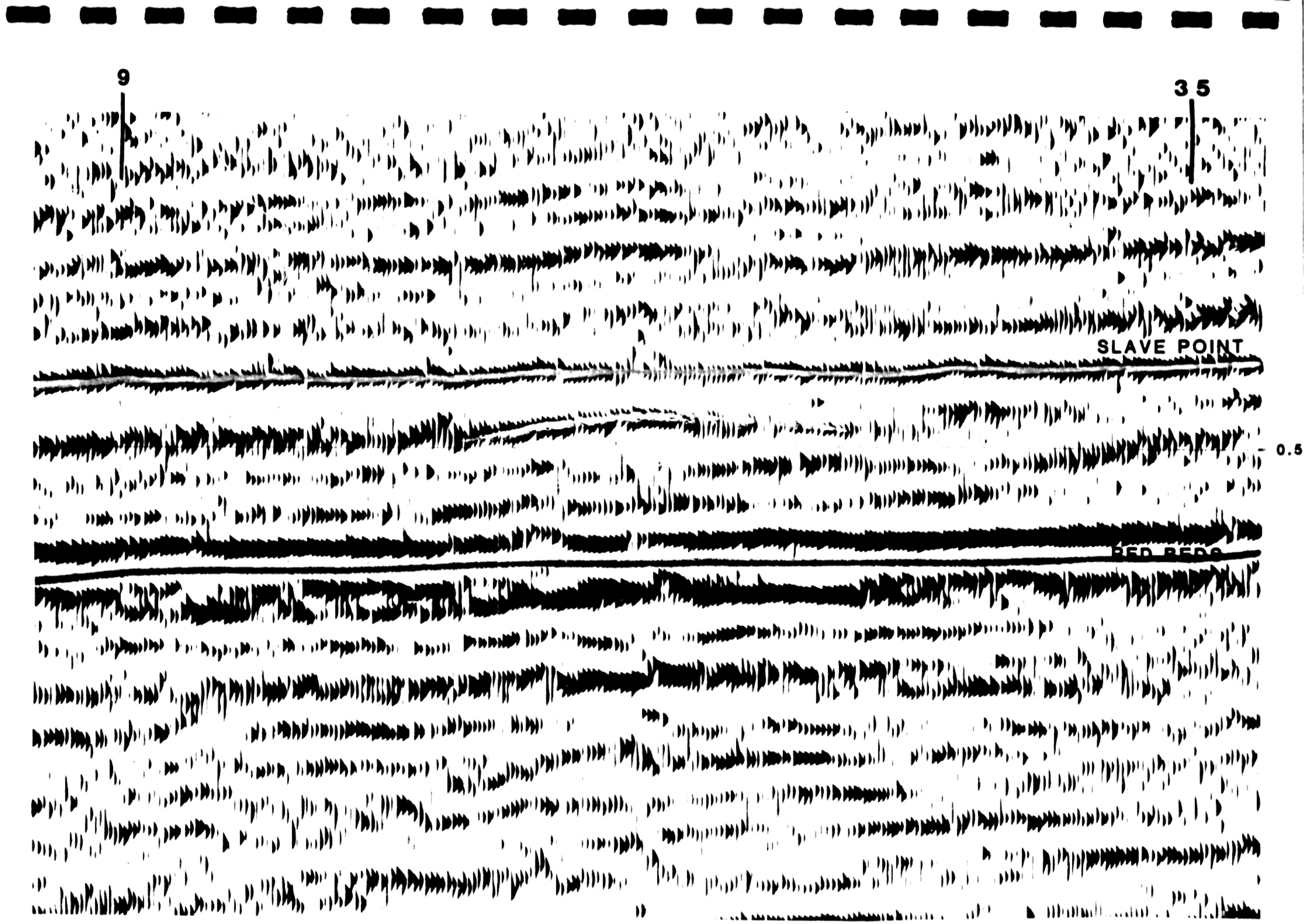

FIGURE 4.8 Possible Keg River Carbonate Buildup - Seismic line JAL-1

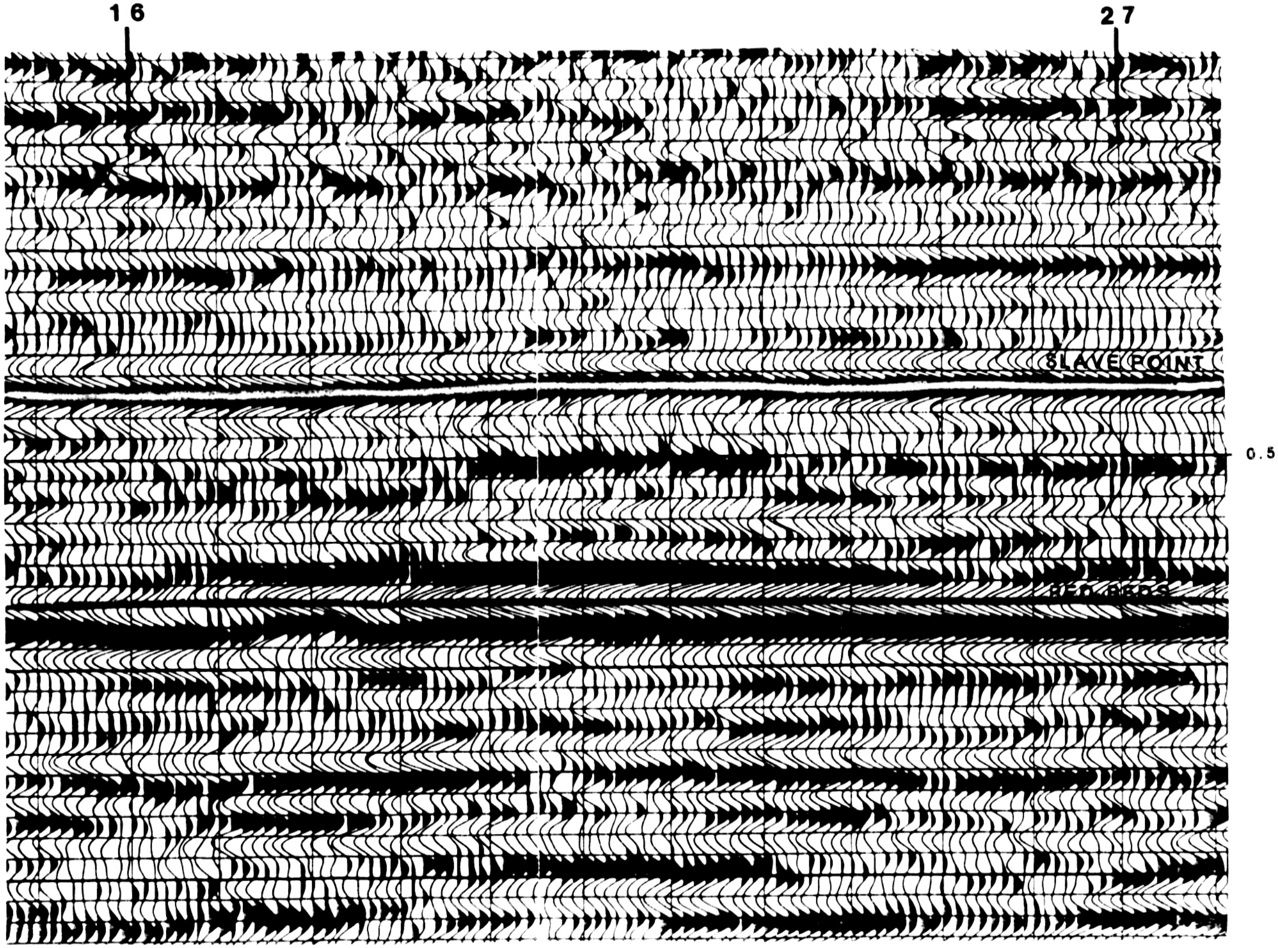

FIGURE 4.9 Possible Keg River Carbonate Buildup - Seismic line JAL-8

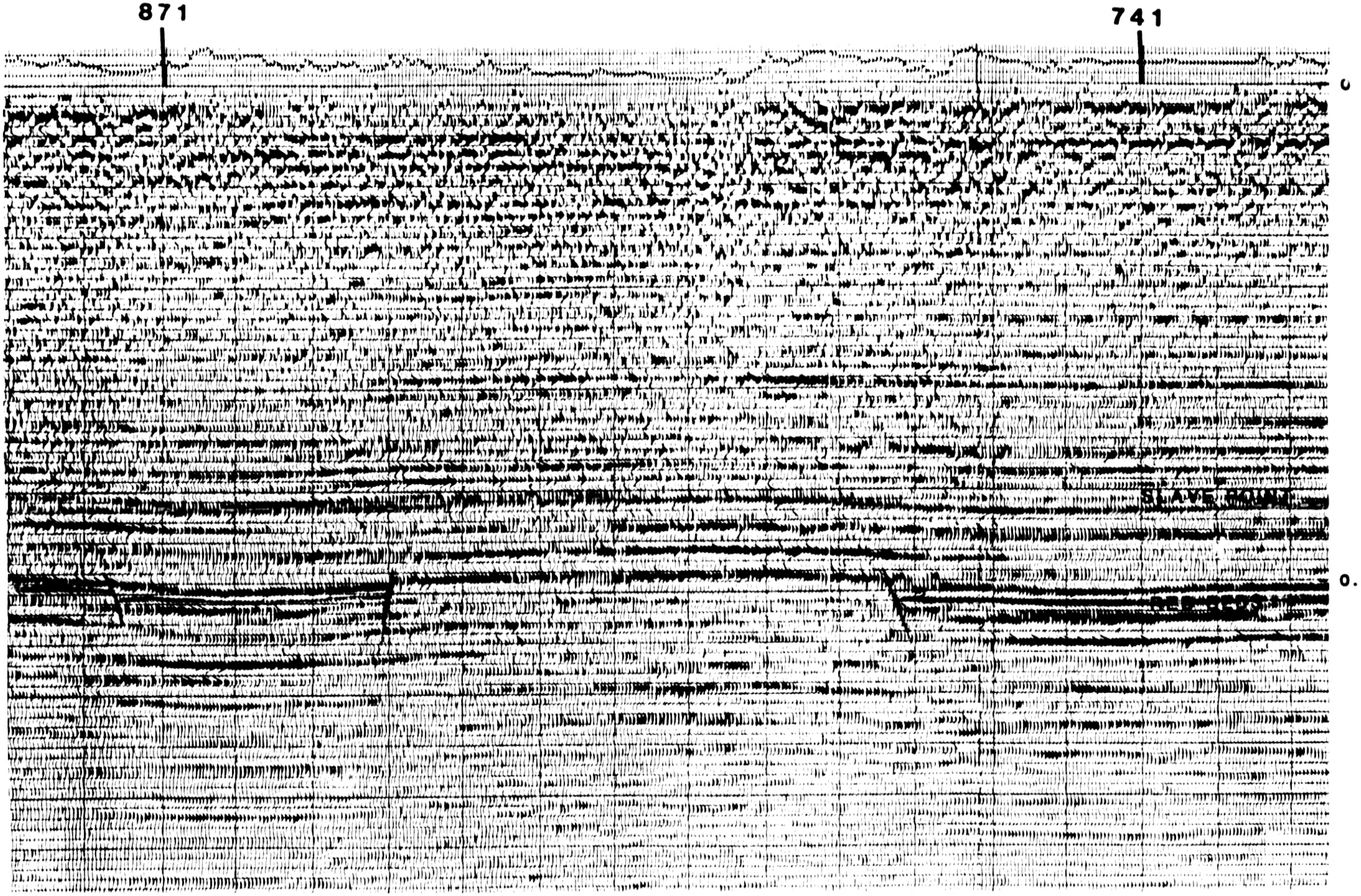

FIGURE 4.10 Possible Sulphur Point Gas Structure – Seismic line 86-8075

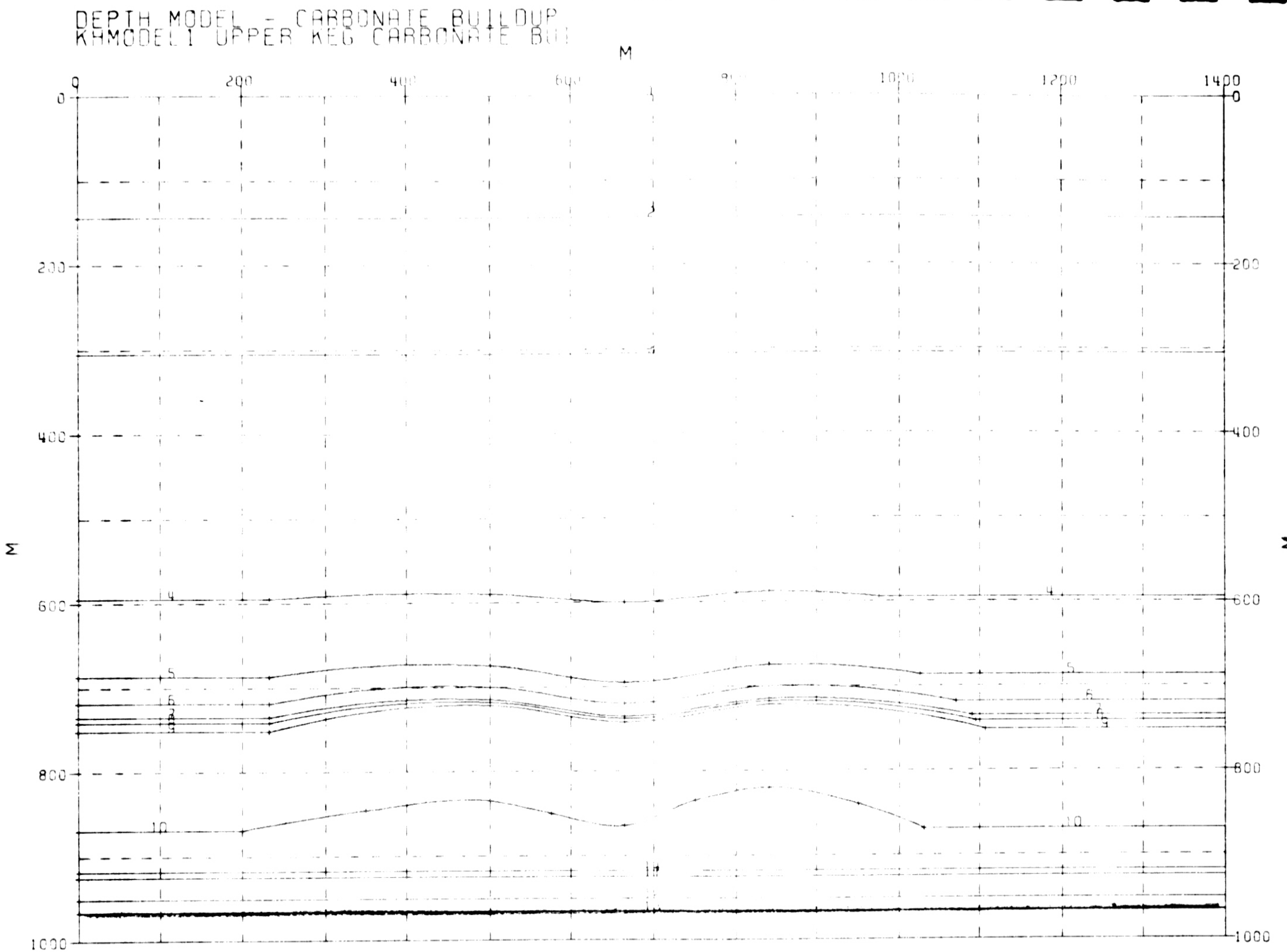

FIGURE 4.11 KHMODEL 1 - Model of a Carbonate Buildup in Depth

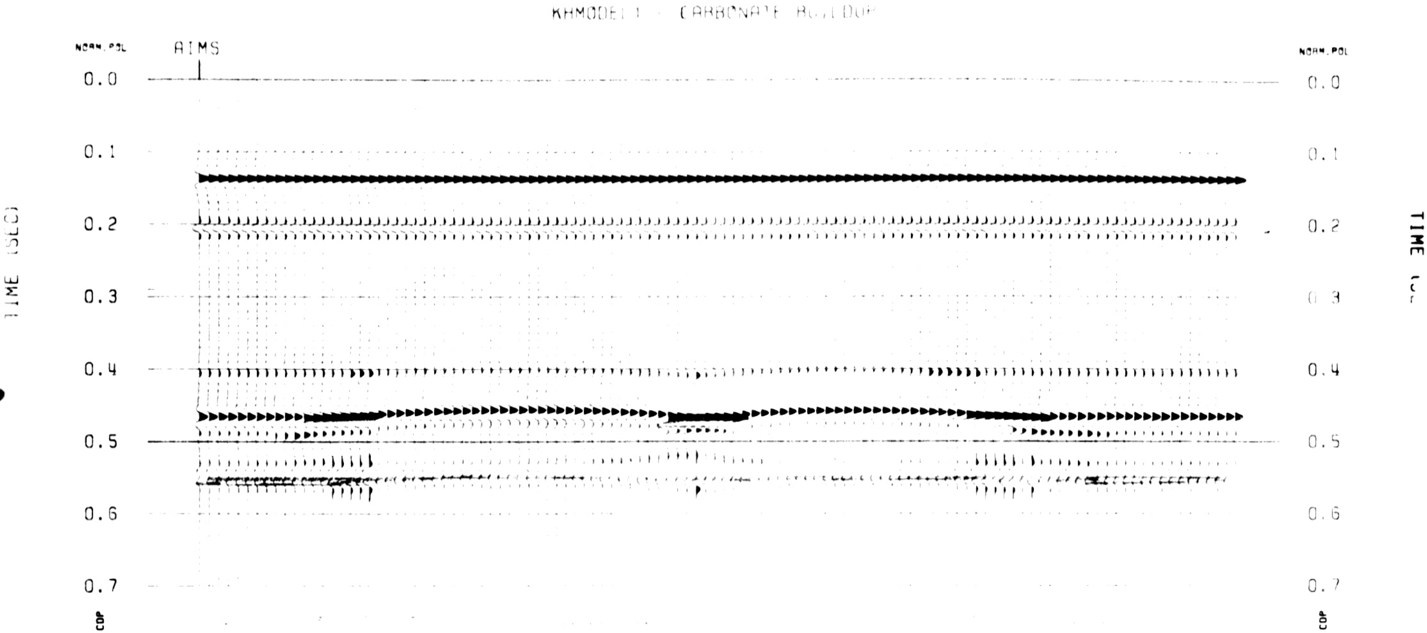

FIGURE 4.12 KHMODEL 1 - Model of a Carbonate Buildup in time

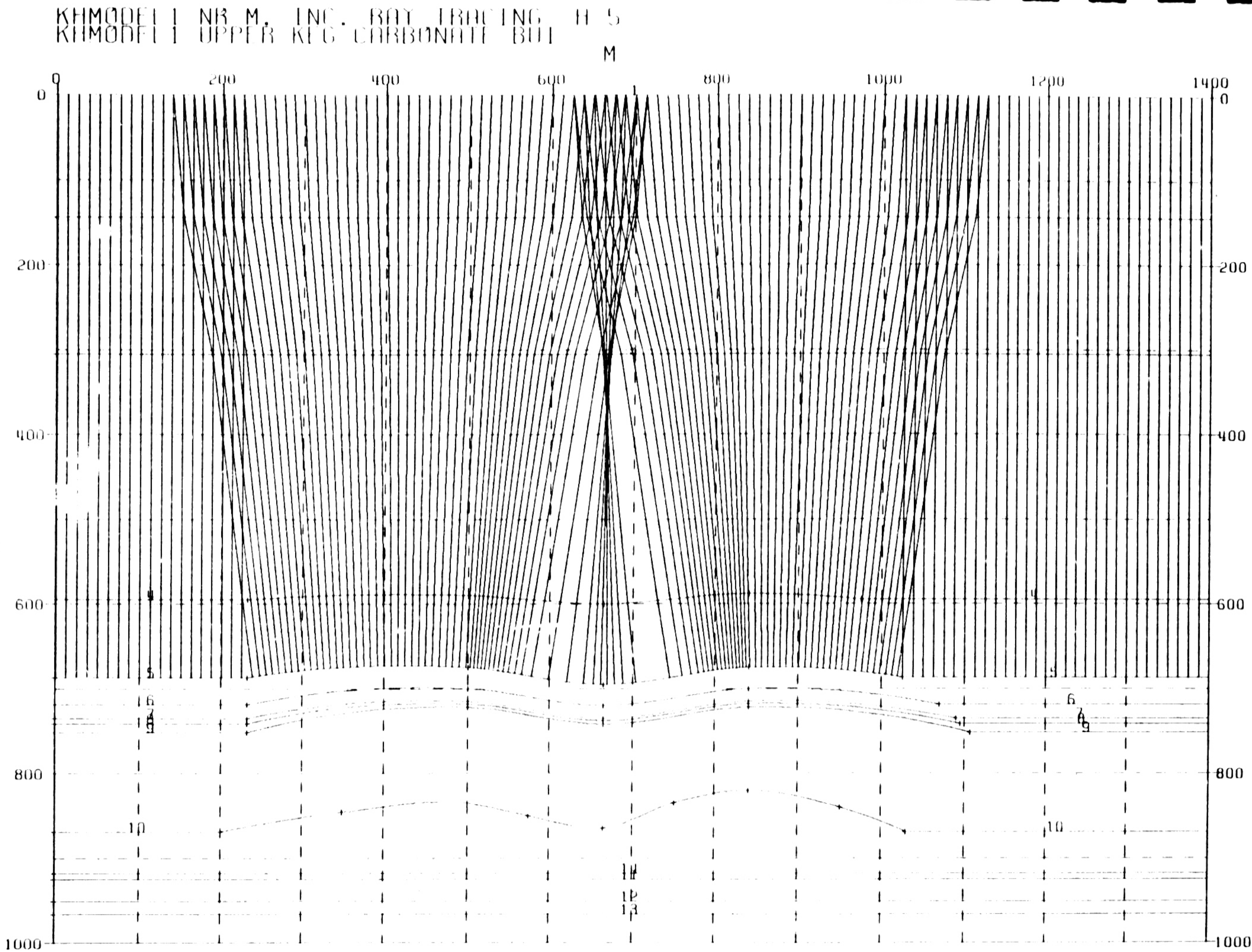

FIGURE 4.13 KHMODEL 1 - Ray Tracing From Slave Point

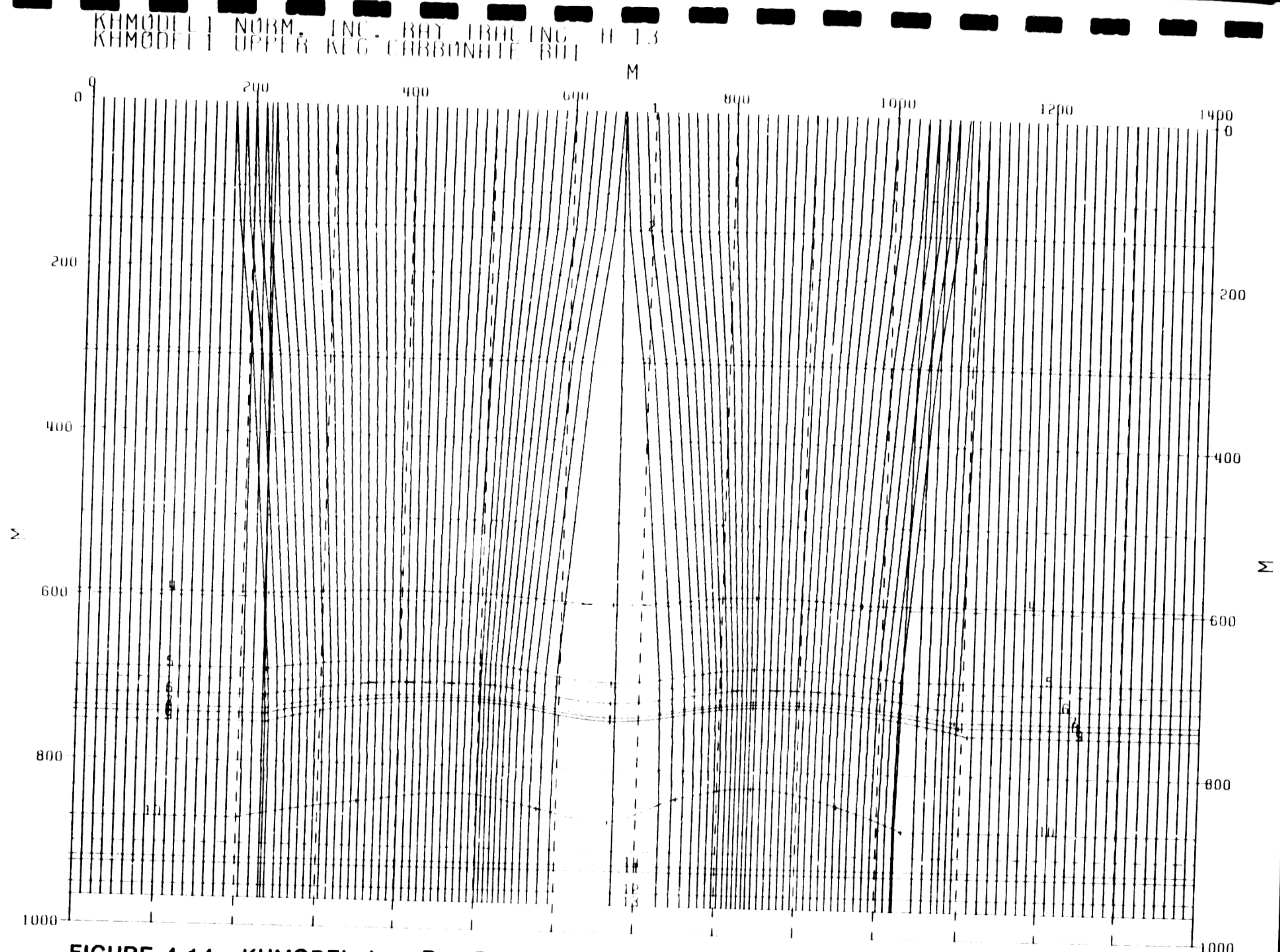

FIGURE 4.14 KHMODEL 1 - Ray Tracing From Red Beds

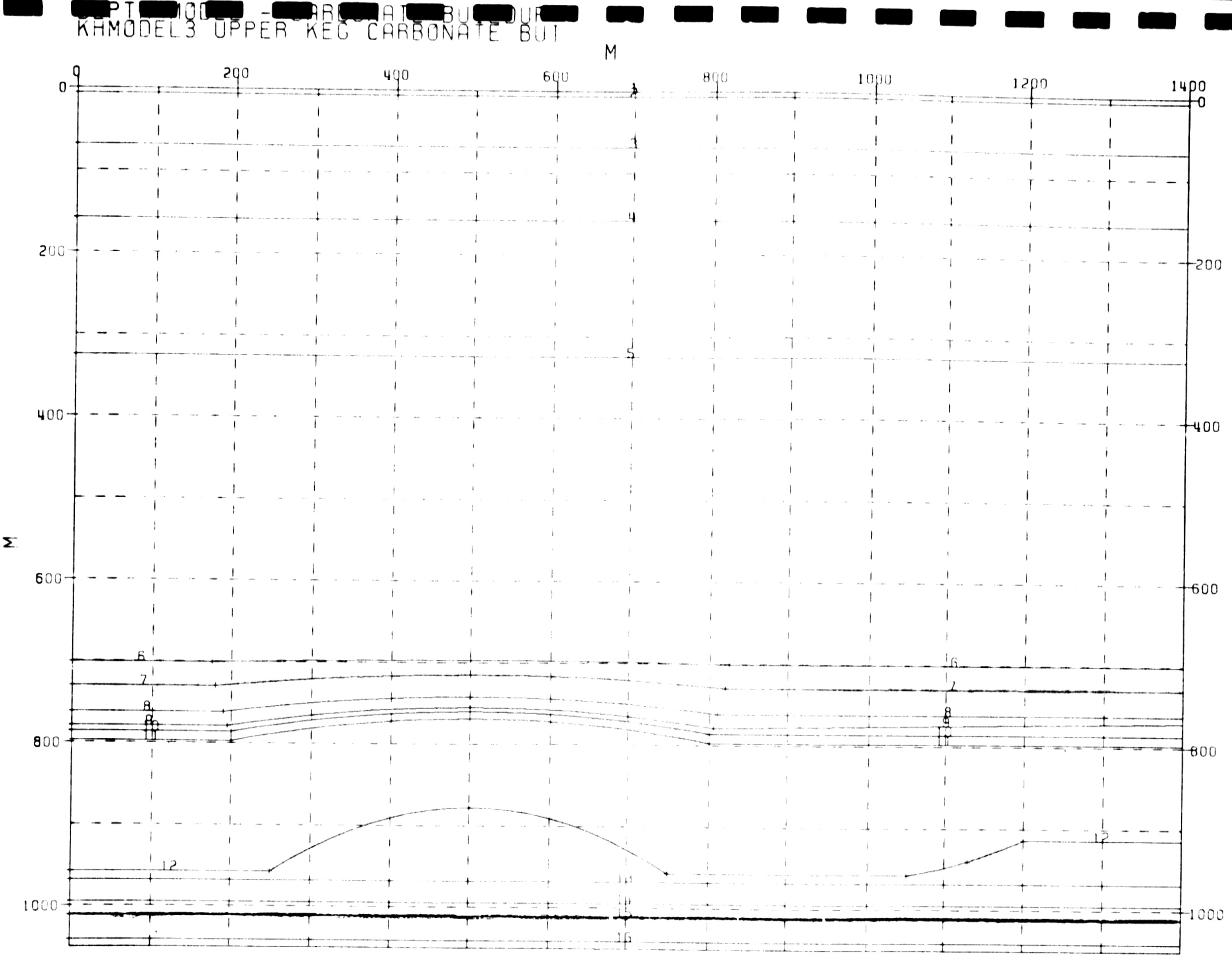

FIGURE 4.15 KHMODEL 3 - Model of a Carbonate Buildup in depth

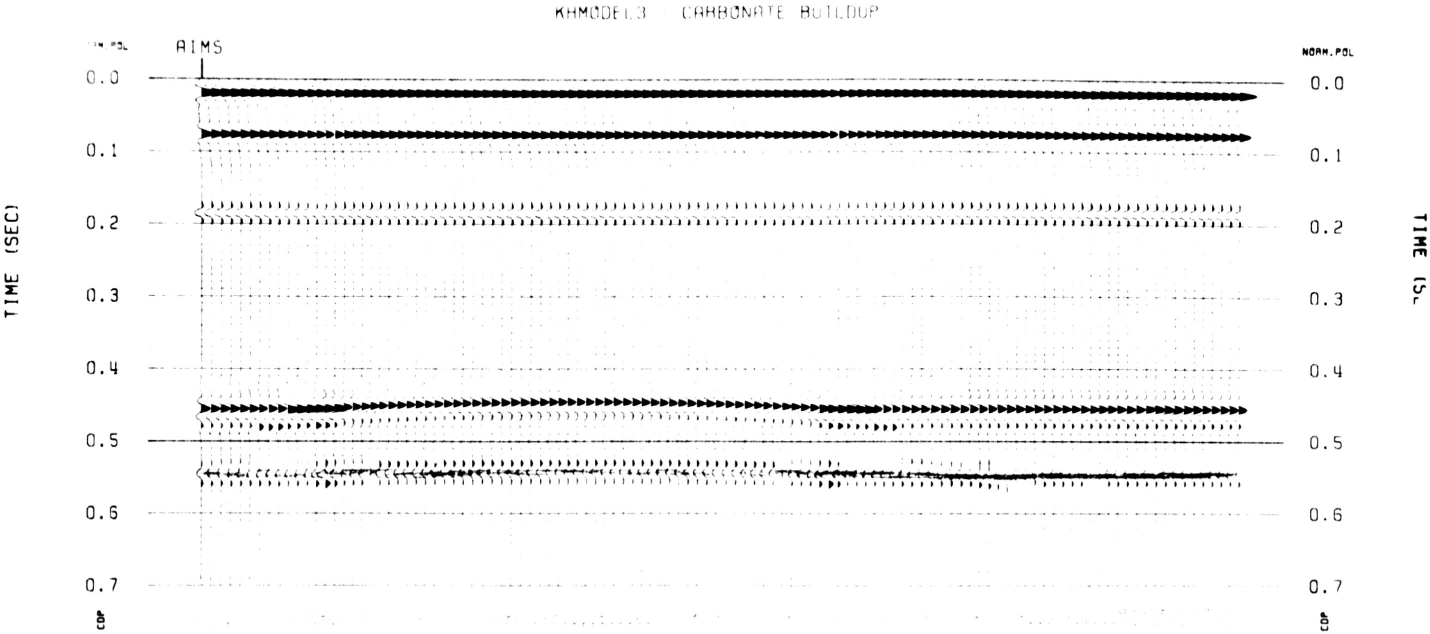

FIGURE 4.16 KHMODEL 3 - Model of a Carbonate Buildup in time

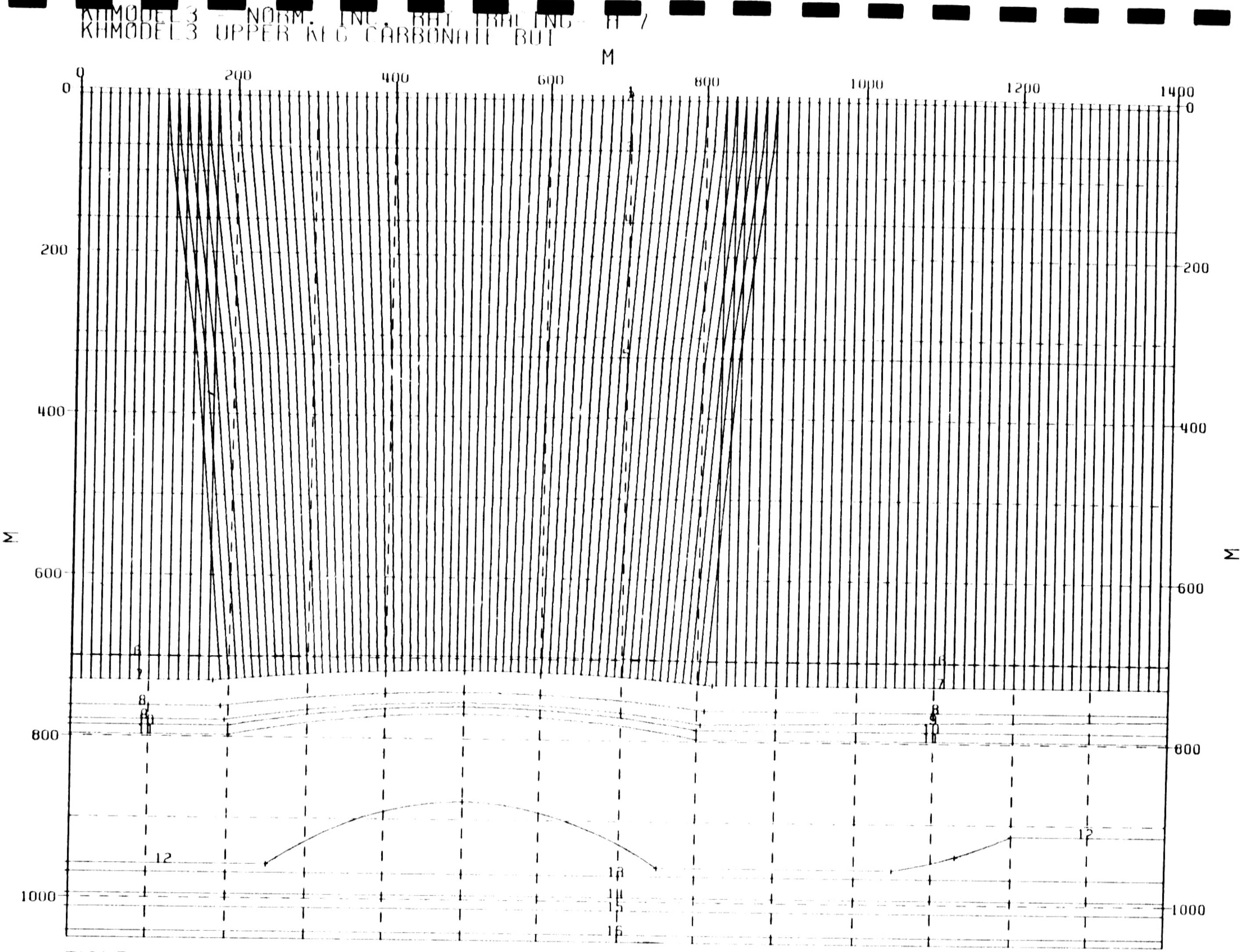

FIGURE 4.17 KHMODEL 3 - Ray Tracing From Slave Pt.

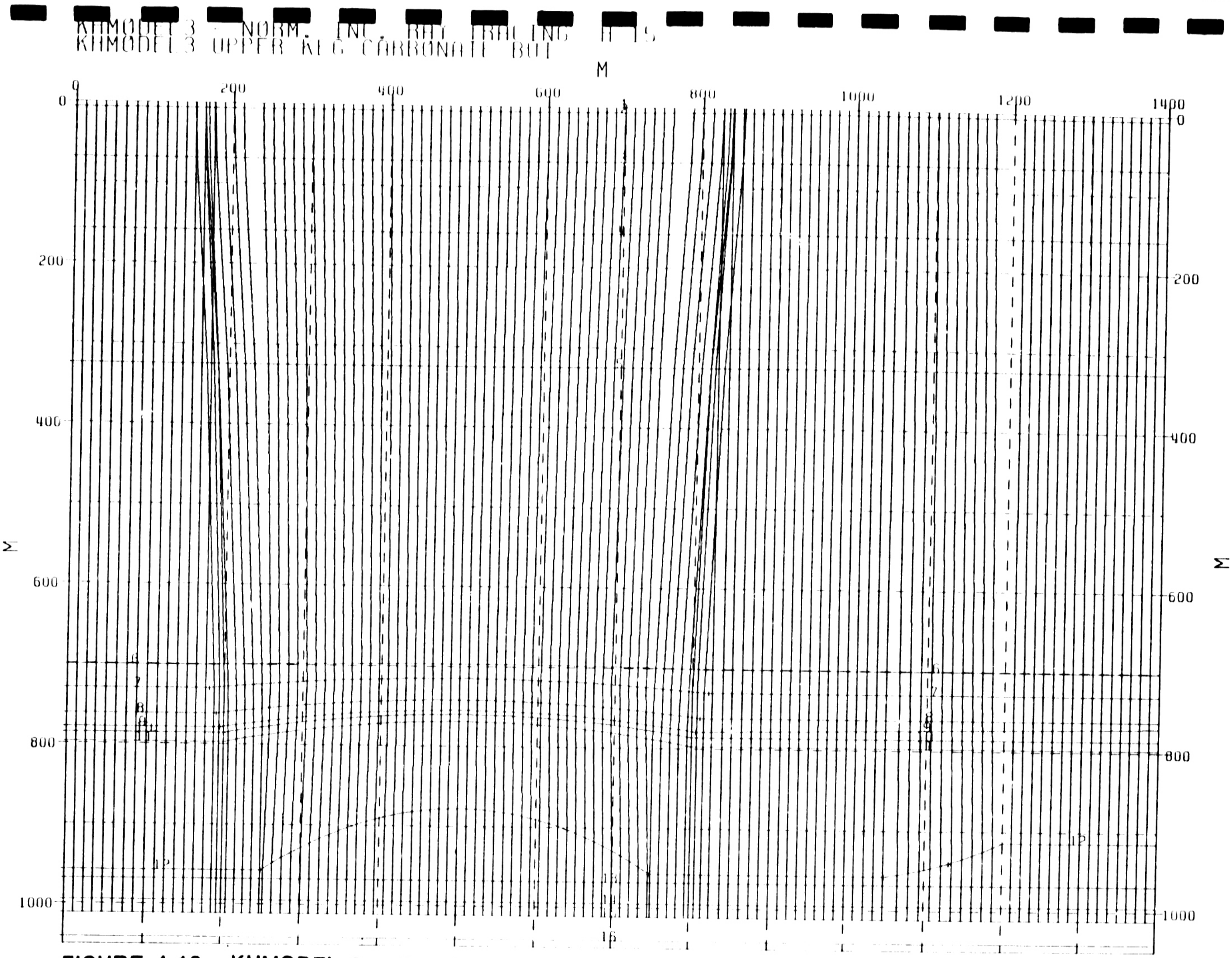

FIGURE 4.18 KHMODEL 3 - Ray Tracing From Red Beds

APPENDIX A

SEISMIC DATA BASE FOR THE S.E. BLOCK OF E.A. 164

1986 (VIBROSEIS): 12-fold
Structural and Migrated Sections
Normal and Reversed Polarities
Horizontal Scales: 12 and 36 traces/inch
(36 TPl = 180 m/inch)
Vertical Scale: 7.5 inches/second
198 km (acquired by PCI)

LINES: 8010, 8012, 8014, 8022, 8024, 8065, 8067, 8069, 8071, 8073, 8075, 8077, 8079, 8081, 8083, 8085, 8087, 8089, 8091, 8093, 8095.

1985 (DYNAMITE): 12-fold
Structural and Migrated Sections
Normal and Reversed Polarities
Horizontal Scales: 12 and 36 traces/inch
(36 TPl = 360 m/inch)
Vertical Scale: 7.5 inches/second
140.5 km (out of 456 km acquired by PCI)

LINES: 8005, 8007, 8009, 8011, 8013.

1969 (DYNAMITE): 6-fold
Structural and F-K Filtered Sections
Normal and Reversed Polarities
Horizontal Scales: 12 and 24 traces/inch
(24 TPl = 552 m/inch)
Vertical Scale: 7.5 inches/second
15.7 km (purchased by PCI, acquired by Teledyne Exploration Ltd. for J.A. Legge & Assoc.)

LINES: JAL-103, -111, -112, -113, -114

1968 (DYNAMITE): 3-fold
Structural and F-K Filtered Sections
Normal and Reversed Polarities
Horizontal Scales: 12 and 24 traces/inch
(24 TPl = 408 m/inch)
Vertical Scale: 7.5 inches/second
141.1 km (purchased by PCI, acquired by Century Geophysical for J.A. Legge & Assoc.)

LINES: JAL-1, -2, -3, -4, -5, -6, -7, -8, -10, -12, -14, -16, -18.

SPECIAL SCALES: Structural Sections played out again at 15 inches/second
Reversed Polarity
Horizontal Scale: 24 traces/inch

LINES: 8010, 8012, 8089, 8093, JAL-1, JAL-3, JAL-8, JAL-18.

APPENDIX B

CALCULATION OF THE UPPER KEG RIVER VELOCITY USING THE WYLLIE TIME-AVERAGE EQUATION

In the modelling of the Cameron Hills (seismic) Anomaly, the effect of a lateral change in the porosity-velocity behaviour was considered. The Upper Keg River was assumed to change from 4% porosity (off-reef) to 7% porosity at the buildup. The velocity of an Upper Keg River carbonate buildup (with an assumed porosity of 7%) can be determined using the Wyllie time-average equation which expresses a relationship between porosity, water saturation, and the velocities of the rock components (matrix, water, and hydrocarbon). This equation is usually applied to liquid-saturated sandstones, however, it is also generally held applicable to carbonates (N.A. Anstey, 1977).

The Wyllie time-average Equation is:

$$\frac{1}{V} = \frac{\phi S_w}{V_w} + \frac{\phi (1-S_w)}{V_h} + \frac{(1-\phi)}{V_m}$$

where V is the velocity of the rock

ϕ is porosity

S_w is water saturation

V_w is water velocity

V_h is hydrocarbon velocity

and V_m is matrix velocity

First, the matrix velocity V_m must be determined using the Wyllie time-average equation and a known rock velocity, V. From the well logs at H-34, the Upper Keg River velocity, V, is 6555 m/s and the porosity is 4%. The water saturation (S_w) is assumed to be 100% in this "off-reef" scenario.

Assuming that, at a depth of 850 to 900 metres, the velocity of water (V_w) is 1300 m/s and the hydrocarbon velocity (V_h) is 1600 m/s (N. Anstey, 1977) the velocity of the matrix can be calculated as follows:

$$\frac{1}{6555} = \frac{(0.04)(1.00)}{1300} + \frac{0.04\ (1-1.00)}{1600} + \frac{(1 - 0.04)}{V_m}$$

V_m = 7882.7 m/s

The velocity of an Upper Keg River carbonate buildup (V_{CB}) can now be calculated assuming 7% porosity and 20% water saturation.

$$\frac{1}{V_{CB}} = \frac{(0.07)(0.20)}{1300} + \frac{0.07\ (1-0.20)}{1600} + \frac{(1 - 0.07)}{7882.7}$$

Therefore,

V_{CB} = 6107 m/s

is the approximate velocity of a carbonate buildup of 7% porosity.

The Wyllie time-average equation is based on several assumptions:

(i) the carbonates are massive and "well-behaved" (that is, the porosity is of interparticle type and not due to fractures or vugs);

(ii) the velocity-porosity behaviour of the rock does not depend on the shape of the pores;

(iii) the formation is liquid-saturated;

(iv) the formation is normally pressured.

These assumptions may over-simplify the problem. (For example, at Shekilie, reef porosity is patchy and irregular). However, for the purposes of this study, the equation provides a workable solution to the velocity-porosity relationship and a reasonable estimate of the carbonate buildup velocity.

APPENDIX C

CALCULATION OF DEPTHS TO THE REFRACTING HORIZONS

The thicknesses of the near surface layers are required for accurate geophysical modelling. The refraction time-distance plots were used to determine the thickness of the drift and Cretaceous layers at both the H-34 location and over the Cameron Hills Anomaly. A three layer case was used even though the refraction survey did not detect the top layer (drift). This is because the group interval was too large to detect the thin layer of drift. Thus, the drift was assumed to have a velocity of 610 m/s which was obtained from the 1985 survey. The refracting horizons were assumed to be horizontal since the dip on them is negligible.

For the three layer case, the first intercept time, t_1, gives the depth to the second refracting horizon, Z_1, and the second intercept time, t_2 is used to determine the depth to the third refracting horizon, $Z_1 + Z_2$. These intercepts are defined by

$$t_1 = \frac{2Z_1 \cos \theta_1}{V_1}$$

$$t_2 = t_1 + \frac{2Z_2 \cos \theta_2}{V_2}$$

where $\sin \Theta_i = \frac{V_i}{V_{itl}}$

and Z_i is the thickness of the ith layer.

Or re-arranging to solve for thickness

$$Z_1 = \frac{V_1 t_1}{2 \cos \left(\sin^{-1} \frac{V_1}{V_2}\right)}$$

$$Z_2 = \frac{V_2 (t_2 - t_1)}{2 \cos \left(\sin^{-1} \frac{V_2}{V_3}\right)}$$

From the refraction time-distance plot over the Cameron Hills Anomaly (line 86-8089, Station 389),

t_1 = .02
t_2 = .07
V_1 = 610 m/s (assumed)
V_2 = 2200 m/s
V_3 = 4700 m/s

Therefore, the calculated thicknesses over the Cameron Hills Anomaly are Z_1 = 6.35 m of drift and Z_2 = 62.2 m of Cretaceous.

Similarly, for the drift and Cretaceous layers at Cameron Hills H-34, Z_1 = 5 m of drift and Z_2 = 39.8 m of Cretaceous.