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Depositional Architecture of the Cadomin and Monteith Formation,

North East British Columbia

by

Eric Shawn Hanson ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of **Master of Science**.

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate studies and Research for acceptance, a thesis entitled **Depositional Architecture of the Monteith and Cadomin Formations, North Eastern British Columbia** submitted by **Eric Shawn Hanson** in partial fulfillment of the requirements for the degree of **Master of Science.**

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Abstract

In the Aitken Creek area of northeastern British Columbia, the uppermost Jurassic and lower Cretaceous section is divided into the Minnes and Bullhead Groups. The quartzose sands of the Monteith Formation (Minnes Group) and the chert rich sands of the Cadomin Formation (Bullhead Group) have been subjected to stratigraphic and sedimentologic analysis. These formations were deposited in a non-marine, braidplain environment throughout the study area. Despite similar depositional histories, these formations are separated by a basin wide unconformity. The braided fluvial system of the Monteith Formation is localized in northeastern British Columbia, while the Cadomin system is more widespread across northeastern British Columbia and Alberta.

Permeability and ultimate reservoir potential for these sandy braidplain sediments is controlled by primary depositional textures, mineralogy, secondary enhancement, and diagenetic modifications that have occurred during burial and compaction. The major reservoir limiting factors include silica cementation, residual bitumen occluding pore spaces, and the presence of detrital and authigenic clays. A secondary pore-system was developed by fracturing and through the leaching of grains by pore fluids, thereby increasing permeability. In northeastern British Columbia, both structural and stratigraphic traps exist within the Monteith and Cadomin Formations. A fundamental understanding of all these factors is needed to locate and exploit economic reservoir quality rocks in these braidplain sediments.

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Stratigraphic Overview

Uppermost Jurassic and Lower Cretaceous strata of northeastern British Columbia belong to the Minnes and Bullhead Groups (Figure 1-1). The Jurassic and Lower Cretaceous Minnes Group is comprised of the Monteith, Beattie Peaks, Monach, and Bickford Formations. The group spans an interval from Late Tithonian to Late Valanginian time. The Minnes Group is separated from the overlying Bullhead Group by the 'sub-Cretaceous' unconformity, a regional surface representing a depositional hiatus. The base of the Cretaceous Bullhead Group is poorly defined as Middle to Late Barremian. Throughout most of the study area, the Cadomin Formation, the lowermost unit of the Bullhead Group (emended) overlies this unconformity. Conformably overlying the Cadomin are the coal bearing beds of the Gething Formation (Figure 1-1).

The Upper Jurassic to Lower Cretaceous Minnes Group consists of a thick sequence of clastic rocks that represent a transition from marine to continental sediments. Lithologically the Minnes Group includes conglomerates, chert and quartzose sandstone, siltstone, shale, and coal. Regionally, the Minnes Group is truncated north and east by the erosional unconformity, which marks the base of the Bullhead Group and tapers out into the Peace River Plains.

The transgressive Bullhead sequence is initiated by Cadomin deposition and is capped at the upper boundary by the transgressive Bluesky Formation. The Cadomin is dominantly composed of conglomerates, conglomerate rich sandstones, and cherty sandstones deposited in a non-marine alluvial-fluvial environment. The Cadomin is a widespread distinctive stratigraphic marker in the foothills of the Rocky Mountains. It extends from north of the Peace River area in northeastern British Columbia to the Canadian/American border; a distance of more than a 1000 km. Homotaxial equivalent conglomerates are found over much of the Western Interior of North America, including

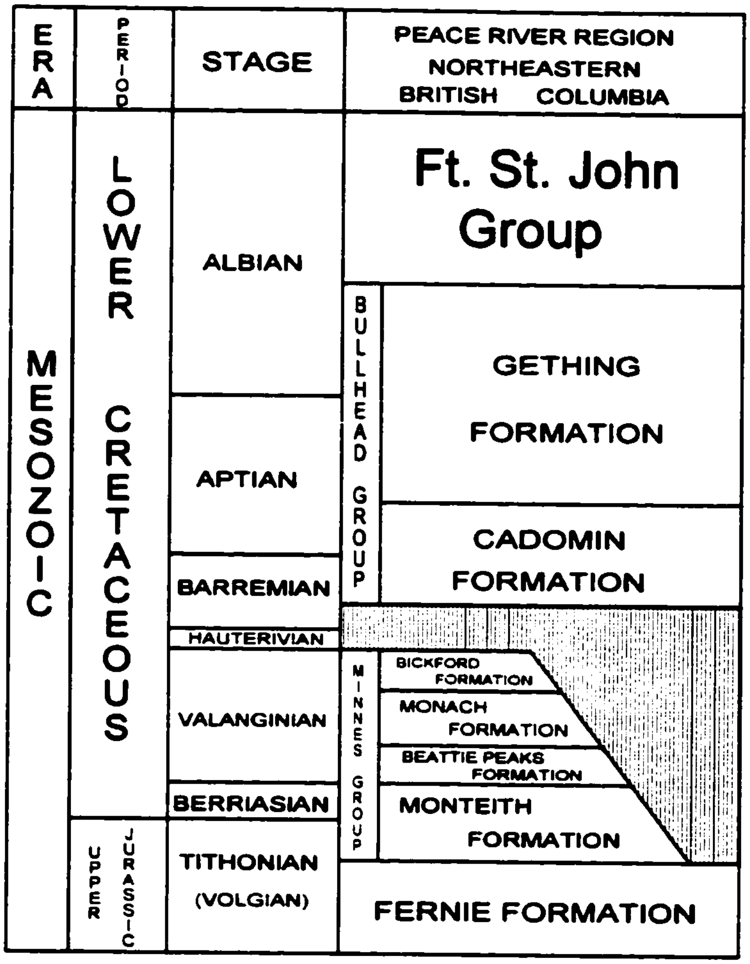


Figure 1-1

Stratigraphic Column for the Peace River Region Northeastern British Columbia

the Ephraim conglomerates of Utah and the Kootenai conglomerate of Montana.

The Gething Formation ranges from non-marine to marine, and comprises the upper portion of the Bullhead Group. It is composed of interstratified conglomerates, sandstones, siltstones, mudstones, and coals. The Gething Formation is the thickest member of the Bullhead Group, and has received considerable attention from geologists because of the economic potential of its thick coal seams. The Gething Formation is capped by the Bluesky Formation, the lowest most Formation of the Ft. St. John Group. The Bluesky Formation is a marine unit that has backstepped transgressively over the non-marine to marginal marine deposits of the Gething Formation.

Study Area

The study area is situated in northeastern British Columbia, northwest of Ft. St. John and north of Williston Lake (Figure 1-2). This region lies along the northwestern edge of the Western Canadian Sedimentary Basin. It encompasses areas 94-B-8, 94-B-9, 94-B-16, 94-A-13, 94-A-12, and Townships 84 to 88-25w6.

Within the study area, there are numerous Lower Cretaceous gas fields. These fields include Fireweed, Aitken Creek, Birch, Blueberry, Blueberry East, Blueberry West, Inga, Beg, Gundy Creek, Daiber, Graham and Kobes. The project area was chosen because of the lack of understanding of Lower Cretaceous strata, and the large amount of crown land available within this area at the initiation of this study (September 1997).

Objectives

Despite the large number of gas and oil fields that produce from Lower Cretaceous strata within northeastern British Columbia, little subsurface research has been done to delineate the complex stratigraphy and clarify current terminology. Stratigraphic nomenclature is often specific to certain reservoirs, with different formation names being used to delineate the same regional stratigraphic horizon. The Upper Jurassic, Lower Cretaceous in the region has been recorded as the Dunlevy, Buick Creek, Dresser, Nikanassin, Rigel Sandstone, Cadomin, Basal Gething and the Monteith.

The main objective of this thesis is to establish a high-resolution stratigraphic framework for subsurface units (Minnes, Cadomin, and Basal Gething) of the Lower Cretaceous deposits within the study area. The project focuses on the Cadomin and Monteith Formations in detail. A predictive facies model within a stratigraphic framework is generated and integrated into a regional palaeoenvironmental setting. The importance of allocyclic versus autocyclic geologic processes is analyzed. Parameters such as tectonics, eustatic changes in sea-level, subsidence rates, sediment accommodation space, sediment flux into the basin, and natural processes associated with depositional systems

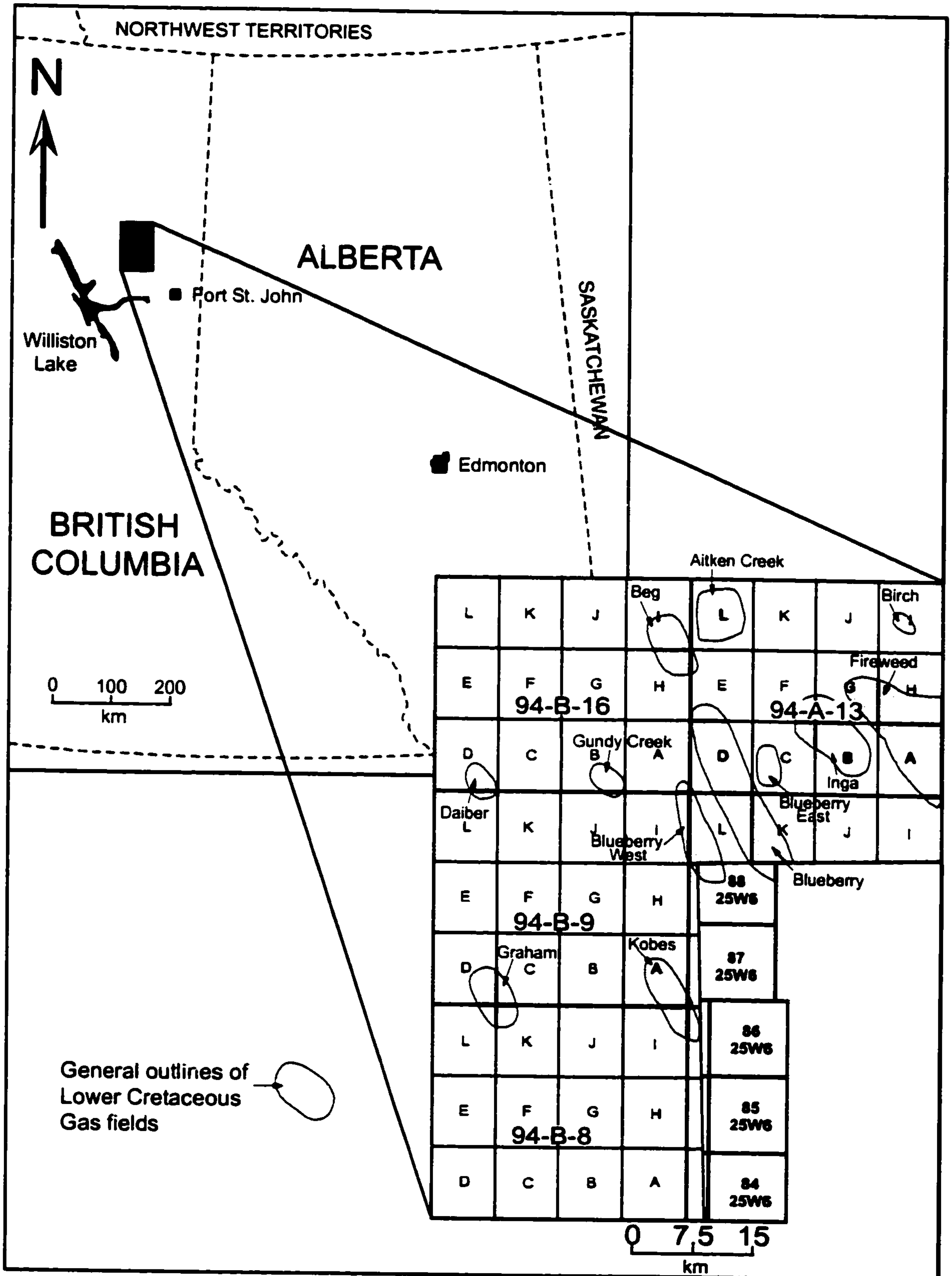


Figure 1-2

Study Area

(*e.g.* channel abandonment and alluvial fan lobe switching) are accounted for to create this model.

Reservoir characteristics (permeability and porosity) of the Lower Cretaceous strata are related to the various lithologies and textures. A detailed diagenetic history is described and any diagenetic modifications are studied to determine their effects on reservoir quality (porosity and permeability). This information could be used in future exploration/exploitation for Lower Cretaceous reservoirs in the study area.

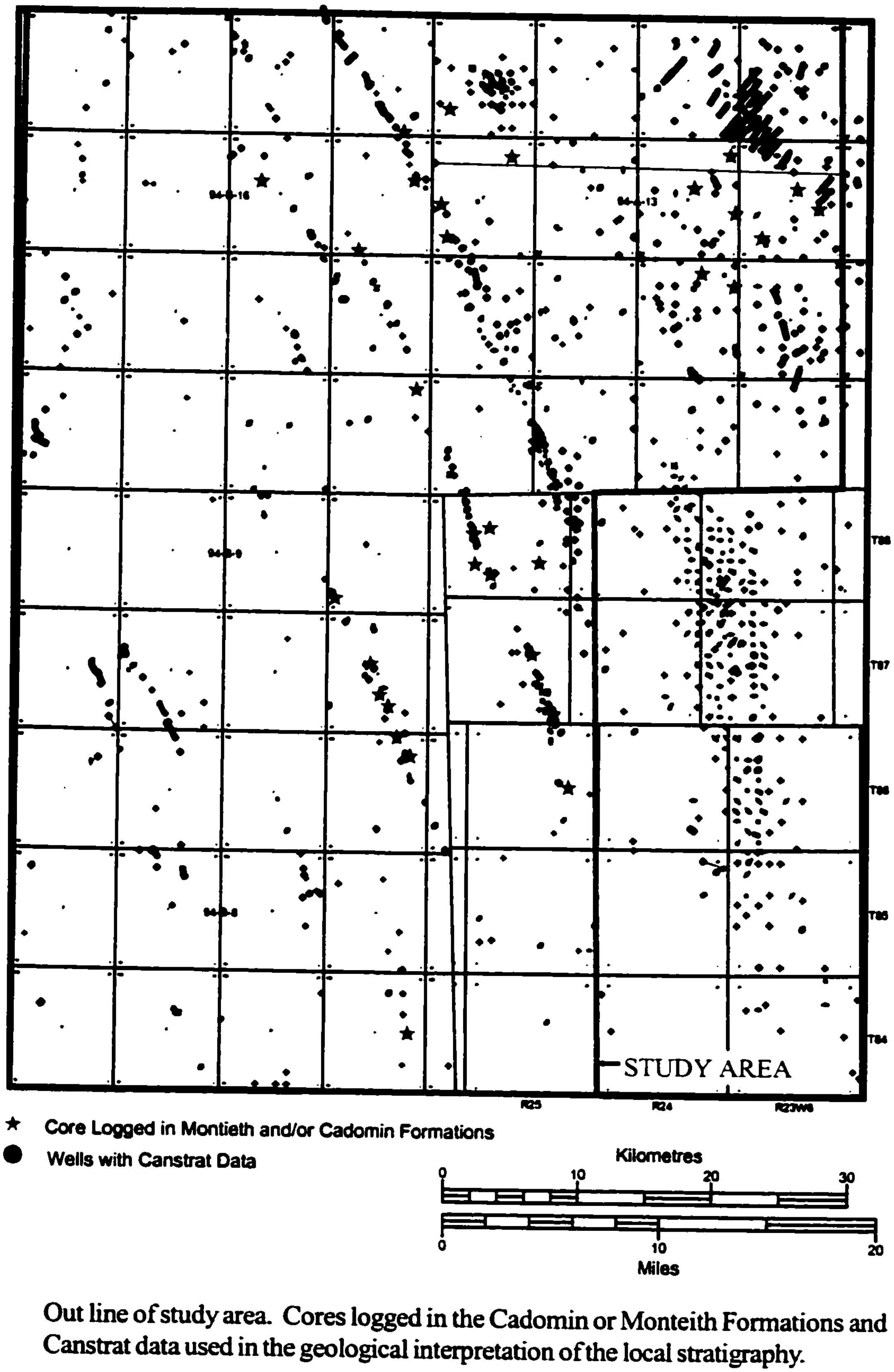
Methodology and Database

Thirty-three wells totaling 800 meters of core from the Upper Jurassic and Lower Cretaceous were logged and correlated with their respective well logs. Core data was then entered into the computer-logging program AppleCORE (Appendix 1). Grain size measurements were made using a Canstrat grain size card and a binocular microscope. Lithology, sedimentary structures, diagenetic alterations, and any possible discontinuities were examined and described in detail.

The study area has been extensively drilled and approximately 600 wells penetrating the Cadomin Formation or deeper, exist within the area. With this large database of geophysical well logs, in conjunction with Canstrat lithology charts, differing formations and their lithologies were defined (Figure 1-3).

During core logging, samples were taken from areas of interest to determine composition, porosity and diagenetic history. Approximately one hundred thin sections (3 x 5") from these samples were cut and described (Appendix 2). Samples were also taken for S.E.M. analysis to aid in the determination of the diagenetic history and for x-ray photography in hopes of highlighting sedimentary structures.

Cross-sections were constructed across the study area using geophysical well logs, Canstrat lithology charts and core data. Once these regional sections were completed, formation tops were picked on a well by well basis throughout the remainder of the study



Out line of study area. Cores logged in the Cadomin or Monteith Formations and Canstrat data used in the geological interpretation of the local stratigraphy.

Figure 1-3

area. These picks were referenced to the cross-sections and entered into a spreadsheet (Appendix 3). With this data, a variety of structural and isopach maps were hand contoured and then digitized.

Previous Work

A considerable amount of work has been conducted on the Lower Cretaceous strata throughout the Peace River region. Initially by European explorers who entered the area in the early 1800's. Work initially focused on the coal seams and later on the hydrocarbon bearing zones in the subsurface. As the years progressed, the complex stratigraphic nomenclature evolved from Selwyn's (1877) single Division III, to present where there are two Groups and seven Formations (Figure 1-4).

In 1792 the first white man, Alexander MacKenzie, entered British Columbia via the Peace River route with plans of expanding the fur trade in this region (MacKenzie 1801). MacKenzie (1801) noticed that some of the cliffs in the Peace River canyon had "stratum of a bituminous substance which resembles coal". He sampled this substance at various localities as a potential fuel. Some appeared to be excellent fuel, while others resisted all attempts at burning.

By 1805, Simon Fraser established fur trading posts at Ft. St. John, Hudson Hope and McLeod Lake (McLearn and Kindle 1950). These fur posts opened up the area and enabled regular visits by agents and voyageurs of the fur trading companies. In 1875, seventy years after the area opened up, Alfred R. C. Selwyn of the Geological Survey of Canada launched the first geological expedition into this region. He described the Lower Cretaceous coal bearing sediments and massive conglomerates, of the Peace River Canyon and tentatively dated them as lower Mesozoic or Paleozoic (Selwyn 1877). The next geological expedition through the Peace River country was lead by George M. Dawson of the Geological Survey of Canada in 1879 en route from Port Simpson on the Pacific Coast to Edmonton (Dawson 1881). During this voyage, Dawson failed to enter

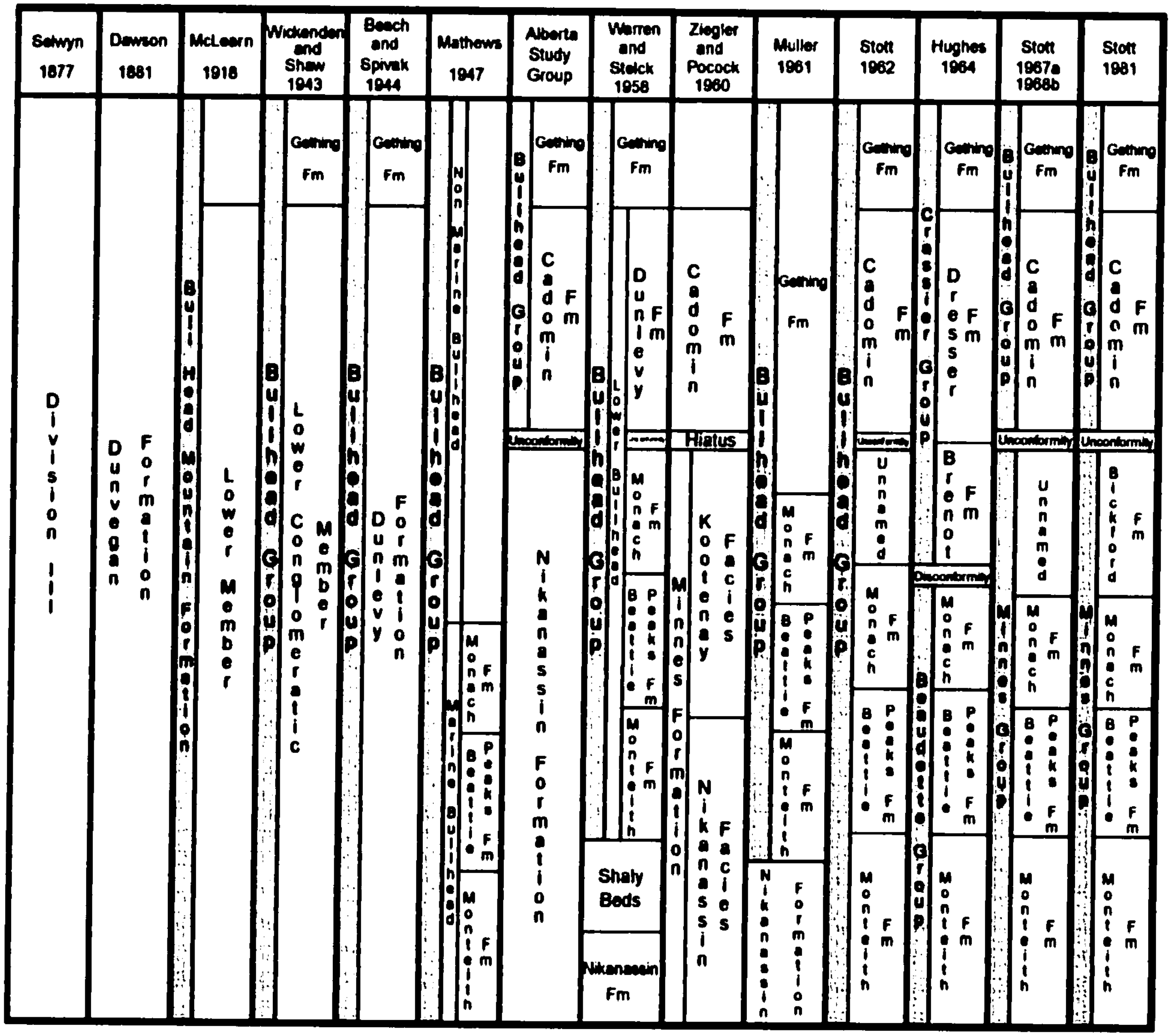


Figure 1-4 Historical Stratigraphic Overview (not a correlation chart)

and investigate the Lower Cretaceous sandstone found in the Peace River Canyon, near Hudson Hope. As a result, he miscorrelated the Division III succession described by Selwyn (1877) as equivalent to the younger Dunvegan sandstone, Dawson had examined on the Pine and Peace Rivers (Stott 1998) (Figure 1-4). This mistake lead to confusion among workers, as for some time they continued to carry on with Dawson's miscorrelation.

The reported occurrences of coal, gold, and petroleum in the Peace River region resulted in geological investigations being initiated by the Government of British Columbia. The first real effort to study the Mesozoic in detail was under taken by F. H. McLearn (1918) of the Geological Survey of Canada (G.S.C.). He examined outcrops along the Peace River from Twelvemile Creek, above Peace River Canyon, down to Vermilion. His study focused on the structure and stratigraphic succession of the Lower Cretaceous rocks with the aim of investigating the area for possible oil exploration. In McLearn's 1918 report, he assigned the name Bull Head Mountain Sandstone to the Lower Cretaceous succession in the region of Peace River Canyon (Figure 1-4).

McLearn also reported the discovery of oil, made during the summer of 1917 in the No. 2 well of the Peace River Oil Company about 15 miles south of the Peace River (McLearn 1918). Several companies drilled wells throughout the Peace River Valley between 1917-1919. Although some wells encountered small gas and oil shows there was no associated production. Results for potential economic hydrocarbons were generally disappointing.

Serious exploration for hydrocarbons in the Peace River region did not begin until the early 1920's. From June 1921 to June 1922 the British Columbia Department of Lands drilled five diamond drill holes, spaced about a mile apart, along Farrell Creek, some 18 miles northwest of Hudson Hope (Dresser 1922). Four of these wells fall within the study area (4,5,7,14-B/94-B-8), the other just outside of it. These wells penetrated the Ft. St. John shales and sandstones and entered the top of the Bullhead sandstones as defined by McLearn. Only minor showings of oil and gas were encountered in these wells (Dresser 1922).

More work was done on the Lower Cretaceous strata in the Peace River Canyon in 1922. McLearn was sent by the G.S.C. to report on the coal deposits found within the canyon. He delineated an upper member of the "Bullhead Formation" and named it the Gething member (McLearn 1923). McLearn also recognized an unconformity at the base of the Lower Cretaceous section and believed that Lower Cretaceous sandstones sat directly on top of Triassic rocks. When Jurassic shales (Fernie Group) were found and identified in the area, he modified this definition to exclude these shales and include only the overlying sandy strata (McLearn and Kindle 1950).

In 1929 MacKay, working in the coal mining area near Cadomin, first introduced the name Cadomin Formation for a conglomeratic unit found near the base of the Lower Cretaceous section. He defined the type locality near the town of Cadomin south of the Athabasca River. MacKay also identified the Nikanassin a sandy unit overlying the Fernie shales and underlying the newly defined Cadomin Formation (MacKay 1929, 1930). By 1940, McLearn concluded that the Bullhead Mountain Formation was composed of three distinct units, a lower sandstone (Nikanassin Formation), a middle conglomerate (Cadomin Formation), and an upper coal bearing horizon (Gething Formation) (McLearn 1940).

The threat of Japanese invasion of Alaska during the Second World War led to the construction of the Alaska Highway, which resulted in an expansion of geological activities within the Peace River region. After extensive fieldwork, Wickenden and Shaw (1943) determined that shales, named the Moosebar Member separated the underlying Bullhead Mountain Formation from the overlying sands, which they named the Commotion Member. Upon making these divisions, they shortened the name to Bullhead and raised the Formation to Group status (Wickenden and Shaw 1943). The Bullhead Group was comprised of the Gething Formation and the Lower Conglomerate

Member (Figure 1-4). With the opening of the Alaska Highway, some of the larger oil companies at the time, (Shell Oil, Imperial Oil Limited, and Phillips Petroleum) began intense hydrocarbon exploration in and around the Peace River area.

After working in the Dunlevy-Portage Mountain map area, north of the Peace River Canyon, Beach and Spivak (1944) introduced the Dunlevy Formation for strata of the lower member of the Bullhead Group. The Dunlevy Formation, as they defined it, included quartzose sands and massive conglomerates, lying below coal bearing strata of the Gething Formation (Beach and Spivak 1944) (Figure 1-4).

Mathews (1947) proposed a subdivision of the Bullhead Group into marine and non-marine members. This new division was based on his work in the Carbon Creek Basin between Pine and Peace rivers and southwest of the Peace River Canyon. He divided the lower marine Bullhead Group into the Monteith, Beattie Peaks, and Monach Formations (Mathews 1947) (Figure 1-4).

Allan and Stelck (1940) compiled the first report entailing a subsurface description of the Cretaceous succession east of the Foothills. In 1954, the Alberta Study Group described in detail, the subsurface Lower Cretaceous stratigraphy of northeastern British Columbia (Workman 1954). This report determined that Beach and Spivak's (1944) lower Dunlevy Formation was largely equivalent to the Nikanassin Formation of the Alberta Foothills and that the Bullhead Group should embrace only the Gething Formation and conglomerates of the Cadomin Formation. Strata between the Cadomin and Fernie Formations was then classified as the Nikanassin Formation (Workman 1954) (Figure 1-4).

Ziegler and Pocock (1960) re-defined the sequence of rocks that lay between the Fernie shales and the Cadomin Formation as the Minnes Formation. Another attempt was made by Hughes (1964) to divide the Lower Cretaceous rocks in the Carbon Creek Basin into a useful system. Unfortunately his new terminology and subdivision of the units were not practical throughout much of the region and were therefore abandoned. Stott

(1967) agreed that Mathews' (1947) three formations (Monteith, Beattie Peaks, and Monach) were useful and also readily recognized throughout much of the region (Figure 1-4). Stott continued studies of the Jurassic-Lower Cretaceous sediments throughout the Foothills of northeastern British Columbia. These studies increased the general knowledge of Jurassic-Lower Cretaceous deposits and refined some of the regional correlations. Stott (1981) established two new Formations, the Bickford and the Gorman Creek, within the Minnes Group (Figure 1-4). He continued working on the Jurassic-Lower Cretaceous in northeastern British Columbia and produced more regional work dealing with the effects of tectonism and the paleogeography of the Peace River region (Stott 1984).

Stott completed his latest research on the Jurassic-Lower Cretaceous in northeastern British Columbia in 1998. He focused on the Fernie Formation and the Minnes Group, in the northern Rocky Mountain Foothills in Alberta and British Columbia. He concluded that the Minnes Group consists of both marine and non-marine sediments recording a complex interaction between tectonic and sea level processes (Stott 1998).

This research will follow the stratigraphy as outlined by Stott (1981) (Figure 1-4).

Chapter 2
Stratigraphy

The Upper Jurassic Minnes Group and the Lower Cretaceous Bullhead Group of northeastern British Columbia comprise a thick succession of interfingering marine shales and continental shales and sandstones. In the Peace River region, a consistent widely used stratigraphic nomenclature is lacking (see Chapter 1). This makes regional geological correlations complex and confusing. The stratigraphic confusion arises from the fact that the terminology for the sandy beds overlying the Jurassic Fernie Formation arose in several different areas. This confusion has been compounded by the practices of the petroleum industry, as numerous names have been applied to the same subsurface unit in different reservoirs within the Peace River region. Stott (1981) has been most successful in normalizing the stratigraphic nomenclature for outcrop units in the Foothills of the region for the Upper Jurassic and Lower Cretaceous strata. He divided this interval into the Minnes and the Bullhead groups. A regional unconformity at the base of the extensive Bullhead Group separates these two units.

Minnes Group

It is standard practice in the petroleum industry to define the Nikanassin as any strata, east of the Foothills that lies between the Fernie Formation shales and the Cadomin Formation. Stott (1998) demonstrates that in fact it is possible to divide this "Nikanassin" interval in the subsurface. He recognized the Monteith Formation as well as younger units of the Minnes Group are contained within this interval in the Peace River region of British Columbia.

The Minnes Formation, as defined by Ziegler and Pocock (1960), includes the entire package of strata between the Jurassic Fernie Formation, and the Lower Cretaceous Cadomin Formation in the northern Foothills of Alberta, and northeastern British Columbia. The type section of the Minnes Group is located northeast of Kakwa Lake at Mount

Minnes, in the Jarvis Lake Map sheet. Stott (1967) elevated the Minnes from formational to group status. This interval contains both continental and marine sediments and can be subdivided into distinctive mappable lithological packages (Stott 1998).

The Minnes Group is sub-divided into four distinct formations in the Peace River region, which include the Monteith, Beattie Peaks, Monach and Bickford. Further south, near the Wapiti River, the strata overlying the Monteith Formation cannot be easily divided (Stott 1998). It has therefore been grouped together to create the Gorman Creek Formation. Moving towards the south and east into Alberta, the Minnes Group becomes laterally equivalent to the Nikanassin Formation.

The Minnes Group forms a clastic wedge that is thickest in the west and thins to its erosional edge in the Alberta plains to the east. This erosional edge trends north to north-west, lying west of Grande Prairie and slightly east of Dawson Creek and Ft. St. John (Stott 1998).

Monteith Formation

Mathews (1947) introduced the Monteith Formation to encompass quartzose sandstones lying above the Jurassic Fernie Formation. He never defined a type section for the Monteith Formation, but his descriptions came from the north face of Mount Monteith and from Beattie Peaks. The best Monteith exposures are found on Beattie Peaks. Stott (1998) measured and described the Beattie Peaks section, and proposed that it be used as the type section for the Monteith Formation.

Mathews originally stated (1947)

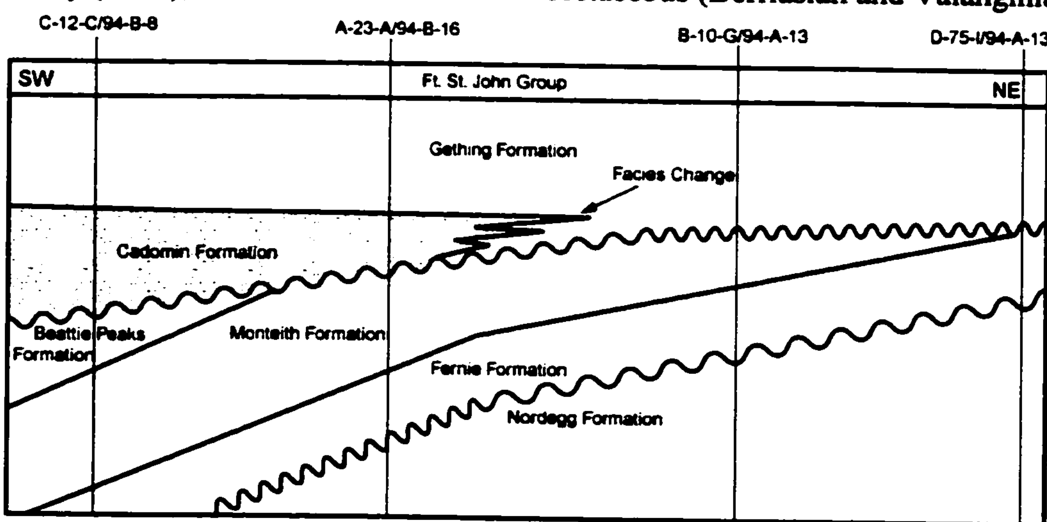
> "The greater part of the Monteith Formation is made up of dark grey arkosic sandstone, massive to flaggy, and in places showing cross-bedding and ripple marks. This sandstone occurs in beds usually from 10 to 30 feet thick, each separated by a few feet of

shale or shaly sandstone. The uppermost 500 feet of the formation is made up of white quartzite, commonly stylolitic and locally vuggy."

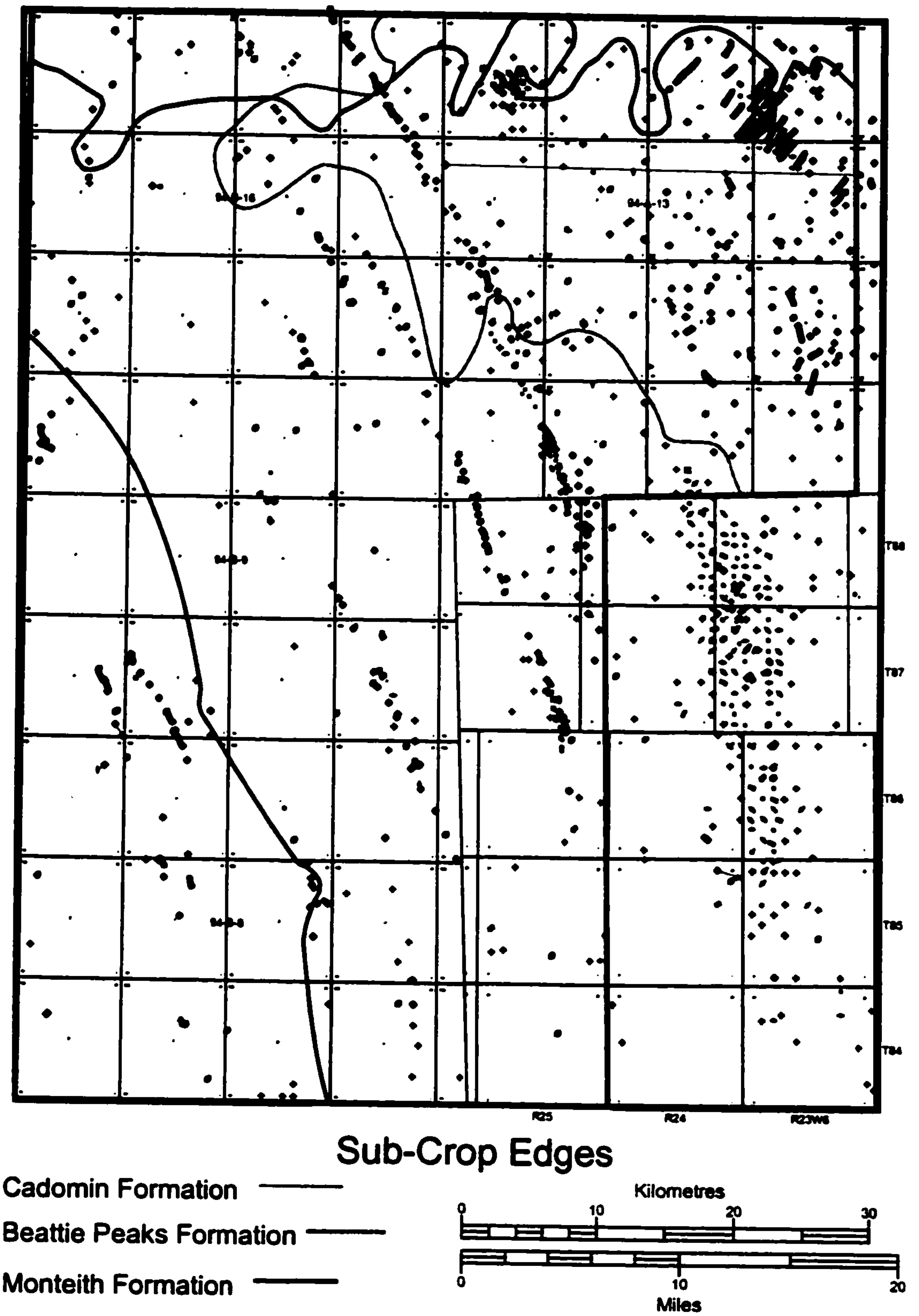
The lower contact of the Monteith is conformable with the underlying Fernie Formation. In outcrop, the contact is placed at the base of the lowest thick-bedded sandstone unit, which lies at the base of differing sandstone beds from one outcrop section to another. In geophysical well logs the base is readily picked when the gamma ray log kicks sharply to the left indicating the clean low radioactive quartzose sand of the Monteith Formation.

In outcrop, the upper contact of the Monteith Formation is located where recessive interbedded shales and sandstones of the Beattie Peaks Formation first appear. This contact is conformable, although a depositional hiatus may be present eastward towards the plains (Stott 1998). In the subsurface, this contact is placed at the top of a series of quartzose sands that are in contact with an overlying silty-shaly interval. In the northeast corner of the study area (94-A-13), the Sub-Cretaceous Unconformity truncates the top of the Monteith Formation, and in some cases, the entire Formation (Figure 2-1 and 2-2).

Jeletzky (1964), remarked that lowermost Cretaceous (Berriasian and Valanginian)



Generalized schematic of subsurface stratigraphy in study area
Figure 2-1



Sub-crop edges based on core data, Canstrat data, and well logs. Note that the Cadomin sub-crop is actually a lateral facies change with the Gething Formation.

Figure 2-2

units are present beneath the Cadomin Formation and that the Jurassic-Cretaceous boundary actually lies within the Monteith Formation, which ranges in age from Tithonian (Upper Jurassic) to earliest Valanginian (Lower Cretaceous). Based on biostratigraphy, Warren and Stelck (1958) placed this contact within the lower part of the massive Monteith quartzose sandstones. No apparent lithology change marks the Jurassic/Cretaceous boundary. This makes this boundary impossible to pick in the subsurface using strictly geophysical well logs.

Beattie Peaks Formation

Mathews (1947) originally defined the Beattie Peaks Formation, the second formation in the Minnes Group, from outcrop along the western slopes of Beattie Peaks, which is now the type section. In outcrop, the Beattie Peaks Formation is a recessive unit composed of interbedded shales and sandstones which lies directly above the Monteith Formation. The lower section of the formation is composed dominantly of silty mudstone with occasional thin interbeds of siltstone and sandstone. The upper section of the formation is comprised of rhythmically bedded silty mudstones and siltstones alternating with thinly bedded sandstones (Stott 1998). The upper part of the formation becomes sandier and eventually grades into the overlying Monach Formation. The Beattie Peaks Formation is considered to be early to late Valanginian (Hughes 1967, Jeletzky 1968, and Stott 1998).

Throughout the study area, the upper contact of the Beattie Peaks Formation is unconformable. Uplift and erosion (Sub-Cretaceous Unconformity) has removed the upper two formations of the Minnes group and has truncated the top of the Beattie Peaks Formation. The Beattie Peaks Formation is thickest in the southwest portion of the study area. In the subsurface, the Beattie Peaks Formation thins to its zero edge in a northward and eastward direction (Figure 2-1 and 2-2).

Monach Formation

The Monach Formation, named by Mathews (1947), consists of continuous massive, medium to coarse-grained quartzose sandstones which overlie the recessive Beattie Peaks Formation. The type section for the Monach Formation is located on the eastern slopes of Mt. Monach within the Carbon Creek basin. The quartzose sandstones of the Monach are very similar to quartzose sandstones of the Monteith Formation. This creates problems for workers on identification and correlation of the Monach Formation. The Monach characteristically contains higher amounts of chert and other lithic fragments which distinguish it from the Monteith. Biostratigraphically the Monach Formation, the third formation of the Minnes Group, has been dated as Late Valanginian.

The basal contact of the Monach Formation is gradational with the underlying Beattie Peaks Formation (Stott 1998). The upper contact with the Bickford Formation is easily distinguished as it marks an abrupt change in lithology. The prominent quartzose beds of the Monach are sharply overlain by the recessive strata of the Bickford Formation. The Monach Formation extends up to 80km beyond the eastern edge of the Foothills, where it is truncated by the Pre-Cadomin Unconformity/Sub-Cretaceous Unconformity (Stott 1998). This erosional event has removed the Monach Formation from the study area.

Bickford Formation

The Bickford Formation, the upper most member of the Minnes Group was identified and named by Stott (1981). He recognized a carbonaceous unit that contained thin interbedded sands and shales. This unit was found between the quartzose sands of the Monach Formation and the chert-rich conglomeratic sandstones of the Cadomin Formation (Stott 1962). The type section is located on a ridge extending westward from the main peak of Mount Bickford. Biostratigraphic age constraints are unavailable for the Bickford Formation as few fossils have been recovered. Since the basal contact of the

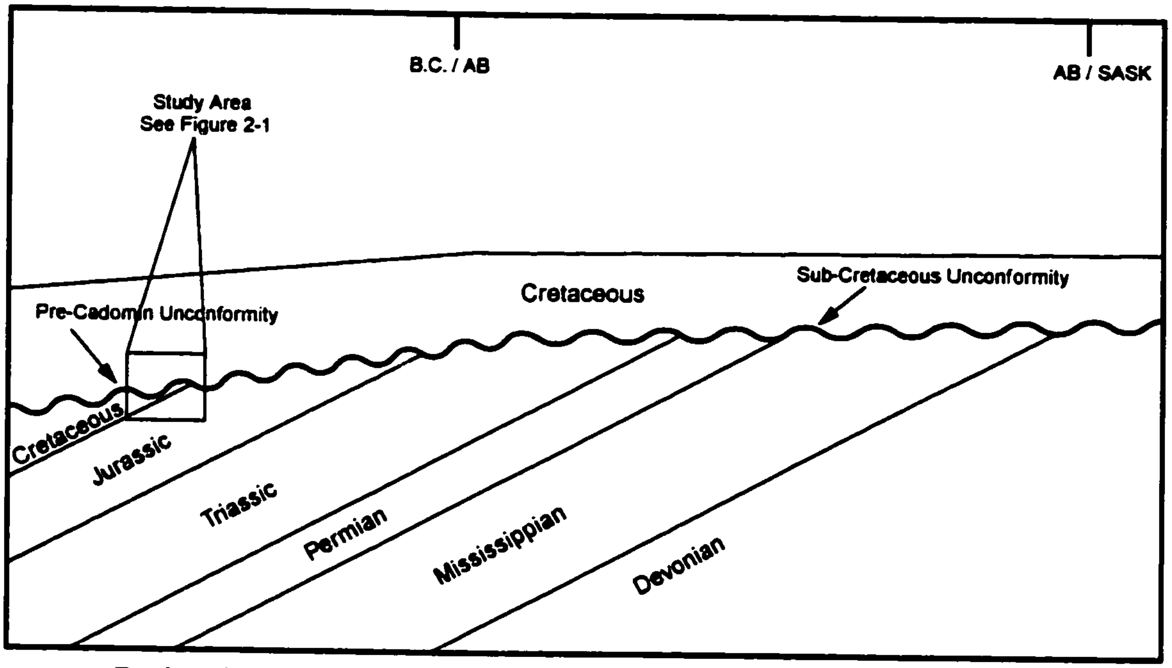
Bickford Formation is conformable it is considered to be latest Valanginian in age (Stott 1998).

The upper contact of the Bickford Formation is sharp and is marked by an abrupt change in lithology from the recessive carbonaceous Bickford Formation to the resistive Cadomin Formation. This contact is a regional angular unconformity that truncates strata in an easterly direction from Cretaceous to Devonian. The Pre-Cadomin Unconformity/ Sub-Cretaceous Unconformity has removed the Bickford Formation from the study area.

Pre-Cadomin Unconformity/Pre-Cretaceous Unconformity

A regional unconformity separates the Minnes Group from the Bullhead Group throughout the entire study area. This unconformity can be traced from northeastern British Columbia into the plains of Alberta and Saskatchewan, and is termed the Pre-Cretaceous Unconformity (Figure 2-3). Within the study area, this unconformity does not separate Cretaceous strata from older underlying sediments, rather it divides the upper Jurassic-early Cretaceous Minnes Group from the mid-Cretaceous Bullhead Group. Utilization of the term Pre-Cretaceous Unconformity in this area is therefore misleading. The term Pre-Cadomin Unconformity has thus been adopted in the study area (Figure 2-3).

The relationship between the Pre-Cretaceous Unconformity and the Pre-Cadomin Unconformity has long been a topic of confusion. It took geologists, many years to determine how these two surfaces were actually related. The pioneer geologists, who first worked on the Lower Cretaceous strata in Western Canada, did not recognize the presence of a major unconformity at the base of the Cadomin (base Bullhead Group). In examining Jurassic and Cretaceous beds in central and southern Alberta, Warren (1938) considered that the contact between these units was of little stratigraphic importance. This misinterpretation came about due to the lack of erosional relief (Springer *et al.* 1964) on the surface and the fact that the contact lacked an angular relationship (Stott 1973).



Basin wide schematic showing the lateral relationship between the Sub-Cretaceous Unconformity and the Pre-Cadomin Unconformity

Figure 2-3

This contact between the Minnes Group and the Bullhead Group is sharp, but lacks any evidence of weathering or soil formation.

McLearn (1944) first recognized that there was a major unconformity within, rather than below, the Lower Cretaceous strata. Warren and Stelck (1958) also recognized that the Jurassic-Cretaceous boundary occurred in the Monteith Formation of the Minnes Group and was not equivalent to the unconformity identified by McLearn (1944). Gussow (1960) disagreed with the works of McLearn, Warren and Stelck. He believed that there was a major unconformity at the base of the Cadomin Formation that was equivalent to the Jurassic-Cretaceous boundary. His ideas are generally not accepted and the existence of Lower Cretaceous strata below the Cadomin is widely recognized.

Further work would reveal the true nature of the unconformity. Loranger (1958) remarked that the Pre-Cadomin Unconformity represented a significant period of erosion that resulted in the truncation of Cretaceous and Jurassic Formations. Detailed work in western Alberta revealed that the unconformity represented eroded sediments from the

Neocomian (Berriasian, Valanginian, Hauterivian, and Barremian) and Aptian Stages (Mellon 1967). In northeastern British Columbia, biostratigraphic analysis recognized that Hauterivian and Barremian fauna were absent, indicating missing strata (Stott 1968).

The total thickness of eroded sediments from the Pre-Cadomin Unconformity in the Peace River Region is unknown. Since, there is no known locality where the top of the Minnes group is conformable with overlying sediments (Stott 1998) it is difficult to determine the total thickness of strata removed. It is evident that the total amount of sediment eroded increases to the east. At Mount Torrens, in the eastern Foothills, the Minnes Group is approximately 1150m thick, but 75 km east, the entire Minnes Group is completely removed (Stott 1998). Again since no conformable section has been found determination of original stratal thickness is still open to conjecture.
McLean (1977) believed that the Pre-Cadomin Unconformity was a diachronous surface. Namely, as erosion took place in the east, sedimentation occurred in the west.

The Pre-Cadomin Unconformity / Pre-Cretaceous Unconformity represents a period of erosion that was penecontemporaneous with isostatic rebound of the crust following thrusting (Cant and Stockmal 1989). This regional unconformity lies at the base of the Cadomin Formation throughout most of the Foothills of British Columbia and Alberta and has been traced into the United States extending into Wyoming, Montana, and Colorado (Weimer 1984). Moving from west to east, the unconformity truncates successively older strata, cutting through the Minnes Group, the Fernie Formation, Triassic strata, and further east in the plains it truncates Paleozoic strata. In the study area, the Pre-Cadomin Unconformity has completely removed the Monach and the Bickford Formations. In the northern section of the study area, the entire Minnes Group has been removed (Figure 2-2).

Bullhead Group

McLearn (1918) first proposed the Bullhead Mountain Formation, for a succession of rocks between Triassic strata and the Ft. St. John Group. This was later shortened to the Bullhead Formation and subsequently promoted to Group status by Wickenden and Shaw (1943). As work continued in the Peace River Region, the Fernie Formation and Minnes Group were deemed independent of McLearn's (1918) definition of the Bullhead Mountain Formation. The Bullhead Group is currently considered to be comprised of a thick succession of non-marine, transitional sediments, and marine sediments respectively of the Cadomin, and Gething Formations. The Bullhead Group forms a clastic wedge which thins from approximately 750 meters in the western Foothills of northeastern British Columbia to only tens of meters in the Peace River Plains. The zero edge of the Bullhead Group is northeast of Ft. St. John (Stott 1973). The Bullhead Group represents an overall transgressive system that culminates in a maximum flooding surface. This regional deepening event marks the end of Bullhead deposition and represents the beginning of the second period of major clastic deposition in the western Canadian Sedimentary Basin.

Cadomin Formation

The lowermost member of the Bullhead Group, the Cadomin Formation, sits unconformably on the underlying Minnes Group. The Cadomin Formation is a prominent and easily recognizable unit throughout the Foothills. It is an important horizon for regional coal prospecting and aids in mapping in areas of complex deformation. The Cadomin Formation was first described and given formation status by MacKay (1929) near the town of Cadomin. He described it as "flattened and well-rounded pebbles of black, white, and green chert, white and grey quartzite, and quartz, which range in diameter from 1/4 to over 3 inches" (MacKay 1929). The Cadomin Formation is mappable from the Peace River plains and southward to the U.S./Canada border.

Throughout the Foothills the Cadomin Formation is dominantly characterized by massive, resistant layers of chert rich conglomerate. In the Peace River region of northeastern British Columbia, the Cadomin Formation primarily consists of thick coarse-grained chert rich sandstones. It can be conglomeratic or consist of disseminated pebbles and/or lenses of conglomerate in chert rich sandstone (Stott 1973). The Cadomin Formation occasionally consists of mudstones, siltstones, finer grained sandstones and locally thin coal seams.

The conglomerates and coarser grained units are thicker and more concentrated along the western margin of the Western Canadian Sedimentary Basin (Stott 1973). The Cadomin Formation in northeastern British Columbia consists of two distinct lobes. One lobe is located between Mount Belcourt and Onion Creek, the other is further north at the Peace River (Stott 1968). The conglomerate and conglomeratic sandstone units rapidly thin north of the Peace River. In the study area, conglomerate units are rare and where present they are thin and laterally discontinuous. This coarser grained material becomes less prominent in the eastern part of the study area.

The lower contact of the Cadomin Formation is sharp, erosional and has been named as the Pre-Cadomin Unconformity. The contact between the Cadomin and the overlying Gething Formation is conformable and varies from gradational to abrupt. Where this contact is abrupt, the top of the Cadomin Formation is composed of conglomerate, conglomeratic sandstone, or coarse grained sandstone that is overlain by finer grained clastic sediments of the Gething Formation. This contact was first defined by McLearn (1923). He stated that the contact "is drawn arbitrarily where conglomerates and grits disappear, coarse sandstone becomes rare, and medium to fine sandstone, shale, clay ironstone, and coal beds become common". Stott (1968) noted that in the Peace River region, the contact "forms no persistent stratigraphic horizon but lies above different conglomeratic beds of the Cadomin from place to place". Upper beds of coarse grained sandstones of the Cadomin Formation grade laterally into inter-bedded coal, sandstone, and shales of the Gething Formation (Stott 1973). This lateral interfingering could be observed in the canyon walls of the Peace River before the construction of the W. A. C. Bennett dam (Stott 1998). Moving north of the Peace River, the conglomeratic units and coarse-grained sandstones grade laterally into finer sandstones and become lithologically indistinguishable from the Gething facies in that region. In the study area, true distinctive Cadomin Formation sediments are found in the south and western portions of the area. To the north and northeast portions of the study area however, the Cadomin grades laterally into the finer grained sediments of the Gething Formation (Figure 2-1 and 2-2).

Gething Formation

The Gething Formation was first delineated as a member of the Bullhead Mountain Formation (McLearn 1918). It is a succession of interbedded fine-grained sandstones, siltstones, mudstones, and coals that were first described from the well-exposed cliffs of the Peace River Canyon (McLearn 1923). Once the Bullhead Formation was raised to Group status, Beach and Spivak (1944) gave formational rank to the Gething strata. Stott (1968) described a better-exposed and more continuous section upstream from McLearn's type section. This outcrop is now used as a reference section for the Gething Formation. North of the Peace River Canyon, the Gething Formation grades from the coal-bearing interval of the type section, to interbedded fine grained sandstones, siltstones and mudstones.

The Gething Formation conformably overlies the Cadomin Formation. The contact is either sharp with a distinct lithologic change or gradational. Where the Cadomin Formation is absent from the study area, the Gething Formation lies unconformably on the Minnes Group. This contact is distinct because it marks the change from the recessive upper formations of the Minnes Group to the resistant Gething Formation. Problems arise when the Gething Formation lies directly on the Monteith Formation as there is difficulty differentiating between the two formations. The distinction can be made based on their mineralogy. The Monteith Formation is a quartz arenite where as the Gething Formation is a chert-rich lithic arenite. In the subsurface, Gething sandstones are finer grained and contain high amounts of carbonaceous debris and clays. This results in high gamma ray (GR) count, making it easily distinguishable from the sands of the underlying Cadomin and Monteith Formations.

The upper contact of the Gething Formation ranges from conformable to disconformable with the overlying Fort St. John Group (Gibson 1992). The Gething Formation is overlain by either the Bluesky Formation, a glauconite rich sandstone/ conglomerate, or by shales of the Moosebar Formation.

Provenance

In the Foothills of Western Canada, Cretaceous clastic sediment was derived from two localities, the craton to the east and the Cordillera to the west.

The highly quartzose sands of the Monteith and Monach Formations are derived from the east. These sands are conglomeratic in their most eastward extent and decrease in grain size to the west. During the Late Jurassic to Early Cretaceous a major river system carried large amounts of quartz-rich sediment north, into various embayments, which formed the south-eastern shoreline of an inland sea (Williams and Stelck 1975). Stott (1998) proposed that the similar quartzose sandstones of the Monteith and Monach Formations were sourced from the Precambrian Athabasca Sandstone, which lies to the northeast.

Regionally the thick sandstones of the Beattie Peaks Formation of the Minnes Group that are exposed in outcrop, are conversely thought to be derived from a western source, the Cordillera. These exposed sandstones of the Beattie Peaks Formation contain a high component of lithic clasts including: chert, carbonate grains, argillaceous fragments, and volcanic clasts (Stott 1998). These lithic fragments are of similar lithology to the Formations found in the Cordillera. In outcrop, the thick sands of the Beattie Peaks Formation also show depositional thinning to the east further supporting a western source for these rocks. However Stott (1998) also suggested a probable eastern source for some of the Beattie Peaks Formation.

As no core penetrated the Beattie Peaks Formation in the study area, provenance was difficult to determine. Source determination was therefore accomplished using CanStrat lithology charts where available. No lithological evidence was observed to support sediment input from the west (ie. large amounts of chert, carbonate grains or volcanic clasts). Stott (1998) also stated that the Minnes Group north of Williston Lake/Peace River suggested the presence of a mid-basin to eastern paleo-shoreline, with little to no evidence for a western shoreline. Thus, within the study area, the quartz rich Monteith Formation and the more recessive Beattie Peaks Formation were derived from an eastern source.

The Cadomin Formation, the most laterally consistent conglomerate in the Cretaceous of western Canada was sourced from the Cordillera to the west. Two main regions of the Cordillera have been argued as the source for the Cadomin.

The first region that early workers believed was the source of the Cadomin Formation was near to or west of the Rocky Mountain Trench. McLearn (1944) believed that large areas of igneous rock were needed to supply the amounts of feldspar for the Lower Cretaceous sands of western Canada. Further study revealed that only trace amounts of feldspar were present in the Lower Cretaceous sands. This eliminated the need for large bodies of igneous source rock. In all, there are only two areas where volcanic clasts have been reported in the Cadomin; minor occurrences at Mount Allan in Kananaskis (Rapson 1965) and in localities in the Peace River to Kakwa River region of northeastern British Columbia (Stott 1968).

Within the study area, extensive petrologic work was done on cores that were logged in the Cadomin formation. In only four cases were trace amounts (less than 1%) of metamorphic rock fragments observed. The lack of volcanic and metamorphic clasts is significant and suggests that the area west of the Rocky Mountain trench did not contribute significant detritus to the Cadomin Formation (Schultheis and Mountjoy 1978).

The second proposed source for the Cadomin Formation as well as other Lower Cretaceous deposits is the eastern part of the Rocky Mountain Main Ranges. Schultheis and Mountjoy (1978) examined thousands of pebbles from the Cadomin Formation and compiled a comprehensive report on their composition. They concluded that the Cadomin conglomerates in the Central Foothills consisted of approximately 75% chert, 15% quartz and sedimentary quartzite, and 10% miscellaneous components. No clasts of metamorphic or volcanic origin were identified.

If the sediment was sourced from the region west of the Rocky Mountain Trench large amounts of volcaniclastic sediments would be expected. The dominance of chert, the scarce but distinctive silicified fossiliferous limestone suite as well as the occurrence of carbonate detritus in the sand-size fraction imply that the source area was rich in cherty limestones and dolomites. Schultheis and Mountjoy (1978) proposed that the area of provenance was in or near the eastern part of the Main Ranges of the Rocky Mountains.

In the study area, sands and rare conglomeratic sediments are of similar character and composition. This suggests that the different grain sizes were all derived from the same source. The general absence of large carbonate clasts (comprise less then 1% of the rock) within the conglomerates and sand sized fraction of the Cadomin, are the result of removal during transport by abrasion and chemical solution. Fossils in the cherts and the silicified fossiliferous limestone clasts have been identified as Lower Carboniferous in age (Schultheis and Mountjoy 1978).

The quartz and quartzites within the Cadomin have the same texture as those of the Lower Cambrian Gog Group of the Main Ranges. The distinct pebble lithology of the Cadomin Formation implies that source rocks were comprised of Mesozoic to Cambrian strata. The majority of data collected on the Cadomin supports that the main source for the Cadomin Formation was the Main Ranges of the Rocky Mountains. Point sources along the Rocky Mountains may have varied and minor input from west of the Rocky Mountain Trench may have occurred in the Crowsnest Pass and Peace River regions (McLean 1977).

Paleogeography

Paleogeography maps for the Cretaceous of the Western Canadian Sedimentary Basin (WSCB) were first attempted by McLearn (1932). The Cretaceous of western Canada was characterized by a varied geography that ranged from the high, newly created mountains in the west to shallow epicratonic seas in the east. McLearn and Kindle (1950) named the northeastern British Columbia seaways of the uppermost Jurassic and lower most Cretaceous the "*Aucella Seas*" (Buchia Seas). Minnes Group sediments record the presence of several transgressive-regressive sequences that existed over the site of the present Foothills in northeastern British Columbia. This seaway may have extended as far south as the Athabasca River Valley. McLearn and Kindle (1950) believed, but were later proved wrong, that these seas were an extension of the Arctic Sea following a path somewhere west of the Mackenzie River Valley.

The Jurassic Fernie sea was the last widespread inundation of Pacific waters to spread into western Canada and extended as far east as Saskatchewan (Frebold 1957). Uplift associated with the Columbian Orogeny expelled the Fernie Sea from the interior of the continent. Warren and Stelck (1958) noted that north of the Athabasca River, marine conditions persisted till a much later date. In the Peace River embayment, marine strata as young as the Valanginian can be found. The fossil faunas present in this area indicated that a Pacific connection was dominant, and not one from the Arctic realm (Warren and Stelck 1958). Jeletzky (1964, 1967, 1968, 1969, 1971,1972) did extensive work on tracing this Pacific connection into northeastern British Columbia.

The latest Jurassic to basal Cretaceous deposits (Minnes Group) found in outcrop in northeastern British Columbia contain marine faunas closely related to or identical with those of the geosynclinal troughs (Tyaughton and Insular Troughs) of western British Columbia (Jeletzky 1964) (Figure 2-4).

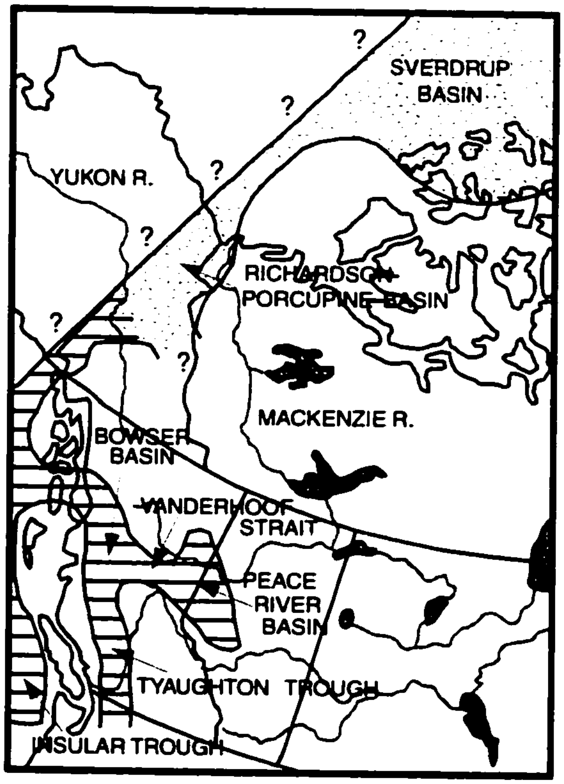
Jeletzky (1967) stated

> "These depositional areas must therefore have been connected by another seaway – the Vanderhoof Strait. This seaway presumably extended from the headwaters of Skeena River into the Carbon Creek area connecting Bowser Basin with the Peace River Basin"(Figure 2-4).

The Vanderhoof Strait was located between the Nelson and the Cassiar-Omineca uplifts. This marine connection between the geosynclinal seas (Tyaughton and Insular Troughs) of western British Columbia and the shelf-sea of the Western Interior region persisted essentially unchanged through the Berriasian and Valanginian (Jeletzky 1968).

Faunas identified by Jeletzky (1968) in Berriasian and Valanginian strata (Minnes Group), are closely allied to contemporary marine faunas of the western Cordillera of Canada and the United States. They have fewer similarities with contemporaries in the northwestern Mackenzie District, northern Yukon, and Arctic Canada (Jeletzky 1968). Fieldwork in the northern Yukon and northwestern Mackenzie District, concluded that the early Lower Cretaceous Arctic seas did not penetrate south of the Richardson Mountains and Dawson area (Jeletzky 1968). Thus, the seas that existed west of the study area, during Minnes Group deposition were entirely of Pacific origin and lacked a connection to Northern Boreal Seas. The retreat of this Pacific tongue occurred by the end of the Valanginian and Pacific waters were not to occupy this area again (Figure 2-4).

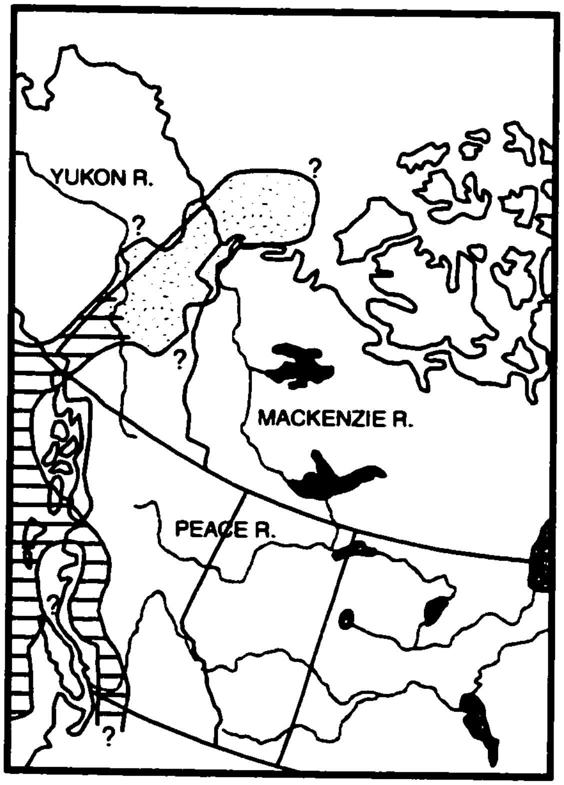
Following the regression of this Pacific sea, a major drainage system developed. A westward draining canyon system incised into the rising Omineca-Nelson batholith geanticline, and fed an estuarine deltaic complex in the Tyaughton – Hazelton area of British Columbia. The Late Jurassic-Early Cretaceous Bowser Basin contains approximately 6000 meters of undifferentiated Upper Jurassic and Lower Cretaceous sedimentary rocks, dominantly argillites, shale, siltstones, minor conglomerate lenses and thin



Berriasian and Valanginian biotic provinces and paleogeography. Inferred maximum extent of Berriasian and Valanginian seas.

- North Pacific Seas

- North American Boreal Seas



Hauterivian and Barremian biotic provinces and paleogeography. Inferred maximum extent of Hauterivian and Barremian seas.

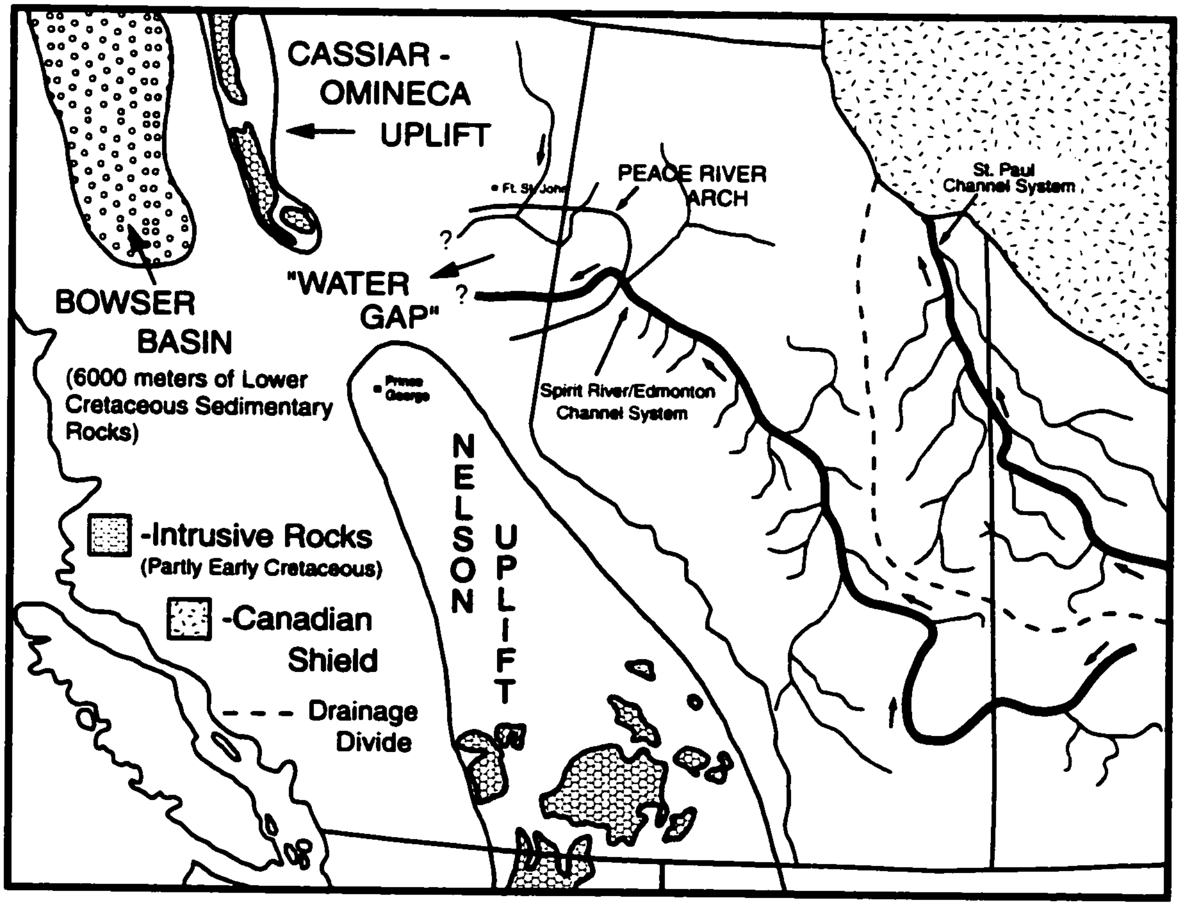
Lower Cretaceous Paleogeography and Biotic Provinces (modified from Jeletzky 1969)

Figure 2-4

coal seams (Rudkin 1960).

Tertiary movement along transcurrent faults located in the Rocky Mountain Trench has moved the Bowser Basin north of its original location. If restored, the Bowser Basin would lie almost directly west of the canyon system that was incised into the Omineca-Nelson batholith geanticline. Gabrielse and Yorath (1992) determined that the Bowser Basin was filled with sediments dominantly derived from the east. This supports the idea of a drainage system through a canyon network that incised into the geanticline (Figure 2-5).

Major channel systems, the Spirit River/Edmonton Channel system and the St Paul Channel system, drained the foreland basin during the lower Mannville (Jackson 1984)



Omineca-Nelson batholith geanticline showing approximate location of a "water gap" and generalized earliest Cretaceous drainage paterns

Figure 2-5

(Figure 2-5). Axial ridges created by Paleozoic highs separated these drainage systems. The eastern St. Paul Channel system flowed far north/northwest to an inundating Boreal Sea, whereas the western Spirit River system flowed to the northwest. Movement on the Peace River Arch confused the drainage pattern of the western channel system making it difficult to interpret. Grabens mapped over this region have been interpreted to have acted as conduits for channels (Cant and Abrahamson 1996). The western system was thought to flow through a gap in the up lifted areas via a "water gap". The "water gap" was located in the structurally sagging Peace River Arch (Cant and Abrahamson 1996). Uplift and later thrusting closed all connections with the Pacific. This was followed in the early Albian by a marine incursion from the north by the Boreal Sea (McLean and Wall 1981).

Tectonic History and its Influence on Sedimentation

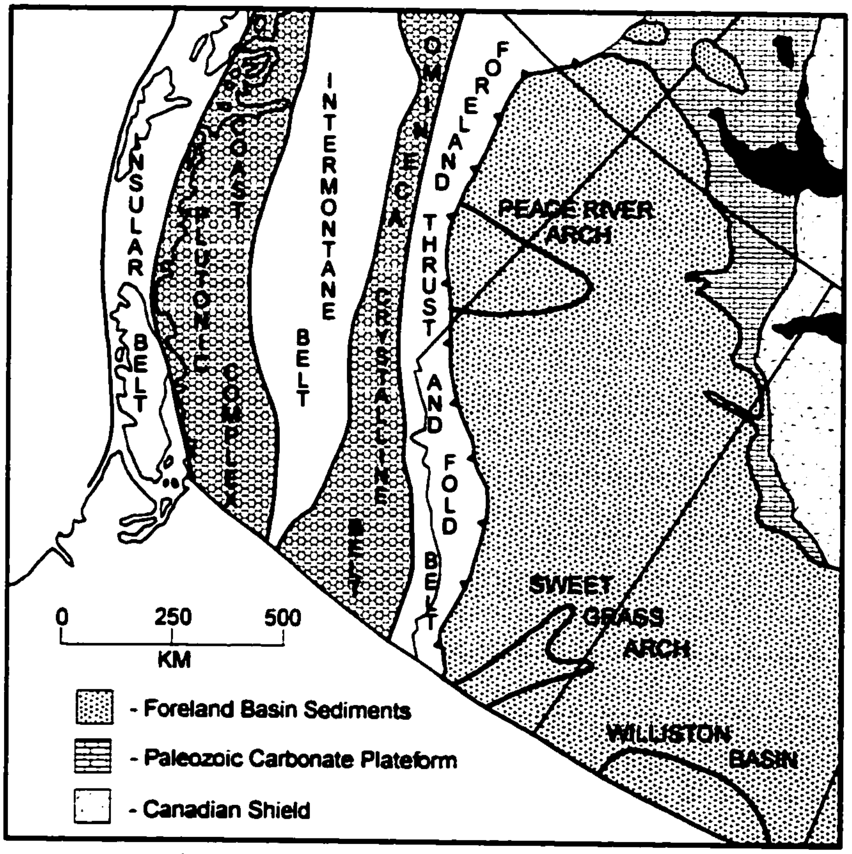
The Cordillera thrust and fold belt contains the record of geodynamic processes that have formed and shaped the western edge of the stable Precambrian crust that forms the core of the North American continent. The development of the Western Canada Sedimentary Basin (WCSB) was directly linked to the origin and evolution of the Cordillera. Periods of subsidence and sediment accumulation in the WCSB were connected to changes resulting from the development of the Cordillera. Most work to date on the Western Canada Sedimentary Basin suggests that two main stages of development, reflecting sedimentation in two profoundly different tectonic settings has occurred. This conventional interpretation originally arose from work done by Bally et al. (1966) in the Southern Rocky Mountains of Canada. This theory of two general phases, one of passive margin, and then compression in the evolution of the Cordillera is an oversimplification.

From the Proterozoic to the Early Jurassic, the western edge of Canada was the site of miogeoclinal deposition. This deposition was dominated in the Paleozoic by thick carbonate sequences that graded westward into shales and cherts. During the Triassic and

Early Jurassic, clastic sediments became dominant and were deposited in westward thickening wedges. In the early Middle Jurassic (180 Ma) initiation of orogenic activity was marked by orgenic movvements of the Slide Mountain terrane and part of the Quesnellia terrane in the present day east central Cordillera (Monger 1989).

The Canadian Cordillera can be broken up into five distinct geological belts. From east to west they are the Foreland, Omineca, Intermontane, Coast and Insular belts (Figure 2-6). The Foreland belt consists of sediment that was native to North America.

Development of the massive Intermontane Superterrane took place along the entire length of the Canadian Cordillera during the Middle Jurassic, and is known as the Columbian Orogeny. With the development of the Intermontane Belt, subsidence occurred in front of the deformed zone. Tectonic thickening and eastward overthrusting of the passive margin caused the downward isostatic flexure of the underlying lithosphere,



The five tectonostratigraphic zones of Western Canada and their relationship to the Western Canadian Foreland Basin (modified from Cant and Stockmal 1989)
Figure 2-6

resulting in the formation of the foreland basin (Price 1973). The development of the Intermontane Belt changed the western margin of Canada from passive margin sedimentation to one of foreland basin deposition.

The exact nature and evolution of the foreland basin has changed through time. Early workers believed that the major period of uplift and thrusting that resulted in the formation of the Rocky Mountains occurred during the Eocene. This theory was later challenged by Bally *et al.* (1966), when they identified Jurassic thrusts in the southern Canadian Rocky Mountains. After extensive work between the Bow and Athabasca Rivers, Price and Mountjoy (1970) stated

> "the Main Ranges and perhaps the western Front Ranges structures emerged as an active zone of thrusting in the Late Jurassic and Early Cretaceous. Thus, the overall pattern which emerges is one of progressive development of successively lower and more northeasterly thrust faults during an interval lasting from Late Jurassic to Paleocene or Eocene."

Supporting evidence for Late Jurassic and Early Cretaceous thrusting came from the Nelson Batholith in southern British Columbia. The Nelson Batholith was thought to be Cretaceous in age due to its similarity to other known Cretaceous granites in British Columbia, and from a single K-Ar radiometric age of 84 Ma (late Cretaceous)(Little 1960). This batholith cuts deformed strata presumed at the time to be Upper Jurassic in age. Utilizing this established geological relationship, deformation of the strata was thought to have occurred in the Upper Jurassic to Lower Cretaceous, before the emplacement of the Nelson Batholith.

The Nelson Batholith has now been reliably dated across the intrusion by U-Pb dates of 172-160 Ma, Middle to early Late Jurassic (Bathonian to Oxfordian) (Murphy et al. 1995). Fossils found in the deformed strata, are dated as early Middle Jurassic in age

(Aalenian to Bajocian). Thus, the strata intruded by the Nelson Batholith was deformed before the Late Jurassic (pre-Oxfordian). No evidence exists to date of a chronologically constrained Late Jurassic – Early Cretaceous thrust fault in the Foreland Belt or adjacent western Omineca Belt. Thus, the theory of continual convergence from the Middle Jurassic (Bathonian) to the Eocene is in question. Evidence of Middle Jurassic and Late Cretaceous to Eocene deformation is well substantiated in the Rocky Mountains. It is unclear whether this represents continuous crustal shortening that migrated eastward over time or if this deformation was discrete, discontinuous and geodynamically unrelated.

The Mid-Late Cretaceous Campanian stage marks the resumption of oblique convergence between North America and the Insular Belt. The accretion of the Insular Belt marks the beginning of the Laramide Orogeny, which continues into the Eocene. Cessation of Laramide deformation is marked by basinal relaxation and the onset of extensional conditions in the Late Eocene and Oligocene time (Price 1965).

A major structural feature influencing sedimentation in northeastern British Columbia is the Peace River Arch/Embayment (Figure 2-6). Theories on its evolution/development have evolved over time. The most supported theory being one of basement controlled faulting. The Arch is thought to be a crustal structure that has experienced extensive positive and negative movement (Barclay *et al.* 1990, O'Connell *et al.* 1990, and Eaton *et al.* 1999). Throughout the Peace River Arch's history, it has alternated between a topographically elevated feature (Late Proterozoic to Late Devonian), and an embayment which resulted in the deposition and preservation of anomalously thick strata (Carboniferous to end Cretaceous) (O'Connell *et al.* 1990). The up-turned edges of these embayments have acted as a major center for the deposition of winnowed sediment. Along the edge of the collapsed arch, relatively coarser and cleaner clastics tend to accumulate (Stelck 1975). At various times this active fault zone exerted partial control on the southern extent of boreal marine advances and on the accumulation of sediments. Stott (1973) observed that the arch/embayment exerted considerable control on the distribution and development of various Bullhead Group facies, noting that the Cadomin Formation showed a sharp increase in pebble size as one approaches the Peace River Arch from the north to the south (out side of study area).

Prior to the deposition of Bullhead Group sediments a northwest trending linear feature, known as the Fox Creek Escarpment was uplifted in north central Alberta (O'Connell *et al.* 1990). This uplifted area subdivided the region into two northwest trending drainage systems. The drainage system to the west of the Fox Creek Escarpment is known as the Spirit River System whereas, the one to the east is the Edmonton Channel System (Figure 2-5). The Fox Creek Escarpment in some regards limits Cretaceous deposition and marks the eastern limit of Cadomin deposition (Smith *et al.* 1984).

The earliest foreland basin sediments were deposited in the foredeep during the Middle Jurassic. These sediments were later deformed as the western basin margin migrated eastward. The zone of maximum subsidence in the basin was directly adjacent to the disturbed belt and the eastern margin of the basin was bordered by a forebulge. The sediment shed into this depression consisted of coarse clastic pulses derived from the tectonically active highlands in the west. The lowermost marine sandstones of the Monteith Formation mark the eastern margin of this trough in the subsurface plains and easternmost foothills of northeastern British Columbia (Stott 1998). During the deposition of the Monteith Formation, sedimentation exceeded the rate of subsidence and Monteith sands prograded westward into the basin from the east.

The formation of the pre-Cadomin unconformity was related to uplift associated with regional movements that affected a large part of the western margin of the continent. This uplift lead to the retreat of Minnes seas from the Western Canadian Sedimentary Basin (Stott 1998). The pre-Cadomin unconformity developed when orogenic overthrusting ceased, and epeirogenic uplift took place. After the development of the pre-Cadomin unconformity, widespread gravels of the Cadomin Formation prograded eastward across the basin. It was suggested that the Cadomin Formation was a result of tectonic uplift associated with thrust faulting and folding during the Late Jurassic and Early Cretaceous (Schultheis and Mountjoy 1978). Traditionally, it has been incorrectly assumed that the Cadomin conglomerates were thought to mark a period of strong tectonic movement along the western edge of North America and were deposited in a subsiding trough in front of the rising Cordillera.

It has been recently shown that during periods of active tectonism, loading in the adjacent thrust belt causes such rapid subsidence that coarse clastics are trapped at the deformed edge of the foreland basin (Blair and Bilodeau 1988). Heller and Paola (1989) stated

> "The effect of significant loading due to emplacement of a thrust sheet would be to increase subsidence and impede the ability of gravel to prograde across a foreland basin".

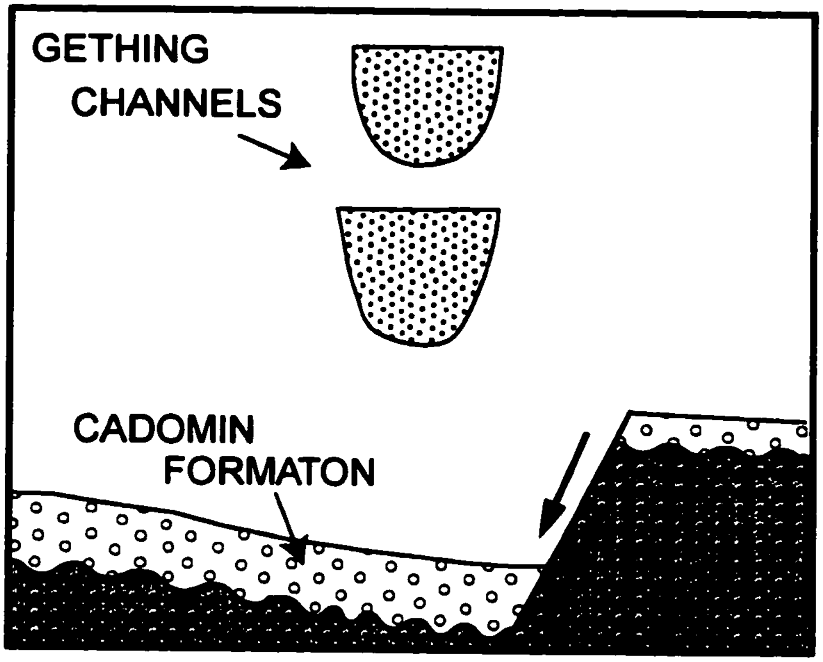
Syntectonic foreland conglomerates are therefore restricted to that part of the basin that is most proximal to the thrust system. The late Early Cretaceous conglomerates of the Cadomin Formation are widespread and have prograded far into the foreland basin. They do not fit the model of syntectonic conglomerates that they have been interpreted to be.

The Cadomin Formation is a relatively thin unit that does not change dramatically in thickness across its wide lateral extent. If conglomerates were syntectonically shed into the foreland trough, one would expect to see a dramatic thinning to the east. Models of foreland basins show that rapid subsidence takes place adjacent to the thrust belt and they tend to develop distal slopes that dip back toward the thrust load (Heller and Paola 1992). This back slope creates problems for transport of gravel in the direction opposite to the foreland basin subsidence gradient (Cant and Abrahamson 1996). On the other hand, a slow reduction in basin subsidence inhibits the ability of sediment to aggrade, leading to a progradation of gravel farther into the basin (Underschultz 1991, Heller and Paola

1992). Subsidence rates can be directly linked to tectonic events. Therefore the progradation of the Cadomin conglomerates across the basin marks a time of relative tectonic quiescence. This clearly indicates that the Cadomin Formation is not syntectonic in nature.

A significant break in the compressional regime can be identified during the Early Cretaceous. Cant and Stockmal (1989) stated that the pre-Cadomin unconformity represents a significant period of tectonic quiescence following the development of the Intermontane Superterrane. Further, the Cadomin Formation was not linked to active thrusting, rather a period of relative tectonic quiescence. A regional (basin wide) east dipping paleoslope was created by regional thermal uplift associated with Jurassic-Cretaceous magmatism (Heller and Paola 1989). The western highlands that sourced the Cadomin were created by this thermal uplift and not by thrust sheets as previously thought.

Throughout the Cordillera evidence suggests that a period of relative tectonic relaxation and extension after the collision of the Intermontane Belt (Columbian Orogeny) occurred. Dilation in the Cordillera is marked by widespread intrusive and extrusive magamatism throughout central British Columbia, the Yukon and eastern Alaska. Plutons intruded between the Early Cretaceous (Hauterivian) and the early Late Cretaceous (Santonian) are areally the most significant plutons in the eastern Canadian Cordillera (Woodsworth *et al.* 1991). In the Peace River region, the thickest accumulations of the Cadomin Formation lie over down thrown blocks of Peace River Arch structures. This reflects that there was downward movement of fault bounded blocks during Cadomin deposition (Cant and Abrahamson 1996). These grabens/half grabens were later infilled by the overlying Gething Formation. Normal faulting increased accommodation space for Cadomin and Gething sediment accumulation. Movement in these faults is restricted to Cadomin deposition as the overlying Gething Formation onlaps the fault boundaries. Cant and Abrahamson (1996) noted that these faults may have depositionally controlled the location of channels in the overlying Gething strata (Figure 2-7). The normal faulting evidenced during Cadomin deposition reflects basinal extension rather than a period of continual compression. Thus, the Cadomin Formation marks a period of epirogenic movement associated with thermal uplift, and low to zero subsidence rates across a rebounding foreland basin.



Normal fault showing Cadomin offset and location of Gething channels

Figure 2-7

Chapter 3

Within the study area, two Formations were examined thoroughly in core, the Upper Jurassic/Lower Cretaceous Monteith Formation of the Minnes Group and the Lower Cretaceous Cadomin Formation of the Bullhead Group. For each formation, individual facies are based primarily on their lithology.

Monteith Formation

In the study area, the Monteith Formation is predominantly composed of a thick succession of medium-grained quartz-rich sandstone with varying amounts of coarser-grained sandstone, siltstone, mudstone, carbonaceous-rich sediments and coal. Two distinctive and easily identifiable facies are recognized as outlined below.

Facies Am - Quartzose Sandstones

Description

Facies Am is the most widespread facies in the Monteith Formation and is the only interval of the Minnes Group that is productive for hydrocarbons in northeastern British Columbia. This facies is comprised of clean, light grey to whitish, fine to very coarse-grained quartzose sandstone. In places it contains scattered quartz pebbles or thin pebble layers (Figure 11e). These sandstones are moderately to well sorted with the grains being dominantly sub-rounded to rounded. In areas of intense bitumen staining, the sandstones may appear dark brown to black in colour.

Sandstones of the Monteith Formation are a stacked series of upward fining-sequences where each sequence is commonly bounded by erosional contacts. Individual fining-upward sequences range from centimeter scale (individual beds) to meter scale (bed sets) beds. Basal lags composed of quartz pebbles with rare coalified wood fragments, mud clasts and carbonaceous debris commonly occur above the numerous scour surfaces. Mud clasts can be up to a few centimeters in size and are generally angular (Figure 13a).

The sedimentary structures observed in the Monteith Formation are marked by grainsize changes in small (cm scale) fining-upward successions. In some cases, bitumen staining of finer sediments enhances the visibility of bedding (Figure 11b,c). Coarser grained sandstones are dominantly massive with rare trough cross-bedding (Figure 11a,b). X-ray analysis of the massive sandstone, failed to yield any identifiable sedimentary structures, verifying that the sandstone is truly massive. As the sandstones fine upward, sedimentary structures generally change from massive to high and low angle tabular bedding (Figure 11c) or more rarely planar parallel bedding. In rare cases where the quartzose sandstone is fine grained, current ripples and climbing ripples are identifiable (Figure 11d).

Vertical and horizontal stylolites are common throughout Facies Am (Figure 12a). Natural open fractures are also found in this facies and will be discussed in more detail in Chapter 5. Carbonaceous material occurs in varying amounts, but it is concentrated above scour surfaces (Figure 12b). Bioturbation was not observed in any sands of the Monteith Formation. Root traces are found penetrating down into the sands from overlying coals or from the pre-Cadomin Unconformity surface (Figure 12c,d). Although rare, some intervals of convolute bedding were observed (Figure 13c). A mottled appearance was seen and was determined, through petrographic examination, to be caused by quartz overgrowth cementation (Figure 13b). In a few cases, scattered vuggy porosity was also observed (Figure 13d). This vuggy porosity has been attributed to aggressive pore fluids leeching out argillaceous grains, mudstone clasts and/or the rare chert grains.

Figure 3-1

Typical sedimentary structures and textures of Facies Am (Monteith Formation)

(A) D-55-H/94-A-13, 1155.1m
Medium grained massive quartz arenite typical of Facies Am.

(B) D-55-G/94-A-13, 1252.4m
Medium grained trough cross-bedded quartz arenite. Forset lamination is defined by preferential bitumen staining (examples arrowed).

(C) A-50-E/94-A-13, 1396.6m
Medium grained tabular cross-bedded quartz arenite. Forset lamination is defined by preferential bitumen staining (examples arrowed).

(D) D-71-B/94-A-13, 1276.6m
Fine grained current rippled cross laminated quartz arenite. Some bed sets display a small degree of climb (example arrowed), suggesting rapid aggradation of sediment.

(E) D-55-H/94-A-13, 1143.7m
Medium grained quartz arenite with abundant quartz pebbles (examples arrowed).

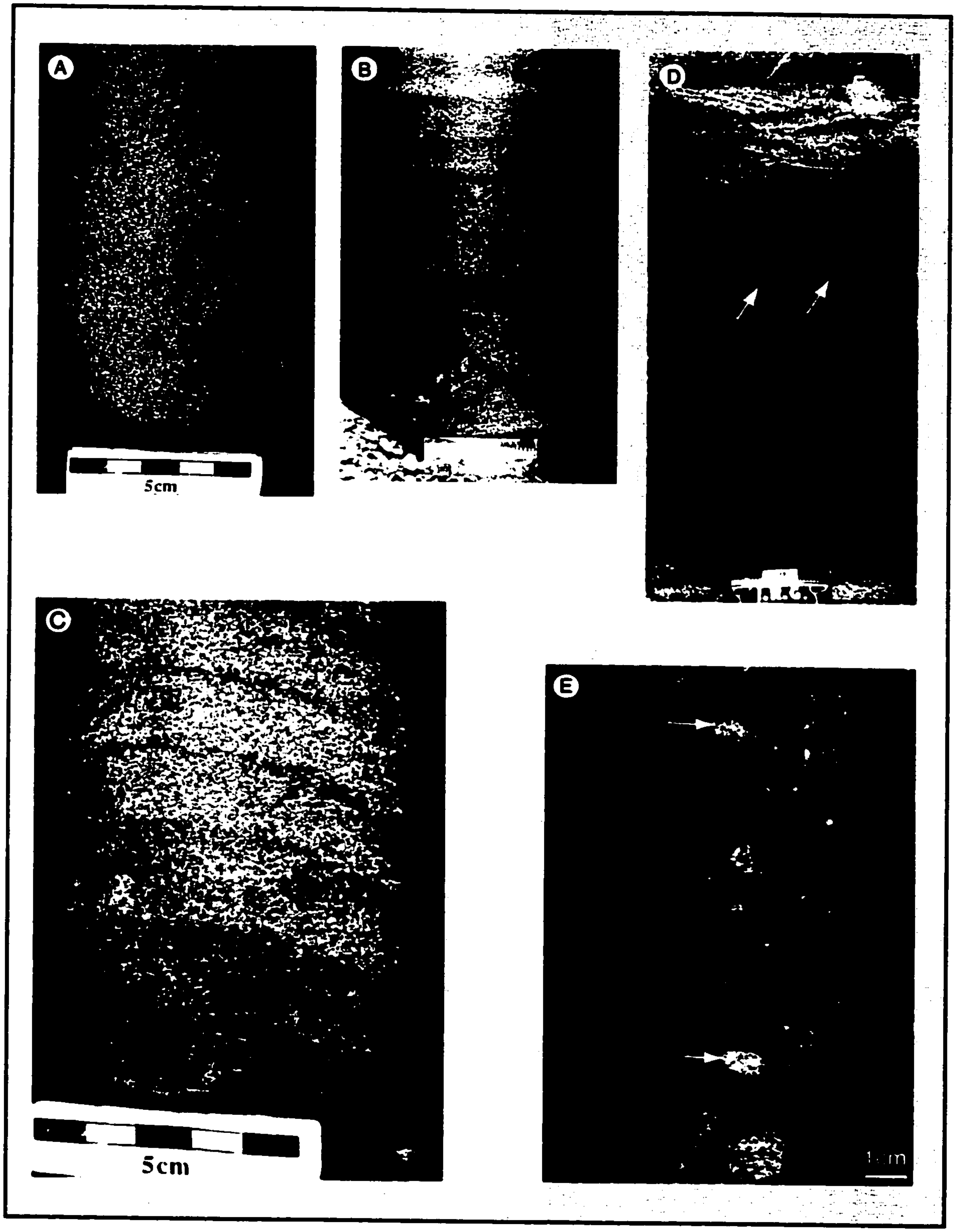


Figure 3-1

Figure 3-2

Sedimentary features of Facies Am (Monteith Formation)

(A) 15-14-86-25w6, 792m

Medium grained trough cross-bedded quartz arenite. Note stylolite (arrowed) defined by organic rich stylocumulate.

(B) A-20-H/94-B-9

Root mottled medium grained quartz arenite. Note subvertical carbonaceous roots (examples arrowed).

(C+D) C-18-H/94-A-13, 1240.5m

Leached root molds in a medium grained quartz arenite, in vertical and bedding plan aspect (Photos (C) and (D) respectively). In Photo (C) roots descend from from the base of a coal (black). These root molds locally enhance vertical permeability.

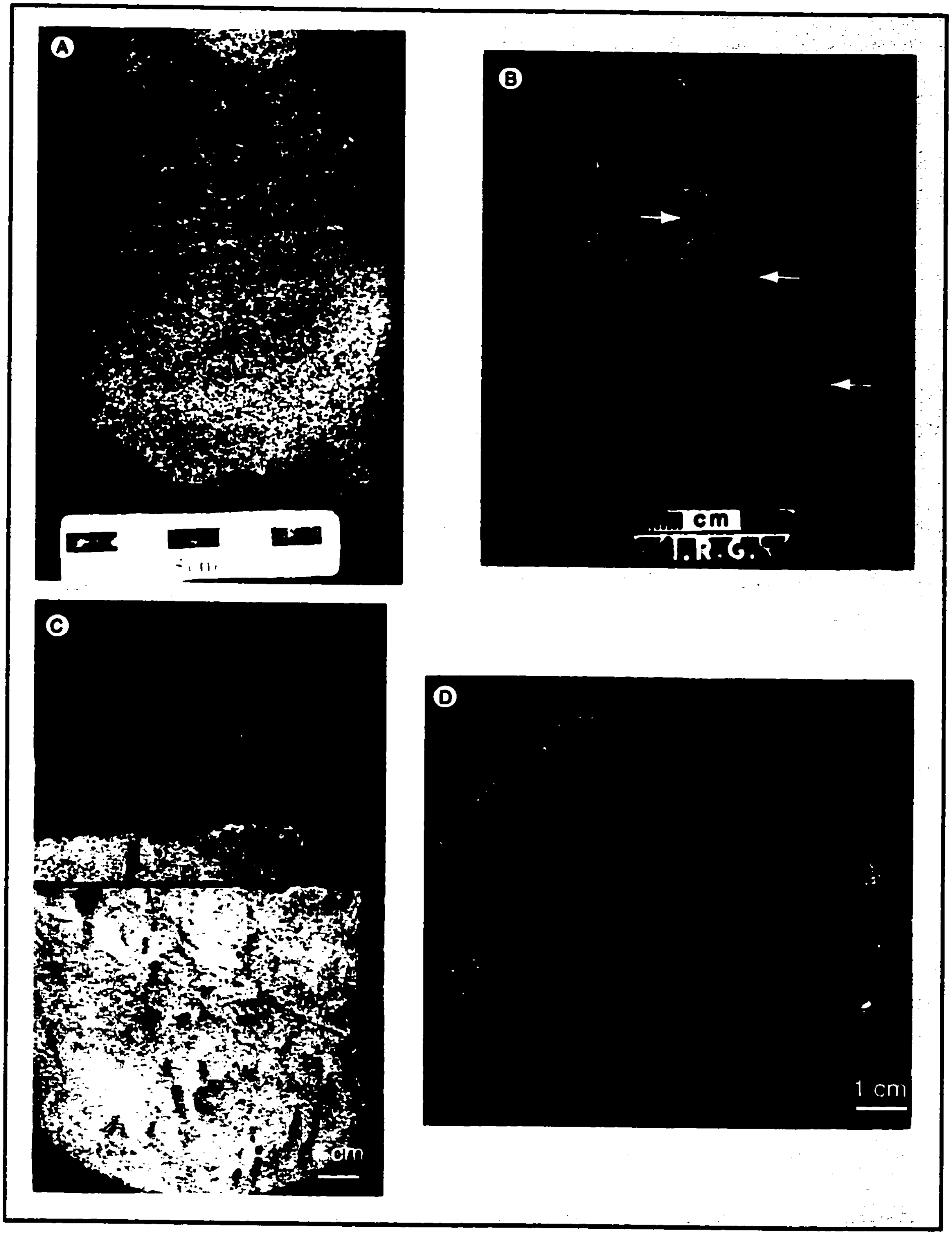


Figure 3-2

Figure 3-3

Sedimentary features of Facies Am (Monteith Formation)

(A) C-18-H/94-A-13, 1247.3m
Angular mudclasts (dark grey) in a medium grained quartz arenite.

(B) Trough cross-bedded (forsets arrowed) medium grained sublitharenite. This zone is pervasively oil stained (dark) except for areas of agressive silica cementation (light).

(C) 3-9-88-25w6, 1012.7m
Convolute bedding in a medium grained quartz arenite. Convolution is interpreted to be a result of dewatering due to rapid sedimentation.

(D) C-81-G/94-A-13, 1223.1m
Moldic pore system (examples arrowed) in a medium grained quartz arenite. Grain molds resulted from either leached chert or argilleous grains.

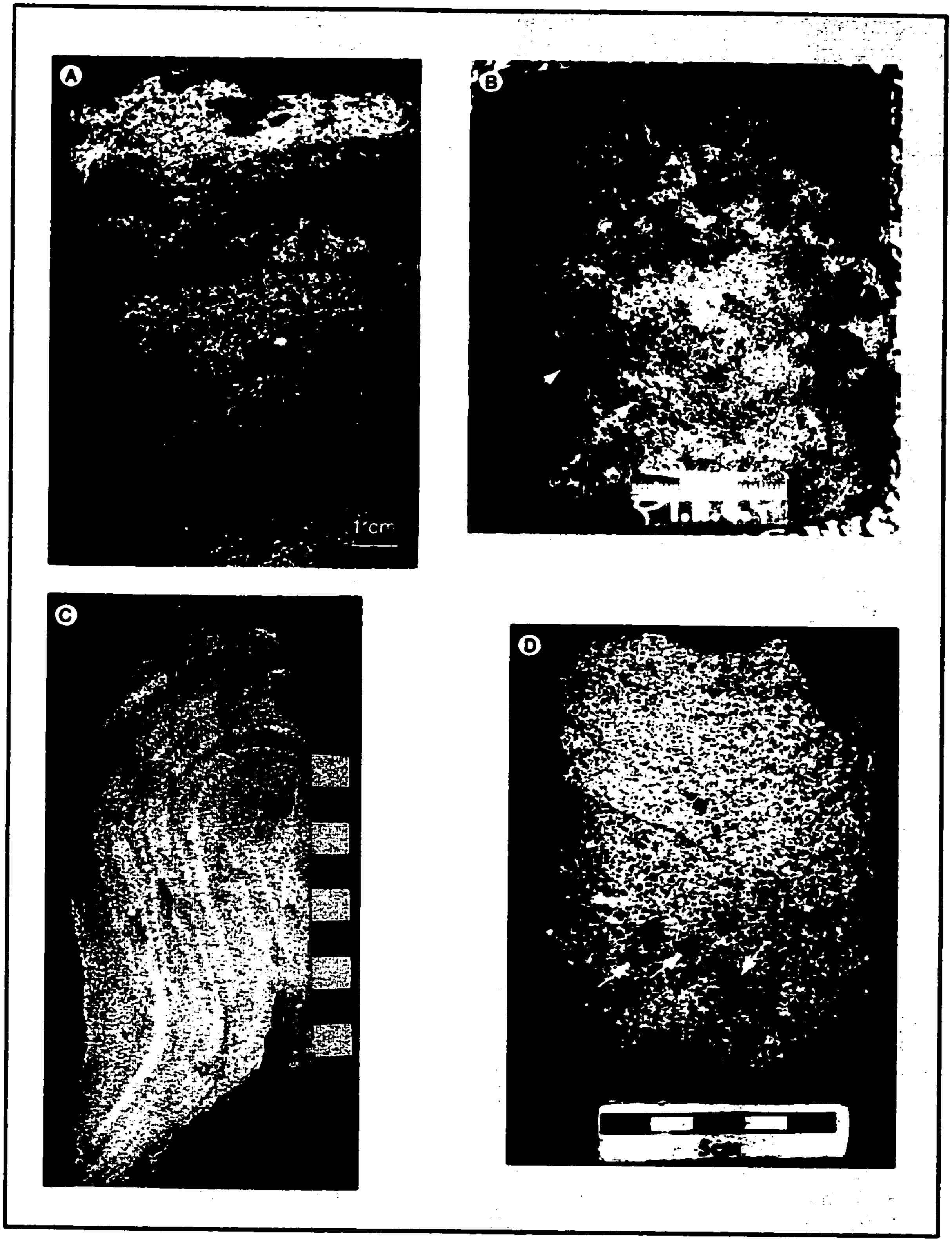


Figure 3-3

Interpretation

The sedimentary structures and the repeated fining upward successions seen in the Monteith Formation formed in a fluvial channel system. No indication of marine influence (i.e. tidal indicators, marine bioturbation) was observed in the examined Monteith core. The combination of cut and fill structures, massive sandstones and basal lags all indicate rapid deposition during times of high current energy. Further, the mudstone clasts are angular and plastically deformed which indicates they did not travel great distances rather they were rapidly buried during high-energy events. Cross-bedded sands represent the migration of subaqueous dunes along the channel floor. The high angle tabular bedding represent foresets, while the low angle tabular bedding represent the bottom sets of large subaqueous dunes. As channel stream velocity decreased, fine-grained, current and climbing ripple laminated sandstones were deposited.

The lack of fine-grained ripple laminations is the result of removal by scouring by the next flooding event. The convolute bedding observed was caused by the rapid deposition of sediment which deformed the unconsolidated sands below. The multiple scour/lag surfaces, the repeated fining upwards sequences, the lack of bioturbation and the numerous indicators of rapid sedimentation indicate that the sediments of facies Am were deposited in a braided fluvial channel system.

Facies Bm - Siltstone, Mudstone, and Coal

Description

Facies Bm occurs as small layers (up to 5 meters) between the dominant quartzose sandstones of facies Am. This facies is composed of siltstones and mudstones, with varying amounts of carbonaceous material and thin coal seams. The presence of scattered sand grains/granules and small lenses of very fine to fine quartz sand in the mudstones and siltstones is rare. These thin sand layers commonly contain parallel or ripple laminations.

The siltstones of Facies Bm are argillaceous, poorly sorted and commonly ripple laminated. The mudstones are dark grey to black, and are usually argillaceous and silty. In some cases, the mudstones are extremely carbonaceous and grade vertically into coal. Thin (1-3cm) layers of ripple laminated to massive siltstones to sandstones are commonly present in the mudstones. Pyrite nodules are common with minor amounts scattered throughout this facies.

Argillaceous coal and highly organic shale are commonly interbedded. True coal seams are present, but were less than a few tens of centimeters thick. Root traces occur in both the mudstone and the siltstone lithologies. No signs of bioturbation were identified in any of the lithologies of this facies.

Interpretation

The sediments in this facies were deposited as an overbank deposit in a swampy flood plain. The massive to ripple-laminated silts and fine sands are the result of an overbank splay introduced during flood stage. The abundant carbonaceous material, root traces and lack of bioturbation in this facies indicate deposition in a non-marine flood plain environment.

Cadomin Formation

Throughout the foothills of the Rocky Mountains, the Cadomin Formation is a distinctive stratigraphic horizon because of its resistant nature and its conglomeratic nature. At the type section near Cadomin Alberta, the Formation is characteristically a single unit of massive conglomerate. In the study area however, the Cadomin is dominated by chert rich sandstone with occasional inter-beds of conglomerate, mudstone, siltstone and rare thin coal seams.

Facies Ac - Lithic Sandstones

Description

Facies Ac is composed of chert rich sandstone with varying amounts of argillaceous grains. This is the dominant facies of the Cadomin Formation in the study area. The sandstone is variable in colour and ranges from medium to light grey, to brownish grey, to dark grey in the finer grained, carbonaceous sands. In areas of intense bitumen staining, the sands appear to be dark brown to blackish in colour.

The sands of the Cadomin are fine grained to very coarse-grained, moderately sorted, and dominantly subangular to rounded. This facies commonly has a salt and pepper appearance as a result of the presence of light grey quartz and abundant black chert (Figure 14a). In coarser grained intervals the total amount of chert is greater.

Scattered pebbles of chert, quartz, quartzite, and other rock types occur randomly in this facies. Pebbles are commonly concentrated in lags overlying scour surfaces and as thin layers (1 to 2cm) at the base of fining upward successions (Figure 14b). In some cases the clasts at the base of lags are well imbricated (Figure 14d).

The sands of Facies Ac are composed of a repeated fining upward succession commonly separated by an erosional surface. Similar to the fining upward successions in Facies Am of the Monteith Formation, the fining upward successions of Facies Ac ranges from individual beds on the cm scale to bed sets on the meter scale (Figure 14c).

Sedimentary structures in this facies are defined by grain size changes which may be accentuated by bitumen staining of the finer grained component. Massive and more rarely trough cross-bedded sands are predominantly found in the coarser grained portions of this facies (Figure 15a). As the sands fine upward, tabular cross bedding (high and low angle) becomes dominant but contains beds of planar bedding (Figure 15b). In the finer grained sediments of this facies current and climbing ripple laminations are present (Figure 15c).

A complete vertical sequence of facies Ac is composed of an erosional base overlain by coarse-grained sandstones. This coarse grained sandstone may contain scattered rounded pebbles, angular siltstone clasts or angular mudstone clasts. This sequence fines upwards into medium grained, massive and/or tabular cross-bedded sands. It then finally grades into finer ripple laminated sands. In the core examined, this sequence is rarely complete, as numerous scour surfaces and fining upward sequences are observed.

Stylolites are present in facies Ac of the Cadomin Formation but are not as common as in facies Am of the Monteith Formation. Coalified fragments and carbonaceous material are scattered throughout this facies with larger fragments localized in the lag deposits.

A soft whitish mineral observed in core was initially thought to be kaolinite. In other localities of the Cadomin Formation, kaolinite is reported in abundance (Figure 15d). Petrographic examination revealed that this soft whitish mineral was in fact partially leached chert grains. Vuggy porosity is common and has been developed where aggressive pore waters have leached out chert, argillaceous grains and mudstone clasts. Convolute bedding is rare and no trace of bioturbation was observed in Facies Ac.

Figure 3-4

Typical sedimentary structures and textures of Facies Ac (Cadomin Formation)

(A) 5-1-87-25w6, 877.2m
Salt and pepper textured medium to coarse grained lithic arenite. Comprised of chert (black and white), argillaceous grains (black), and quartz (grey). Note scale in cm.

(B) Low angle laminated medium grained lithic arenite. Note the sharp scour surface with chert pebble lag, and sutured contacts due to compaction (example arrowed). Prior to compaction the scour fill was a matrix supported conglomerate.

(C)10-11-88-25w6, 1350.7m
Normally graded conglomeratic lithic arenite with grains composed of chert (black and white) and quartz (grey). The grading occurs above a sharp scour (arrowed).

(D) 10-11-88-25w6, 1352.7m
Imbricated chert pebbles demarcating a bedding surface in a medium grained lithic arenite.

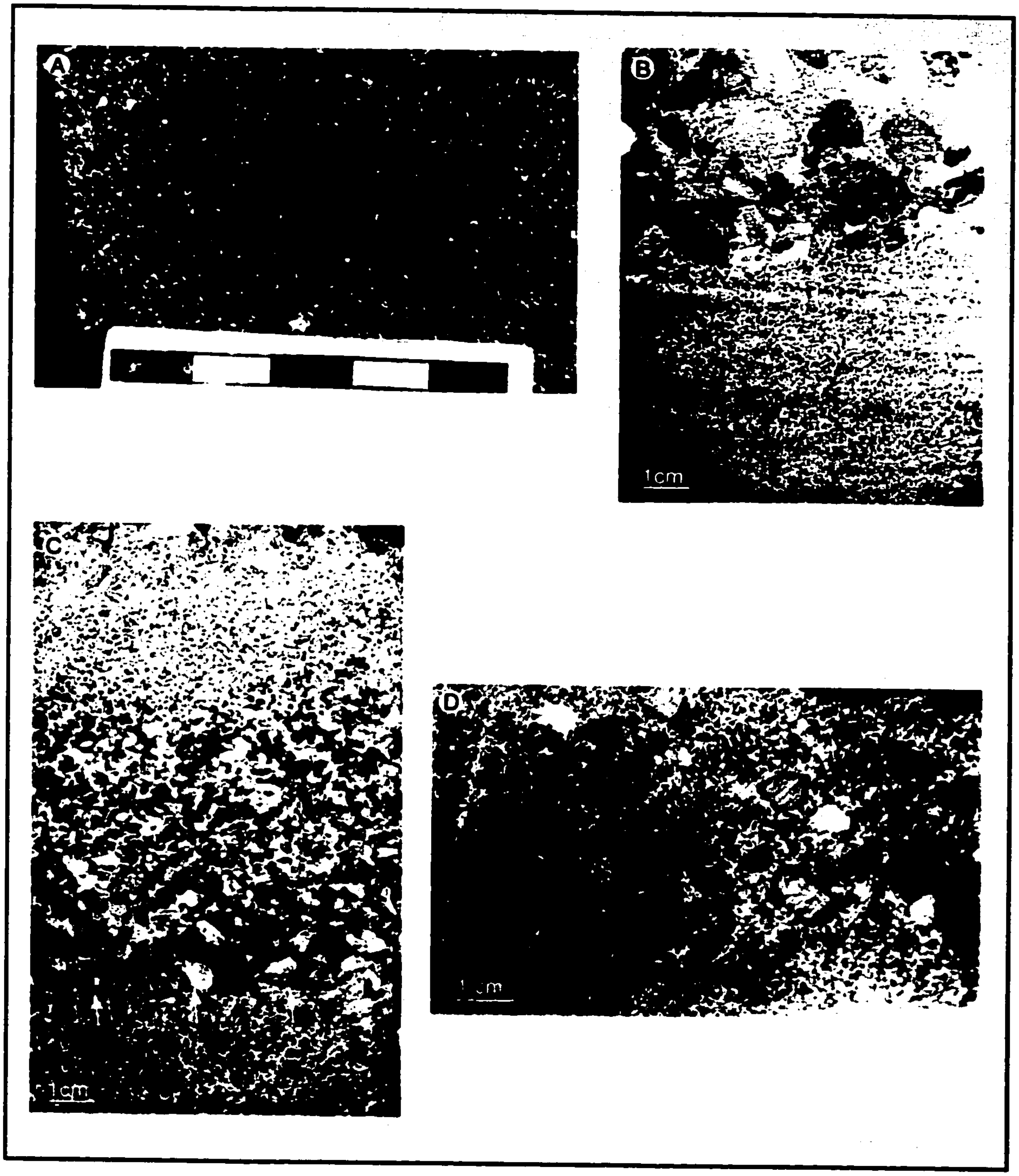


Figure 3-4

Figure 3-5

Sedimentary features of Facies Ac (Cadomin Formation)

(A) 2-20-88-25w6, 1052.9m

Trough cross-bedded medium grained lithic arenite. Note the sharp, high angle intersection between bedsets (arrowed).

(B) B-24-A/94-B-9, 964.3m

High angle cross-bedded pebbly medium grained lithic arenite. Individual bed forms display normally graded bedding internally. Pebbles comprised primarly of chert.

(C) D-94-I/94-B-8, 867.3m

Current rippled fine grained lithic arenite.

(D) 5-1-87-25w6, 874.8m

Massive medium grained lithic arenite with abundant partially leached chert grains (arrowed LC). This soft partially leached chert creates a secondary intragranular porosity.

(E) 5-1-87-25w6, 880.7m

Clast supported conglomerate with grains comprised of chert, lithic fragments and quartz. Typical of Facies Bc of the Cadomin Formation. Note the compactional dissolution boundaries between some grains (example arrowed).

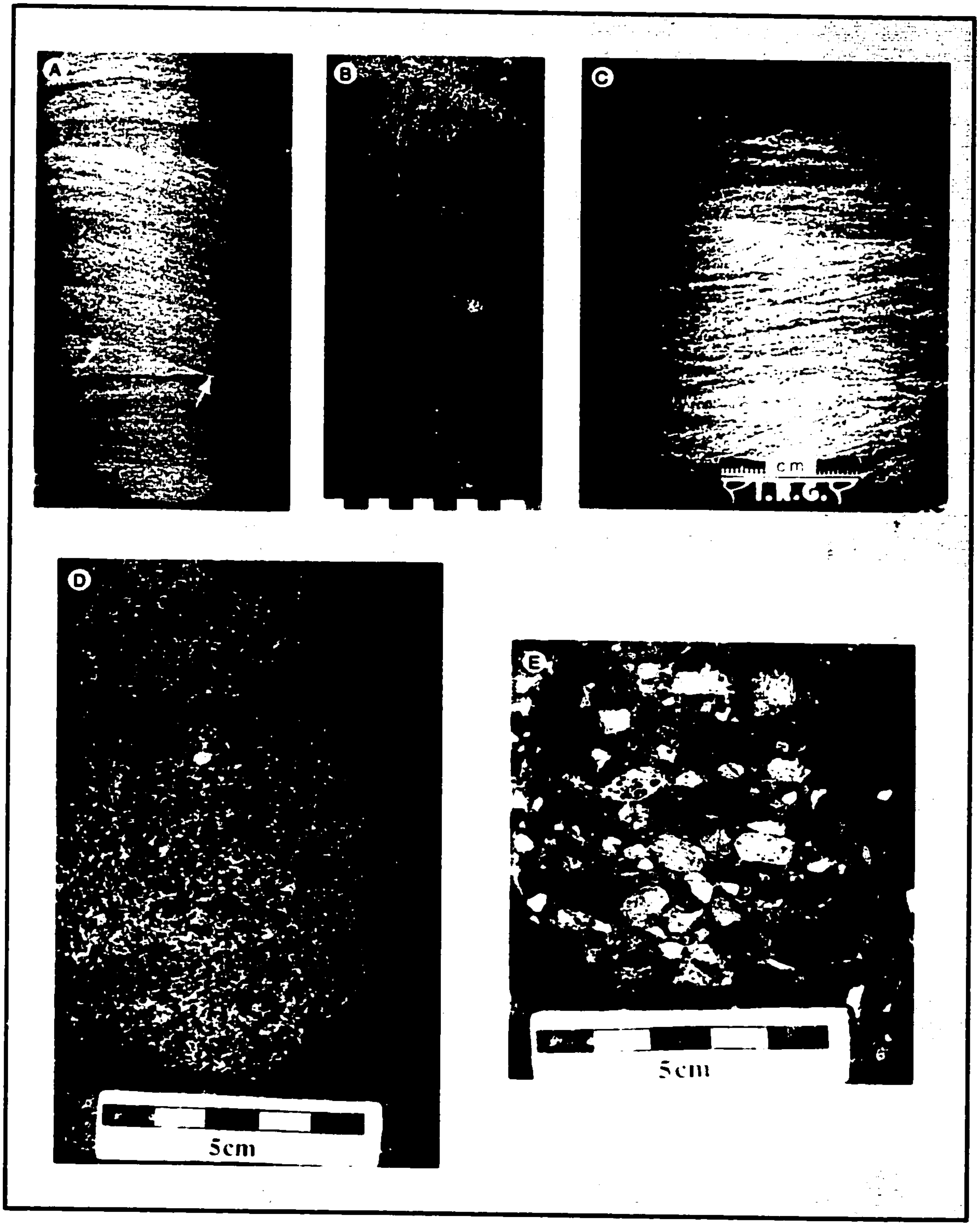


Figure 3-5

Interpretation

Facies Ac is very similar to facies Am of the Minnes Group, with the only major difference being the composition of the sandstone. As interpreted in the Minnes Group, the repeated fining upward secessions, numerous scour surfaces, and the sedimentary structures indicate that this facies was deposited in a fluvial setting.

The massive and trough cross bedded sandstones were deposited under uppermost lower flow regime conditions where as the high/low angle tabular bedding and occasional planar bedding developed in the lower flow regime. Trough cross-bedded sands are generally found in minor channel fills and upper flow regime dunes (Miall 1977).

As stream velocity decreased, the ripple laminated finer grained sands were deposited. The repeated-fining upward sequences suggest rapid changes (decrease then increase) in stream capacities. During floods, the lower unit is scoured into, removing the finer grained sands. Deposition of the relatively coarse sands and/or gravels occurs when this flooding starts to abide. This sequence of events was repeated as the Cadomin continued to vertically aggrade and prograde across the basin.

Facies Bc - Conglomerate

Description

Facies Bc of the Cadomin Formation is composed of conglomerate to conglomeratic sandstone (Figure 15d). Though not found in abundance in the study area, it is typically associated with the coarser grained sands of Facies Ac. Clast sizes average 0.8 cm, with the maximum observed clast size at 5 cm. The conglomerates are composed of moderately to poorly sorted, subrounded to well-rounded pebbles. The clasts are dominantly chert, with varying amounts of quartzites and argillaceous clasts. The chert is commonly white, grey, or black but can be bluish grey to pale green. Quartzite clasts are generally light coloured but most commonly pink.

The conglomerate is either clast or matrix supported, where the matrix is composed of fine to coarse grained chert and quartz sand. The conglomerate typically grades upwards from being clast supported to matrix supported. Three distinct textures were seen in this facies: a bimodal, a unimodal moderately sorted, and a unimodal poorly sorted texture. The unimodal moderately sorted is the most common. No discernible stratification or obvious imbrication was seen in this facies.

The lower boundaries of these conglomerates are sharp and erosional. The upper boundary is either sharp or gradational with Facies Ac. Numerous thinly bedded conglomerates can be observed vertically stacked, separated only by sharp erosional scours.

The conglomerates range in thickness to a maximum of ~2.0 meters as seen in well 3-9-88-25w6. These thick conglomerate horizons cannot be correlated between adjacent wells. This makes the geometry of individual conglomerate lenses hard to predict and interpret.

Interpretation

The conglomerates of Facies Bc were deposited during maximum flow (flooding) events. Powerful stream velocities carried pebbles downstream and as the flood subsided the conglomerates were deposited. As flow diminished, finer gravels were laid down followed by pore filling matrix sized material. The gravel traps the finer matrix material which is thus protected from removal by the next flood. These conglomerates were either deposited as longitudinal bars or as lag deposits in a braided fluvial system.

Facies Cc - Siltstone, Mudstone, and Coal

Description

Few examples of this facies were observed in core. When present, it constitutes the upper component of a fining-upward sequence and has a gradational contact with the underlying sandstones of Facies Ac. This facies is rare due to the fact that it is usually removed by scouring.

Facies Cc is composed of siltstone to mudstone with varying amounts of carbonaceous material and rare thin coal seams. The siltstone is medium to dark grey, commonly very sandy and argillaceous, with rare thin interbeds of fine to very fine grained, massive to ripple laminated sandstone. The siltstone is dominantly ripple laminated with current and climbing ripples.

The mudstone is dark grey to black, with variable concentrations of carbonaceous material. In some areas, the carbonaceous-rich mudstone graded vertically into a thin coal seam. These coal seams are rare and were under a meter in thickness. Thin 1 to 3 cm laminae of fine sands or silts were observed in the mudstones.

Throughout Facies Cc, minor amounts of pyrite laminae (millimeter scale) and nodules are present. Numerous root traces were observed in this facies, but no traces of bioturbation were detected in any of the lithologies.

Interpretation

Similar to Facies Bm of the Monteith Formation, this facies is interpreted as having been deposited in a floodplain environment. This includes crevasse/overbank splays and minor lacustrine deposits (ie. abandoned channel meanders) for the clean mudstones. The coals formed in swampy lowlands. The numerous root traces, abundant carbonaceous material, overall lack of bioturbation and sedimentary structures support this interpretation.

Depositional Model

The Monteith Formation and the Cadomin Formation, although separated by an unconformity and sourced from opposite directions were deposited in similar environments. The lithologies, sedimentary structures and other observations are characteristic of distal assemblage in a braidplain environment (Rust 1978b). The braided fluvial model best describes the depositional environment of these two formations in the study area.

Depositional Setting of the Monteith Formation

The Monteith Formation is dominantly localized by depositional and erosional processes to northeastern British Columbia. The formation has been interpreted as a large deltaic complex where it outcrops at Williston Lake (Stott 1998). Northeast of this delta complex, in the study area, an extensive system of medium-grained channel sandstones, and associated overbank deposits have been identified. This large river system, paralleling the present Peace River, deposited quartzose sands along the northern margin of the ancient Peace River Arch (Stott 1998). This river system fed the Monteith delta complex identified along present day Williston Lake. These sediments were then further reworked by waves and littoral currents, which spread the quartzose sands further north and south of the Monteith delta complex at Williston Lake (Stott 1998).

The fairly uniform nature of the Monteith Formation in the study area suggests multiple; laterally migrating and shifting channels. These coarse grained, cross-bedded sandstones are interpreted as bedload deposits of high-energy braided streams. Stott (1998) suggested that the quartzose sands are transported along the basin margin from numerous sources, rather than from a single point source which fed the large delta identified at Williston Lake.

The Monteith Formation of the study area appears to have been deposited in a multiple channel, braided river system. This river system flowed east to west and emptied into the Berriasian Embayment via the delta complex located at Williston Lake. Braided fluvial systems will be explained in detail in the discussion of the Cadomin Formation.

Depositional Setting of the Cadomin Formation

Numerous models have been proposed for the depositional environment of the Cadomin Formation. This formation has a widespread distribution across western Canada and as a result depositional models have been put forward based on different facies examined at various localities. Although each facies differs, all were deposited in the same general depositional setting across Alberta and northeastern British Columbia.

The Cadomin Formation is generally comprised of conglomerate throughout outcrop in the foothills. The most common depositional environments for conglomerates include: 1) shorelines, 2) alluvial plains, 3) alluvial fans, 4) deep-sea submarine fans and 5) glacial environments (Walker 1975). Deep-sea submarine fans and glacial environments can be eliminated as depositional environments for the Cadomin Formation. The absence of deep-water sediments as well as the lack of any till fabric or evidence for Cretaceous glaciation, make these two depositional models unlikely candidates.

Other depositional models for conglomerates include beaches and lakes. MacKay (1930) and Schultheis (1970) believed that the well sorted nature of the Cadomin was the result of the reworking of fluvial sediment by a series of migrating, shallow, ephemeral lakes. This theory was discounted due to the vast extent of the Cadomin Formation across the basin. Any lacustrine deposits identified in the Cadomin would be of local extent and would only occur in the topographic lows of the Pre-Cadomin Unconformity surface.

MacKenzie (1910) originally described the Cadomin Formation in the Crowsnest Pass area of Alberta as an alluvial fan deposit. The type section near Cadomin Alberta, was also interpreted as an alluvial fan deposit (Mackay 1929). The alluvial fan model for the Cadomin Formation is generally accepted for outcrops described in the Foothills of the Canadian Rocky Mountains. This model cannot however, be expanded into the plains to explain depositional patterns of the Cadomin Formation in the subsurface. In outcrop, six alluvial fans in the Cadomin Formation have been identified. Stott (1968, 1973) described three distinct alluvial fan lobes in the Northern Foothills, termed the Smoky, Belcourt and Peace fans. The Wapiabi fan has been identified in the Central Foothills and the Wind Ridge and Fernie fans in the southern Foothills.

Warren and Stelck (1958) proposed that the Cadomin Formation was the depositional product of one river flowing to the northwest. McLean (1976) partially agreed with this theory but suggested that all of the Cadomin, throughout its length of occurrence, was fluvial in origin with alluvial-fan deposits restricted to the western region. He further proposed that the sediments of the Cadomin Formation were deposited relatively rapidly.

Another theory on the development of the Cadomin Formation is through the process of pedimentation. Mountjoy (1960), Stott (1968), McLean (1977), and Schultheis and Mountjoy (1978) interpreted the Cadomin as a pediment veneer. McLean (1977) changed his original interpretation from fluvial/alluvial fan (McLean 1976) stating that the Cadomin Formation accumulated over a long period of time by the process of pedimentation.

A pediment is a smooth, gently sloping surface of erosion that is cut across bedrock and adjacent to the base of a highland that is lightly veneered by debris (Stokes 1950, Hadley 1967). Generally a pediment is a surface of transport that is being eroded. It can explain the presence of some thin conglomerates that overlie a surface unconformity (Schultheis and Mountjoy 1978). Stokes (1950) suggested the following features as characteristic of pediment sedimentation:

- continental and fluvial in origin
- clearly marked erosion unconformity at the base, but in practically all cases grade into overlying beds
- exceptionally widespread for continental units and at the same time remarkably thin
- age is difficult to fix
- unconformity represents a significant hiatus or the unconformity and overlying conglomerate represents a significant hiatus
- fossil evidence is non-existant, weak or non-diagnostic
- the rocks constituting the pebbles are of the most durable sorts – mainly quartz, chert, and quartzite. Fossils present were derived from sedimentary beds of a distal origin
- bedrock surface shows little or no weathering, and soil profiles have had no opportunity to form
- underlying bedrock surface of erosion is remarkably smooth, with evidence of only small-scale channeling

Many of these features can be recognized in the Cadomin Formation on a regional scale.

Schultheis and Mountjoy (1978) stated that a major component of the Cadomin Formation pediment was derived from the underlying strata. Yet, the Cadomin Formation in the study area is dominantly a medium-grained chert-rich, lithic arenite while the underlying strata is a dirty argillaceous fine grained sandstone to siltstone or a quartzose sandstone with only trace amounts of chert. Therefore the majority of the chert and quartzose sediments of the Cadomin Formation must have been derived from another source and not from the erosion of the underlying unconformity surface. Thus, it is unlikely that pedimentation has played a significant role in the formation of the Cadomin within the study area.

The chert rich sediment of the Cadomin Formation was sourced from the erosion of Pre-Cambrian and Paleozoic strata in the western Main Ranges (Schultheis and Mountjoy 1978). The bulk of Cadomin sediment was transported fluvially from the west with pedimentation playing a minor to negligible role in deposition.

The Cadomin Formation in the study area differs from the classic Cadomin in that it contains only minor amounts of conglomerate. The Cadomin in the study area was deposited in an alluvial plain environment with braided fluvial processes (west to east) depositing and reworking the sediment.

The Cadomin sediments now exposed in the Foothills represent alluvial fan deposition. In the subsurface to the east, this system grades into a braidplain environment. This lateral change in environments explains the regional sediment dispersal pattern, which shows an overall decrease in maximum grain size and decrease in percentage of conglomerate. In the study area, the Cadomin Formation grades laterally eastward into the finer grained sediments of the Gething Formation (Figure 2-1, and Figure 2-2).

The widespread uniform nature of the Cadomin Formation in the subsurface of Northeastern British Columbia is the result of sediment reworking by shallow channels which migrated across the Pre-Cadomin Unconformity surface. These channels winnowed fines and deposited the clean, chert-rich sands of the Cadomin Formation found in the study area. In braidplain systems, all parts become active and can migrate large distances in relatively short periods of time (Rust 1977).

Humid conditions during deposition are inferred by the presence of thin coal seams in the Cadomin Formation and by the thick and numerous coal seams found in the overlying Gething Formation (McLean 1977). Further, the lack of red beds and caliche deposits indicate these sediments were not deposited in arid conditions (Ricketts 1986). More evidence of humid conditions was demonstrated by Varley (1984), who states that many chert clasts have a weathered outer rim, indicated by variations in colour, that resulted from subaerial exposure in a humid environment. The alluvial fans identified in outcrop lack the debris flow deposits typical of arid region alluvial fans (McLean 1977). Thus, the Cadomin Formation can be interpreted to be a product of a more humid environment. These alluvial fans were created by braided streams flowing more or less continuously, in contrast to the ephemeral, flash flood deposits of arid fans.

A general picture of the depositional model for the Cadomin Formation has chert-rich sediment shed from highlands to the west and carried eastward, out of the restricted mountain valleys where sediment is deposited in alluvial fans. A braided river system is active on the alluvial fans, reworking the sediment and flowing from the toe of the fans northeastward onto a broad, low relief braidplain. This eastward to northeastward flowing system then merges with the Spirit River Channel system, which ultimately drains to the northwest. The Fox Creek Escarpment marks the eastern limit of this system.

The fluvial braid plain model best describes the observations seen in the three facies (facies Ac, Bc, Cc) described from the Cadomin Formation. The overall fining upward trends indicate waning energy conditions in the channels. Studies of modern braided rivers show that fining upward sequences are the result of channel fill due to the migration of lateral bars or to the accumulation of sediment on abandoned mid-channel bars (Cant and Walker 1976).

The structureless conglomerates and sandstones of the Cadomin were deposited rapidly during flood stage with the coarser grained component being deposited during exceptionally high floods. The numerous thin pebble layers that define the base of the fining upward sand sequences are lag gravels at the base of bars. These lags represent the coarsest bedload component of the stream which is moved only at high discharge levels (Walker 1975). After the lag gravel has settled, the bar is built upward through the accumulation of finer material still in suspension. Thus, as finer sediment continues to settle out there is a net upward fining (Walker 1975).

Autocyclic changes, such as channel switching and migration, resulted from variability in seasonal sediment discharge. The migration of channels across the braidplain reworks the sediment and removes the fines from the system. This explains why vertical accretion deposits, such as mudstones and coals, are rare in the study area. Although these mudstones and coals were deposited, continual channel migration cannibalized these sediments and transported them downstream. Lateral channel avulsion continually reworked the unconsolidated sediment on the braidplain, leaving behind the thin, laterally extensive sheet like deposit of the Cadomin Formation.

Modern Analog

The proposed modern depositional analog for the Cadomin Formation is the humid alluvial megafan of the Kosi River in India (Figure 3-6). The Kosi River, a tributary of the Ganges River, flows through a gorge in the Himalayas and empties onto the Gangetic plains. This river is sourced in Tibet, an upland terrain that includes the world's highest mountains; it then drains a large part of Nepal before emerging onto the Gangetic plains (Sinha and Friend 1994).

In front of the rising Himalayas lies the worlds most extensive deposit of Quaternary alluvial sediments (Parkash and Kumar 1991). Numerous alluvial megafans radiate out from the Himalayan mountain front creating a huge area of alluvial sedimentation. The Kosi alluvial megafan is the best developed in the Indogangetic Plains. These megafans all developed in a humid environment by large, predominantly braided river systems that rapidly migrated laterally across the developing fan (Singh et al. 1993).

The Kosi River is braided over a considerable portion of its course. It forms a megafan with a radius of approximately 60-km, with the alluvial fan/plain deposit covering approximately 16,000 square kilometers (Singh et al. 1993). The Kosi braided fluvial system contains channels spread over a width of 6-14 km, which have laterally shifted position in an east to west direction over 110 kilometers in the last 210 years (Figure 3-6, Williams 1982).

The rapid migration of channels across the Kosi alluvial fan could explain the well sorted, thin, yet laterally extensive nature of the Cadomin Formation. Over geologic time, the braided system of the Cadomin megafan would have repeatedly migrated laterally and continually reworked the sediment on the plains that lay in front of the Rocky Mountains.

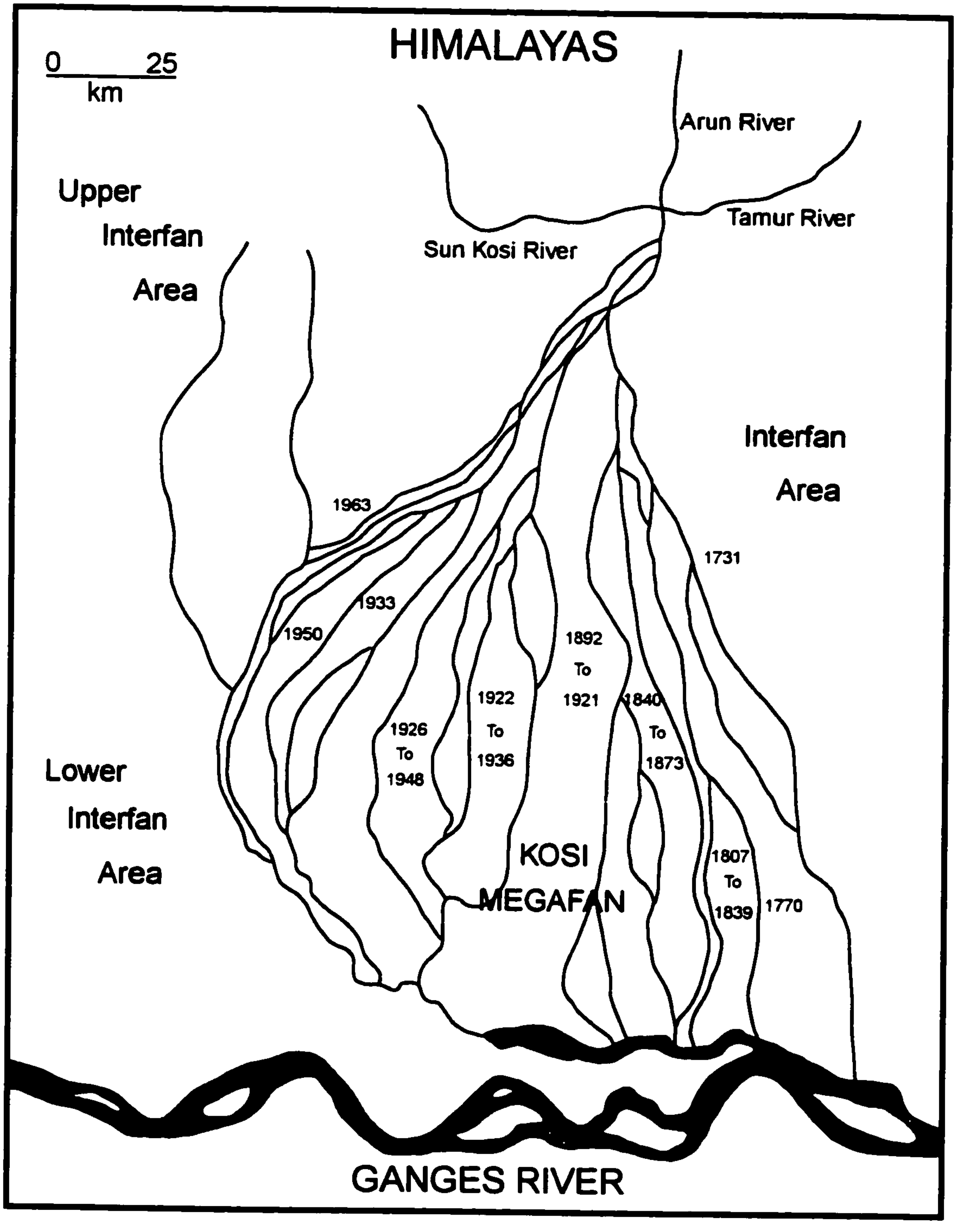


Figure 3-6

Modern analog for the braided sediments of the Cadomin Formation, the Kosi Megafan of the Indogangetic Plains. Just one of many humid megafans shed off the rising Himalayas. Dates shown indicate active channels during those years. (Modified Miall 1992).

Chapter 4
Petrography

Introduction

Detailed textural and compositional data for the Monteith and Cadomin Formations were obtained through petrographic analysis. Over 100 thin sections and 10 scanning electron microscope samples were examined (Appendix 2).

Monteith Formation

The sands of the Monteith Formation are dominantly arenites as they contain less then 5% matrix. The sands are dominantly quartz, thus most samples of the Monteith Formation are quartz arenites. Rare samples of sublitharenite were observed (Figure 4-1). Minor to rare amounts of argillaceous grains, chert, carbonaceous debris, micaceous flakes, and metamorphic grains are present but rarely exceed 5% of the total rock volume. When rock constituents other than quartz exceed 5%, they are dominantly argillaceous grains. The pure quartz arenites observed are generally medium grained and moderately well sorted.

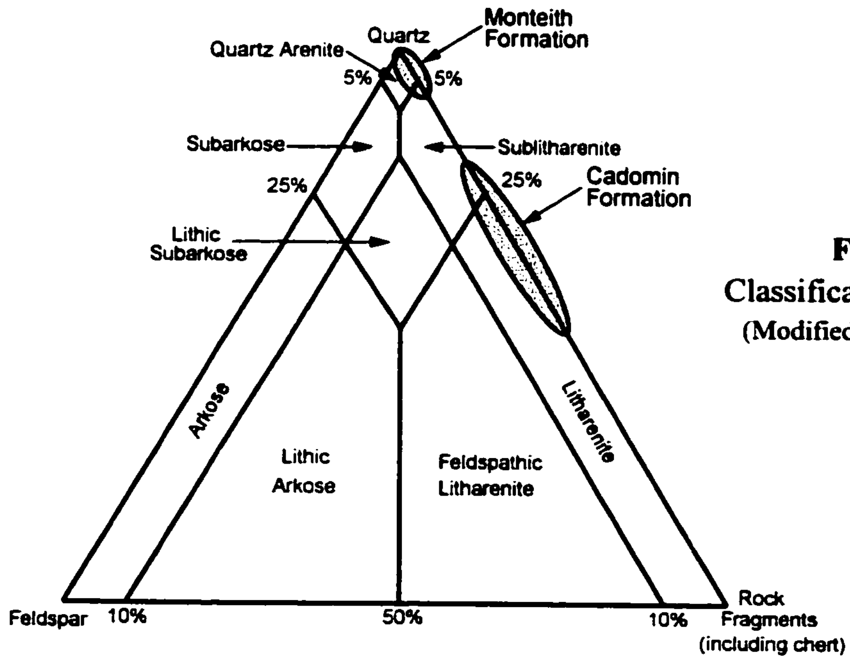


Figure 4-1
Classification of sandstones
(Modified from McBride 1963)

Quartz grains in the Monteith Formation show little to no strain and have a normal optical extinction pattern. These grains are generally clear but may contain small dust like inclusions that are commonly aligned. The inclusions consist of globules of gas, as well as fine micaceous and opaque dust. The original quartz grains are sub-rounded to well rounded, but the development of overgrowths has produced a more angular appearance. The original shape of the quartz grains can still be distinguished by rims of dust at the interface of the original grain and the overgrowth (Figure 4-2a,e). Where these rims are absent, it is difficult to distinguish the overgrowth from the detrital grain.

Quartz overgrowths are the major porosity-reducing factor in the Monteith Formation. Silica cementation appears as overgrowths on quartz grains and quartzite fragments. Secondary quartz overgrowths are generally in optical continuity with the original quartz grain. In some instances, overgrowths in the quartz arenites have grown together in the pore spaces, creating an interlocking mosaic of grains, which effectively eliminates porosity (Figure 4-2a,d). Pressure solution caused by compaction at grain boundaries causes the suturing of grains which also eliminates porosity (Figure 4-2b). In larger pore systems, overgrowths may terminate in well-developed crystal faces that incompletely fill the pore (Figure 4-2e). Interstitial clays which coat detrital quartz grains can prevent the formation of extensive quartz overgrowths. These clays can however promote chemical compaction and suturing of grain boundaries (Figure 4-2c).

Clays are a minor component in the sandstone of the Monteith Formation. The clays are commonly bitumen stained and thus dark in appearance, making identification difficult to impossible in thin section (Figure 4-3b). A scanning electron microscope was used to determine clay types. Clays are dominantly interstitial mixed-layer illitic clay which thinly coats quartz grains (Figure 4-3a). These mixed layer illitic clays show anomalous high readings of titanium, likely due to a

Figure 4-2

Petrography of the Monteith Formation

(A) Fine to medium grained quartz arenite; excellent original porosity almost completely occluded by extensive quartz overgrowths. Boundaries betweem the original quartz grains and the overgrowths are distinguished by rims of dust (examples arrowed). Remaining primary porosity consists of small, relatively isolated pores (Pr).

(B) Fine to medium grained quartz arenite. Silica solution along grain boundaries causes the suturing of grains (examples arrowed). Patchy bitumen (Bit) fills some pores.

(C) Medium grained quartz arenite. Clay rim on quartz grains prevents the formation of quartz overgowths (examples arrowed). Note sutured contact between the two quartz grains.

(D) Fine grained quartz arenite, tightly cemented by quartz overgrowths. Straight crystal faces arise from quartz overgrowths (examples arrowed). Remaining primary porosity consists of small, relatively isolated pores (Pr).

(E) Medium grained quartz arenite. Boundaries betweem the original quartz grains and the overgrowths are distinguished by rims of dust (examples arrowed red). Well developed crystal faces can be seen on the quartz overgrowths (examples arrowed yellow). Patchy bitumen (Bit) occludes some pores.

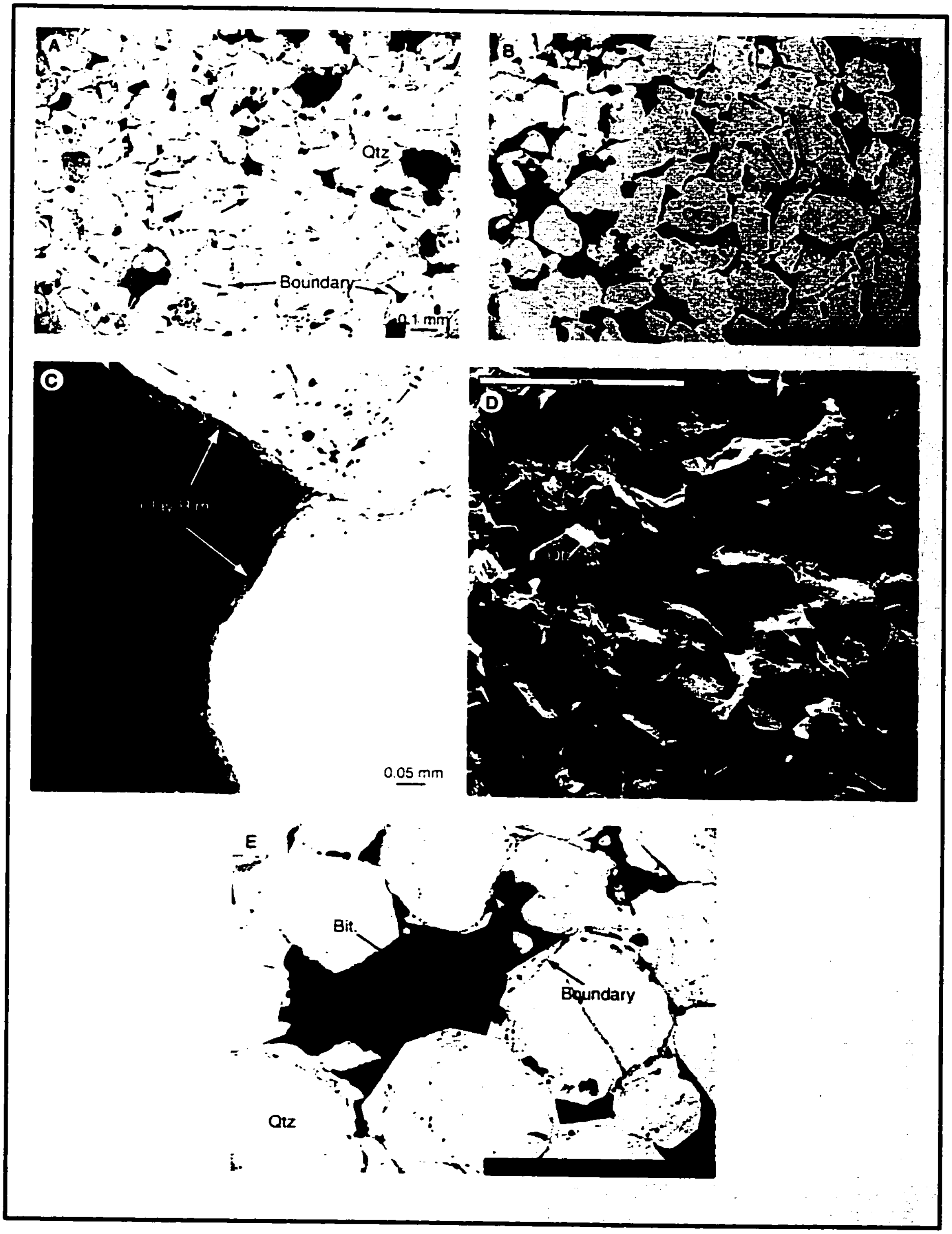


Figure 4-2

Figure 4-3

Petrography of the Monteith Formation

(A) Quartz arenite. Mixed-layer ilitic clay thinly coating quartz grains. Quartz growth lines in the overgrowths (examples arrowed).

(B) Medium grained quartz arenite viewed under crossed nicols. Clays stained with bitumen (examples arrowed).

(C) Poorly sorted quartz arenite. Irregular pore filling by Bitumen.

(D) Fine to medium grained quartz arenite. Pervasive brown-black bitumen completely occluding porosity.

(E,F) Fine grained quartz arenite. Authigenic kaolinite (K) clay occluding porosity. Note kaolinite is not stained by the bitumen, indicating that its formation post dates the placement of the bitumen.

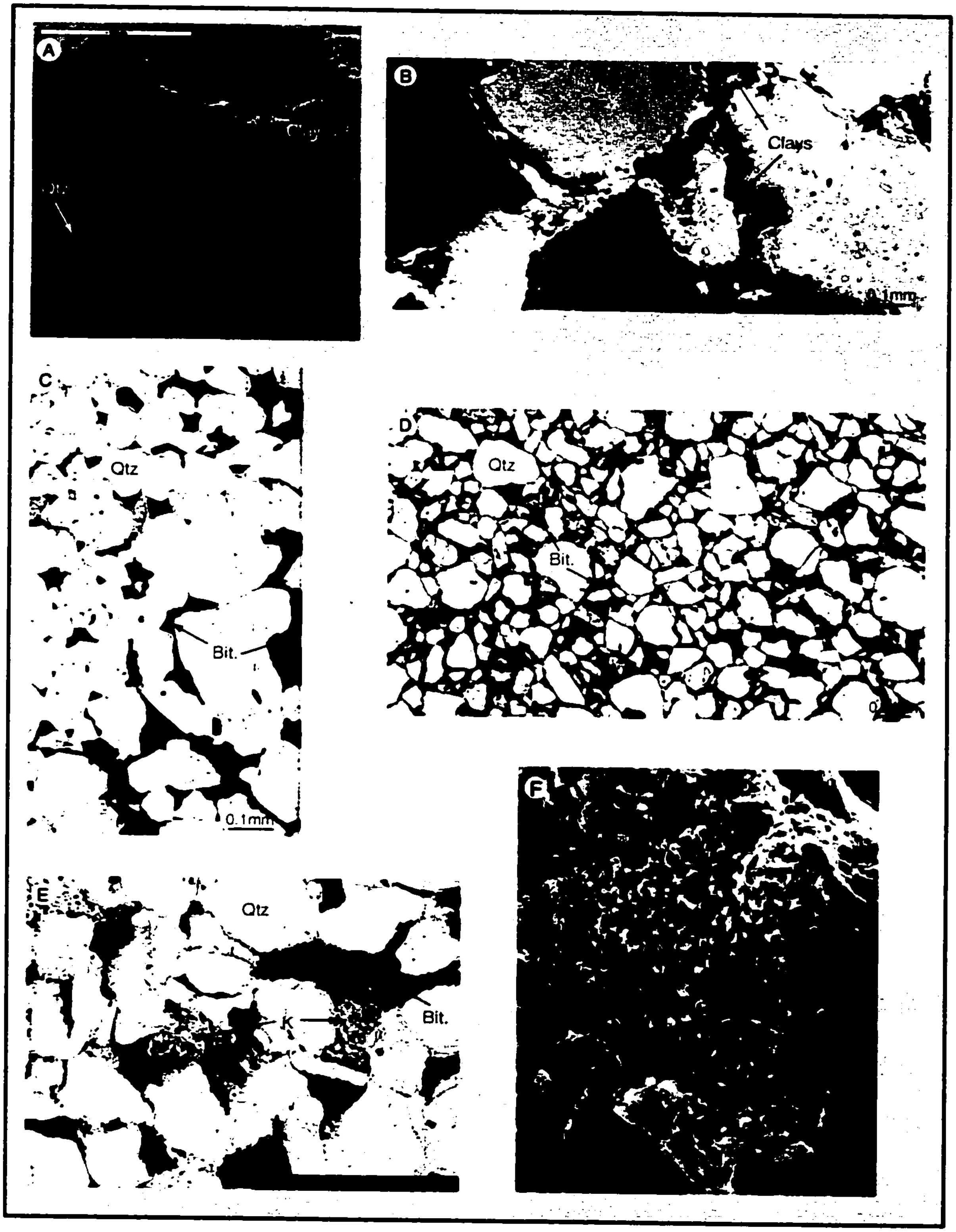


Figure 4-3

titanium oxide. Infiltrated clays can be observed creating geopetal structures in open pores. Minor to moderate amounts of authigenic pore filling kaolinite clay is rarely present (Figure 4-3e,f).

The argillaceous grains present in the Monteith sandstones are typically affected by aggressive pore fluids. The effect of these fluids can result in minor to total leaching of argillaceous and chert grains. This secondary porosity enhancement is limited in the Monteith Formation by the fact that the overall rock volume of these argillaceous grains is small. In many cases secondary porosity development is commonly reduced by bitumen staining of these partially leached finer grained argillaceous grains.

Other cement types identified in the Monteith Formation were bitumen, and calcite. Bitumen, the second most abundant cement type, was observed in quantities ranging from very minor to abundant. It is found as an irregular pore filling, as a pore space lining separating grains, and as a matrix in which quartz grains appear to float (Figure 4-3c,d). Bitumen was predominantly trapped in the finer grained material, where it emphasized sedimentary structures. Calcite cement was observed in a few samples, but where present, played a major role in occluding porosity. It can be concluded that calcite cement significantly affects porosity on a local basis only.

Cadomin Formation

The Cadomin Formation is classified as an arenite, as it contains less then 5% matrix. Throughout the study area, Cadomin sandstones range from the dominant lithic arenite to sublitharenite (Figure 4-1). Large amounts of chert in the Cadomin Formation makes it easy to distinguish in thin section from the quartz arenites of the underlying Monteith Formation. The Cadomin sands are composed of quartz and chert. Argillaceous grains and quartzite pebbles are common throughout, while carbonate grains, carbonaceous debris, micaceous flakes, and metamorphic grains are rare. Trace amounts of very fine detrital glauconite are present. When grains are bitumen stained, differentiating between argillaceous grains and chert can be extremely difficult in thin section.

The composition of chert grains is variable in the Cadomin Formation. Some grains are clear and quartz-like while others are fossiliferous or phosphatic. The most abundant chert observed in the Cadomin Formation is argillaceous and silty, grey to dark brown and characterized by a high iron and sulphide content. Pure chert, composed of microcrystalline quartz is observed, but uncommon. Fossiliferous chert is rare whereas, phosphatic chert is fairly common and ranges in colour from light to dark brown. These differing chert types grade into each other making precise separation difficult.

In the Cadomin Formation, the most favorable pore-system is developed where both chert and quartz make up the pore walls (Figure 4-4a). Where there is a high percentage of chert, a higher degree of compaction occurred decreasing the primary porosity (Figure 4-4e). With the high rock volume of chert and argillaceous grains contained in the Cadomin sands, a well-developed secondary porosity is often developed through leaching by aggressive formation fluids (Figure 4-4b,c,d).

Similar to the Monteith Formation, the quartz grains in the Cadomin Formation are free of intense strain features, though some do show slight undulose extinctions. Small dust like inclusions can be seen in the quartz grains and are most abundant at the boundary between detrital quartz grains and overgrowths. Detrital quartz grains of the Cadomin are subangular to rounded, but texture may be obscured by quartz overgrowths (similar to the Monteith Fm.).

The most common diagenetic feature and major cause of porosity reduction in the sands of the Cadomin Formation is the development of quartz overgrowths. A

Figure 4-4

Petrography of the Cadomin Formation

(A) Medium grained litharenite. Favorable pore-system (Pr) is developed where both chert and quartz make up the pore walls (examples arrowed). Where quartz grains comprise the entire pore boundary, quartz cement eliminates the primary porosity by growing together to create an inter-locking texture (Qtz). Chert grains show little to no secondary porosity development (Ch).

(B) Medium grained litharenite. Secondary porosity is moderately developed, with only partial leaching of lithic grains (examples arrowed). Syntaxial quartz overgrowths effectively occlude porosity where quartz grains comprise the entire pore boundary (Qtz).

(C) Medium grained litharenite. Well developed secondary porosity in aggressively leached impure chert. Bitumen is trapped in the finer grained impurities of the chert (examples arrowed).

(D) S.E.M. photo showing secondary porosity development in chert (examples arrowed).

(E) Medium grained litharenite. Primary porosity is reduced by compaction and deformation of the softer chert grains. Where there is a high percentage of chert, a higher degree of compaction occurs.

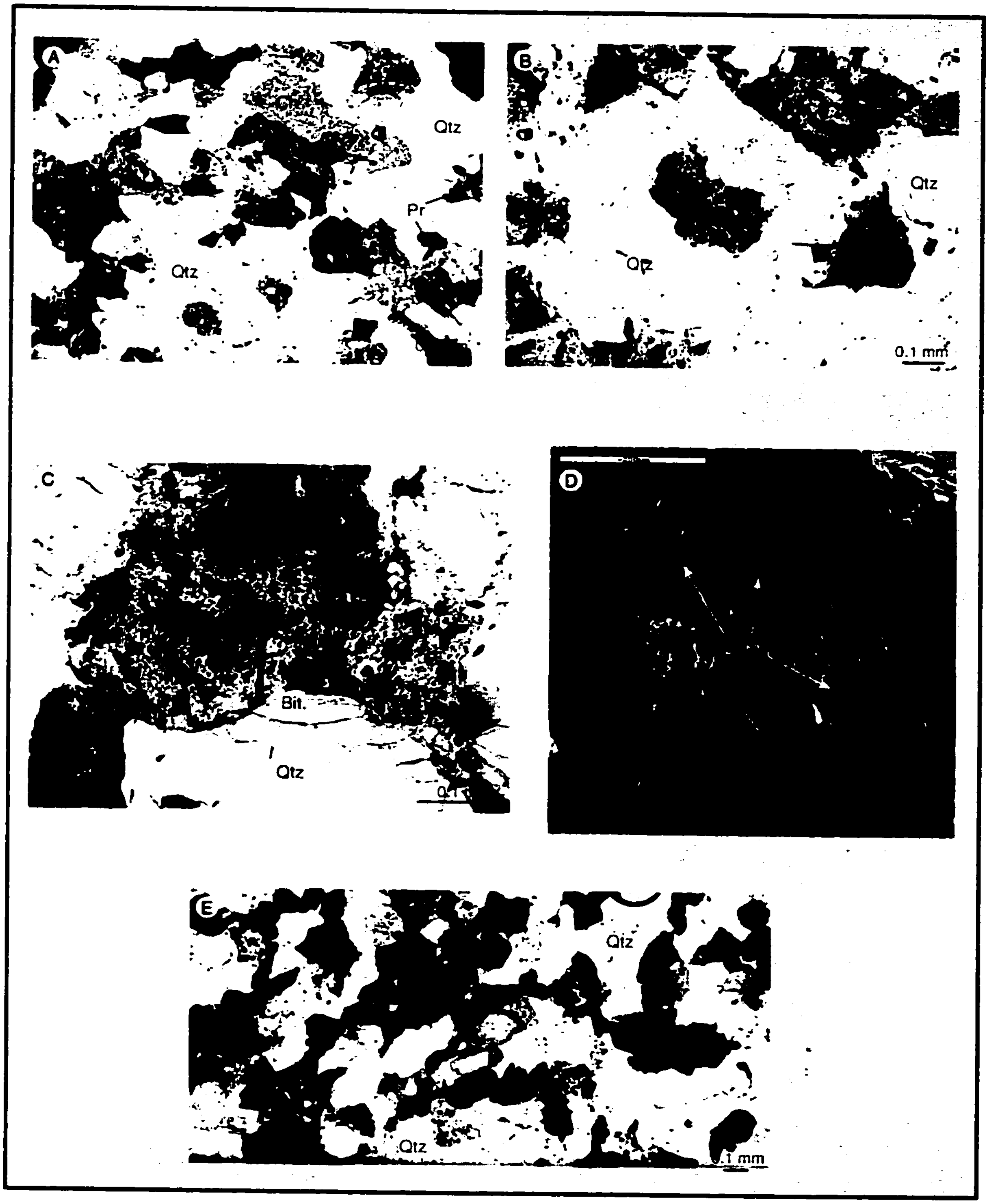


Figure 4-4

secondary silica cement takes the form of optically continuous overgrowths on quartz grains. In areas where quartz comprises all of the pore boundaries, syntaxial quartz overgrowths can grow together to create an inter-locking texture that effectively eliminates porosity (Figure 4-4a,b). The presence of detrital clay inhibits the development of quartz overgrowths as the clay envelope blocks the nucleation sites for further growth. Compactional features, such as long grain contacts and grain suturing, are common in the Cadomin but can be hard to distinguish due to quartz cementation. Some chert grains have cryptocrystalline quartz druse growths when examined under the S.E.M., this has a minor effect on the overall pore-system (Figure 4-5a,b).

The sands of the Cadomin Formation are predominantly clean with only minor amounts of clay. Mixed layer illitic clay and authigenic clay have been identified in the Cadomin sands. The mixed layer illitic clays are dominantly interstitial but infiltrated clays also rarely occur. McLean (1977) and Varley (1983) reported high quanties of kaolinite in the Cadomin Formation but, only small amounts of pore-filling kaolinite clay were observed in the study area (Figure 4-5c).

Bitumen, calcite and barite are present in varying amounts in the Cadomin Formation. Bitumen residue/coating plays a major roll in the reduction of porosity within the Cadomin. The bitumen is present in varying amounts, from minimal bitumen residue to total pore space saturation. Similar to the Monteith Formation, the bitumen helps define the sedimentary structures present in the sands. This highlighting of structures is due to trapped bitumen in the finer grained material.

Calcite cement in the Cadomin is uncommon in the study area. In areas where it is present it occludes the majority of porosity. Barite cement is rare and only seen in a few samples. When observed, it is localized in small patches and occluded only small areas of porosity.

Figure 4-5

Petrography of the Cadomin Formation

(A, B) S.E.M. photos of a litharenite. Cryptocrystalline quartz druse on chert (Cy. Qtz). It has a minor effect on the overall pore-system. Intergranular porosity (Pr) is developed where both quartz and chert grains make up the pore walls. Well developed crystal faces can be seen on the quartz overgrowths (Qtz), as well as the actual quartz growth lines (Qtz G.L.). Bitumen (Bit.) can be seen plugging primary porosity.

(C) Medium grained litharenite. Intergranular porosity is occluded by pore filling kaolinite (examples arrowed).

(D) S.E.M. photo of a litharenite. Intergranular porosity (Pr) is developed where both quartz and chert grains make up the pore walls. Primary porosity is reduced by quartz cementation, a fluid inclusion (arrowed) can be seen trapped in the quartz cement.

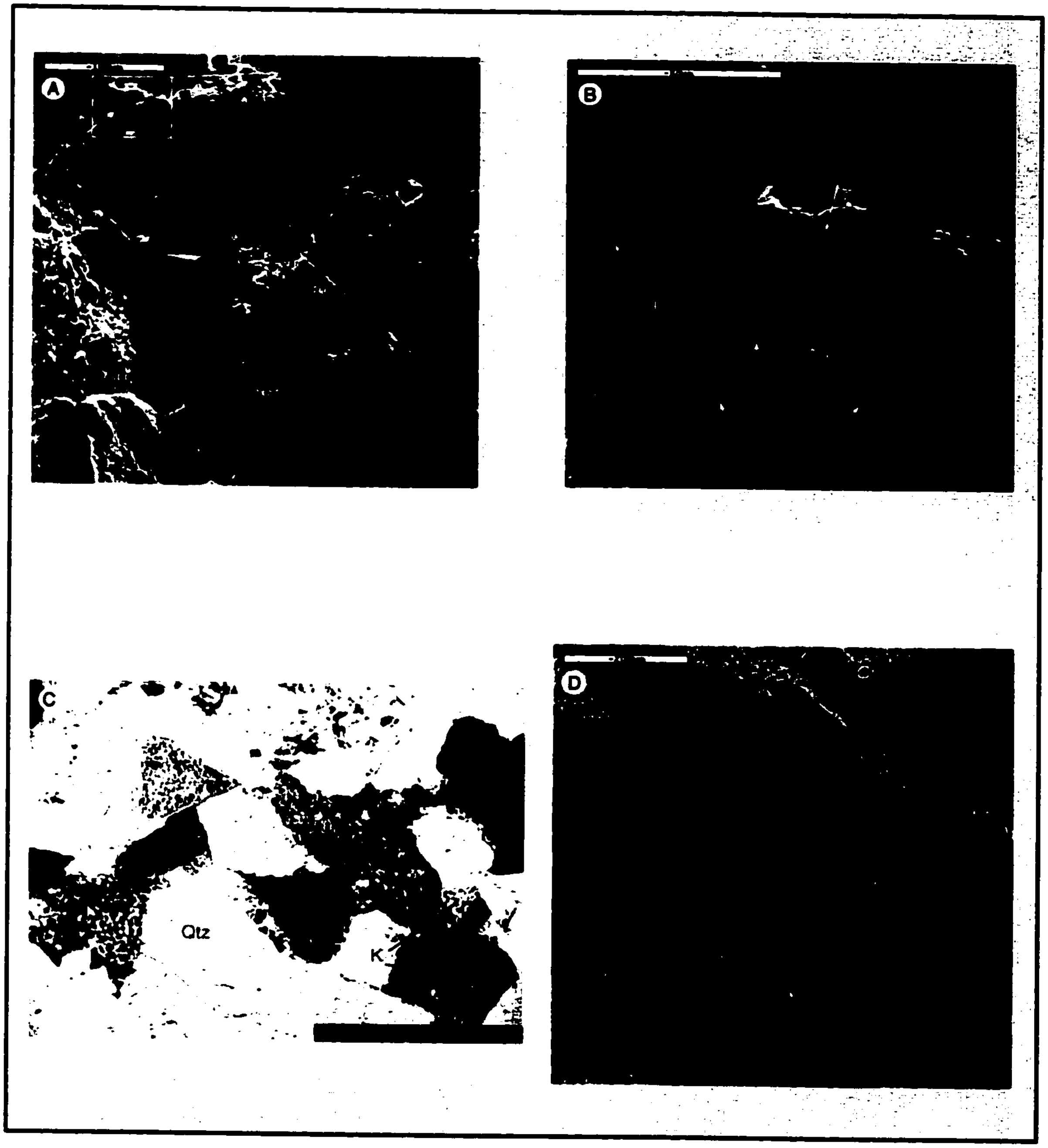


Figure 4-5

The argillaceous grains observed in the Cadomin ranged from angular to rounded. Generally, larger clasts show an immature texture, whereas smaller grains are more mature. Carbonate grains identified are smaller than the quartz and chert grains that they are associated with, and are rounded to well-rounded. The trace amounts of glauconite seen in the Cadomin Formation are small well-rounded grains of a detrital origin. Their smaller size and mature texture is a result of their low resistance to reworking in a fluvial setting.

Diagenesis

Diagenetic processes generally begin to reduce primary porosity in sandstones shortly after deposition (Hutcheon 1990). The diagenetic history of the Monteith and Cadomin Formations are very similar. The one significant difference is the occurrence of rare barite cement in the Cadomin Formation. The diagenetic processes and timing of events are the same in both formations.

1) Early calcite cementation:

Calcite was the first cement precipitated, and was probably more abundant then its present distribution would suggest. Where present, calcite fills the larger pore systems, typically in the coarser grained material. Carbonate cements are present as a uniform pore filling over large areas of a rock unit or alternatively their distribution can be very patchy. This patchy distribution is due to partial removal of the more evenly distributed calcite cement during burial. This occurs as aggressive ground water passes through the rocks leeching the carbonate cement. In the Monteith and Cadomin Formations calcite cement is rare, but where present it occluded the majority of porosity.

2) Compaction and quartz overgrowth cementation:

Compaction and quartz overgrowth cementation are the major causes of porosity and permeability reduction within the Monteith and Cadomin Formations. Pressure solution along grain contacts was evident by the presence of stylolites in both formations. Along quartz/quartz or quartz/chert grain contacts, silica dissolves and moves into the fluid filled pores where pressure is lower. It can then precipitate as overgrowths on the surfaces of quartz grains bounding the pore space (Hayes 1979). Pressure solution is accelerated by the presence of chert, which is highly susceptible due to its lack of crystal structure. The rate of quartz cementation can be directly linked to depth of burial and temperature, but can also be strongly influenced by grain coatings such as mixed layer clays and bitumen (Hutcheon 1990).

3) Secondary Porosity Development:

Secondary porosity developed when aggressive pore fluids circulated through the rock matrix leaching the more soluble rock constituents there by enlarging the overall pore-system. The most affected constituents are chert grains, silicified argillaceous grains and calcite cement. During this stage, the majority of early calcite cement was removed from the Monteith and Cadomin Formations. Varying amounts of silica dissolution occurred in both the Monteith and Cadomin Formations, resulting in minor porosity enhancement to total dissolution and the development of grain mouldic pores. In the Monteith Formation, evidence of silica dissolution can be observed as the rounding of quartz grains/overgrowths or by the presence of irregular grain edges. These distinctive attributes generally increase the overall pore diameter. In the Cadomin, the effect of silica dissolution is more pronounced. Aggressive pore fluids have leached the abundant chert grains, leaving a well-developed secondary pore-system. The result of this leaching ranges from partially corroded grains to the total removal of some of the chert grains. Where impure cherts and silicified argillaceous grains are leached, a fine clay residuum usually remains in the leached pore. This clay material is chemically stable and does not dissolve into solution. These movable clays can migrate and block pore throats, there by limiting effective porosity.

4) Authigenic Clay Cementation:

Authigenic clay cementation (growth *in situ*) of kaolinite and, to a minor extent, mixed layer illitic clays infill the intergranular pores, decreasing porosity and permeability. Kaolinite fills the larger pore networks, but leaves the smaller pores open. Kaolinite crystallization is the last diagenetic modification in the Monteith and Cadomin Formations, as it occludes both the primary and secondary pore-systems. The presence of kaolinite in the pore system, with small pore throat diameters, can pose a fines migration problem during reservoir development.

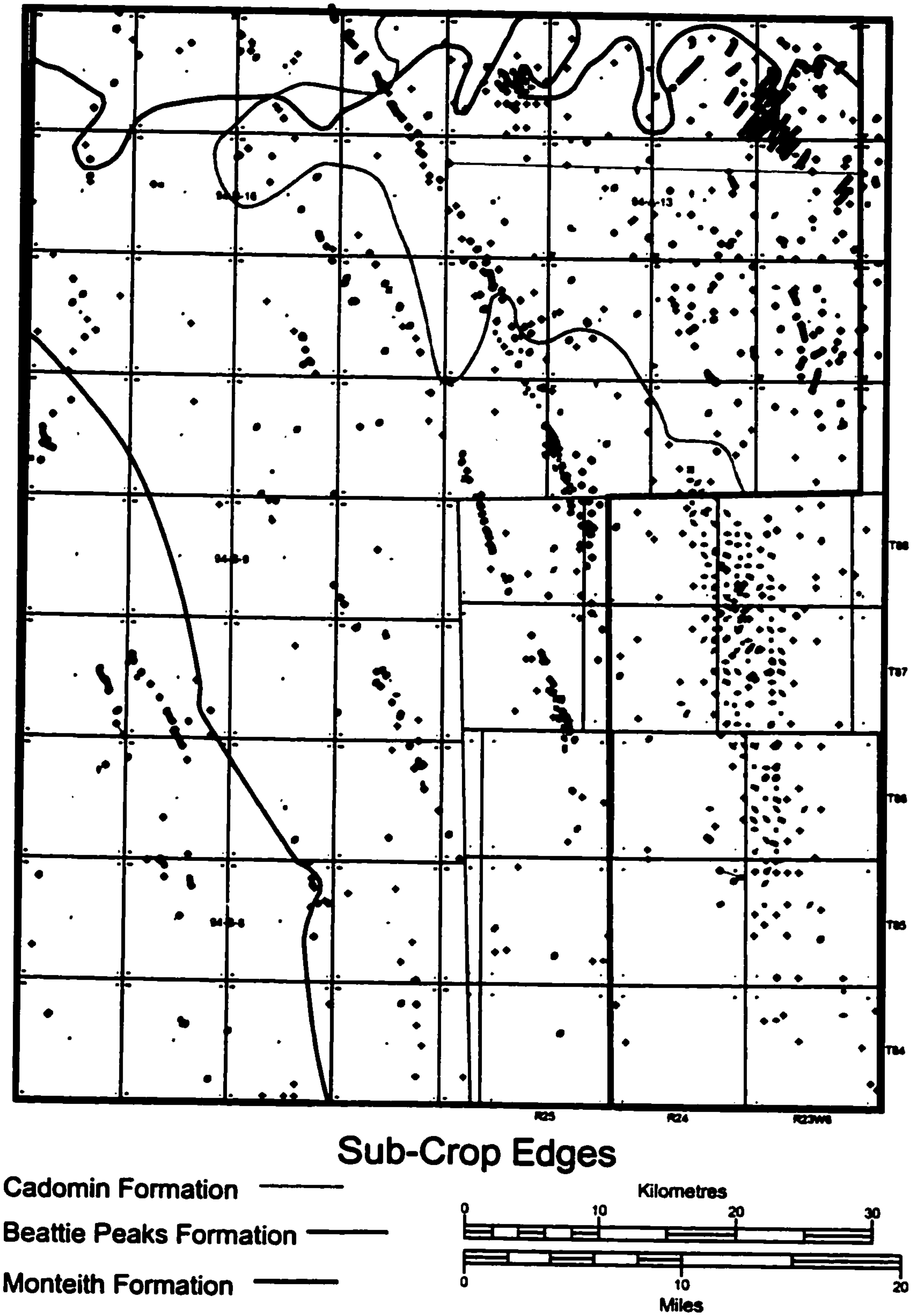
Chapter 5

Applications to Petroleum Exploration/Exploitation

In the study area, natural gas reserves for the Dunlevy (a general term for the Cadomin and Monteith Formations) are estimated at 810 billion cubic feet (Bcf) original gas in place (British Columbia Ministry of Energy and Mines, 1998). Traditionally, the term Dunlevy has been used to group both the Cadomin and the Monteith Formations. The majority of these reserves are found within the Monteith Formation. The more productive eastern portion of the study area is predominantly comprised of the Monteith Formation as the Cadomin Formation is absent from that area (Figure 5-1). Unfortunately, where the Cadomin and Monteith Formations are both present, the production from each zone has not been separated, rather grouped together under the 'Dunlevy' term.

Proven reserves from the Cadomin and Monteith Formations are found in 20 pools in 11 different fields within the study area. The largest pool, the Dunlevy 'A' Pool in the Blueberry Field, has production from both the Cadomin and Monteith Formations. Original gas in place for this pool (OGIP) is estimated at 445.2 Bcf (British Columbia Ministry of Energy and Mines, 1998), with a recovery factor between 20% and 25% of OGIP. This low recovery factor is mostly due to the fact that both the Cadomin and Monteith Formations are characterized by 'tight', low permeability sands.

To fully understand the reservoir and the best zones for gas recovery, it is important to take into account the depositional environment, tectonic structuring, mineralogy, diagenetic modifications and secondary enhancement of these relatively tight sands.



Sub-crop edges based on core data, Canstrat data, and well logs. Note that the Cadomin sub-crop is actually a lateral facies change with the Gething Formation.

Figure 5-1

The Reservoir

Reservoir facies in the Cadomin and Monteith Formations are composed of an upper medium to lower medium grained sandstone, but can range from a conglomerate in the Cadomin Formation to a clean lower fine-grained sandstone in the Monteith Formation. A 10% porosity cut-off separates reservoir rock from non-reservoir rock throughout the study area. A cross plot of porosity vs. maximum permeability from numerous cored wells suggests that 10% porosity, corresponds to a permeability of 2 to 5mD.

Due to the depositional nature of the Cadomin and Monteith Formations, (namely a braided fluvial setting), the reservoir is composed of multiple sand bodies. Both formations are dominantly comprised of numerous fining upward sequences, and as a result, the reservoir is a combination of stacked coalescing fining-upward successions. Due to the nature of this reservoir, the porosity is scattered through the sequence, and rarely localized to a specific interval. In rare cases, correlation of porosity intervals is possible between adjacent wells or closely spaced wells but overall this is not the case on a more regional scale. Generally speaking, the thicker the overall net sand package (multiple stacked sand bodies), the higher the chance of encountering a thicker net reservoir quality rock.

Reservoir Areas

Natural gas reservoirs in the Cadomin and Monteith Formations are found throughout the study area. In the western portion of the study area, these reservoirs are restricted to structural highs that are commonly found on the hanging wall of northwest/ southeast trending Laramide thrusts. Moving eastward, these thrusts become less pronounced in the Lower Cretaceous sediments and thus this trapping style type becomes less dominant. In the eastern portion of the study area, namely east of the Blueberry Field, structural highs in the Monteith Formation are created by a combination of Laramide thrusts and channeling on the overlying pre-Cadomin unconformity (Figure 5-1). Gething channels on the unconformity surface cut down and define where these easternmost reservoirs are localized within the Monteith Formation (Map 1 - Structure Map Monteith).

The best reservoirs in the Cadomin/Monteith are thick sand deposits that are located along structural highs. Wells drilled in Monteith/Cadomin structural lows typically encounter wet thin sands, with sand thickness decreasing eastward and northward. In the eastern portion of the study area wells drilled along the flanks of highs, commonly contain thinner sands than those that penetrate the crest of the highs. These wells can encounter an oil leg, which is generally uneconomic, or gas that may produce for a short period of time before watering out.

The thickness of the Cadomin Formation is generally uniform across the study area compared to the isopach of the Monteith Formation. Subtle variations in thickness away from the sub-crop edge can be related to the underlying unconformity, while the thickening in the west and south of the study area can be related to proximity to an alluvial fan (Map 3 - Isopach map of Cadomin Formation). The isopach of the Monteith Formation changes drastically from east to west across the study area (Map 2 - Isopach map of Monteith Formation). The Monteith isopach shows a steady thickening to the west. The effects of the pre-Cadomin unconformity are more dominant in the eastern and northern sections of the study area. Despite the fact that the sand is thicker in the west, the best reservoirs lie in the east, due to their differing amounts of quartz cementation, which can be directly linked to the depth of burial.

Reservoir Limiting Factors

There are a number of factors that limit the effectiveness (permeability/porosity) of the reservoir. The first and most significant is quartz cementation. Silica overgrowths are more pervasive in the Monteith Formation than in the Cadomin Formation. This is because the Monteith Formation is a quartz arenite. The Cadomin shows less of an effect because it is composed of a mixture of quartz, chert and rock fragments (litharenite).

On quartz grains, syntaxial overgrowths create an inter-locking texture which eliminates porosity and reduces permeability. Quartz cementation is limited on chert grains, as only cryptocrystalline quartz druse may form. This cement has a minor effect on the porosity and permeability of the reservoir.

In the western portion of the study area, the Monteith Formation has undergone substantial amounts of quartz cementation. This is directly related to the greater depths of burial that this area has undergone compared to the eastern portion of the study area. The Monteith reservoirs in this western area are generally poor, with lower permeability and porosity relative to the reservoirs in the east.

The second major factor reducing reservoir quality is the presence of bitumen. Bitumen staining varies across the study area and is scattered throughout the Cadomin and Monteith Formations. In some intervals it is observed as an uneven pore filling. Whereas in other cases it forms a matrix in which some of the grains appeared to float. There is no horizon or mappable pattern that would indicate predictable areas of high bitumen concentration and staining.

The third factor that decreases the effectiveness of a reservoir is the presence of clays. Both interstitial mix-layer clays and authigenic kaolinite have been identified in the Cadomin and Monteith Formations. If the interstitial clays are abundant their presence promotes chemical compaction leading to the reduction of porosity and permeability. Authigenic kaolinite in-fills the intergranular pores and decreases the overall porosity and permeability. The presence of kaolinite in the pore system, with small interconnections between pores gives rise to potential fines migration during production. When a well is put on production, initial flow rates in the near well bore area may be excessive and cause turbulent flow that dislodges clay particles. These clay particles then migrate and lodge in the pore throats. Once in the pore throat, kaolinite will act as a choke, reducing permeability and consequently causing a loss of productivity. Kaolinite, is considered to be especially susceptible to migration as it occurs as loosely packed stacks of clay booklets that are clustered in the centers of pores rather than being attached to surrounding grain surfaces (Pittman and Thomas 1978, Almon and Davies 1977). The potential for migration of fines problems in the Cadomin and Monteith reservoirs are present, but are limited as the amount of kaolinite observed was relatively small.

Reservoir Enhancement

There are two main factors that enhance reservoir parameters in the Cadomin and Monteith Formations; fracturing and secondary porosity development by the leaching of grains.

The presence of unhealed, uncemented open fractures greatly enhances the permeability of the relatively tight gas reservoirs of the Cadomin and Monteith Formations. Fractures can act as primary conduits for fluid migration and play an important role in the development of hydrocarbon reservoirs in the Cadomin and Monteith Formations.

It is important to distinguish whether fractures are natural or artificially induced. Clean breaks and unmineralized surfaces should not be interpreted as natural fractures unless there is further supporting evidence. Coring induced fractures are common and typically run parallel to one another (Figure 5-2a). Mineralized surfaces along fractures and the presence of stylolites grading into fractures are indicative of natural fracture systems (Figure 5-2b,c,d and Figure 5-3).

Figure 5-2

Fracture Types: Cadomin and Monteith Formation

(A) D-55-H/94-A-13, 1160.5m

Massive medium grained quartz arenite. Parallel unmineralized fractures (examples arrowed) are caused during coring.

(B) 6-21-88-25w6, 1150.3m

Massive medium grained lithic arenite. Natural open fractures (examples arrowed).

(C) 6-21-88-25w6, 1151.9m

Medium grained lithic arenite. Mineralized rubble indicating the presence of open fractures.

(D) 6-21-88-25w6, 1152.5m

Massive medium grained lithic arenite. Natural open fractures. In some areas fractures grade into styolites, a good indication of natural fractures (example arrowed).

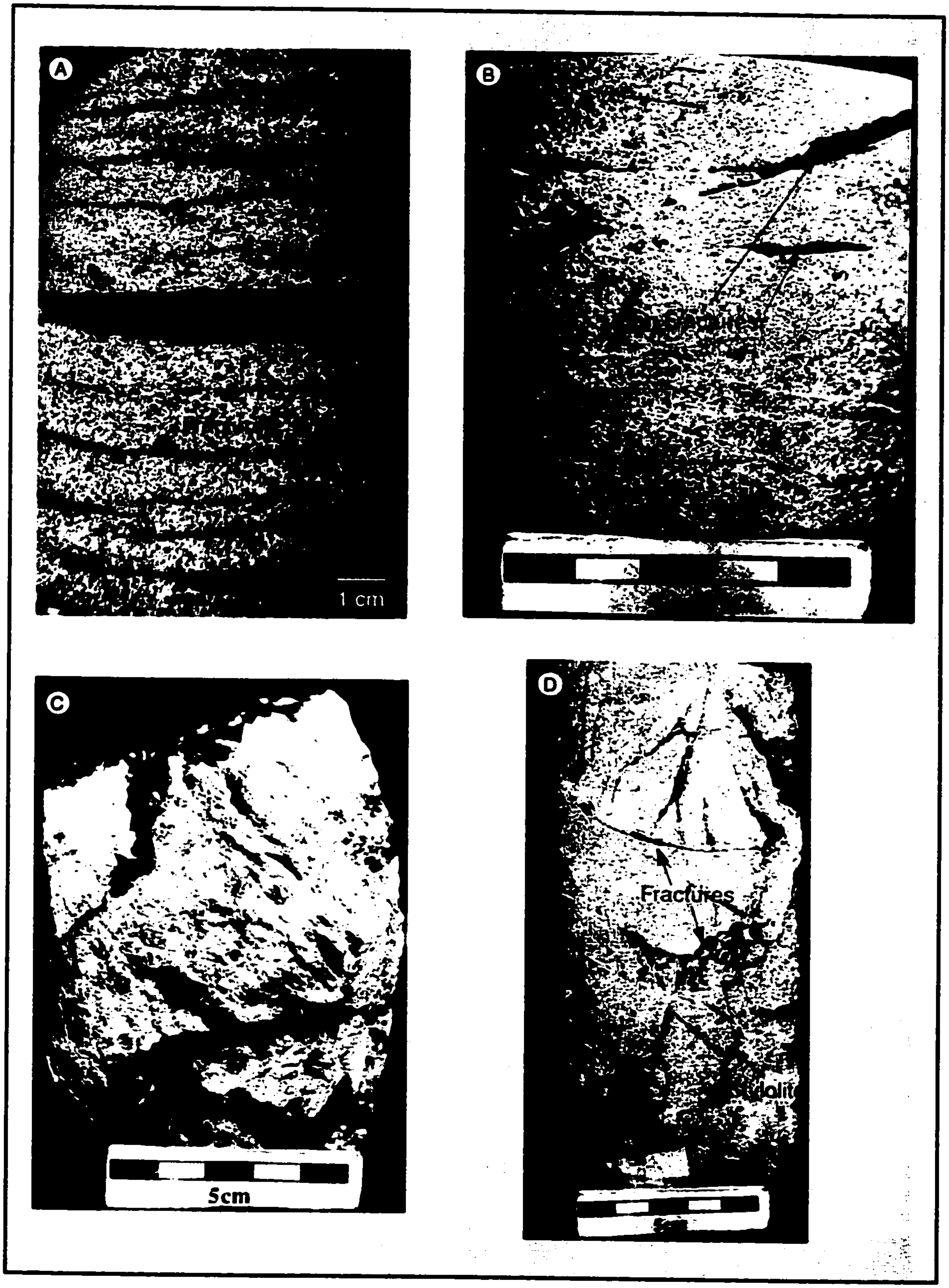


Figure 5-2

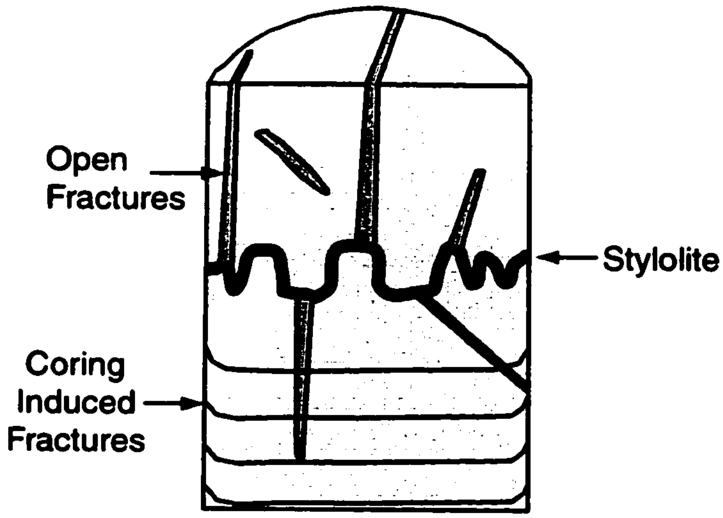


Figure 5-3

Fracture Types in the Cadomin and Monteith Formations. Coring induced fractures are generally parallel to bedding, while open fractures are related to structural deformation.

Faulting of Paleozoic strata in the study area has lead to fracturing and folding in the younger Lower Cretaceous sediments. Structural deformation can induce fracturing in the thick, relatively competent Monteith and Cadomin Formations enhancing reservoir quality (Figure 5-4). Core analyses in the Monteith and Cadomin Formations show fractures greatly enhance reservoir permeability, with the potential of increasing permeability several hundred millidarcies.

The second factor that enhances overall reservoir quality is the development of secondary porosity by leaching. Circulation of aggressive pore fluids leads to the dissolution and removal of some constituents. Particularly, chert grains, silicified argillaceous grains, and calcite grains and cements are the most affected. Dissolution commonly occurs during increasing burial temperatures and when organic acids are present in the pore water. The Cadomin Formation, with its variable composition is more susceptible to secondary porosity development then the dominantly monomineralic Monteith Formation. Grain moldic porosity is formed by the total leaching of some grains. Point counting of thin section samples indicates that this form of secondary porosity can increase overall reservoir porosity by 3-5%. Partially dissolved grains can

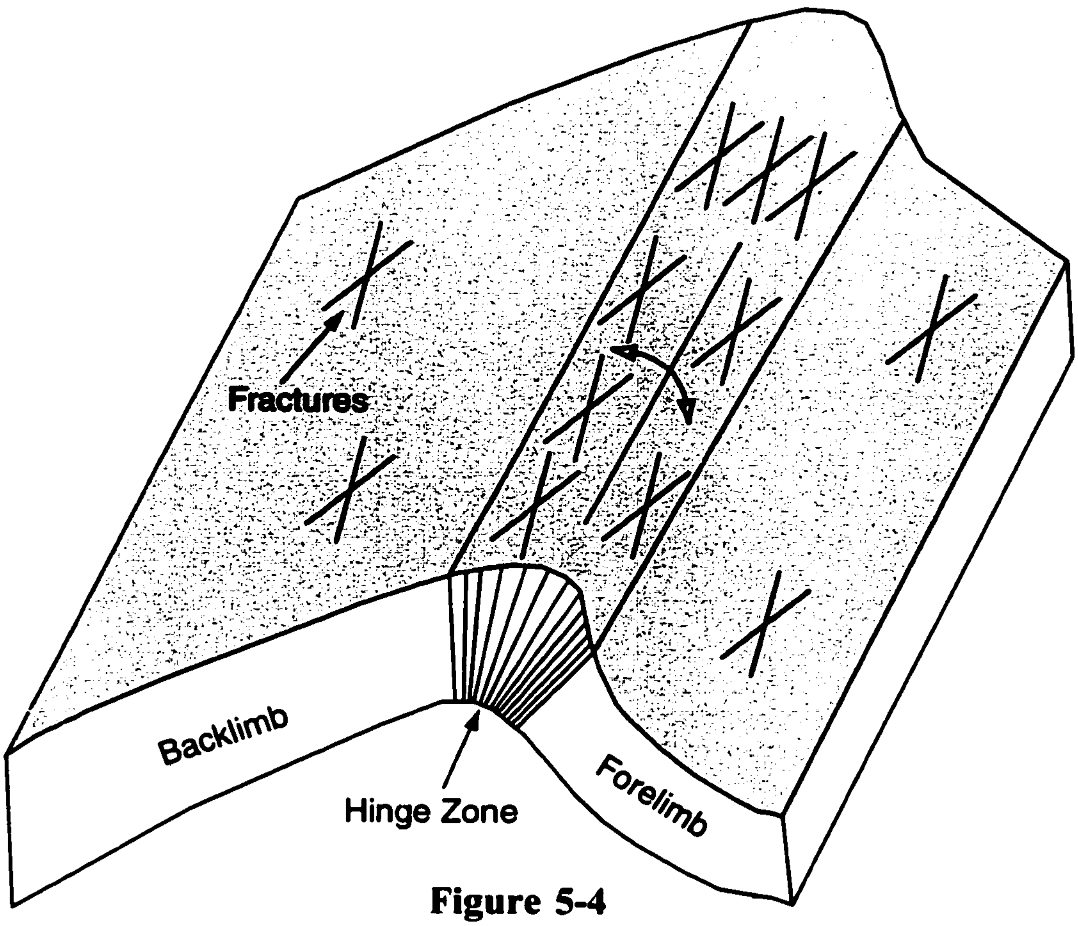


Figure 5-4

Origins of fracture development in the Cadomin and Monteith Formations. Most intense fracturing occurs in the hinge zone.

be left with a corroded irregular surface, but will still contribute to increased porosity. Where impure chert and silicified argillaceous grains are leached, insoluble clay residue usually remains in the leached pores. This fine clay residue may be a concern for later migration during reservoir production.

Exploration Strategy

The Monteith and Cadomin Formations are well developed, mature plays. In the eastern portion of the study area, the prospects for a new pool discovery in the Monteith are slim but may exist along the northern edge of the Monteith sub-crop. Development opportunities for the Monteith Formation in the eastern portion of the study area still abound. The use of production histories and pressure versus time plots more accurately define pool boundaries. Using this information in conjunction with detailed structural and stratigraphic mapping, underdeveloped pools may be identified and then exploited.

In the western and more structurally complex portion of the study area, better chances exist for untapped virgin reservoirs in the Cadomin and Monteith Formations. Structures exist which have few penetrations but contain reservoir sands that are thick and continuous. Structural closures are needed at the Cretaceous level to trap hydrocarbons, but these can be identified through detailed mapping or seismic where well control is limited. To take advantage of any natural fracturing that might be present in the reservoirs, a useful technique may be to horizontally drill along the structural trend, perpendicular to fracture trends.

Chapter 6

Conclusions

Upper Jurassic and Lower Cretaceous strata of northeastern British Columbia belong to the Minnes and Bullhead Groups. The Monteith Formation is the lowermost unit of the Minnes Group, while the Cadomin Formation is the lowermost unit of the Bullhead Group. These two formations are separated by the Pre-Cadomin unconformity throughout the study area.

The Monteith Formation ranges in age from Upper Jurassic to Lower Cretaceous, with the Jurassic/Cretaceous boundary located in the lower part of the Monteith Formation. Dominantly composed of pure quartz arenites, this formation is comprised of medium grained quartzose sandstone with variable amounts of coarser-grained sandstone, siltstone, mudstone, and coal.

The Cadomin Formation lies unconformably atop the underlying Minnes Group and is present in the south and western portions of the study area. To the north and northeast, the Cadomin Formation grades laterally into the finer grained sediments of the Gething Formation. The sediments of the Cadomin are dominated by chert-rich sandstone, with occasional interbeds of conglomerate, mudstone, and siltstone. The sandstones of the Cadomin Formation can be classified as litharenites to sublitharenites, but are dominantly lithic arenites. The Cadomin sands are predominantly composed of quartz and chert, making them easy to distinguish from the monomineralic sands of the Monteith Formation.

The Monteith and the Cadomin Formations were deposited in very similar environments. Despite the fact that these two formations are separated by a regional erosional unconformity and have been sourced from different directions, they both were deposited in a braided fluvial system.

In the study area, the sediments of the Monteith Formation were deposited in a multiple channel braided river system which flowed from east to west, emptying into the Berriasian Embayment via a delta complex located at the present day position of Williston Lake. The Cadomin Formation was deposited in a humid alluvial plain environment that drained to the northeast from the present front and main ranges, with braided fluvial processes reworking and depositing the sediment.

The Cadomin Formation was deposited during a time of relative tectonic quiescence, and is not related to active thrusting. The Cadomin Formation was deposited during a significant break in the regional compressional tectonic regime after the collision of the Intermontane Belt (Columbian Orogeny). This period of relative quiescence is marked by tectonic relaxation and extension leading to extensive intrusive and extrusive magamatism in central British Columbia. The deposition of the Cadomin Formation took place during a period of epeirogenic movement associated with thermal uplift, and low to zero subsidence rates across a rebounding foreland basin.

The paragenesis for both the Monteith and Cadomin Formations are the same.

1) Early calcite cementation

2) Compaction and quartz overgrowth cementation

3) Secondary porosity development

4) Authigenic clay crystallization

The Monteith Formation is the most affected by quartz cementation due to its relatively pure quartz mineralogy whereas the Cadomin Formation is more susceptible to compaction due to its high chert and argillaceous content.

Between the Cadomin and Monteith Formations, the Monteith is by far the dominant hydrocarbon producer in the study area. Overall, a low recovery factor is typical from both formations due to silica cementation, residual bitumen, compaction and/or the presence of detrital and authigenic clays which are all factors that limit the effectiveness of the reservoir. The development of secondary porosity through fracturing and leaching does however enhance the quality of the reservoir. The best reservoirs in the Cadomin/Monteith are located in structural highs in conjunction with thick sand deposits.

The Monteith and Cadomin Formations are considered mature plays. Successful exploitation of the Monteith and Cadomin will depend on a fundamental understanding of the stratigraphy, depositional environment, structure and reservoir forming characteristics that result from the original texture, secondary structural overprints, and the diagenetic modifications.

REFERENCES

Allan, J.A., and Stelck, C.R., 1940, Subsurface formations of the Pouce Coupe River district, Alberta: Royal Society of Canada, Transactions, 3rd ser., v. 34, sec. 4, p. 15-20.

Almon, W.R., and Davies, D.K., 1977, Understanding diagenetic zones vital: Oil and Gas Journal, 75;23, pp. 209-216.

Bally, A.W., Gordy, P.L., and Stewart, G.S., 1966, Structure, seismic data and orogenic evolution of the southern Canadian Rockies: Bulletin of Canadian Petroleum Geology, v. 14, p. 337-381.

Barclay, J.E., Krause, F.F., Campbell, R.I. and Utting, J., 1990, Dynamic casting and growth faulting: Dawson Creek Graben Complex, Carboniferous-Permian Peace River Embayment, Western Canada: Bulletin of Canadian Petroleum Geology, v. 38A, p. 115-145.

Beach, H.H., and Spivak, J., 1944, Dunlevy-Portage Mountain map-area, British Columbia: Geological Survey of Canada, Paper 44-19.

Blair, T.C., and Bilodeau, W.L., 1988, Development of tectonic cyclothems in rift, pull-apart, and foreland basins: Sedimentary response to episodic tectonism: Geology, 16, 517-520.

British Columbia Energy and Mines Division 1998, Hydrocarbon and by-product reserves in British Columbia 1998, Ministry of Energy and Mines.

Cant, D.J., and Abrahamson, B., 1996, Regional distribution and internal stratigraphy of the lower Mannville: Bulletin of Canadian Petroleum Geology, v. 44, p. 508-529.

Cant, D.J., and Stockmal, G.S., 1989, The Alberta foreland basin: relationship between stratigraphy and Cordilleran terrane-accrtetion events: Canadian Journal of Earth Sciences 26, p. 1964-1975.

Cant, D.J., and Walker, R.G., 1976, Development of braided-fluvial facies model for the Devonian Battery Point Sandstone, Quebec: Canadian Journal of Earth Sciences, v. 13, p. 102-119.

Dawson, G.M., 1881, Report on an Exploration from Port Simpson, on the Pacific Coast, to Edmonton on the Saskatchewan, Embracing a Portion of the Northern Part of British Columbia and Peace River Country, 1879: Geological Survey of Canada, Report in Progress, 1879-1880, pt. B, pp. 1-142.

Dresser, J.A., 1922, A summary report on exploration for oil and gas in the Peace River district, British Columbia: British Columbia Department of Lands, 27 p.

Eaton, D.W., and Gerald, R.M., and Jacqueline, H., 1999, The rise and fall of a cratonic arch; a regional seismic perspective on the Peace River Arch, Alberta: Bulletin of Canadian Petroleum Geology, vol. 47, pp. 346-361.

Engebretson, D.C, Cox, A, and Gordon, R.G., 1995, Relative motions between oceanic and continental plates in the Pacific Basin: Geological Society of America, Special Paper 206, 59 p.

Frebold, H., 1957, The Jurassic Fernie Group in the Canadian Rocky Mountains and Foothills; Geological Survey of Canada, Memoir 287.

Gibson, D.W., 1992, Stratigraphy, Sedimentology, Coal Geology and Depositional Environments of the Lower Cretaceous Gething Formation, Northeastern British Columbia and West-Central Alberta: Geological Survey of Canada, Bulletin 431, 127 p.

Gussow, W.C., 1960, Jurassic-Cretaceous boundary in western Canada and Late Jurassic age of the Kootenay Formation: Transactions of the Royal Society of Canada, v. LIV, ser. III, p. 45-64.

Gabrielse, H., and Yorath, C.J., 1992, eds., Geology of the Cordilleran orogen in Canada: Geological Society of America, Geology of North America, v. G-2 (Geological Society of Canada), 844 p.

Hadley, R.F., 1967, Pediments and pediment-forming processes: Journal Geology Education, v. 15, p.83-89.

Hayes, J.B., 1979, Sandstone diagenesis - the hole truth: *in* Scholle, P.A. and Schluger, P.R., eds., Aspects of Diagenesis: Society of Economic Paleontologists and Mineralogists, Special Publication 26, p. 127-139.

Heller, P.L., and Paola, C., 1989, The paradox of Lower Cretaceous gravels and the initiation of thrusting in the Sevier orogenic belt, United States Western Interior: Geological Society of America Bulletin, v. 101, p. 864-875.

Heller, P.L., and Paola, C., 1992, The large-scale dynamics of grain-size variation in alluvial basins, 2: Application to syntectonic conglomerate: Basin Research, v. 4, p. 91-102.

Hughes, J.E., 1964, Jurassic and Cretaceous strata of the Bullhead succession in the Peace and Pine River Foothills. British Columbia Department of Mines and Petroleum Resources, Bulletin 51.

Hughes, J.E., 1967, Geology of the Pine Valley, Mount Wabi to Solitude Mountain, northeastern British Columbia: British Columbia Department of Mines and Petroleum Resources, Bulletin 52, 137 p.

Hutcheon, I., 1990, Aspects of the Diagenesis of Coarse-Grained Siliciclastic Rocks, *in* McIlreath, I.A., and Morrow, D.W., eds., Diagenesis: Geoscience Canada, Reprint Series 4, p. 165-176.

Jackson, P.C., 1984, Paleogeography of the Lower Cretaceous Mannville Group of Western Canada: AAPG Memoir 38 - Elmworth - Case study of a Deep Basin Gas Field, p. 49-77.

Jeletzky, J.A., 1964, Illustrations of Canadian fossils, Lower Cretaceous marine index fossils of western and Arctic Canada: Geological Survey of Canada, Paper 64-11, 101 p.

Jeletzky, J.A., 1967, Jurassic-Cretaceous Transition Beds in Canada: Colloque du Jurassique A Luxembourg, Memoires Du B.R.G.M., Bureau De Recherches Geologiques et Minieres, no. 75, 701-707.

Jeletzky, J.A., 1968, Macrofossil zones of the marine Cretaceous of the Western Interior of Canada and their correlation with the zones and stages of Europe and Western Interior of the United States: Geological Survey of Canada, Paper 67-72, 66 p.

Jeletzky, J.A., 1969, Marine Cretaceous Biotic Provinces of Western and Arctic Canada: Proc. North American Paleontological Convention: p. 1638-1659.

Jeletzky, J.A., 1971, Biochronology of Jurassic-Cretaceous Transition Beds in Canada: Geological Survey of Canada Paper, 71-16, p. 1-8.

Jeletzky, J.A., 1972, Biochronology of the marine boreal latest Jurassic, Berriasian and Valanginian in Canada: *In* The Boreal Lower Cretaceous Geological Journal Special Issue No. 5, (ed.) R. Casey and P.F. Rawson, p. 41-80.

Leckie, D.A., and Smith, G.D., 1992, Regional Setting, Evolution and Depositional Cycles of the Western Canada Foreland Basin: *In* Foreland Basins and Fold Belts, eds. R.W. Macqueen and D.A. Leckie, American Association of Petroleum Geologists Memoir 55.

Little, H.W., 1960, Nelson Map-Area, West Half, British Columbia: Geological Survey of Canada, Memoir 308, 205 p.

Loranger, D.M., 1958, The Cretaceous-Jurassic contact in west-central Alberta: Alberta Society of Petroleum Geologists, Eighth Annual Field Conference Guidebook, p. 29-38.

MacKay, B.R., 1929, Brule mines coal area, Alberta: Geological Survey of Canada, Summary Report 1928, pt. B, p. 1-29.

MacKay, B.R., 1930, Stratigraphy and structure of bituminous coalfields in the vicinity of Jasper Park, Alberta; Trans. Can. Inst. Mining Met., v. 33, p. 473-509.

Mackenzie, A., 1801, Voyages from Montreal on the River St. Lawrence, through the continent of North America, to the Frozen and Pacific Oceans in the years 1789 and 1793: London, 412 p. (facsimile published 1981, M.G. Hurtig Ltd., Edmonton, Alberta.)

MacKenzie, J.D., 1910, South Fork Coal area, Oldman River, Alberta: Geological Survey of Canada, Summary Report, 1912, P. 235-246.

McBride, E.F., A classification of common sandstones: Journal of Sedimentary Petrology, v. 33, p.664-669.

Mathews, W.H., 1947, Geology and Coal Resources of the Carbon Creek-Mount Bickford Map-area, 1947: British Columbia Department of Mines, Bulletin No. 24.

McLean, J.R., 1976, Cadomin Formation: eastern limit and depositional environment: Geological Survey of Canada, Paper 76-1B, p. 323-327.

McLean, J.R., 1977, The Cadomin Formation: Stratigraphy, Sedimentology and Tectonic implications: Bulletin of Canadian Petroleum Geology, v. 25, p. 742-827.

McLean, J.R., and Wall, J.H., 1981, The early Cretaceous Moosebar Sea in Alberta: Bulletin of Canadian Petroleum Geology, v. 29, p. 334-377.

McLearn, F.H., 1918, Peace River section, Alberta: Geological Survey of Canada, Summary Report, 1917, Part C, p. 14-21.

McLearn, F.H., 1923, Peace River Canyon coal area, British Columbia, Geological Survey of Canada, Summary Report, 1922, Pt. B, p. 1-46.

McLearn, F.H., 1932, Problems of the Lower Cretaceous of the Canadian Interior: Transactions of the Royal Society of Canada, 3rd ser., sec. 4, v. 26, p.157-175.

McLearn, F.H., 1940, Notes on the geography and geology of the Peace River foothills: Transactions of the Royal Society of Canada, 3rd ser., sec. IV, v. XXXIV, p. 63-74.

McLearn, F.H., 1944, Revision of the Paleogeography of the Lower Cretaceous of western interior of Canada: Geological Survey of Canada, Paper 44-32.

McLearn, F.H., and Kindle, E.D., 1950, Geology of Northeastern British Columbia: Geological Survey of Canada, Memoir 259.

Mellon, G.B., 1967, Stratigraphy and petrology of the Lower Cretaceous Blairmore and Mannville Groups, Alberta Foothills and Plains. Alberta Research Council, Bulletin 21, 270 p.

Miall, A.D., 1977, Lithofacies types and vertical profile models in braided river deposits: a summary: *in* A.D. Miall (ed.), Fluvial Sedimentology: Canadian Society of Petroleum Geologists, Memoir 5, p. 597-604.

Miall, A.D., 1992, Aluvial Deposits: *in* R.G. Walker and N.P. James (ed.), Facies Models, Response to sea level change. Geological Association Of Canada, p. 119 to 142.

Mountjoy, E.W., 1960, Structure and stratigraphy of the Miette and adjacent areas, Eastern Jasper National Park, Alberta: Unpublished Ph. D. Thesis University of Toronto.

Monger, J.W.H., 1989, Overview of Cordilleran geology: in B.D. Ricketts, ed., Western Canada sedimentary Basin, a case history: Calgary, Alberta, Canadian Society of Petroleum Geologists, p. 9-32.

Monger, J.W.H., Price, R.A., and Tempelman-Kluit. D.J., 1982, Tectonic accretion and the origin of two metamorphic and plutonic welts in the Canadian Cordillera. Geology, v. 10, p. 70-75.

Murphy, D.C., Van der Heyden, P., Parrish, R.A., Klepacki, D.W., Millan, W., Struick, L.C., and Gabites, J., 1995, New geochronological constraints on Jurassic deformation of the Western Edge of North America, southeastern Canadian Cordillera: Geological Society of America, Special Paper 299, p. 159-171.

O'Connell, S.C., Dix, G.R., and Barclay, J.E., 1990, The origin, history, and regional structural development of the Peace River Arch, Western Canada: Bulletin of Canadian Petroleum Geology, v. 38A, p. 4-24.

Parkash, B., and Kumar, S., 1991, The Indo-Gangetic Basin, *in* Tandon, S.K., Pant, C.C., and Casshypa, S.M., eds., Sedimentary Basins of India, Tectonic Context, p. 147-170.

Pittman, E.D., and Thomas, J.B., 1979, Some applications of scanning electron microscopy to the study of reservoir rock: Society of Petroleum Engineers of AIME, 53, 3 pages.

Price, R.A., 1965, Flathead map area, British Columbia and Alberta: Geological Survey of Canada, Memoir 336, 221 p.

Price, R.A., 1973, Large-scale gravitational flow of supracrustal rocks, southern Canadian Rockies: *in* Gravity and tectonics, (eds.), K.A. De Jong and R.A. Scholten, New York, John Wiley, p. 491-502.

Price, R.A., and Mountjoy, E., 1970, Geologic structure of the Canadian Rocky Mountains between Bow and Athabasca Rivers - a progress report: Geological Association of Canada, Special Paper No. 6, p. 7-25.

Rapson, J.E., 1965, Petrography and derivation of Jurassic-Cretaceous clastic rocks, southern Rocky Mountains, Canada: Bulletin of the American Association of Petroleum Geologists, v. 49, p. 1426 – 1452.

Ricketts, B.D., 1986, Styles of Alluvial Fan – Braid Plain Sedimentation in Orogenic Foredeeps – Examples From the Canadian Cordilleran Orogen: Bulletin of Canadian Petroleum Geology, vol. 34, no. 1, p. 1-16.

Rust, B. R., 1977, Depositional models for braided alluvium: *In* (ed.) A.D. Miall, Fluvial Sedimentology, Canadian Society of Petroleum Geologists, Memoir 5, p. 605-625.

Rust, B. R., 1978, Depositional models for braided alluvium: *In* Fluvial Sedimentology, A.D. Miall (ed.), Canadian Society of Petroleum Geologists, Memoir 5, p. 187-198.

Selwyn, A. R. C., 1877, Report on exploration in British Columbia in 1875. Geological Survey of Canada, Report of Progress 1875-76, p. 28-86.

Schultheis, N.H., 1970, Petrography, source, and origin of Cadomin conglomerate, between the North Saskatchewan and Athabasca rivers. Msc. Thesis, McGill University.

Schultheis, N. H., and Mountjoy, E.W., 1978, Cadomin conglomerate of Western Alberta - A result of early Cretaceous uplift of the Main Ranges, Bulletin of Canadian Petroleum Geology, v. 26, p. 297-342.

Singh, H., Parkash, B. and Gohain, K., 1993, Facies analysis of the Kosi megafan deposits: Sedimentary Geology, 85, p. 87-113.

Sinha, R. and Friend, P.F., 1994, River systems and their sediment flux, Indo-Gangetic plains, Northern Bihar, India: Sedimentology, 41, p. 825-845.

Smith, D.G., Zorn, C.E., Sneider, R.M., 1984, The Paleogeography of the Lower Cretaceous of Western Alberta and Northeastern British Columbia in and Adjacent to the Deep Basin of the Elmworth Area: AAPG Memoir 38 - Elmworth - Case study of a Deep Basin Gas Field, p. 79-114.

Springer, G.D., MacDonald, W.D. and Crockford, M.B.B., 1964, Jurassic: *In* Geological History of Western Canada, Calgary, Alberta Society of America Bulletin, v. 61, p. 91-98.

Stelck, C.R., 1975, Basement Control of Cretaceous Sand Sequences in Western Canada: Geological Association of Canada - Special Paper 13, Cretaceous System in the Western Interior of North America, p. 427-440.

Stokes, W.L., 1950, Pediment concept applied to Shinarump and similar conglomerates: Geological Society of America Bulletin, v. 61, p. 91-98.

Stott, D.F., 1962, Cretaceous Rocks of Peace River Foothills: Edmonton Geological Society, Fourth Annual Field Trip Guildbook, p. 22-45.

Stott, D.F., 1967, The Fernie and Minnes strata north of Peace River, foothills of north-eastern British Columbia: Geological Survey of Canada, Paper 67-19, Pt. A, 58 p.

Stott, D.F., 1968, Lower Cretaceous Bullhead and Fort St. John Groups, between Smoky and Peace Rivers, Rocky Mountain Foothills, Alberta and British Columbia: Geological Survey of Canada, Bulletin 152, 279 p.

Stott, D.F., 1973, Lower Cretaceous Bullhead Group between Bullmoose Mountain and Tetsa River, Rocky Mountain Foothills, Northeastern British Columbia: Geological Survey of Canada, Bulletin 219.

Stott, D.F., 1981, Bickford and Gorman Creek, two new formations of the Jurassic Cretaceous Minnes Group, Alberta and British Columbia: *In* Current Research, Part B. Geological Survey of Canada, Paper 81-1B, p. 1-9.

Stott, D.F., 1984, Cretaceous sequences of the foothills of the Canadian Rocky Mountains, *in* Stott, D.F. and Glass, D.J., eds., The Mesozoic of Middle North America: Canadian Society of Petroleum Geologists, Memoir 9, p. 85-107.

Stott, D.F., 1998, Fernie Formation and Minnes Group (Jurassic and Lowermost Cretaceous), Northern Rocky Mountain Foothills, Alberta and British Columbia: Geological Survey of Canada, Bulletin 516.

Underschultz, J.R., 1991, Tectonic loading, sedimentation, and sea-level changes in the foreland basin of north-west Alberta and north-east British Columbia, Canada: Basin Research, 3, p. 165-174.

Varley, C.J., 1984, The Cadomin Formation: A Model for the Deep Basin Type Gas Trapping Mechanism: in Stott, D.F. and Glass, D.J., eds., The Mesozoic of Middle North America: Canadian Society of Petroleum Geologists, Memoir 9, p. 471-484.

Walker, R.G., 1975, Conglomerate: sedimentary structures and facies models: In Depositional environments as interpreted from primary sedimentary structures and stratification sequences, Society Economic Paleontologists,, Mineralogists, Short Course 2, Dallas, p. 133-161.

Warren, P.S., 1938, The Blairmore conglomerate: Transactions of the Royal Canadian Institute, v. 22, p. 7-20.

Warren, P.S. and Stelck, C.R., 1955, The Nikanassin-Luscar hiatus in the Canadian Rockies: Royal Society of Canada, Transactions, Series 3, v. LII, p. 55-62.

Warren, P.S. and Stelck, C.R.,1958, Lower Cenomanian Ammonoidea and Pelecypoda from Peace River area, western Canada: Research Council, Alberta, Geology Division, Bulletin pt. 2.

Weimer, R.J., 1984, Relation of unconformities, tectonics, and sea-level changes, Cretaceous of Western Interior, U.S.A. *In* Interregional Unconformities and Hydrocarbon Accumulation, J.S. Schlee (ed.). American Association of Petroleum Geologists, Memoir 36, p. 7-35.

Wickenden, R.T.D., and Shaw, G., 1943, Stratigraphy and Structure in Mount Hulcross-Commotion Creek Map-area, British Columbia: Geological Survey of Canada, Paper 43-13.

Williams, G.D. and Stelck, C.R., 1975, Speculations on the Cretaceous Paleogeography of North America: *In* The Cretaceous System in the Western Interior of North America, W. G. E. Caldwell (ed.), Geological Association of Canada, Special Paper 13, p. 1-20.

Williams, V.S., 1982, Tectonic tilting of mountain-front alluvial fans near the Sapt Kosi gorge, eastern Nepal: *In* Himalaya: Landforms and Processes, V.K. Verma and P.S. Saklani (eds.), Today and Tomorrow, New Delhi, p. 115-132.

Woodsworth, G.J., Anderson, R.G., and Armstrong, R.L., 1991, Plutonic regimes, Chapter 15 in Geology of the Cordilleran Orogen in Canada, H. Gabrielse and C.J. Yorath (eds.); Geological Survey of Canada, Geology of Canada, no. 4, p. 491-531.

Workman, L.E., 1954, Lower Cretaceous of The Peace River Region: *In* Western Canada Sedimentary Basin-A Symposium, L.M. Clark (ed.), American Association of Petroleum Geologists, Ralph Leslie Rutherford Memorial Volume, p. 268-278.

Ziegler, W.H., and Pocock, S.A.J., 1960, The Minnes Formation; Guidebook: Edmonton Geological Society, 1960.

APPENDIX I

Core Logs

Wells logged and placed into AppleCore:

15-14-86-25w6
5-01-87-25w6
6-23-87-25w6
10-08-88-25w6
3-09-88-25w6
10-11-88-25w6
D-87-D/94-A-13
C-18-H/94-A-13
A-20-H/94-A-13
A-43-H/94-A-13
D-55-H/94-A-13
D-55-G/94-A-13
C-81-G/94-A-13
A-29-L/94-A-13
C-42-A/94-B-8
B-82-I/94-B-8
D-94-I/94-B-8
B-35-A/94-B-9
C-56-A/94-B-9
D-82-I/94-B-9

Wells logged but not placed into AppleCore:

2-20-88-25w6
6-21-88-25w6
D-71-B/94-A-13
C-84-B/94-A-13
D-19-E/94-A-13
A-08-H/94-A-13
A-50-E/94-A-13
A-83-E/94-A-13
D-31-G/94-A-13
B-24-A/94-B-9
C-57-G/94-B-16
B-62-H/94-B-16
B-03-I/94-B-16

Suncor et al W Blueberry

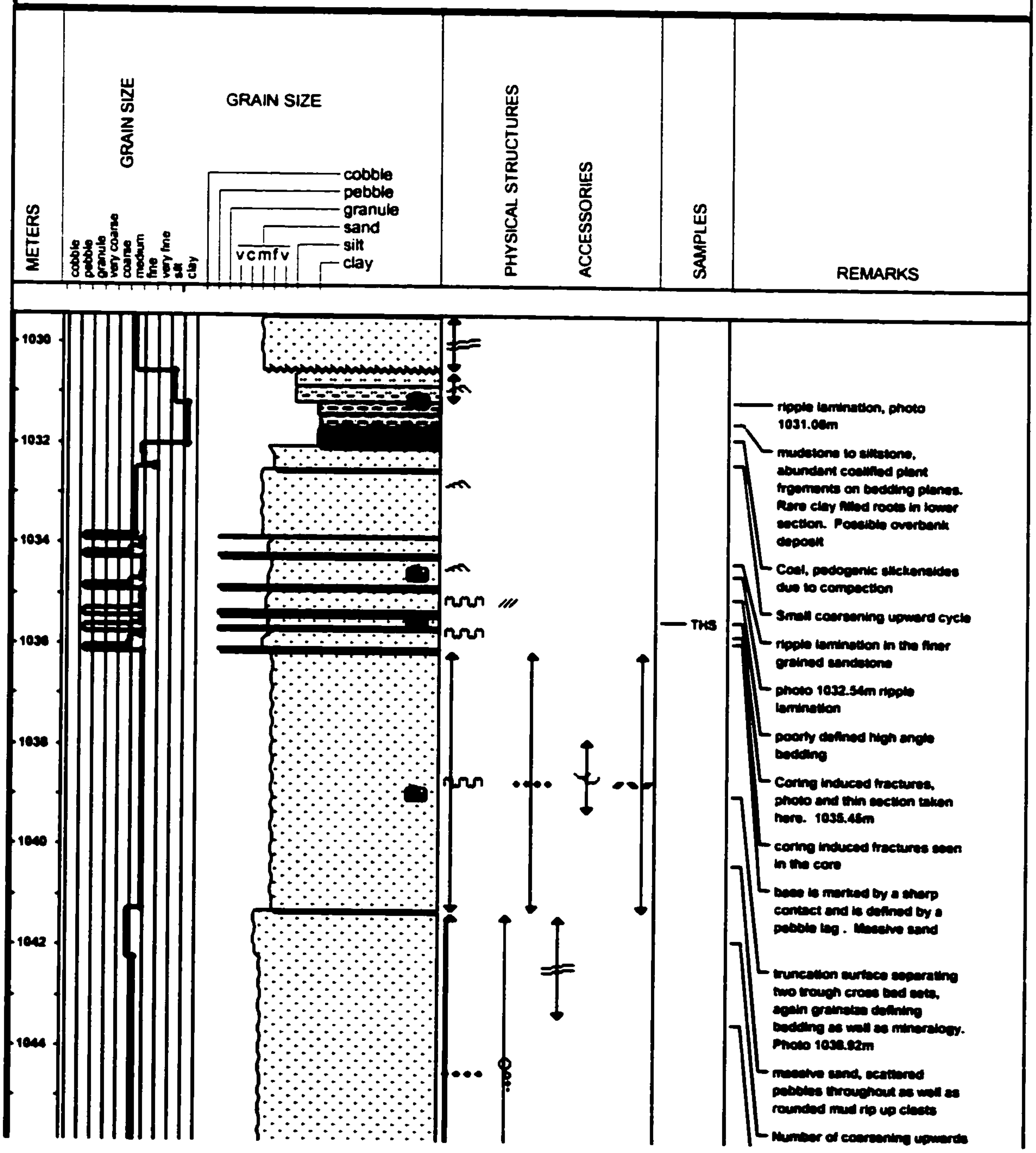
10 -08-88-25w6

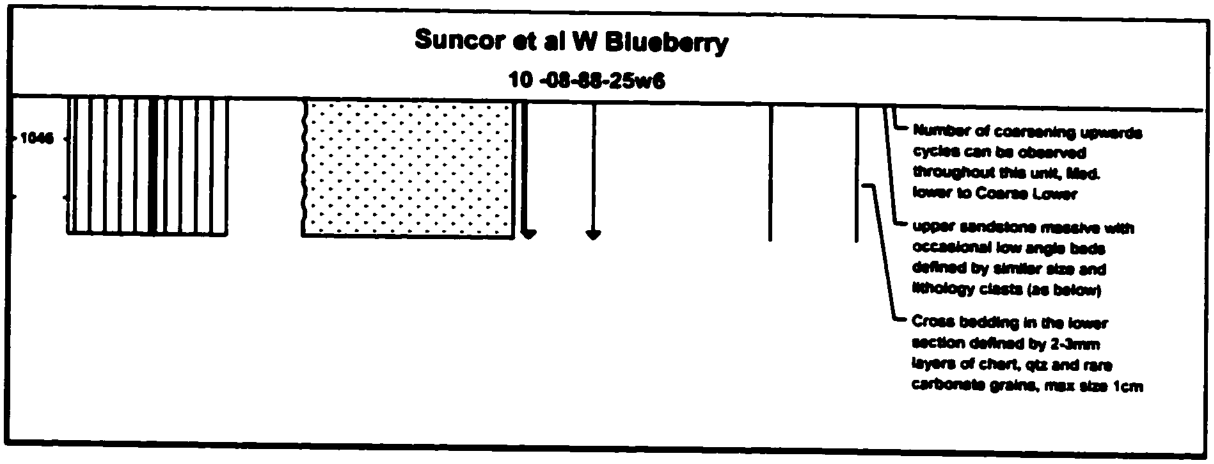
Date Logged: November 19, 1998

Logged by: Eric Hanson and Jason Lavigne

Datum elevation: 713.90 m

Remarks:




Suncor et al W Blueberry
10 -08-88-25w6
1046
Number of coarsening upwards cycles can be observed throughout this unit, Med. lower to Coarse Lower
upper sandstone massive with occasional low angle beds defined by similar size and lithology clasts (as below)
Cross bedding in the lower section defined by 2-3mm layers of chert, qtz and rare carbonate grains, max size 1cm

Canhunter Bernadet

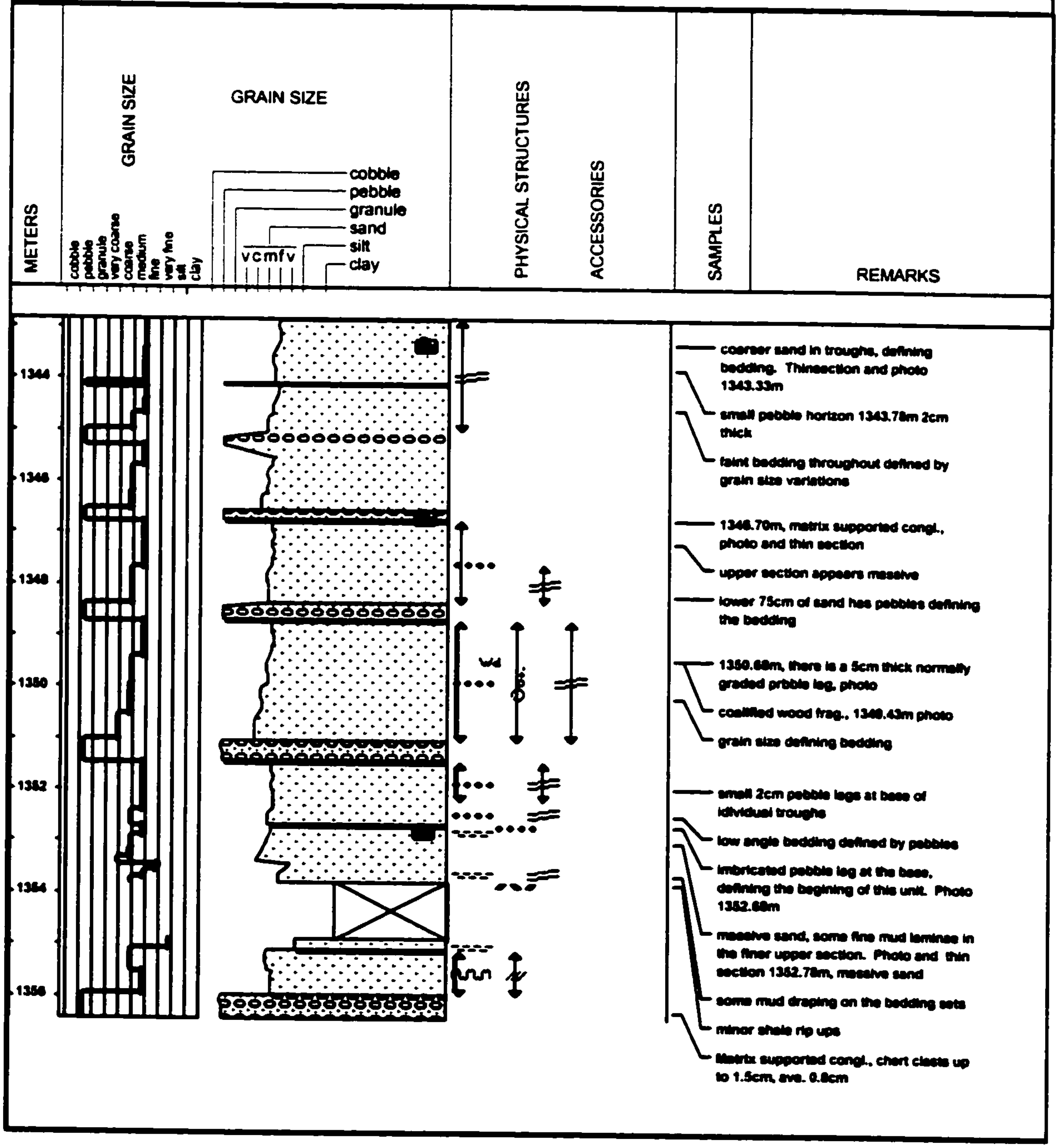
10-11-88-25w6

Date Logged: November 19, 1998

Logged by: Eric Hanson

Datum elevation: 914.10 m

Remarks:



Fargo et al Indian Reserve No. 1

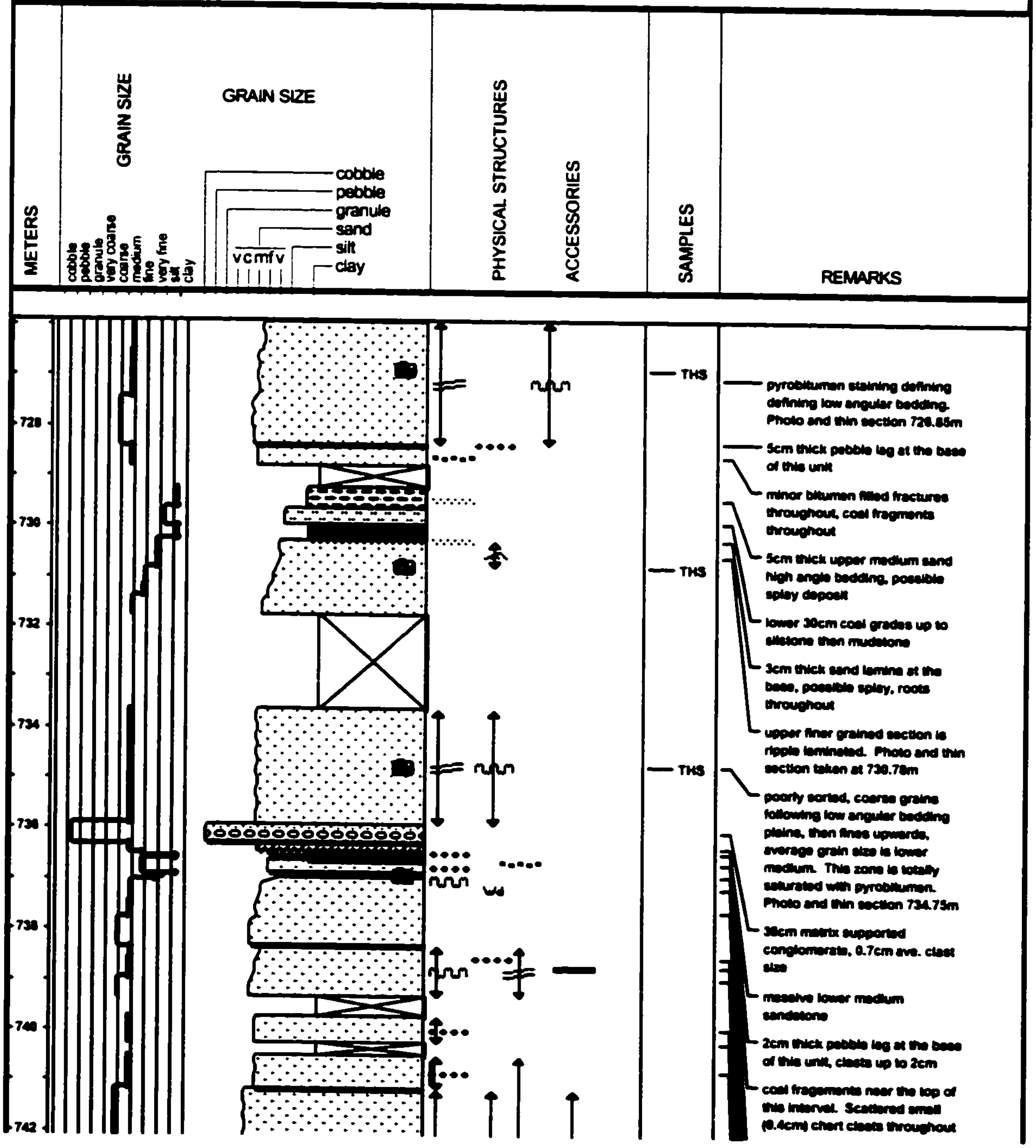
15-14-86-25w6

Date Logged: November 24, 1998

Logged by: Eric Hanson

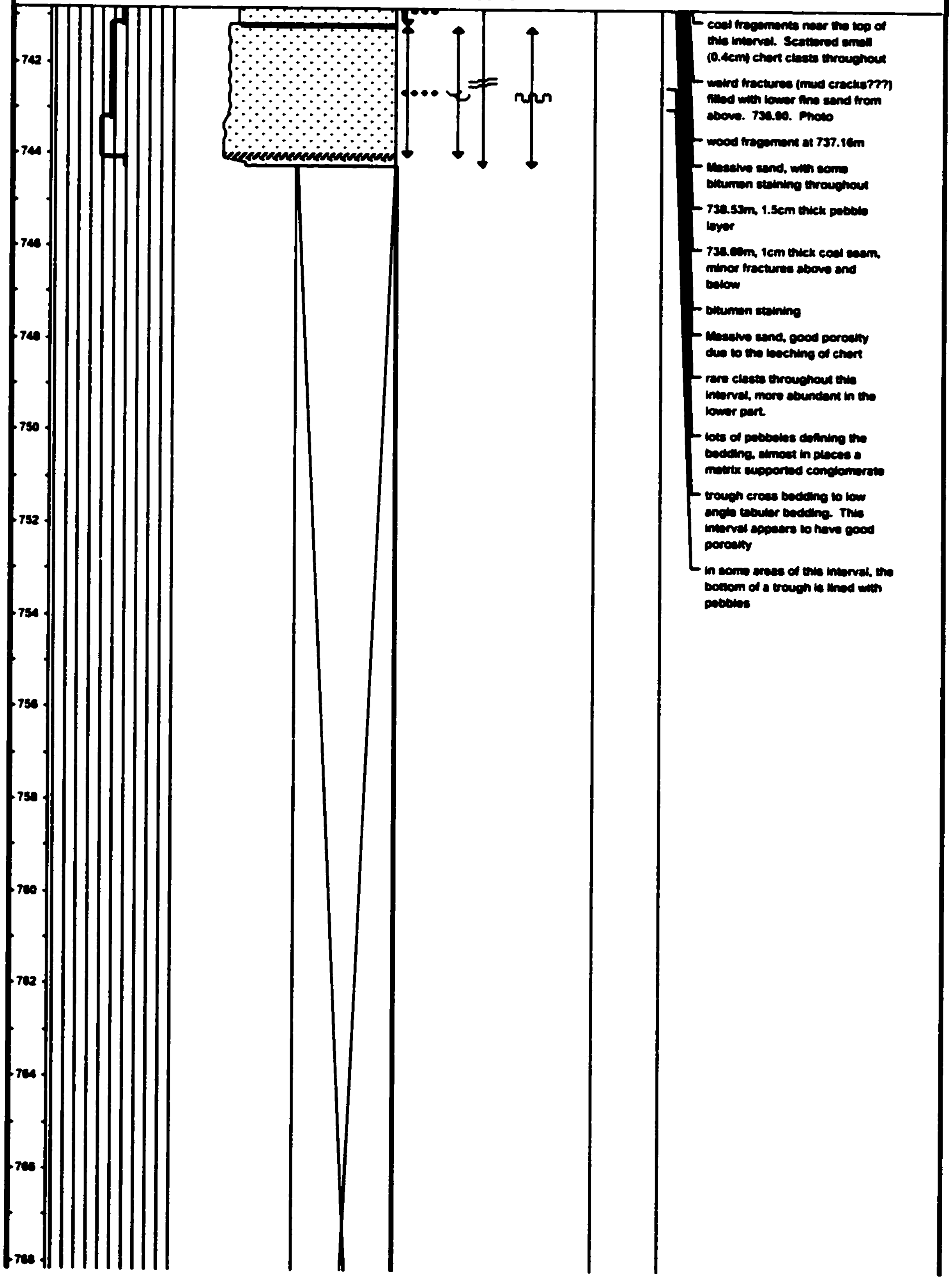
Datum elevation: 569.70 m

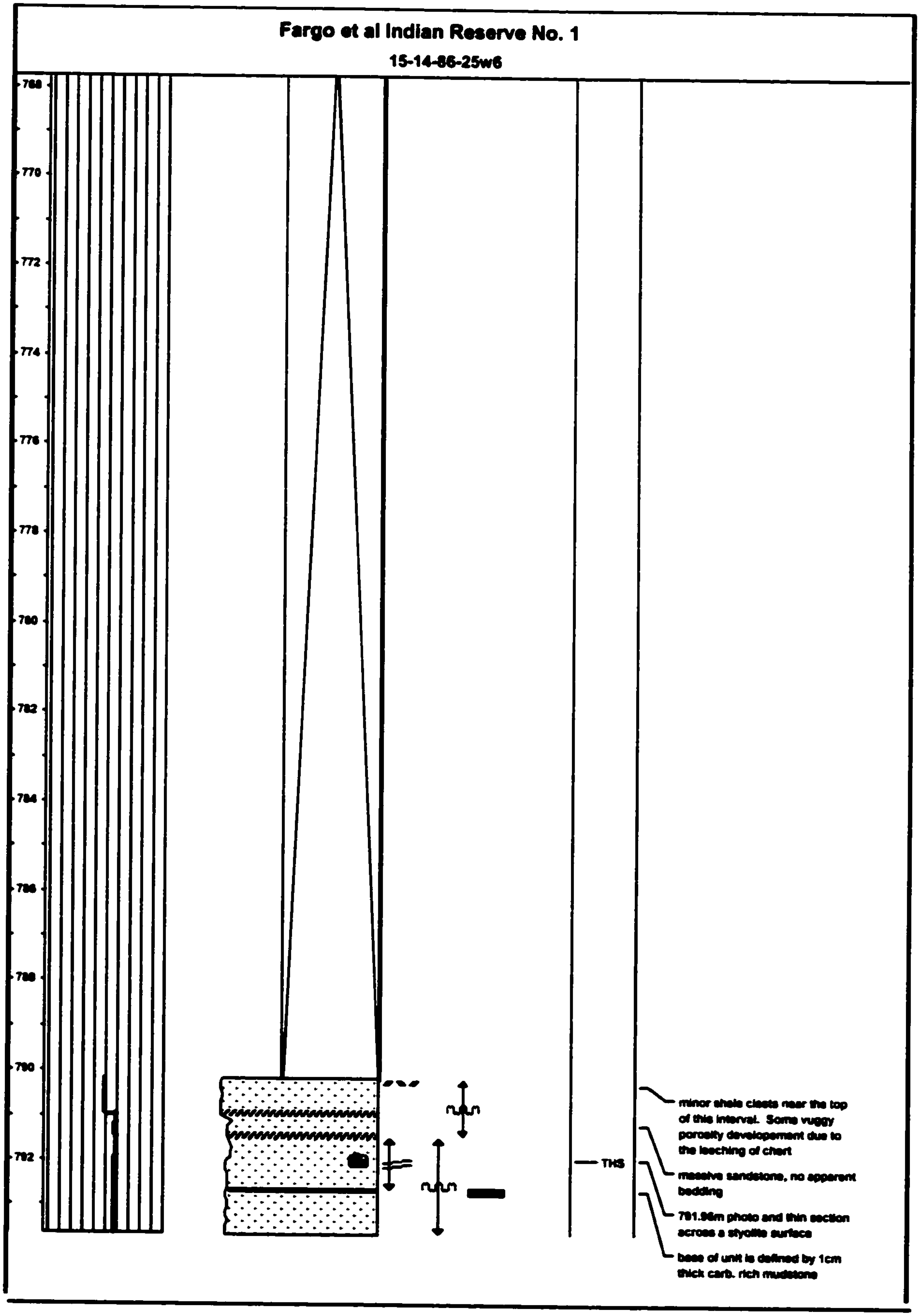
Remarks:



Fargo et al Indian Reserve No. 1

15-14-86-25w6




Fargo et al Indian Reserve No. 1
15-14-86-25w6
768
770
772
774
776
778
780
782
784
786
788
790
792
THS
minor shale clasts near the top of this interval. Some vuggy porosity developement due to the leaching of chert
massive sandstone, no apparent bedding
791.96m photo and thin section across a styolite surface
base of unit is defined by 1cm thick carb. rich mudstone

Fargo et al West Blueberry No. 1 8

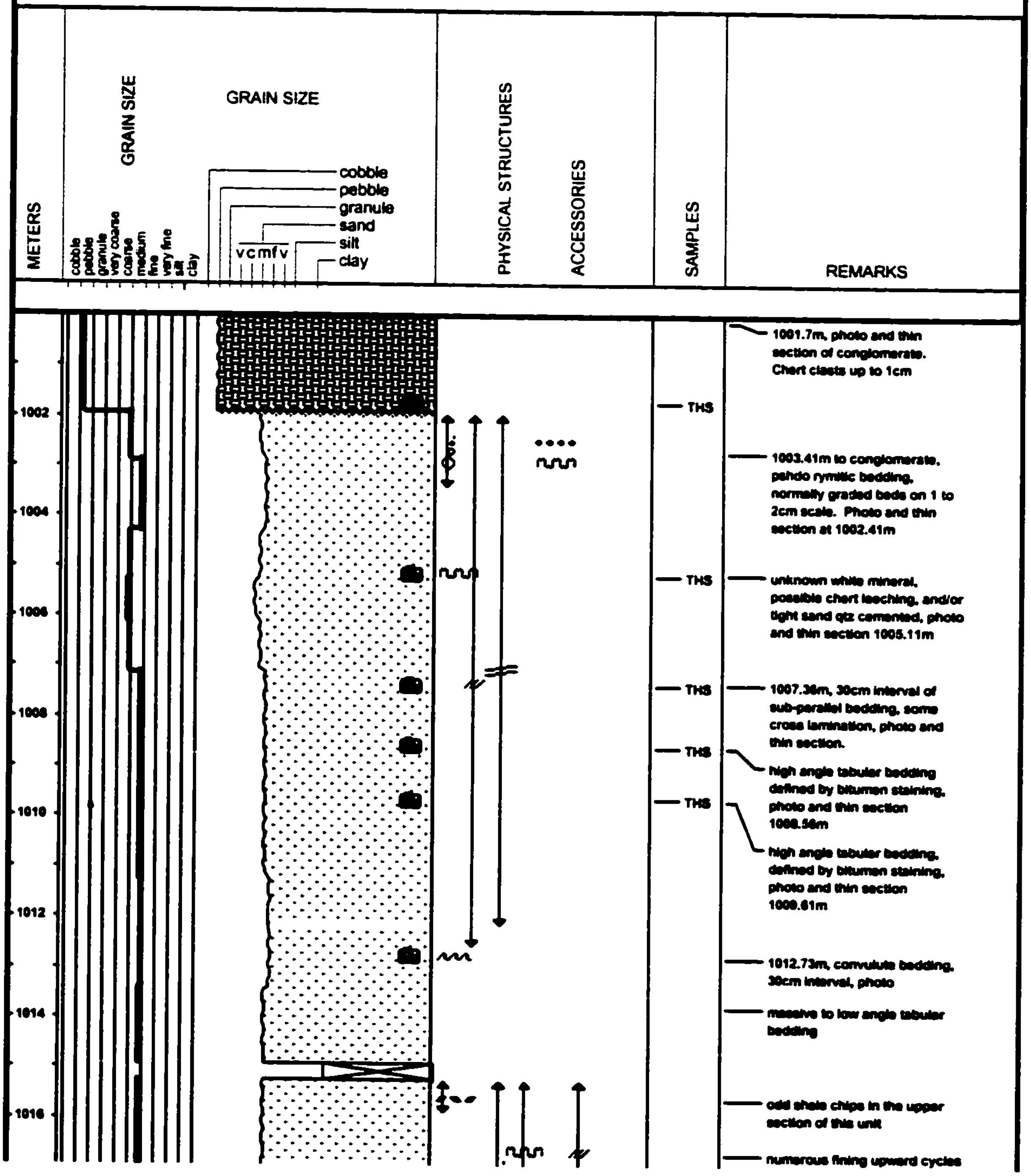
3-09-88-25w6

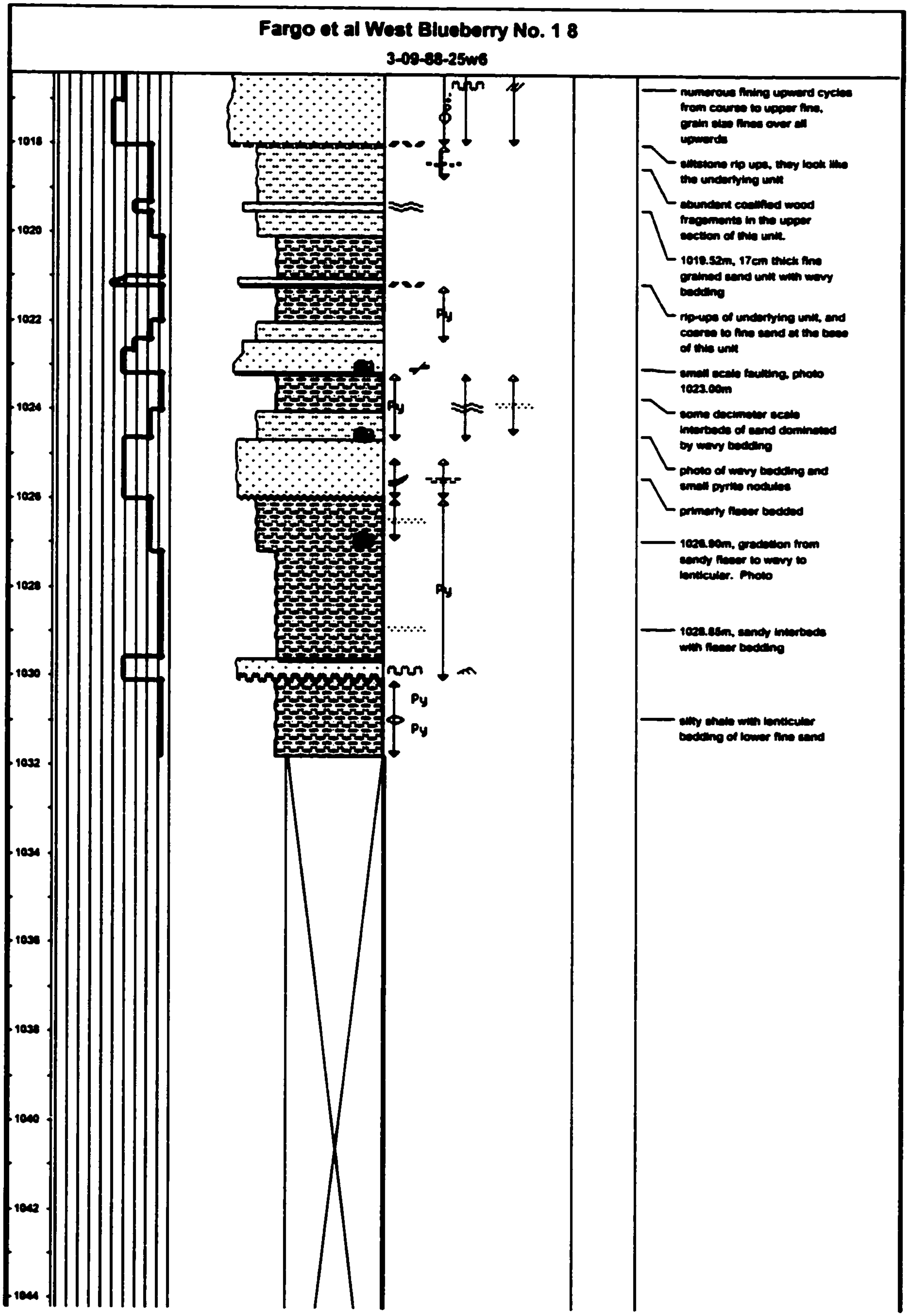
Date Logged: November 24, 1998

Logged by: Eric Hanson

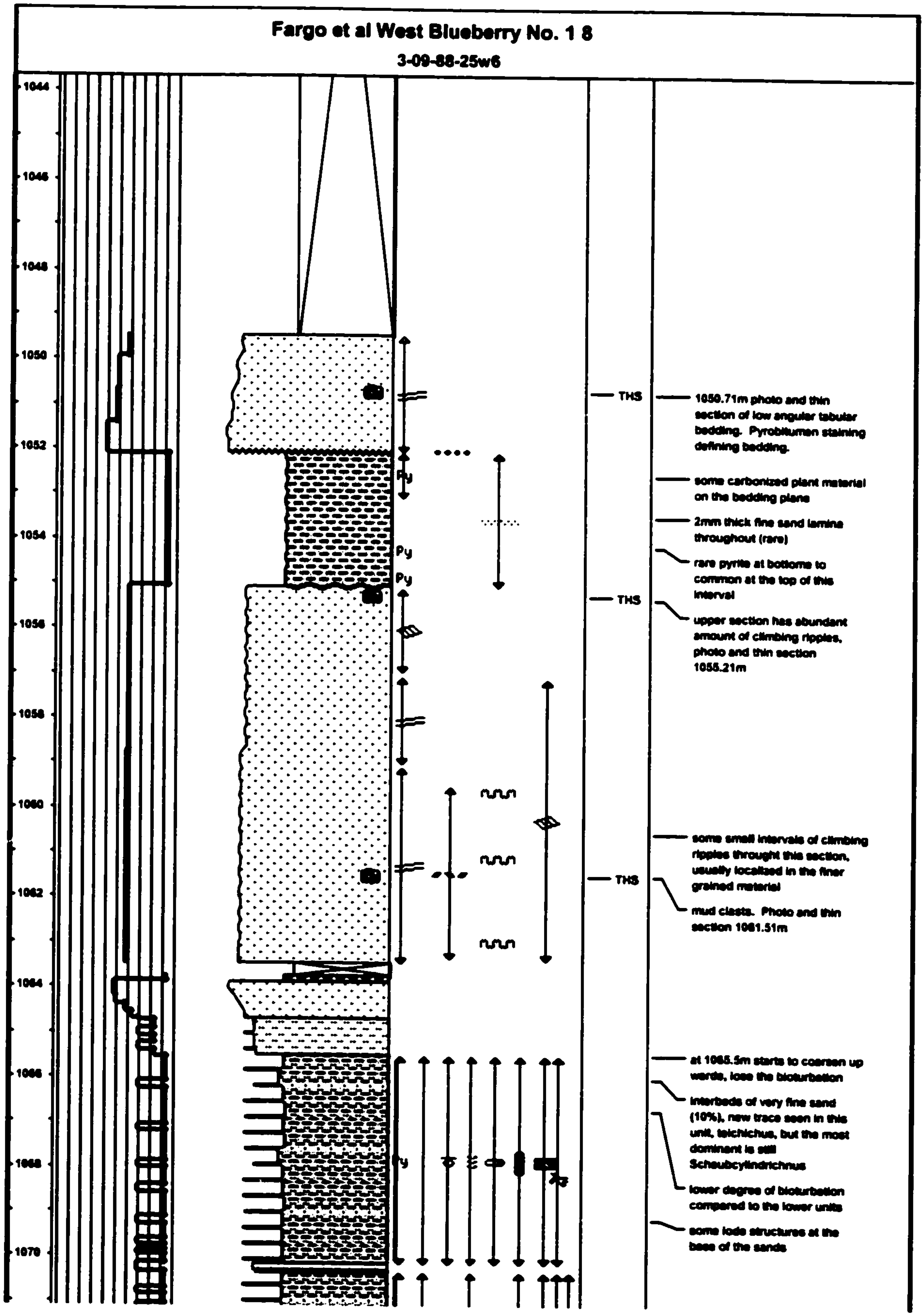
Datum elevation: 680.30 m

Remarks:

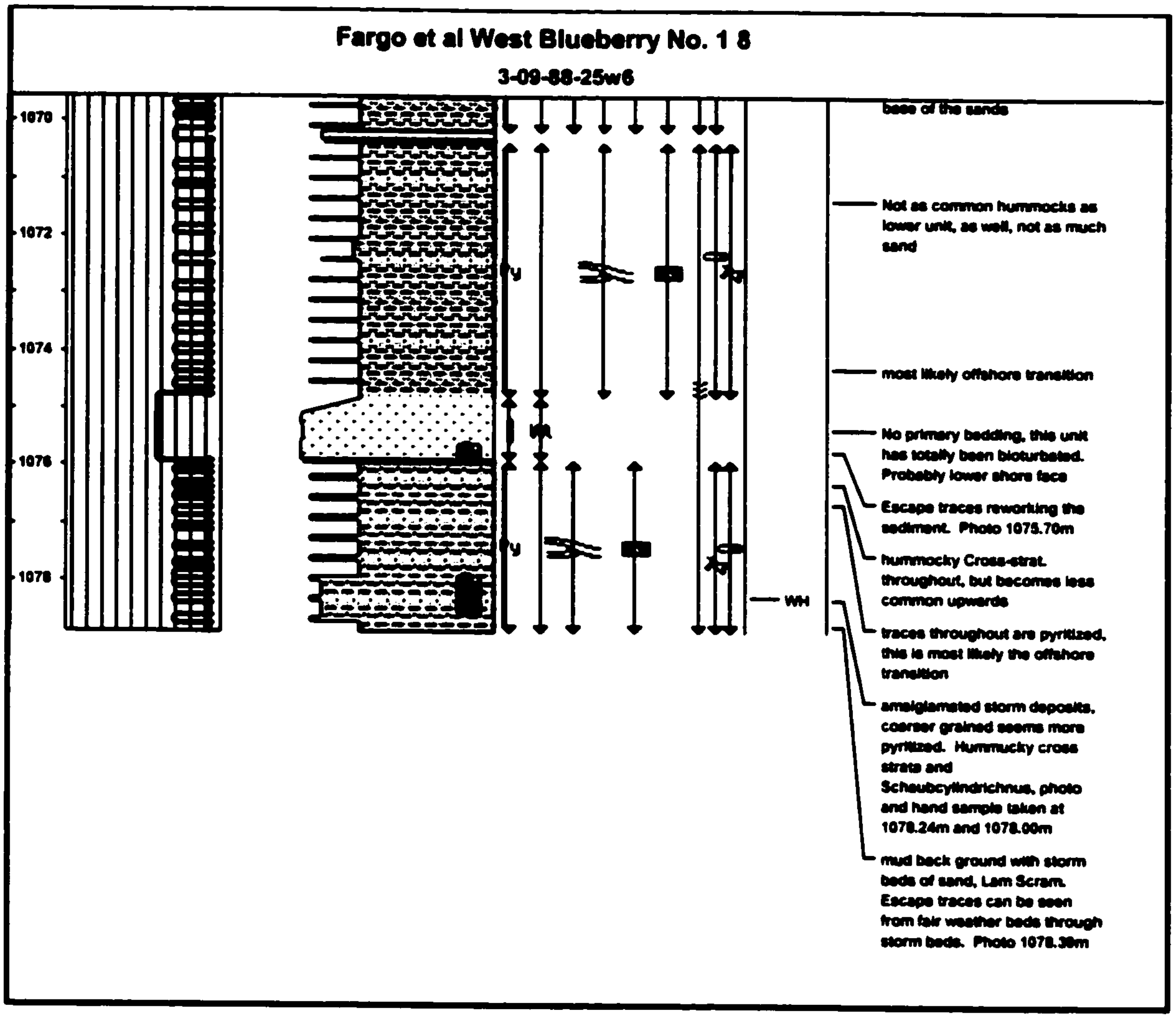




Fargo et al West Blueberry No. 1 8
3-09-88-25w6
1018
1020
1022
1024
1026
1028
1030
1032
1034
1036
1038
1040
1042
1044
Py
Py
Py
Py
numerous fining upward cycles from course to upper fine, grain size fines over all upwards
siltstone rip ups, they look like the underlying unit
abundant coalified wood fragements in the upper section of this unit.
1019.52m, 17cm thick fine grained sand unit with wavy bedding
rip-ups of underlying unit, and coarse to fine sand at the base of this unit
small scale faulting, photo 1023.00m
some decimeter scale interbeds of sand dominated by wavy bedding
photo of wavy bedding and small pyrite nodules
primarly flaser bedded
1026.90m, gradation from sandy flaser to wavy to lenticular. Photo
1028.85m, sandy interbeds with flaser bedding
silty shale with lenticular bedding of lower fine sand



Fargo et al West Blueberry No. 1 8
3-09-88-25w6
1044
1046
1048
1050
1052
1054
1056
1058
1060
1062
1064
1066
1068
1070
Py
Py
Py
Py
THS
THS
THS
1050.71m photo and thin section of low angular tabular bedding. Pyrobitumen staining defining bedding.
some carbonized plant material on the bedding plane
2mm thick fine sand lamine throughout (rare)
rare pyrite at bottoms to common at the top of this interval
upper section has abundant amount of climbing ripples, photo and thin section 1055.21m
some small intervals of climbing ripples throught this section, usually localized in the finer grained material
mud clasts. Photo and thin section 1061.51m
at 1065.5m starts to coarsen up wards, lose the bioturbation
interbeds of very fine sand (10%), new trace seen in this unit, teichichus, but the most dominant is still Schaubcylindrichnus
lower degree of bioturbation compared to the lower units
some lode structures at the base of the sands


Fargo et al West Blueberry No. 1 8
3-09-88-25w6
1070
1072
1074
1076
1078
WH
base of the sands
Not as common hummocks as lower unit, as well, not as much sand
most likely offshore transition
No primary bedding, this unit has totally been bioturbated. Probably lower shore face
Escape traces reworking the sediment. Photo 1075.70m
hummocky Cross-strat. throughout, but becomes less common upwards
traces throughout are pyritized, this is most likely the offshore transition
amalglamated storm deposits, coarser grained seems more pyritized. Hummucky cross strata and Schaubcylindrichnus, photo and hand sample taken at 1078.24m and 1078.00m
mud back ground with storm beds of sand, Lam Scram. Escape traces can be seen from fair weather beds through storm beds. Photo 1078.38m

Pex Kobes D-94-I

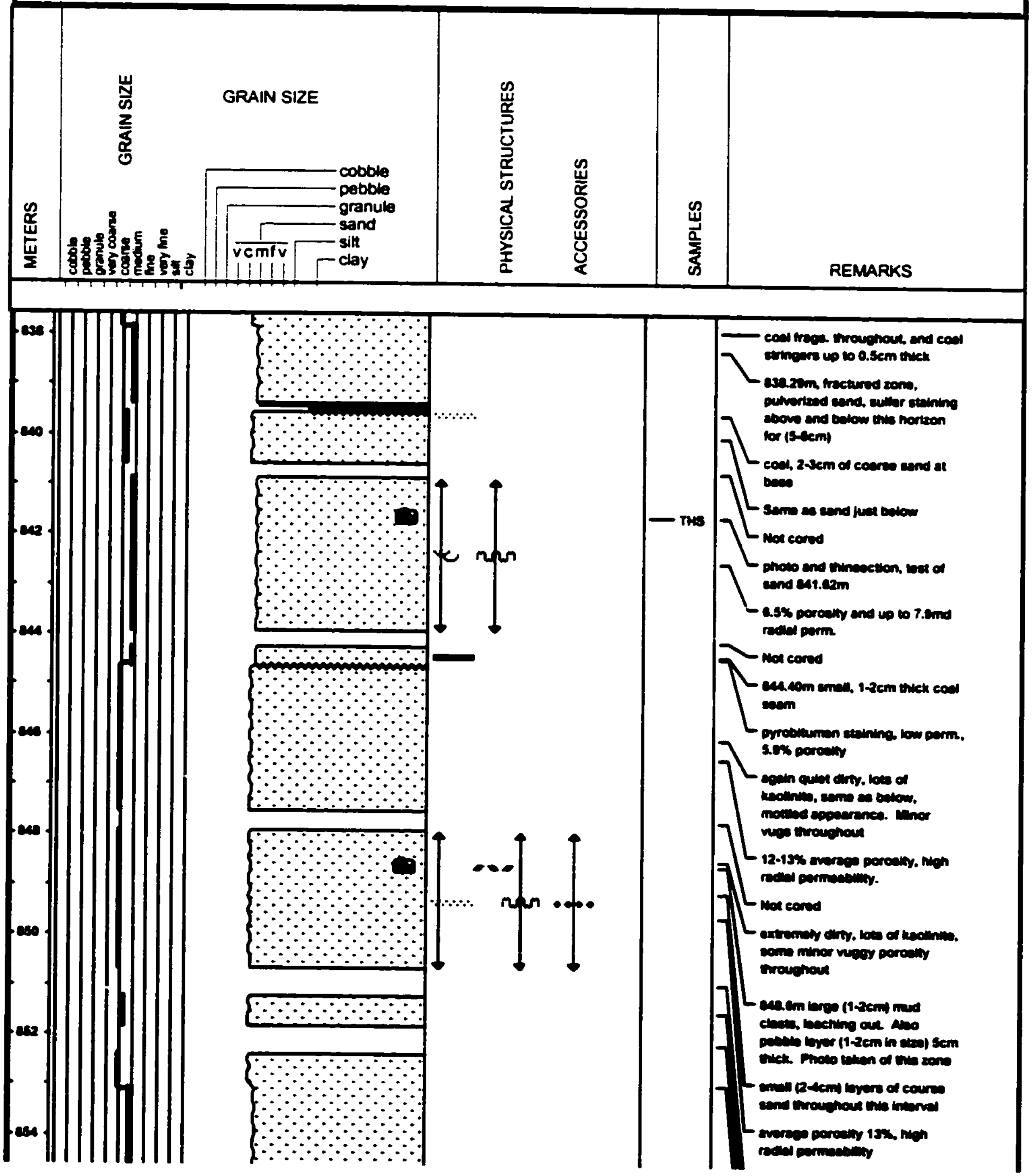
D-94-I/94-B-8

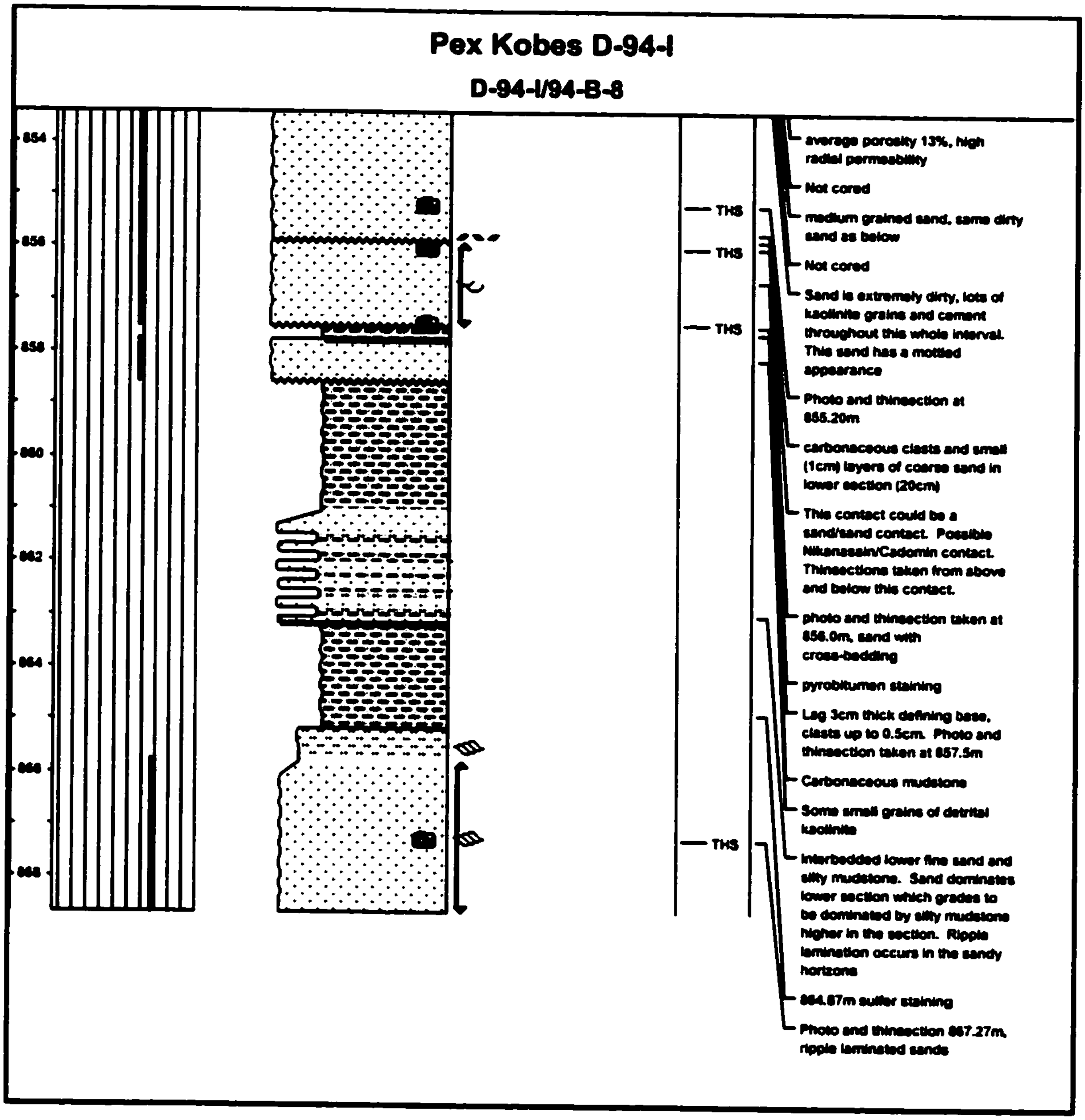
Date Logged: July 13, 1998

Logged by: Eric Hanson

Datum elevation: 637.90 m

Remarks:




Pex Kobes D-94-I
D-94-I/94-B-8
854
856
858
860
862
864
866
868
THS
THS
THS
THS
average porosity 13%, high radial permeability
Not cored
medium grained sand, same dirty sand as below
Not cored
Sand is extremely dirty, lots of kaolinite grains and cement throughout this whole interval. This sand has a mottled appearance
Photo and thinsection at 855.20m
carbonaceous clasts and small (1cm) layers of coarse sand in lower section (20cm)
This contact could be a sand/sand contact. Possible Nikanassin/Cadomin contact. Thinsections taken from above and below this contact.
photo and thinsection taken at 856.0m, sand with cross-bedding
pyrobitumen staining
Lag 3cm thick defining base, clasts up to 0.5cm. Photo and thinsection taken at 857.5m
Carbonaceous mudstone
Some small grains of detrital kaolinite
Interbedded lower fine sand and silty mudstone. Sand dominates lower section which grades to be dominated by silty mudstone higher in the section. Ripple lamination occurs in the sandy horizons
864.87m sulfer staining
Photo and thinsection 867.27m, ripple laminated sands

Suncor et al Blueberry D-87-D

D-87-D/94-A-13

Date Logged: December 3, 1998

Logged by: Eric Hanson

Datum elevation: 943.95 m

Remarks: This core has numerous boxes missing. The core is scrambled in some areas, and therefore this core was not logged. The sand throughout this well appears qtrz rich with minor amounts (10%) of chert. Rare pebbles and no conglomerate were observed in this well.

Suncor et al Blueberry D-82-I

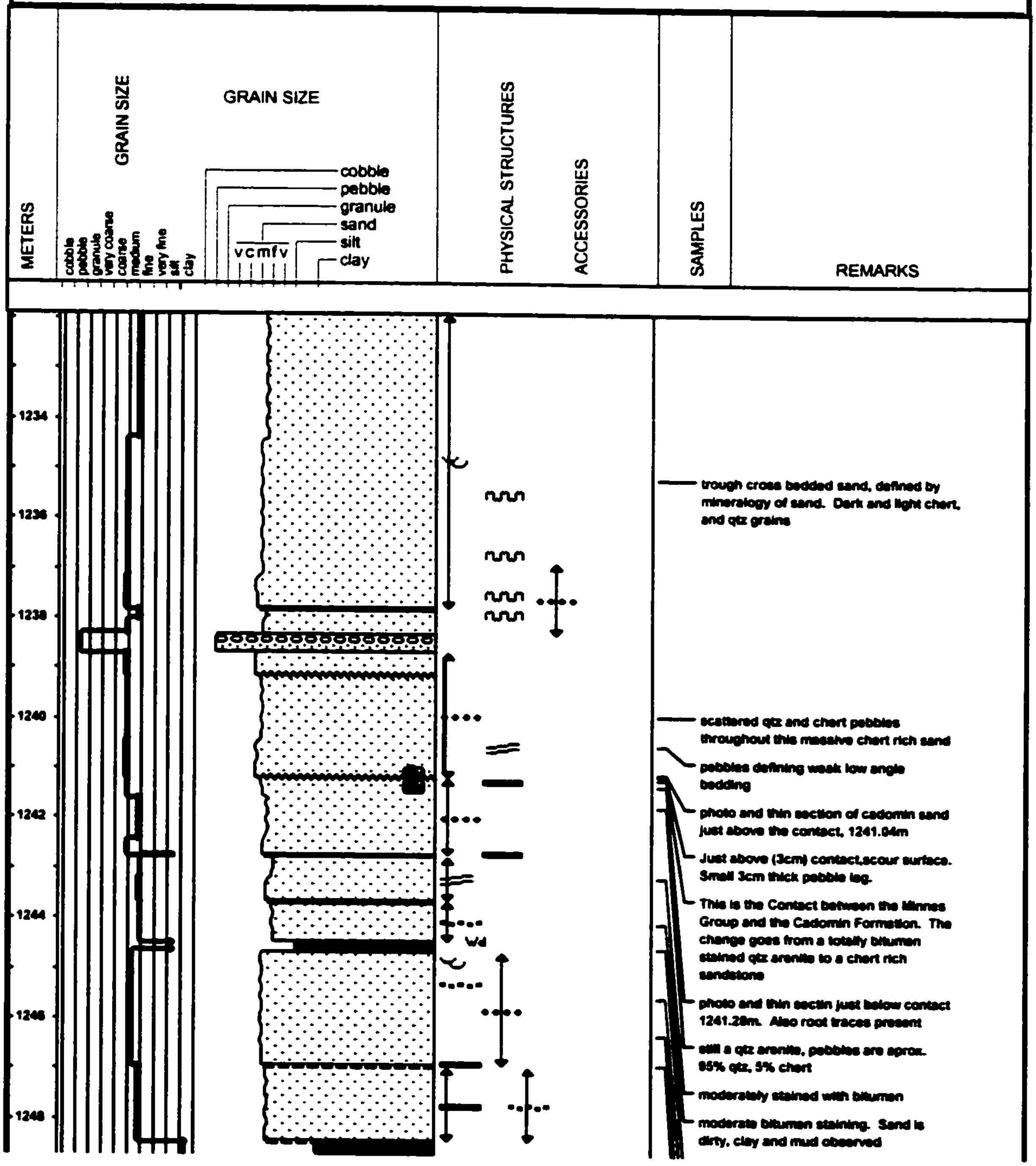
D-82-I/94-B-9

Date Logged: December 2, 1998

Logged by: Eric Hanson

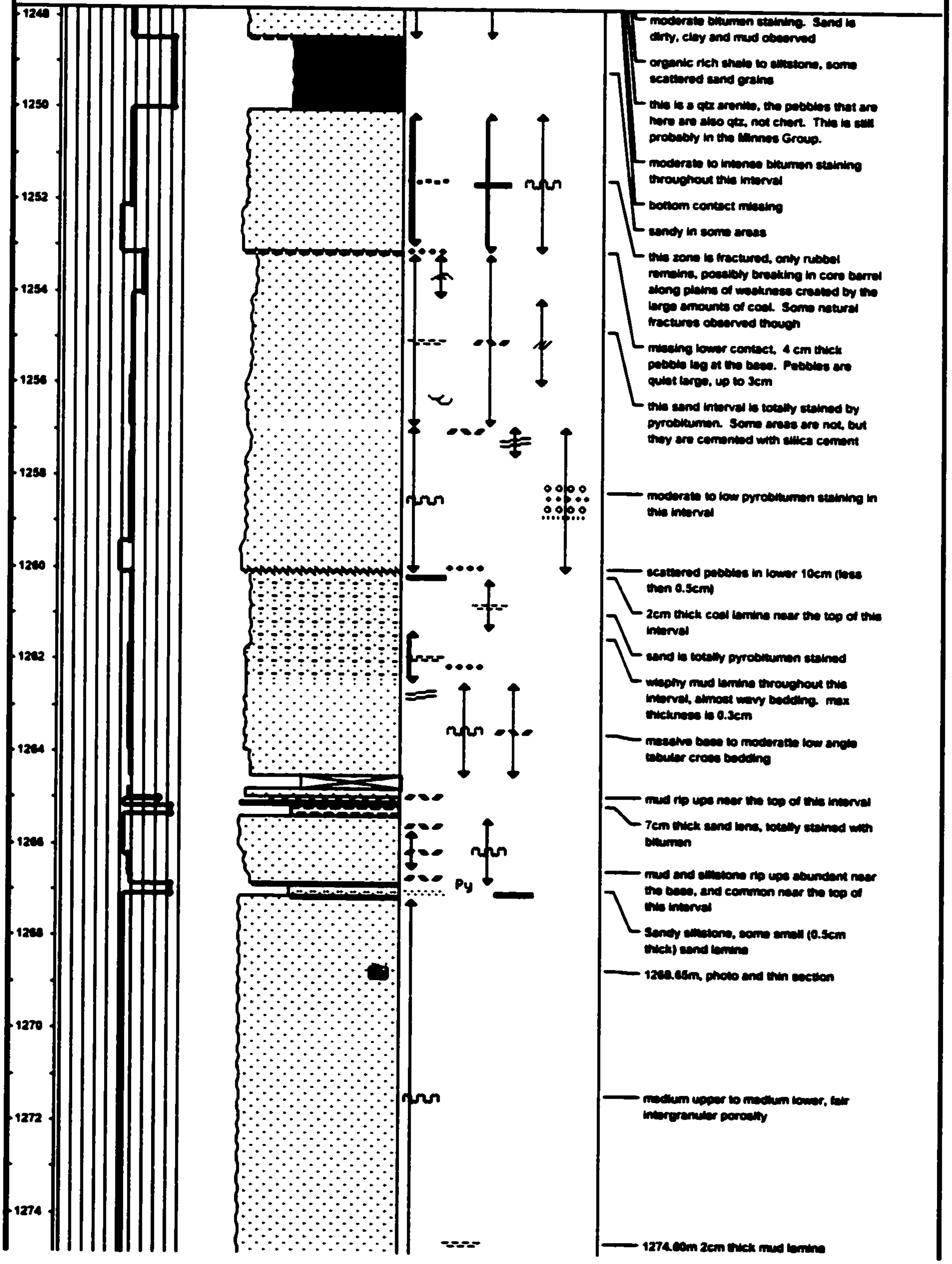
Datum elevation: 855.00 m

Remarks:



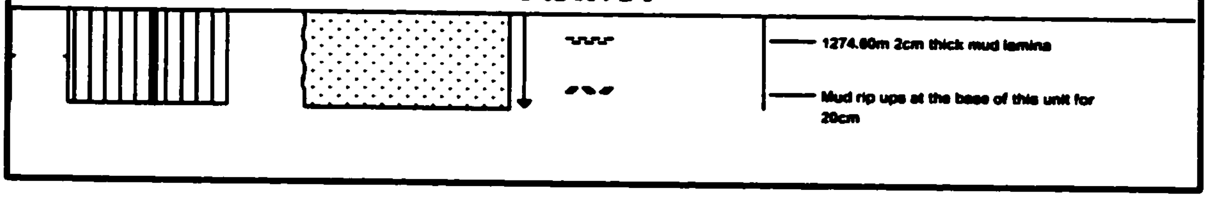
Suncor et al Blueberry D-82-I

D-82-I/94-B-9



Suncor et al Blueberry D-82-I

D-82-I/94-B-9



Unocal Fireweed

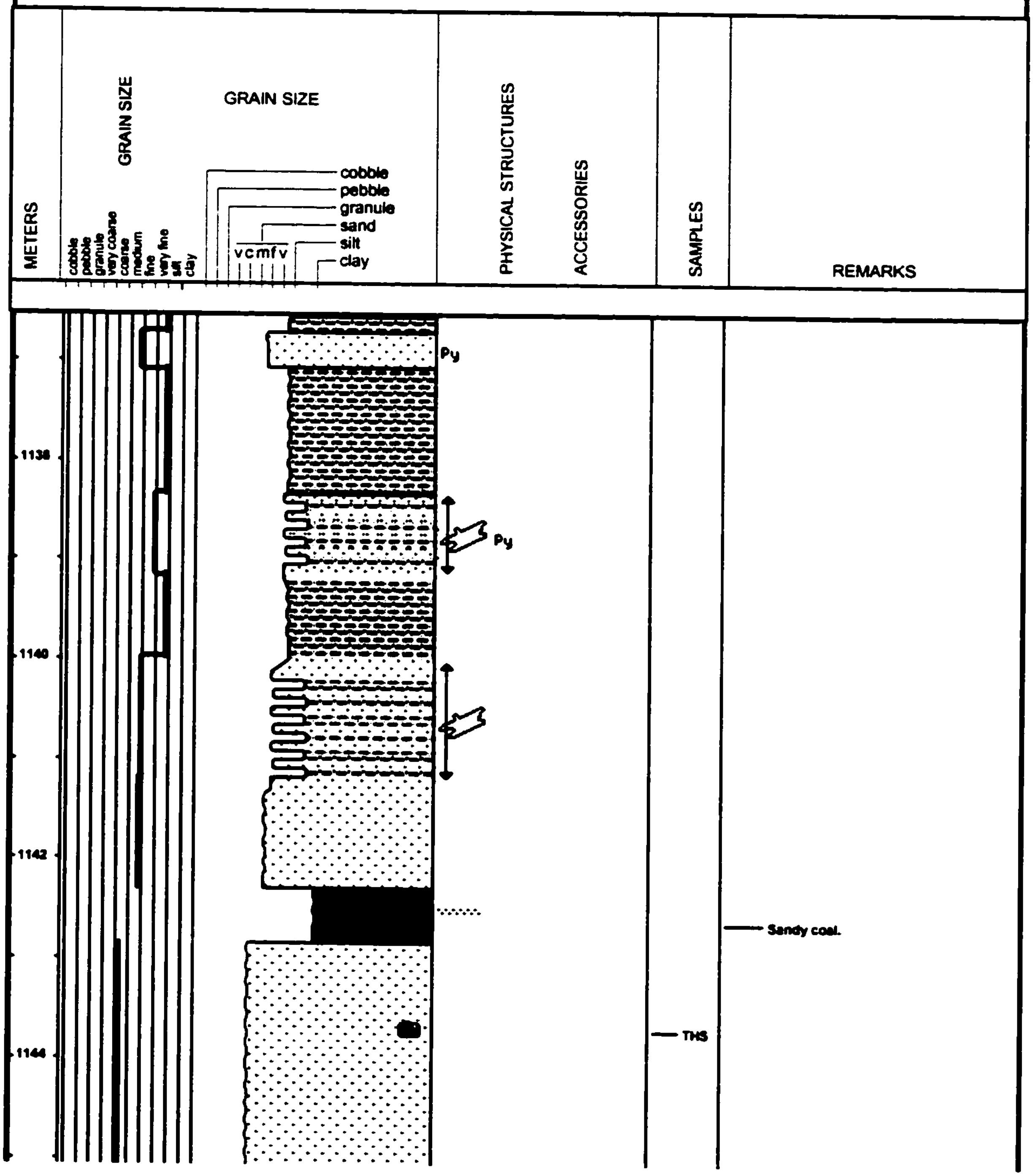
D-55-H/94-A-13

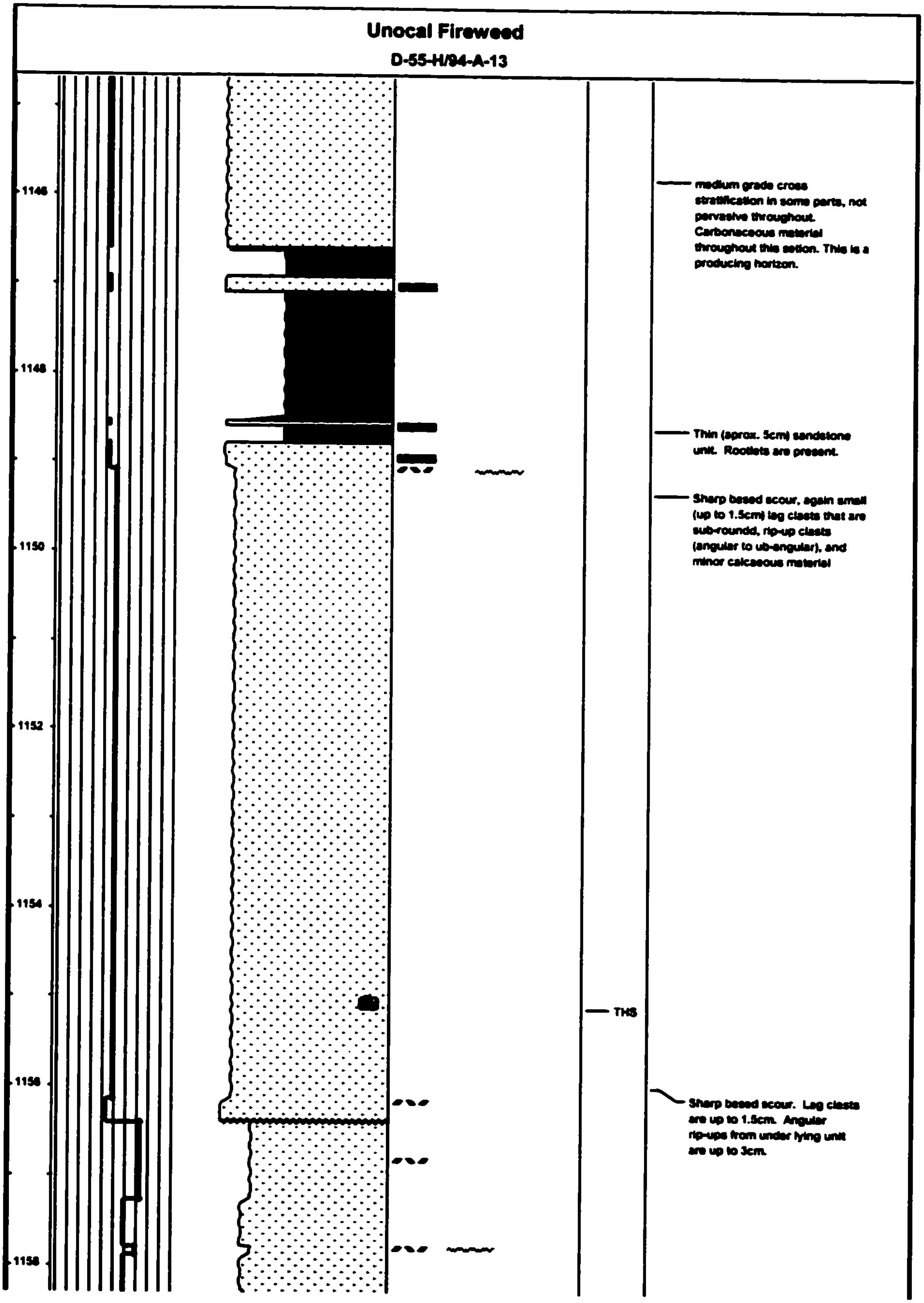
Date Logged: December 1, 1997

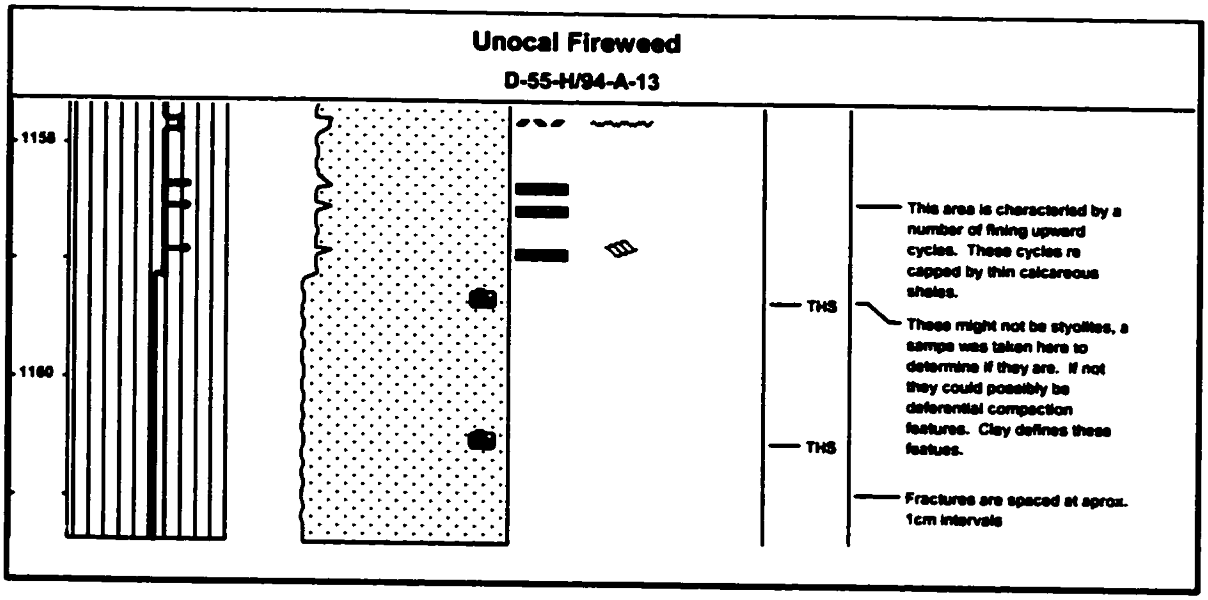
Logged by: Eric Hanson

Datum elevation: 755.90 m

Remarks: unslabbed core; Cadomin Formation from the Dunlevy - B Pool




Unocal Fireweed
D-55-H/94-A-13
1146
1148
1150
1152
1154
1156
1158
medium grade cross stratification in some parts, not pervasive throughout. Carbonaceous material throughout this setion. This is a producing horizon.
Thin (aprox. 5cm) sandstone unit. Rootlets are present.
Sharp based scour, again small (up to 1.5cm) lag clasts that are sub-roundd, rip-up clasts (angular to ub-angular), and minor calcaeous material
THS
Sharp based scour. Lag clasts are up to 1.5cm. Angular rip-ups from under lying unit are up to 3cm.


Unocal Fireweed
D-55-H/94-A-13
1158
1160
THS
THS
This area is characteried by a number of fining upward cycles. These cycles re capped by thin calcareous shales.
These might not be styolites, a sampe was taken here to determine if they are. If not they could possibly be deferential compaction features. Clay defines these featues.
Fractures are spaced at aprox. 1cm intervals

Central-Del Rio Oris

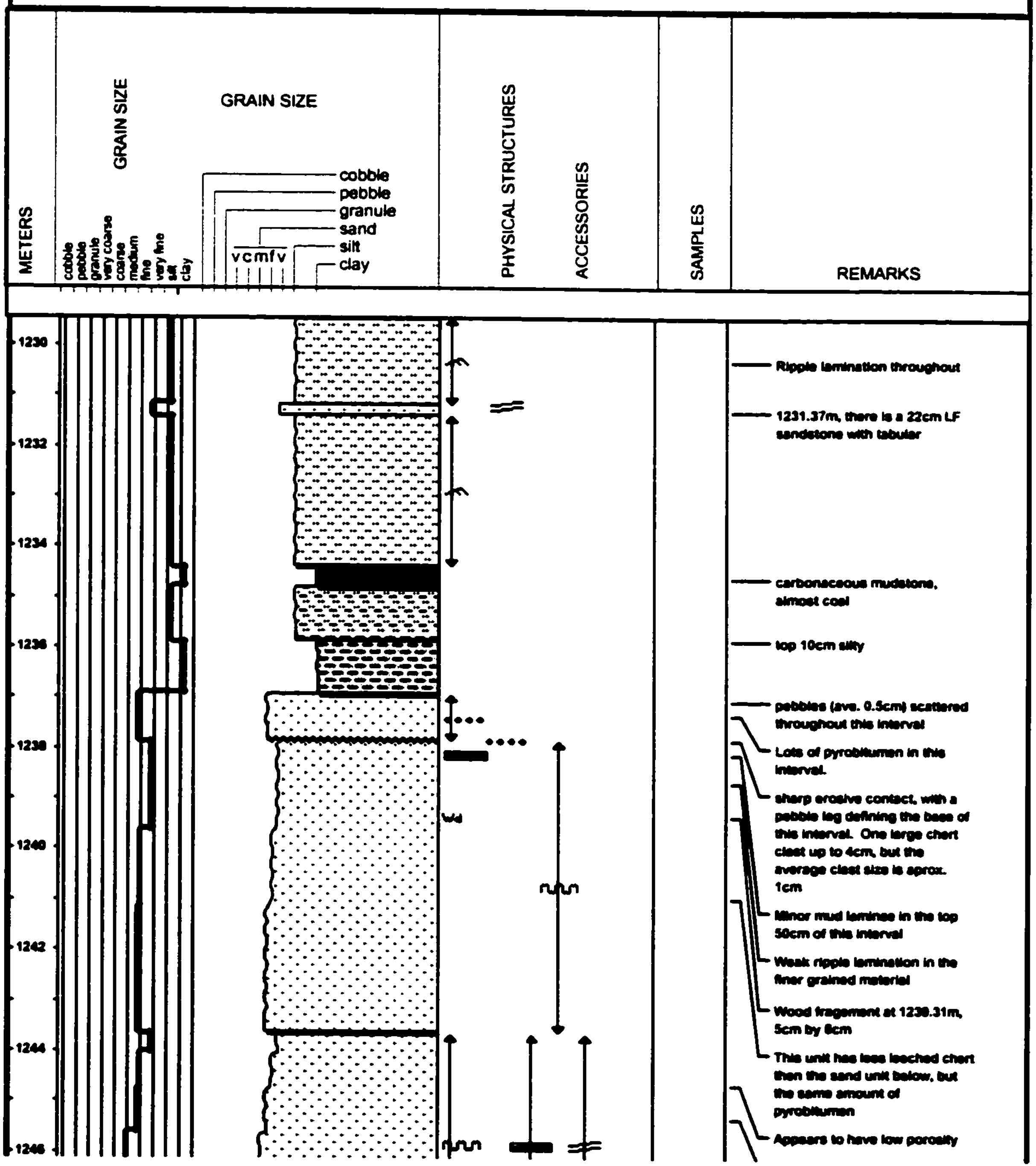
D-55-G/94-A-13

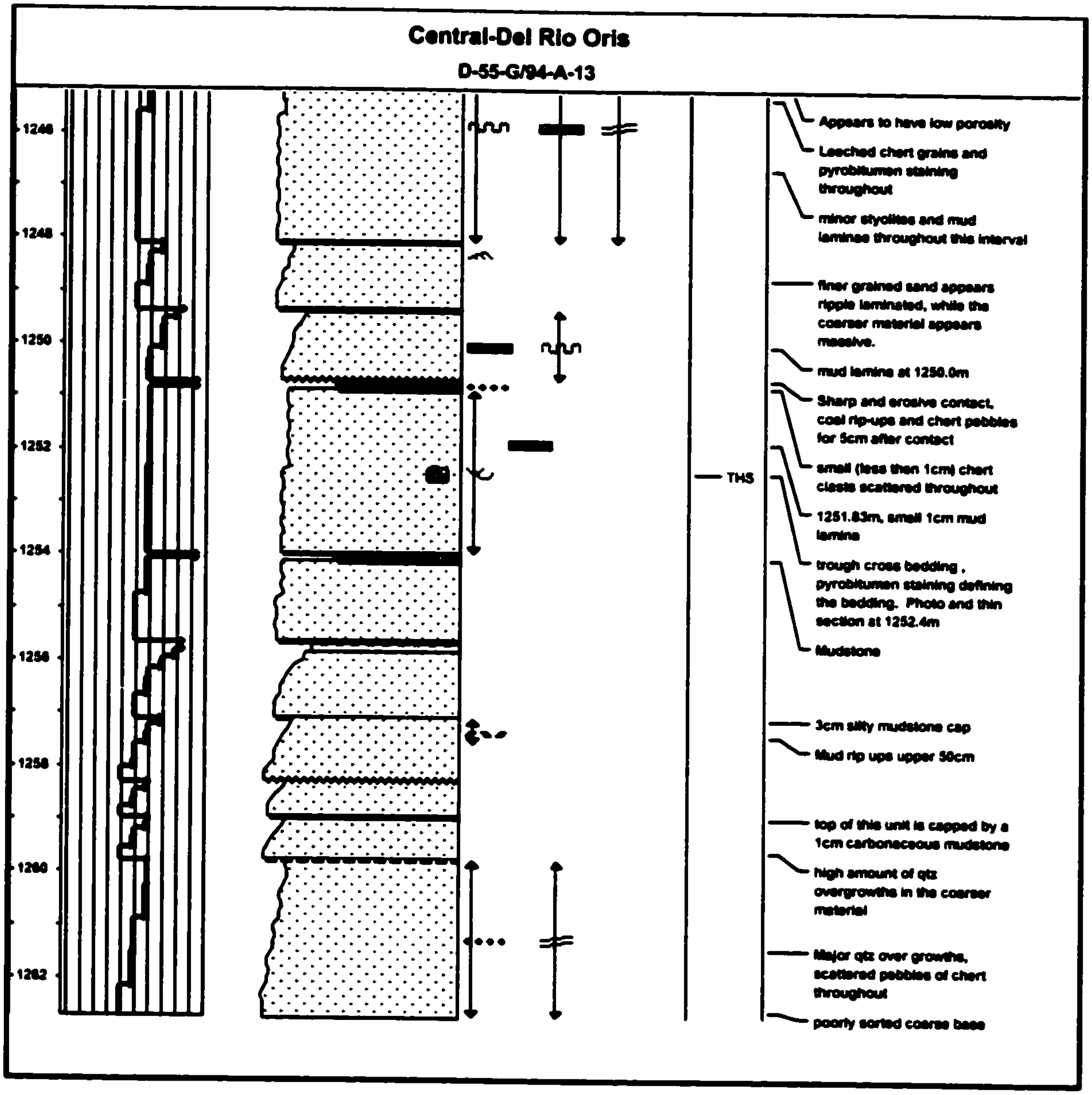
Date Logged: May 14, 1998

Logged by: Eric Hanson

Datum elevation: 0.00 m

Remarks:




Central-Del Rio Oris
D-55-G/94-A-13
1246
1248
1250
1252
1254
1256
1258
1260
1262
THS
Appears to have low porosity
Leached chert grains and pyrobitumen staining throughout
minor stylolites and mud laminae throughout this interval
finer grained sand appears ripple laminated, while the coarser material appears massive.
mud lamina at 1250.0m
Sharp and erosive contact, coal rip-ups and chert pebbles for 5cm after contact
small (less then 1cm) chert clasts scattered throughout
1251.83m, small 1cm mud lamina
trough cross bedding, pyrobitumen staining defining the bedding. Photo and thin section at 1252.4m
Mudstone
3cm silty mudstone cap
Mud rip ups upper 50cm
top of this unit is capped by a 1cm carbonaceous mudstone
high amount of qtz overgrowths in the coarser material
Major qtz over growths, scattered pebbles of chert throughout
poorly sorted coarse base

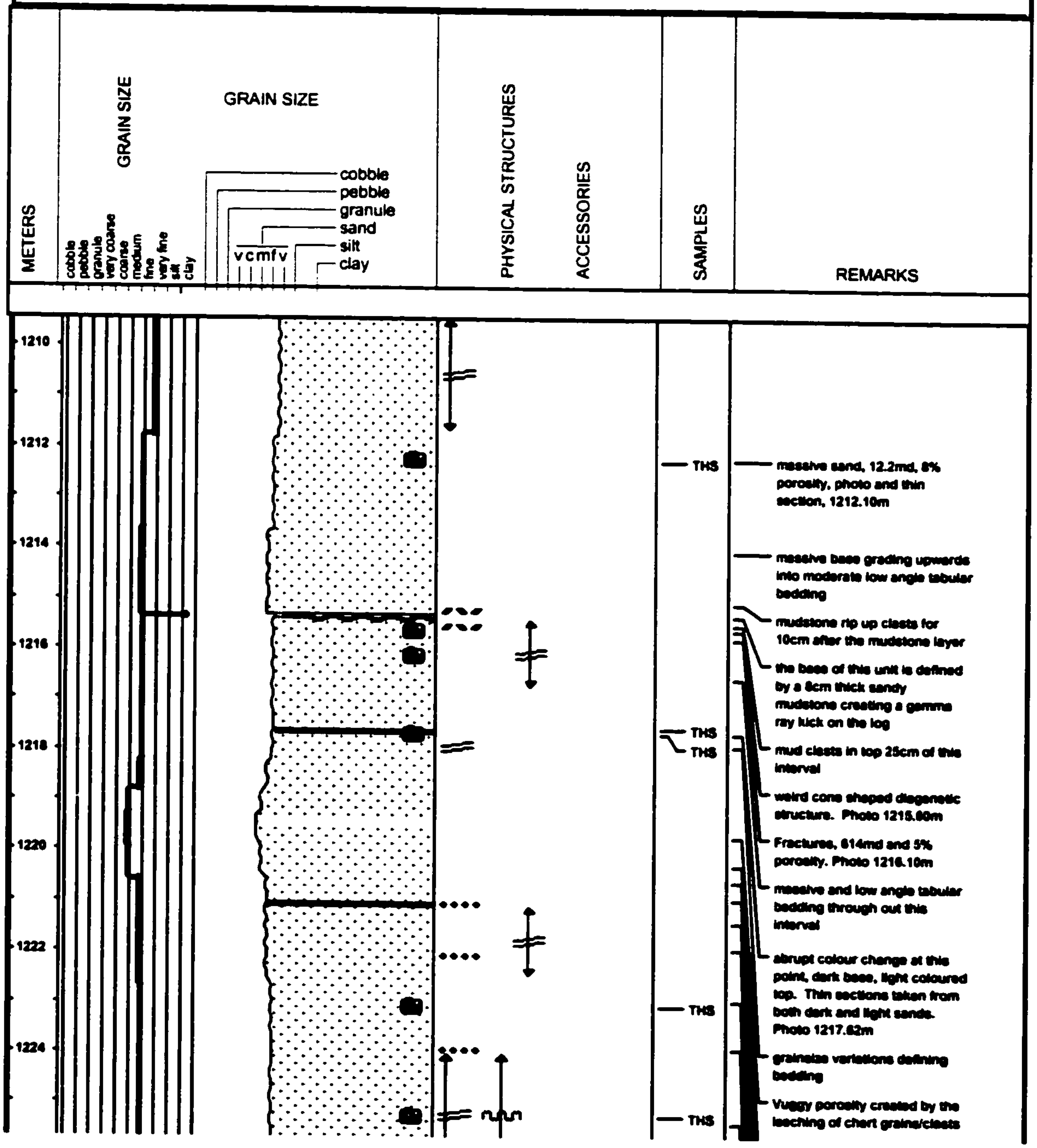
C-81-G/94-A-13

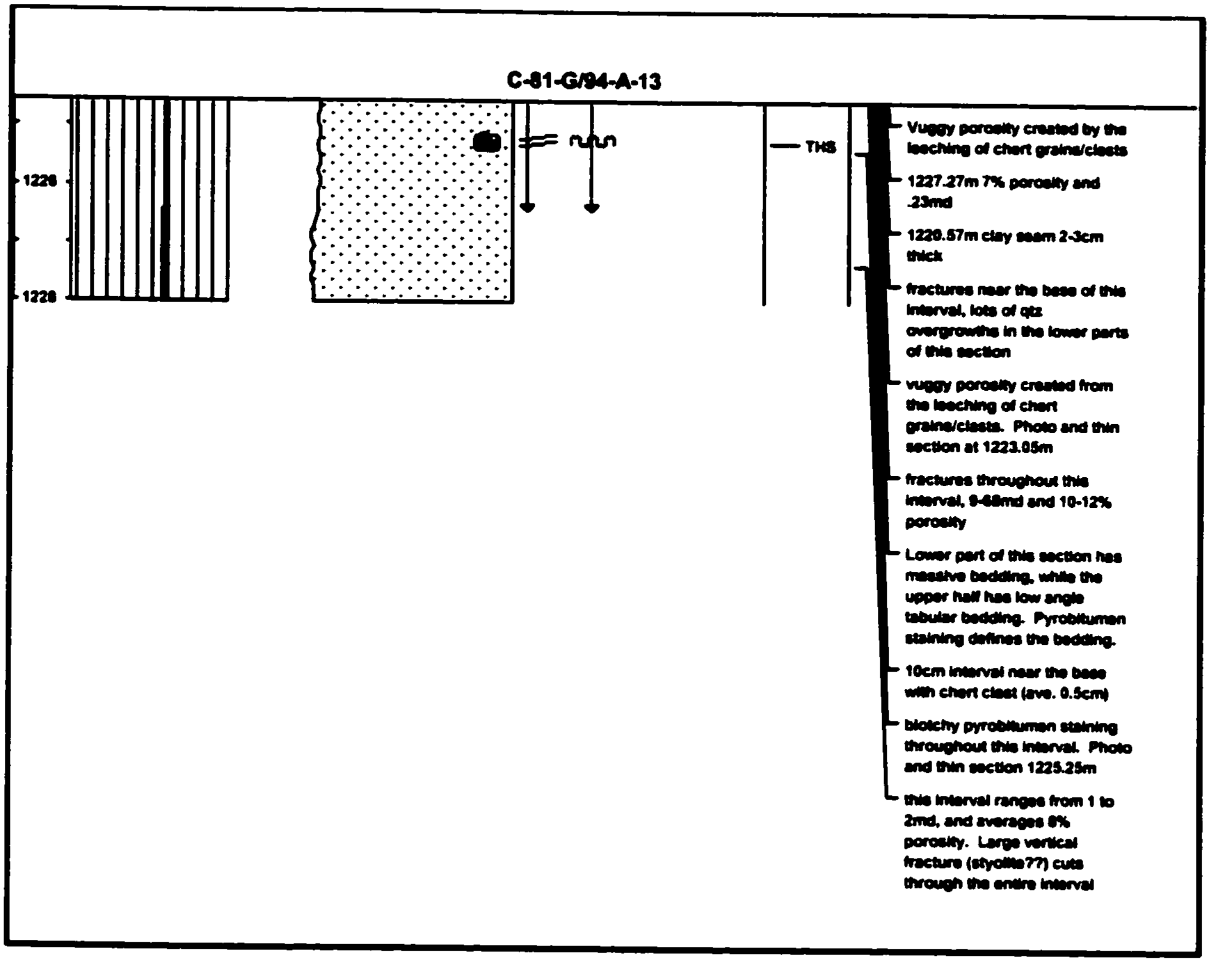
Date Logged: November 8, 1998

Logged by: Eric Hanson

Datum elevation: 0.00 m

Remarks:




C-81-G/94-A-13
1226
1228
THS
Vuggy porosity created by the leeching of chert grains/clasts
1227.27m 7% porosity and .23md
1220.57m clay seam 2-3cm thick
fractures near the base of this interval, lots of qtz overgrowths in the lower parts of this section
vuggy porosity created from the leeching of chert grains/clasts. Photo and thin section at 1223.05m
fractures throughout this interval, 9-68md and 10-12% porosity
Lower part of this section has massive bedding, while the upper half has low angle tabular bedding. Pyrobitumen staining defines the bedding.
10cm interval near the base with chert clast (ave. 0.5cm)
blotchy pyrobitumen staining throughout this interval. Photo and thin section 1225.25m
this interval ranges from 1 to 2md, and averages 8% porosity. Large vertical fracture (styolite??) cuts through the entire interval

Canhunter Kobes C-56-A

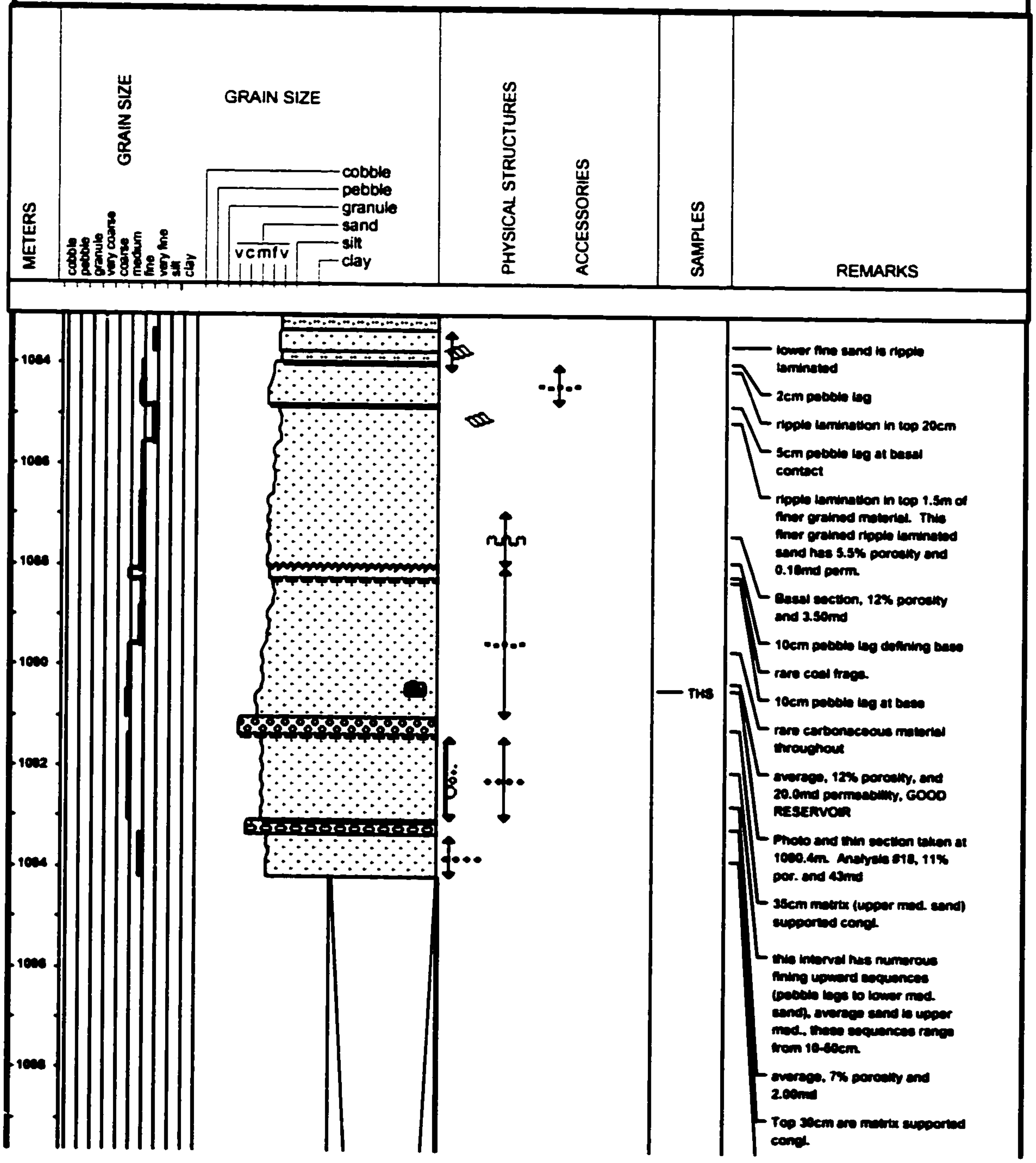
C-56-A/94-B-9

Date Logged: July 14, 1998

Logged by: Eric Hanson

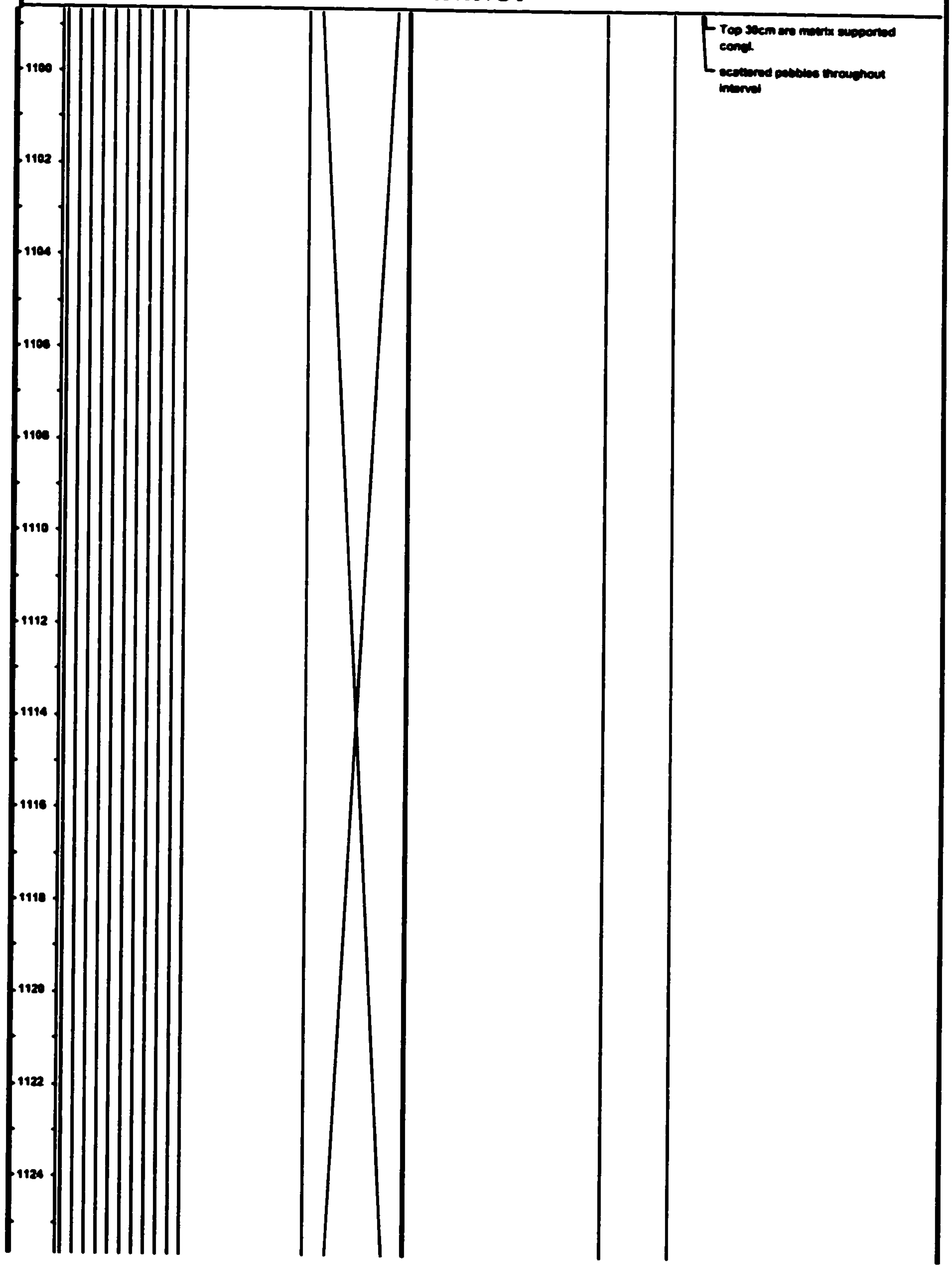
Datum elevation: 864.40 m

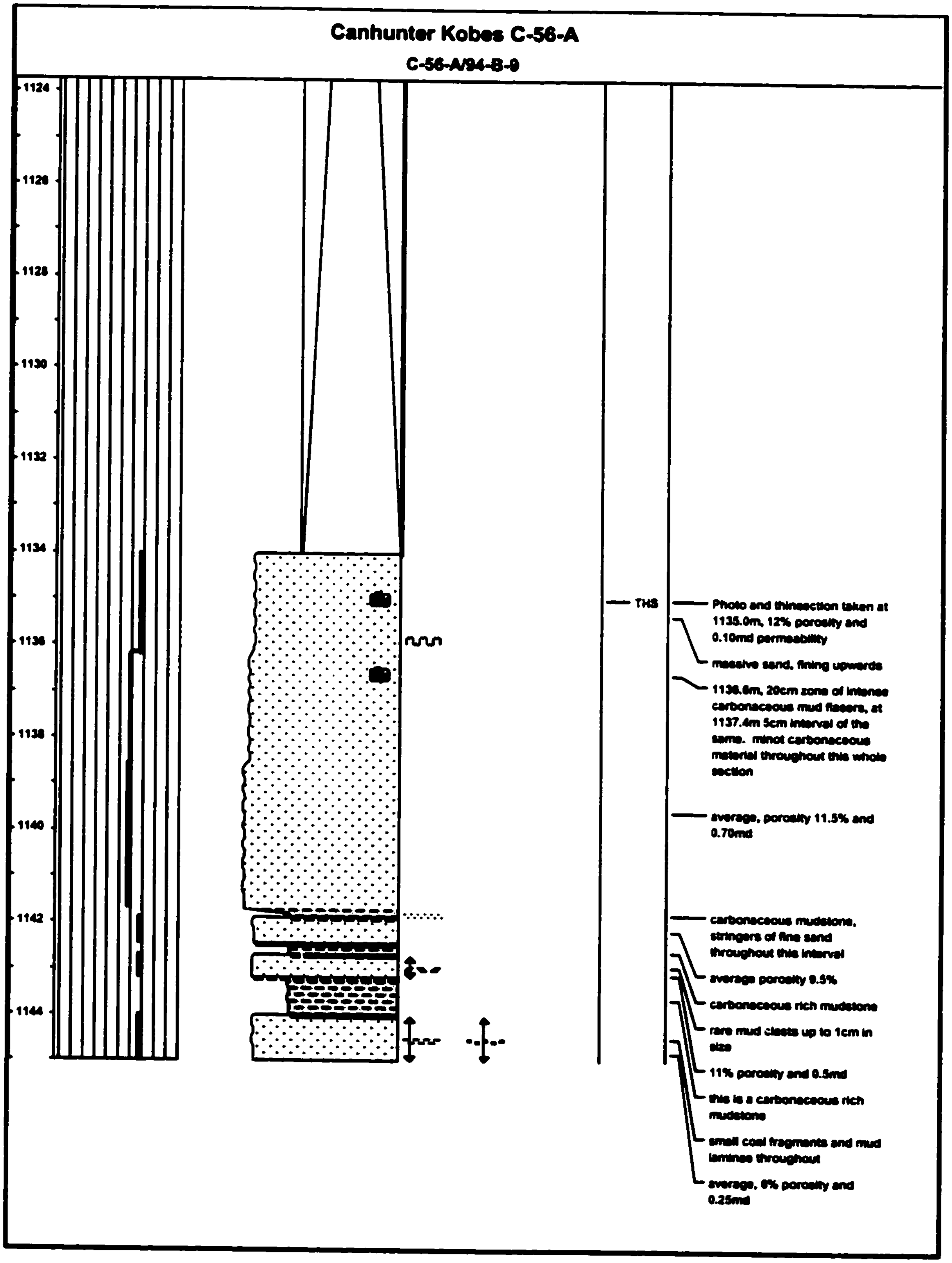
Remarks:



Canhunter Kobes C-56-A

C-56-A/94-B-9





Canhunter Kobes C-56-A
C-56-A/94-B-9
1124
1126
1128
1130
1132
1134
1136
1138
1140
1142
1144
THS
Photo and thinsection taken at 1135.0m, 12% porosity and 0.10md permeability
massive sand, fining upwards
1136.6m, 20cm zone of intense carbonaceous mud flasers, at 1137.4m 5cm interval of the same. minot carbonaceous material throughout this whole section
average, porosity 11.5% and 0.70md
carbonaceous mudstone, stringers of fine sand throughout this interval
average porosity 9.5%
carbonaceous rich mudstone
rare mud clasts up to 1cm in size
11% porosity and 0.5md
this is a carbonaceous rich mudstone
small coal fragments and mud laminae throughout
average, 8% porosity and 0.25md

Imp Pac Altares C-42-A

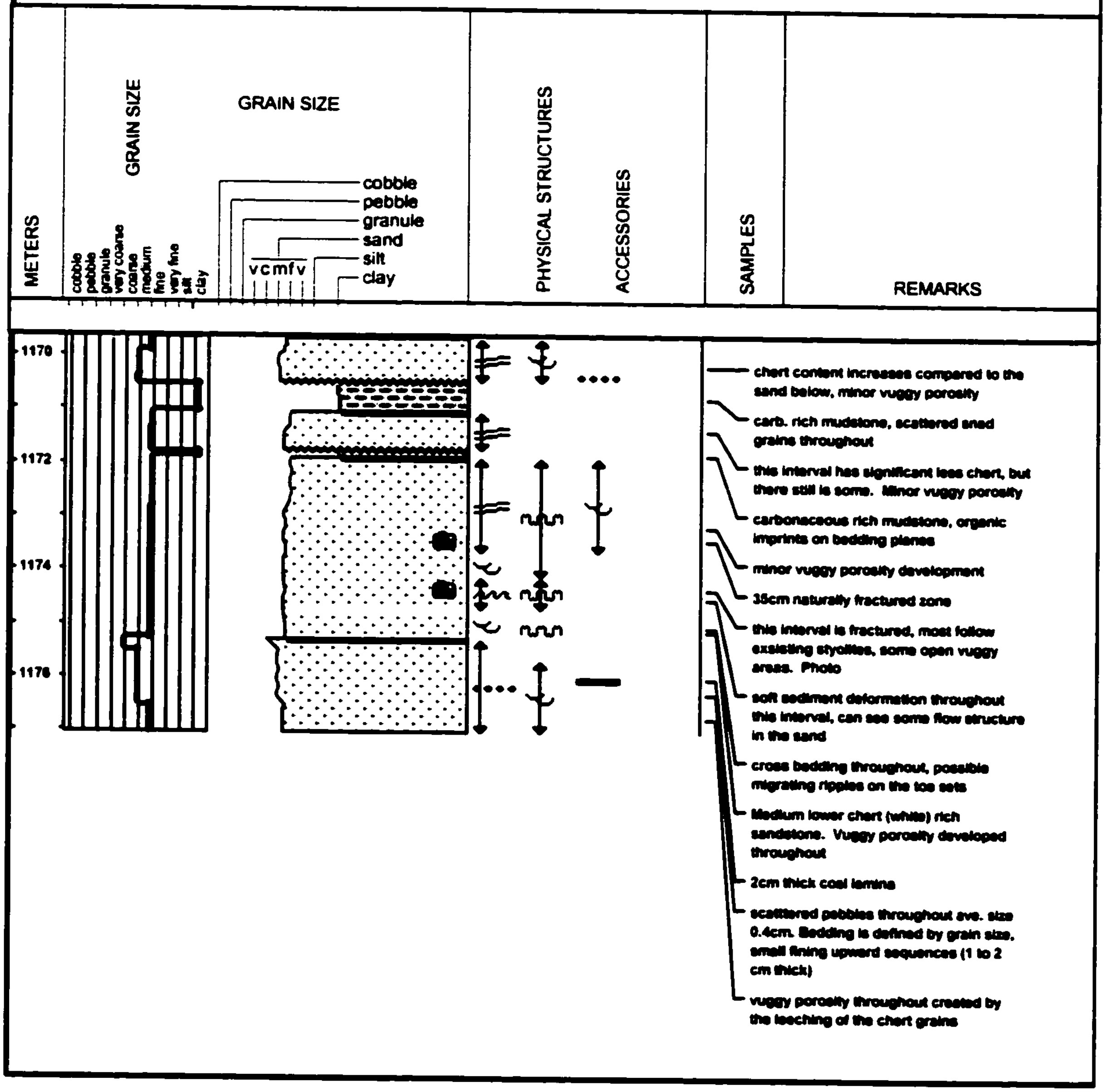
C-42-A/94-B-8

Date Logged: December 2, 1998

Logged by: Eric Hanson

Datum elevation: 773.58 m

Remarks:



CNRL Fireweed

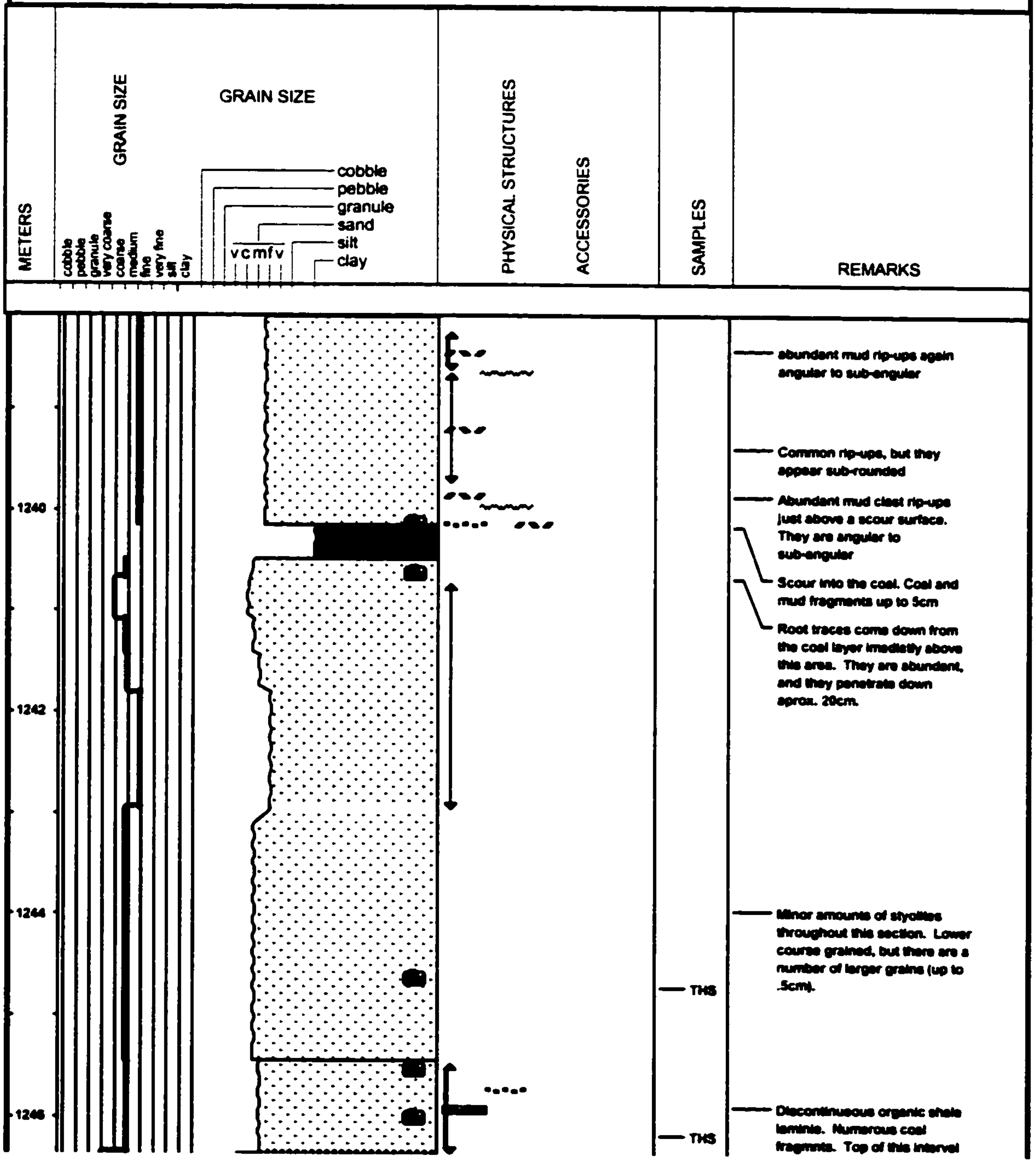
C-18-H/94-a-13

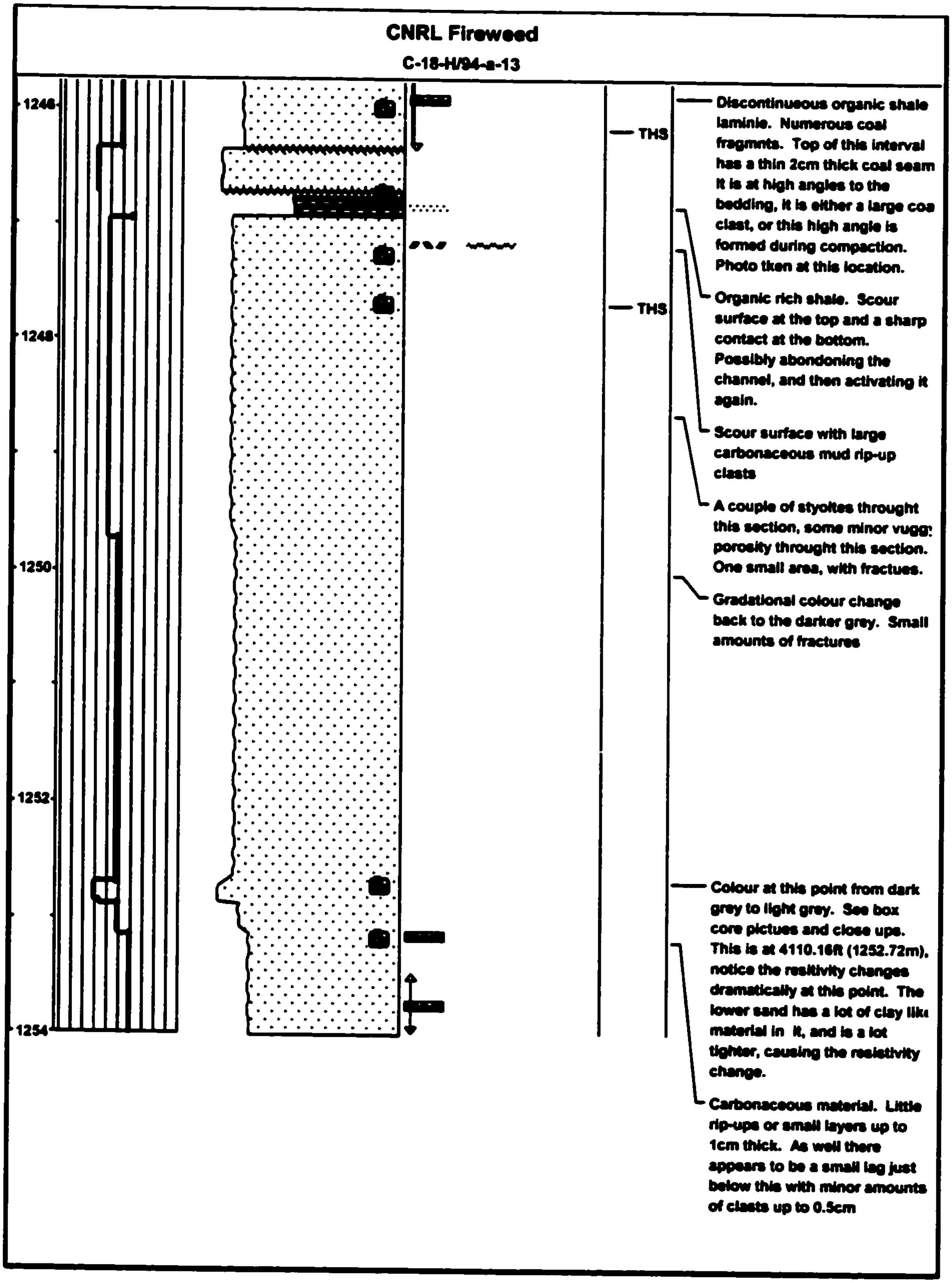
Date Logged: December 2, 1997

Logged by: Eric Hanson

Datum elevation: 842.20 m

Remarks: Not slabbed. Fireweed field, Dunlevy-A pool




CNRL Fireweed
C-18-H/94-a-13
1246
1248
1250
1252
1254
THS
THS
Discontinuous organic shale laminie. Numerous coal fragmnts. Top of this interval has a thin 2cm thick coal seam It is at high angles to the bedding, it is either a large coa clast, or this high angle is formed during compaction. Photo tken at this location.
Organic rich shale. Scour surface at the top and a sharp contact at the bottom. Possibly abondoning the channel, and then activating it again.
Scour surface with large carbonaceous mud rip-up clasts
A couple of styoltes throught this section, some minor vugg: porosity throught this section. One small area, with fractues.
Gradational colour change back to the darker grey. Small amounts of fractures
Colour at this point from dark grey to light grey. See box core pictues and close ups. This is at 4110.16ft (1252.72m). notice the resitivity changes dramatically at this point. The lower sand has a lot of clay lik material in it, and is a lot tighter, causing the resistivity change.
Carbonaceous material. Little rip-ups or small layers up to 1cm thick. As well there appears to be a small lag just below this with minor amounts of clasts up to 0.5cm

Pex Kobes B-82-I

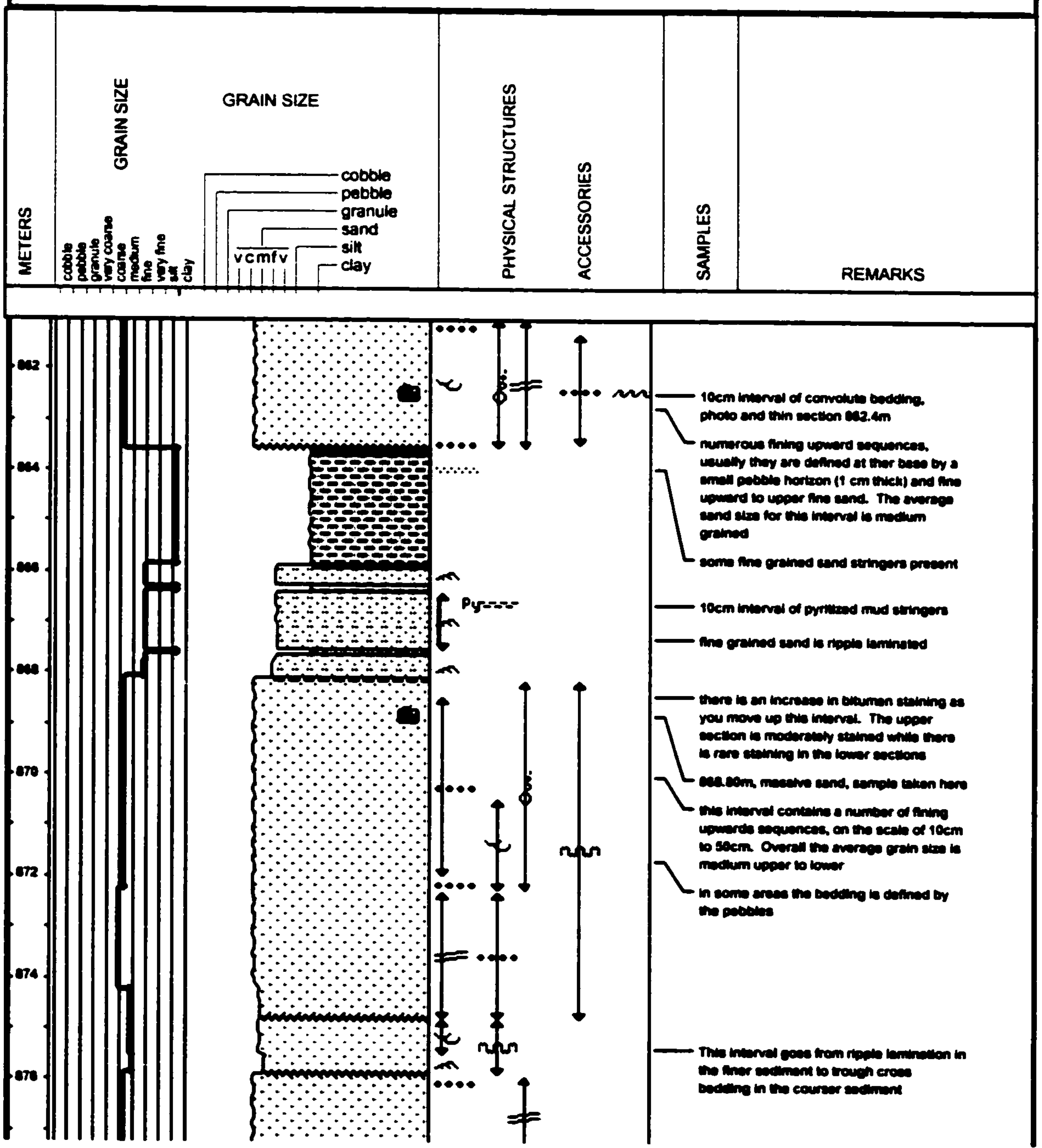
B-82-I/94-B-8

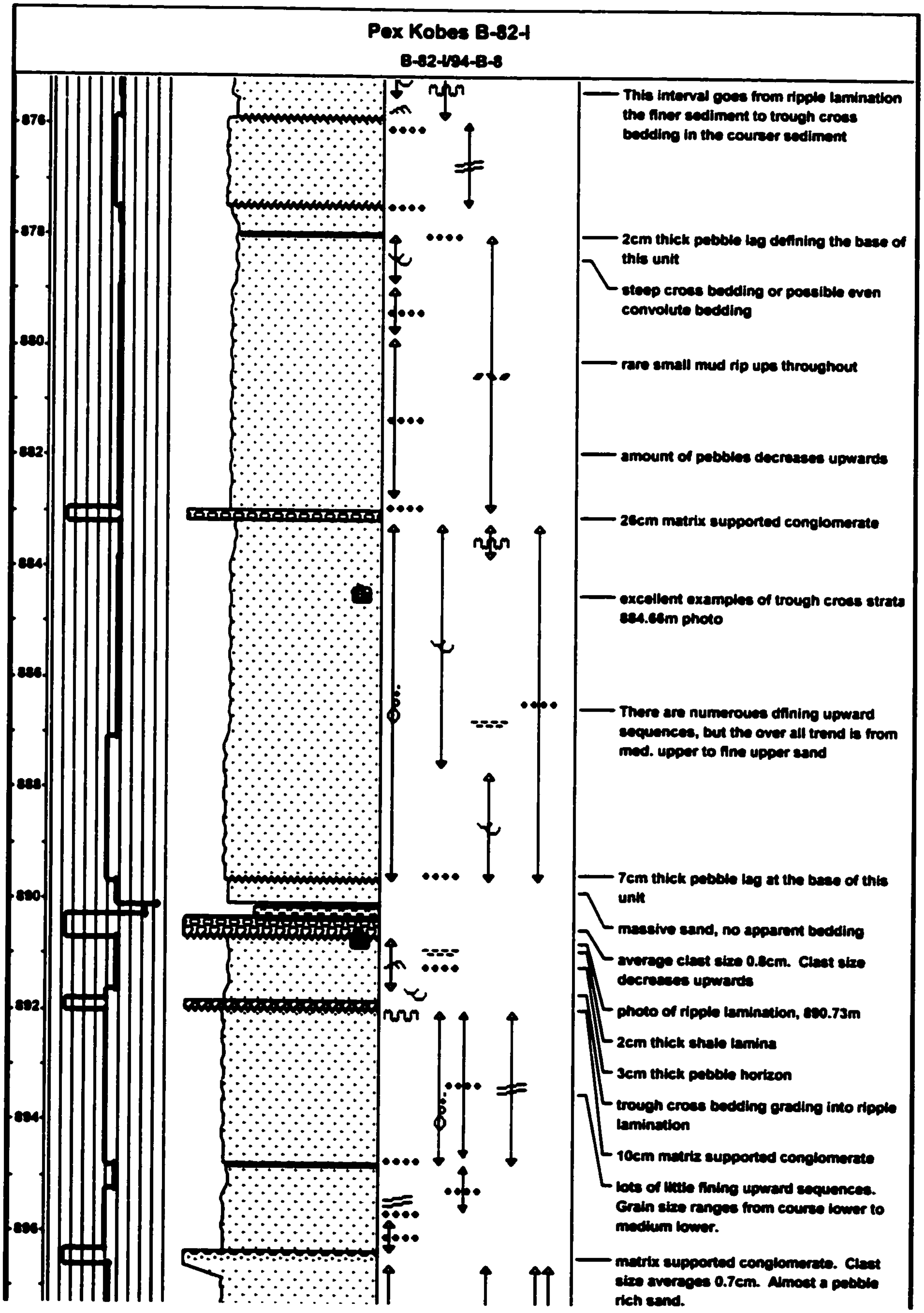
Date Logged: December 2,1998

Logged by: Eric Hanson

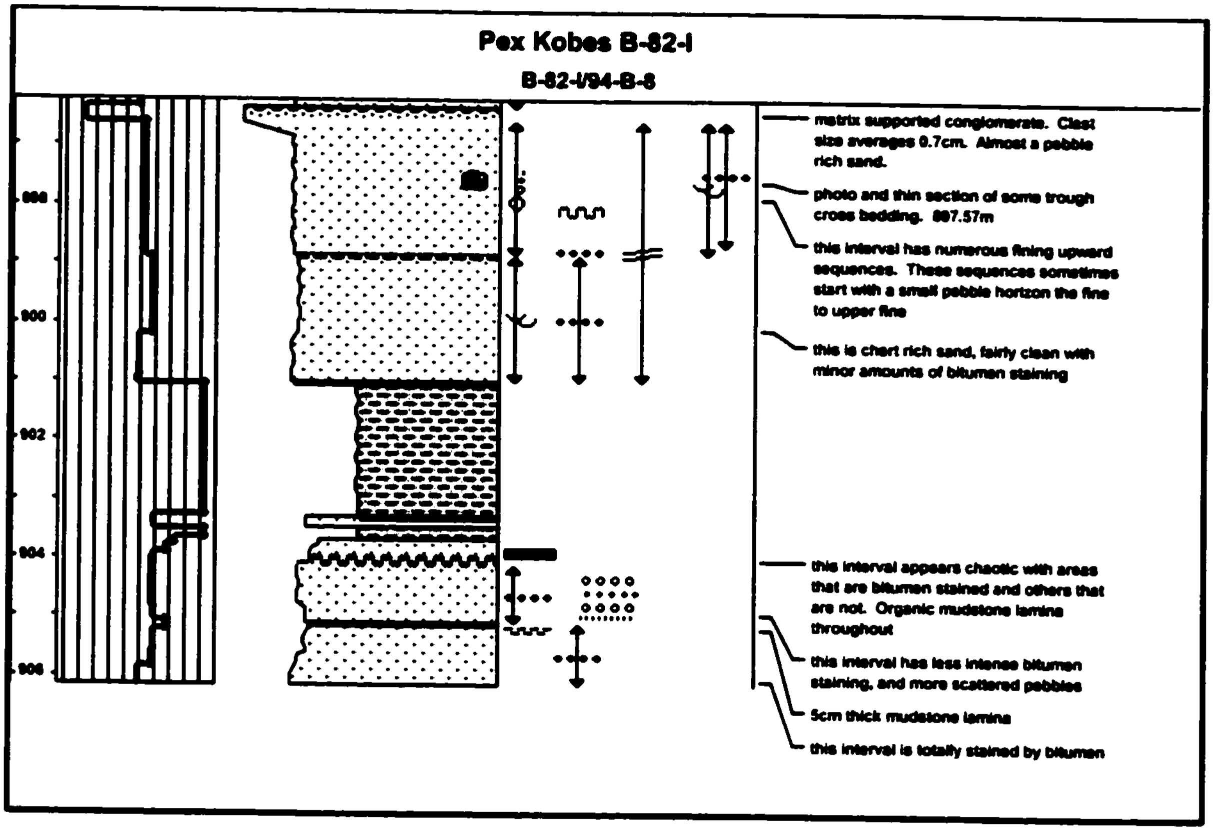
Datum elevation: 667.17 m

Remarks:





Pex Kobes B-82-I
B-82-I/94-B-8
876
878
880
882
884
886
888
890
892
894
896
This interval goes from ripple lamination the finer sediment to trough cross bedding in the courser sediment
2cm thick pebble lag defining the base of this unit
steep cross bedding or possible even convolute bedding
rare small mud rip ups throughout
amount of pebbles decreases upwards
26cm matrix supported conglomerate
excellent examples of trough cross strata 884.66m photo
There are numeroues dfining upward sequences, but the over all trend is from med. upper to fine upper sand
7cm thick pebble lag at the base of this unit
massive sand, no apparent bedding
average clast size 0.8cm. Clast size decreases upwards
photo of ripple lamination, 890.73m
2cm thick shale lamina
3cm thick pebble horizon
trough cross bedding grading into ripple lamination
10cm matriz supported conglomerate
lots of little fining upward sequences. Grain size ranges from course lower to medium lower.
matrix supported conglomerate. Clast size averages 0.7cm. Almost a pebble rich sand.



Pex Kobes B-82-I
B-82-I/94-B-8
900
902
904
906
matrix supported conglomerate. Clast size averages 0.7cm. Almost a pebble rich sand.
photo and thin section of some trough cross bedding. 897.57m
this interval has numerous fining upward sequences. These sequences sometimes start with a small pebble horizon the fine to upper fine
this is chert rich sand, fairly clean with minor amounts of bitumen staining
this interval appears chaotic with areas that are bitumen stained and others that are not. Organic mudstone lamina throughout
this interval has less intense bitumen staining, and more scattered pebbles
5cm thick mudstone lamina
this interval is totally stained by bitumen

Pex Kobes B-35-A

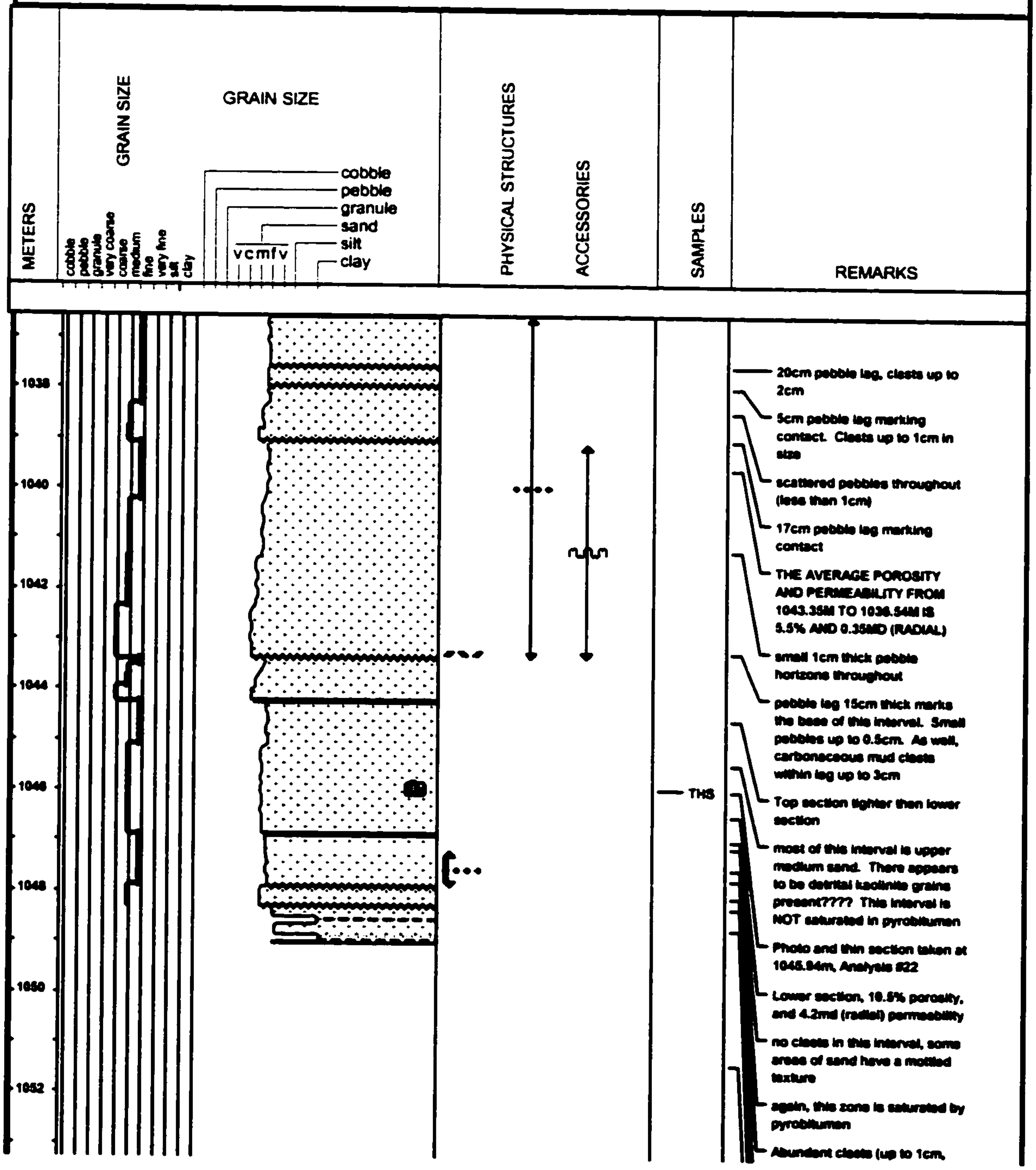
B-35-A/94-B-9

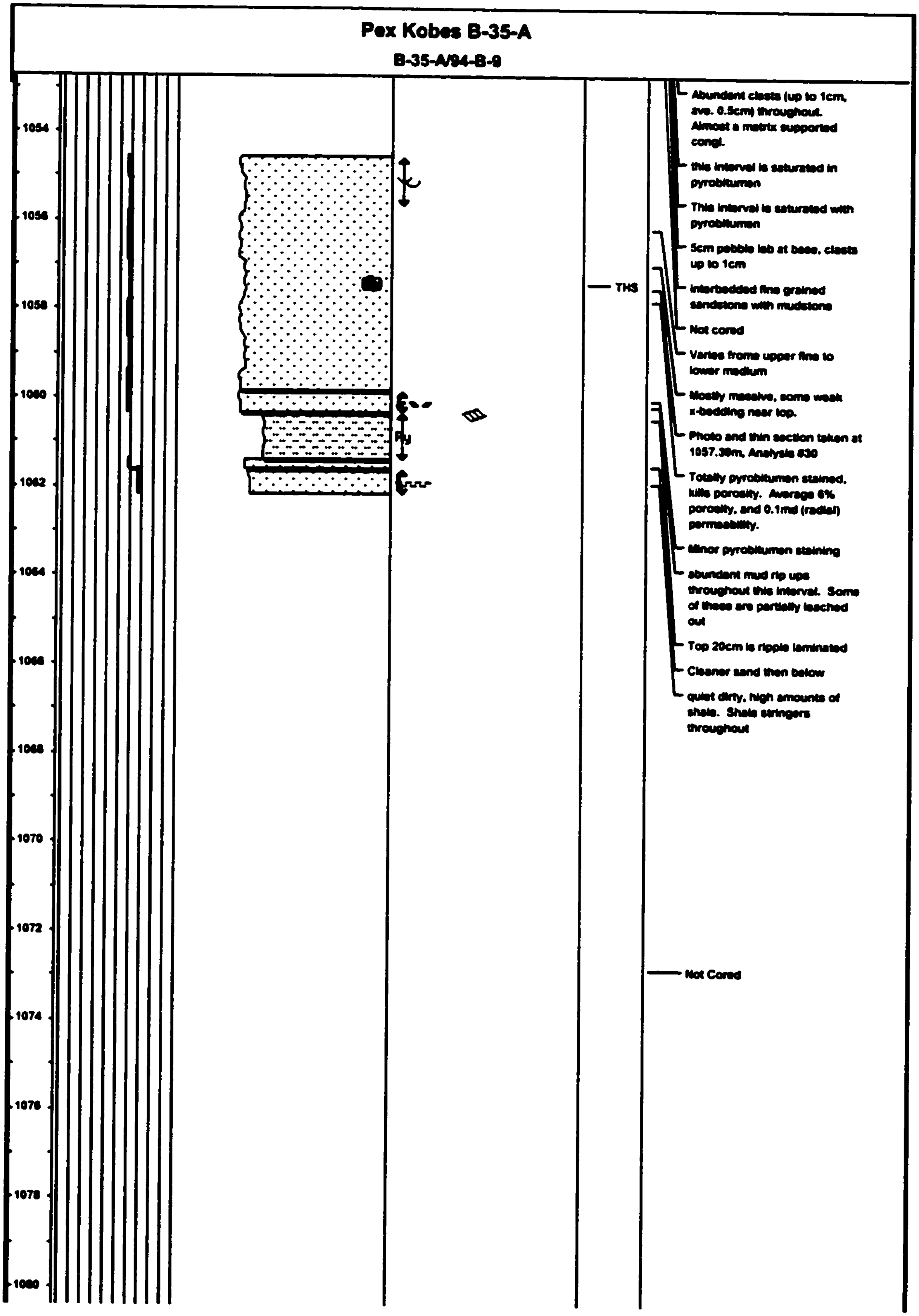
Date Logged: July 14, 1998

Logged by: Eric Hanson

Datum elevation: 817.80 m

Remarks:

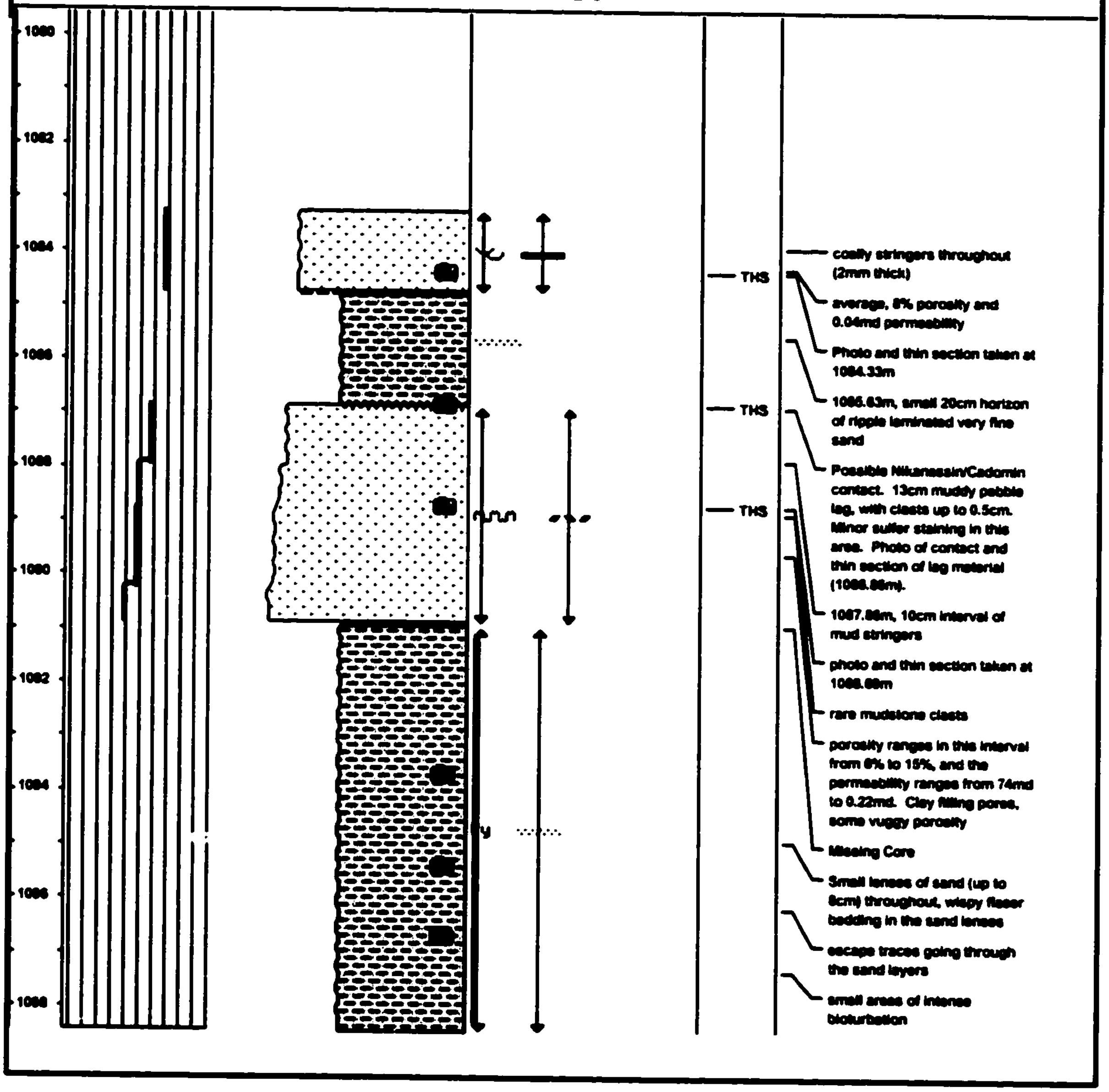




Pex Kobes B-35-A
B-35-A/94-B-9
1054
1056
1058
1060
1062
1064
1066
1068
1070
1072
1074
1076
1078
1080
Py
THS
Abundant clasts (up to 1cm, ave. 0.5cm) throughout. Almost a matrix supported congl.
this interval is saturated in pyrobitumen
This interval is saturated with pyrobitumen
5cm pebble lab at base, clasts up to 1cm
interbedded fine grained sandstone with mudstone
Not cored
Varies frome upper fine to lower medium
Mostly massive, some weak x-bedding near top.
Photo and thin section taken at 1057.38m, Analysis #30
Totally pyrobitumen stained, kills porosity. Average 6% porosity, and 0.1md (radial) permeability.
Minor pyrobitumen staining
abundant mud rip ups throughout this interval. Some of these are partially leached out
Top 20cm is ripple laminated
Cleaner sand then below
quiet dirty, high amounts of shale. Shale stringers throughout
Not Cored

Pex Kobes B-35-A

B-35-A/94-B-9



PEX Kobes

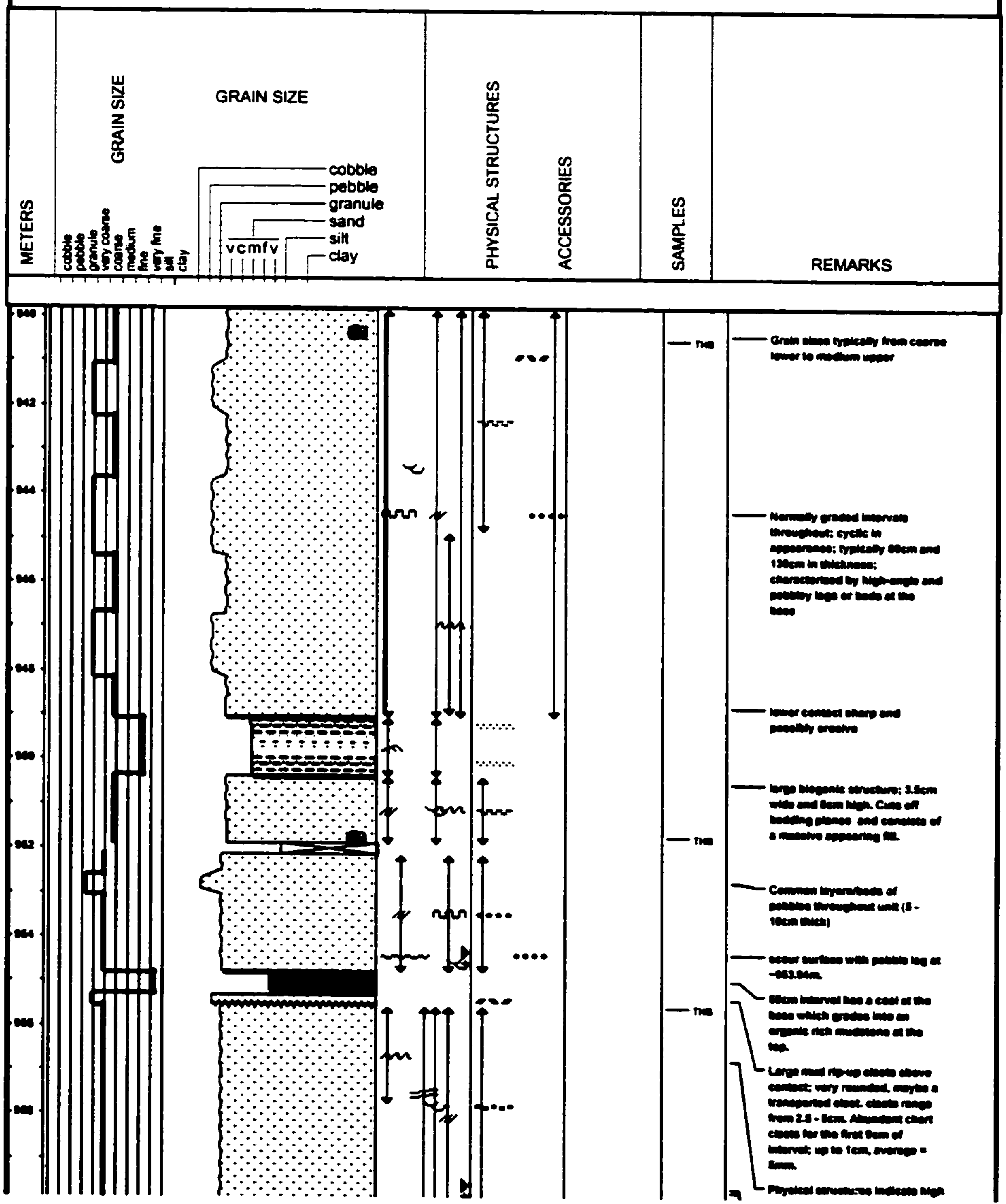
B-24-A/94-B-9

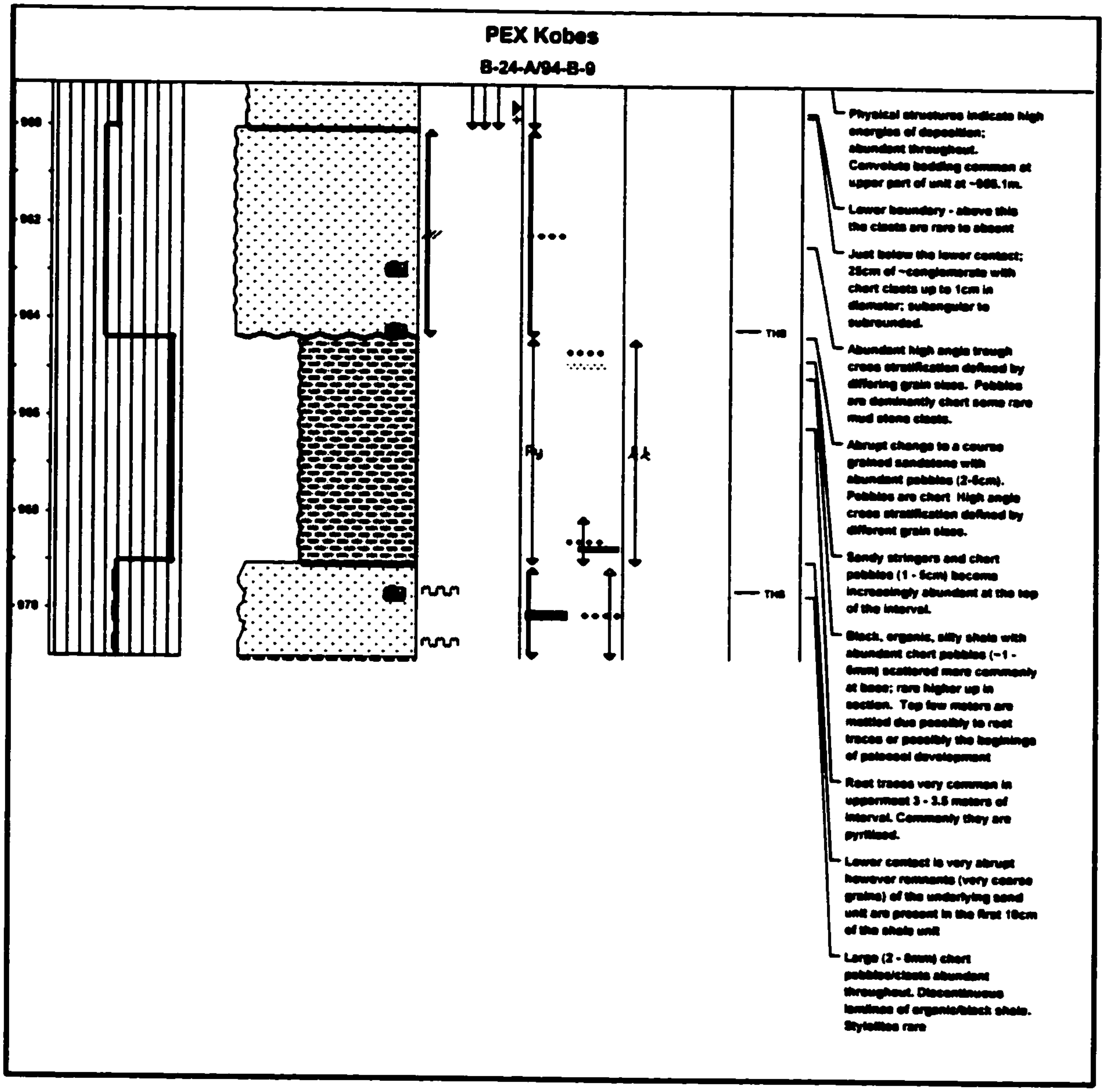
Date Logged: December 3, 1997

Logged by: Eric Hanson

Datum elevation: 740.40 m

Remarks: unslabbed core; Cadomin Fmtn; Dunlevy - A Pool




PEX Kobes
B-24-A/94-B-9
THS
THS
Physical structures indicate high energies of deposition; abundant throughout. Convolute bedding common at upper part of unit at ~960.1m.
Lower boundary - above this the clasts are rare to absent
Just below the lower contact; 25cm of ~conglomerate with chert clasts up to 1cm in diameter; subangular to subrounded.
Abundant high angle trough cross stratification defined by differing grain sizes. Pebbles are dominantly chert some rare mud stone clasts.
Abrupt change to a course grained sandstone with abundant pebbles (2-6cm). Pebbles are chert High angle cross stratification defined by different grain sizes.
Sandy stringers and chert pebbles (1 - 5cm) become increasingly abundant at the top of the interval.
Black, organic, silty shale with abundant chert pebbles (~1 - 6mm) scattered more commonly at base; rare higher up in section. Top few meters are mottled due possibly to root traces or possibly the beginings of paleosol development
Root traces very common in uppermost 3 - 3.5 meters of interval. Commonly they are pyritized.
Lower contact is very abrupt however remnants (very coarse grains) of the underlying sand unit are present in the first 10cm of the shale unit
Large (2 - 8mm) chert pebbles/clasts abundant throughout. Discontinuous laminae of organic/black shale. Stylolites rare

Inverness et al Fireweed A-43-H

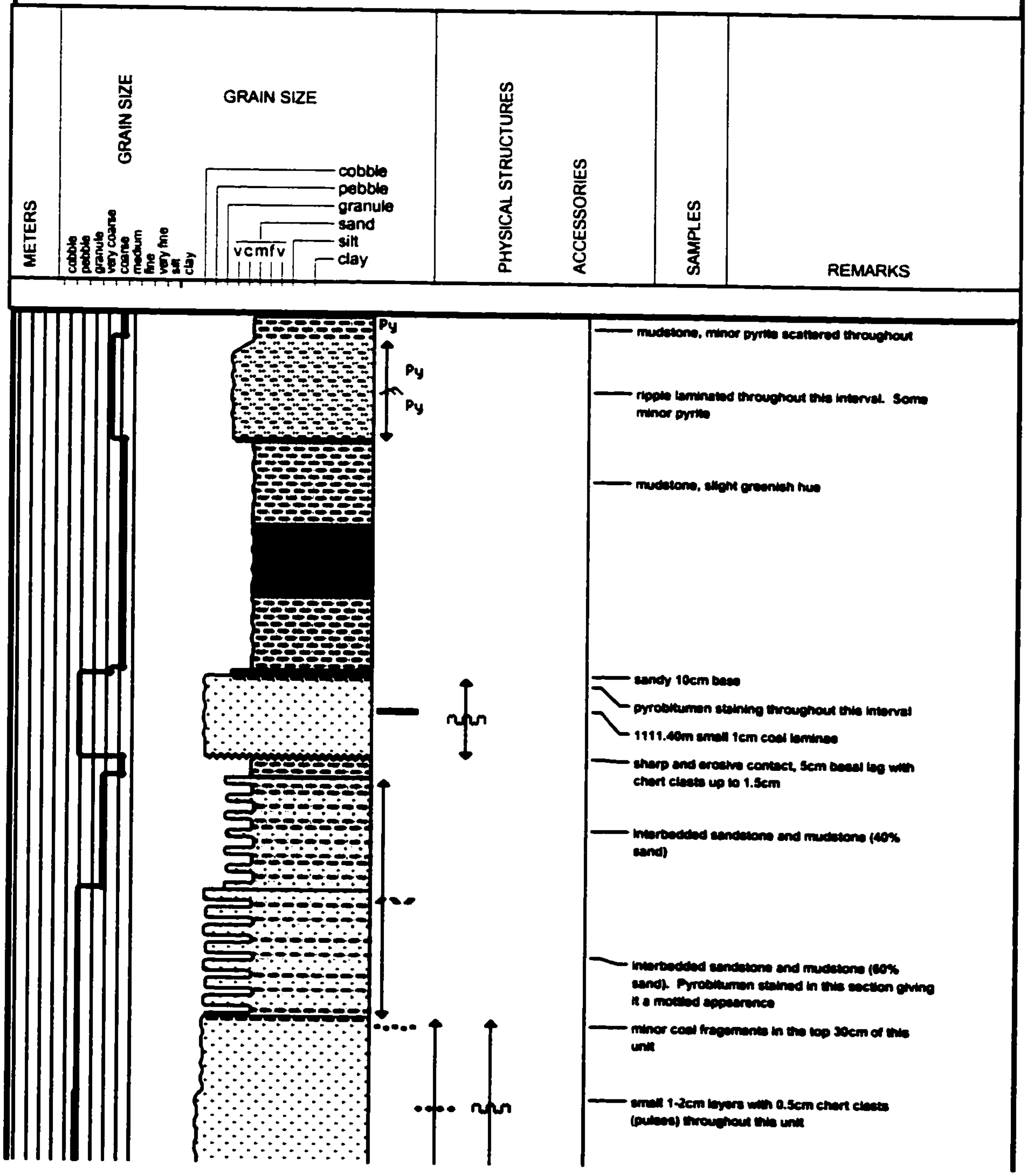
A-43-H/94-A-13

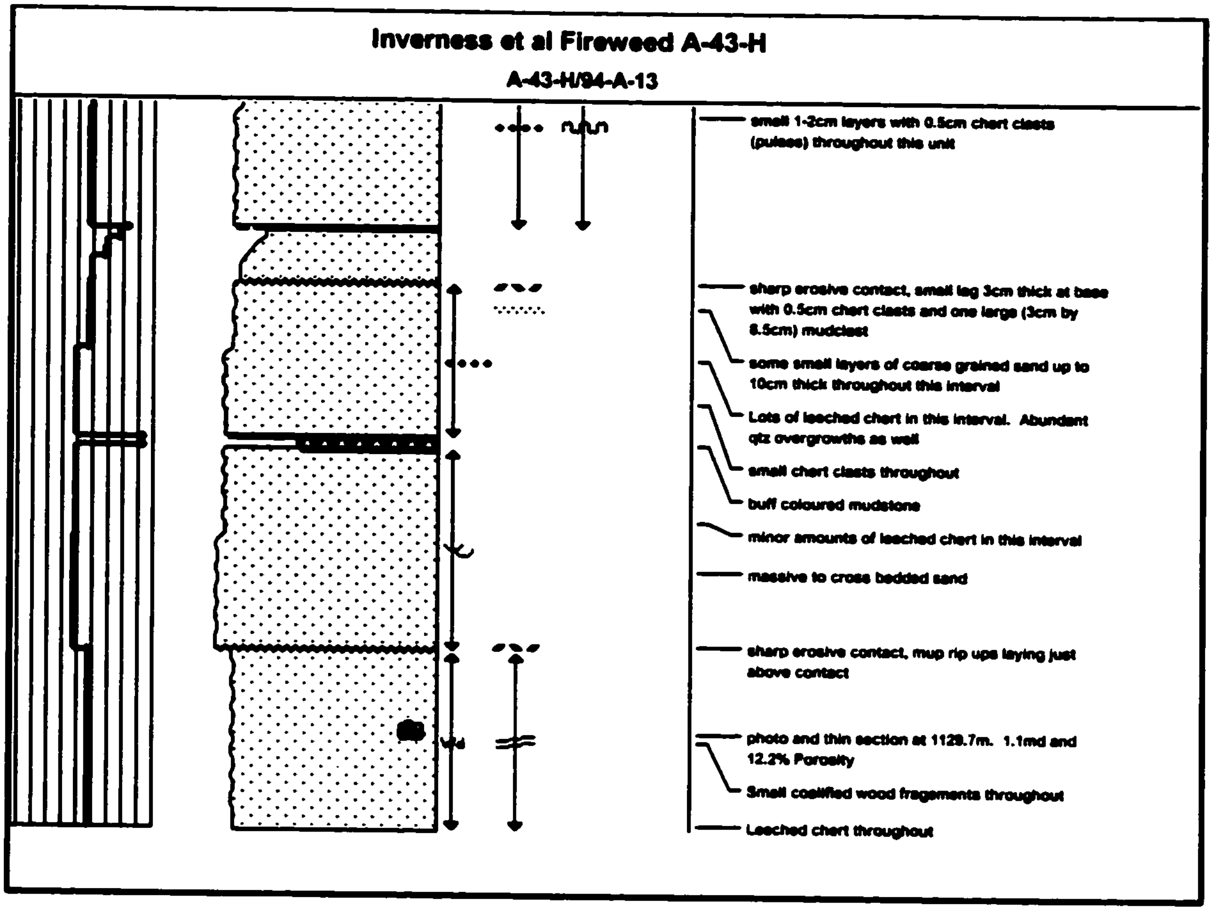
Date Logged: May 12, 1998

Logged by: Eric Hanson

Datum elevation: 718.10 m

Remarks:





Inverness et al Fireweed A-43-H
A-43-H/94-A-13
small 1-2cm layers with 0.5cm chert clasts (pulses) throughout this unit
sharp erosive contact, small lag 3cm thick at base with 0.5cm chert clasts and one large (3cm by 8.5cm) mudclast
some small layers of coarse grained sand up to 10cm thick throughout this interval
Lots of leached chert in this interval. Abundant qtz overgrowths as well
small chert clasts throughout
buff coloured mudstone
minor amounts of leached chert in this interval
massive to cross bedded sand
sharp erosive contact, mup rip ups laying just above contact
photo and thin section at 1129.7m. 1.1md and 12.2% Porosity
Small coalified wood fragments throughout
Leached chert throughout

Amoco Aitken A-29-L

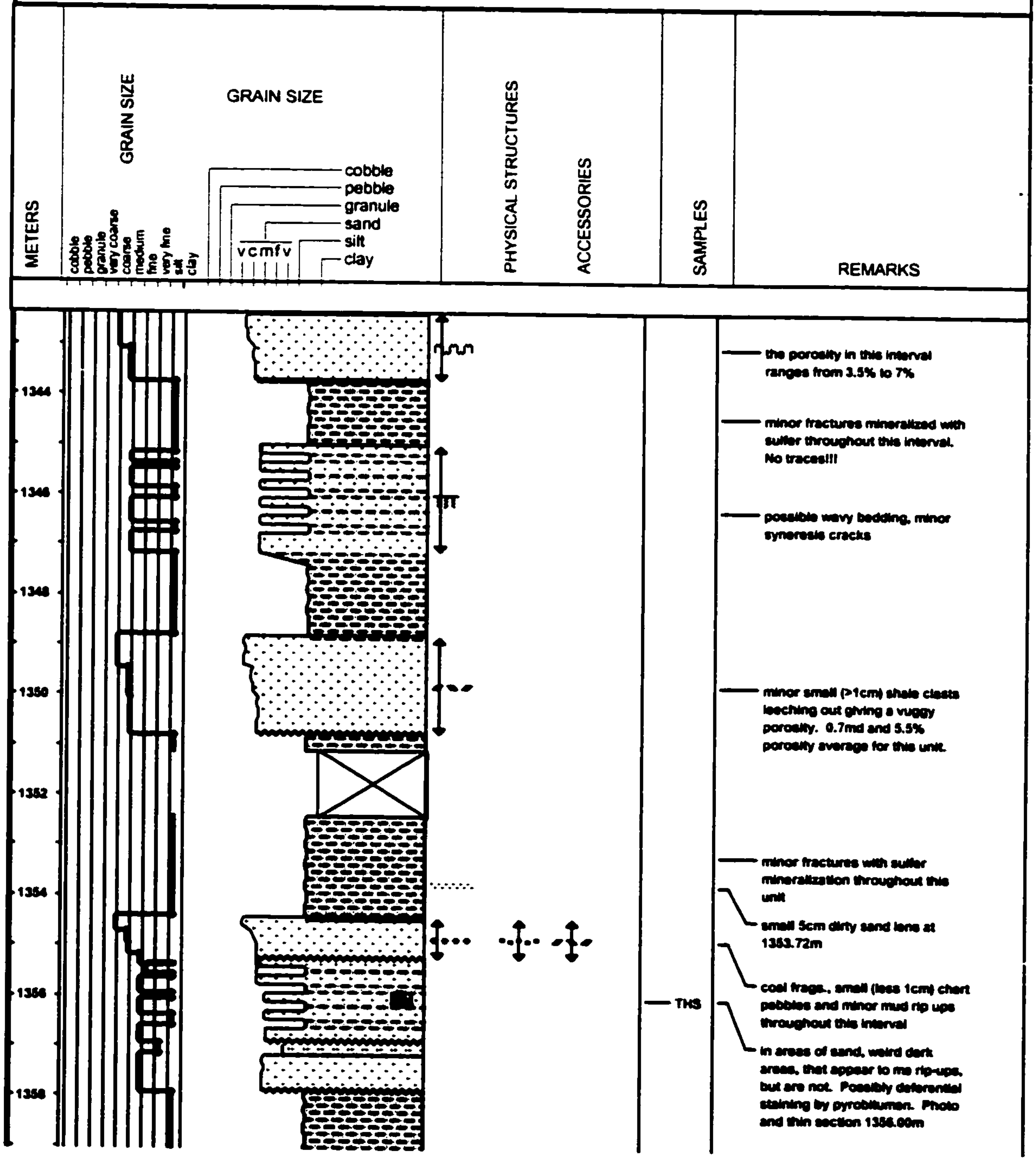
A-29-L/94-A-13

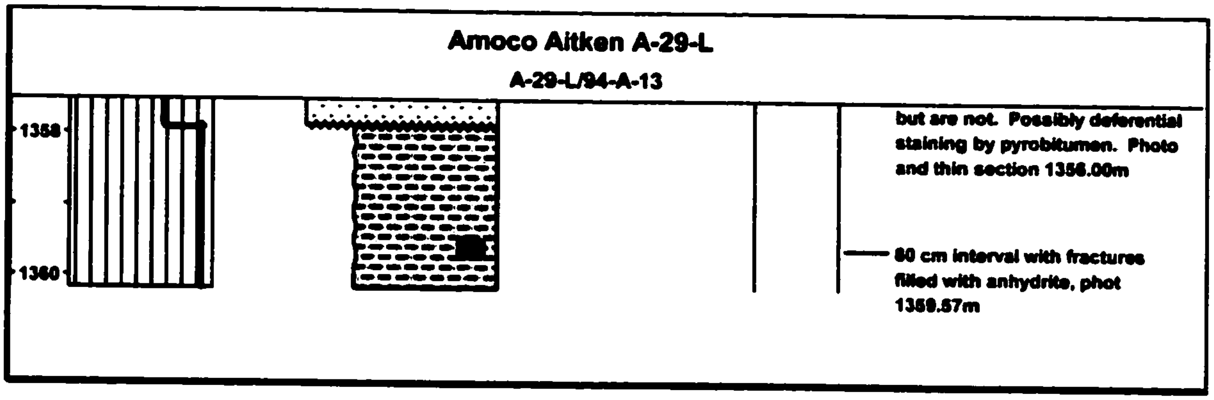
Date Logged: May 12, 1998

Logged by: Eric Hanson

Datum elevation: 0.00 m

Remarks:




Amoco Aitken A-29-L
A-29-L/94-A-13
1358
1360
but are not. Possibly deferential staining by pyrobitumen. Photo and thin section 1356.00m
80 cm interval with fractures filled with anhydrite, phot 1359.57m

Pex Kobes A-20-H

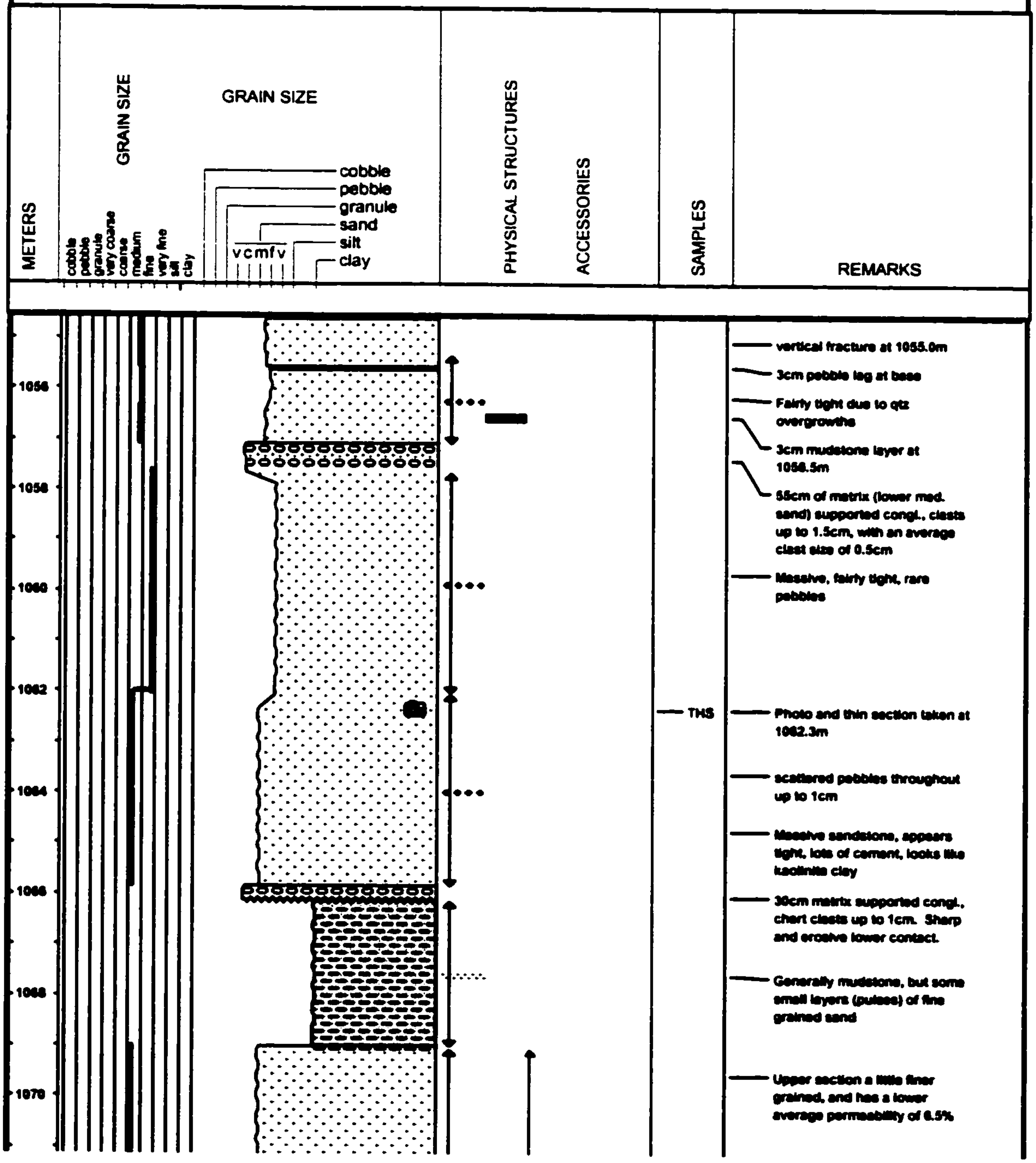
A-20-H/94-B-9

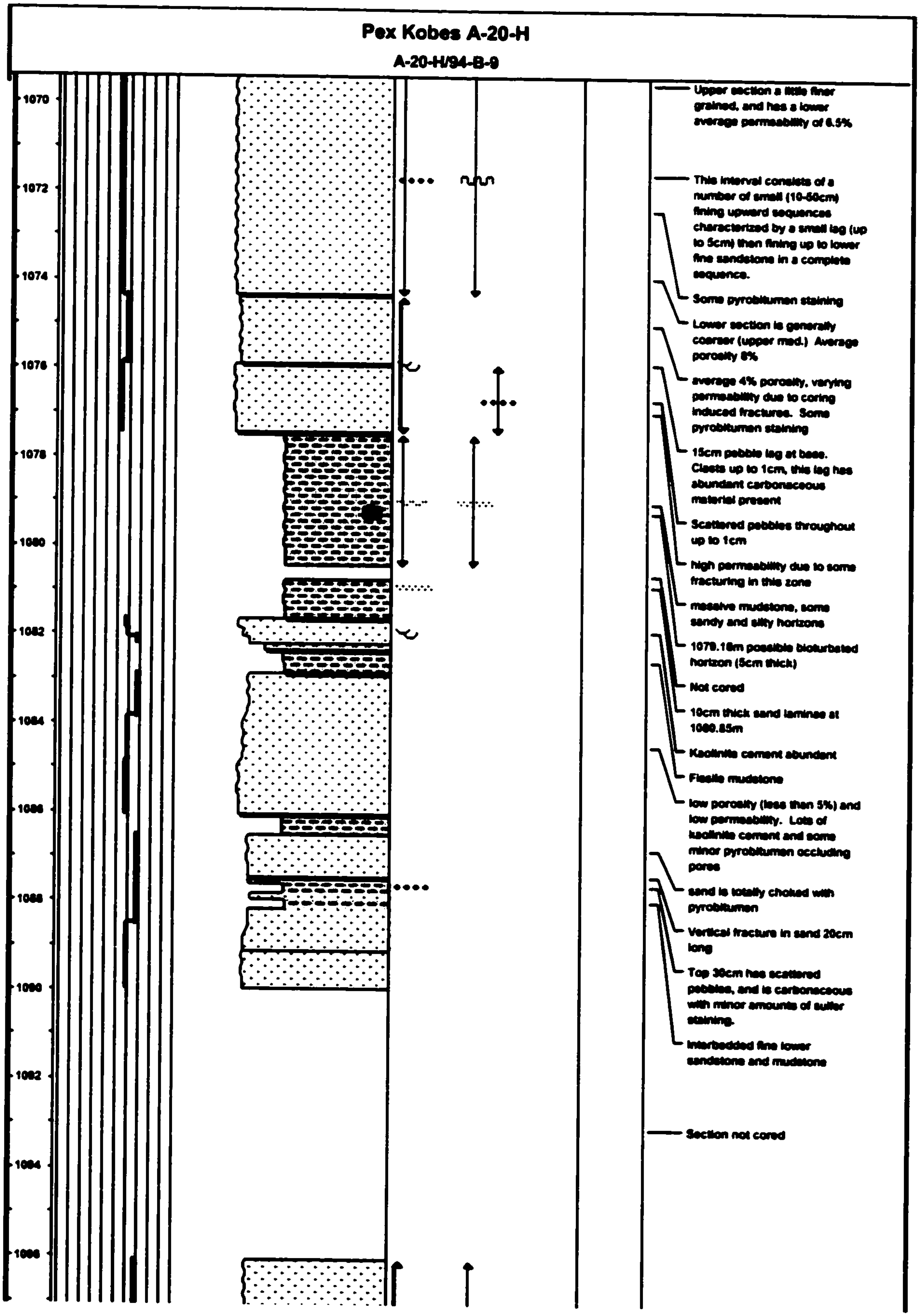
Date Logged: July 16, 1998

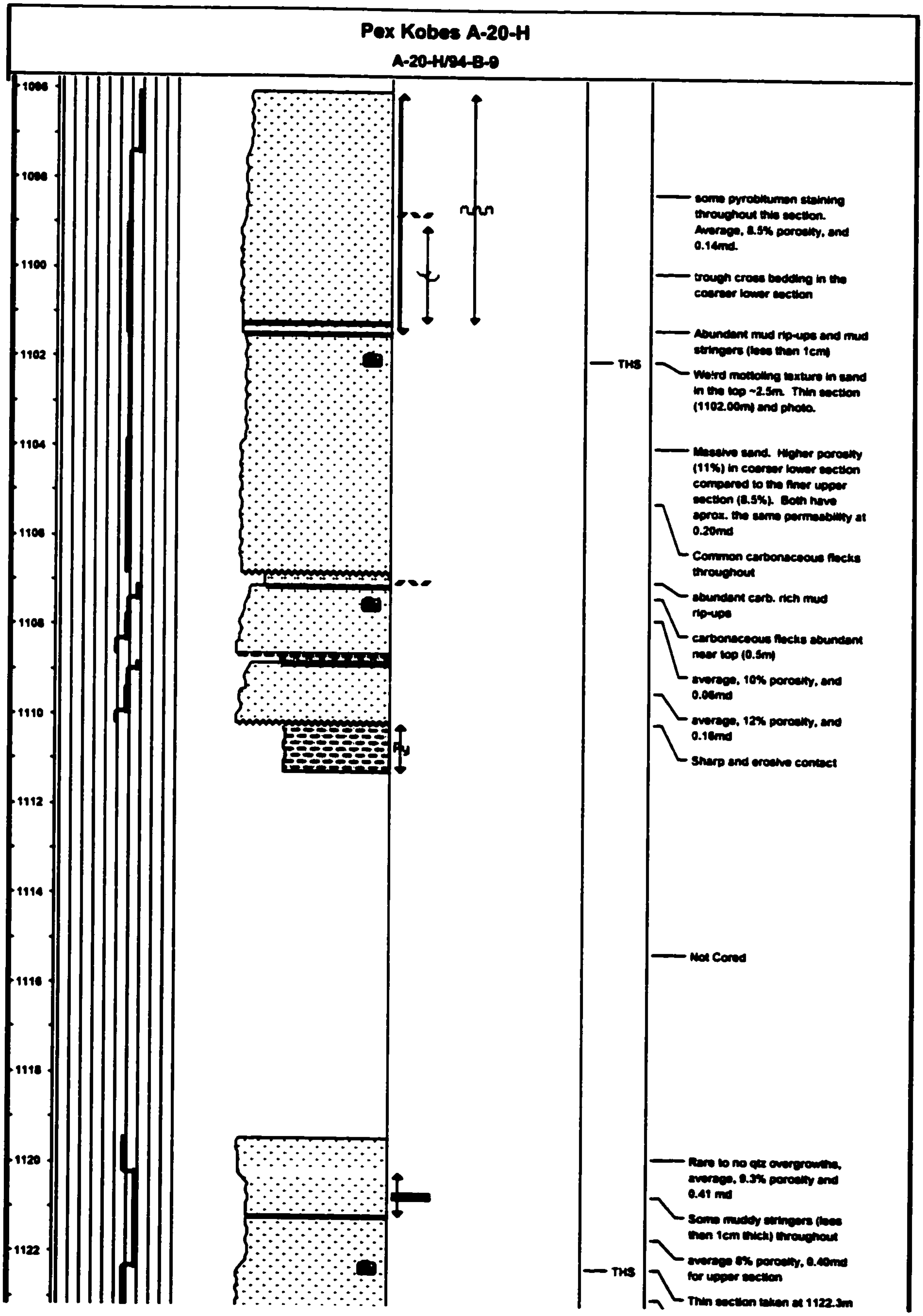
Logged by: Eric Hanson

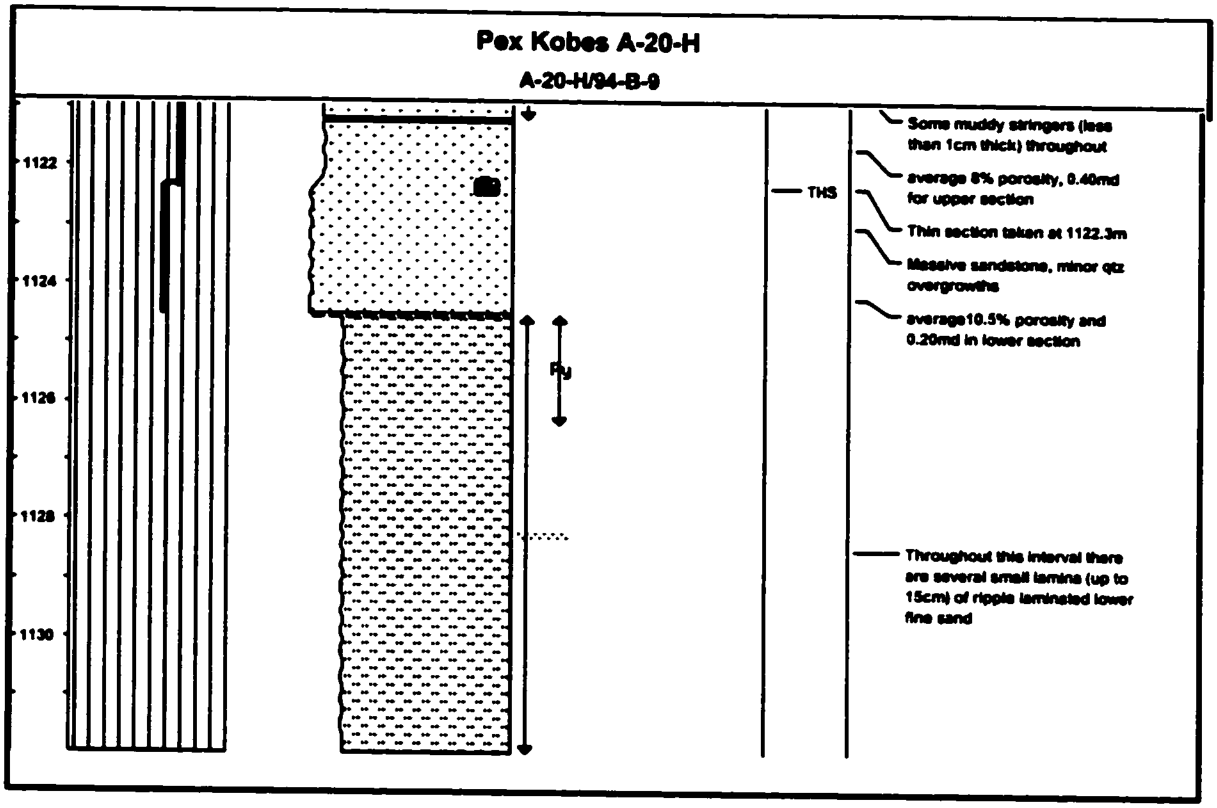
Datum elevation: 777.50 m

Remarks:




Pex Kobes A-20-H
A-20-H/94-B-9
1070
1072
1074
1076
1078
1080
1082
1084
1086
1088
1090
1092
1094
1096
Upper section a little finer grained, and has a lower average permeability of 6.5%
This interval consists of a number of small (10-50cm) fining upward sequences characterized by a small lag (up to 5cm) then fining up to lower fine sandstone in a complete sequence.
Some pyrobitumen staining
Lower section is generally coarser (upper med.) Average porosity 8%
average 4% porosity, varying permeability due to coring induced fractures. Some pyrobitumen staining
15cm pebble lag at base. Clasts up to 1cm, this lag has abundant carbonaceous material present
Scattered pebbles throughout up to 1cm
high permeability due to some fracturing in this zone
massive mudstone, some sandy and silty horizons
1079.18m possible bioturbated horizon (5cm thick)
Not cored
10cm thick sand laminae at 1080.85m
Kaolinite cement abundant
Fissile mudstone
low porosity (less than 5%) and low permeability. Lots of kaolinite cement and some minor pyrobitumen occluding pores
sand is totally choked with pyrobitumen
Vertical fracture in sand 20cm long
Top 30cm has scattered pebbles, and is carbonaceous with minor amounts of sulfer staining.
Interbedded fine lower sandstone and mudstone
Section not cored


Pex Kobes A-20-H
A-20-H/94-B-9
1096
1098
1100
1102
1104
1106
1108
1110
1112
1114
1116
1118
1120
1122
THS
THS
some pyrobitumen staining throughout this section. Average, 8.5% porosity, and 0.14md.
trough cross bedding in the coarser lower section
Abundant mud rip-ups and mud stringers (less than 1cm)
Weird mottling texture in sand in the top ~2.5m. Thin section (1102.00m) and photo.
Massive sand. Higher porosity (11%) in coarser lower section compared to the finer upper section (8.5%). Both have aprox. the same permeability at 0.20md
Common carbonaceous flecks throughout
abundant carb. rich mud rip-ups
carbonaceous flecks abundant near top (0.5m)
average, 10% porosity, and 0.06md
average, 12% porosity, and 0.16md
Sharp and erosive contact
Not Cored
Rare to no qtz overgrowths, average, 9.3% porosity and 0.41 md
Some muddy stringers (less than 1cm thick) throughout
average 8% porosity, 0.40md for upper section
Thin section taken at 1122.3m


Pex Kobes A-20-H
A-20-H/94-B-9
1122
1124
1126
1128
1130
THS
Some muddy stringers (less than 1cm thick) throughout
average 8% porosity, 0.40md for upper section
Thin section taken at 1122.3m
Massive sandstone, minor qtz overgrowths
average10.5% porosity and 0.20md in lower section
Throughout this interval there are several small lamina (up to 15cm) of ripple laminated lower fine sand

Fargo et al Halfway No. 2

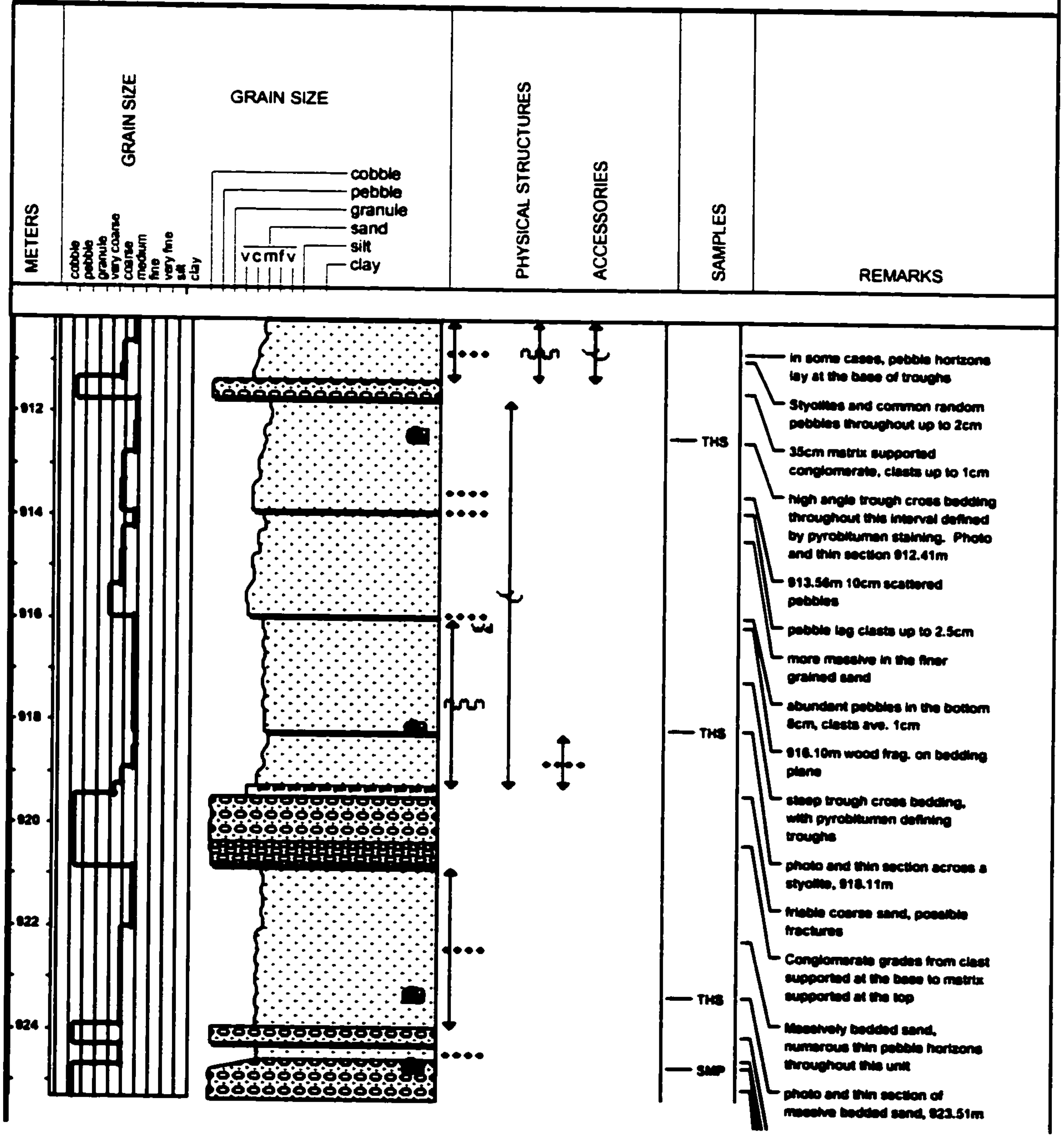
6-23-87-25w6

Date Logged: November 24, 1998

Logged by: Eric Hanson

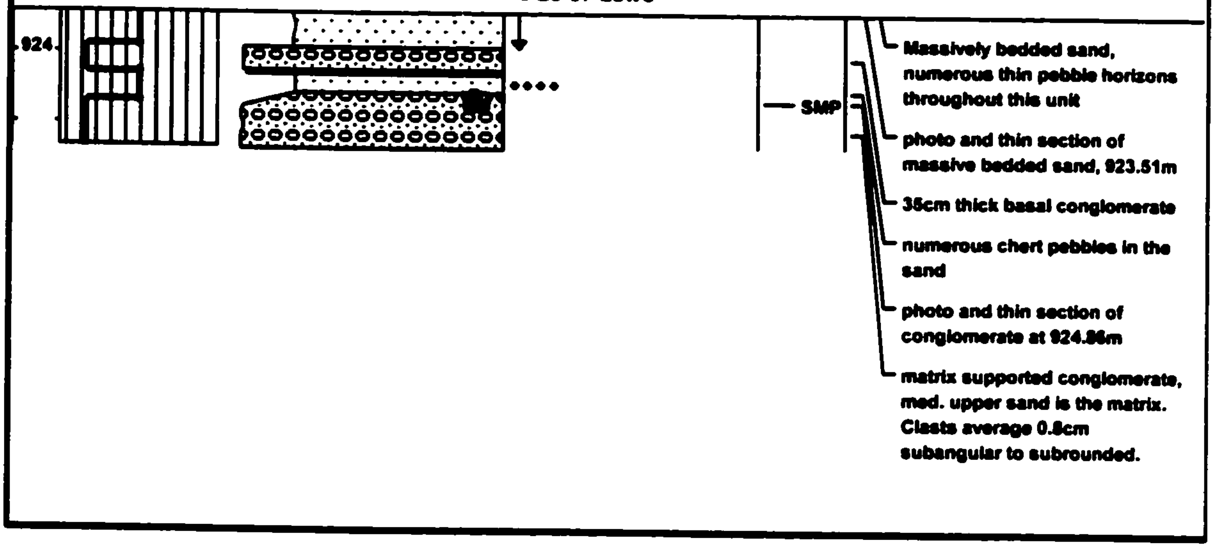
Datum elevation: 667.50 m

Remarks:



Fargo et al Halfway No. 2

6-23-87-25w6



Saba et al Halfway

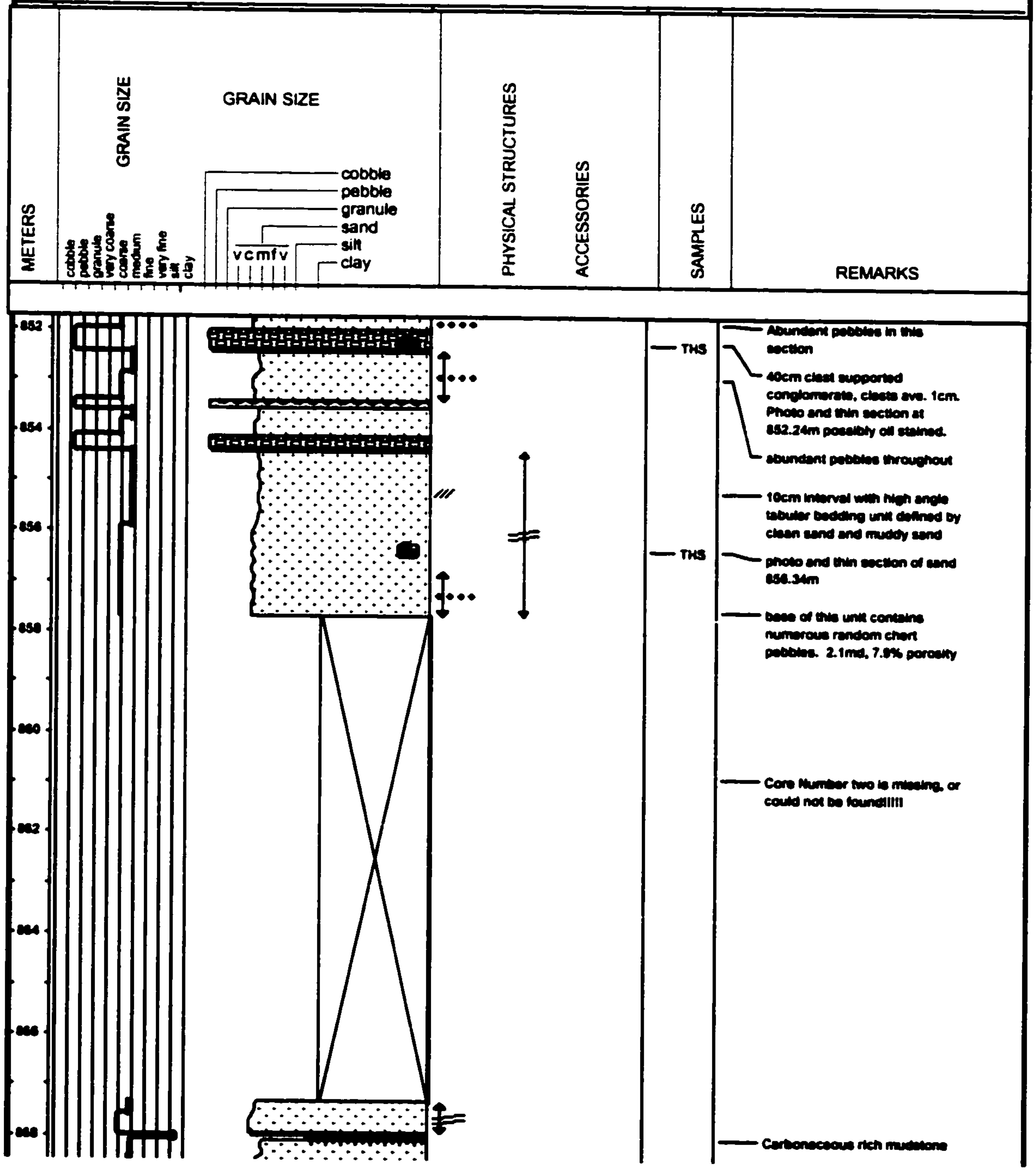
5-01-87-25w6

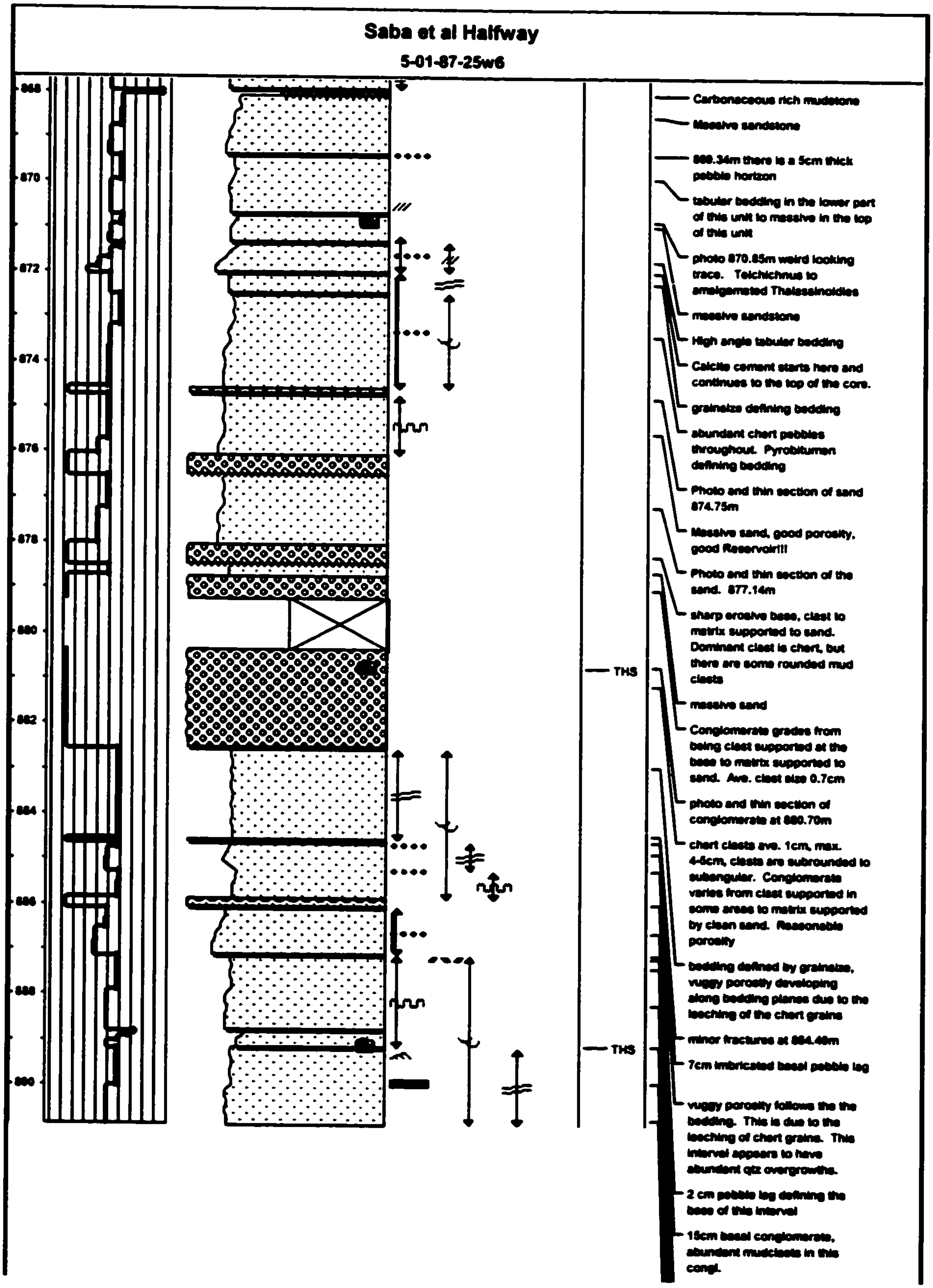
Date Logged: November 23, 1998

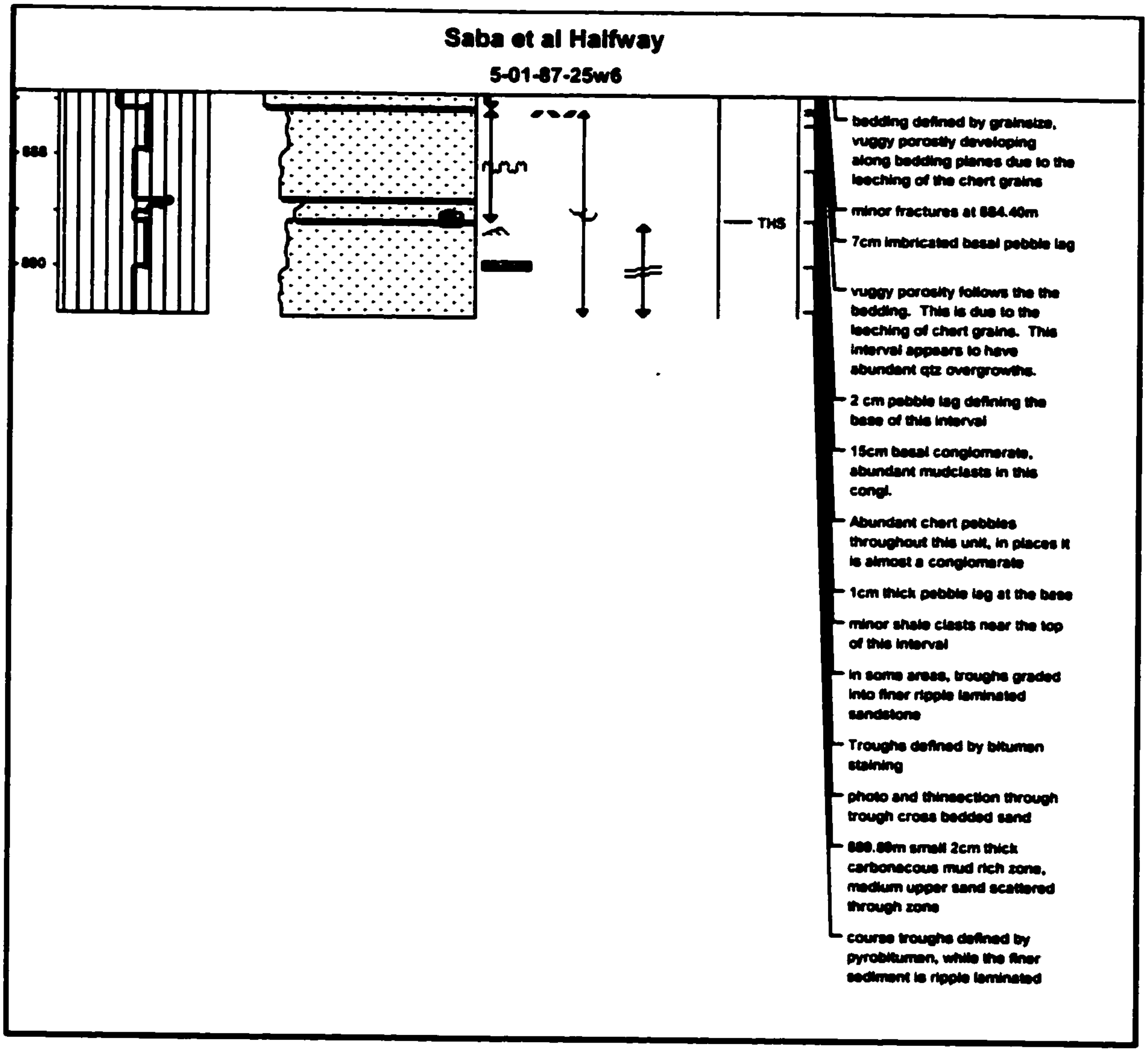
Logged by: Eric Hanson

Datum elevation: 723.90 m

Remarks:




Saba et al Halfway
5-01-87-25w6
868
870
872
874
876
878
880
882
884
886
888
890
THS
THS
Carbonaceous rich mudstone
Massive sandstone
888.34m there is a 5cm thick pebble horizon
tabular bedding in the lower part of this unit to massive in the top of this unit
photo 870.85m weird looking trace. Teichichnus to amalgamated Thalassinoidies
massive sandstone
High angle tabular bedding
Calcite cement starts here and continues to the top of the core.
grainsize defining bedding
abundant chert pebbles throughout. Pyrobitumen defining bedding
Photo and thin section of sand 874.75m
Massive sand, good porosity, good Reservoir!!!
Photo and thin section of the sand. 877.14m
sharp erosive base, clast to matrix supported to sand. Dominant clast is chert, but there are some rounded mud clasts
massive sand
Conglomerate grades from being clast supported at the base to matrix supported to sand. Ave. clast size 0.7cm
photo and thin section of conglomerate at 880.70m
chert clasts ave. 1cm, max. 4-6cm, clasts are subrounded to subangular. Conglomerate varies from clast supported in some areas to matrix supported by clean sand. Reasonable porosity
bedding defined by grainsize, vuggy porosity developing along bedding planes due to the leaching of the chert grains
minor fractures at 884.46m
7cm imbricated basal pebble lag
vuggy porosity follows the the bedding. This is due to the leaching of chert grains. This interval appears to have abundant qtz overgrowths.
2 cm pebble lag defining the base of this interval
15cm basal conglomerate, abundant mudclasts in this congl.


Saba et al Halfway
5-01-87-25w6
THS
bedding defined by grainsize, vuggy porosity developing along bedding planes due to the leeching of the chert grains
minor fractures at 884.40m
7cm imbricated basal pebble lag
vuggy porosity follows the the bedding. This is due to the leeching of chert grains. This interval appears to have abundant qtz overgrowths.
2 cm pebble lag defining the base of this interval
15cm basal conglomerate, abundant mudclasts in this congl.
Abundant chert pebbles throughout this unit, in places it is almost a conglomerate
1cm thick pebble lag at the base
minor shale clasts near the top of this interval
In some areas, troughs graded into finer ripple laminated sandstone
Troughs defined by bitumen staining
photo and thinsection through trough cross bedded sand
889.89m small 2cm thick carbonecous mud rich zone, medium upper sand scattered through zone
course troughs defined by pyrobitumen, while the finer sediment is ripple laminated

APPENDIX II

Thin Section Descriptions

Thin section descriptions were made on 104 samples taken from Lower Cretaceous strata from the following wells:

B-82-I/94-B-8
D-94-I/94-B-8
B-90-K/94-B-8
B-24-A/94-B-9
B-35-A/94-B-9
C-56-A/94-B-9
A-20-H/94-B-9
D-82-I/94-B-9
A-08-H/94-B-16
B-62-H/94-B-16
B-03-I/94-B-16
D-71-B/94-A-13
C-84-B/94-A-13
A-50-E/94-A-13
A-83-E/94-A-13
D-31-G/94-A-13
D-55-G/94-A-13
C-81-G/94-A-13
C-18-H/94-A-13
A-43-H/94-A-13
D-55-H/94-A-13
A-29-L/94-A-13
15-14-86-25w6
5-1-87-25w6
6-23-87-25w6
10-8-88-25w6
3-9-88-25w6
10-11-88-25w6
2-20-88-25w6
6-21-88-25w6
Peace River Canyon Sample

b-82-I/94-B-8

<u>897.57m</u> - Lithic arenite
- Trace Glauconite
- Chert dominant compared to argillaceous clasts
- Moderate leaching of rock fragments
- Porosity developed where chert and quartz make the pores
- Cadomin Formation

<u>862.40m</u> - Lithic arenite→ more chert than quartz
- Trace Glauconite, trace muscovite, trace carbonate grains
- Porosity developed where chert and quartz make the pores
- Common argillaceous grains
- Good porosity

d-94-I/94-B-8

<u>867.27m</u> - Lithicarenite to a sublitharenite
- Layering defined by quartzose layers and chert/argillaceous rich layers
- Quartz rich layers contain more silica cementation
- Poor porosity, no secondary porosity development
- Lots of compaction in this sample

<u>857.5m</u> - Lithic arenite, quartz grains are more rounded then the chert grains
- Bimodal coarse fraction, subrounded to rounded, this is the lag
- Sand above LAG is a lithic arenite

<u>855.20m</u> - Mottled sand appearance is due to uneven silica cementation (light areas),
less silica cementation and more residual bitumen in the darker areas
- Quartzose sublitharenite
- Poorly sorted, fine to coarse grained
- Chert grains are highly leached

<u>841.62m</u> - Lithic Arenite, sample was point counted
- Barite cement
- Some fine grained sandstone fragments
- Thin clay rims around some chert grains
- Thin film of bitumen surrounding some chert

b-90-K/94-B-8

<u>1161.20m</u> - Lithic arenite, much more chert than argillaceous grains
- Moderate leaching of chert
- Good porosity
- Best porosity developed where chert and quartz makes the pore boundaries

b-24-A/94-B-9

<u>969.55m</u>
- Quartz arenite
- 1-2% chert
- Monteith Formation
- Quartz overgrowths common → major porosity occluder
- Fair porosity
- Minor bitumen staining along grain boundaries
- Poorly sorted, sub-angular to rounded
- Compaction suturing quartz grains together

<u>964.25m</u>
- Pebble LAG
- Glauconite pebbles III
- Both chert and quartz pebbles → more chert
- Minor to rare secondary porosity development in the cherts
- Litharenite
- Fossiliferous chert observed
- No bitumen or clays occluding porosity
- Cadomin Formation

<u>955.54m</u>
- Litharenite
- Barite cement → appears to be after silica cement and compaction
- Porosity created by quartz chert contacts
- Glauconite IIII
- Lots of quartz overgrowths
- Minor to moderate porosity in some areas, compaction of cherts, silica cement and barite cement destroy porosity
- Rare secondary porosity
- No clay or bitumen

<u>951.75m</u>
- Litharenite, 50% quartz
- Glauconite IIII
- Minor muscovite flakes
- Bitumen staining of cherts (destroying secondary porosity) and staining of clays
- Minor leeching of chert
- Dolomite and/or limestone clasts observed (5-10% of rock)
- Minor porosity
- Fine grained

<u>939.80m</u>
- Litharenite
- Glauconite II
- More chert then quartz
- Rare mica flakes
- Rare small limestone grains (II seen)
- Fair porosity
- Some fine clay rims around quartz grains preventing quartz overgrowths

b-35-A/94-B-9

<u>1088.69m</u> - Quartz arenite, subrounded to rounded moderately sorted dominantly upper

medium to lower coarse grained

- Lots of quartz overgrowths → excellent examples
- Bitumen staining chert filling microporosity and staining clays
- Moderate porosity ~ 8-10%

<u>1086.86m</u> - poorly sorted very fine sand to pebbles in a matrix of silty shale

- No porosity, clay matrix is strongly bitumen stained
- Minor chert pebbles

<u>1084.33m</u> - Quartzose sublithareniteto to quartz arenite

- Minor mica flakes
- Minor clays (bitumen stained) coating quartz grains
- Some secondary porosity development in chert (minor)

<u>1057.39m</u> - Lithic arenite Cadomin formation

- Rare (<1%) small limestone grains
- Lots of microporosity developed in the leached chert grains
- Glauconite grains I
- Point count preformed on this sample

<u>1045.99m</u> - Quartzose lithic arenite, border line with sublitharenite, to lithic arenite

- No secondary porosity development
- Chert, impure chert, and argillaceous clasts, high variety of rock fragments
- Some low grade metamorphic clasts and mica flakes
- Silty argillaceous grains make this sample susceptible to compaction

c-56-A/94-B-9

<u>1135.00m</u> - Quartz arenite (Minnes Group)

- Moderately well to well sorted subangular to rounded mid- to upper fine grained
- Interstitial bitumen stains the clays

<u>1090.40m</u> - Lithic arenite (Cadomin)

- well sorted, well rounded upper medium to lower coarse grained chert-quartz sandstone with excellent remnant intergranular porosity preserved where both quartz and chert make up the pore wall
- Good reservoir 11-12% porosity
- Most chert grains are leached and microporous, a minor amount of residual bitumen coats some grain surfaces

a-20-H/94-B-9

1122.30m - moderately sorted lower fine to lower coarse grained quartzarenite/quartzose sublitharenite
- Bitumen staining clays and chert
- Minor muscovite flakes
- Monteith Formation
- Intergranular porosity is strongly reduced by silica cement, close grain packing and suturing of grain contacts along interstitial clays
- Most porosity is micro-porosity in leached clasts and interstitial clays, but some secondary dissolution pores after leached grains and minor remnant reduced intergranular pores are also present

1102.00m - moderately well sorted subangular to rounded, dominantly subrounded, mid-fine to mid-medium grained quartzarenite with interstitial mixed-layer illitic clay stained by bitumen
- Kaolinite clay filling pores (moderate amount)
- Muscovite flakes are present (rare)
- Clays have prevented formation of extensive quartz overgrowth development in some areas of the sample, but clays have also promoted chemical compaction and suturing of grain boundaries
- Mottled texture due to areas of intense silica cement (light coloured) and bitumen stained clays and filling pores (dark areas)

1073.24m - moderately well sorted mid to uppper medium grained, Chert arenite
- Minor secondary porosity development
- Rare fine carbonate grains
- Cadomin Formation
- Minor pyrobitumen
- Reduction of intergranular porosity where chert makes up all of the pore wall by close grain packing and suturing of grain contacts

1062.30m - Bimodal moderately sorted mid-fine to mid-medium grained chert litharenite matrix with scattered coarse sand to pebble sized chert
- Intergranular porosity is often preserved where both quartz and chert make up the pore walls
- Some reduced intergranular porosity is filled or lined by pyrobitumen
- Chert is generally leached and microporous
- Trace leached glauconite, trace detrital dolomite, trace corroded dolomite rhombs, trace pore filling calcite cement
- Pores are occluded by silica cement where quartz makes up all of the pore wall
- Cadomin Formation

d-82-I/94-B-9

<u>1268.65m</u> - Sublitharenite
- Good porosity, possibly due to grain plucking
- Argillaceous grains as common as chert
- High amount of leaching of rock fragments

<u>1241.28m</u> - Quartz arenite to quartzose sublitharenite
- Porosity created where grains are leached out
- Poorly sorted
- Some carbonaceous material

<u>1241.04m</u> - Lithic arenite
- Chert 60% argillaceous grains 40% → of the rock fragments
- Minor to no leaching of chert
- Trace Glauconite
- Porosity created where chert and quartz make the pore boundaries
- Cadomin Formation

a-8-H/94-B-16

<u>1347.14m</u> - Poorly to moderately sorted very fine to coarse grained quartzarenite
- Monteith Formation
- Dark layers visible macroscopically are argillaceous and strongly compacted, light colored layers are cleaner and have extensive silica cement.
- Very low porosity

b-62-H/94-B-16

<u>1289.25m</u> - Quartz arenite
- Fair intergranular porosity
- Compaction has sutured quartz grains together destroying porosity
- Minor pyrobitumen staining, fine rim around grains

b-3-I/94-B-16

<u>1353.40m</u> - Quartz arenite
- Bimodel → coarse grained and fine grained
- The rare chert that is present is highly leached
- Silica cement and suturing of grains reduces the porosity
- Minor bitumen staining, usually concentrated in the finer grained section

<u>1347.42m</u> - Quartz arenite
- Moderately sorted, fairly strained quartz
- Where rare chert or clays are present they are stained by bitumen

d-71-B/94-A-13

1304.15m
- Quartzose Sublitharenite
- 12.3% porosity, from core analysis
- High amount of leaching of rare chert grains
- Moderate quartz overgrowths
- Monteith Formation

1285.78m
- Quartz arenite, coarse grained, moderately well to well sorted
- High effective porosity, good reservoir
- Minor quartz overgrowths
- Minor bitumen staining
- Good intergranular porosity
- Monteith Formation

c-84-B/94-A-13

1283.17m
- Layers and areas that are clean are quartz arenite, other areas that are dirty and are sublitharenite
- Dirty areas have abundant interstial clays, and clay along grain boundaries
- Fine grained
- Gething Formation
- Trace muscovite

a-50-E/94-A-13

1396.60m
- Quartz arenite
- Intense silica cementing
- Clay rims around quartz grains
- The bedding is defined by the bitumen staining of the clays

1394.45m
- This section is quite dirty → a fair amount of clay between grains, moderately stained with pyrobitumen
- Sublitharenite → who knows what formation
- Wavy appearance created by two things → bitumen staining of the finer grained sections (dark layers) and silica cementing other layers (light layers)
- No porosity → either silica cemented shut or clays and bitumen filling pores

1382.60m
- Quartzose sublitharenite
- Chert here is highly leached, some pores are created by the total leeching of the chert grains
- Primary porosity reduced by silica cement and bitumen plugging
- This could be the basal section of the Cadomin, then again, it might not be
- Lots of quartz overgrowths

1380.00m - This sample is almost a litharenite
- Minor porosity created by leaching of quartz grains
- Stained clays between quartz grains creates this structure, outside of this it is totally silica cemented

a-83-E/94-A-13

1410.24m - Quartz arenite
- Some intergranular porosity and rare secondary porosity
- Intense quartz overgrowths
- Monteith Formation

d-31-G/94-A-13

1281.10m - Quartz arenite
- Totally bitumen plugged, no porosity
- No quartz overgrowths, few compactional features

1280.50m - Quartz arenite, moderately sorted, subrounded to rounded grains
- fair amount of zircon and tourmaline grains present
- Good porosity
- Minor quartz overgrowths, and more compaction features compared to 1281.10m, this could be due to early oil migration in the lower area???
- Rare argillaceous clasts

1275.95m - Quartz arenite
- Minor interstial clay
- top of slide totally silica cemented, bottom bitumen stained with some silica cementation, no obvious reason for sharp contact
- strained quartz, some type of tectonic activity, some of the quartz grains have been granulated to fine quartz powder
- both top and bottom have ground up quartz
- some compaction features, sutured grains

1274.13m - Quartz arenite
- top part has brownish gold infiltrated clays, most likely kaolinite and mixed layer clays
- clays restrict movement of silica into upper layer
- section as a whole is poorly sorted, upper part is coarser grained
- top of slide totally bitumen stained, bottom of slide totally silica cemented

1273.00m - Quartz arenite, well rounded, moderately sorted
- coarser areas less cemented, 1st cement is calcite so it fills coarser area first, then silica cement can only fill finer grained material, then calcite cement removed by leaching and bitumen in fills newly created porosity
- remenants of some calcite cement preserved

1262.00m - Lithic arenite → looks like the Cadomin, but it is the Gething
- Trace Glauconite
- Moderate bitumen staining of chert and interstial clays
- Porosity developed where chert and quartz make the pore boundaries
- Common argillaceous grains
- Trace carbonate grains

d-55-G/94-A-13

1252.40m - Quartzose sublitharenite
- grain size defining bedding
- Common quartz overgrowths and compaction features
- Argillaceous clasts more abundant than chert
- Some bitumen staining of grains and between grains
- Moderate to good porosity

c-81-G/94-A-13

1225.25m - Lithic arenite → this sample is a bit weird almost no chert but lots of argillaceous grains
- Clay and argillaceous grains are stained by bitumen
- Sample has a fair amount of clay
- Extremely bad thin section → way too thick

1223.03m - Quartz arenite to quartzose sublitharenite
- This sample generally all quartz, but a few larger chert fragments
- High degree of porosity, this could be due to the total leeching of chert, vuggy porosity seen in the core
- Poorly to moderately sorted

1217.62m - Quartz arenite
- Lots of bitumen staining, hard to tell if it is just filling the pores or if it is staining interstistial clays (most likely)
- No quartz overgrowths and minor compactional features
- Dark sample

1217.62m - Quartz arenite to quartzose sublitharenite
- Lots of quartz overgrowths and compactional features
- Minor bitumen between grains
- Monteith Formation
- Light Sample

1212.10m - Quartz arenite, minor chert
- Trace carbonate grain, trace muscovite
- Moderate bitumen staining
- Good intergranular porosity

c-18-H/94-A-13

1247.69m - Quartzose sublitharenite
- Moderate bitumen staining
- Poorly sorted
- Minor quartz overgrowths

1246.18m - Quartz arenite
- Minor carbonaceous material
- Minor quartz overgrowths, compaction has reduced porosity to zero
- Moderate bitumen staining
- Minor quartz overgrowths

1244.61m - Quartz arenite
- Minor quartz overgrowths
- Moderate intergranular porosity
- Monteith Formation

a-43-H/94-A-13

1129.70m - Sublitharenite, argillaceous grains as common as chert
- High degree of leaching of chert and argillaceous grains
- Trace muscovite grains
- Moderate porosity
- Mixed layer clays have prevented quartz overgrowths, in areas of no clay, you get quartz overgrowths

d-55-H/94-A-13

1160.50m - Sublitharenite, argillaceous clasts as common as chert
- Common quartz overgrowths
- Moderate bitumen staining of chert and argillaceous clasts
- Majority of porosity is microporosity

1155.12m - Quartzose sublitharenite, well rounded, good porosity
- Infiltrated clays, geopedal structures present
- Almost no quartz overgrowths, most likely due to clay content
- Bitumen stained clays
- Poor sample, lots of plucking

1143.71m - Quartz arenite
- Poorly sorted → pebble to fine grained
- Calcite cement (moderate)
- Calcite cement must be early, because in areas of calcite cement there are no compactional features
- Minor interstial clay (possibly first because where there is clay there appears to be compaction → clay restricted the calcite cement formation
- Good intergranular porosity

a-29-L/94-A-13

<u>1356.00m</u> - Fine grained sublitharenite
- Dark bands bitumen stained, while the light coloured bands are silica cemented shut
- This does not look like the Cadomin formation
- Some muscovite flakes
- Dirty layers contain more chert

15-14-86-25W6

<u>791.96m</u> - Sublitharenite
- Lots of interstial clay
- Lots of grain plucking in this sample
- Quartz overgrowths and compaction occlude the porosity
- No chert, this is the Minnes group

<u>741.45m</u> - Litharenite, Cadomin formation
- Coarse sand
- Minor quartz overgrowths, bitumen is the major destroyer of porosity
- Porosity greatest where pore is bordered by both chert and quartz
- Glauconite present (trace)
- Moderate secondary porosity development in leached cherts, but with this amount of chert, surprising that it is not higher
- Fossiliferous chert present

<u>736.90m</u> - This sample is on the border between sublitharenite and litharenite
- Lots of silica cement
- Poor porosity due to the amount of silica cement, minor secondary porosity development
- Muscovite flakes observed (trace), small carbonate grains (trace)

<u>734.75m</u> - Litharenite
- Poorly sorted, coarse to fine grained
- Bitumen fills all pore spaces
- This sample is saturated with pyrobitumen → no porosity
- Minor quartz overgrowths
- Fossiliferous chert observed
- Cadomin Formation

<u>730.78m</u> - This sample is muddy, lots of clay, argillaceous clasts, trace Glauconite, minor muscovite, metamorphic rock fragments
- Fine grained
- Litharenite
- No porosity, compaction and the clays have destroyed it all

726.85m - Litharenite 50/50 Quartz/Chert
- Argillaceous grains common
- No porosity, bitumen fills all pores
- Fossiliferous chert present, trace Glauconite, trace muscovite

5-1-87-25W6

889.05m - Sublitharenite (Base Cadomin)
- Moderate pyrobitumen staining
- Chert that is present is highly leeched
- Minor quartz overgrowths, compaction and suturing of grains is the major cause of reduced porosity
- Some argillaceous grains

880.70m - Conglomerate
- Clasts are dominantly chert
- Trace Glauconite grains
- Some contacts of grains are styolitic
- Minor argillaceous grains and clasts
- Moderate leaching of chert grains and clasts
- Matrix is poorly sorted, and quite dirty, fair amount of clay

877.14m - Litharenite
- Thin section poorly made, major plucking of grains
- Minor argillaceous grains, moderate leaching of the chert grains
- Cadomin Formation

874.75m - Litharenite
- Good intergranular porosity
- Best porosity is where chert and quartz make up the pore boundaries
- Minor quartz overgrowths
- Argillaceous grains, chert much more dominant
- In areas of just quartz, the grains are sutured together
- Poor quality of thin section

856.34m - Litharenite 50% chert/50% quartz
- Moderate amount of carbonate grains
- Common argillaceous grains
- Pores largest when the are bordered by both chert and quartz
- Interstial clays are stained by bitumen (Minor)
- Trace Glauconite grains
- Moderated leaching of chert grains
- Some calcite cement → looks like it was before bitumen staining
- Cadomin Formation

852.24m - Chalcedony replacement in a chert grain
- Major calcite cement infilling fractures in chert pebbles, and in matrix to occlude all the porosity
- Conglomerate
- The pebbles are all chert
- The matrix is poorly sorted, consists of quartz, chert, argillaceous grains
- Fair amount of interstitial clay
- Trace Glauconite in matrix

6-23-87-25W6

924.86m - Conglomerate
- Good intergranular porosity, where chert/quartz make pore boundaries
- Fossiliferous chert
- Pebbles are chert, quartz, and argillaceous clasts
- Well sorted matrix, medium grained
- Trace Glauconite
- Chert moderately leached

918.11m - Litharenite 10% argillaceous grains, 40% chert, 50% quartz
- Trace Glauconite, trace carbonate grains
- Pyrobitumen filling of pores, and staining of interstitial clays
- Poor porosity

912.41m - Litharenite Chert (dominant) and argillaceous (minor) clasts
- No porosity due to infilling by calcite cement (lots)
- This sample would have had great porosity if it was not infilled by calcite cement
- Trace Glauconite
- Little to no quartz overgrowths, little compactional features
- Cadomin Formation

889.05m - Litharenite argillaceous clasts (minor) and chert (dominant)
- Medium to coarse grained
- Good porosity, no calcite cement like 912.41m
- Compactional features common as well as quartz overgrowths
- Most pores are lined with chert and quartz
- Chert is moderately leached, some is fossiliferous

10-08-88-25W6

- Litharenite, chert and argillaceous clasts
- Trace Glauconite
- Almost no leaching of chert
- Minor to rare bitumen staining
- Poor porosity
- White blotchy appearance due to areas of high quartz cementation

3-9-88-25W6

<u>1061.51m</u> - Sublitharenite, argillaceous clasts dominate over chert
- This sample comes from an area of mud rip ups
- Porosity created by the removal of argillaceous clasts
- Bits of argillaceous material trapped between quartz grains
- Minor kaolinite cement observed filling some pores

<u>1055.21m</u> - Sublitharenite, almost a lithicarenite, argillaceous clasts dominate over rare chert
- dirty sandstone, lots of interstitial clay
- Bitumen staining, of clay/clay clasts
- No porosity
- Trace muscovite

This sample comes from an area of mud rip ups
- Fossiliferous chert

<u>1051.71m</u> - Quartzose sublitharenite, argillaceous clasts and rare chert
- Minor kaolinite, appears in patches
- Highly leeched argillaceous clasts and chert
- Lots of quartz overgrowths
- Moderate porosity, medium grained
- Moderate bitumen staining

<u>1009.61m</u> - Common interstitial kaolinite
- Quartzose sublitharenite
- Moderate bitumen staining
- Moderate to low porosity

<u>1008.56m</u> - Common barite cement
- Sublitharenite, chert more abundant than argillaceous grains
- Trace muscovite grains
- Minor kaolinite
- Moderate porosity, moderate bitumen staining
- Some clay ringing quartz grains, preventing silica cementation

<u>1007.36m</u> - Sublitharenite
- Kaolinite filling pores as well as some mixed layer clays
- Carbonaceous layers, mica flakes concentrated at these layers
- Lots of quartz overgrowths
- Moderate interstitial clay and staining by bitumen

<u>1005.11m</u> - Poorly sorted – fine to coarse grained
- Moderate bitumen staining throughout
- Sublitharenite
- White blotch in photo created by coarse grained quartz with minimal pyrobitumen staining in that area
- Common kaolinite throughout this sample
- Trace muscovite
- Kaolinite and pyrobitumen are the major reducers of porosity

1002.41m - Sublitharenite, poorly sorted
- Normally graded beds → coarse to fine grained
- Argillaceous clasts as common as chert
- Coarse grained layers totally silica cemented
- Kaolinite moderate to common, bitumen staining of clays

1001.70m - Conglomerate – clast supported
- Dominant clasts are chert
- Trace Glauconite
- No porosity
- Cadomin Formation

10-11-88-25W6

1346.70m - Chert rich conglomerate, Cadomin Formation
- Fairly good intergranular porosity, quartz/chert boundaries
- Minor to rare bitumen staining

1343.33m - Lithic arenite, quartz/chert equal, might be a bit more chert
- Trace Glauconite, trace carbonate grains
- Common argillaceous grains
- Compaction has reduced the porosity to almost zero
- Moderate quartz overgrowths

2-20-88-25W6

1102.44m - Quartzose, sublitharenite → more argillaceous clasts than chert
- Lots of quartz overgrowths and suturing of grains
- Minor bitumen staining of interstitial clays and argillaceous clasts
- Some porosity created by total leaching of argillaceous clasts

1096.71m - Quartzose, sublitharenite
- Minor kaolinite cement observed
- Compaction and quartz overgrowths have reduced porosity to almost zero
- Porosity created by the total leeching of chert and argillaceous grains
- Minor bitumen staining of chert and argillaceous grains

1088.99m - Quartz arenite to quartzose sublitharenite
- Common interstitial kaolinite
- Good example that kaolinite comes before the pyrobitumen
- This sample is bimodal in some areas, coarse grains with in-filling around them by fine sand

1083.75m - Sand is a quartz arenite to quartzose sublitharenite
- Pebbles are dominantly quartz, but a few are chert
- Quite a bit of interstitial clay
- Muscovite flakes concentrated along argillaceous seam
- Moderate staining of clays by bitumen

1080.96m - Sublitharenite → argillaceous grains dominant, chert rare
- Trace to rare muscovite
- Common interstitial clay
- Poor porosity due to compaction

1079.56m - Large fossiliferous clast
- Sand is quartz arenite to quartzose sublitharenite
- Almost no porosity in the sand due to suturing of quartz grains
- Minor quartz overgrowth

1079.16m - Matrix is quartz arenite
- big chert pebbles, bimodal sand fraction
- Trace well rounded carbonate grains
- Well leached argillaceous clasts

1074.72m - Quartz arenite
- Poor porosity due to compaction and suturing of grains
- Some minor pyrobitumen in pores

1073.25m - Quartz arenite
- Trace muscovite
- Fine grained to medium
- Bedding defined by the grain size
- Some carbonaceous material, most likely roots
- Minor bitumen in pores
- Poor porosity

1069.35m - Chert rich conglomerate, Cadomin Formation
- Fairly good porosity, but this could be due to plucking
- Clast supported

1067.05m - Lithic arenite, Cadomin
- 10% porosity, looks good
- Porosity development where chert and quartz make pore boundary
- Chert dominant, but some argillaceous grains
- Medium to coarse grained
- Trace Glauconite, minor to rare leaching of chert

1052.92m - Lithic arenite → more chert than quartz
- No porosity due to compaction
- Trace Glauconite
- Common argillaceous grains fine grained
- Cadomin Formation

6-21-88-25W6

1166.80m - Lithic arenite
- Trace Glauconite, trace muskovite, trace metamorphic rock fragments
- Common argillaceous grains
- Good porosity development where both quartz and chert make the pore boundaries
- Some areas of intense pressure solution

<u>1160.28m</u> - Lithic arenite

- Rare to minor carbonate grain (quite a bit of carbonate material compared to other sections)
- Trace Glauconite, trace muscovite grains
- Moderate argillaceous grains
- Most porosity due to the total leaching of chert grains

<u>1159.06m</u> - Lithic arenite (sand)

- Pebbles are chert and quartz
- No difference between sand below contact and that between the pebbles of chert
- Abundant argillaceous grains
- Trace Glauconite
- No porosity in the sand

<u>1152.60m</u> - Sublitharenite

- Argillaceous clasts more abundant than chert
- Trace muscovite flakes
- Dirty, common clay along grain boundaries
- Moderate bitumen staining of clays
- Fractures are open, no clay in filling

<u>1150.30m</u> - Quartzose sublitharenite

- Argillaceous clasts equal chert
- Minor quartz overgrowths
- Compaction → suturing of grains
- Common leaching of rock fragments
- Clay along grain boundaries, minor bitumen staining
- Zones of crushed quartz
- Some minor filling of fractures by bitumen

Peace River Canyon Sample

<u>Surface Sample taken from Cadomin Formation at Bennett Dam</u>

- Well sorted to moderately well sorted, subangular to rounded, dominantly subrounded (quartz on average better rounded than chert), mid-medium grained litharenite
- Rock fragments are dominantly chert, but impure chert, metamorphic rock fragments, volcanic rock fragments, siliceous argillite, shale and silty shale, and detrital dolomite fragments are also present
- Closely packed, with minor remnant reduced intergranular porosity
- Secondary porosity has formed by partial to complete leaching of unstable clasts. Porosity is often filled by authigenic kaolinite
- Silica cement occludes pores bounded entirely by quartz grains

APPENDIX III

Tops Database

The following is a list of wells with tops that have been picked throughout the study area.

KB - Kelly Bushing
SSCadomin - Sub-Sea Elevation Cadomin Formation
SS B.P. - Sub-Sea Elevation Beattie Peaks Formation
SS Monteith - Sub-Sea Elevation Monteith Formation
IsoCadomin - Isopach thickness (meters) of Cadomin Formation
Isopach B.P. - Isopach thickness (meters) of Beattie Peaks Formation
IsoMonteith - Isopach thickness (meters) of Monteith Formation
NP - Formation Not Penetrated
NA - Formation Not Present
(??) - Questionable Pick

100/10-22-084-25W6/00	720	860	1029.5	NA	1093	1268	1352	1379.8	-309.5	NA	-373	63.5	NA	175
100/12-08-085-25W6/00	717.1	855	1026.5	NA	1083.5	NP	NP	NP	-309.4	NA	-366.4	57	NA	
100/02-12-085-25W6/00	708.3	775.7	912.5	NA	976.5	1126.5	1212.4	1242.3	-204.2	NA	-268.2	64	NA	150
100/08-13-085-25W6/00	671.6	725	860	NA	926.5	1053	1139	1167	-188.4	NA	-254.9	66.5	NA	126.5
100/10-32-085-25W6/00	695.1	877.5	1064	NA	1103	1231	1322	1358	-368.9	NA	-407.9	39	NA	128
100/06-11-086-25W6/00	654.1	724.2	885.1	NA	902.8	1022.6	1111.2	1136.2	-231	NA	-248.7	21	NA	119.8
100/15-14-086-25W6/00	573	586.7	723	NA	763.5	883.3	974.1	999.1	-150	NA	-190.5		NA	119.8
100/07-19-087-24W6/00	839.7	1129.5	1251.5	NA	1284.5	1356	1442	1472	-411.8	NA	-444.8	33	NA	71.5
100/11-31-087-24W6/00	775.1	1013.7	1128.3	NA	1157	1220.4	1295.3	1325.2	-353.2	NA	-381.9	28.7	NA	63.4
100/10-02-087-25W6/00	730.9	795.8	931.4	NA	960.7	1069.2	1152.8	1178	-200.5	NA	-229.8	29.3	NA	108.5
100/16-10-087-25W6/00	751.3	884.5	1028	NA	1050.9	1145.1	1237.4	1263.6	-276.7	NA	-299.6	22.9	NA	94.2
100/09-11-087-25W6/00	736	759	888	NA	923.5	1016	1106.5	1131.5	-152	NA	-187.5	35.5	NA	92.5
100/06-14-087-25W6/00	727	772.5	906.5	NA	934	1029.5	1121	1154	-179.5	NA	-207	27.5	NA	95.5
100/07-22-087-25W6/00	686	822.5	954	NA	981	1071.3	1154	1180	-268	NA	-295	27	NA	90.3
100/06-23-087-25W6/00	671.1	771.7	908.6	NP	NP	NP	NP	NP	-237.5	NP	NP		NP	NP
100/08-36-087-25W6/00	883	1142	1261.5	NA	1295	NP	NP	NP	-378.5	NA	-412	33.5	NA	52+
100/03-06-088-24W6/00	732.3	975.5	1088	NA	1120	1181	1255	1280	-355.7	NA	-387.7	32	NA	61
100/11-19-088-24W6/00	837.9	1102.7	1202.1	NA	1233.2	1281.9	1345.9	1366	-364.2	NA	-395.3	29.5	NA	48.7
100/06-30-088-24W6/00	845.8	1113	1216	NA	1244	1284	NP	NP	-370.2	NA	-398.2	28	NA	40
100/08-01-088-25W6/00	800.7	1055.5	1172.8	NA	1202.1	1264.2	1337.4	1362.4	-372.1	NA	-401.4	29.3	NA	62.1
100/10-04-088-25W6/00	692.8	849.7	974.7	NA	997.3	1069.8	1149.6	1176.5	-281.9	NA	-304.5	22.6	NA	72.5
100/03-09-088-25W6/00	684	850.7	975.9	NA	1001.5	1065.5	NP	NP	-291.9	NA	-317.5	25.6	NA	64
100/10-11-088-25W6/00	918.8	1218.5	1340	NA	1361	1421	1505	1521	-421.2	NA	-442.2	21	NA	60
100/09-13-088-25W6/00	716.6	961	1073	NP	NP	NP	NP	NP	-356.4	NP	NP		NP	NP
100/10-14-088-25W6/00	862.3	1165.5	1280.2	NA	1310	1360.5	1431	1452	-417.9	NA	-447.7	29.8	NA	50.5
100/02-20-088-25W6/00	747.4	930.2	1052.1	NA	1080.2	1133.8	1204.5	1227.1	-304.7	NA	-332.8	31	NA	53.6

100/14-20-088-25W6/00	749.8	928.5	1050	NA	1078	1126	1195	1217	-300.2	NA	-328.2	30	NA	48
100/09-24-088-25W6/00	734.3	966.8	1063.7	NA	1093	1149	1210	1231	-329.4	NA	-358.7	29.3	NA	56
100/06-25-088-25W6/00	722.4	944.8	1053.9	NA	1077.7	1120.4	1185.6	1209	-331.5	NA	-355.3	23.8	NA	42.7
100/14-25-088-25W6/00	727.6	954	1054.6	NA	1077.4	1126.2	1187.7	1206.9	-327	NA	-349.8	22.8	NA	48.8
100/10-26-088-25W6/00	775	1032	1135.5	NA	1158	1210	NP	NP	-360.5	NA	-383	22.5	NA	52
100/12-29-088-25W6/00	764.5	942	1059	NA	1086.5	1128	1198.5	1221	-294.5	NA	-322	31	NA	41.5
200/b-028-D 094-A-05/00	781	930	1125	NA	1196	1413.5	1524.5	1546	-344	NA	-415	71	NA	217.5
200/a-030-L 094-A-05/00	775.1	865.6	1047.9	NA	1093.9	1225.2	1312.4	1356.3	-272.8	NA	-318.8	46	NA	131.3
200/a-023-A 094-B-08/00	779.3	910.7	1115.5	NA	1187.4	1414.2	1539.8	1559.9	-336.2	NA	-408.1	71.9	NA	226.8
200/a-063-A 094-B-08/00	803.7	906	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
200/b-084-A 094-B-08/00	831.6	964	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
200/a-005-B 094-B-08/00	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL
200/d-014-B 094-B-08/00	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL
200/a-081-B 094-B-08/00	970.9	1171.6	1355.1	NA	1401.4	1678.8	1796.7	1859.2	-384.2	NA	-430.5	46.3	NA	277.4
200/b-064-C 094-B-08/00	955.2	415.2	744	811.9	956.6	1239.3	1368.5	1436.5	211.2	143.3	-1.4	67.9	144.7	282.7
200/a-089-E 094-B-08/00	815.6	NA	767	785	1027	1240	1357	1420.5	48.6	30.6	-211.4	18	242	213
200/d-074-F 094-B-08/00	776.7	602.5	886	903.5	940	1276.5	1400	NL	-109.3	-126.8	-163.3	17.5	36.5	336.5
200/c-098-F 094-B-08/00	914.7	708.5	974	984.5	1060	1378.5	1498.5	1553	-59.3	-69.8	-145.3	10.5	75.5	318.5
200/a-061-G 094-B-08/00	776.2	1007	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
200/a-063-G 094-B-08/00	767.2	1002	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
200/b-082-G 094-B-08/00	772.1	994	1170	1180	1229.5	1435	1562	1589	-397.9	-407.9	-457.4	10	49.5	205.5
200/d-093-G 094-B-08/00	772.3	1025.3	1210.6	1234.4	1249.6	NL	NL	NL	-438.3	-462.1	-477.3	23.8	15.2	NL
200/c-014-H 094-B-08/00	773.3	927.2	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
200/d-075-H 094-B-08/00	743.1	938.7	1140.5	NA	1174.9	1338.9	1454.4	1484.3	-397.4	NA	-431.8	34.4	NA	164
200/a-041-I 094-B-08/00	807.4	882	1053.6	NA	1066.7	1220.7	1325.8	1350.2	-246.2	NA	-259.3	13.1	NA	154

200/c-073-I 094-B-08/00	622.4	671	827.8	NA	855.8	997.9	1097	1137	-205.4	NA	-233.4	28	NA	142.1
200/a-083-I 094-B-08/00	612.2	642	802.5	NA	828	966	1067	1093	-190.3	NA	-215.8	25.5	NA	138
200/b-095-I 094-B-08/00	675.4	808	994.2	NA	1011.3	1142.3	1249.6	1272.2	-318.8	NA	-335.9	17.1	NA	131
200/b-004-K 094-B-08/00	773	593.5	860.2	890	926	1276	1402	1452	-87.2	-117	-153	29.8	36	350
200/a-085-K 094-B-08/00	718.9	736	968.5	987	1050	1301.5	1415	1437	-249.6	-268.1	-331.1	18.5	63	251.5
200/a-095-K 094-B-08/00	733.8	730.5	993.5	1017	1037	1284	1391	1435	-259.7	-283.2	-303.2	23.5	20	247
200/d-013-A 094-B-09/00	687.9	948.5	1138.4	NA	1153.9	NP	NP	NP	-450.5	NA	-466	15.5	NA	
200/b-024-A 094-B-09/00	744.3	786.3	939.3	NA	966.2	NP	NP	NP	-195	NA	-221.9	26.9	NA	
200/b-035-A 094-B-09/00	821.4	868.6	1024.7	NA	1049.7	1166.1	1260.6	1289.2	-203.3	NA	-228.3	25	NA	116.4
200/b-046-A 094-B-09/00	850.8	910.5	1052.5	NA	1069.5	1203	1299	1336.5	-201.7	NA	-218.7	17	NA	133.5
200/a-056-A 094-B-09/00	868.6	940	1086	NA	1107.5	1211	1323.5	1361	-217.4	NA	-238.9	21.5	NA	103.5
200/d-057-A 094-B-09/00	867.1	940.6	1086.3	NA	1111.2	1225.2	1320.3	1359.3	-219.2	NA	-244.1	24.9	NA	114
200/a-099-A 094-B-09/00	842.8	949.1	1096.6	NA	1120.4	1239	1328.3	1364.2	-253.8	NA	-277.6	23.8	NA	118.6
200/b-002-C 094-B-09/00	720.2	865	1115.5	1159.1	1166.4	1355.7	1450	1492.2	-395.3	-438.9	-446.2	43.6	7.3	189.3
200/b-014-C 094-B-09/00	682.1	736	948	998	1028.5	1275	1400	1412	-265.9	-315.9	-346.4	50	30.5	246.5
200/a-027-C 094-B-09/00	689.4	715.1	919.5	990	1007	1232	1329	1366	-230.1	-300.6	-317.6	70.5	17	225
200/d-044-C 094-B-09/00	848.6	1074.7	1250.8	1284.1	1319.1	1469.1	1564.5	1630	-402.2	-435.5	-470.5	33.3	35	150
200/b-059-C 094-B-09/00	698.7	745	985	1026	1045	1242	1370	1413	-286.3	-327.3	-346.3	41	19	197
200/c-032-D 094-B-09/00	771.9	713.2	925.3	970.1	NP	NP	NP	NP	-153.4	-198.2	NP	44.8	NP	NP
200/a-092-F 094-B-09/00	1032.9	1389.2	1545.9	NA	1581.8	1675.7	1765	1791.5	-513	NA	-548.9	35.9	NA	93.9
200/a-087-G 094-B-09/00	803.6	999	1141	NA	1155.5	1254	1340	1370	-337.4	NA	-351.9	14.5	NA	98.5
200/a-020-H 094-B-09/00	781.2	910.7	1049.7	NA	1077.7	1171	1273.1	1300	-268.5	NA	-296.5	28	NA	93.3
200/d-057-H 094-B-09/00	702.3	1041	1164	NA	1183	1281.5	1370	1397	-461.7	NA	-480.7	19	NA	98.5
200/d-059-I 094-B-09/00	732.7	1066.1	1187.4	NA	1214.6	1261.8	1330.4	1356.3	-454.7	NA	-481.9	27.2	NA	47.2
200/a-067-I 094-B-09/00	726.7	1070	1194	NA	1218	1254	1325	1347.5	-467.3	NA	-491.3	24	NA	36

200/d-082-I 094-B-09/00	858.6	1124	1231.3	NA	1244.1	1280.7	1343.5	1363.9	-372.7	NA	-385.5	12.8	NA	36.6
200/a-008-J 094-B-09/00	791.4	1022.9	1160.6	NA	1171.9	1281	1360.6	1391	-369.2	NA	-380.5	11.3	NA	109.1
200/c-058-J 094-B-09/00	775.6	1066.5	1214	NA	1229	1309.5	1395	1416	-438.4	NA	-453.4	15	NA	80.5
200/c-029-L 094-B-09/00	842	742	1046.5	1083.8	1214	1323.5	1399	1453.5	-204.5	-241.8	-372	37.3	130.2	109.5
200/b-049-L 094-B-09/00	893.7	819.9	1029.5	1072.8	1252.7	1370	1435.5	1491(??)	-135.8	-179.1	-359	43.3	179.9	117.3
200/c-076-L 094-B-09/00	1067.7	1181	1363	1398.4	1554.7	1669	1735.4	1772.6	-295.3	-330.7	-487	35.4	156.3	114.3
200/a-023-A 094-B-16/00	863.7	1159	1260	NA	1274	1310	1269	1393.5	-396.3	NA	-410.3	14	NA	36
200/b-033-A 094-B-16/00	834.1	1131.5	1227	NA	1238	1273	1337	1360	-392.9	NA	-403.9	11	NA	35
200/a-045-A 094-B-16/00	749.5	1048.2	1144.2	NA	1158.8	1193.2	1254.2	NP	-394.7	NA	-409.3	14.6	NA	34.4
200/b-069-A 094-B-16/00	1017.1	1312.4	1404.4	NA	1414.8	1445.9	1513	1539.2	-387.3	NA	-397.7	10.4	NA	31.1
200/a-076-A 094-B-16/00	795.5	1091.1	1167.3(??)	NA	1186.8(??)	1223.4(??)	1279.2	??	-371.8?	NA	-391.3?	19.5	NA	36.6
200/c-080-A 094-B-16/00	937	1235(??)	1323.4(??)	NA	1342.9(??)	NP	NP	NP	-386.4?	NA	-405.9?	19.5	NA	
200/b-097-A 094-B-16/00	888.4	1191.7	1274	NA	1285	1306.3	1368.8	1394.4	-385.6	NA	-396.6	11	NA	21.3
200/d-004-B 094-B-16/00	733.3	972.9	1089.3	NA	1105.8	1175.6	1239.3	1268.5	-356	NA	-372.5	16.5	NA	69.8
202/b-013-B 094-B-16/00	748	980.5	1098	NP	NP	NP	NP	NP	-350	NP	NP		NP	NP
200/a-034-B 094-B-16/00	735.7	978.5	1094	NA	1119	1173.8	1234.8	1262.2	-358.3	NA	-383.3	25	NA	54.8
200/d-035-B 094-B-16/00	762	1014.9	1136.2	NA	1154.5	1213.7	1274	1305.7	-374.2	NA	-392.5	18.3	NA	59.2
200/c-091-B 094-B-16/00	848.3	1149	1231.3	NA	1248.1	1281.3	1342	1356.3	-383	NA	-399.8	16.8	NA	33.2
200/a-007-D 094-B-16/00	1100.6	1164	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
200/c-025-D 094-B-16/00	927.9	869.3	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
200/a-040-D 094-B-16/00	1011.7	1226	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
200/c-056-D 094-B-16/00	977.8	894.2	1166.1(??)	NA	1192.9(??)	1329.5	1406.3	1431.1(??)	-188.3?	NA	-215.1?	26.8	NA	136.6
200/b-065-D 094-B-16/00	1027.4	977	1232.5	NA	1268.1	1395.4	1470.6	1541.8	-205.1	NA	-240.7	35.6	NA	127.3
200/c-098-D 094-B-16/00	1079.5	1082.9	1330.4	NA	1363.6	1485.8	1552	1590.4	-250.9	NA	-284.1	33.2	NA	122.2
200/d-055-E 094-B-16/00	922.9	1131.1	1288	NA	1317.9	1343.5	1402	1436.8	-365.1	NA	-395	29.9	NA	25.6

200/d-075-E 094-B-16/00	953.1	1159.5	1329.5	NA	NA	1352.8	1421	1458	-376.4	NA	NA	23.3	NA	NA
200/d-059-F 094-B-16/00	844	1322	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
200/d-002-G 094-B-16/00	843.3	1147.8	1226.8	NA	1243.5	1272.8	1333.4	1360	-383.5	NA	-400.2	16.7	NA	29.3
200/c-012-G 094-B-16/00	787.6	1095.4	1180.7	NA	1197.2	1221	1285	1305.1(??)	-393.1	NA	-409.6	16.5	NA	23.8
200/c-057-G 094-B-16/00	829.6	1174	NA	NA	1263	1301	NP	NP	NA	NA	-433.4	NA	NA	38
200/c-089-G 094-B-16/00	978.7	1323	NA	NA	1395	1436	1506	1534	NA	NA	-416.3	NA	NA	41
200/a-008-H 094-B-16/00	943.3	1246.6	1325.8	NA	1342.9	1368.2	1426.4	1452.3	-382.5	NA	-399.6	17.1	NA	25.3
200/b-061-H 094-B-16/00	956.3	1260	NA	NA	1327	1357	1411.8	1436.5	NA	NA	-370.7	NA	NA	30
200/c-062-H 094-B-16/00	953.3	1241.5	NA	NA	1306	1336	1389	1413	NA	NA	-352.7	NA	NA	30
200/a-083-H 094-B-16/00	977.4	1258	NA	NA	1314	1361	1411	1436.5	NA	NA	-336.6	NA	NA	47
200/b-087-H 094-B-16/00	966.7	1307.5	NA	NA	1369	1404	1459	1484	NA	NA	-402.3	NA	NA	35
200/d-094-H 094-B-16/00	975.6	1251.5	NA	NA	1310	1347.5	NP	NP	NA	NA	-334.4	NA	NA	37.5
200/c-004-I 094-B-16/00	1013.5	1290	NA	NA	1352	1379	1431.2	1458	NA	NA	-338.5	NA	NA	27
200/a-015-I 094-B-16/00	1015.4	1295	NA	NA	1352.5	NP	NP	NP	NA	NA	-337.1	NA	NA	
200/b-025-I 094-B-16/00	1016.5	1299.6	NA	NA	1363.6	1384.9	1434	1459.4(??)	NA	NA	-347.1	NA	NA	21.3
200/d-026-I 094-B-16/00	1028	1312	NA	NA	1370.5	1395.5	1446	1471.5	NA	NA	-342.5	NA	NA	25
200/b-036-I 094-B-16/00	990.3	1291.1	NA	NA	1365.4	1374.6	1415.4	1441.9(??)	NA	NA	-375.1	NA	NA	9.2
200/b-057-I 094-B-16/00	992	1295	1362	NA	NA	1373	1423.5	1444	-370	NA	NA	11	NA	NA
200/a-069-I 094-B-16/00	961.6	1257.5	1346.2	NA	NA	1350.2	1377.6	1404.1	-384.6	NA	NA	4	NA	NA
200/d-071-I 094-B-16/00	981.7	1353.9	NA	NA	NA	1415.4	1455.3	1419.7	NA	NA	NA	NA	NA	NA
202/a-090-I 094-B-16/00	971.1	1275	1357	NA	NA	1367	1385	1411	-385.9	NA	NA	10	NA	NA
202/b-090-I 094-B-16/00	908.5	1204	1292	NA	NA	1299.5	1323.5	NP	-383.5	NA	NA	7.5	NA	NA
200/c-016-J 094-B-16/00	895.5	1210	NA	NA	1319.1	1322.8	1364.2	1390.4	NA	NA	-423.6	NA	NA	3.7
200/c-055-J 094-B-16/00	940	1312.2	1431.5	NA	NA	1450	NP	NP	-491.5	NA	NA	18.5	NA	NA
200/c-069-J 094-B-16/00	949.5	1252.7	1370.3	NA	NA	1383.1	1386.2	1413	-420.8	NA	NA	12.8	NA	NA
200/b-090-J 094-B-16/00	1008	1316.7	1429.4	NA	NA	NA	1450.5	1475.8	-421.4	NA	NA	21.1	NA	NA

200/c-091-J 094-B-16/00	942	1247.5	1324	NA	NA	1343	1359	1386	-382	NA	NA	19	NA	NA
200/b-070-K 094-B-16/00	1038.1	1307.5	1470.9	NA	NA	1491.6	1503.2	1535.8	-432.8	NA	NA	20.7	NA	NA
200/d-091-K 094-B-16/00	1022.1	1331.9	1447.7	NA	NA	NA	1480.6	1493.4	-425.6	NA	NA	32.9	NA	NA
200/d-033-L 094-B-16/00	1065.3	1329.5	1495	NA	NA	1527	1559.3	1594	-429.7	NA	NA	32	NA	NA
200/b-082-L 094-B-16/00	1025.9	1336.8	1492.3	NA	NA	1517.8	1529.7	1563.5	-466.4	NA	NA	25.5	NA	NA
200/c-032-I 094-A-12/00	801.9	1147.2	NA	NA	1231.3	1250.8	1292.3	1310.6	NA	NA	-429.4	NA	NA	19.5
200/b-062-I 094-A-12/00	818.4	1163	NA	NA	1233	1256	1294	1313.5	NA	NA	-414.6	NA	NA	23
200/b-064-I 094-A-12/00	853.2	1197.5	NA	NA	1271.5	1294	1331.5	1350.5	NA	NA	-418.3	NA	NA	22.5
200/d-077-I 094-A-12/00	845	1195	NA	NA	1276	1288	1330	1349	NA	NA	-431	NA	NA	12
200/b-082-I 094-A-12/00	792.4	1129.2	NA	NA	1203.3	1224	1264.9	1284.4	NA	NA	-410.9	NA	NA	20.7
200/d-006-J 094-A-12/00	882.7	1242.9	1321.5	NA	1342.9	1370.3	1424.6	1445.3	-438.8	NA	-460.2	21.4	NA	27.4
200/d-008-J 094-A-12/00	840.3	1212.1	1298.4	NA	1317.9	1335	1392.9	1416.6	-458.1	NA	-477.6	19.5	NA	17.1
200/c-016-J 094-A-12/00	883.3	1251.4	1323.4	NA	1346.5	1373.4	1427	1447.1	-440.1	NA	-463.2	23.1	NA	26.9
200/c-020-J 094-A-12/00	877.8	1253.3	1339.2	NA	1360.6	1386.2	1438.6	1459.9	-461.4	NA	-482.8	21.4	NA	25.6
200/d-028-J 094-A-12/00	894	1268.5	1347.2	NA	1356.3	1378.8	1439.8	1462.4	-453.2	NA	-462.3	9.1	NA	22.5
200/d-042-J 094-A-12/00	784.3	1140.5	NA	NA	1230.7	1251.4	1296.6	1316.1	NA	NA	-446.4	NA	NA	20.7
200/d-049-J 094-A-12/00	896.1	1277.7		NA	1365.4	1380.7	1440.1	1460.2		NA	-469.3		NA	15.3
200/b-075-J 094-A-12/00	777.9	1125	NA	NA	1209(??)	1224(??)	NP	NP	NA	NA	-431.1(??)	NA	NA	15(??)
200/c-094-J 094-A-12/00	803.3	1148.2	NA	NA	1225	1242	NP	NP	NA	NA	-421.7	NA	NA	17
200/c-008-K 094-A-12/00	739.7	961.7	1070	NA	1091	1127.8	1192	1214.3	-330.3	NA	-351.3	21	NA	36.8
200/b-017-K 094-A-12/00	846.6	1125	1233.5	NA	1257	NP	NP	NP	-386.9	NA	-410.4	23.5	NA	33+
200/d-019-K 094-A-12/00	751.9	995.1	1099.1	NA	1120.1	1154.2	1214.3	1235.6	-347.2	NA	-368.2	21	NA	34.1
200/a-029-K 094-A-12/00	800.7	1048.5	1152.7	NA	1180.1	1205.1	1266.7	1289.2	-352	NA	-379.4	27.4	NA	25
200/c-029-K 094-A-12/00	778.5	1027.7	1125.9	NA	1164.9	1179.5	1236.8	1260.9	-347.4	NA	-386.4	39	NA	14.6

202/b-036-K 094-A-12/00	890	1217.5	1315	NA	1335	1357.5	1417.5	1438	-425	NA	-445	20	NA	22.5
200/b-039-K 094-A-12/00	792.5	1038.3	1134	NA	1163	1188.5	1248	1267	-341.5	NA	-370.5	29	NA	25.5
200/d-040-K 094-A-12/00	755	1003.4	1093	NA	1121.9	1152.7	1213.7	1235	-338	NA	-366.9	28.9	NA	30.8
202/b-049-K 094-A-12/00	877.4	1127	1232	NA	1243	1269.2	NP	NP	-354.6	NA	-365.6	11	NA	26.2
202/a-050-K 094-A-12/00	801.7	1048	1157	NA	1179.6	1194	NP	NP	-355.3	NA	-377.9	22.6	NA	14.4
200/d-050-K 094-A-12/00	834.8	1085	1188.7	NA	1205.1	1229.8	1291.4	1311.8(??)	-353.9	NA	-370.3	16.4	NA	24.7
200/b-060-K 094-A-12/00	798	1058.8	1164.9	NA	1182	1200.2	1268.5	1288.6	-366.9	NA	-384	17.1	NA	18.2
202/c-060-K 094-A-12/00	887.8	1155	1250.5	NA	1266	1286.8	1352	1373	-362.7	NA	-378.2	15.5	NA	20.8
200/d-084-K 094-A-12/00	855.5	1227.1	1307.5	NA	1327.6	1346.5	1398.4	1418.5	-452	NA	-472.1	20.1	NA	18.9
200/b-100-K 094-A-12/00	936.3	1262.1	1346.5	NA	1366.4	1391.3	1452	1484.3	-410.2	NA	-430.1	19.9	NA	24.9
200/c-018-L 094-A-12/00	746.7	935.5	1052	NA	1083.7	1119	1184	1206	-305.3	NA	-337	31.7	NA	35.3
200/b-028-L 094-A-12/00	756.1	945	1057	NA	1082.7	1124.7	1192	1215	-300.9	NA	-326.6	25.7	NA	42
200/a-039-L 094-A-12/00	773.4	970	1076.5	NA	1105.5	1149.7	1215.5	1236	-303.1	NA	-332.1	29	NA	44.2
200/d-041-L 094-A-12/00	759.6	1020.4	1129.2	NA	1155.1	1172.2	1238	1259.4	-369.6	NA	-395.5	25.9	NA	17.1
200/c-071-L 094-A-12/00	880.6	1148.4	1250.8	NA	1271	1294.4	1350.8	1370	-370.2	NA	-390.4	20.2	NA	23.4
200/d-082-L 094-A-12/00	853.1	1125.3	1215.2	NA	1239.6	1264.9	1328.9	1349	-362.1	NA	-386.5	24.4	NA	25.3
200/b-092-L 094-A-12/00	806.2	1086.6	1178.3	NA	1196.3	1222.8	1286.8	1307.2	-372.1	NA	-390.1	18	NA	26.5
200/b-010-A 094-A-13/00	818.4	1161.2	NA	NA	1241.4	1255.7	1299	1317.3	NA	NA	-423	NA	NA	14.3
200/d-014-A 094-A-13/00	794.6	1126.5	NA	NA	1193.5(??)	1213(??)	1249.6(??)	1266.6(??)	NA	NA	-398.9(??)	NA	NA	19.5(??)
200/a-021-A 094-A-13/00	813.8	1166.1	NA	NA	1230.7	1258.2	1298.4	1316.1	NA	NA	-416.9	NA	NA	27.5
202/c-024-A 094-A-13/00	810.3	1134.5	NA	NA	1188	1221.5	1262	1280.2	NA	NA	-377.7	NA	NA	33.5
200/b-028-A 094-A-13/00	781.7	1134.5	NA	NA	1211.2	1226	1263.5	1280	NA	NA	-429.5	NA	NA	14.8
200/c-035-A 094-A-13/00	837.8	1162	NA	NA	1206	1243.5	1288	1306.5	NA	NA	-368.2	NA	NA	37.5
200/b-042-A 094-A-13/00	835.5	1163.4	NA	NA	1208.8	1250.8	1292.3	1309.7	NA	NA	-373.3	NA	NA	42
200/c-046-A 094-A-13/00	860.3	1184.8	NA	NA	1231.5	1267.5	1310	1328.8	NA	NA	-371.2	NA	NA	36

200/c-054-A 094-A-13/00	829.8	1164.9	NA	NA	1204.5	1244.1	NP	NP	NA	NA	-374.7	NA	NA	39.6
200/a-069-A 094-A-13/00	842.1	1193	NA	NA	1261.7	1282	1310.5	1327	NA	NA	-419.6	NA	NA	20.3
200/b-077-A 094-A-13/00	864.9	1195	NA	NA	1240	1267.3	1312.4	1331.4	NA	NA	-375.1	NA	NA	27.3
200/d-077-A 094-A-13/00	875.9	1209.1	NA	NA	1261.8	1289.2	1327.3	NP	NA	NA	-385.9	NA	NA	27.4
200/a-081-A 094-A-13/00	832.1	1156.4	NA	NA	1196.6	1242.9	NP	NP	NA	NA	-364.5	NA	NA	46.3
200/a-005-B 094-A-13/00	822.7	1167.3	NA	NA	1246.6	1275.8	1307.5	1325.2	NA	NA	-423.9	NA	NA	29.2
200/a-022-B 094-A-13/00	788.2	1136.8	NA	NA	1202.7	1223.1	1267.9	1289.9	NA	NA	-414.5	NA	NA	20.4
200/d-038-B 094-A-13/00	859.5	1212.5	NA	NA	1288.7	1306	1356.5	1375.8	NA	NA	-429.2	NA	NA	17.3
200/a-047-B 094-A-13/00	804	1148	NA	NA	1224	1242.5	1288	1307	NA	NA	-420	NA	NA	18.5
200/d-053-B 094-A-13/00	811.8	1164.9	NA	NA	1214.9	1249.6	NP	NP	NA	NA	-403.1	NA	NA	34.7
200/d-055-B 094-A-13/00	819	1171.6	NA	NA	1217.3	1261.2	1308.1	1325.8	NA	NA	-398.3	NA	NA	43.9
200/c-058-B 094-A-13/00	865.2	1217.5	NA	NA	1280	1307	1358.5	1378	NA	NA	-414.8	NA	NA	27
200/b-068-B 094-A-13/00	851	1199.9	NA	NA	1252.1	1294.4	NP	NP	NA	NA	-401.1	NA	NA	42.3
200/d-071-B 094-A-13/00	875.6	1225	NA	NA	1276	1312	NP	NP	NA	NA	-400.4	NA	NA	36
200/c-078-B 094-A-13/00	825.7	1178.9	NA	NA	1224	1271	1321.2	1341.1	NA	NA	-398.3	NA	NA	47
200/d-091-B 094-A-13/00	882	1227	NA	NA	1279.3	1306	NP	NP	NA	NA	-397.3	NA	NA	26.7
200/d-100-B 094-A-13/00	882	1234	NA	NA	1277	1320	1369	1390	NA	NA	-395	NA	NA	43
200/b-036-C 094-A-13/00	837.6	1196.3	1274	NA	1288	1305.1	1360.3	1378.8	-436.4	NA	-450.4	14	NA	17.1
200/d-047-C 094-A-13/00	897.6	1256	NA	NA	1316.6	1361.8	1421.2	1439.2(??)	NA	NA	-419	NA	NA	45.2
200/d-052-C 094-A-13/00	855.1	1216.5	NA	NA	1271	1317	NP	NP	NA	NA	-415.9	NA	NA	46
200/c-059-C 094-A-13/00	869.2	1230(??)	NA	NA	1313(??)	NP	NP	NP	NA	NA	-443.8(??)	NA	NA	
200/d-006-D 094-A-13/00	860.5	1207.3	1312.4	NA	1333.4	1355.1	1417.9	1440.4	-451.9	NA	-472.9	21	NA	21.7
200/b-013-D 094-A-13/00	829.4	1120.4	1218.5	NA	1231.9	1250.8	1314.8	1341.1(??)	-389.1	NA	-402.5	13.4	NA	18.9
200/b-024-D 094-A-13/00	931.4	NL	NL	NL	NL	NL	NL	NL	NL	NA	NL	NL	NA	NL
200/c-032-D 094-A-13/00	895.5	1197.8	NA	NA	1291.4	1321.2	1384.3	1403.5	NA	NA	-395.9	NA	NA	29.8

200/b-035-D 094-A-13/00	967.1	1266	1350.2	NA	1377.6	1405.1	1465	1484.5(??)	-383.1	NA	-410.5	27.4	NA	27.5
200/c-041-D 094-A-13/00	945	1290	NA	NA	1371	NP	NP	NP	NA	NA	-426	NA	NA	10+
200/d-046-D 094-A-13/00	943.1	1238.3	1319.7	NA	1341.1	1367	1432.8	1452.3	-376.6	NA	-398	21.4	NA	25.9
203/d-057-D 094-A-13/00	980.9	1282	NA	NA	1359	1411	NP	NP	NA	NA	-378.1	NA	NA	52
200/c-065-D 094-A-13/00	920.8	1192.3	1269.1	NA	1281.6	1306.3	1366.7	1392.6	-348.3	NA	-360.8	12.5	NA	24.7
200/a-072-D 094-A-13/00	932.7	1302.5	NA	NA	1374	1402.5	NP	NP	NA	NA	-441.3	NA	NA	28.5
200/c-076-D 094-A-13/00	959.4	1233	NA	NA	1293	1342.3	1402.2	1425	NA	NA	-333.6	NA	NA	49.3
200/b-095-D 094-A-13/00	957.1	1260.5	NA	NA	1320.2	NP	NP	NP	NA	NA	-363.1	NA	NA	22+
200/a-098-D 094-A-13/00	886.7	1174.9	NA	NA	1242.3	NP	NP	NP	NA	NA	-355.6	NA	NA	25+
200/b-016-E 094-A-13/00	895	1221.5	NA	NA	1275.5	NP	NP	NP	NA	NA	-380.5	NA	NA	40+
200/c-040-E 094-A-13/00	957	1259.4	NA	NA	1344.1	1359.3	1414.2	1439.2	NA	NA	-387.1	NA	NA	15.2
200/a-083-E 094-A-13/00	926	1309.4	NA	NA	1403.2	1413.6	1435	1457.5(??)	NA	NA	-477.2	NA	NA	10.4
200/b-010-F 094-A-13/00	829.3	1205.4	NA	NA	1269.7(??)	1301.1	1355.7	1379.1	NA	NA	-440.4(??)	NA	NA	31.4(??)
202/d-011-F 094-A-13/00	873.7	1230.4	NA	NA	1278	1316.5	1360		NA	NA	-404.3	NA	NA	38.5
200/b-028-F 094-A-13/00	873	1248.5	NA	NA	1298.8	1334	1386	1407.5	NA	NA	-425.8	NA	NA	35.2
200/a-033-F 094-A-13/00	914.7	1270	NA	NA	1319.8	1350.8	1397.4	1420.1(??)	NA	NA	-405.1	NA	NA	31
200/d-079-F 094-A-13/00	875	1249	NA	NA	1303.3	1321.9	1368	1390.7	NA	NA	-428.3	NA	NA	18.6
200/d-097-F 094-A-13/00	912.6	1279	NA	NA	1341	1362	1386	1409	NA	NA	-428.4	NA	NA	21
200/b-004-G 094-A-13/00	884	1235.2	NA	NA	1281.5	1316	1360	NP	NA	NA	-397.5	NA	NA	34.5
200/b-013-G 094-A-13/00	871	1208	NA	NA	1249	1292.5	NP	NP	NA	NA	-378	NA	NA	43.5
200/a-014-G 094-A-13/00	877.8	1221.5	NA	NA	1263	NP	NP	NP	NA	NA	-385.2	NA	NA	5+
200/a-025-G 094-A-13/00	899.9	1248	NA	NA	1290	1326.5	1370	1391	NA	NA	-390.1	NA	NA	36.5
200/d-037-G 094-A-13/00	915	1270.2	NA	NA	1314	1330	NP	NP	NA	NA	-399	NA	NA	16
200/d-053-G 094-A-13/00	816.5	1157	NA	NA	1191.7(??)	1227.7(??)	1266.1	1283.8(??)	NA	NA	-375.2(??)	NA	NA	36(??)
200/d-057-G 094-A-13/00	871.3	1228	NA	NA	1270	1299	1342	1363	NA	NA	-398.7	NA	NA	29
200/a-061-G 094-A-13/00	811.3	1177.7	NA	NA	1221	1235.6	1271	1290.5	NA	NA	-409.7	NA	NA	14.6

200/c-081-G 094-A-13/00	812.3	1174	NA	NA	1210	1241	NP	NP	NA	NA	-397.7	NA	NA	31
200/b-004-H 094-A-13/00	811.7	1151.5	NA	NA	1198.4	1230.1	1260.3	NP	NA	NA	-386.7	NA	NA	31.7
200/b-008-H 094-A-13/00	859.2	1205.7	NA	NA	1260	1279.5	1311.2	1331.9	NA	NA	-400.8	NA	NA	19.5
200/c-016-H 094-A-13/00	810.2	1153	NA	NA	1197.2	1227.7	1262.4	NP	NA	NA	-387	NA	NA	30.5
200/b-022-H 094-A-13/00	751	1083.5	NA	NA	1133.2	1157	1191.1	1210	NA	NA	-382.2	NA	NA	23.8
200/d-039-H 094-A-13/00	829	1177	NA	NA	1226	1244.5	1283	1303	NA	NA	-397	NA	NA	18.5
200/a-043-H 094-A-13/00	722.1	1057	NA	NA	1098.4	1132	1159.4	1178.9	NA	NA	-376.3	NA	NA	33.6
200/d-053-H 094-A-13/00	790.3	1132.6	NA	NA	1173.4	1199.6	1231.3	1250.8	NA	NA	-383.1	NA	NA	26.2
200/b-075-H 094-A-13/00	772.3	1121	NA	NA	1159.5	1188.5	NP	NP	NA	NA	-387.2	NA	NA	29
200/d-077-H 094-A-13/00	769.2	1123.5	NA	NA	1162.8	1187.7	1217	1238.4	NA	NA	-393.6	NA	NA	24.9
200/a-085-H 094-A-13/00	781	1128	NA	NA	1176	1188.7	1220	1239	NA	NA	-395	NA	NA	12.7
200/d-087-H 094-A-13/00	827.7	1175.5	NA	NA	1210.5	1242	1269	1290	NA	NA	-382.8	NA	NA	31.5
202/d-088-H 094-A-13/00	807	1159.8	NA	NA	1193	1222	1246	1270	NA	NA	-386	NA	NA	29
200/b-098-H 094-A-13/00	812.5	1160	NA	NA	1192.5	1223.5	1249	1267	NA	NA	-380	NA	NA	31
200/b-099-H 094-A-13/00	787	1135.3	NA	NA	1168(??)	1196.9(??)	1229(??)	1247.5(??)	NA	NA	-381(??)	NA	NA	28.9(??)
200/b-007-I 094-A-13/00	824.6	1172	NA	NA	1204	1232.8	NP	NP	NA	NA	-379.4	NA	NA	28.8
200/d-009-I 094-A-13/00	785	1144	NA	NA	1186.5	1195	1225	1243	NA	NA	-401.5	NA	NA	8.5
200/c-011-I 094-A-13/00	815.1	1152	NA	NA	1203.5	1220	1225	1242	NA	NA	-388.4	NA	NA	16.5
200/d-018-I 094-A-13/00	791.5	1146.2	NA	NA	1194(??)	1208.9	1230.6(??)	1247.2	NA	NA	-402.5(??)	NA	NA	14.9(??)
200/d-020-I 094-A-13/00	787	1148	NA	NA	NA	1203	1226.5	1251	NA	NA	NA	NA	NA	NA
200/d-029-I 094-A-13/00	823.4	1179.3(??)	NA	NA	NA	1143(??)	1258(??)	1279(??)	NA	NA	NA	NA	NA	NA
200/d-038-I 094-A-13/00	830.2	NL	NL	NA	NL	NL	NL	NL	NL	NA	NL	NL	NA	NL
200/d-040-I 094-A-13/00	796	1155	NA	NA	NA	1216	1248.7(??)	1258	NA	NA	NA	NA	NA	NA
200/a-045-I 094-A-13/00	817	1153	NA	NA	1203.5	1206.4	1225	1246	NA	NA	-386.5	NA	NA	2.9
200/d-049-I 094-A-13/00	803.6	1163	NA	NA	1226.5(??)	1229	1243	1265	NA	NA	-422.9(??)	NA	NA	2.5(??)

200/d-053-I 094-A-13/00	825	1163	NA	NA	1223	1230	1237	1252	NA	NA	-398	NA	NA	7
200/d-059-I 094-A-13/00	808.4	1160.5	NA	NA	1231.8	1236	1243.7(??)	1266.2	NA	NA	-423.4	NA	NA	4.2
200/b-064-I 094-A-13/00	859.5	1184.1	NA	NA	1246.3	1253.9	1270(??)	1278.1	NA	NA	-386.8	NA	NA	7.6
200/d-075-I 094-A-13/00	869.3	1208.5	NA	NA	NA	1266.5	1275	1297.5	NA	NA	NA	NA	NA	NA
200/b-088-I 094-A-13/00	844.2	1182.5	NA	NA	NA	1163.5	1269	1289	NA	NA	NA	NA	NA	NA
200/b-001-J 094-A-13/00	821.5	1182	NA	NA	1221.5	1233	1268.6(??)	1285	NA	NA	-400	NA	NA	11.5
200/b-002-J 094-A-13/00	791.6	1156.3	NA	NA	1201	1208.5	1245.6(??)	1261.2	NA	NA	-409.4	NA	NA	7.5
200/d-011-J 094-A-13/00	819.4	1183.3	NA	NA	1234	1250	1265	1286	NA	NA	-414.6	NA	NA	16
200/d-017-J 094-A-13/00	856.1	1222.5	NA	NA	1277.1	1281.9	1308.5(??)	1329.8	NA	NA	-421	NA	NA	4.8
200/d-026-J 094-A-13/00	822.7	1190	NA	NA	1228	1237	1276.3	1297	NA	NA	-405.3	NA	NA	9
200/d-032-J 094-A-13/00	837.4	1203	NA	NA	1271	1280	1292(??)	1305	NA	NA	-433.6	NA	NA	9
200/c-040-J 094-A-13/00	862.9	1222	NA	NA	NA	1303.5	1326(??)	1333	NA	NA	NA	NA	NA	NA
200/d-048-J 094-A-13/00	850	1214.3	NA	NA	1279.9	1292.9	1300(??)	1322.8	NA	NA	-429.9	NA	NA	13
200/d-053-J 094-A-13/00	854	1217.9	NA	NA	1292.3(??)	1302.7	1312.4(??)	1323.4	NA	NA	-438.3(??)	NA	NA	10.4(??)
200/d-066-J 094-A-13/00	852	1215.8	NA	NA	1279	1290	??	??	NA	NA	-427	NA	NA	11
200/a-083-J 094-A-13/00	819.5	1180.1	NA	NA	1239.3	1262.4	1270.3	1280.1	NA	NA	-419.8	NA	NA	23.1
200/a-087-J 094-A-13/00	835.8	1192.3	NA	NA	1254.5	1271.6	1279.2(??)	1294.1	NA	NA	-418.7	NA	NA	17.1
200/d-011-K 094-A-13/00	865.9	1233.6	NA	NA	NA	1303.9	1324.6	1346.2	NA	NA	NA	NA	NA	NA
200/d-051-K 094-A-13/00	824.9	1175	NA	NA	NA	1262.3	1276	1281.3	NA	NA	NA	NA	NA	NA
200/b-064-K 094-A-13/00	837.2	1182	NA	NA	1275.2	1291.1	1299.3(??)	1313.6(??)	NA	NA	-438	NA	NA	15.9
200/b-088-K 094-A-13/00	918.3	1272.8	NA	NA	1378	1385.5	(??)	1389	NA	NA	-459.7	NA	NA	7.5
200/d-004-L 094-A-13/00	934.6	1317.5	NA	NA	1425	1428.5	1438	1463	NA	NA	-490.4	NA	NA	3.5
200/d-021-L 094-A-13/00	942.7	1311.5	NA	NA	1417.5	1421.8	1433.5	1443.5	NA	NA	-474.8	NA	NA	4.3
200/d-023-L 094-A-13/00	927	1303	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/d-024-L 094-A-13/00	960.6	1331.3	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/d-026-L 094-A-13/00	916.2	1292.3	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP

200/d-030-L 094-A-13/00	926.5	1291.1	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/d-033-L 094-A-13/00	929.1	1304.5	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/d-037-L 094-A-13/00	923.2	1289.2	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/b-043-L 094-A-13/00	946.9	1314.2	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/a-044-L 094-A-13/00	960	1318	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/b-045-L 094-A-13/00	959.2	1312.1	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/a-046-L 094-A-13/00	935.6	1290	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/a-053-L 094-A-13/00	955.8	1313	NA	NA	NA	1396.5	1419.1	1444.1	NA	NA	NA	NA	NA	NA
200/b-055-L 094-A-13/00	954.5	1312.9	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/d-059-L 094-A-13/00	916.7	1281.3	NP	NA	NP	NP	NP	NP	NP	NA	NP	NP	NA	NP
200/b-070-L 094-A-13/00	964.3	1335.6	NA	NA	1423.9	1429.1	1438.6	1466	NA	NA	-459.6	NA	NA	5.2