GEOLOGY OF DEVONIAN LIMESTONES IN NORTHEAST ALBERTA

Prepared for
Canada-Alberta MDA Project M92-04-14

by

D.K. Cotterill
Parallax Resources Ltd.

and

W.N. Hamilton
Alberta Geological Survey

Alberta Geological Survey
Alberta Research Council
Open File Report 1995-07
March, 1995

TABLE OF CONTENTS

LIST OF FIGURES

Introduction

This study of the Devonian rocks in northeast Alberta grew out of a broader MDA project, to evaluate the resource potential of limestones in Alberta for industrial use. Northeast Alberta is the only area in the province outside the Rocky Mountains belt where limestone rocks are found in outcrop. These rocks are part of a Devonian sedimentary succession which onlaps crystalline rocks of the Precambrian Shield to the northeast. The Devonian rocks include variably argillaceous limestones and dolomites that crop out extensively in the valleys of the major rivers and their tributaries draining the area. Evaporites and redbed clastics also comprise part of the succession in the deeper subsurface, but do not crop out in the study area.

Although most of the Devonian outcrops have been mapped and described by previous workers, no 3-dimensional framework existed into which the outcrop data could be referenced. Devonian geology had been viewed simply as a wedge of carbonate and evaporite strata resting undisturbed on Precambrian crystalline basement. However, a more complex picture was becoming apparent from scattered evidence of fault tectonics, salt collapse structures, and widespread karstification. A better model of the structural and stratigraphic framework was needed to evaluate the resource potential for these Devonian rocks.

The resource focus initially was on industrial mineral aspects of limestone. During the course of the work, some anomalous assay results for precious metals in the Devonian rocks were reported, suggesting a much broader resource potential that included the potential for hosting metalliferous deposits.

Purpose and Scope of Study

The objective of this study was to map the subsurface distribution and structure of major Devonian stratigraphic units in northeast Alberta. This included detailed stratigraphic analysis of the Waterways Formation - the Devonian unit that directly underlies the Cretaceous cover in most of the area - and mapping of its member subdivisions, with specific attention given to the main limestone-bearing members. The study is based on data from exploratory drilling (much of it during the past 25 years) and from outcrops.

The initial phase involved extraction of the well data from AGSWDB, an Alberta Geological Survey data base which houses select elements of drillhole data covering western Canada and NWT. For this study area, approximately 160 wells exist that have penetrated the Devonian section either completely or to a significant depth. A much larger array of well data was available for mapping the Devonian erosion surface (sub-Cretaceous unconformity). From these well data, log picks were obtained for the main mappable horizons in the Devonian subsurface, the picks determined by reference to a grid of standardized correlation sections constructed for the study area. Lithologic identities of the map units were established through detailed logging of available core from five wells that cored a major part of the Devonian section. Detailed lithology logs for these wells are presented in the Appendix.

Based on these well data, a suite of preliminary subsurface maps was constructed with the aid of a computer mapping software package. The maps included isopach, structure, and depth contours for each of the map units. From these data the subcrop boundaries on the Devonian erosion surface were derived.

The next phase of the study involved field examination of outcrops. All the main outcrop sections in the area were logged and sampled in detail. Karst trends and anomalous structural features also were noted. The outcrop data were integrated with the subsurface data and the maps revised and refined accordingly for presentation in this report.

Outcrop samples, along with selected samples from core, were subjected to whole rock chemical analyses and/or ICP geochemical (30 element) analyses. The analytical data will be presented in subsequent MDA reports on limestone and precious metal resource evaluations for the area.

Previous Investigations

Devonian rocks in northeast Alberta have been subjected to many investigations that go back to the days of early explorers during the 1800's. Interest in these rocks stemmed largely from their juxtaposition with the overlying oil sands, which are the dominant outcrop feature of the area. A historical summary of those early works is given in Norris (1963), whose report presents the most detailed mapping available of the Devonian outcrops in this region. Another key reference is Carrigy (1959), who provides a comprehensive geological analyses of the region, including a breakdown of the Paleozoic (Devonian) geology.

The above references summarize the results from previous Devonian studies, most of which were directed toward stratigraphic definition of the succession. At the time, drill hole information for the area was quite limited, making it impossible to do any detailed subsurface mapping of the Devonian. It wasn't until the 1970's that exploratory drilling began on a sustained basis, to give rise to the level of subsurface coverage existing for the current study.

Acknowledgments

This project was funded by the Canada-Alberta Partnership Agreement on Mineral Development and by the Alberta Research Council. Support for the field component of the project was given by Brian Rottenfusser and Tim Berezniuk of Alberta Geological Survey, and by Tom Ross and Olwen Wirth of Alberta Department of Energy.

Preparation of various graphic elements of the report was assisted by Tim Berezniuk, Campbell Kidston, Jim Matthie, and Dan Magee, all of AGS.

Geographic and Geologic Setting

The northeast Alberta study area encompasses townships 81 to 104, ranges 1 through 19 west of the 4th meridian (Figure 1). The area, commonly called the Athabasca region, can be divided into three geographic sectors based upon bedrock geology and prominent topographic features (Figure 2). These include the Canadian Shield, the lowlands juxtaposed to the major drainage systems, and the dissected highlands that ascend from the adjoining plains to the west, south, and east of the drainage basin (Hamilton and Mellon, 1973).

Precambrian rocks of the Canadian Shield, upon which Devonian and Cretaceous sedimentary successions onlap, are exposed in the northeast corner of the study area. Although glacial and recent deltaic deposits conceal most of the Shield, exposures of granite, quartz monzonite, and derived cataclastic rocks are present within this sector (Godfrey, 1970). The bedrock geology within the remaining region consists of Cretaceous and Devonian strata (Figure 3).

Lowlands next to the Athabasca River progressively broaden to the north and are most commonly floored by resistant Devonian carbonates of the Elk Point and Beaverhill Lake groups (Figure 2). Exposures of Devonian and Cretaceous strata are confined to the valleys of the Athabasca and Clearwater Rivers and the lower reaches of tributaries that feed them. These valleys often expose a regional sub-Cretaceous unconformity, at which oil sands of the Lower Cretaceous McMurray Formation rest directly upon dipping Devonian strata.

The Athabasca and Clearwater valleys are incised as deeply as 150 m below the surrounding plains. Bedrock in the plains region is generally covered by a veneer of

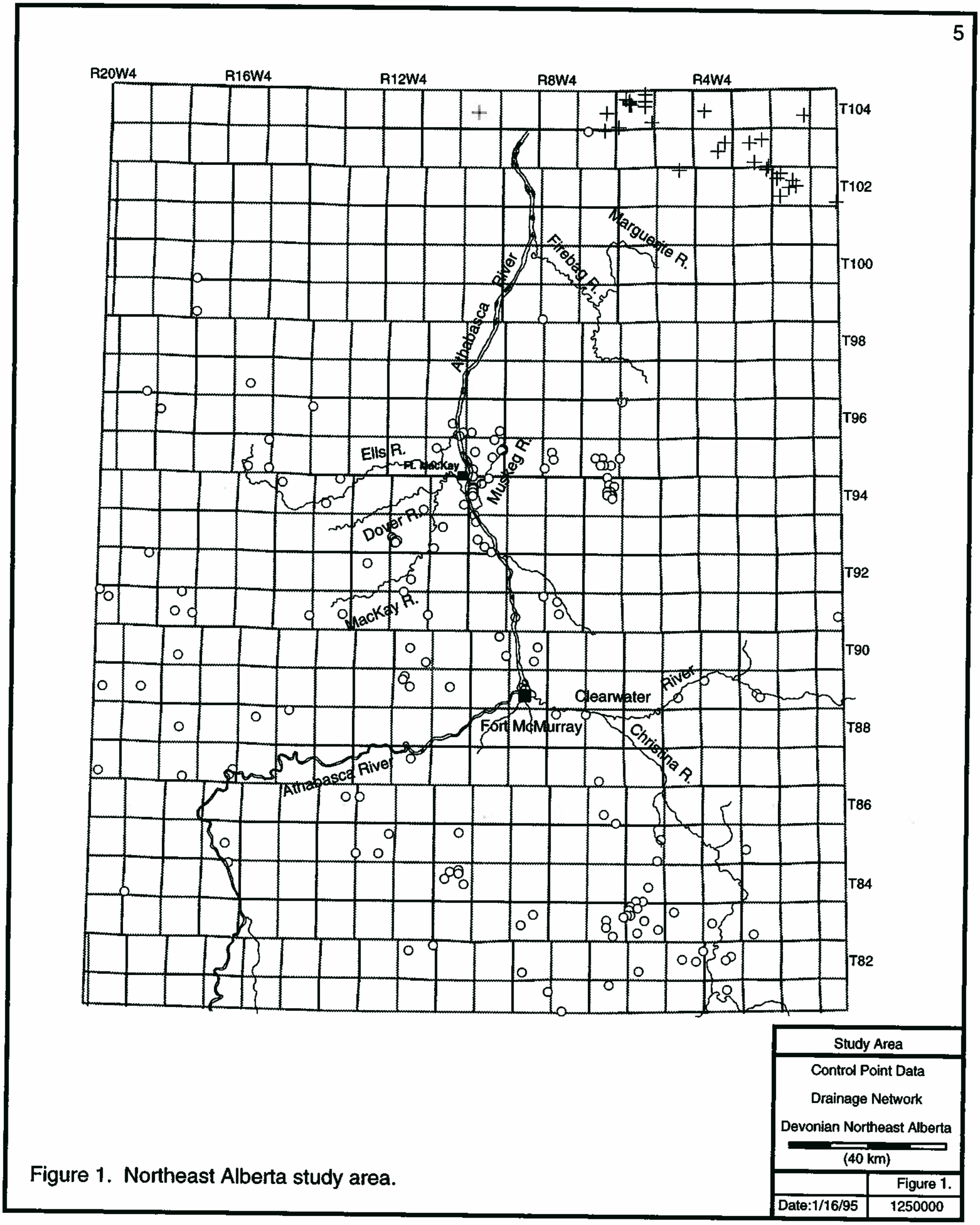


Figure 1. Northeast Alberta study area.

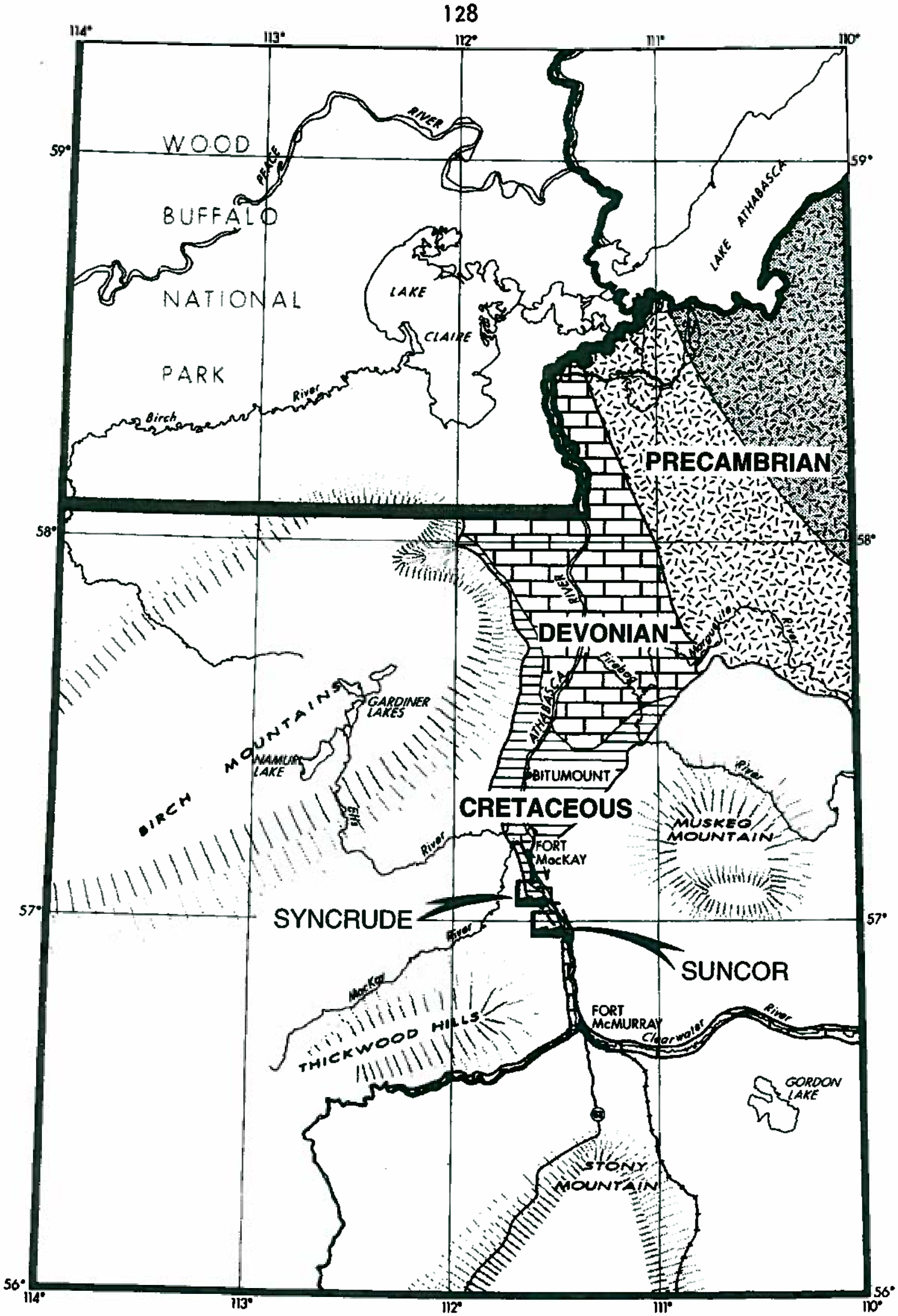


Figure: 2. Physiography and general geology of the Northeast Alberta.

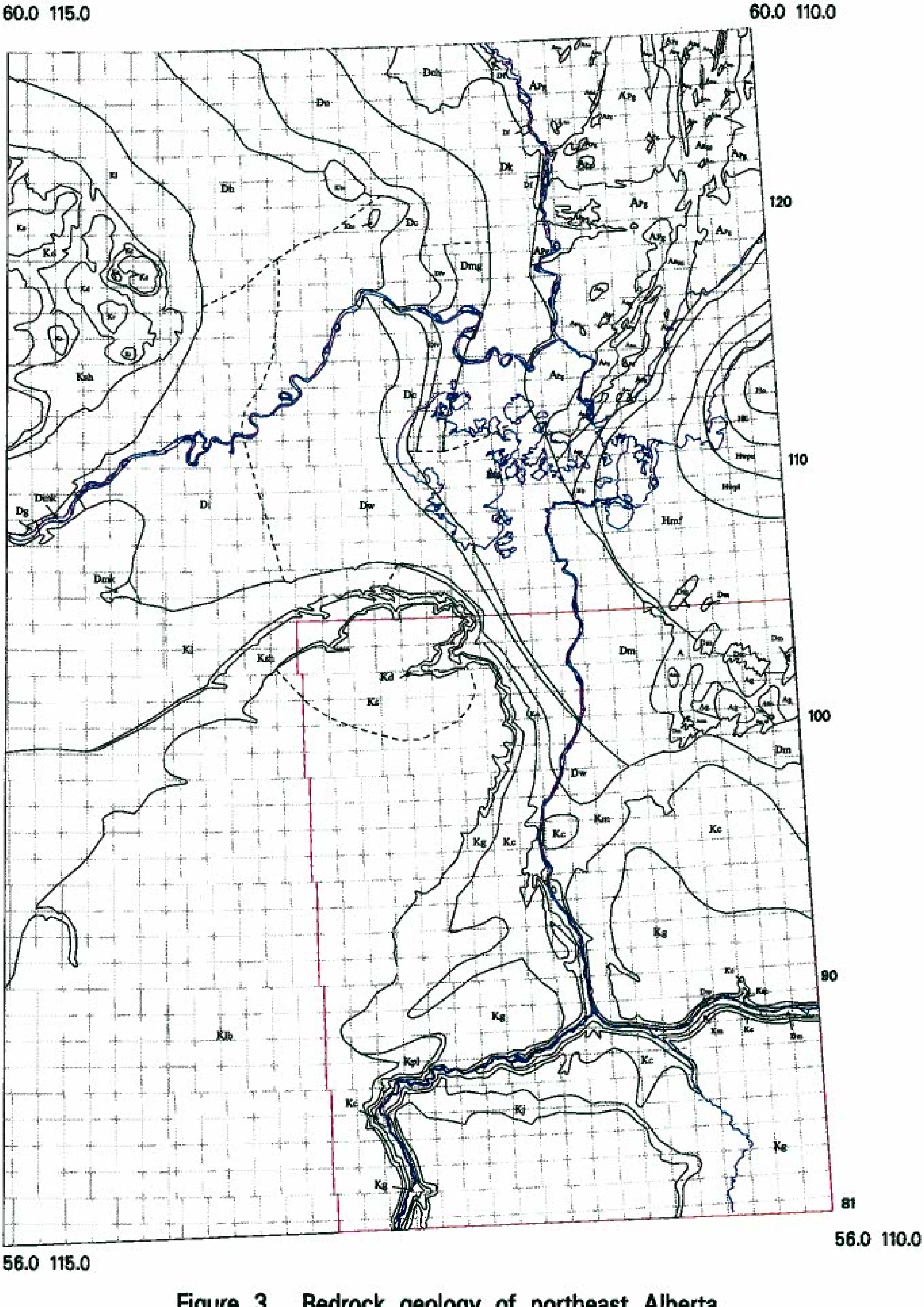


Figure 3. Bedrock geology of northeast Alberta.

LEGEND FOR FIGURE 3

NORTH CENTRAL ALBERTA

	CRETACEOUS
Kwt	Wapiti Formation
Ks	Smoky Group
Kd	Dunvegan Formation
Ksh	Shaftesbury Formation
Kl	Loon River Formation
Kb	Basal Cretaceous?
	DEVONIAN
Dg	Grosmont Formation
Dmk	Mikkwa Formation
Di	Ireton Formation
Dw	Waterways Formation
Dc	Caribou Member Slave Point Formation
Dn	Nyarling Formation

NORTHEASTERN ALBERTA

CRETACEOUS	
Klb	Labiche Formation
Kpl	Pelican Formation
Kj	Joli Fou Formation
Kac	Alice Creek Tongue, Grand Rapids Formation
Kg	Grand Rapids Formation
Kc	Clearwater Formation
Km	McMurray Formation
	DEVONIAN
Dh	Hay River Formation
Dc	Caribou Member
Dfv	Fort Vermilion Member, Slave Point Formation
Dmg	Muskeg Formation
Dk	Keg River Formation
Dch	Chinchaga Formation
Df	Fitzgerald Formation
	HELIKIAN
Ho	Otherside Formation
Hll	Locker Lake Formation
Hwpu	Upper Wolverine Point Formation
Hwpl	Lower Wolverine Point Formation
Hmf	Manitou Falls Formation
Hfp	Fair Point Formation
	APHEBIAN
APm	Low Grade Metasedimentary Rocks
APg	Granitoids
	APHEBIAN/ARCHEAN - Undivided
Amx	Mylonitic Rocks
Ag	Granitoids
A	Undifferentiated
	ARCHEAN
ARg	Charles Lake Granitoids
ARm	High Grade Metasedimentary Rocks
ARgg	Granite Gneisses

glacial deposits and muskeg. However, in parts of the region a network of Pleistocene drainage channels are incised deeply into Cretaceous sands and shales (Petroleum Geology and Basin Analysis Group, 1992, Horne and Seve, 1991).

The lowlands and plains coalesce with a series of dissected highlands which rim the Athabasca drainage basin to the west, south and east. The Birch, Stony, and Muskeg mountains and the Thickwood Hills (Figure 2) attain elevations of up to 450 m above the adjacent plains. In the west, tributaries of the Athabasca River, namely the MacKay, Dover and Ells rivers, originate within and dissect the Birch Mountains and Thickwood Hills. In the east, the Firebag River drains a region at the foot of Muskeg Mountain. These highlands (with the possible exception of Muskeg Mountain) are remnants of a thick, siliciclastic succession of Cretaceous strata worn down by periods of post-Cretaceous erosion, the last significant event being Pleistocene glaciation.

Stratigraphy

The sedimentary succession in northeast Alberta comprises a lithologically diverse Devonian sequence of carbonates, evaporites and clastics, overlain unconformably by Cretaceous siliciclastics. Devonian and Cretaceous sediments are separated by a major erosional unconformity. Devonian strata exceed 900 m in the southwest and taper to zero along the onlap margin of the Canadian Shield in the northeast. Cretaceous sands and shales, which attain thicknesses of over 500 m, also thin to a zero edge against the onlapping Devonian strata along the Shield margin (Petroleum Geology and Basin Analysis Group, 1991). Cretaceous sediments are variable in thickness due to post-Cretaceous erosional events. Today the drainage network downcuts through the siliciclastic succession in many places, bottoming out in resistive Devonian carbonates.

The Devonian succession comprises strata from the Elk Point, Beaverhill Lake, and Woodbend groups. The eastward tapering wedge of sediment is bounded unconformably at the base by the Precambrian basement and at the top by a regional sub-Cretaceous unconformity.

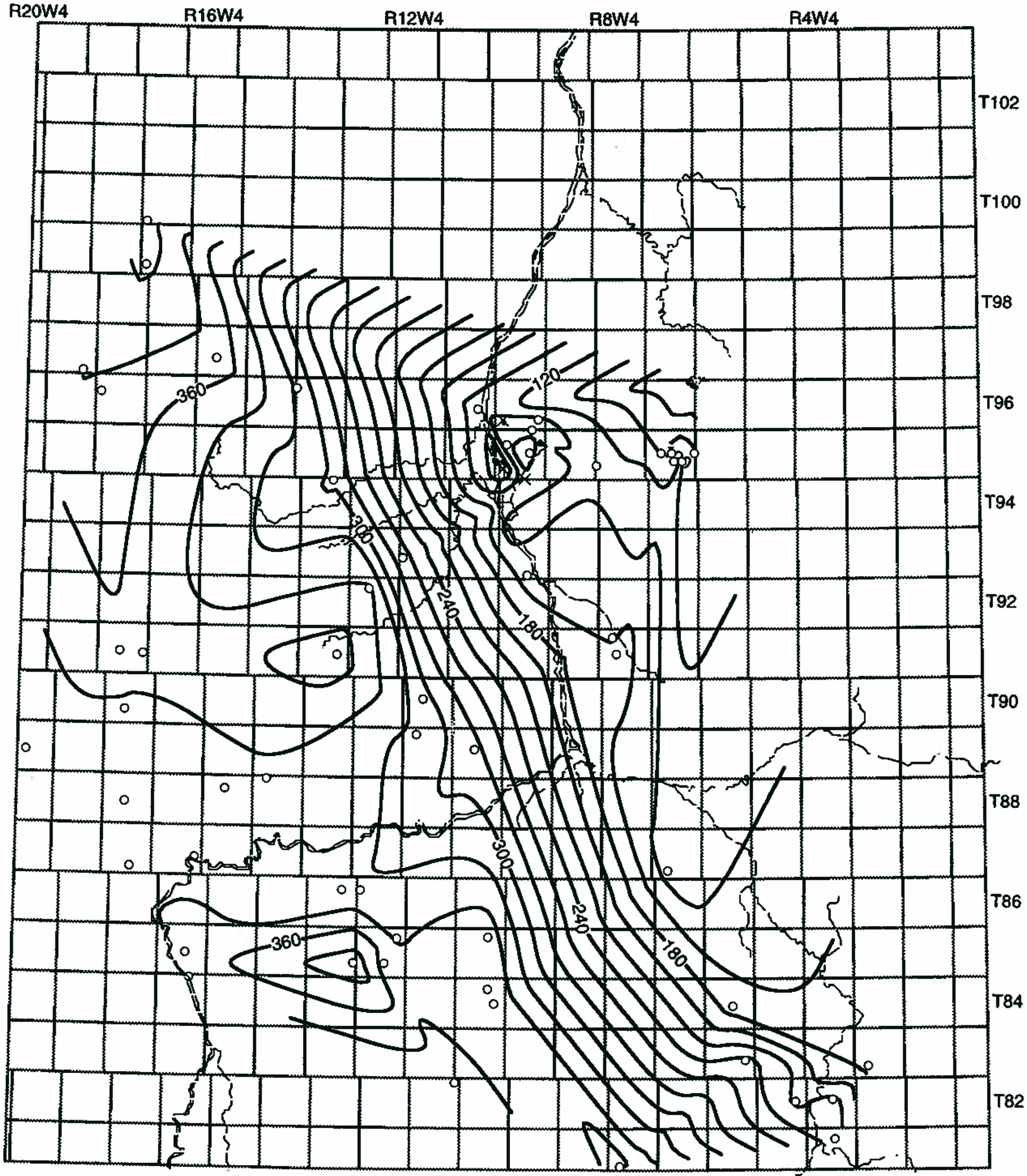
Elk Point Group

McGehee (1949) first introduced the name Elk Point Formation for a series of evaporites, dolomites and shales bound between the Waterways Formation and Cambrian strata in east-central Alberta. Belyea (1952) later raised the Elk Point sequence to group status in north-central Alberta.

In northeast Alberta, Lower and Middle Devonian formations of the Elk Point Group consist of, in ascending order: Granite Wash, Lotsberg, Ernestina Lake, Cold Lake, Contact Rapids, Winnipegosis, Prairie Evaporite, and Watt Mountain. The succession attains a thickness of over 400 m in the west and thins uniformly to the east along a northwest trend (Figure 4). Elk Point strata has been further subdivided (Sherwin, 1962) into lower and upper subgroups. The contact between the two subgroups is placed at the base of the Winnipegosis Formation (Figure 5).

A thin regolith comprised of coarse to pebbly, arkosic sandstone of the so-called Granite Wash (La Loche Formation of Norris, 1963) marks the base of the Elk Point Group. Overlying successions of Lotsberg, Ernestina Lake, and Cold Lake formations, where present, consist of evaporites (primarily salt) with minor shales, limestones, and dolomites. These three units are absent in most of the Fort McMurray area, although they may be seen in the deeper subsurface to the southwest and northwest.

The Contact Rapids Formation is made up of dolomite, dolomitic siltstone and variably sandy shales, with minor anhydrite and gypsum. This lithologically diverse unit varies considerably in thickness throughout the area. Anomalously thick successions (greater than 100 m) are confined to regions in the south and northwest. In the central region the unit averages about 50 m thick.



Isopach Map

Elk Point Group

Contour Interval = 20 m

Devonian Northeast Alberta

(40 km)

Figure 4

Date:3/21/95 1250000

Figure 4. Isopach of the Elk Point Group.

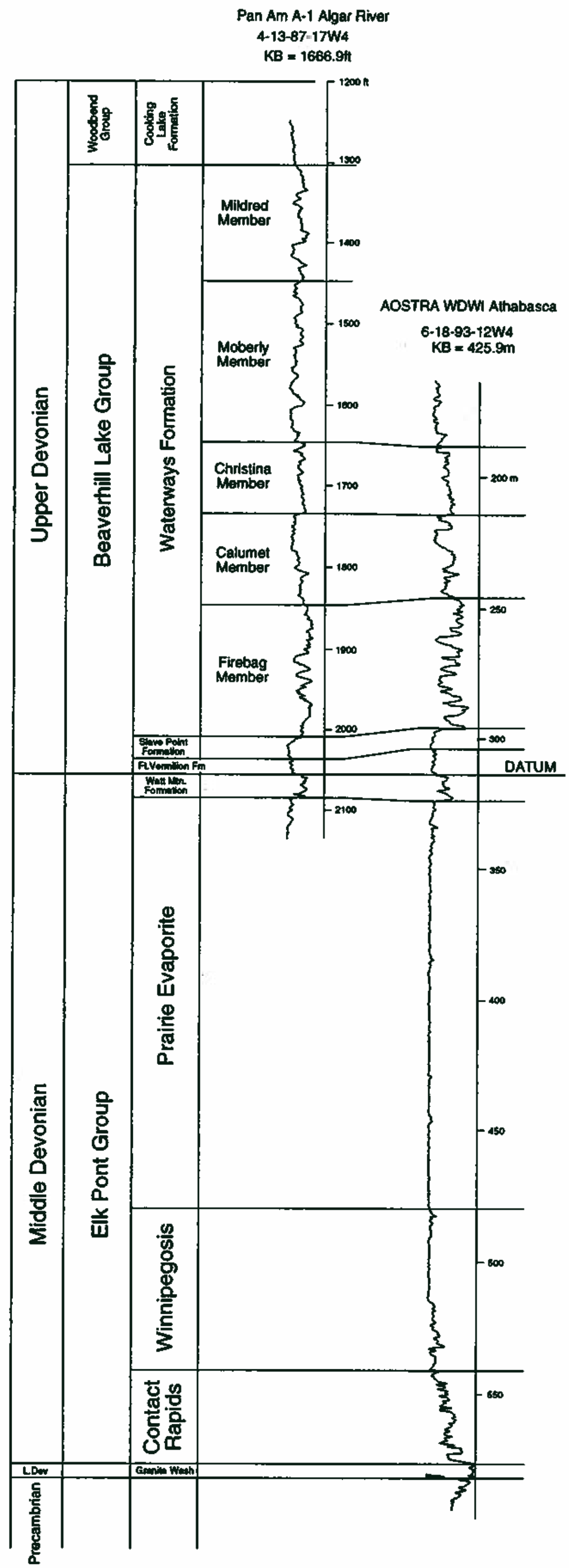


Figure 5. Reference wells for the Devonian succession (4-13-87-17W4 modified after Keith 1992)

The Contact Rapids Formation is conformably overlain by the Winnipegosis Formation. Sediments of the Winnipegosis succession comprise reef and non-reef carbonates of variable thickness. Off reef regions average about 55 m thick (Figure 6). Reefal successions along the eastern margin and in the northwest exceed 90 m in places. A reef buildup of over 100 m in the extreme southeast corresponds to a structural high on the underlying Contact Rapids Formation. Lithologies include clean, often porous, dolomites at the top that become increasingly argillaceous toward the base.

The Prairie Evaporite Formation, overlying Winnipegosis dolomites, consists of an eastward thinning wedge of salt and anhydrite with thin interbeds of carbonate and shale. This evaporitic unit is greater than 200 m thick in the west and thins dramatically eastward along a north-northwest linear trend that marks the location of the present day salt dissolution edge (Figure 4).

Distinctive, dolomitic shales of the Watt Mountain Formation disconformably blanket the Prairie Evaporite Formation, averaging about 9 m thick throughout the region. The Watt Mountain Formation is conformably overlain by strata of the Upper Devonian Beaverhill Lake Group.

The basal Contact Rapids and the uppermost Watt Mountain formations of the Elk Point Group serve as useful stratigraphic datums in the area. Both are laterally extensive and easily identified on logs.

Beaverhill Lake Group

Formations within the Beaverhill Lake Group consist of, in ascending order: Fort Vermilion, Slave Point, and Waterways (Figure 5). The Waterways Formation has been further subdivided into the Firebag, Calumet, Christina, Moberly and Mildred members. The Beaverhill Lake Group attains a thickness of over 250 m in the west

Isopach Map

Winnipegosis Formation

Contour Interval = 10 m

Devonian Northeast Alberta

(40 km)

Figure 6

Date:3/21/95 | 1250000

Figure 6. Isopach of the Winnipegosis Formation

and progressively thins to the east (Petroleum Geology and Basin Analysis Group, 1991), due mainly to pre-Cretaceous erosion (Figures 7 and 8).

Fort Vermilion Formation

Lithologies of the Fort Vermilion Formation consist of white to bluish white anhydrite, dolostone, and minor lime mudstone. Anhydrite and dolostone are sometimes delicately interlaminated. The unit thins uniformly from northwest to southeast (Figure 8).

Slave Point Formation

Conformably overlying the Fort Vermilion succession is the Slave Point Formation. Pale brown to light brownish grey, skeletal wackestones and argillaceous lime mudstones with intermixed dark brown shale laminations characterize this unit. The Slave Point Formation is generally less than 15 m thick within the study area, thinning from northwest to southeast similar to, but to a lesser degree than the underlying Fort Vermilion Formation.

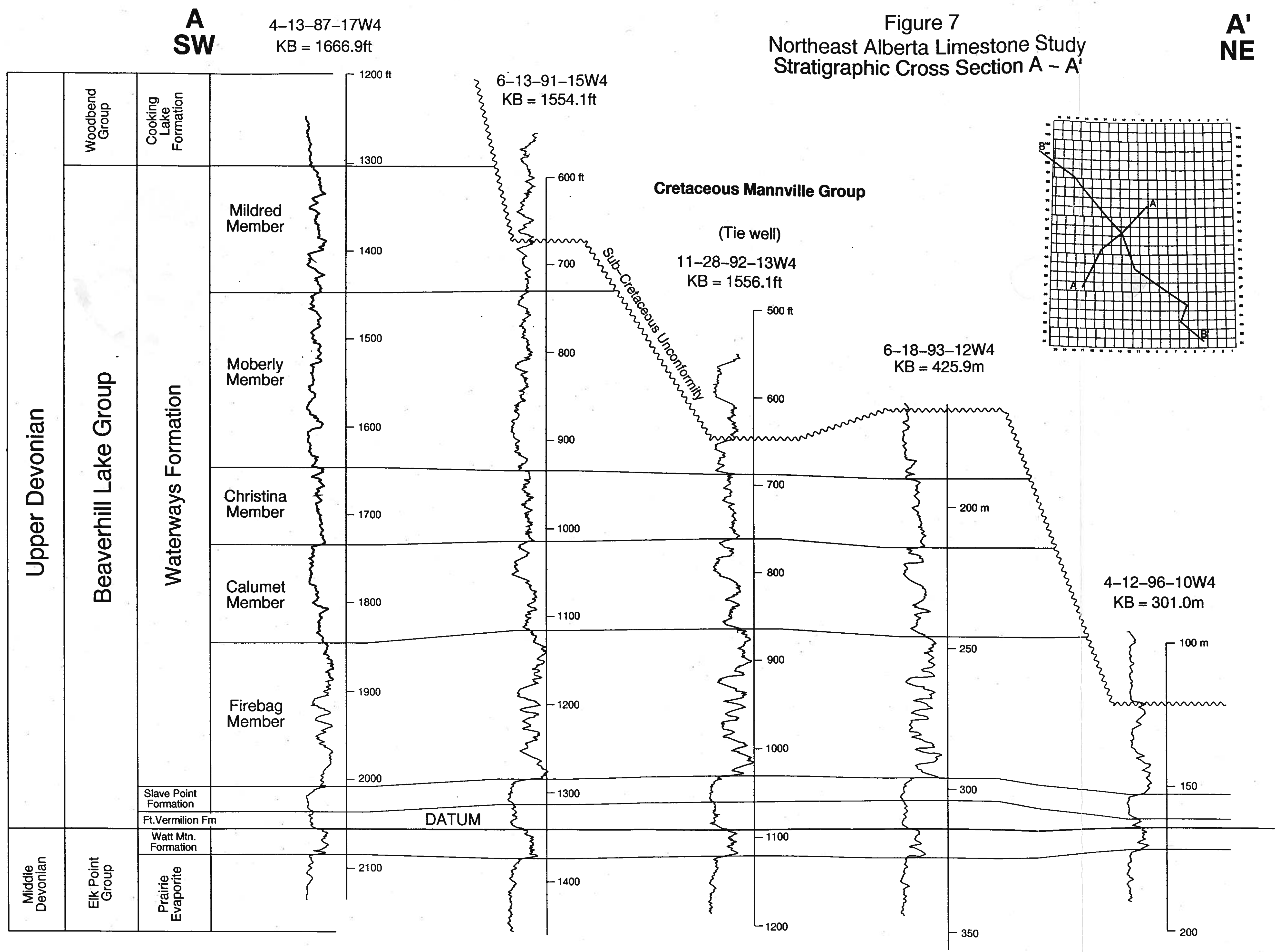
Waterways Formation

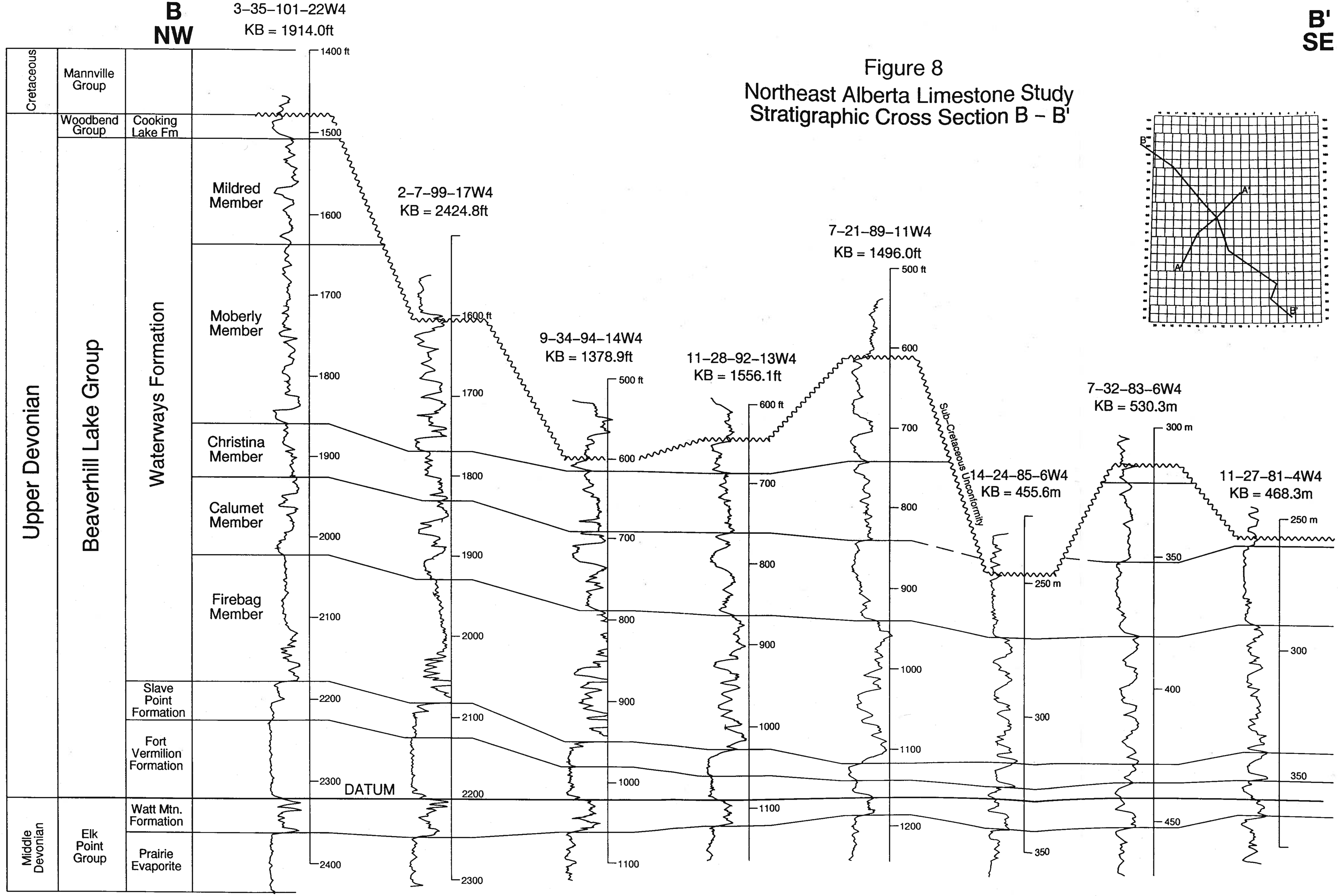
The Waterways Formation was introduced by Warren (1933) for a series of Devonian strata capping an evaporitic succession in the lower Athabasca River area. The formation was later subdivided by Crickmay (1957) into five mappable members as shown in Figure 5.

<u>Firebag Member</u>

The Firebag, the basal member of the Waterways Formation, disconformably overlies the Slave Point Formation. Two lithologic units characterize the Firebag Member: a lower unit consisting of variably argillaceous, lenticular to nodular bedded lime

Figure 7
Northeast Alberta Limestone Study
Stratigraphic Cross Section A – A'




B
NW
B'
SE
Figure 8
Northeast Alberta Limestone Study
Stratigraphic Cross Section B – B'
3-35-101-22W4
KB = 1914.0ft
2-7-99-17W4
KB = 2424.8ft
9-34-94-14W4
KB = 1378.9ft
11-28-92-13W4
KB = 1556.1ft
7-21-89-11W4
KB = 1496.0ft
14-24-85-6W4
KB = 455.6m
7-32-83-6W4
KB = 530.3m
11-27-81-4W4
KB = 468.3m
Cretaceous
Upper Devonian
Middle Devonian
Mannville Group
Woodbend Group
Beaverhill Lake Group
Elk Point Group
Cooking Lake Fm
Waterways Formation
Slave Point Formation
Fort Vermilion Formation
Watt Mtn. Formation
Prairie Evaporite
Mildred Member
Moberly Member
Christina Member
Calumet Member
Firebag Member
DATUM
Sub-Cretaceous Unconformity

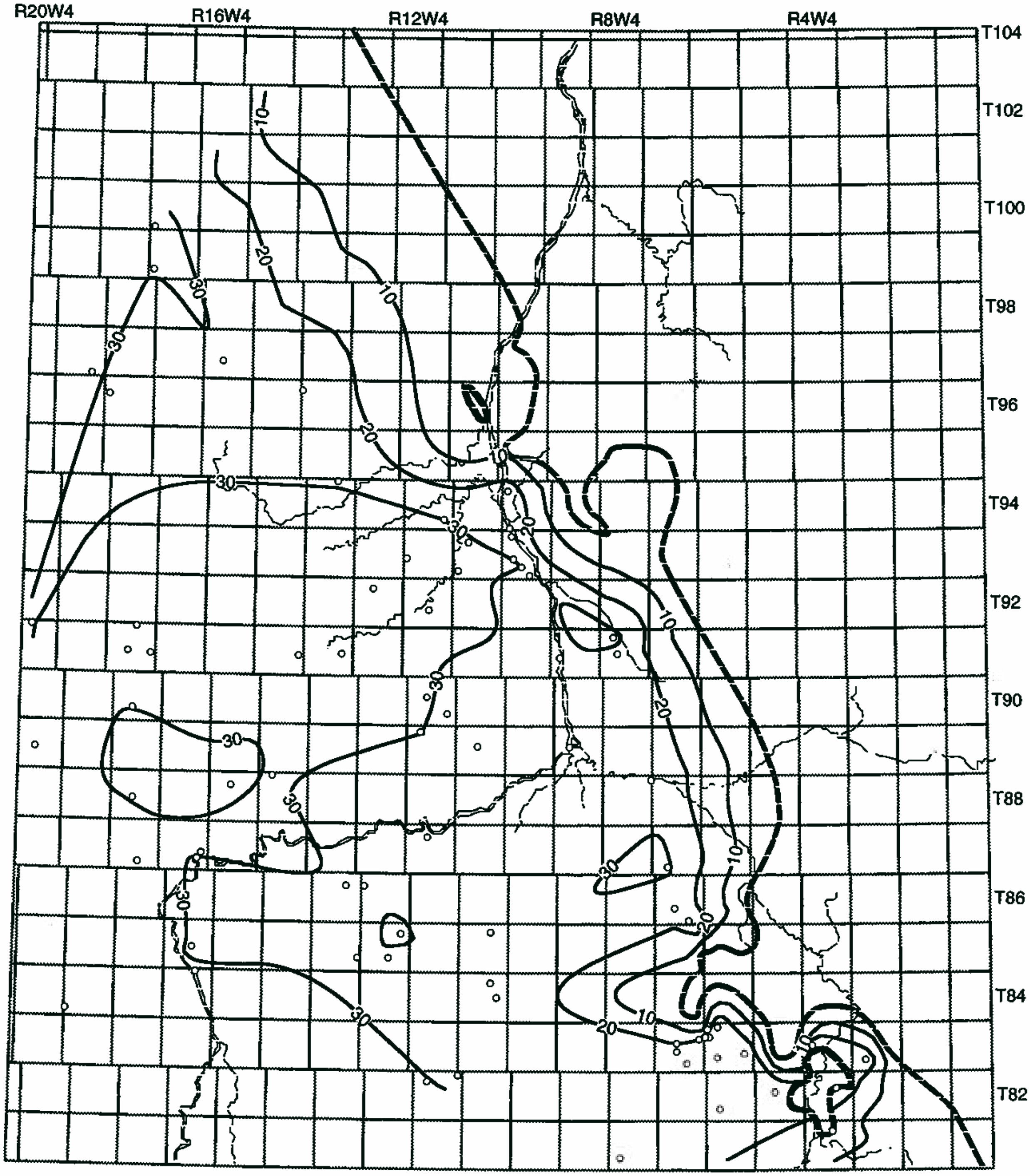
mudstones alternating with dark greenish grey calcareous shale; and an upper unit consisting of greyish green to greenish grey, faintly laminated calcareous shale, containing thin, brachiopod-rich beds (Figure 7). The Firebag Member maintains a uniform thickness of about 50 m throughout the study area. Norris (1963) describes sections along the Athabasca and Clearwater rivers where Firebag strata crop out.

Calumet Member

The Firebag Member is overlain by the Calumet Member, a dominantly limestone bearing unit within the Waterways succession. Although the Calumet Member is remarkably uniform in thickness throughout the region, lithologies are variable. They consist of variably argillaceous, skeletal, nodular lime mudstones and wackestones interbedded with greyish green calcareous shales. Calumet strata become increasingly argillaceous from southeast to northwest (Figure 8). The thickest and cleanest limestones occur south of township 90. West of the erosional subcrop belt the Calumet Member maintains its 30 m thickness, but within the confines of the subcrop belt it thins to a zero edge along a northwest trend (Figure 9). Fossiliferous limestones of the member crop out in several places along a stretch of the Clearwater River, and at one location on the Athabasca River (Norris, 1973).

Christina Member

Greenish grey to greyish green calcareous shales of the Christina Member conformably overlie the Calumet Member. The upper section contains minor interbeds of argillaceous lime mudstone and occasional thin, skeletal wackestone and packstone beds. Several hardground surfaces, commonly littered with blackened clasts and skeletal remains, are found within this unit, some of which can be correlated over lengthy distances. The Christina succession is about 25 m thick throughout the study area. Portions of the Christina Member are exposed on the banks of the Christina and Athabasca rivers (Norris, 1973).



Isopach Map	
Calumet Member	
Contour Interval = 10 m	
Devonian Northeast Alberta	
(40 km)	
	Figure 9
Date:3/21/95	1250000

Figure 9. Isopach of the Calumet Member

Moberly Member

The Moberly Member conformably overlies the Christina Member. Lithologies consist of variably argillaceous, nodular to lenticular bedded lime mudstones, skeletal wackestones, and shale, with some thin, skeletal packstone interbeds. A prominent zone, unique to the Waterways strata within the study area, consists of stromatoporoid rudstones, bindstones and floatstones. The zone is found within a clean, blocky carbonate unit situated at the base of the Moberly Member (Figure 8). Several pronounced hardground surfaces, correlatable throughout the area, can be used to subdivide Moberly strata into smaller mappable units. These discontinuities are sharp, commonly blackened and highlighted by different sediment types above and below. The Moberly Member is about 60 m thick and thins to a zero edge along its northwest-trending subcrop belt in the central region (Figure 10). The succession crops out at numerous locations along the Athabasca, Clearwater, MacKay, and Muskeg rivers (Norris, 1973).

Mildred Member

The Moberly Member is conformably overlain by the Mildred, the uppermost member of the Waterways Formation. Variably argillaceous, nodular lime mudstones and calcareous shales characterize this unit. West of the Mildred subcrop belt the succession maintains a uniform thickness of 40 to 45 m. In the western part of the map area, the Mildred Member is conformably overlain by the Upper Devonian Cooking Lake Formation.

Woodbend Group

Strata of the Woodbend Group conformably overly the Beaverhill Lake Group in northeast Alberta. Thick, clean, limestones of the Cooking Lake Formation overly the Waterways Formation in the west. The Cooking Lake Formation, in turn, is overlain by shales and limestones of the Ireton Formation. The Grosmont Formation, consisting of limestones, dolomites and minor anhydrite, cap Ireton strata.

Structural Geology

Devonian and Cretaceous sedimentary sequences form two eastwardly converging sedimentary wedges. The Devonian wedge rests on the Precambrian cratonic platform. A Cretaceous sedimentary wedge caps the Devonian succession. Devonian strata thus are bounded by two regional unconformities; at the base by the Precambrian basement surface, and at the top by the sub-Cretaceous unconformity (Figures 11 and 12). The Precambrian basement served as a platform onto which Paleozoic sediments onlapped. The upper bounding unconformity is formed on an erosionally bevelled block of west dipping Middle to Upper Devonian strata, resulting in a series of northwest trending subcrop belts that increase in age to the east (Figure 13). Structural features specific to the Devonian succession include regional tilting, unconformities, salt collapse, karsting, faulting and folding. These features are often reflected within the architecture of the overlying Cretaceous units, especially features related to tectonic events that remained active during the Cretaceous period.

Basement

The Precambrian basement surface in northeast Alberta dips to the southwest at 4-5 m/km (Petroleum Geology and Basin Analysis Group, 1991). Localized irregularities on the basement surface interrupt an otherwise uniform regional dip (Figure 11). Although sparse, basement control in the central and northeast areas suggests the presence of regional, northeast trending lineament sets. Undoubtedly, other locally elevated and depressed regions exist but remain hidden due to poor subsurface control.

Elk Point Group

The resultant structural features within the Elk Point Group are due to a combination of tectonic, depositional, and post-depositional solution processes. Structure on the lowermost Contact Rapids Formation generally mimics the Precambrian basement

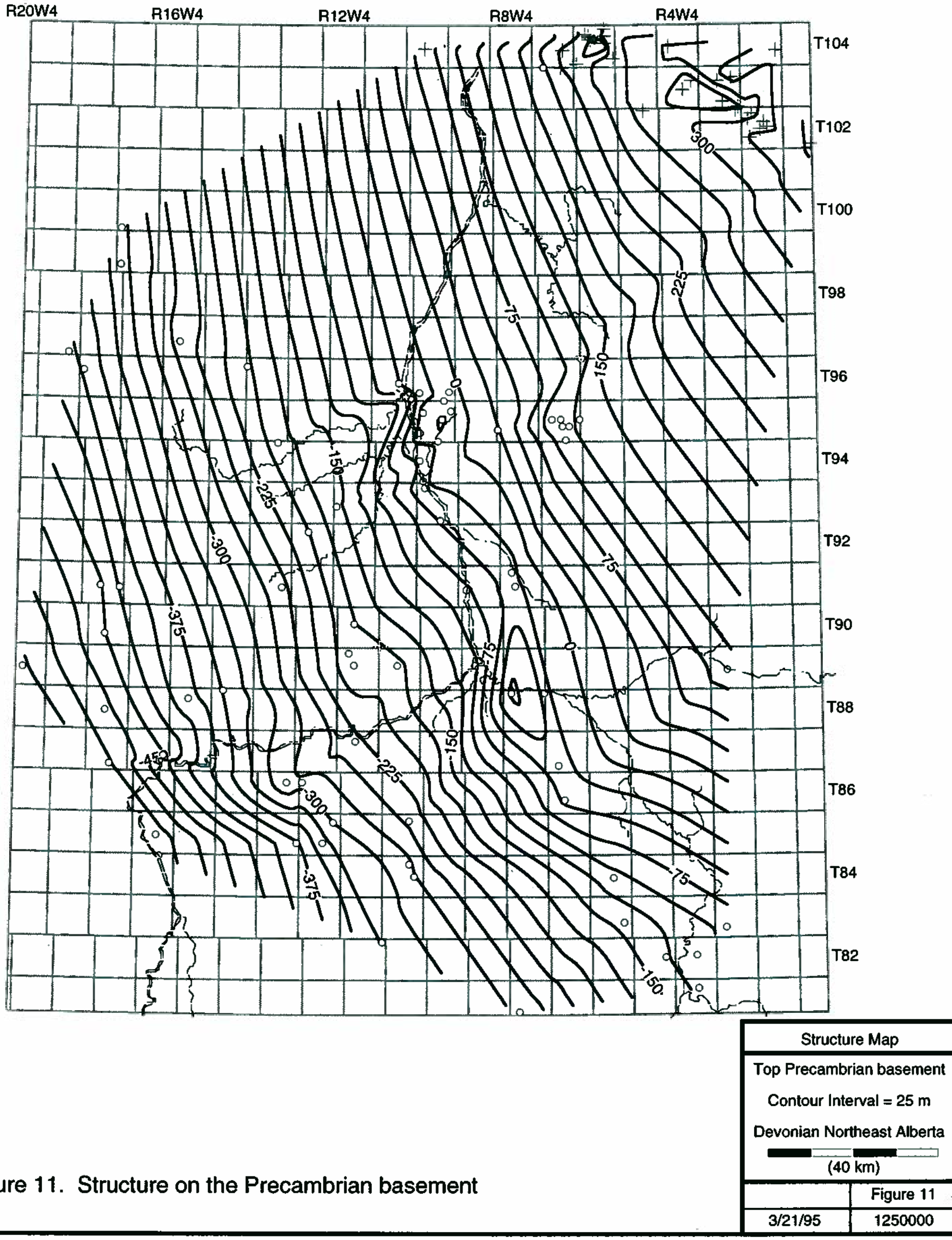


Figure 11. Structure on the Precambrian basement

(Figure 14). Two highs apparent on the basement surface in the south-central region are also reflected on the top of the Contact Rapids Formation. A localized structural high in the southeast likely influenced carbonate deposition within the overlying Winnipegosis Formation.

Structure on top of the Winnipegosis Formation is more variable than the preceding surfaces (Figure 15). Depositional processes within the formation reflect structural deviations from the underlying Contact Rapids Formation. Significant structural highs exist in the north-central and southeast region. These elevated highs along with other more subtle paleotopographic relief commonly reflect biohermal buildups within the area. A north-south reef trend borders the eastern margin of the study area. Other localized buildups occur west of the main reef trend.

The top of the Elk Point Group is marked by the thin, latterly extensive Watt Mountain Formation. Structure on the Watt Mountain surface shows a uniform dip from the central region to the southwest, with a northwest-southeast strike coincident with underlying Elk Point units (Figure 16). In the central region the surface flattens and drops, then continues updip to the northeast at a rate similar to the southwest. Structural flattening in the central region defines the salt dissolution subcrop belt within the Prairie Formation. A southwest migration of the salt dissolution front resulted in tectonic downwarping and often collapse of the overlying Beaverhill Lake Group.

Beaverhill Lake Group

<u>Calumet Member, Waterways Formation</u>

Structure on the Calumet Member depicts a homoclinal surface that rises uniformly from southwest to northeast until the central region of the study area, where elevations flatten, reverse, then continue to rise to the subcrop edge (Figure 17). The structural rollover defines the western edge of the salt solution subcrop. Depth to the top of the

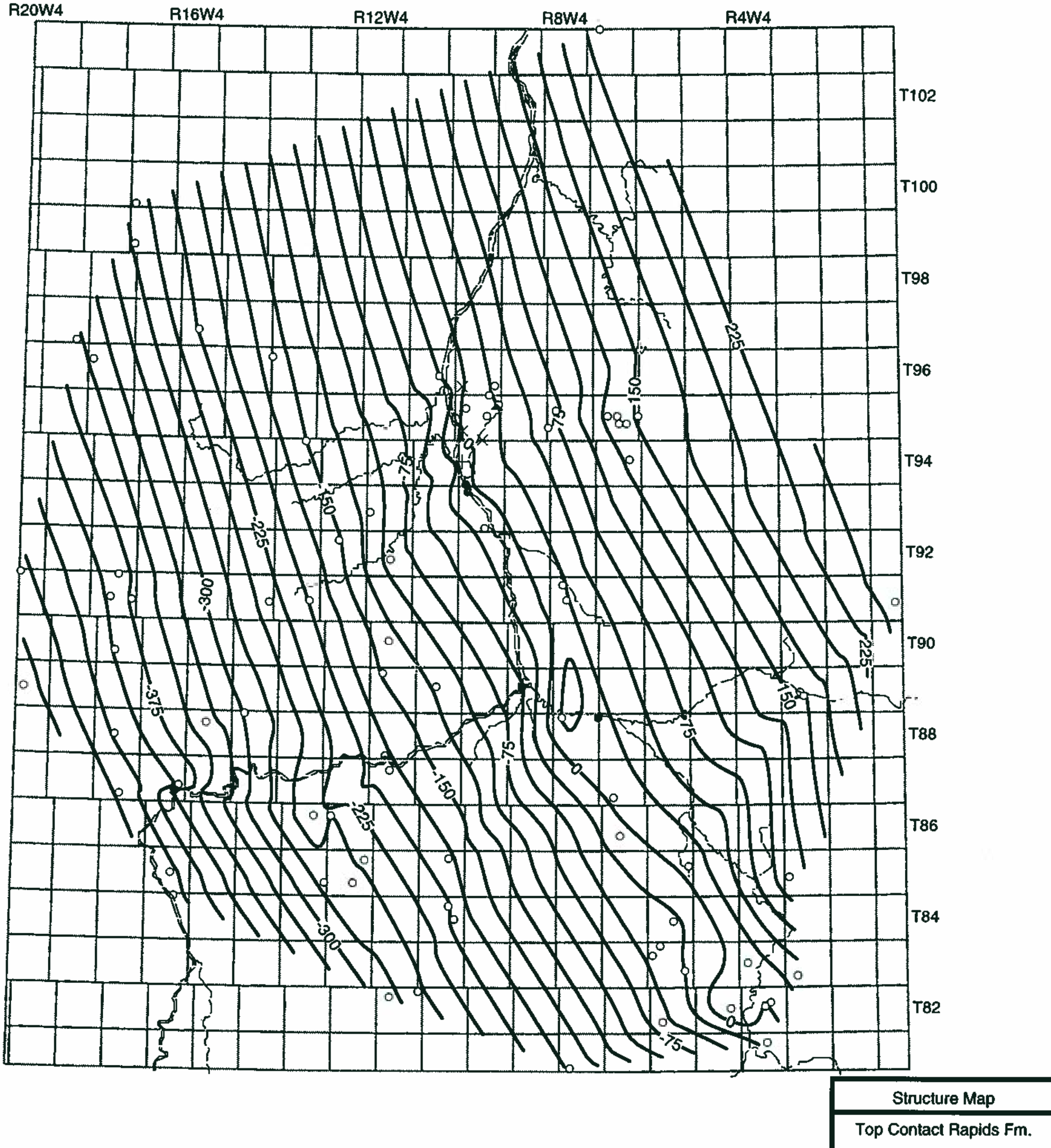


Figure 14. Structure on the Contact Rapids Formation

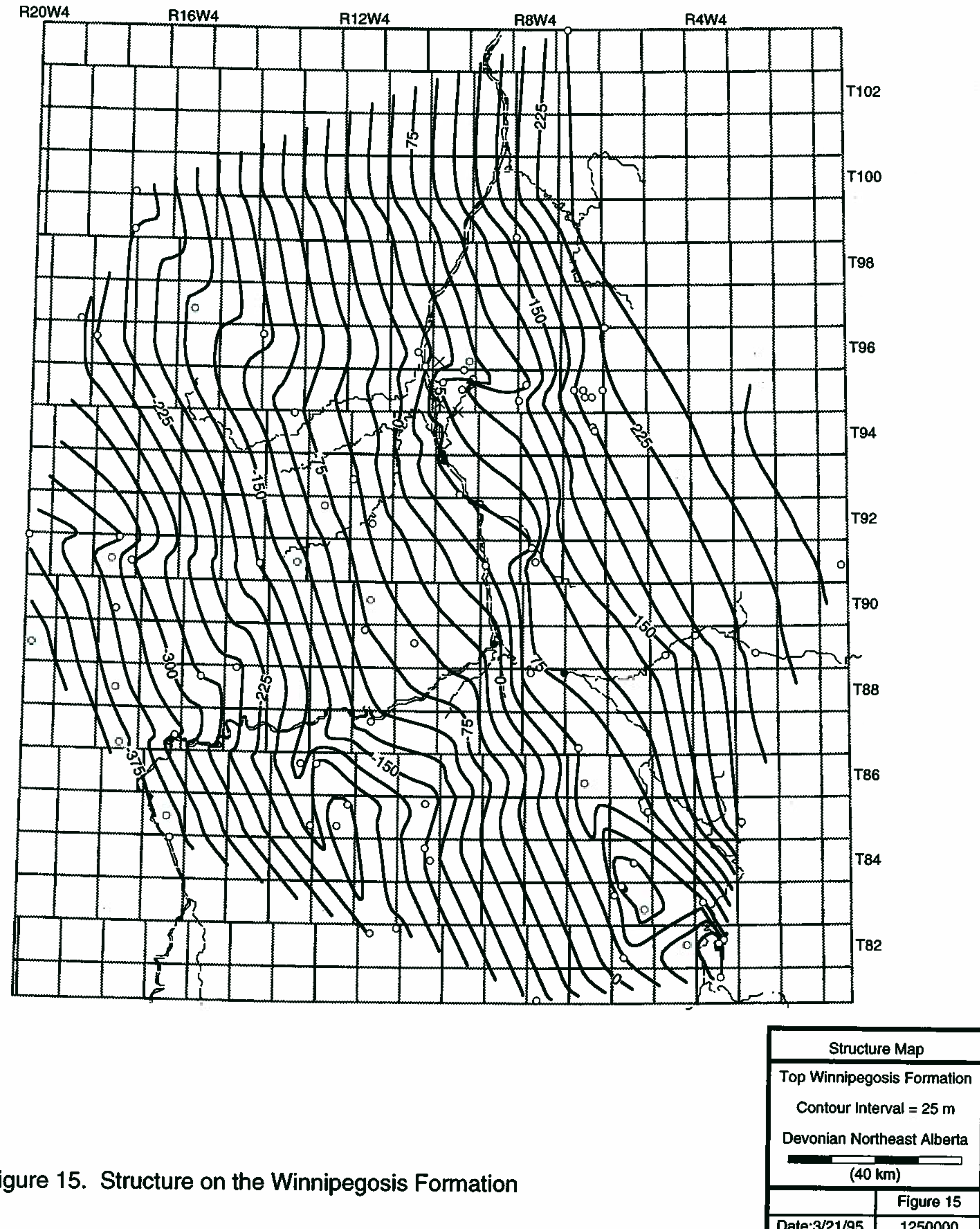
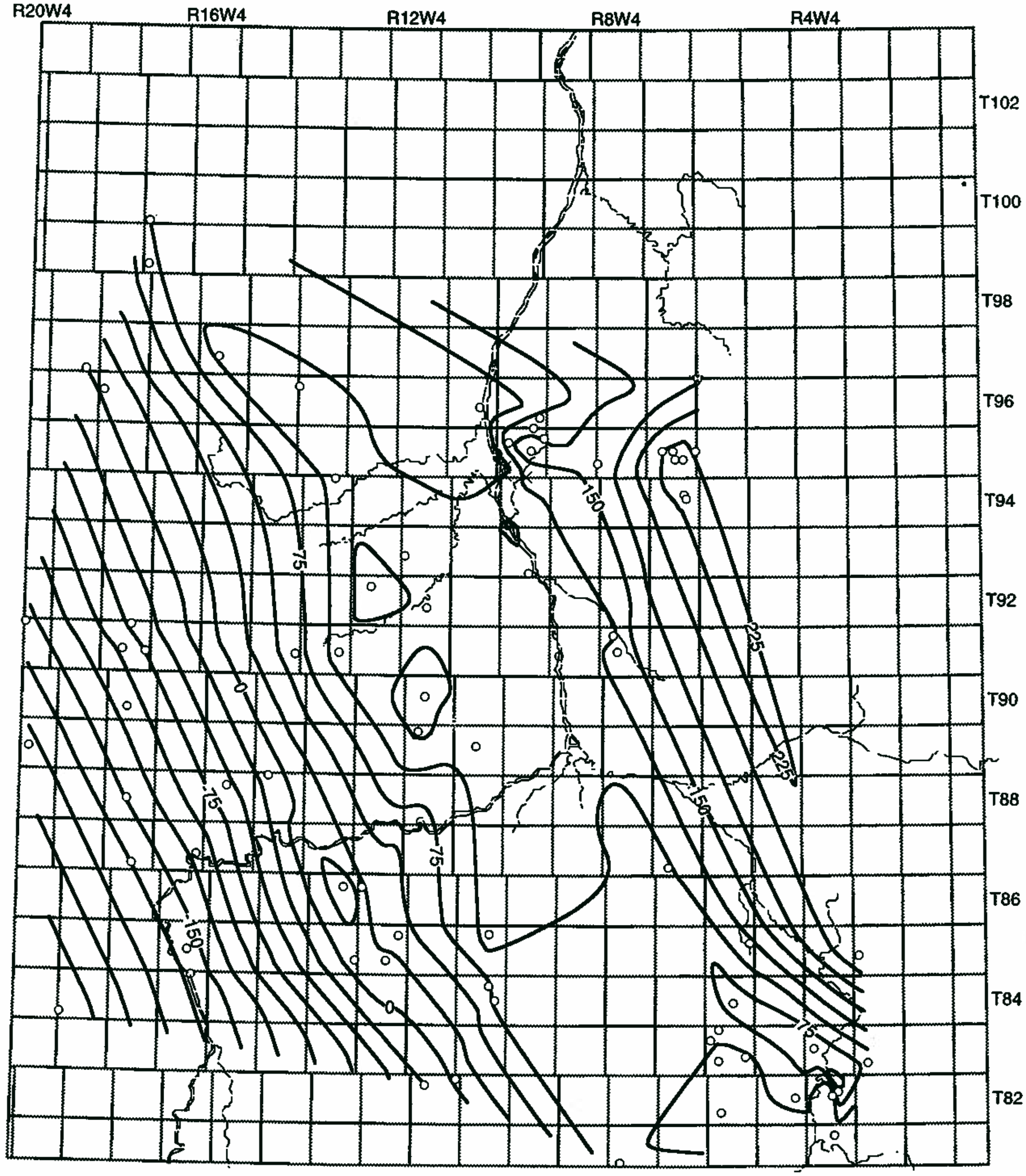


Figure 15. Structure on the Winnipegosis Formation



Structure Map	
Top Elk Point Group Contour Interval = 25 m Devonian Northeast Alberta (40 km)	
	Figure 16
Date:3/21/95	1250000

Figure 16. Structure on the Elk Point Group

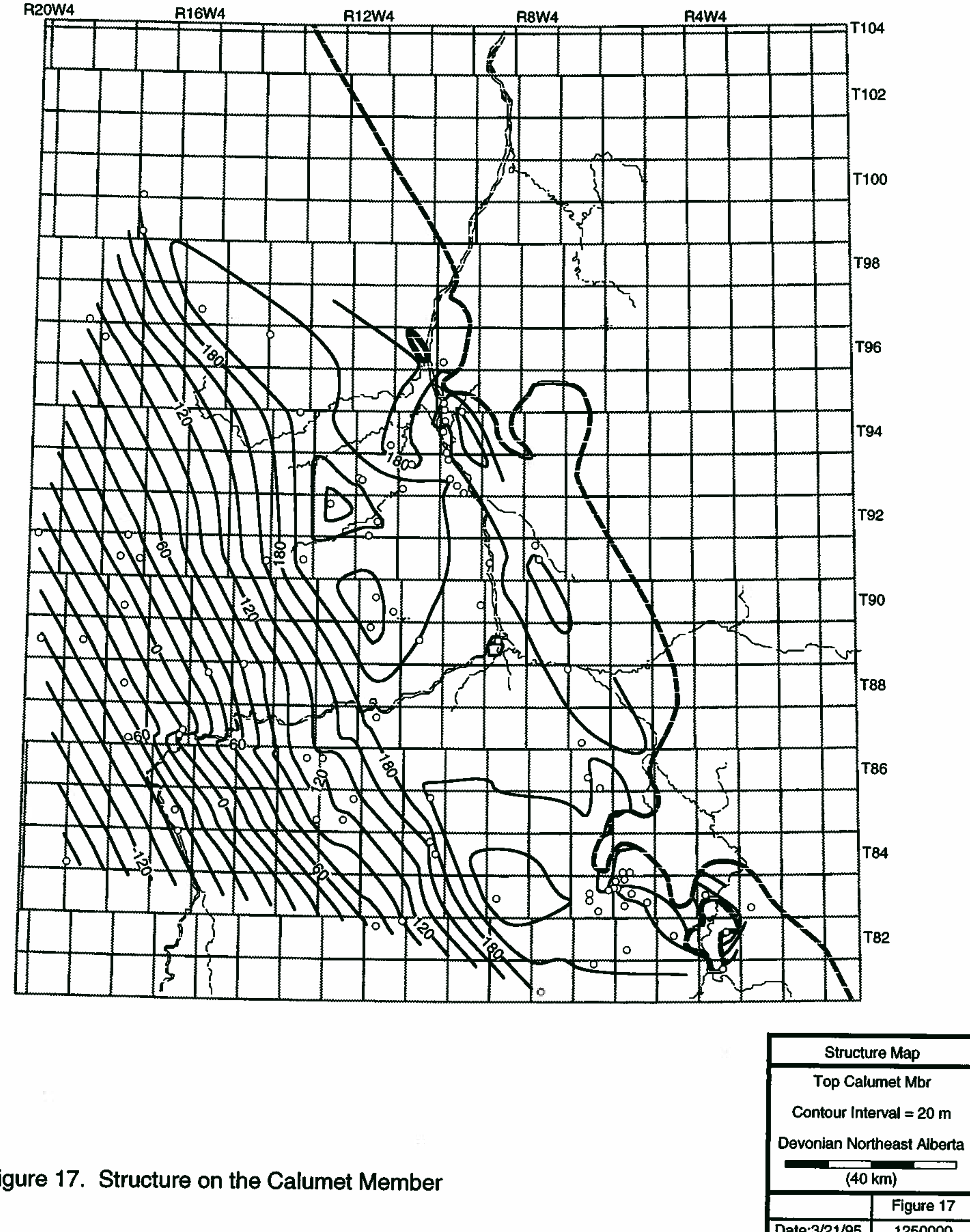


Figure 17. Structure on the Calumet Member

Calumet Member ranges from greater than 800 m in the southwest to surficial exposures along the Athabasca and Clearwater rivers (Figure 18).

Moberly Member, Waterways Formation

Similar to the Calumet Member, the structure on the Moberly Member depicts a surface elevation rising uniformly to an elevation of 240 m, where the surface is intersected by the sub-Cretaceous unconformity. The eroded Moberly Member surface continues to rise to over 300 m elevation, then rolls over and becomes structurally complex to the erosional subcrop edge. (Figure 19). Drill depth to the Moberly Member ranges from greater than 700 m to surface exposures near the subcrop edge (Figure 20). Moberly outcrops commonly display low amplitude, anticlinal folding along the Clearwater, MacKay, Dover, and Muskeg rivers and the north-south stretch of the Athabasca River below Fort McMurray. This folding is believed to be due to salt solution. Along the east-west stretch of the Athabasca River above Fort McMurray (west of the salt solution limit), the Moberly outcrops show none of this folding.

Sub-Cretaceous Unconformity

Several pronounced topographic features exist on the sub-Cretaceous unconformity. These include the Grosmont High in the west, a high on Beaverhill Lake strata in the central region, and an extensive valley complex in the east (Figure 12). These structural anomalies have a general northward trend and are primarily the result of differential erosion of variably argillaceous carbonate units and tectonic movement resulting from Elk Point salt dissolution. The Grosmont High is a regional, northwest trending set of ridges formed of resistive carbonates of the Grosmont Formation. The ridges are in the extreme western portion of the study area and beyond. East of the Grosmont High another topographic high, formed of Beaverhill Lake strata, borders a large north-northwest trending valley system (Figure 12). The linear depression can also be viewed more subtly from the structure on top of the Watt Mountain Formation

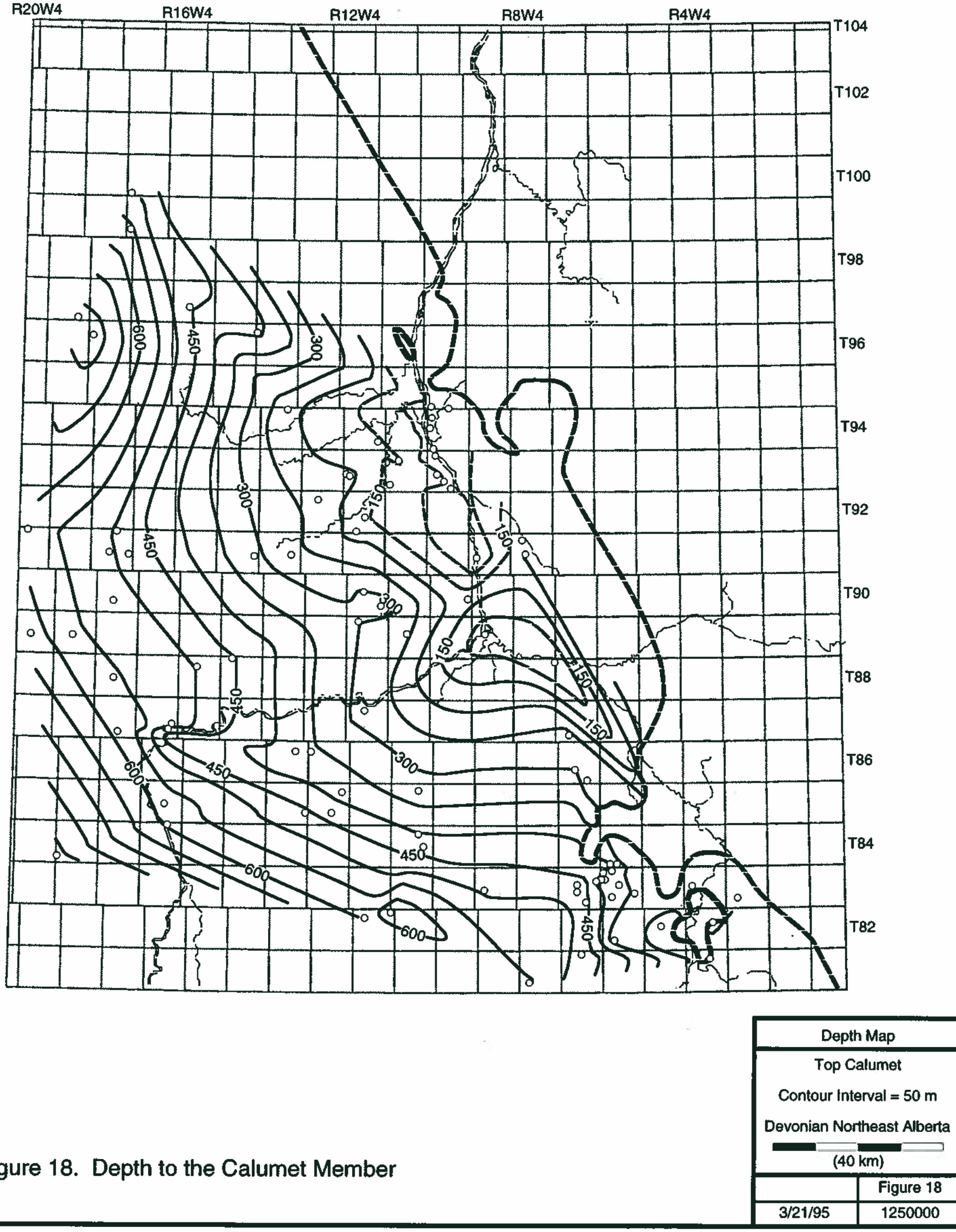


Figure 18. Depth to the Calumet Member

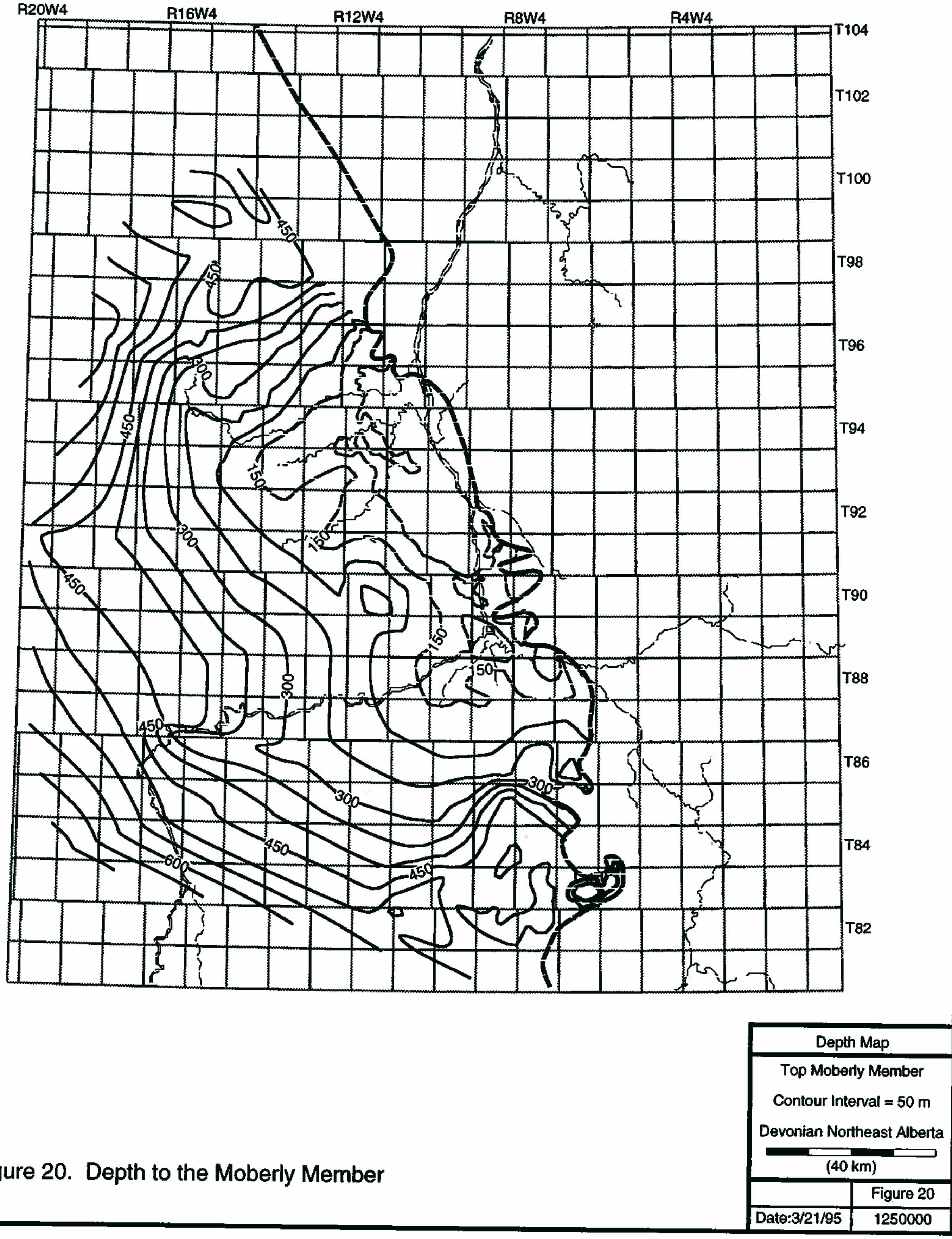


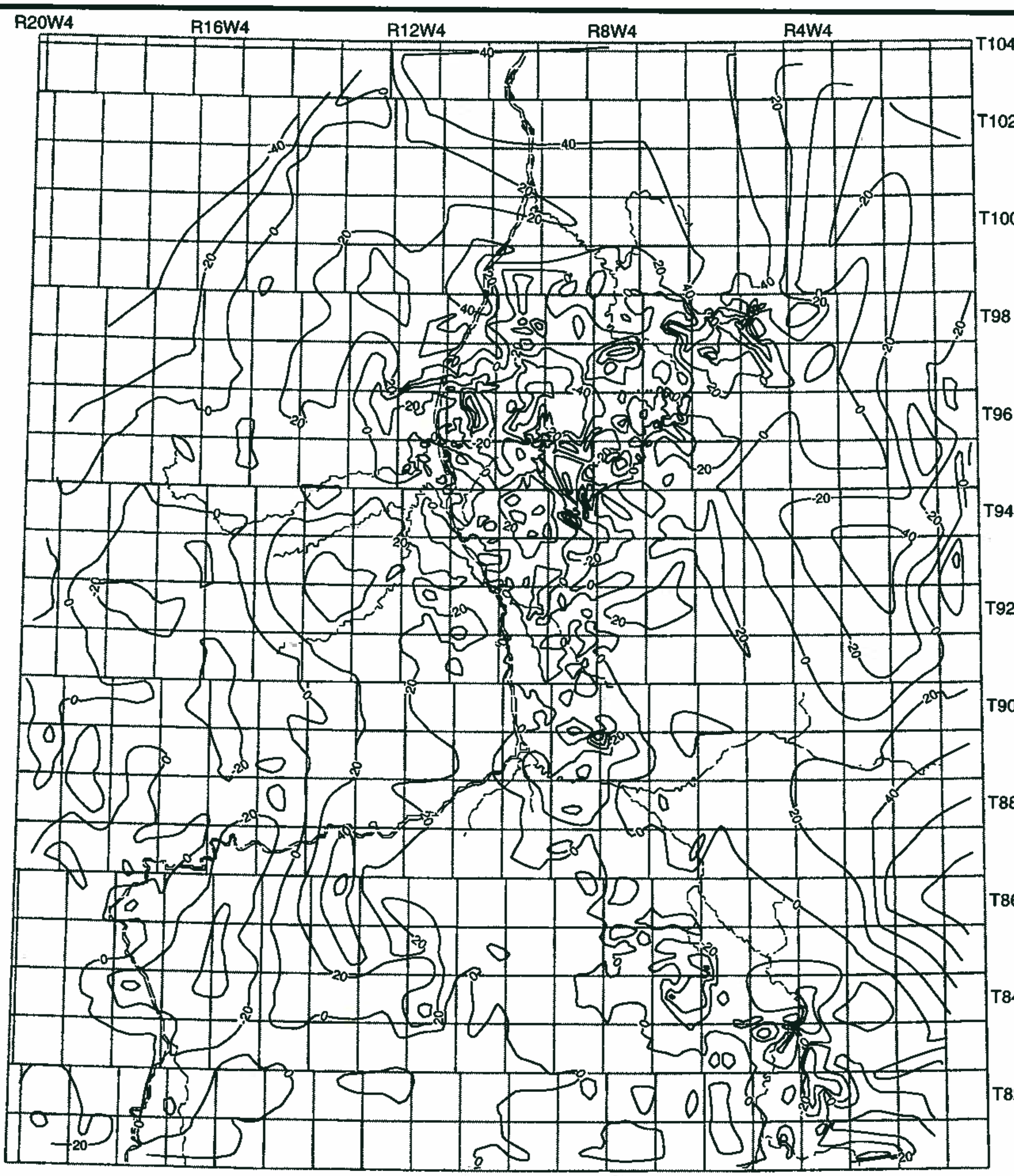
Figure 20. Depth to the Moberly Member

(top of the Elk Point Group, Figure 16). Valley incision, in places, cuts deeply into strata of the Beaverhill Lake Group. Leaching of salt due to mobile, subsurface fluids resulted in the downwarping and collapse of overlying members of the Waterways Formation. The eastern limit of the Athabasca River valley generally coincides with the present day salt solution edge of the Prairie Formation. Another salt solution edge, situated farther north (Hamilton, 1971), stems from the removal of salt from the underlying Cold Lake Formation (Figure 13).

Topography on the sub-Cretaceous unconformity is best defined by a residual map (Figure 21). The residual map is a product derived from trend surface analysis of the sub-Cretaceous unconformity surface. Trend surfaces are simplified representations of complex surfaces expressed algebraically in equation form. Trend surface analysis separates map data into a regional component and a local component. The regional component consists of large scale fluctuations and the local component of small scale variables. In northeast Alberta the regional component includes broad structural features such as the regional dip of the basin. Superimposed over the regional component are localized positive and negative anomalies (topographic highs and lows) often called residuals. The residuals are derived by subtracting the regional component from the actual sub-Cretaceous unconformity data. Areas of karst development within and proximal to the valley system are also mappable features.

Karsting

Active karsting in northeast Alberta is often reflected at surface by sinkholes, saline lakes and larger scale depressed regions. Karst development likely progressed coevally with the southwest migration of the Prairie Formation salt solution edge. Surficial mapping by Bayrock (1971) and Bayrock and Reimchen (1974) have identified regions containing sinkholes and locally depressed areas paralleling the two salt solution edges. The sinkholes often appear as small, circular ponds and may occur as single holes or in swarms. Occasionally, drill holes intersect these sinkholes,



Paleotopography Map
Sub-Cretaceous Unconformity
Contour Interval = 20 m
Devonian Northeast Alberta
(50 km)

	Figure 21
3/21/95	1250000

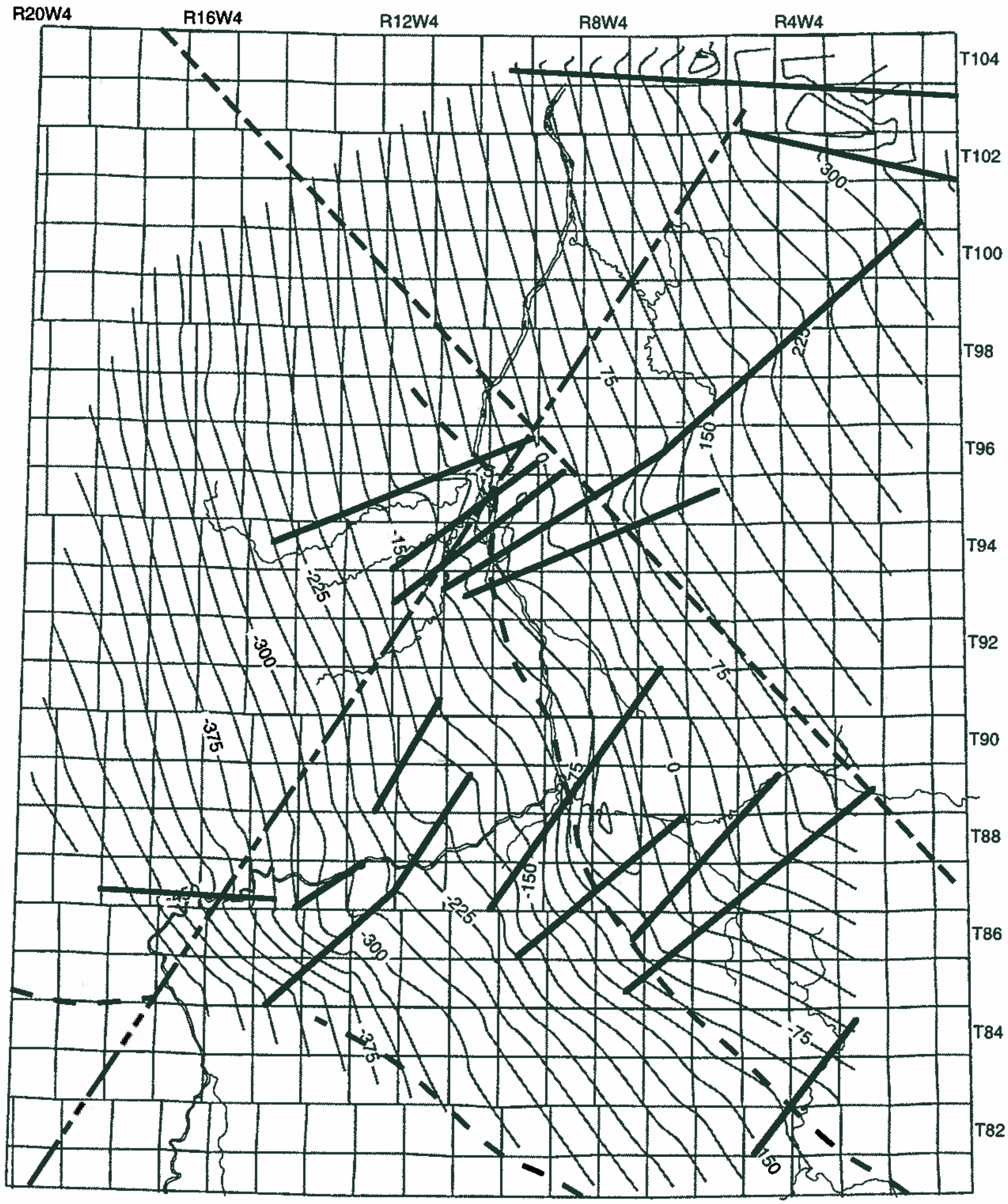
Figure 21. Paleotopography on the sub-Cretaceous unconformity

some of which contain brecciated limestone intermixed with oil sand from thé overlying McMurray Formation (Tckarsky, pers. comm.). A detailed log of one drill hole that cored through a sinkhole is included in the Appendix (Shell Eatha EV 12-6-99-8W4), describing the lithologies and karst features encountered in the Devonian section.

Faults

Four postulated fault zones, two on the Precambrian basement and two within the Devonian succession, are described in the literature. Hackbarth and Nastasa (1973) hypothesized two fault zones on the Precambrian basement, a minor one in the southwest and a more extensive lineament coinciding with the Prairie Evaporite salt scarp (Figure 22). The fault in the southwest, is based solely upon a noticeable offset along the structural trend. Evidence for the larger fault is based upon vertical relief, gravity maps, and proposed faulting within overlying units along the same trend. Carrigy (1959) suggests post-Beaverhill Lake activity along a northwest trending fault that tangentially approaches the Prairie Evaporite salt solution edge in the north. Vertical movement of about 60 m along the fault is proposed. The fault movement combined with a post-Cretaceous collapse of a further 60 m is thought to account for the deep trough known as the Bitumount basin (Figure 21). Carrigy (1959) also suggests an alternative explanation, by which the Prairie Evaporite thickens by 60 m northeast of the proposed fault. Martin and Jamin (1963) describe a fourth, northeast trending, strike-slip fault zone of Devonian age that traverses the entire study area. Both the previously described ridges comprising Grosmont and Beaverhill Lake strata are thought to be laterally offset by the fault. Martin and Jamin (1963) also suggest that several valley trends, particularly those with very steep sides, may be related to localized faulting and fracture systems.

Additional faults are postulated in this report based on the subsurface mapping data. Structure contouring on some of the map units reveal a number of anomalous linear features that appear to be due to structural offsets or discontinuities. The features are



Hackbarth and Nastasa, 1979 (Precambrian basement)
Martin and Jamin, 1963 (Devonian)
Carrigy, 1959 (Devonian)
This report (Precambrian)

Figure 22. Structure on the Precambrian basement, with postulated fault lineaments superimposed.

seen most distinctly on the Precambrian basement surface (Figure 22), but some are visible on overlying map units as well, at least up to the Contact Rapids surface, and are most readily explained by faulting. Above the Contact Rapids, irregularities on the surfaces caused by biohermal reef growth (Winnipegosis Formation, Figure 15) or by salt dissolution (Watt Mountain Formation, Figure 16) would tend to mask the effects of faulting even if it extended up into these horizons. Thus, if the features seen on Figure 22 are indeed faults, the age of the faulting is difficult to establish. At least some are Devonian in age, possibly reactivations of basement faults that existed prior to Devonian sedimentation.

The contour pattern shows a distinct linearity to the features, in directions consistent with fault patterns observed for the Peace River Arch structure (O'Connell et al, 1990). The pattern suggests a series of horst-graben features in a general northeast-southwest alignment, with fault boundaries extending 50 km or more in length. This also is consistent with interpretations of the Peace River Arch, the structural axis of which aligns with the study area. Any faults that may exist perpendicular to those indicated (i.e., faults running northwest-southeast) would not show up in the contour pattern because of being parallel to the regional strike.

Precise mapping of faulting in northeast Alberta is prohibited by the sparse well control. The evidence strongly indicates the existence of faults, but until additional drilling data become available and are coupled with new and advanced geophysical data, the exact locations and nature of the faults will remain speculative.

Folding

Folding in the form of small scale domes and basins within strata of the Waterways Formation can be observed in many places along the Athabasca and Clearwater rivers. These small scale flexures have amplitudes of 15 to 30 m and lengths of 100 m up to 1600 m (Norris, 1963, Carrigy, 1959). As stated previously, the folds are believed to be caused by salt solution along the regional solution front of the Prairie Evaporite salt.

Summary

The overall structure for the area reflects a regional bulging upward. This is best displayed on the Precambrian basement surface (Figure 22) but is seen also on higher Devonian horizons (Figures 14, 15). The bulging is apparent from the convex, arcuate pattern of the structure contours, which in a basinal configuration (i.e., during Devonian deposition) would be expected to be straighter or even concaved slightly. The bulging involved some differential uplift in a series of horst-like features, with the bulk of the uplift occurring sometime after Devonian deposition.

Outcrop work

The present day river network of northeast Alberta incises deeply into Cretaceous strata, and in places downcuts to the underlying sub-Cretaceous unconformity. As a result, several localized exposures of Middle and Upper Devonian strata crop out along the Athabasca drainage system. Due to limited subsurface control below the sub-Cretaceous unconformity these exposures become an important addition when resolving the stratigraphic architecture of the Devonian succession.

Most of the Devonian strata that crop out in northeast Alberta have been well documented by Norris (1963, 1983) and Carrigy (1959). Surface exposures confined to the current study area include sections within Winnipegosis and Waterways formations. The Winnipegosis Formation crops out along the Clearwater River near the Saskatchewan border and on the lower reaches of the Marguerite and Firebag rivers. Members of the Waterways Formation crop out along the Athabasca, Clearwater, MacKay, Muskeg, Steepbank and Dover rivers.

In all, seventy-two Devonian outcrops were described in northeast Alberta. Many sections were sampled for limestone quality assessment and for geochemical characterization. Most of the accessible sections consist of limestones from the Moberly Member of the Waterways Formation. The Moberly Member is best exposed along the MacKay and Muskeg rivers. The Waterways and Winnipegosis formations are exposed in sequence (top to bottom) from the west along the Athabasca River (west of Fort McMurray) to the east along the Clearwater River.

Some of the main outcrop sections are presented graphically in Figures 23 and 24 (in pockets), showing their spatial and stratigraphic relationships to the geologic column as defined in selected wells nearby. These wells are any of the five reference wells logged in detail for this study and included in the Appendix (along with one well that intersected a sinkhole).

Conclusions and Economic Considerations

The economic mineral interest behind this study initially was industrial limestone. Quality assessment of the limestones was not part of this study and will be presented in another MDA report. However, from a stratigraphic approach the study establishes that the best limestone potential for the area lies primarily with the Moberly Member, and secondarily with the Calumet Member, of the Waterways Formation. Although both members have significant argillaceous sections, they include several relatively clean limestone beds. Both members have limited surface exposure with few prospective sites for quarrying, although the Moberly Member has a decided advantage in that regard.

Limestone potential for this area in the future may be considered from the standpoint of underground mining recovery in the shallow subsurface. The high-purity limestone beds could be mined selectively underground as nearly flat-lying deposits having virtually unlimited extent. Figures 17 and 20 are depth contour maps of the Calumet and Moberly members respectively and can serve as limestone resource maps for this area.

The potential of Devonian limestones in northeast Alberta for hosting metallic mineral deposits was under active exploration at the time of writing. This exploration was predicated initially on assays, reported by industry, of anomalous gold and other precious metals in limestone samples from the area, indicating possible mineralization (Dufresne et al, 1994). Subsequently, analytical results were published that confirmed the presence of gold and assorted metal alloys in Devonian limestones and other rocks of the area, although in minute quantities (Feng and Abercrombie, 1994). With continuing exploration, an integral part of the effort has involved seeking an explanation for emplacement of the metals. The models being promulgated generally cite faulting as a major factor, the faults serving as conduits for mineralizing fluids invading the sediments. If this should prove to be correct, then the precise mapping of the faults referred to in a previous section becomes an important requirement of future studies.

References

Bayrock L. A. (1971): Surficial geology of the Bitumount area, NTS 74E, Research Council of Alberta, Map 34 (blue line, Map 140), Scale 1:250,000

Bayrock L. A. and T. H. F. Reimchen (1974): Surficial geology of the Waterways area, Alberta, NTS 74D, Research Council of Alberta, Map 148, Scale 1:250,000

Belyea, H. R. (1952): Notes on the Devonian System of the north-central plains of Alberta; Geological Survey of Canada, Paper 52-27, 66 p.

Carrigy, M.A. (1959): General geology of the McMurray area. Geology of the McMurray Formation, Part III. Research Council of Alberta, Memoir 1, 130 p.

Crickmay, C.H. (1957): Elucidation of some western Canada Devonian formations; publ. by author, E. de Mille Books, Calgary, Alberta, 14 p.

Dufresne, M.B., Henderson, B.A., Fenton, M.M., Pawlowicz, J.G. and R.J.H. Richardson (1994): The mineral deposits potential of the Marguerite river and Fort MacKay areas, northeast Alberta; Alberta Research Council Open File Report 1994-09, 67 p.

Feng, R. and H.J. Abercrombie (1994): Disseminated Au-Ag-Cu mineralization in the Western Canadian Sedimentary Basin, Fort MacKay, northeastern Alberta: a new gold deposit type; in Current Research 1994-E; Geological Survey of Canada, p. 121-132.

Godfrey, J.D. (1970): Geology of the Marguerite River area, Alberta; Research Council of Alberta Map, scale 1 inch to 1 mile.

Hackbarth, D.A., and N. Nastasa (1979): The hydrogeology of the Athabasca oil sands area, Alberta. Alberta Research Council, Bulletin 38, 39 p.

Hamilton, W.N. (1971): Salt in east-central Alberta; Research Council of Alberta Bulletin 29, 53 p.

Hamilton, W. N. and G. B. Mellon (1973): Industrial Mineral Resources of the Fort McMurray Area; in Guide to the Athabasca Oil Sands area (M.A. Carrigy and J.W. Kramers, editors), Alberta Research Council, Information Series 65, p. 122-161

Holter, M.E. (1976): Limestone resources of Alberta; Research Council of Alberta, Economic Geology Report 4.

Horne, E. and G. Seve, (1991): Pleistocene "buried valley" outwash channels-east bank, Athabasca River; CIM Paper 76, Fifth District Five Meeting, Fort McMurray, September 17-20, 1991, 15 p.

Keith, J. W. (1990): The influence of the Peace River Arch on Beaverhill Lake sedimentation; In: Geology of the Peace River Arch (S. C. O'Connel and J. S. Bell, editiors), Canadian Society of Petroleum Geologists,Special Volume 38A, p. 55-65

Martin, R. and F.G.S. Jamin (1963): Paleogeomorphology of the buried Devonian landscape in northeastern Alberta; in Athabasca OIl Sands (M.A. Carrigy), Alberta Research Council, Information Series 45, p. 31-42

McGehee, J.R. (1949): Pre-Waterways Paleozoic stratigraphy of Alberta Plains; Bull. Am. Assoc. Petrol. Geol., vol. 33. no. 4, p. 603-613.

Norris, A.W. (1973): Paleozoic (Devonian) geology of northeastern Alberta and northwestern Saskatchewan; in Guide to the Athabasca Oil Sands area (M.A. Carrigy and J.W. Kramers, editors), Alberta Research Council, Information Series 65, p. 17-76

Norris, A.W. (1963): Devonian stratigraphy of northeastern Alberta and northwestern Saskatchewan; Geological Survey of Canada, Mem. 313, 168 p.

O'Connell, S., Dix, G.R. and J.E. Barclay (1990): The origin, history and regional structural development of the Peace River Arch, Western Canada; In: Geology of the Peace River Arch (S. C. O'Connel and J. S. Bell, editiors), Canadian Society of Petroleum Geologists,Special Volume 38A, p. 4-24.

Petroleum Geology and Basin Analysis Group (1992): Baseline hydrogeological regime at the intermediate scale, AOSTRA Underground Test Facility. Report Environment Canada, Conservation and Protection, 134 p.

Petroleum Geology and Basin Analysis Group (1991):Regional geology and hydrostratigraphy in northeast Alberta. Report Environment Canada, Conservation and Protection, 161 p.

Sherwin, D.F. (1962): Lower Elk Point section, in east-central Alberta; Jour. Alberta Soc. Petrol. Geol., vol. 10, no. 4, pp. 185-191.

Warren, P.S. (1933): Age of Devonian limestone at McMurray, Alberta; Can. Field Nat., vol. 47, no. 8, pp. 148-149.

APPENDIX

Core Logs for Selected Wells

1. DDH - 1R RICHARDSON 6-94-10W4
2. BC03 AOSTRA UTF 1-18-93-12W4
3. SYNCRUDE 05-26-9-1 AB6-9-93-10W4
4. BEAR RODEO 1 8-20-89-9W4
5. BEAR BILTMORE 1 7-11-87-17W4
6. SHELL EATHA EX 12-6-99-8W4

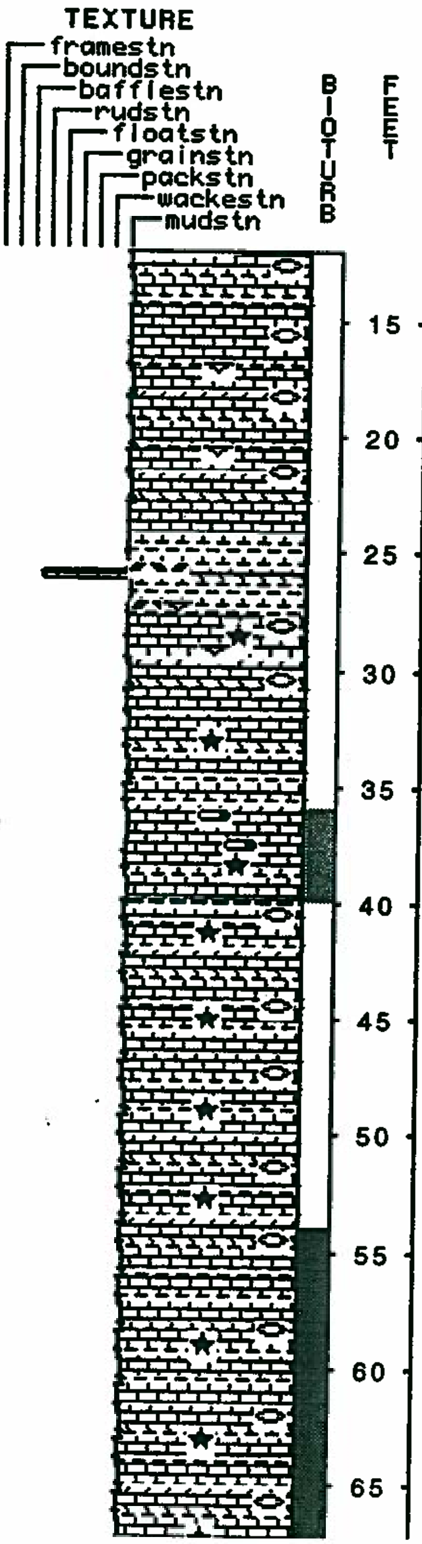
DDH-1R Richardson Property
6-94-10w4

Date logged: December 8, 1993

Logged by: D. K. Cotterill (Alberta Geological Survey)

Ground: 843.00 ft KB: 0.00 ft

Remarks: Cored Succesion: Moberly Member to Precambrian basement
Logged Interval: Moberly Member to Precambrian basement
Core Location: MCRF Edmonton
2 1/2 inch core, excellent condition



MOBERLY MEMBER (eroded)

Medium to dark grey, argillaceous, nodular, lime mudstone

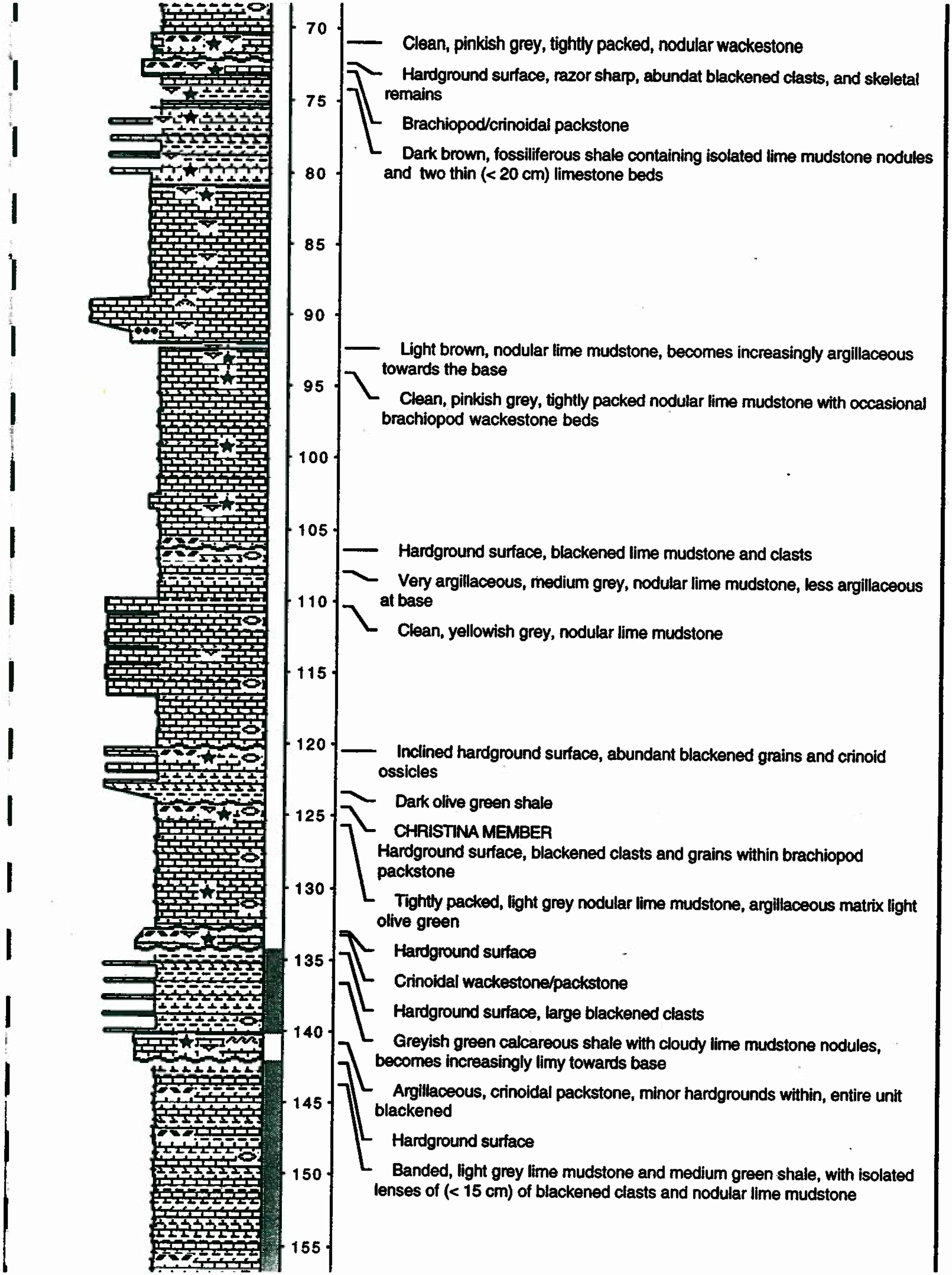
Light brown, nodular lime mudstone, fractures are bitumen stained

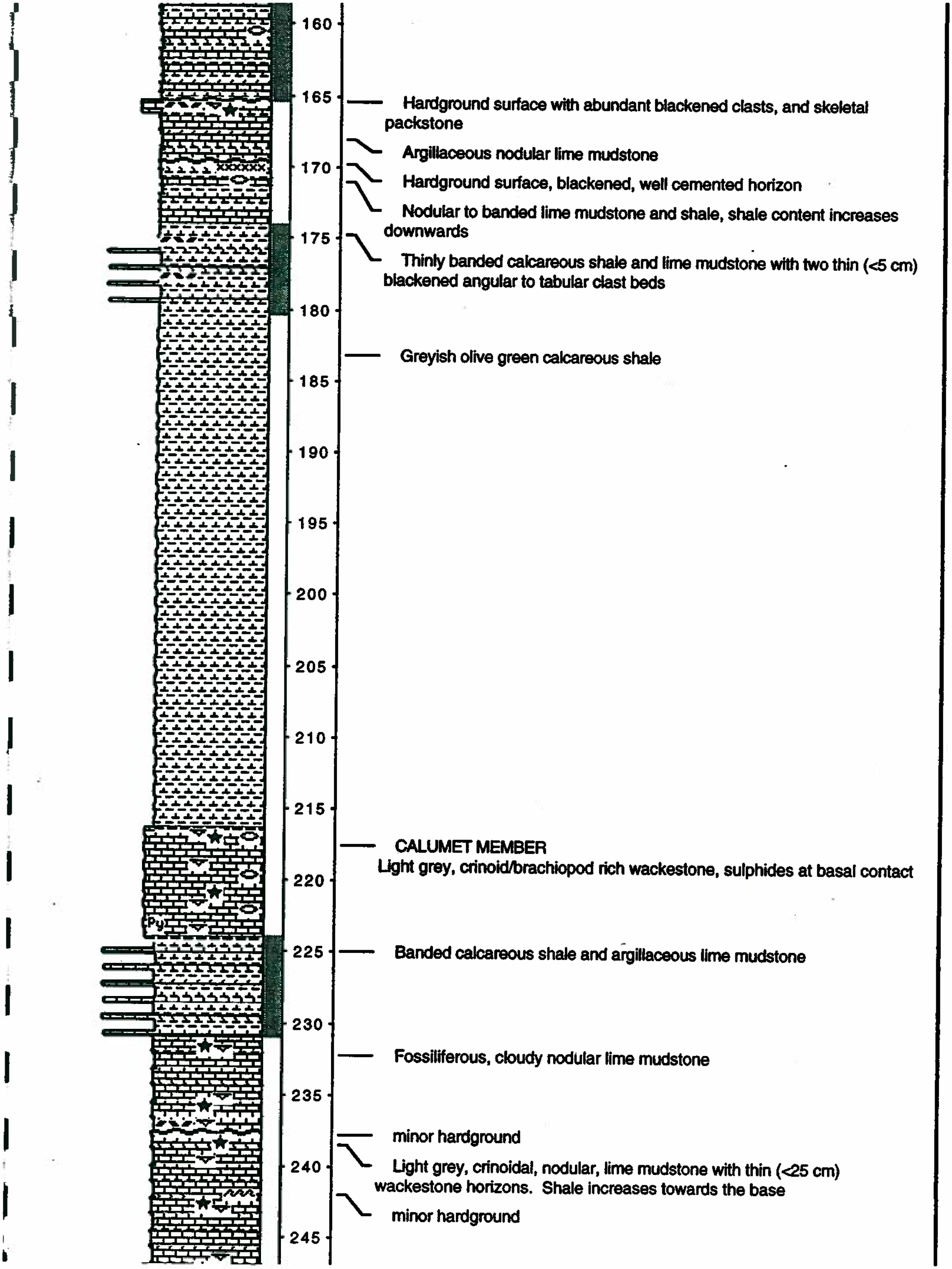
Dark greyish green shale with isolated lime mudstone nodules

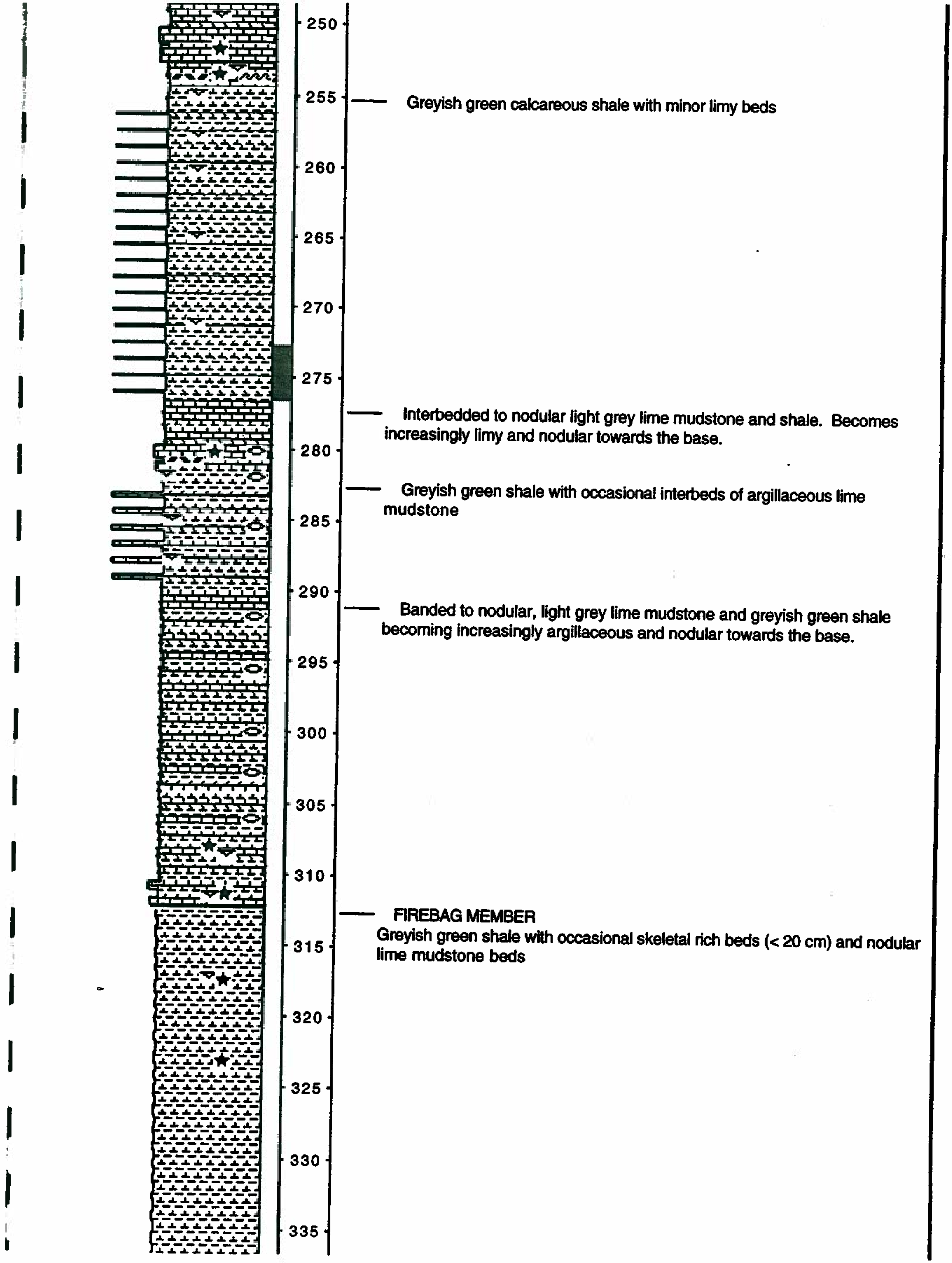
Blackened clasts

Pale yellowish brown, tightly packed nodular lime mudstone. Argillaceous matrix, dark greenish grey

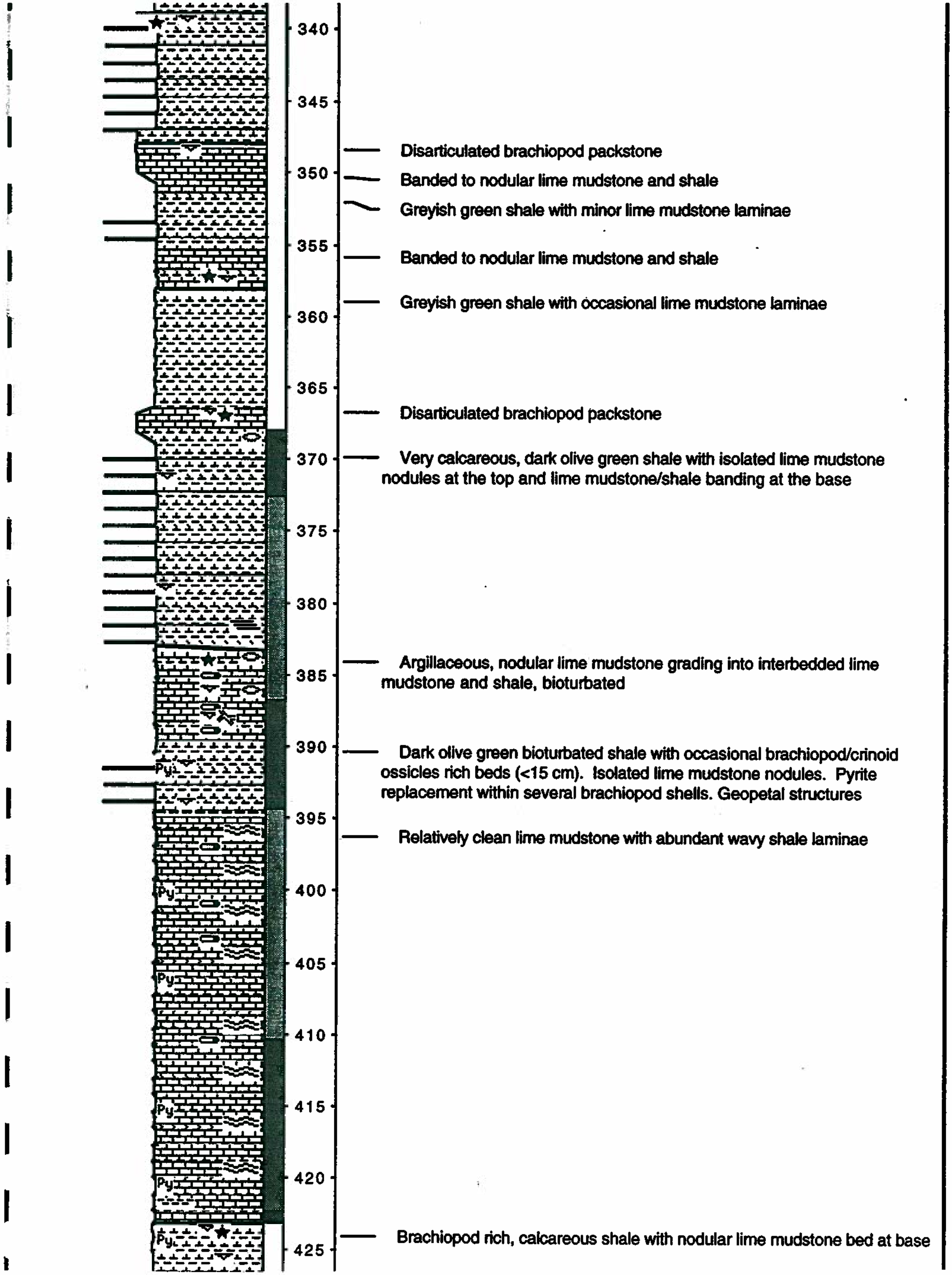
Nodular to interbedded, argillaceous lime mudstone and shale

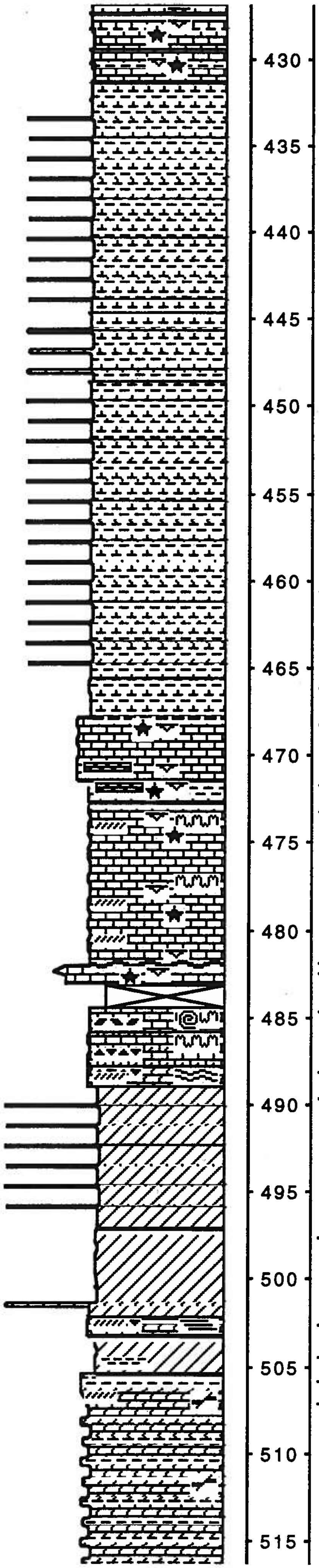

70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
Clean, pinkish grey, tightly packed, nodular wackestone
Hardground surface, razor sharp, abundat blackened clasts, and skeletal remains
Brachiopod/crinoidal packstone
Dark brown, fossiliferous shale containing isolated lime mudstone nodules and two thin (< 20 cm) limestone beds
Light brown, nodular lime mudstone, becomes increasingly argillaceous towards the base
Clean, pinkish grey, tightly packed nodular lime mudstone with occasional brachiopod wackestone beds
Hardground surface, blackened lime mudstone and clasts
Very argillaceous, medium grey, nodular lime mudstone, less argillaceous at base
Clean, yellowish grey, nodular lime mudstone
Inclined hardground surface, abundant blackened grains and crinoid ossicles
Dark olive green shale
CHRISTINA MEMBER
Hardground surface, blackened clasts and grains within brachiopod packstone
Tightly packed, light grey nodular lime mudstone, argillaceous matrix light olive green
Hardground surface
Crinoidal wackestone/packstone
Hardground surface, large blackened clasts
Greyish green calcareous shale with cloudy lime mudstone nodules, becomes increasingly limy towards base
Argillaceous, crinoidal packstone, minor hardgrounds within, entire unit blackened
Hardground surface
Banded, light grey lime mudstone and medium green shale, with isolated lenses of (< 15 cm) of blackened clasts and nodular lime mudstone


160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
Hardground surface with abundant blackened clasts, and skeletal packstone
Argillaceous nodular lime mudstone
Hardground surface, blackened, well cemented horizon
Nodular to banded lime mudstone and shale, shale content increases downwards
Thinly banded calcareous shale and lime mudstone with two thin (<5 cm) blackened angular to tabular clast beds
Greyish olive green calcareous shale
CALUMET MEMBER
Light grey, crinoid/brachiopod rich wackestone, sulphides at basal contact
Py
Banded calcareous shale and argillaceous lime mudstone
Fossiliferous, cloudy nodular lime mudstone
minor hardground
Light grey, crinoidal, nodular, lime mudstone with thin (<25 cm) wackestone horizons. Shale increases towards the base
minor hardground



250
255
Greyish green calcareous shale with minor limy beds
260
265
270
275
Interbedded to nodular light grey lime mudstone and shale. Becomes increasingly limy and nodular towards the base.
280
Greyish green shale with occasional interbeds of argillaceous lime mudstone
285
290
Banded to nodular, light grey lime mudstone and greyish green shale becoming increasingly argillaceous and nodular towards the base.
295
300
305
310
FIREBAG MEMBER
Greyish green shale with occasional skeletal rich beds (< 20 cm) and nodular lime mudstone beds
315
320
325
330
335


340
345
350
355
360
365
370
375
380
385
390
395
400
405
410
415
420
425
Py
Disarticulated brachiopod packstone
Banded to nodular lime mudstone and shale
Greyish green shale with minor lime mudstone laminae
Banded to nodular lime mudstone and shale
Greyish green shale with occasional lime mudstone laminae
Disarticulated brachiopod packstone
Very calcareous, dark olive green shale with isolated lime mudstone nodules at the top and lime mudstone/shale banding at the base
Argillaceous, nodular lime mudstone grading into interbedded lime mudstone and shale, bioturbated
Dark olive green bioturbated shale with occasional brachiopod/crinoid ossicles rich beds (<15 cm). Isolated lime mudstone nodules. Pyrite replacement within several brachiopod shells. Geopetal structures
Relatively clean lime mudstone with abundant wavy shale laminae
Brachiopod rich, calcareous shale with nodular lime mudstone bed at base



Nodular lime mudstone grading to interbedded lime mudstone and shale towards base

Dark greenish grey, calcareous shale with occasional interbedded lime mudstone

Shale color dark grey

Dark grey, calcareous shale

SLAVE POINT FORMATION

Pale brown, brachiopod wackestone with occasional organic rich, dark brown shale

Dark brown, organic rich, skeletal, slightly calcareous shale

Pale brown lime mudstone, organic rich microlaminations throughout, rare gypsum crystals along vertical fractures,stylolitic

Basal contact--creamy white, clean, lime mudstone overlying hardground containing blackened lime clasts

Pale brown packstone/grainstone with creamy white lime laminations and organic rich, stylolites

Microlaminated lime mudstone, light brown at top grading to light medium grey at the base, some vertical fractures, becomes increasingly dolomitic towards base.

FORT VERMILION FORMATION

Microlaminated dolostone, anhydritic, pale brown to medium grey

Nodular to chicken wire textured, white to bluish white anhydrite with frequent shale and light brown dolostone laminations

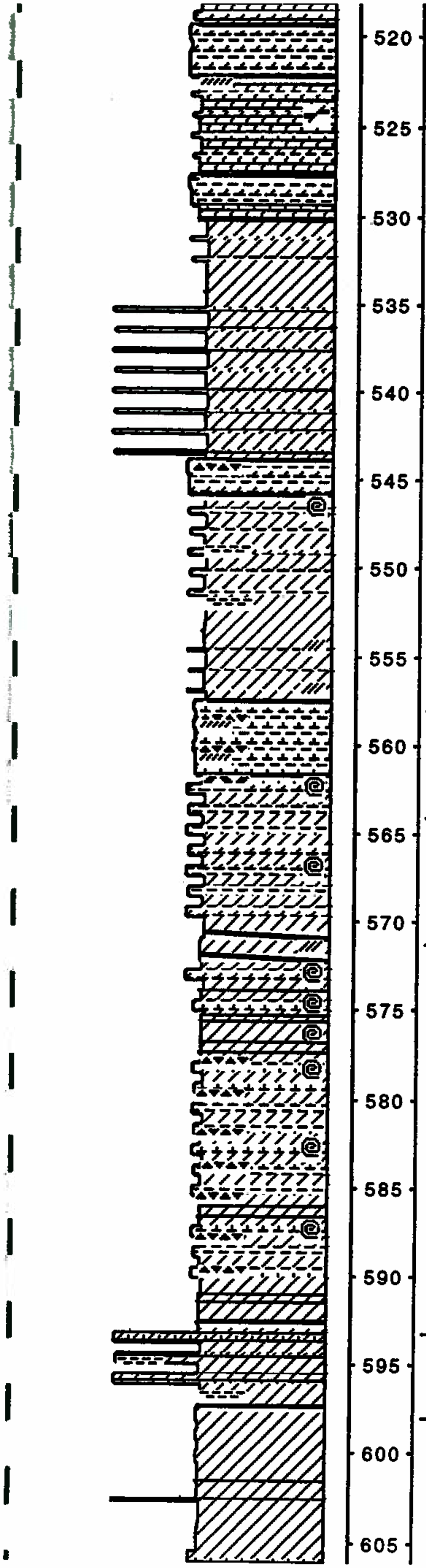
Massive whitish blue anhydrite grading downwards into fine nodular to chicken wire anhydrite and discontinuous light brown dolostone laminations

Light brown dolostone grading downwards to greyish brown, microlaminated and brecciated at top

Bluish white to pearly white, nodular to chicken wire textured anhydrite

Dark grey dolomitic shale, few anhydrite laminae

Light brown and mediun grey, argillaceous dolostone, microlaminated throughout with occasional thin (< 5cm) brecciated horizons



WATT MOUNTAIN FORMATION
Medium dark grey grading downwards in greyish green dolomitic shale, well lithified to soft and fissile.

Argillaceous, light brown and medium grey dolostone capped by thin bed of nodular anhydrite, microlaminated, vertical fracture anhydrite filled

Dark greyish green dolomitic shale

Pale brown dolostone with occasional dark brown shale laminae

PRAIRIE EVAPORITE FORMATION
Nodular to fine chicken textured, argillaceous, greenish white anhydrite grading downwards into white, nodular anhydrite intermixed with light brown dolostone

Brecciated dolomitic shale, tabular to rectangular clasts, anhydrite filled vertical and sub-vertical fractures

Nodular, very light grey, argillaceous, anhydrite grading downwards into cleaner, light brownish grey, high angle bedded anhydrite. Upper portion contains couple of dolomitic shale beds (< 20 cm) with fracture infilled anhydrite

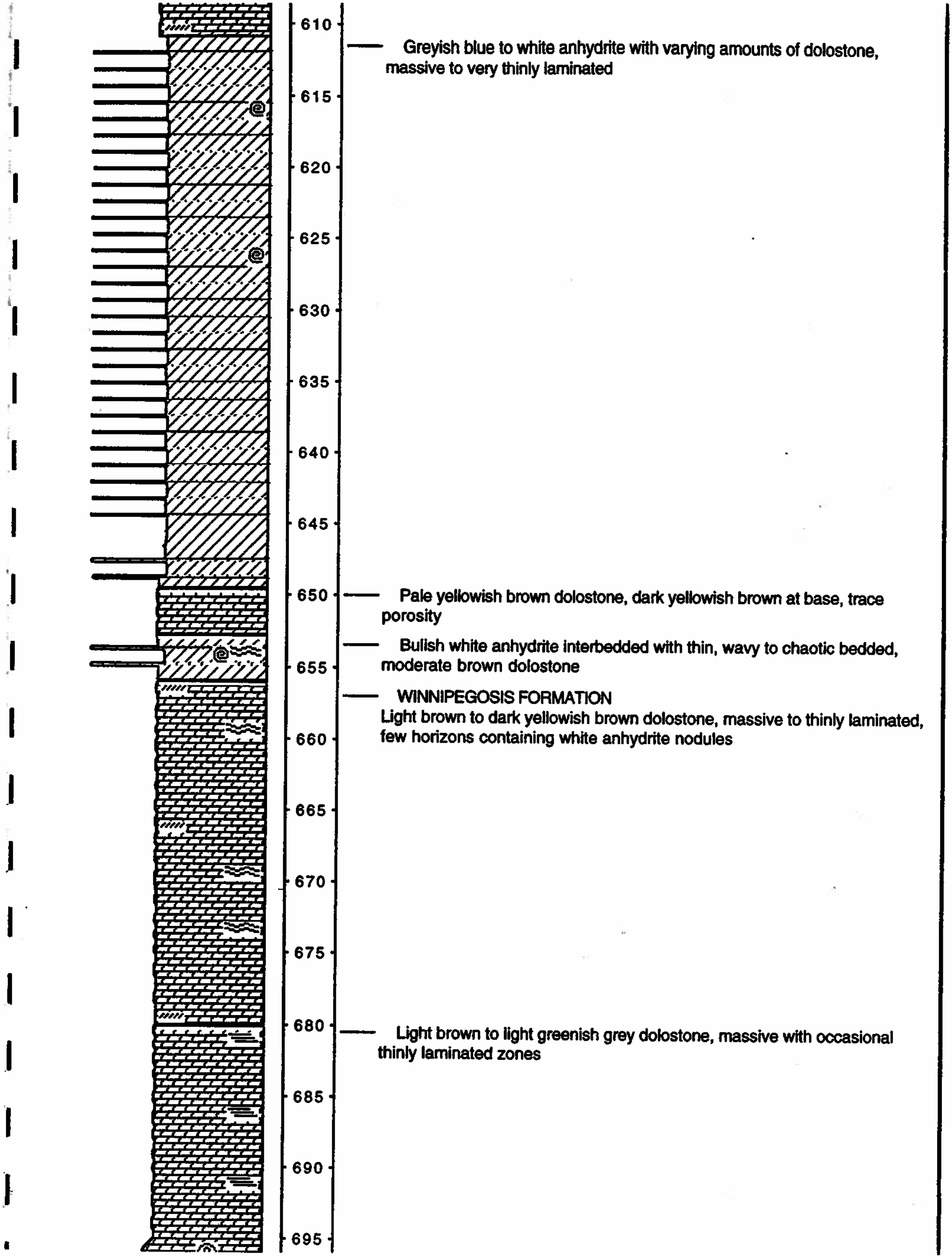
Heavily brecciated, dark greenish grey, calcareous shale containing tabular to rectangular clasts of dolostone, limestone, and some nodular anhydrite, fractures anhydrite filled

Chaotically bedded, nodular anhydrite and dolomitic to calcareous dark greenish grey shale, abundant sub-vertical fractures infilled with anhydrite. Lower half contains abundant brecciated horizons, tabular to rectangular clasts

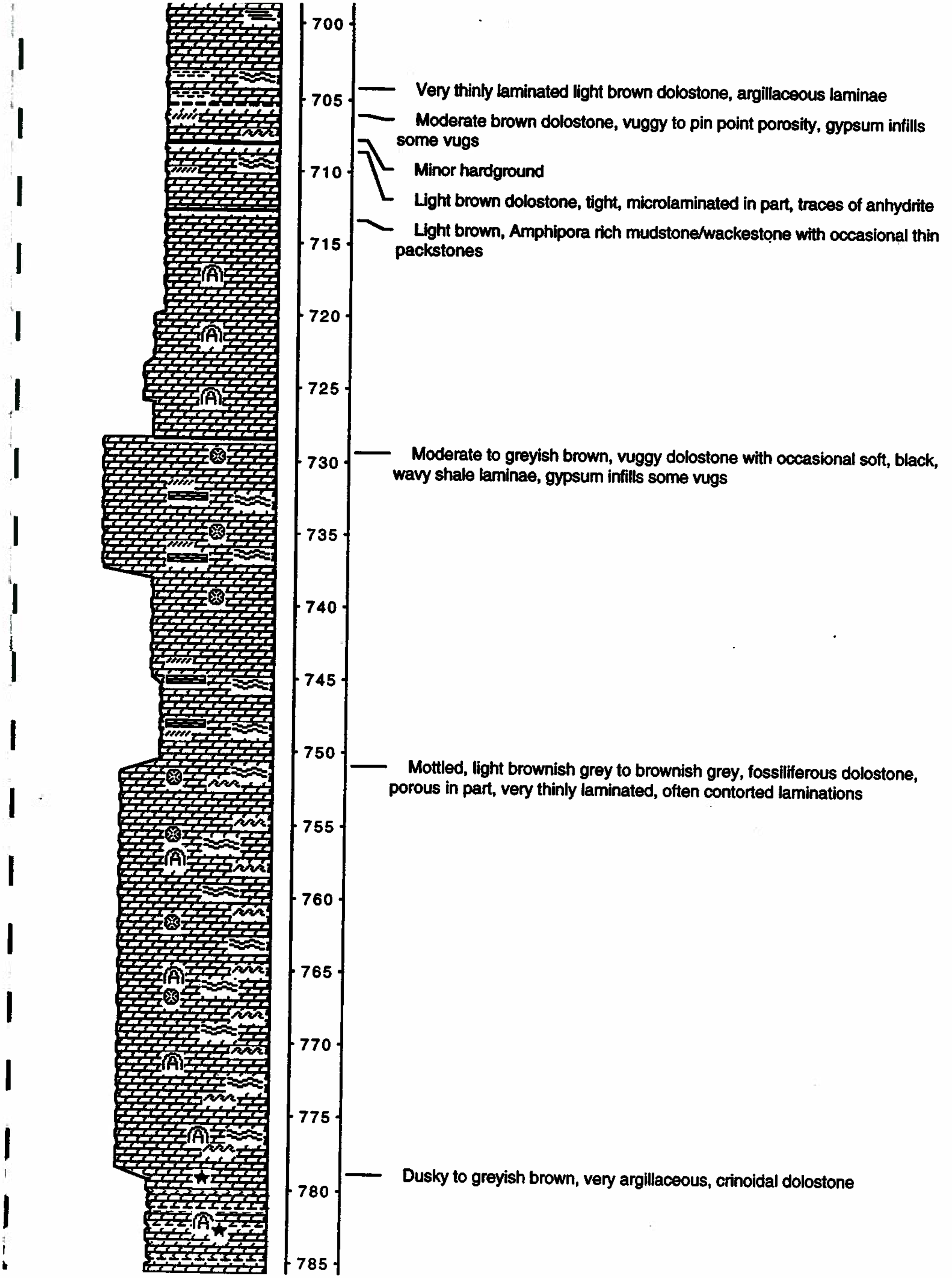
High angle bedded nodular anhydrite

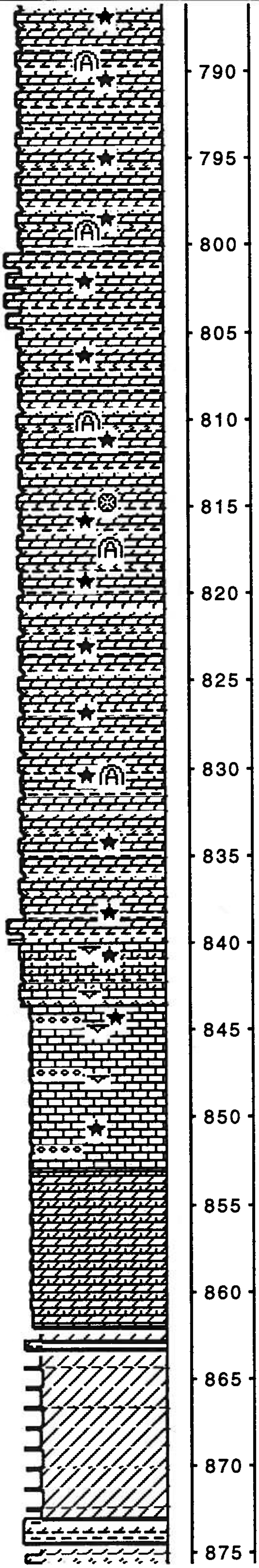
Very thinly laminated anhydrite and calcareous dolostone, white and very pale orange, argillaceous in part

Massive to large, nodular, greyish blue to white anhydrite grading downwards into fine nodular to chicken wire anhydrite with increasing amounts of very thin dolostone laminae



610
615
620
625
630
635
640
645
650
655
660
665
670
675
680
685
690
695
Greyish blue to white anhydrite with varying amounts of dolostone, massive to very thinly laminated
Pale yellowish brown dolostone, dark yellowish brown at base, trace porosity
Bulish white anhydrite interbedded with thin, wavy to chaotic bedded, moderate brown dolostone
WINNIPEGOSIS FORMATION
Light brown to dark yellowish brown dolostone, massive to thinly laminated, few horizons containing white anhydrite nodules
Light brown to light greenish grey dolostone, massive with occasional thinly laminated zones


700
705
710
715
720
725
730
735
740
745
750
755
760
765
770
775
780
785
Very thinly laminated light brown dolostone, argillaceous laminae
Moderate brown dolostone, vuggy to pin point porosity, gypsum infills some vugs
Minor hardground
Light brown dolostone, tight, microlaminated in part, traces of anhydrite
Light brown, Amphipora rich mudstone/wackestone with occasional thin packstones
Moderate to greyish brown, vuggy dolostone with occasional soft, black, wavy shale laminae, gypsum infills some vugs
Mottled, light brownish grey to brownish grey, fossiliferous dolostone, porous in part, very thinly laminated, often contorted laminations
Dusky to greyish brown, very argillaceous, crinoidal dolostone



Dusky brown to medium grey dolomitic lime wackestone with occasional thin packstone beds (< 10 cm). Fossils include brachiopods and abundant crinoid ossicles

Light to medium grey, fossiliferous, lime mudstone, scattered blackened grains

Mottled, very light brown to medium grey calcareous dolostone, nodular appearance in portions (contorted bedding ?)

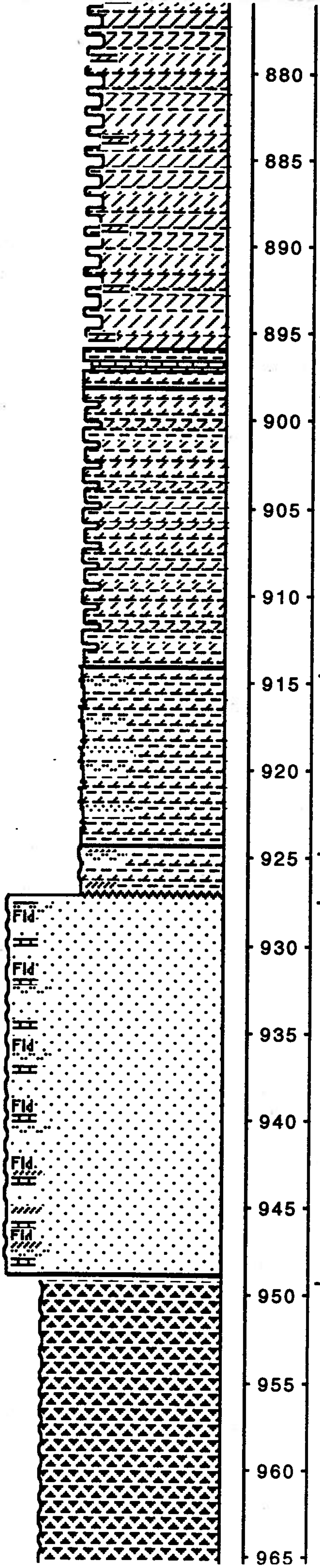
CONTACT RAPIDS FORMATION

Light to medium light grey anhydrite with minor dolomitic shale partings (< 5cm), shale greyish black to black

Fissile, greenish grey shale

Dark greenish grey, dolomitic shale

Interbedded light grey anhydrite and medium light grey to dark grey



anhydritic, dolomitic shale, contains very thin bedded to laminated tan dolostone, brecciated appearance in part

Greenish black dolomitic shale

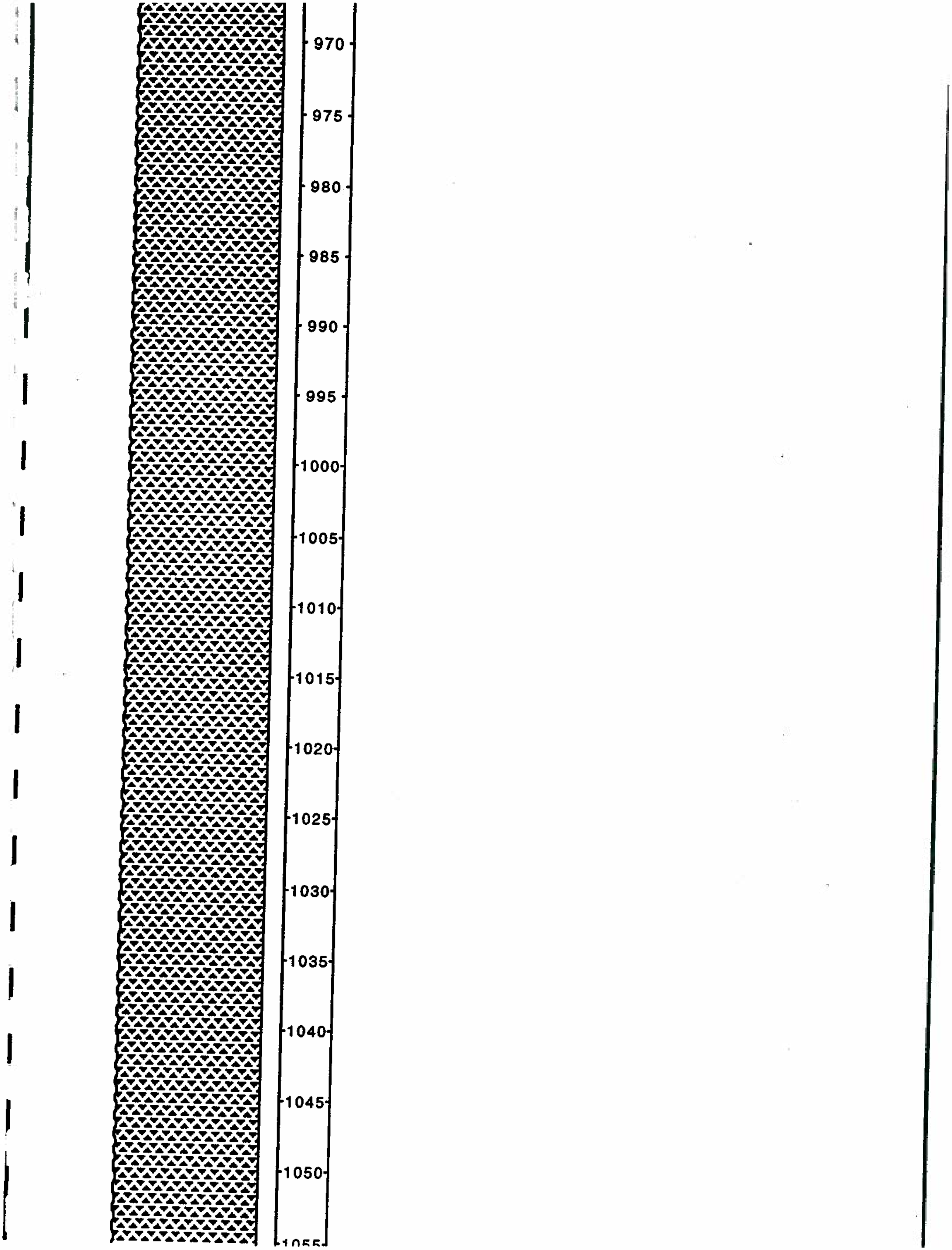
Interbedded, medium grey, dense dolomitic shale and light grey anhydrite, occasional buff, dolostone granules/clasts scattered within shale and anhydrite, gypsum filled partings (?)

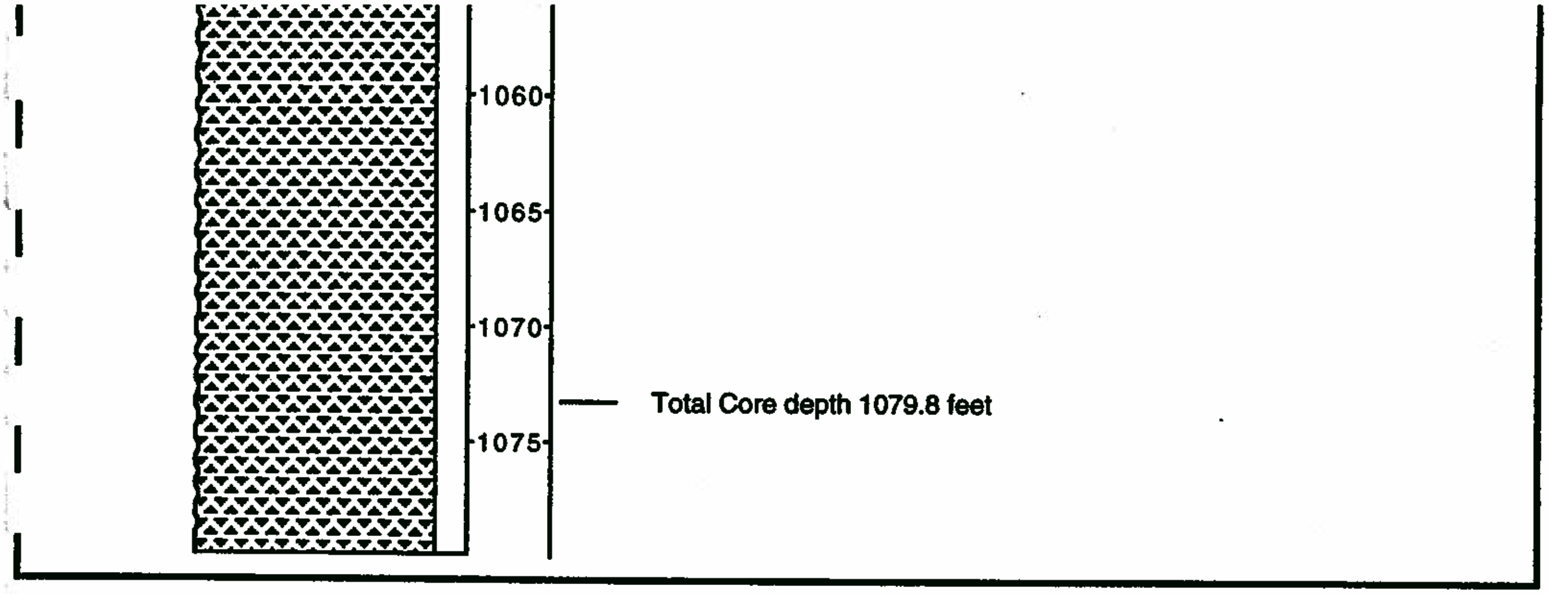
Interbedded, medium grey dolomitic shale and moderate red, argillaceous to sandy shale, horizontal and inclined parting often gypsum (??) filled

Very dark red, dolomitic shale, silty, anhdritic

GRANITE WASH
Moderate red to pale olive, very coarse to granular, arkose, poorly sorted, porous in part, abundant crystaline gypsum within basal section

PRECAMBRIAN BASEMENT
Moderate pink to red, hornblende granite, cyrstaline gypsum within uppermost section, occasional vertical to inclined fractures, quartz filled


970
975
980
985
990
995
1000
1005
1010
1015
1020
1025
1030
1035
1040
1045
1050


1060
1065
1070
1075
Total Core depth 1079.8 feet

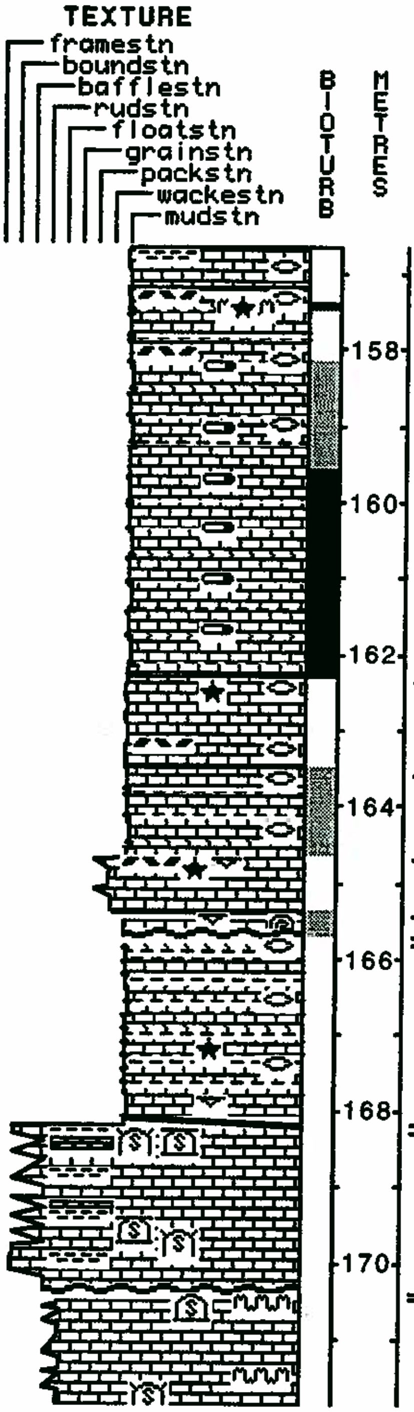
BC03 AOSTRA UTF
1-18-93-12w4

Date logged: December 6, 1993

Logged by: D. K. Cotterill (Alberta Geological Survey)

Ground: 428.02 m KB: 0.00 m

Remarks: Cored Succession: Lower Moberly to middle Calumet
Logged Interval: Lower Moberly to middle Calumet
Core Location: UTF Fort McMurray
2 1/2 inch, slabbed
Sampled for limestone purity



MOBERLY MEMBER (eroded)

Lime mudstone, light to medium grey grading downwards into pale orange brown, occasional blackened pebbles

Lime mudstone nodules encased within very thin shale beds to laminae, nodules are clast to mud supported. Several thin, packstone horizons (< 10 cm) containing blackened pebbles and crinoid ossicles. Light grey nodules within light olive green mud matrix.

Bioturbated lime mudstone, light to mediumn grey, occassional light olive green shale laminae

Nodular lime mudstone, light grey nodules within a medium grey, argillaceous matrix, occasional blackened pebble horizons

Nodular lime mudstone interbedded with very thin shale beds and laminae

Light grey, argillaceous, brachiopod wackestone/packstone grading downwards into a cleaner, light pinkish grey crinoidal wackestone

Lime mudstone, clean, light pinkish grey, possibly burrow mottled ??

Major hardground surface, blackened, irregular surface containing light pinkish grey mudstone from above

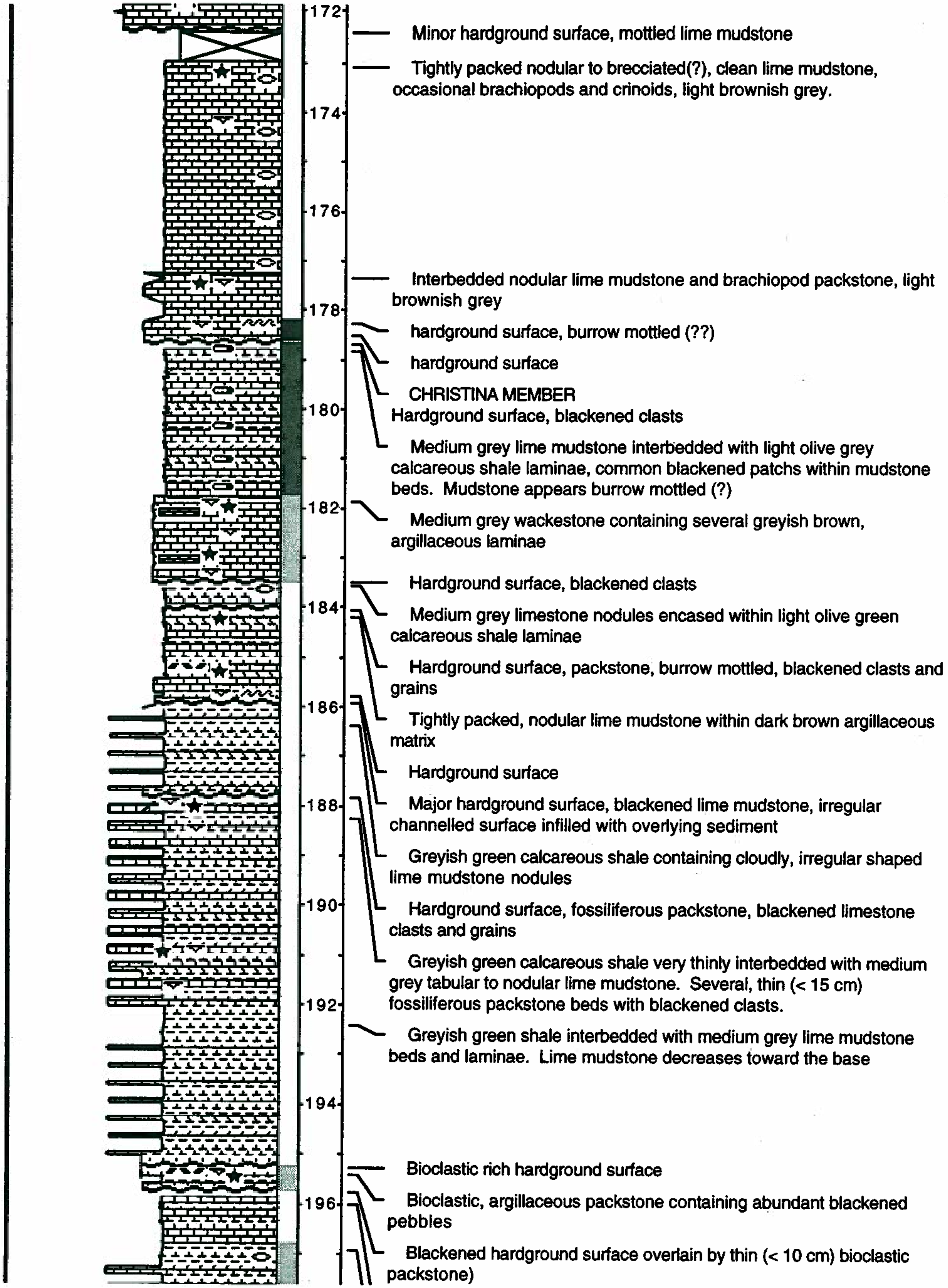
Lime mudstone nodules encased within light grey green calcareous shale. Contains a few thin (< 10 cm), crinoidal wackestone beds

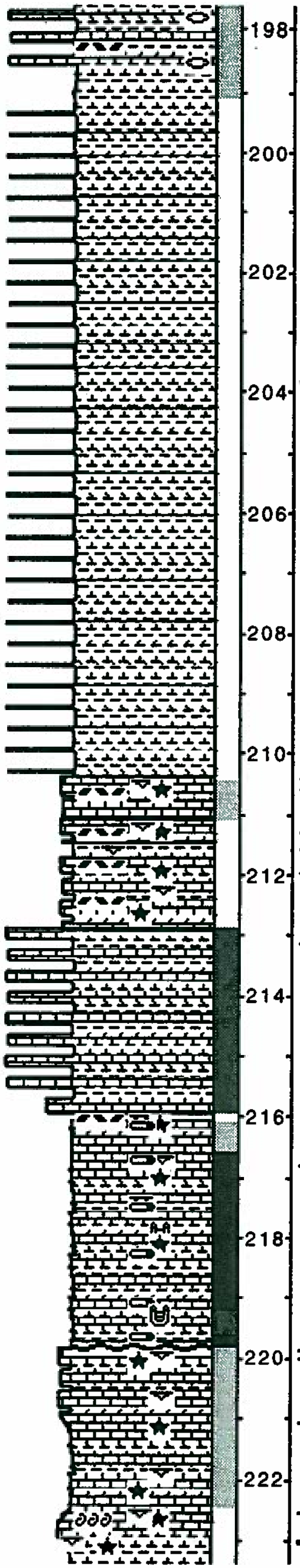
Very thin dark brown shale

Stromatoporoid rudstone/bindstone, light tan to buff tabular to branching stroms within a dark brown argillaceous matrix

Minor hardground surface

Hemishperical and branching stromatoporoid floatstone with occasional rudstone horizons, light tan to light brown


172
174
176
178
180
182
184
186
188
190
192
194
196
Minor hardground surface, mottled lime mudstone
Tightly packed nodular to brecciated(?), clean lime mudstone, occasional brachiopods and crinoids, light brownish grey.
Interbedded nodular lime mudstone and brachiopod packstone, light brownish grey
hardground surface, burrow mottled (??)
hardground surface
CHRISTINA MEMBER
Hardground surface, blackened clasts
Medium grey lime mudstone interbedded with light olive grey calcareous shale laminae, common blackened patchs within mudstone beds. Mudstone appears burrow mottled (?)
Medium grey wackestone containing several greyish brown, argillaceous laminae
Hardground surface, blackened clasts
Medium grey limestone nodules encased within light olive green calcareous shale laminae
Hardground surface, packstone, burrow mottled, blackened clasts and grains
Tightly packed, nodular lime mudstone within dark brown argillaceous matrix
Hardground surface
Major hardground surface, blackened lime mudstone, irregular channelled surface infilled with overlying sediment
Greyish green calcareous shale containing cloudly, irregular shaped lime mudstone nodules
Hardground surface, fossiliferous packstone, blackened limestone clasts and grains
Greyish green calcareous shale very thinly interbedded with medium grey tabular to nodular lime mudstone. Several, thin (< 15 cm) fossiliferous packstone beds with blackened clasts.
Greyish green shale interbedded with medium grey lime mudstone beds and laminae. Lime mudstone decreases toward the base
Bioclastic rich hardground surface
Bioclastic, argillaceous packstone containing abundant blackened pebbles
Blackened hardground surface overlain by thin (< 10 cm) bioclastic packstone)



Medium grey, nodular lime mudstone interbedded with greyish green shale laminae

Greyish green shale interbedded with tabular to nodular lime mudstone

Greyish green, well lithified, very calcareous shale containing thin, wispy limestone laminae. Limestone decreases towards the base.

CALUMET MEMBER

Greyish pink to greyish green crinoidal wackestone, minor hardgrounds

Greyish green, crinoidal, nodular wackestone

Brachiopod rich calcareous shale

Argillaceous, crinoidal packstone contained scattered blackened pebbles

Faintly banded medium grey lime mudstone and dark greenish grey calcareous shale

Bioturbated, very argillaceous, cloudy, nodular lime mudstone. Sparse crinoid ossicles and brachiopod remains.

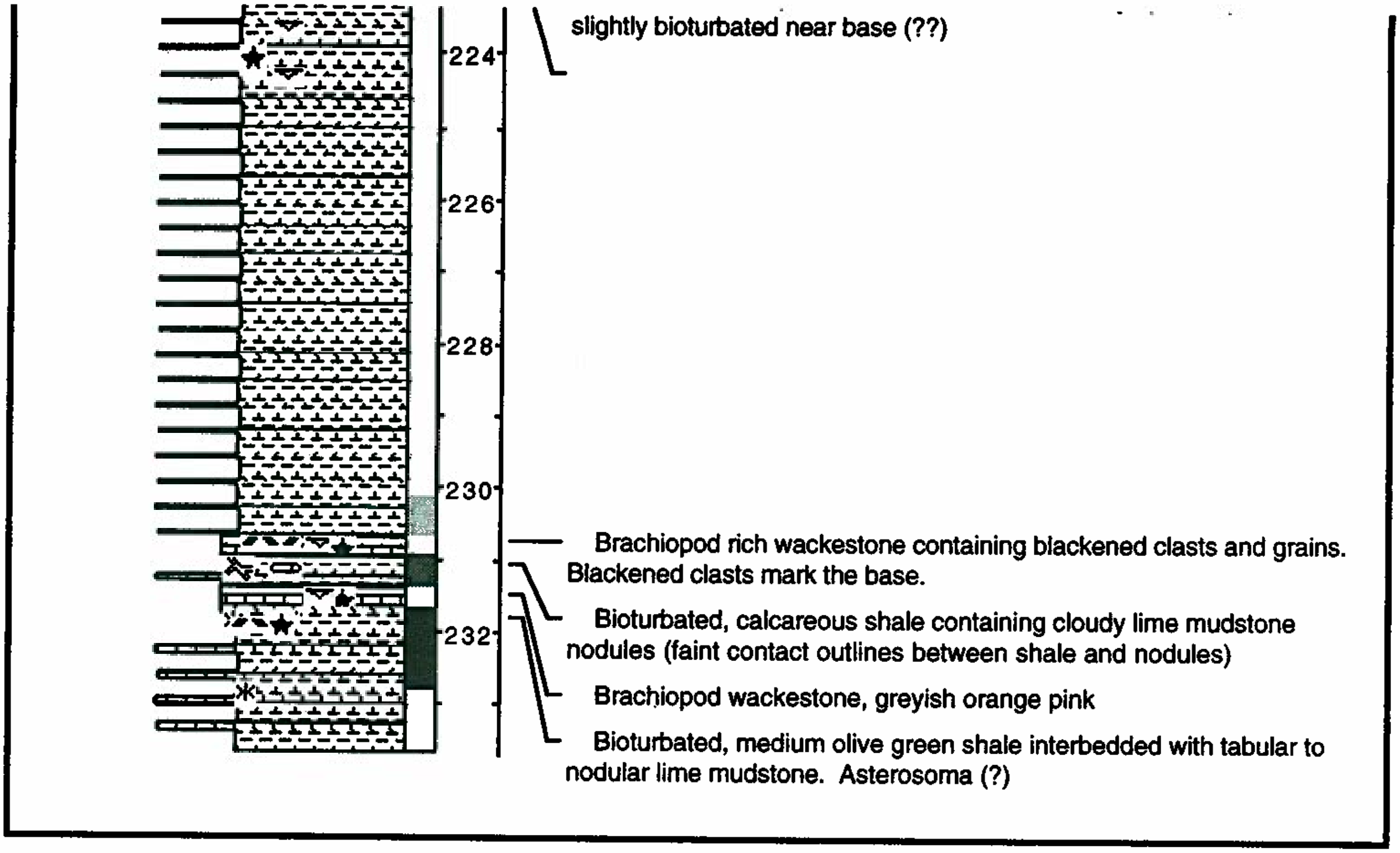
Bioclastic rich hardground with blackened, irregular, burrow mottled (?) surface

Tightly packed nodular wackestone

Light to medium grey, argillaceous, cloudy, nodular lime mudstone

Crinoidal/brachiopod, argillaceous wackestone

Well lithified, very calcareous shale. Greenish grey, faintly bedded,


slightly bioturbated near base (??)
224
226
228
230
232
Brachiopod rich wackestone containing blackened clasts and grains. Blackened clasts mark the base.
Bioturbated, calcareous shale containing cloudy lime mudstone nodules (faint contact outlines between shale and nodules)
Brachiopod wackestone, greyish orange pink
Bioturbated, medium olive green shale interbedded with tabular to nodular lime mudstone. Asterosoma (?)

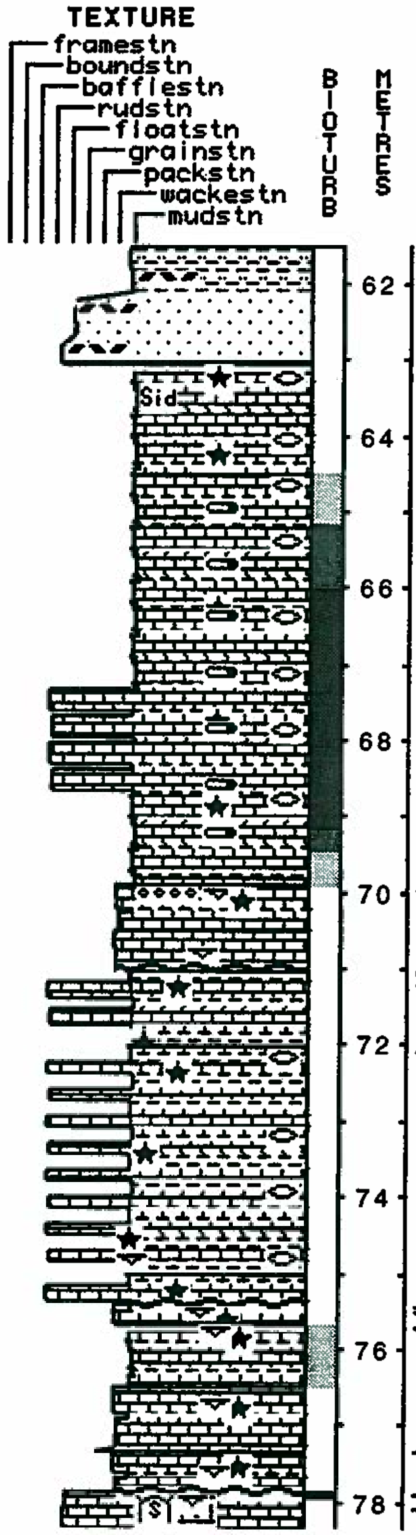
SYNCRUDE 05-26-9-1
AB6-9-93-10w4

Date logged: January 4, 1994

Logged by: D. K. Cotterill (Alberta Geological Survey)

Ground: 0.00 m KB: 316.20 m

Remarks: Cored Succession: Middle Moberly to basal Firebag
Logged Interval: Middle Moberly to basal Firebag
Core Location: ERCB Core Research Centre
2 1/2 inch, slabbed, excellent condition
Sampled for limestone purity



McMURRAY FORMATION (Lower Cretaceous)
Light grey, silty shale containing sideritized rip up clasts

Bitumen sand, fines upward, siderite clasts and tabular shale clasts

MOBERLY MEMBER (eroded)
Light yellowish grey, nodular lime mudstone, matrix muds light greenish grey to pale orange

Banded to nodular, light grey lime mudstone, bioturbation increases downwards, light olive grey mud matrix

Pinkish grey, tightly packed nodular wackestone, abundant crinoid ossicles, blackened pebble horizon at top

Hardground surface, blackened limestone overlies surface

Thin, pinkish grey banded wackestone

Medium grey lime mudstone nodules encased within greenish grey calcareous shale, shale increases downwards, occasional crinoid packstone laminae

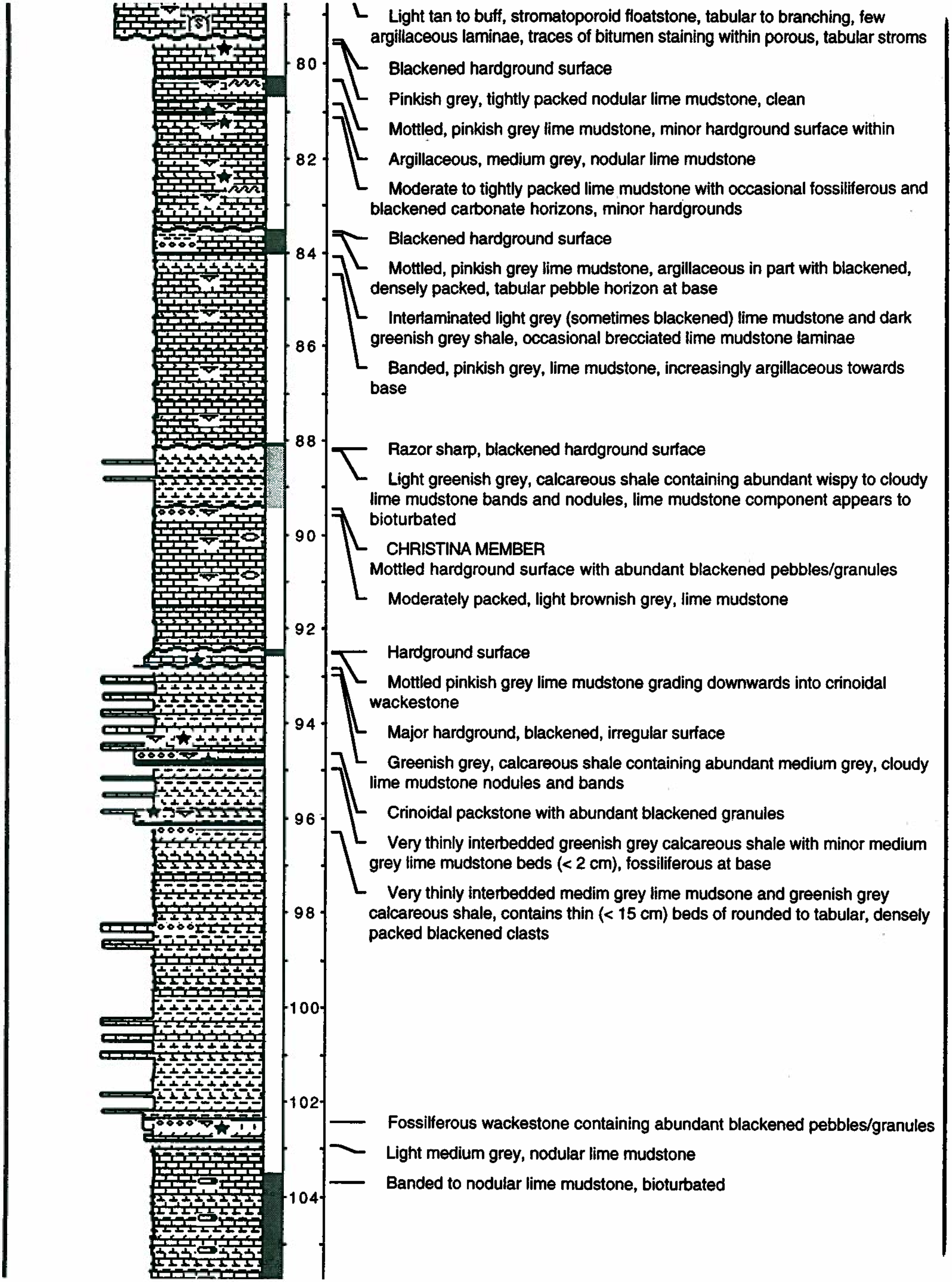
Medium grey, rounded to tabular lime mudstone nodules encased within light olive grey to medium light grey calcareous shale, occasional crinoid ossicle rich horizons/laminae

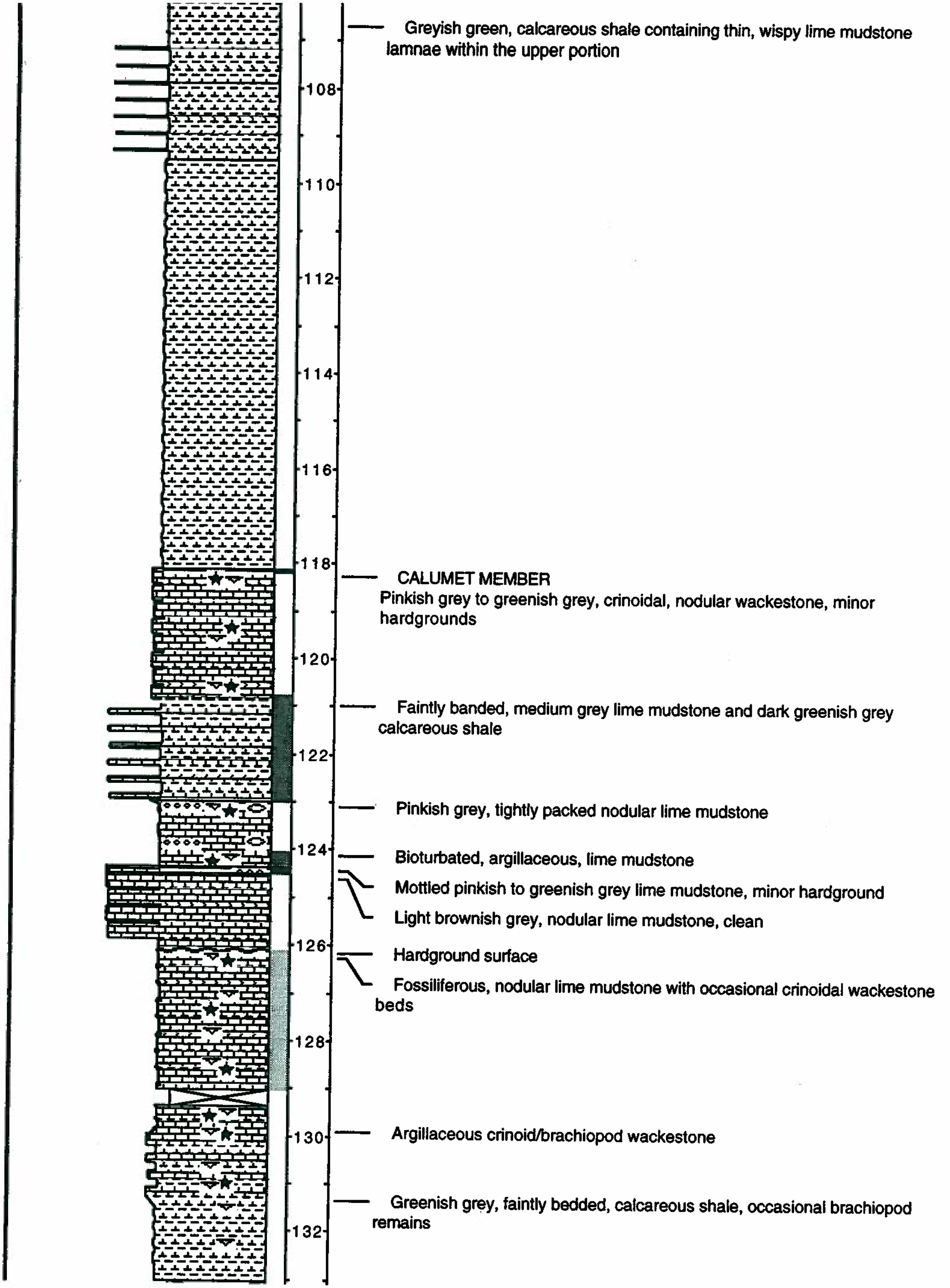
Hardground surface

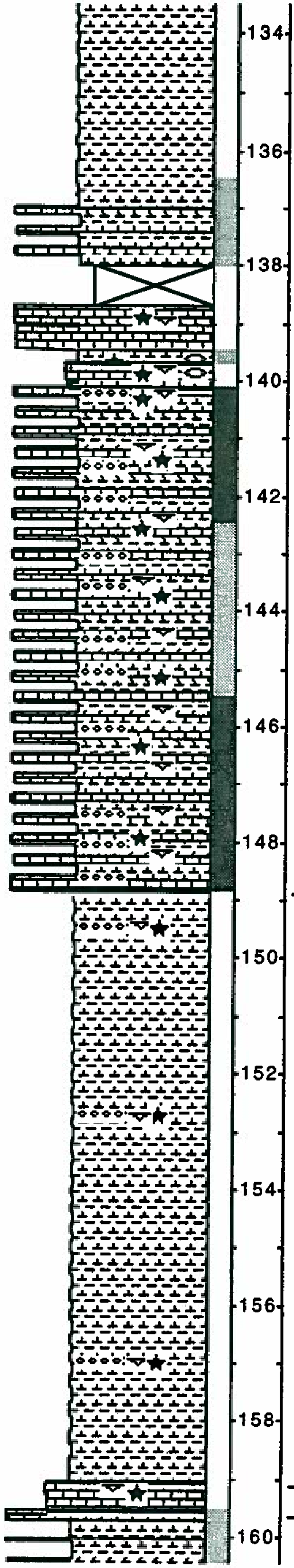
Light pinkish grey, fossiliferous wackestone, possibly burrow mottled

Light grey to light brownish grey nodular lime mudstone, shaly matrix, brownish grey to brownish black

Brachoipod rich wackestone/packstone


80
82
84
86
88
90
92
94
96
98
100
102
104
Light tan to buff, stromatoporoid floatstone, tabular to branching, few argillaceous laminae, traces of bitumen staining within porous, tabular stroms
Blackened hardground surface
Pinkish grey, tightly packed nodular lime mudstone, clean
Mottled, pinkish grey lime mudstone, minor hardground surface within
Argillaceous, medium grey, nodular lime mudstone
Moderate to tightly packed lime mudstone with occasional fossiliferous and blackened carbonate horizons, minor hardgrounds
Blackened hardground surface
Mottled, pinkish grey lime mudstone, argillaceous in part with blackened, densely packed, tabular pebble horizon at base
Interlaminated light grey (sometimes blackened) lime mudstone and dark greenish grey shale, occasional brecciated lime mudstone laminae
Banded, pinkish grey, lime mudstone, increasingly argillaceous towards base
Razor sharp, blackened hardground surface
Light greenish grey, calcareous shale containing abundant wispy to cloudy lime mudstone bands and nodules, lime mudstone component appears to bioturbated
CHRISTINA MEMBER
Mottled hardground surface with abundant blackened pebbles/granules
Moderately packed, light brownish grey, lime mudstone
Hardground surface
Mottled pinkish grey lime mudstone grading downwards into crinoidal wackestone
Major hardground, blackened, irregular surface
Greenish grey, calcareous shale containing abundant medium grey, cloudy lime mudstone nodules and bands
Crinoidal packstone with abundant blackened granules
Very thinly interbedded greenish grey calcareous shale with minor medium grey lime mudstone beds (< 2 cm), fossiliferous at base
Very thinly interbedded medim grey lime mudsone and greenish grey calcareous shale, contains thin (< 15 cm) beds of rounded to tabular, densely packed blackened clasts
Fossilferous wackestone containing abundant blackened pebbles/granules
Light medium grey, nodular lime mudstone
Banded to nodular lime mudstone, bioturbated


Greyish green, calcareous shale containing thin, wispy lime mudstone lamnae within the upper portion
108
110
112
114
116
118
CALUMET MEMBER
Pinkish grey to greenish grey, crinoidal, nodular wackestone, minor hardgrounds
120
Faintly banded, medium grey lime mudstone and dark greenish grey calcareous shale
122
Pinkish grey, tightly packed nodular lime mudstone
124
Bioturbated, argillaceous, lime mudstone
Mottled pinkish to greenish grey lime mudstone, minor hardground
Light brownish grey, nodular lime mudstone, clean
126
Hardground surface
Fossiliferous, nodular lime mudstone with occasional crinoidal wackestone beds
128
130
Argillaceous crinoid/brachiopod wackestone
Greenish grey, faintly bedded, calcareous shale, occasional brachiopod remains
132



Faintly banded, calcareous shale and medium grey lime mudstone

Fossiliferous wackestone, light greenish grey

Greenish grey calcareous shale

Dark greenish grey, calcareous shale with abundant, cloudy limy nodules

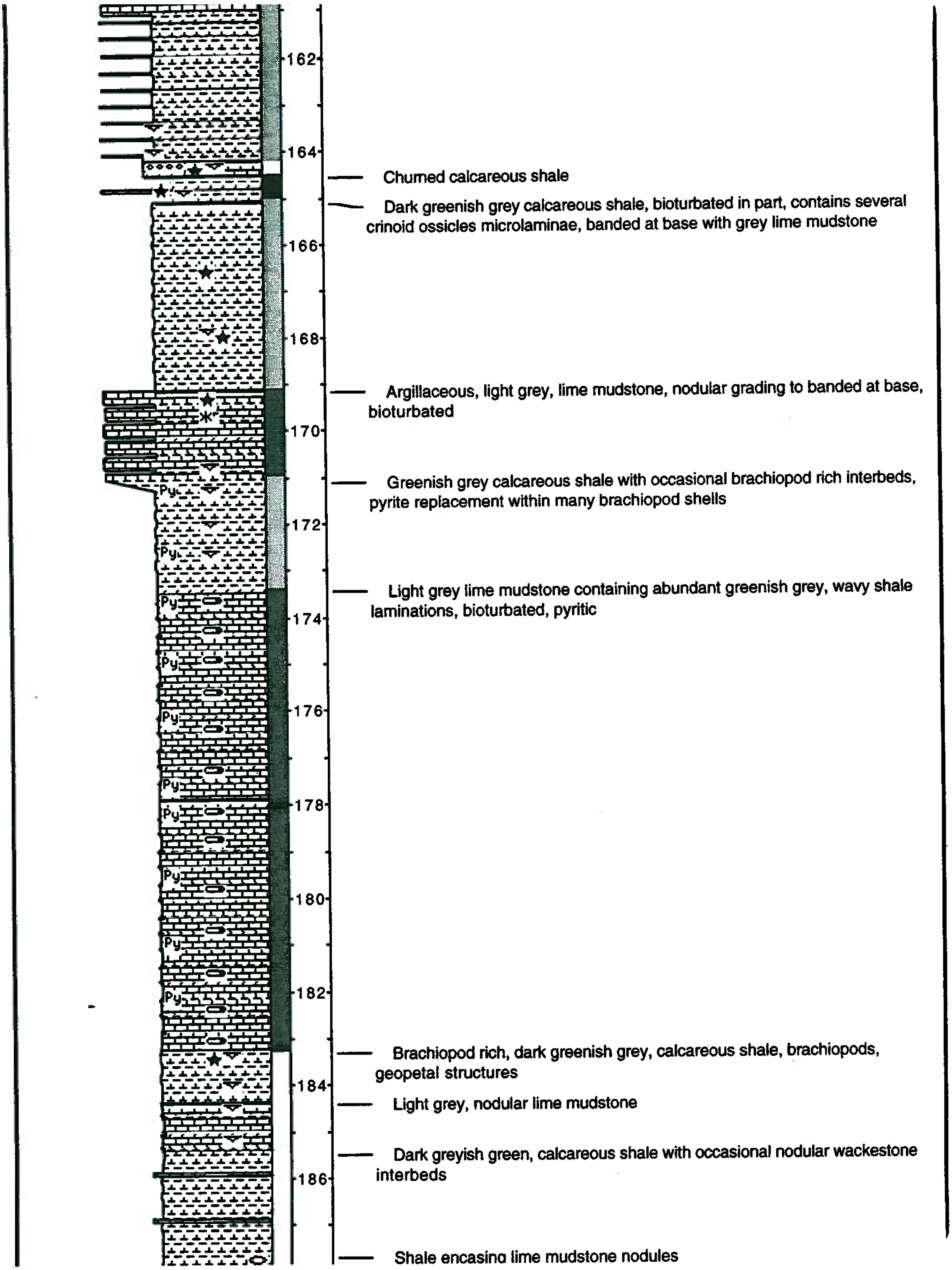
Fossiliferous, pinkish grey, nodular wackestone, contains abundant blackened granules

Banded to nodular, light greenish grey, lime mudstone and dark greenish grey shale, numerous horizons of concentrated crinoid ossicles, brachiopod shells and blackened clasts

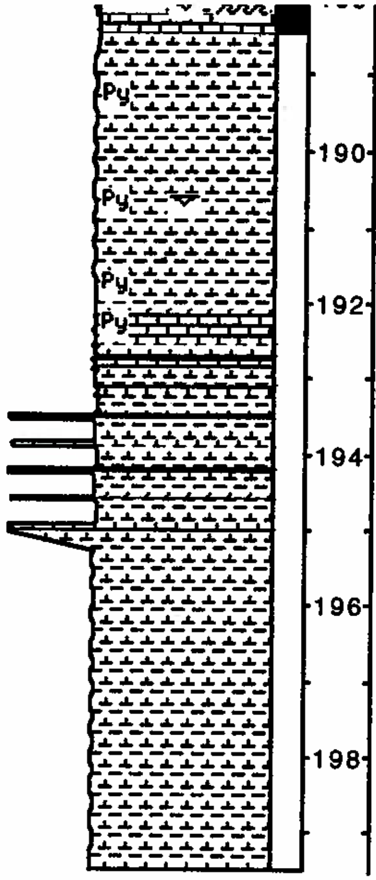
FIREBAG MEMBER
Dark greenish grey, calcareous shale, contains a few brachiopod/crinoid packstone beds (< 15 cm), occasional wispy, lime laminae

Nodular, brachiopod packstone/wackestone, light olive to greenish grey

Faintly bedded calcareous shale with regions of banded (interbedded to interlaminated) lime mudstone and shale



162
164
166
168
170
172
174
176
178
180
182
184
186
Churned calcareous shale
Dark greenish grey calcareous shale, bioturbated in part, contains several crinoid ossicles microlaminae, banded at base with grey lime mudstone
Argillaceous, light grey, lime mudstone, nodular grading to banded at base, bioturbated
Greenish grey calcareous shale with occasional brachiopod rich interbeds, pyrite replacement within many brachiopod shells
Light grey lime mudstone containing abundant greenish grey, wavy shale laminations, bioturbated, pyritic
Brachiopod rich, dark greenish grey, calcareous shale, brachiopods, geopetal structures
Light grey, nodular lime mudstone
Dark greyish green, calcareous shale with occasional nodular wackestone interbeds
Shale encasing lime mudstone nodules



Mottled, pinkish grey, lime mudstone interbedded with bioturbated limy shale, blackened granules

Dark greenish grey shale containing occasional lime mudstone nodules, pyrite within some nodules, also replaces some brachiopod shells, fissile

Very thinly interbedded lime mudstone and shale grading downwards into calcareous shale with occasional thin lime interbeds

Dark greenish grey to medium grey, calcareous shale, fissile, faintly bedded

End of core-T.D. within Firebag Member of Waterways Formation

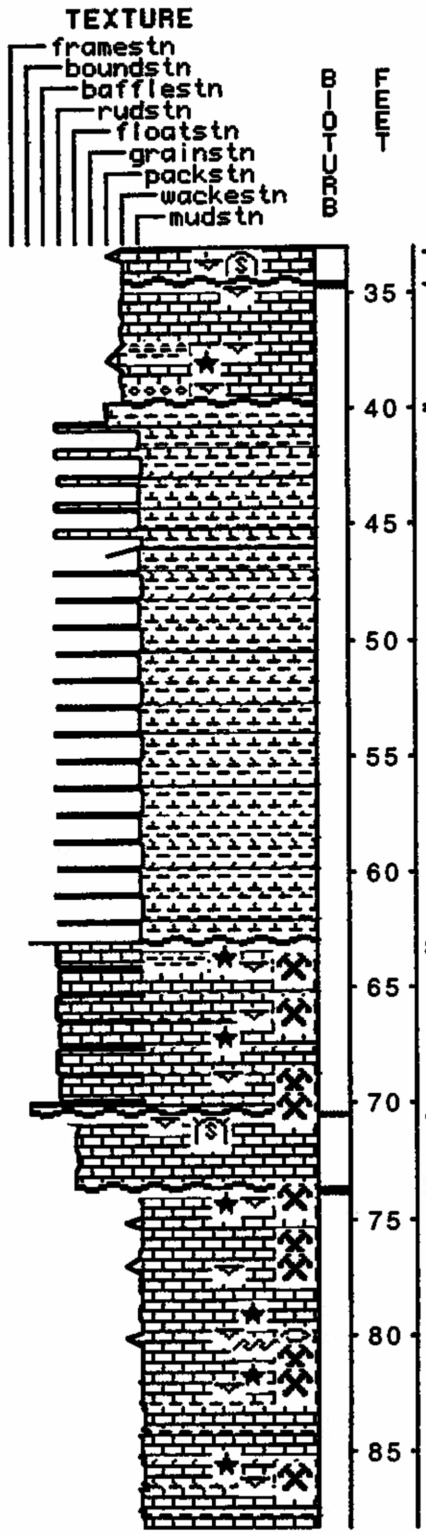
Bear Rodeo 1
8-20-89-9w4

Date logged: January 13, 1994

Logged by: D.K. Cotterill (Alberta Geological Survey)

Ground: 817.00 ft KB: 0.00 ft

Remarks: Cored Succession: Moberly Member to Precambrian basement
Logged Interval: Moberly Member to Fort Vermilion Fm.
Core Location: ERCB Core Research Centre
Sampled for limestone purity



MOBERLY MEMBER (eroded)

Pinkish grey, nodular, crinoidal wackestone with occasional blackened pebble horizons and thin, argillaceous crinoidal packstone beds

Razor sharp, inclined hardground surface

Hardground surface, blackened pebbles

Banded (laminated) lime mudstone and shale grading downwards into greenish grey calcareous shale, few thin crinoidal packstones within upper section

Hardground surface

Interbedded, pinkish grey, nodular lime mudstones and wackestones, argillaceous in part

Hardground surface, flat

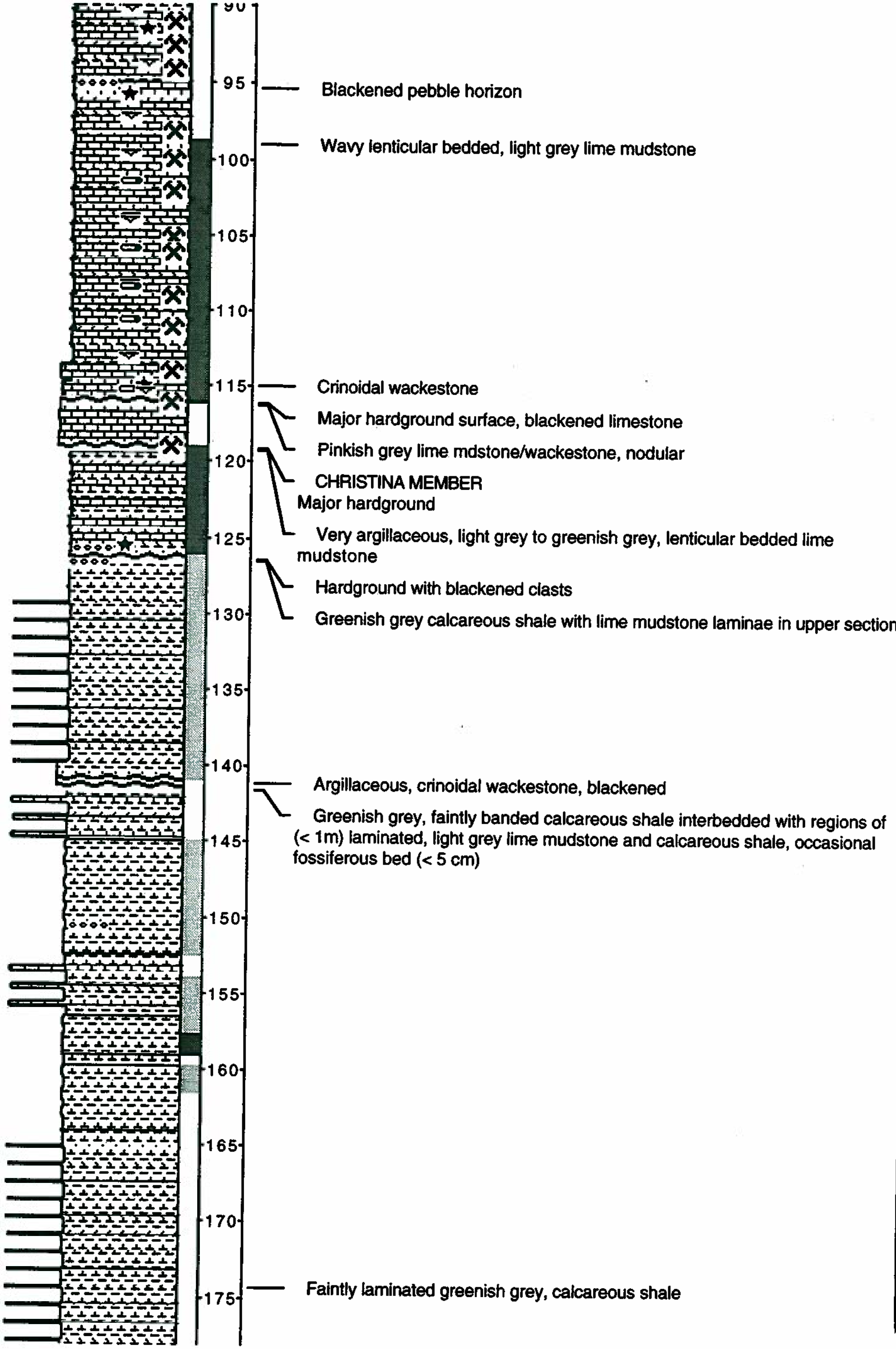
Thin, tabular stromatoporoid boundstone underlain by clean, branching stromatoporoid floatstone

Hardground surface

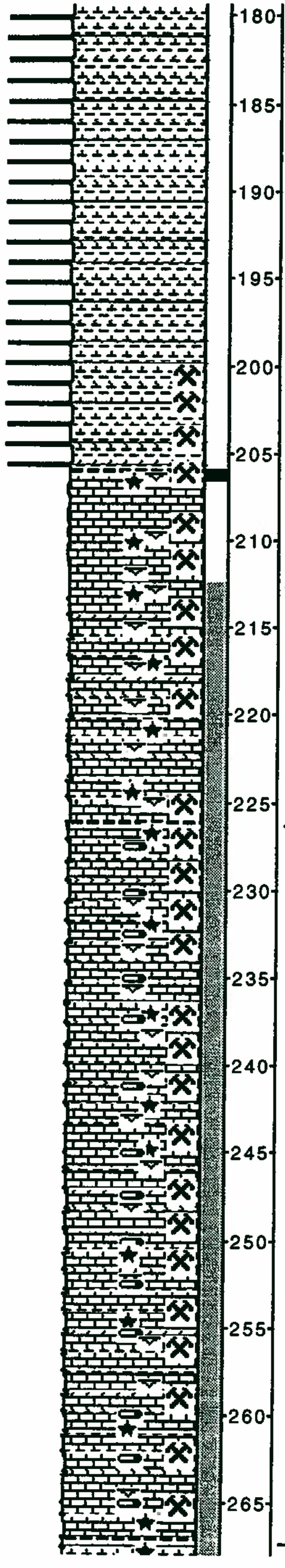
Pinkish grey, skeletal, tightly packed, nodular lime mudstone with occasional thin wackestone beds

Minor hardground

Nodular to lenticular bedded, light grey, argillaceous lime mudstone, thin (< 5 cm) crinoid and brachiopod wackestone beds



90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
Blackened pebble horizon
Wavy lenticular bedded, light grey lime mudstone
Crinoidal wackestone
Major hardground surface, blackened limestone
Pinkish grey lime mdstone/wackestone, nodular
CHRISTINA MEMBER
Major hardground
Very argillaceous, light grey to greenish grey, lenticular bedded lime mudstone
Hardground with blackened clasts
Greenish grey calcareous shale with lime mudstone laminae in upper section
Argillaceous, crinoidal wackestone, blackened
Greenish grey, faintly banded calcareous shale interbedded with regions of (< 1m) laminated, light grey lime mudstone and calcareous shale, occasional fossiferous bed (< 5 cm)
Faintly laminated greenish grey, calcareous shale

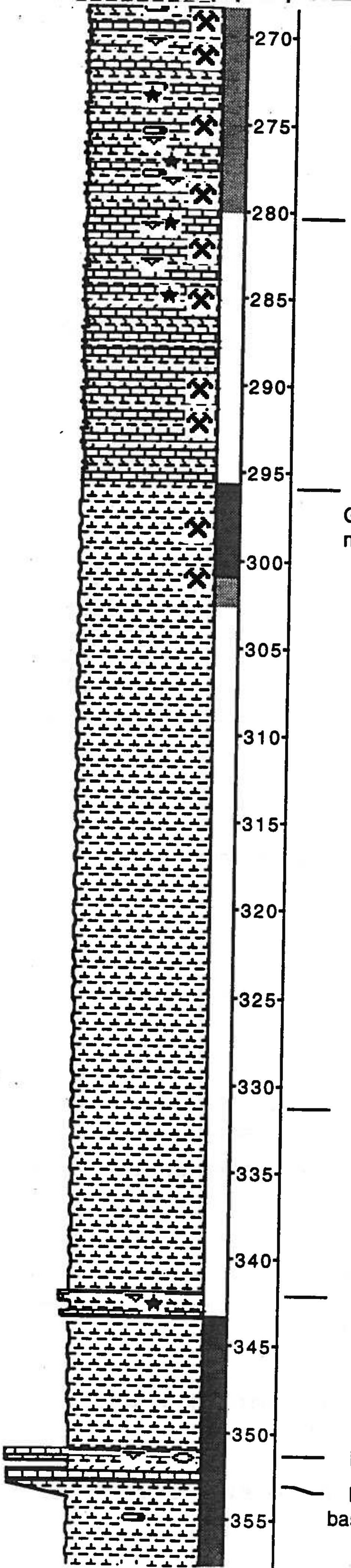


CALUMET MEMBER
Pinkish grey, skeletal lime mudstone, burrow mottled at top, nodular in part

Light olive to greenish grey, argillaceous, skeletal lime mudstone, wackestone in part

Light grey lime mudstone grading downwards into increasingly argillaceous, faintly nodular lime mudstone

Medium interbedded pinkish grey, nodular, skeletal lime mudstone and



greyish green calcareous shale

Light grey and greenish grey, argillaceous, nodular lime mudstone

FIREBAG MEMBER

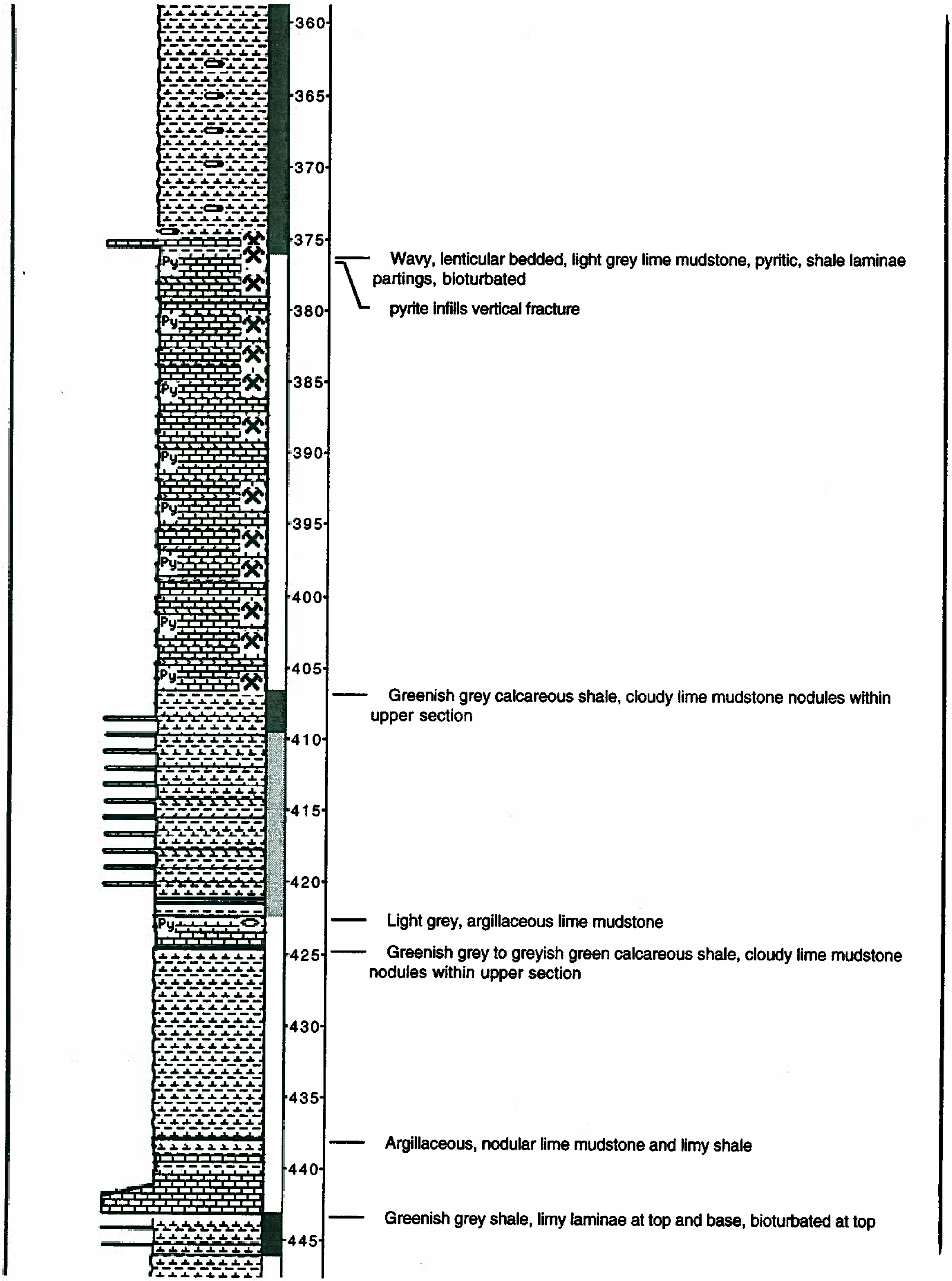
Greyish green, calcareous shale, bioturbated, contains cloudy lime mudstone nodules within upper section

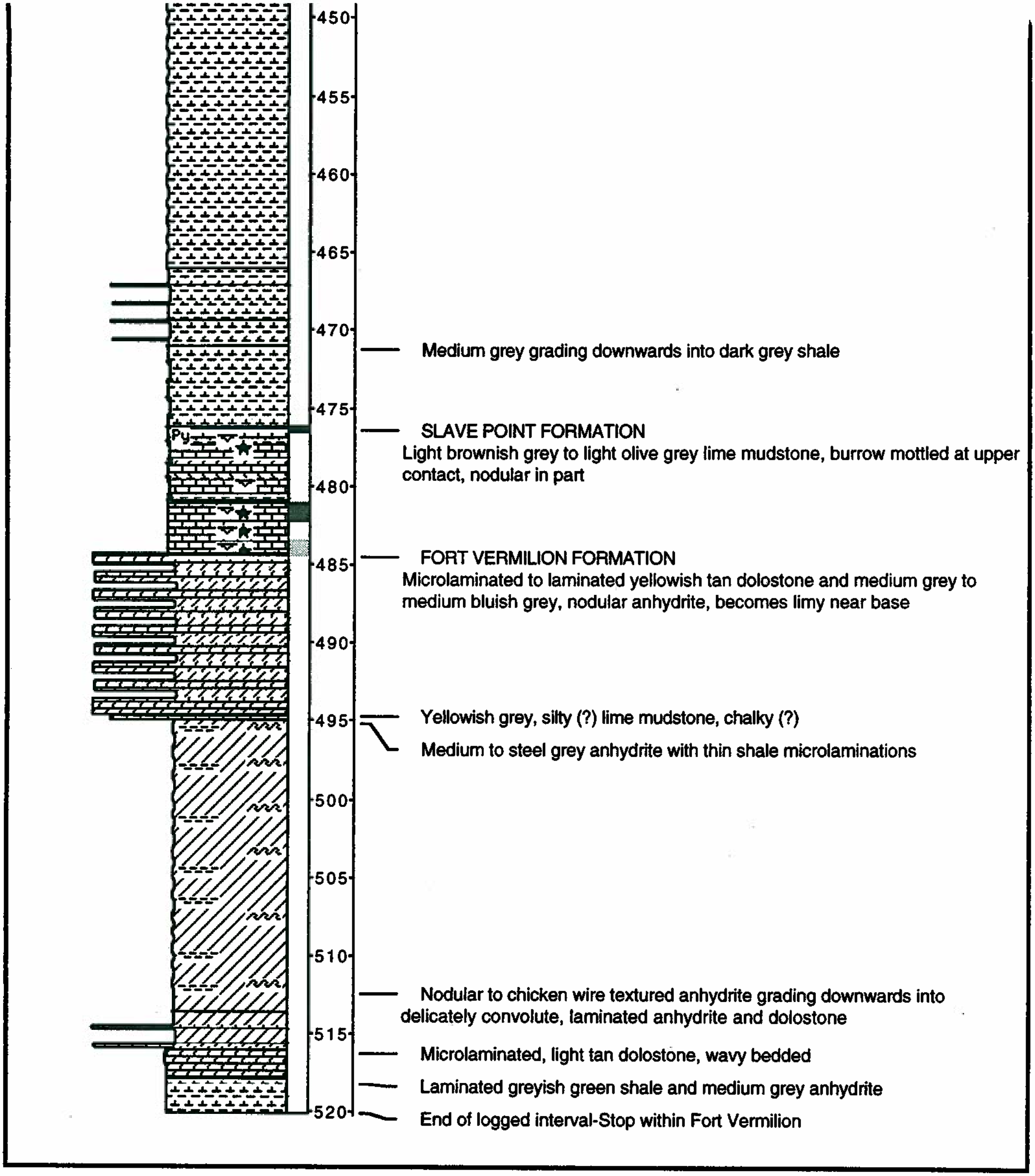
Faintly laminated greyish green shale

Argillaceous, brachiopod wackestone

Light grey and greyish green nodular lime mudstone, very argillaceous

Faintly laminated, greyish green calcareous shale, limy in part especially at base, bioturbated


360
365
370
375
Wavy, lenticular bedded, light grey lime mudstone, pyritic, shale laminae partings, bioturbated
pyrite infills vertical fracture
380
Py
385
390
395
400
405
Greenish grey calcareous shale, cloudy lime mudstone nodules within upper section
410
415
420
Light grey, argillaceous lime mudstone
425
Greenish grey to greyish green calcareous shale, cloudy lime mudstone nodules within upper section
430
435
Argillaceous, nodular lime mudstone and limy shale
440
Greenish grey shale, limy laminae at top and base, bioturbated at top
445


450
455
460
465
470
Medium grey grading downwards into dark grey shale
475
Py
SLAVE POINT FORMATION
Light brownish grey to light olive grey lime mudstone, burrow mottled at upper contact, nodular in part
480
FORT VERMILION FORMATION
485
Microlaminated to laminated yellowish tan dolostone and medium grey to medium bluish grey, nodular anhydrite, becomes limy near base
490
Yellowish grey, silty (?) lime mudstone, chalky (?)
495
Medium to steel grey anhydrite with thin shale microlaminations
500
505
510
Nodular to chicken wire textured anhydrite grading downwards into delicately convolute, laminated anhydrite and dolostone
515
Microlaminated, light tan dolostone, wavy bedded
Laminated greyish green shale and medium grey anhydrite
520
End of logged interval-Stop within Fort Vermilion

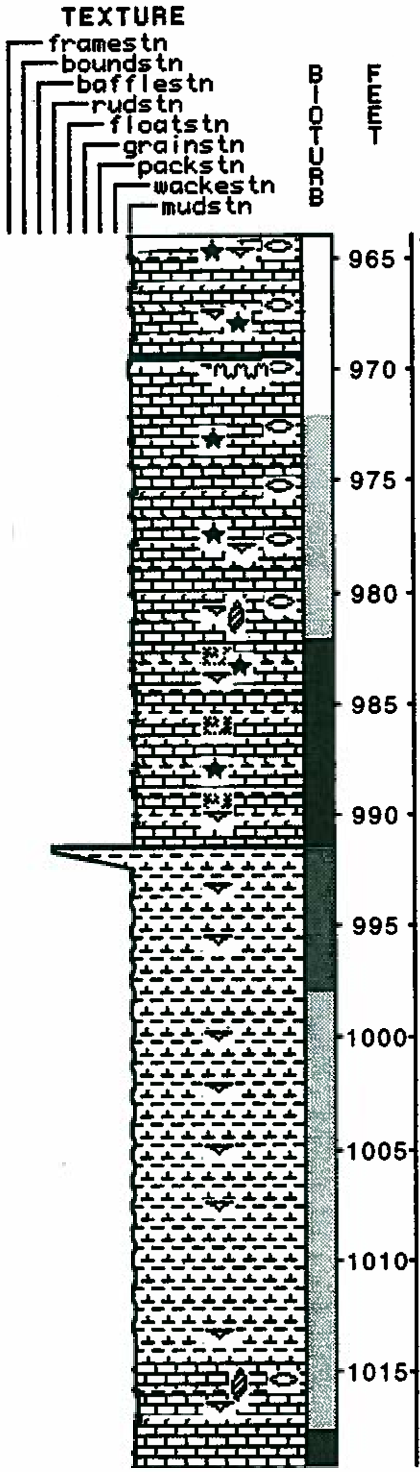
BEAR BILTMORE1
7-11-87-17w4

Date logged: January 4, 1994

Logged by: D.K.Cotterill (Alberta Geological Survey)

Ground: 1445.00 ft   KB: 0.00 ft

Remarks: Cored Succession: Ireton Formation to Precambrian
Logged Interval: Basal Cooking Lake to Upper Ft. Vermilion
Core Location: ERCB Core Research Centre
2 1/2 inch core, excellent condition



COOKING LAKE FORMATION

Light brownish grey, nodular lime mudstone

Light buff, chalky, nodular lime mudstone, clean

Light tan grey, nodular lime mudstone, most nodules mottled tan grey and blackened

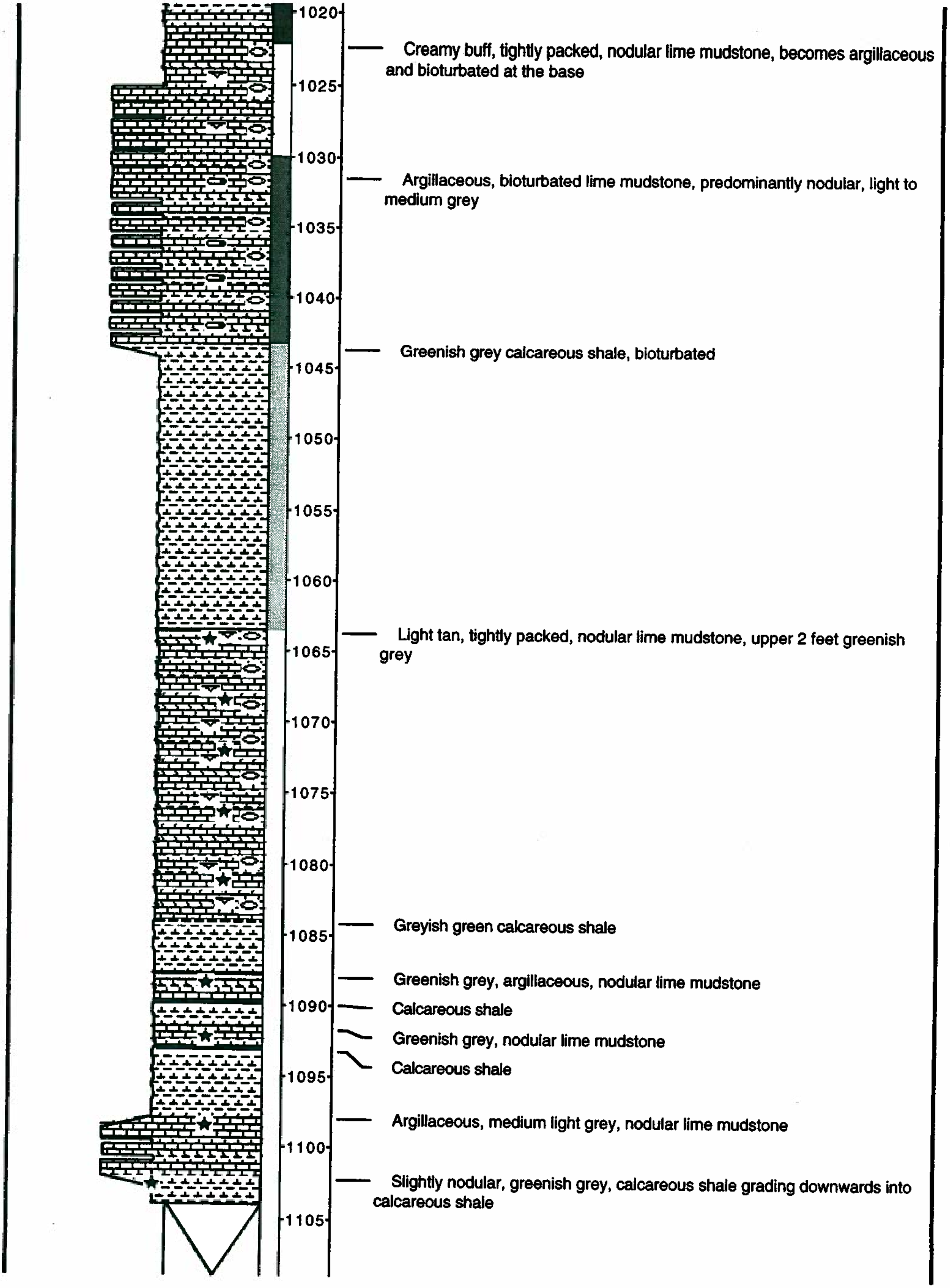
MILDRED MEMBER

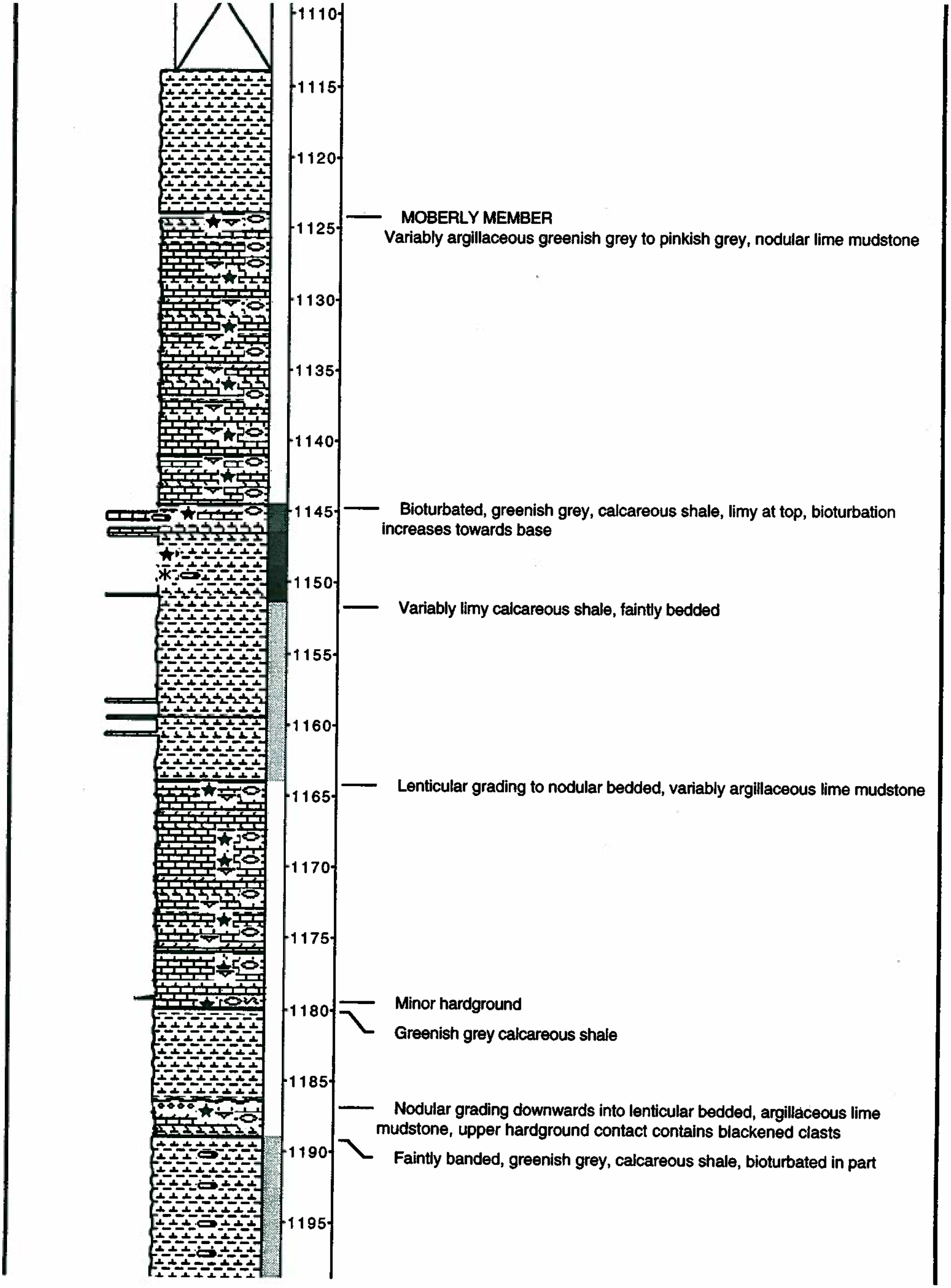
Light medium grey, heavily bioturbated lime mudstone, argillaceous, Macaronichnus ??

Medium grey, calcareous shale, bioturbated in part, occasional brachiopod shells

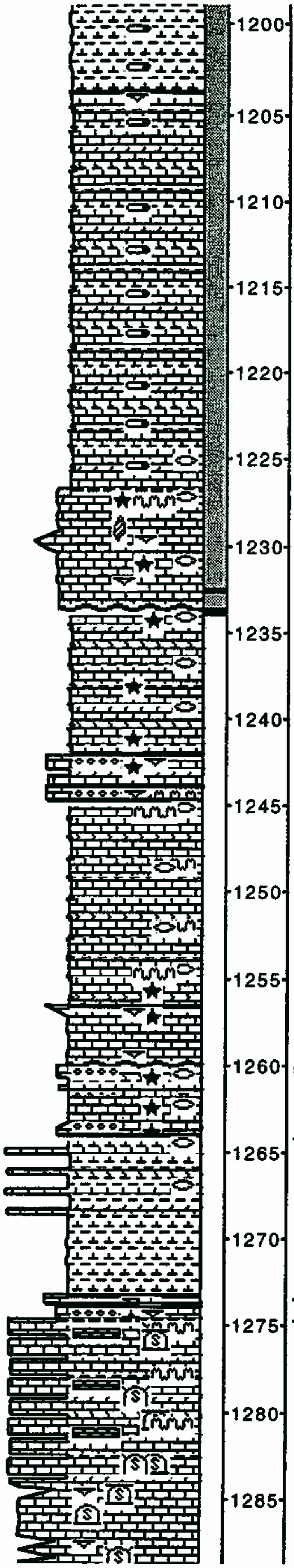
Light greenish grey to pinkish grey, nodular lime mudstone, occasional blackened grains

Bioturbated, argillaceous lime mudstone, greenish grey


1020
1025
1030
1035
1040
1045
1050
1055
1060
1065
1070
1075
1080
1085
1090
1095
1100
1105
Creamy buff, tightly packed, nodular lime mudstone, becomes argillaceous and bioturbated at the base
Argillaceous, bioturbated lime mudstone, predominantly nodular, light to medium grey
Greenish grey calcareous shale, bioturbated
Light tan, tightly packed, nodular lime mudstone, upper 2 feet greenish grey
Greyish green calcareous shale
Greenish grey, argillaceous, nodular lime mudstone
Calcareous shale
Greenish grey, nodular lime mudstone
Calcareous shale
Argillaceous, medium light grey, nodular lime mudstone
Slightly nodular, greenish grey, calcareous shale grading downwards into calcareous shale



1110
1115
1120
1125
1130
1135
1140
1145
1150
1155
1160
1165
1170
1175
1180
1185
1190
1195
MOBERLY MEMBER
Variably argillaceous greenish grey to pinkish grey, nodular lime mudstone
Bioturbated, greenish grey, calcareous shale, limy at top, bioturbation increases towards base
Variably limy calcareous shale, faintly bedded
Lenticular grading to nodular bedded, variably argillaceous lime mudstone
Minor hardground
Greenish grey calcareous shale
Nodular grading downwards into lenticular bedded, argillaceous lime mudstone, upper hardground contact contains blackened clasts
Faintly banded, greenish grey, calcareous shale, bioturbated in part



Lenticular, wavy bedded, light greenish grey lime mudstone, lime mudstone beds (< 10 cm) separated by thin, wavy shale laminations

Very tightly packed, mottled, pinkish grey to light brownish grey, nodular wackestone with thin interbed of sketetal grainstone/packstone

Razor sharp, inclined hardground

Light greenish grey grading downwards into pinkish grey, nodular lime mudstone, less argillaceous towards base

Light greyish green, skeletal packstone, blackened pebbles/granules throughout

Light tan, very tightly packed, nodular mudstone, clean, brecciated appearance ??, mottled in part, two sketetal packstone interbeds

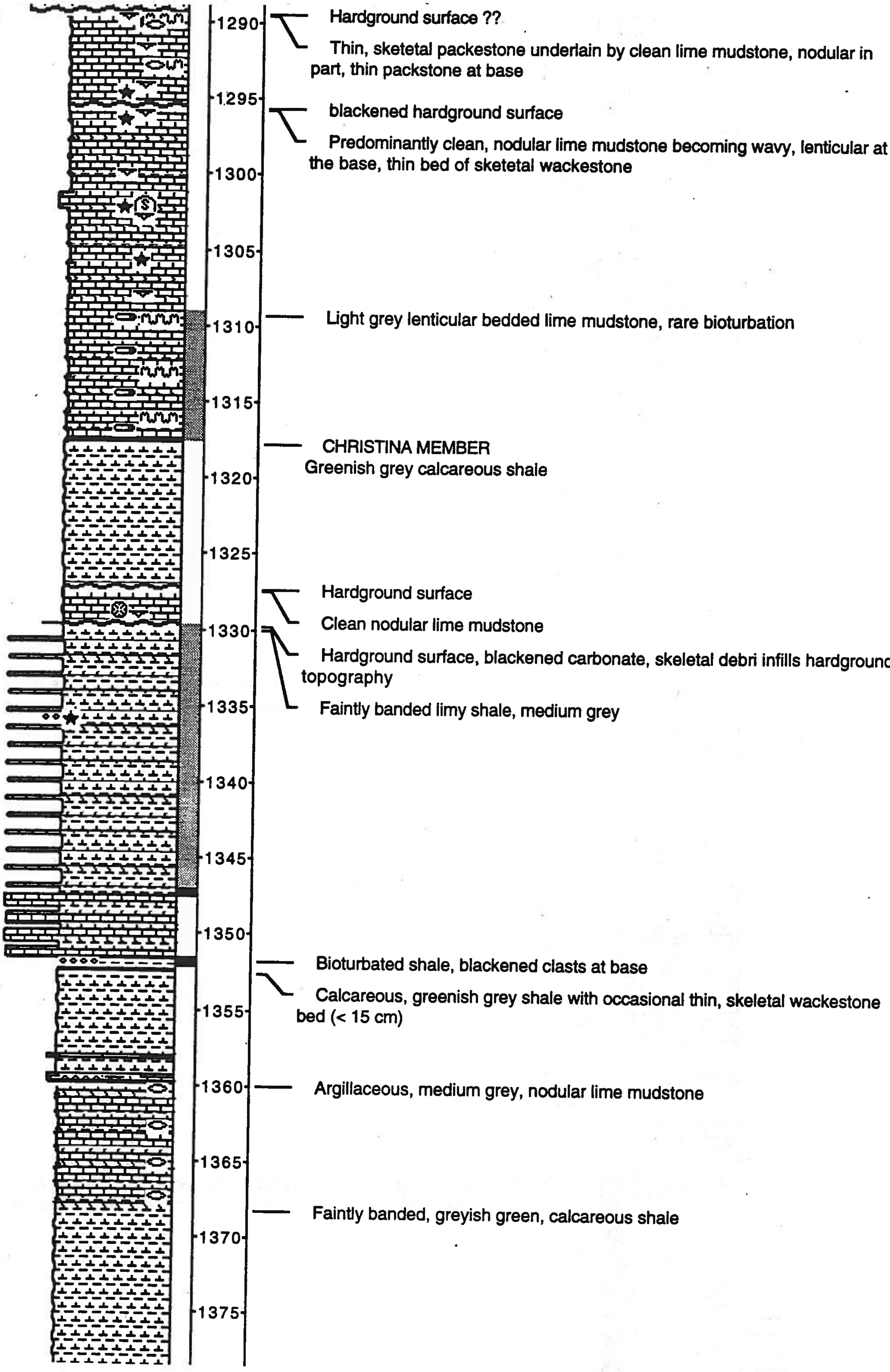
Hardground surface, blackened clasts

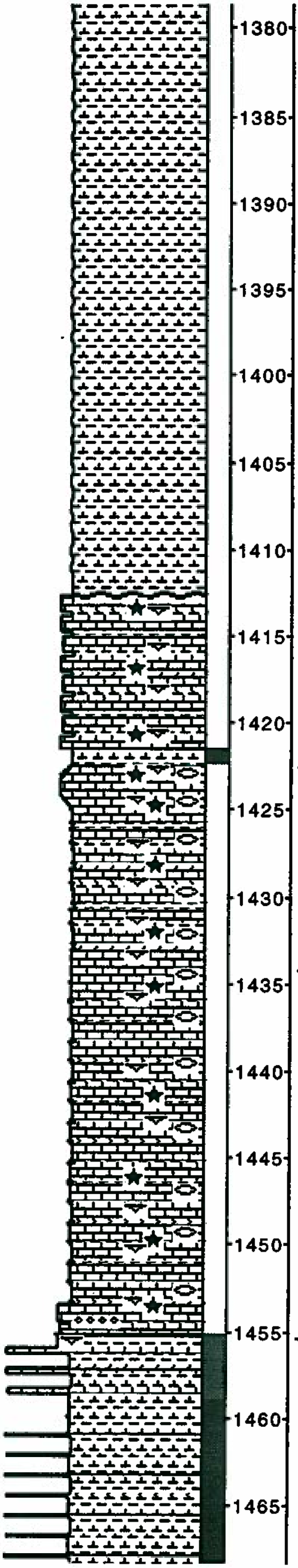
Dark greenish grey sketetal wackestone grading downwards into light greenish grey nodular lime mudstone, argillaceous wackestone at base

Dark greenish grey, calcareous shale with limy nodules in upper portion

Skeletal wackestone/grainstone

Branching to tabular stromatoporoid argillaceous rudstones grading downwards into clean stromatoporoid floatstones interbedded with clean lime mudstones/wackestones containing thin shelled brachiopods. Sketetal material pinkish grey to light tan, argillaceous component within upper portion brownish black


1290
1295
1300
1305
1310
1315
1320
1325
1330
1335
1340
1345
1350
1355
1360
1365
1370
1375
Hardground surface ??
Thin, sketetal packestone underlain by clean lime mudstone, nodular in part, thin packstone at base
blackened hardground surface
Predominantly clean, nodular lime mudstone becoming wavy, lenticular at the base, thin bed of sketetal wackestone
Light grey lenticular bedded lime mudstone, rare bioturbation
CHRISTINA MEMBER
Greenish grey calcareous shale
Hardground surface
Clean nodular lime mudstone
Hardground surface, blackened carbonate, skeletal debri infills hardground topography
Faintly banded limy shale, medium grey
Bioturbated shale, blackened clasts at base
Calcareous, greenish grey shale with occasional thin, skeletal wackestone bed (< 15 cm)
Argillaceous, medium grey, nodular lime mudstone
Faintly banded, greyish green, calcareous shale

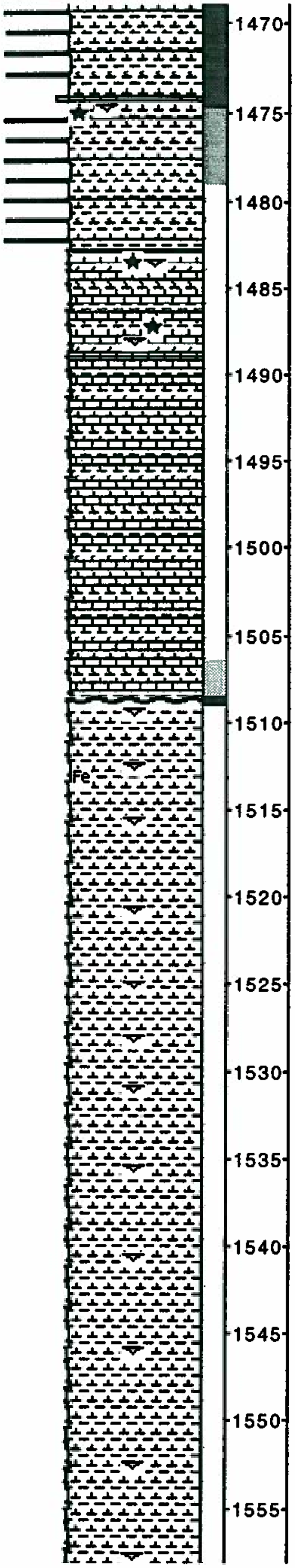


CALUMET MEMBER
Light olive grey, skeletal, argillaceous, wackestone

Light greenish grey, nodular wackestone grading to lime mudstone, becomes increasingly argillaceous down section

Lenticular wavy to nodular bedded, pinkish to yellowish grey, lime mudstone, clean, compacted nodular horizons, wackestone at base

Greenish grey to greyish green calcareous shale, cloudy lime mudstone nodules and fossiliferous within upper portion, variably bioturbated

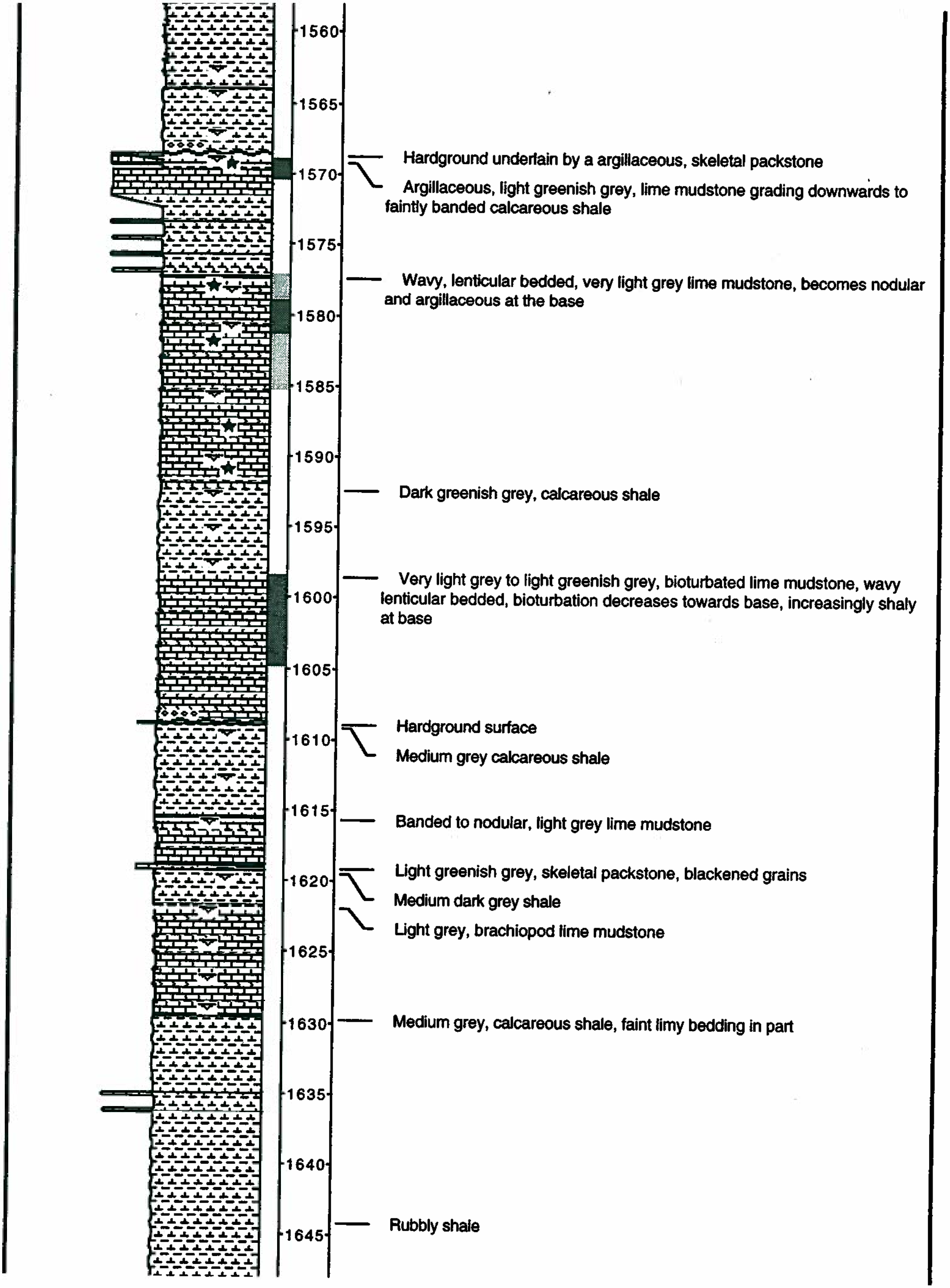


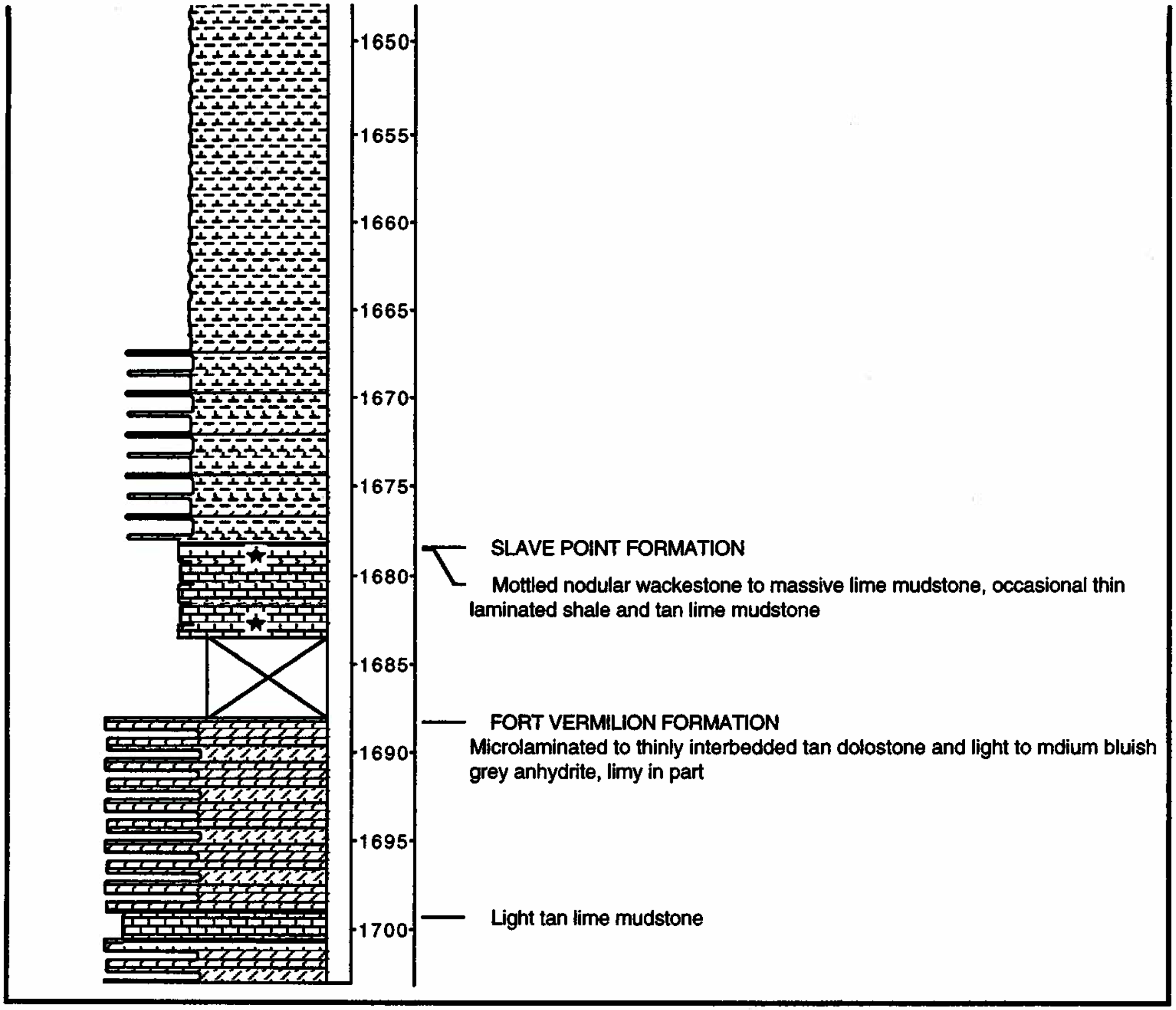
Medium grey shale

Lenticular to nodular bedded, medium light grey lime mudstone and dark greenish grey calcareous shale, occasional skeletal remains

FIREBAG MEMBER

Dark greenish grey to medium grey, calcareous shale, occasional lime mudstone laminae and brachiopods, carbonized plant remains (??)


1560
1565
1570
1575
1580
1585
1590
1595
1600
1605
1610
1615
1620
1625
1630
1635
1640
1645
Hardground underlain by a argillaceous, skeletal packstone
Argillaceous, light greenish grey, lime mudstone grading downwards to faintly banded calcareous shale
Wavy, lenticular bedded, very light grey lime mudstone, becomes nodular and argillaceous at the base
Dark greenish grey, calcareous shale
Very light grey to light greenish grey, bioturbated lime mudstone, wavy lenticular bedded, bioturbation decreases towards base, increasingly shaly at base
Hardground surface
Medium grey calcareous shale
Banded to nodular, light grey lime mudstone
Light greenish grey, skeletal packstone, blackened grains
Medium dark grey shale
Light grey, brachiopod lime mudstone
Medium grey, calcareous shale, faint limy bedding in part
Rubbly shale


1650
1655
1660
1665
1670
1675
1680
1685
1690
1695
1700
SLAVE POINT FORMATION
Mottled nodular wackestone to massive lime mudstone, occasional thin laminated shale and tan lime mudstone
FORT VERMILION FORMATION
Microlaminated to thinly interbedded tan dolostone and light to mdium bluish grey anhydrite, limy in part
Light tan lime mudstone

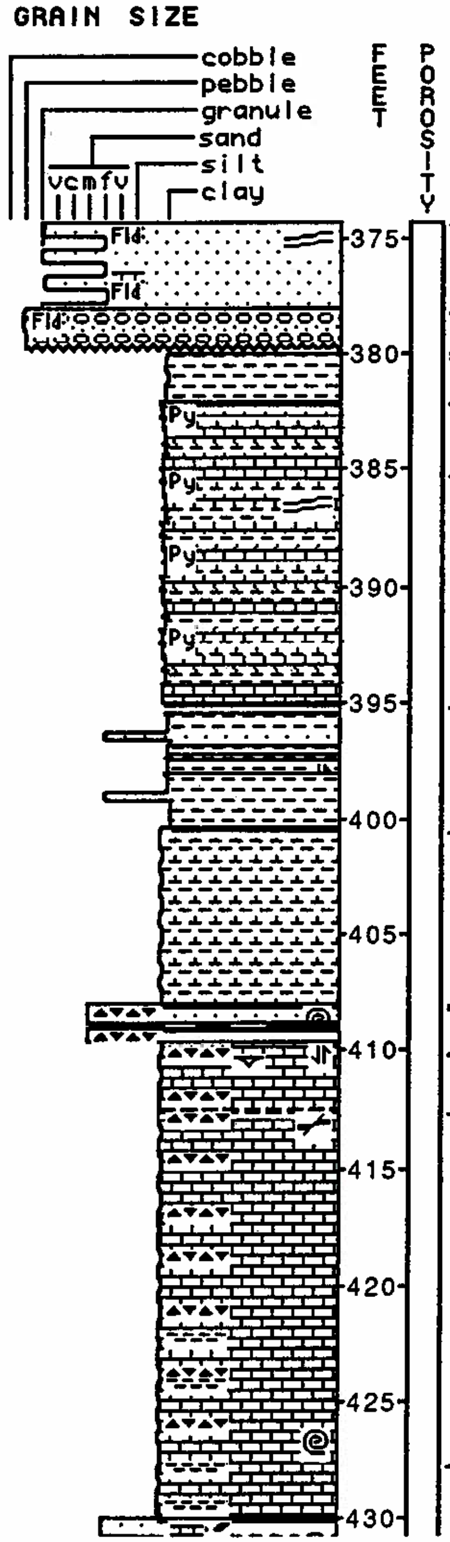
Shell Eatha EV
12-6-99-8w4

Date logged: October 3, 1994

Logged by: D.K. Cotterill (Alberta Geological Survey)

Ground: 1004.90 ft KB: 1012.10 ft

Remarks: Cored through sinkhole??



granular to very fine grained, poorly sorted sandstone, calcareous, thin bedded in part

matrix supported pebble conglomerate, matrix consists of very fine grained, clean sand, pebbles dominated by quartz, some feldspar, subangular, calcareous

Mottled cream and greyish pink lime mudstone, contorted bdding

medium grey shale, soft, non calcareous

argillaceous lime mudstone, competant, pyritic, light medium grey

very argillaceous lime mudstone grading to calcareous shale in places, light to medium grey, pyritic, some inclined lie rich banding

sandy shale with sand rich horizons, sand poorly sorted very fine to coarse grained, one section consists of a vertical contact with shale and coarse grained sand, unit becomes increasingly shaly downwards

medium grey, soft, fissile, waxy shale

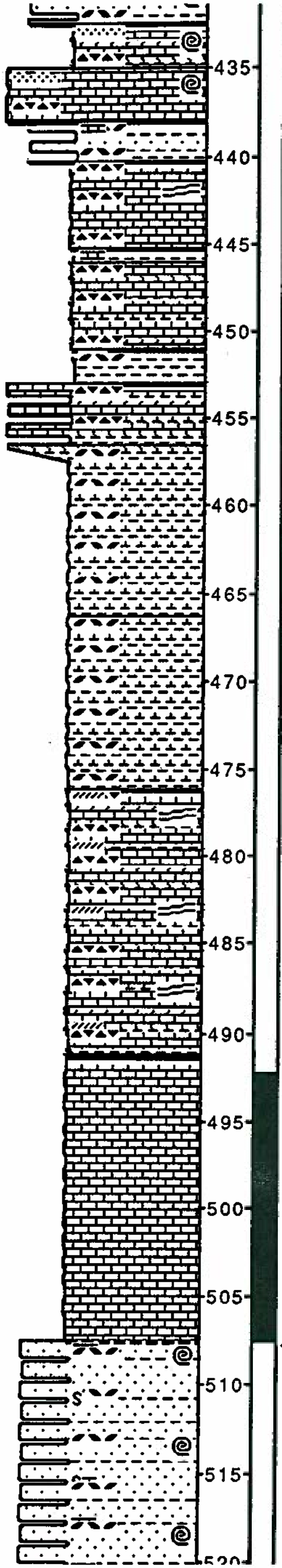
base Firebag Member??

fine to medium grained sandstone containing laminated, clean, lime mudstone clasts (tabular) and a thin pyritic limestone bed

top Slave Point Formation??
Brecciated lime mudstone, choatically orientated tabular to rounded clasts, pinkish grey, brachiopods, sandy at top of section

Clean, brecciated lime mudstone, very light brown, breccia rich horizons, clast size 2 mm to 40mm, infills vertical fractures in places (2mm to 7 mm) becomes increasingly argillaceous downwards

Shaly sandstone with lime mudstone breccia clasts, calcareous



Brecciated, argillaceous limestone, sandy in part, medium grey

very agrillaceous sandstone containing abundant rip up clasts of lime mudstone

light brown to medium grey brecciated lime mudstone, some very thin to laminated bedding

slightly calcareous, grey shale

brecciated lime mudstone and shale, breccia clasts infill some vertical fractures, light grey to light brown, tabular to blocky clasts

dolomitic shale with small tabular lime mudstone clasts, dark medium grey

argillaceous, brecciated lime mudstone, tabular to blocky clasts

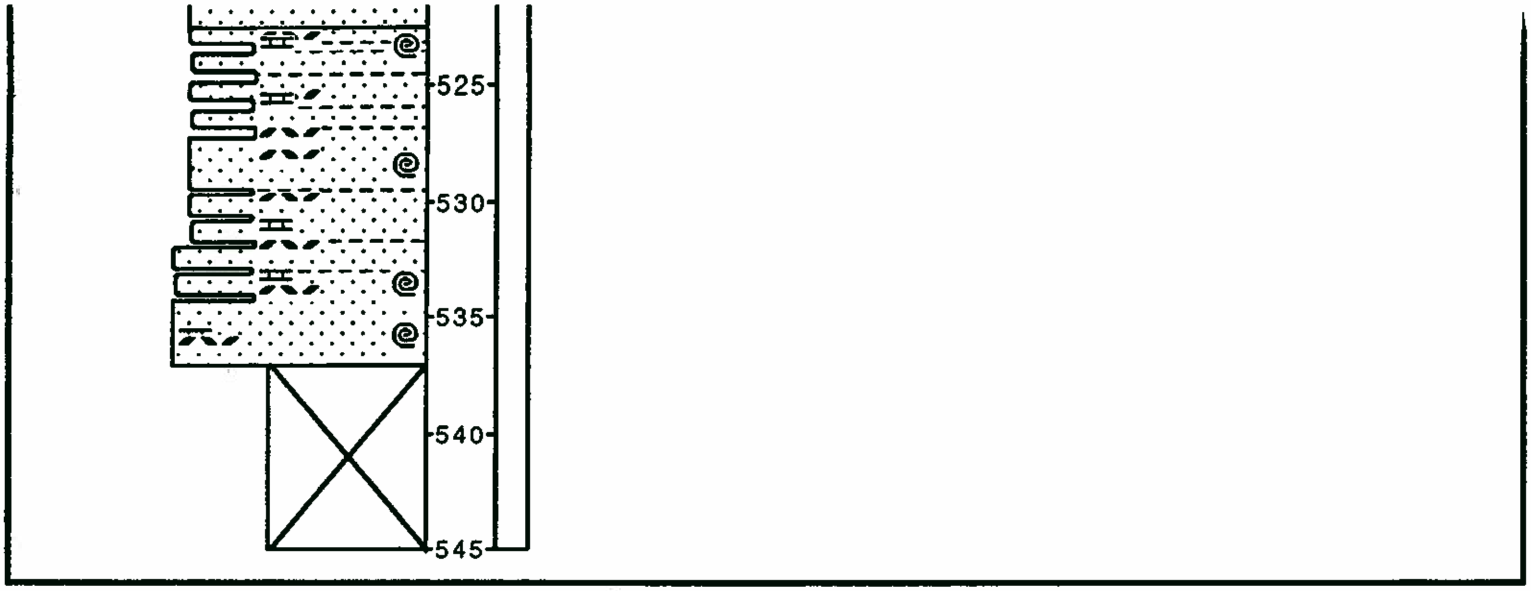
dark grey calcareous shale with abundant small to moderate sized lime mudstone clasts (tabular to blocky, 2 to 20 mm), soft

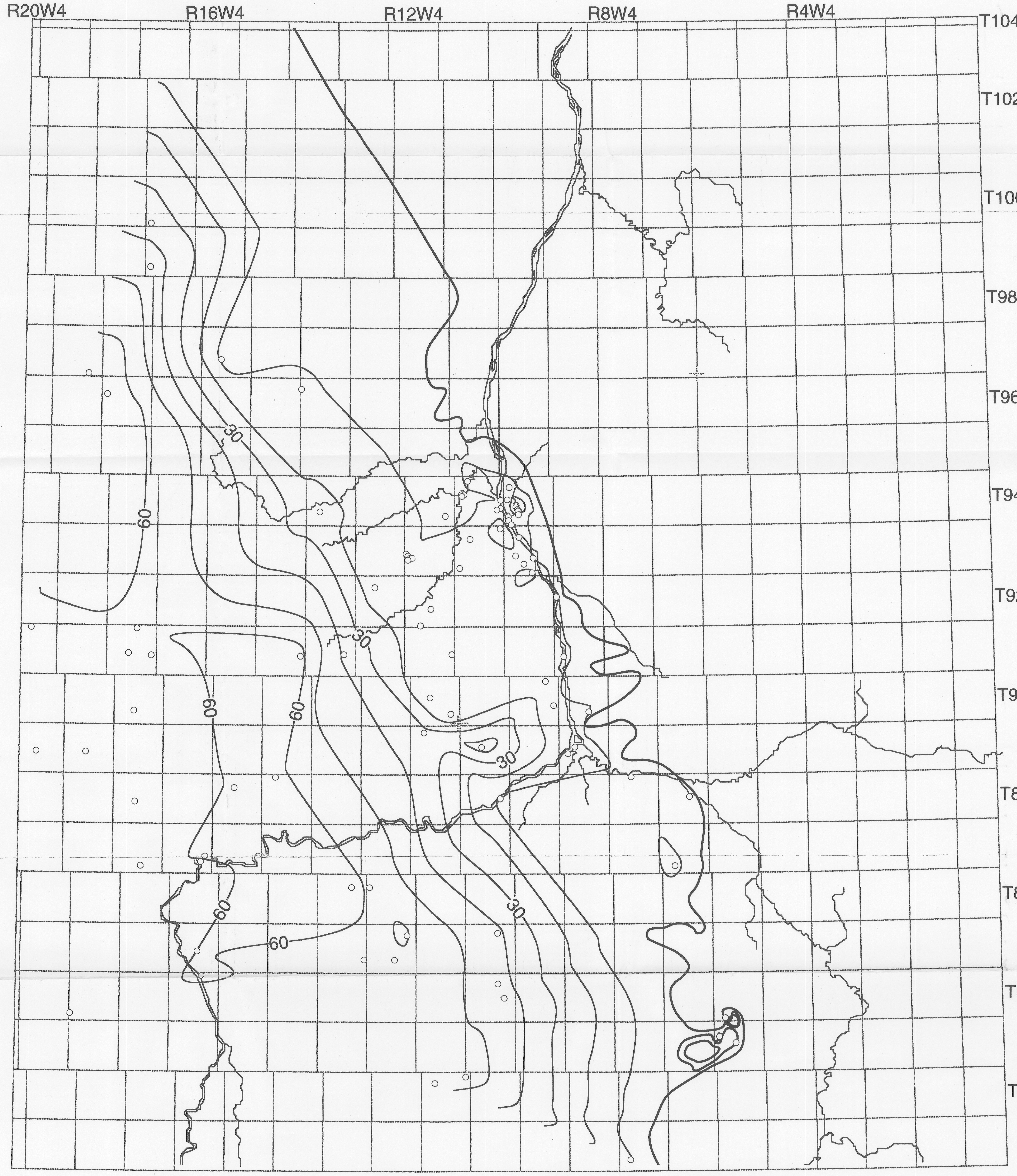
large rip up clasts, light brown to light grey, blocky (up to 7 cm)

intermix of small scale brecciated lime mudstone and thinly laminated, low angle bedded limestone, light brown to light grey, trace anhydrite

recrystallized limestone, mottled white, cream, and grey, very porous, vuggy, vugs (2 mm to 5 cm), calcite lined

variably argillaceous, calcareous sandstone containing abundant lime mudstone rip up clasts, sulfur especially at top


525
530
535
540
545



Isopach Map	
Moberly Member	
Contour Interval = 10 m	
Devonian Northeast Alberta	
(40 km)	
	Figure
Date:7/13/95	500000

Figure 10. Isopach of the Moberly Member

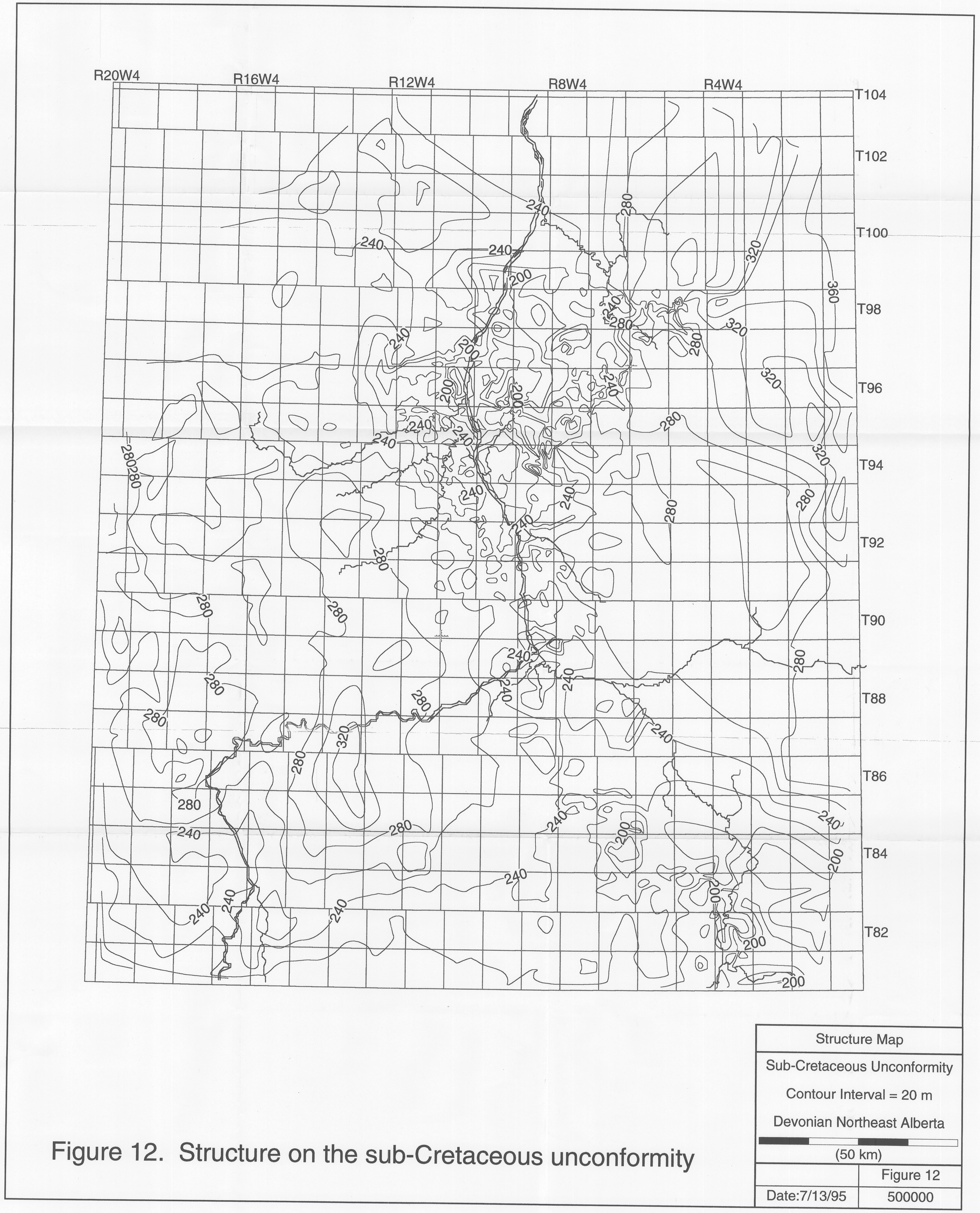


Figure 12. Structure on the sub-Cretaceous unconformity

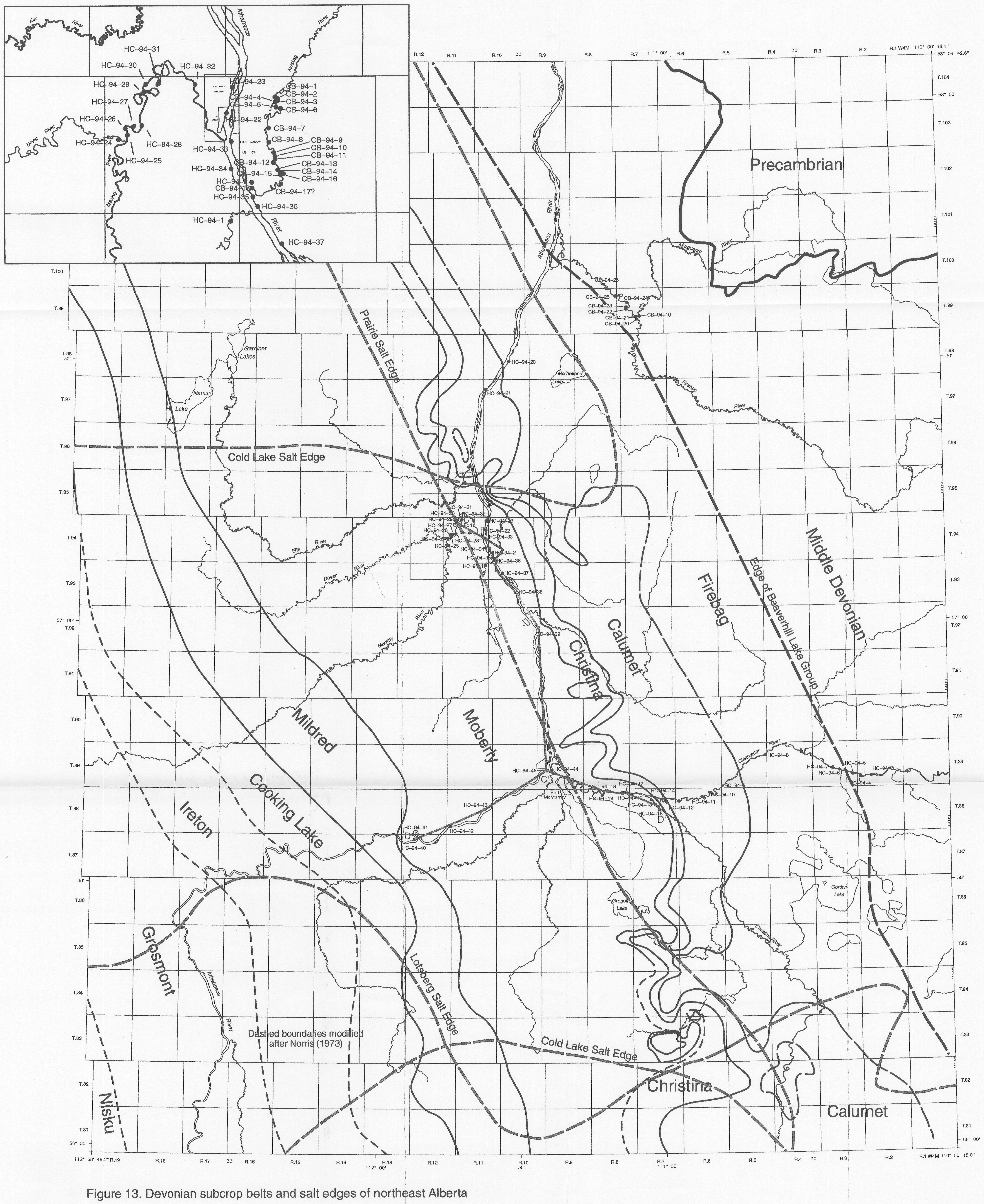


Figure 13. Devonian subcrop belts and salt edges of northeast Alberta

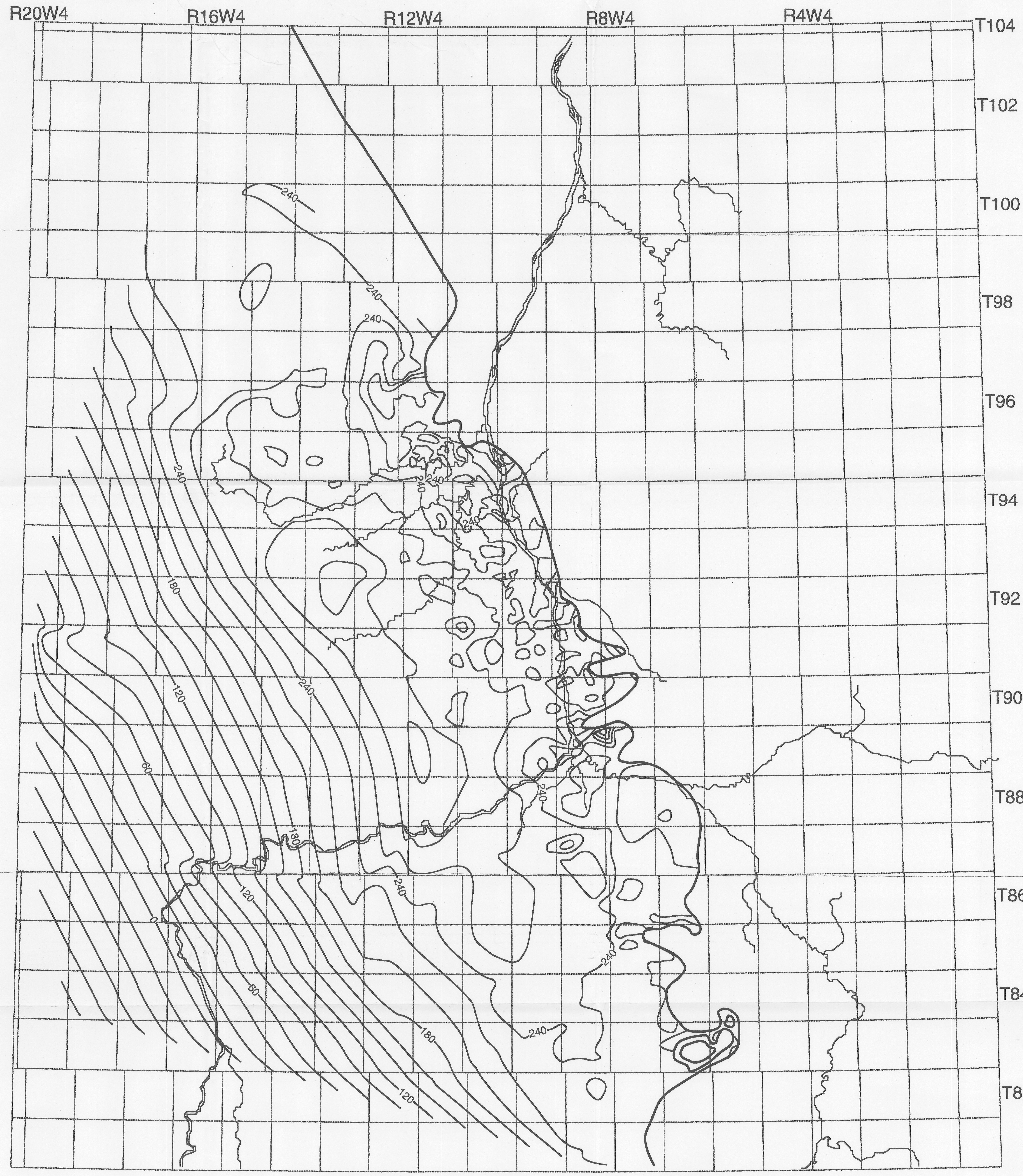


Figure 19. Structure on the Moberly Member

Structure Map

Top Moberly Member

Contour Interval = 20 m

Devonian Northeast Alberta

(40 km)

Figure 19

Date:3/3/95

1:500000

Figure 23. Stratigraphic Cross Section C-C'

(refer to Figure 13 for line of section)

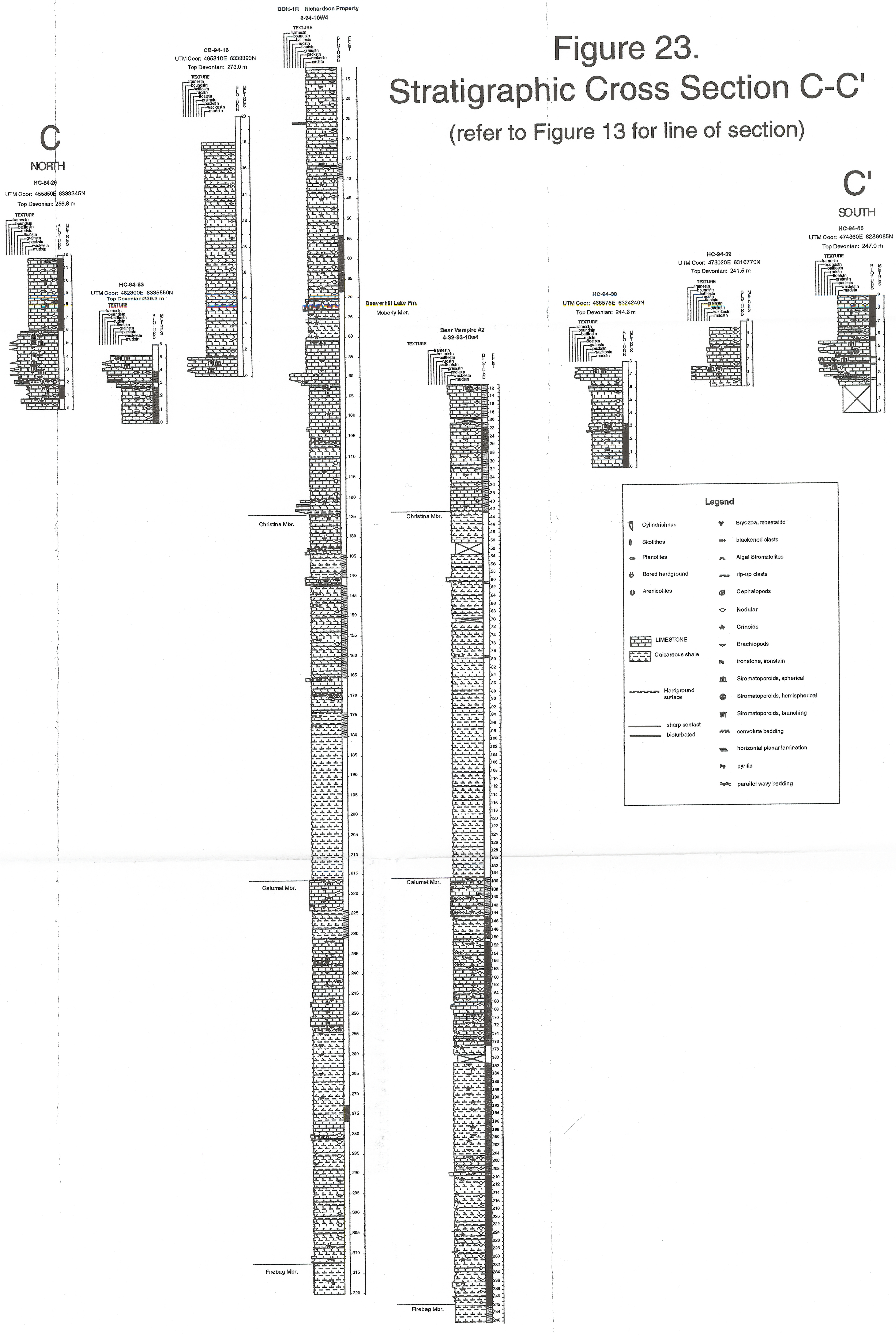


Figure 24.
Stratigraphic Cross Section D-D'
(refer to Figure 13 for line of section)