UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Depositional Environments of the Eagle Sandstone, North-Central Montana-- an Aid for Hydrocarbon Exploration

(Modified from a talk presented to the Rocky Mountain Section AAPG-SEPM Meeting, Billings, Montana, March 30, 1976)

By

Dudley D. Rice

Open-file report 76-423

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By Dudley D. Rice

Since the discovery of shallow gas accumulations in the Upper Cretaceous Eagle Sandstone at Tiger Ridge in 1966, there has been active exploration for similar new accumulations in the surrounding areas of north-central Montana. Although gravity faulting and associated structure along the flanks of the Bearpaw Mountains are the primary trapping mechanisms of these accumulations today, I believe the initial control was stratigraphic, as will be discussed later. An understanding of depositional environments as interpreted from outcrop studies is therefore important and this knowledge can be applied to subsurface studies and used as an exploration tool.

As shown in figure 1, the Eagle Sandstone is in the lower part of an intertonguing sequence of Upper Cretaceous rocks which consists of eastward thinning deposits of nearshore marine and continental origin--Eagle, Judith River, Fox Hills, and equivalent units--and westward thinning wedges of marine shale--the Claggett and Bearpaw.

The Eagle is conformably underlain by the Telegraph Creek Formation which is a transitional unit from predominantly shale of the underling Niobrara Formation to sandstone of the Eagle. The Claggett Shale conformably overlies the Eagle Sandstone and represents a widespread transgression which was accompanied at the beginning by intense volcanism which resulted in the deposition of the Ardmore Bentonite Bed.

In northwestern Montana, the Virgelle, or basal member of the Eagle, is treated as a formation and the nonmarine equivalents of the upper Eagle and Claggett are included in the lower part of the Two Medicine Formation. East of approximately the Musselshell River, nearshore and shoreline deposits of the Telegraph Creek and Eagle grade into offshore shales of the Gammon.

The name Eagle Sandstone was given by W. H. Weed in 1899 for exposures along the Missouri River at the mouth of Eagle Creek as shown on the index map (fig. 2). The Eagle is well exposed along the Missouri River and its tributaries from the town of Virgelle to the mouth of the Judith River, and was studied in detail at the outcrops indicated on figure 2.

At its type section and over the entire study area, the Eagle Sandstone can be divided into three members: the basal Virgelle Sandstone Member which ranges in thickness from 80 to 130 ft (24-40 m) and the informally designated middle and upper members which together are as thick as 180 ft (60 m). The total Eagle Sandstone ranges from approximately 200 to 300 ft (61-91 m) in thickness. Each of these members consists of genetically associated facies which can be related to depositional environments using a combination of criteria including relationship with other units, lithology, sedimentary structures, trace fossils, and geometry.

The basal Virgelle Sandstone Member is interpreted as being deposited along a prograding sandy shoreline. Along a modern coast, the shoreline profile can be divided into several zones, each of which has a distinct depositional product (fig. 3). These zones are:

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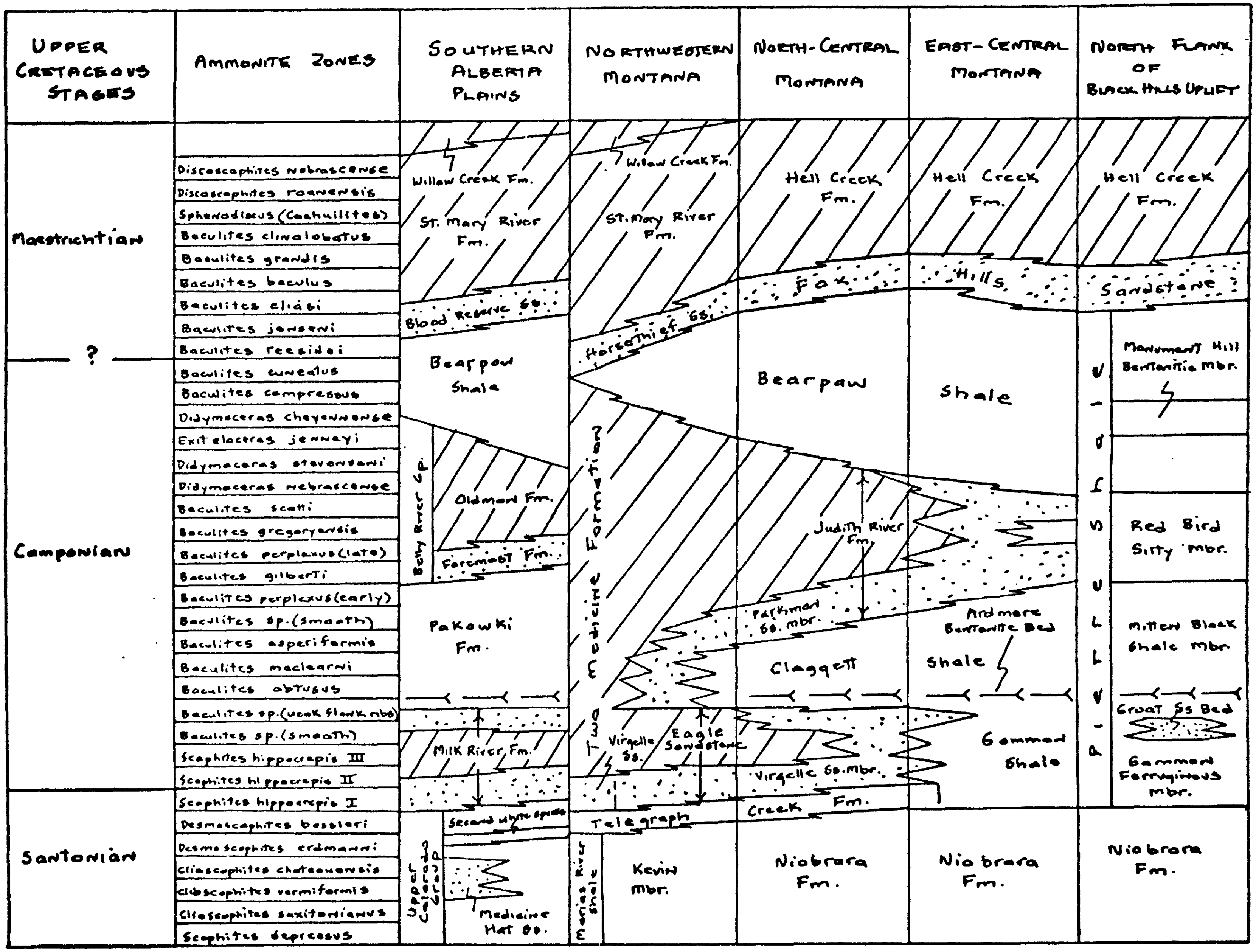

Figure 1 Correlation and stratigraphic relations of Eagle Sandstone and Upper Cretaceous rocks of North-central Montana with adjacent areas in Montana and Canada.

Marine siltstone and shale | Nearshore marine sandstone | Nonmarine rocks the Eagle, is treated as a formation and the nonmarine equivalents of the upper Eagle and Claggett are included in the lower part of the Two Medicine Formation. East of approximately the Musselshell River, nearshore and shoreline deposits of the Telegraph Creek and Eagle grade into offshore shales of the Gammon.

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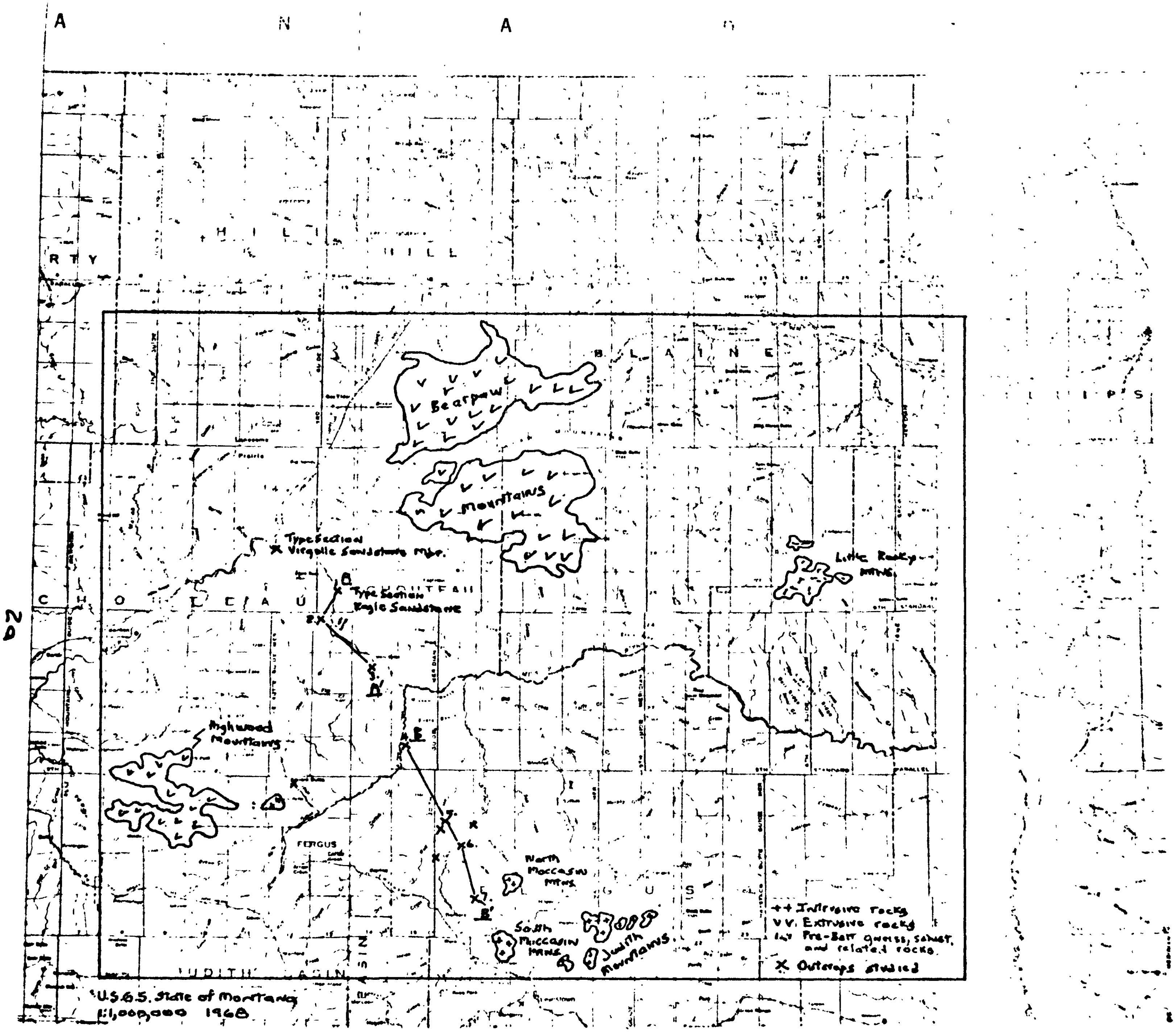

Figure 2 Index Map of North-Central Montana

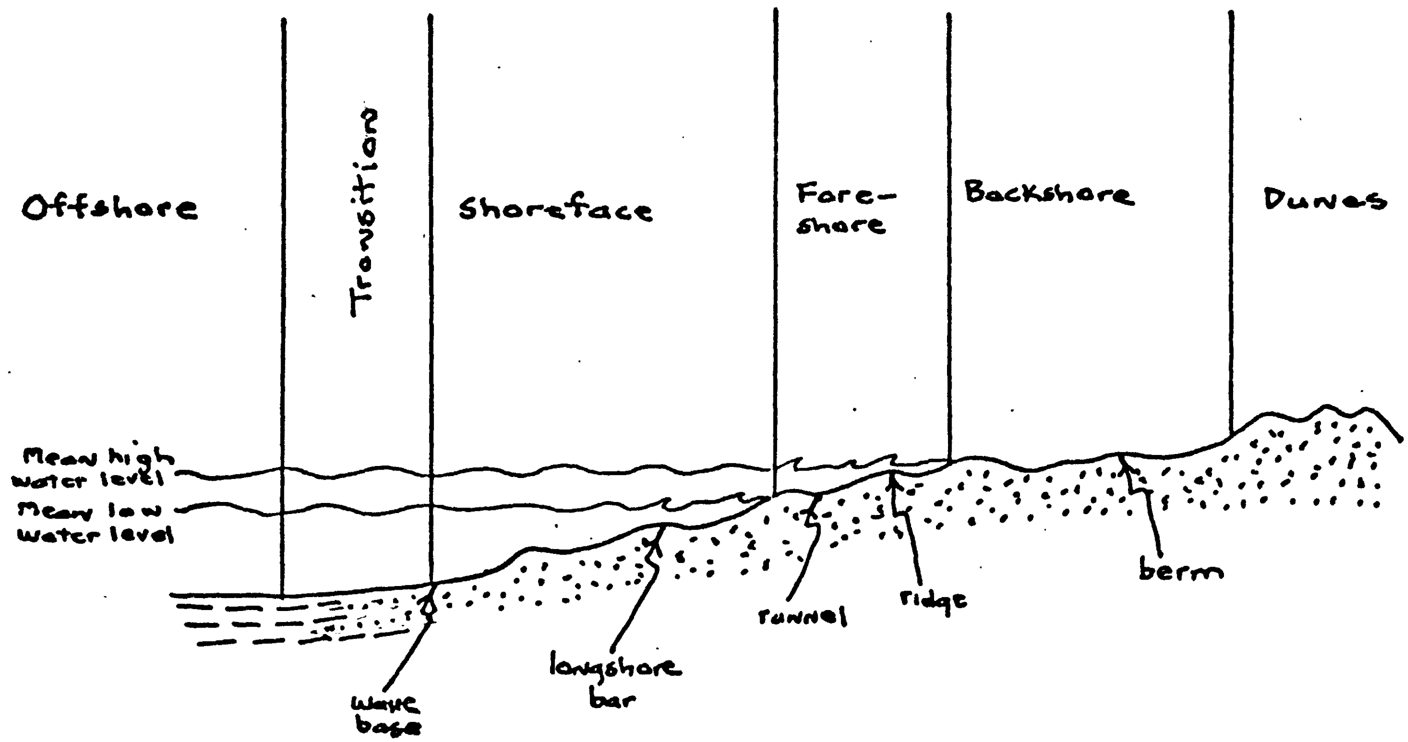

Figure 3 Shoreline profile of a modern sandy coast

(1) Dunes--The area always above water and exposed to wind activity.

(2) Backshore--The zone between mean high water level and storm flood level.

(3) Foreshore--The region between mean high water and mean low water or the intertidal zone which is commonly referred to as the beach.

(4) Shoreface--Usually the zone of highest energy which extends from the base of foreshore to lower limit of maximum wave base.

A similar shoreline profile probably existed during Eagle time and many of the zones can be recognized in the facies of a typical Virgelle sequence as shown in figure 4.

The upper few feet of the Virgelle are often assigned to the backshore facies. Parallel and bidirectionally dipping tabular crossbedded sandstone is the dominant feature of this facies. Although this area was exposed to wind activity, deposition was controlled by surge action during storms. Seaward and landward dipping crossbeds were deposited along beach ridges and berms which paralleled the shoreline. In northwestern Montana, concentrations of titaniferous magnetite in ledges at the top of the Virgelle probably accumulated in the backshore.

The foreshore facies consists of parallel bedded sandstones with low angle laminae dipping uniformly seaward. Deposition in this intertidal zone was controlled by swash action.

A root zone is commonly developed at the top of the foreshore or backshore facies where present. This root zone often occurs in a red hematitic sandstone which together with the root zone indicate subaerial exposure.

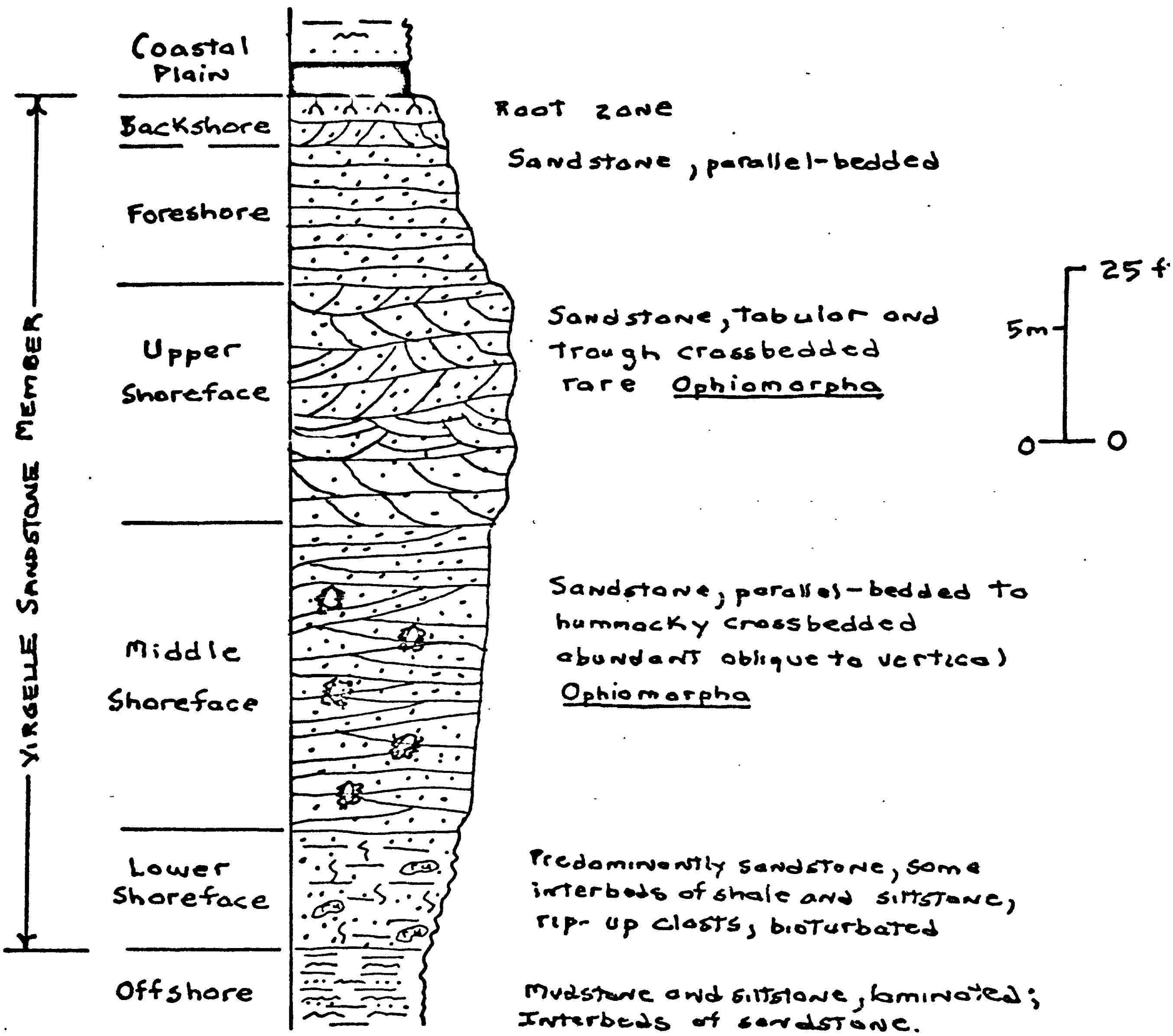

Figure 4 Typical Virgelle Prograding Sequence

The shoreface can be divided into three subfacies in the Virgelle, the upper, middle and lower. The upper shoreface is represented by fine- to medium-grained sandstone, the coarsest facies in this shoreline sequence. This sandstone is characteristically trough and tabular crossbedded with scattered, large Ophiomorpha. This facies accumulated in the highest energy regime along the coast, where sediment moved in dunes or sand waves by wave energy, and longshore and rib currents.

Parallel to hummocky crossbedded sandstone with abundant organic detritus typifies the middle shoreface. Ophiomorpha burrows are abundant and sometimes destroy the original bedding. In this zone, deposition was by suspension from sand eroded from the upper shoreface and foreshore during storm activity. The lower shoreface is a thin zone of predominantly sandstone with laminae and rip-up clasts of siltstone and shale at the base of the Virgelle sequence. These beds were probably deposited as horizontal laminae with bioturbation destroying most of the original bedding. Sedimentation was similar to the middle shoreface with shale and siltstone carried in from the offshore by weak bottom currents and storm activity.

As shown in figure 5, the middle member of the Eagle Sandstone in the western part of study area accumulated in a coastal plain environment, a low, broad area in the lower reaches of a river system. These rocks, deposited mainly by suspension, are differentiated into three facies:

(1) Channel sandstones--Lenticular sandstones with erosional bases are occasionally developed in this facies. They were deposited in local meandering streams along the coastal plain.

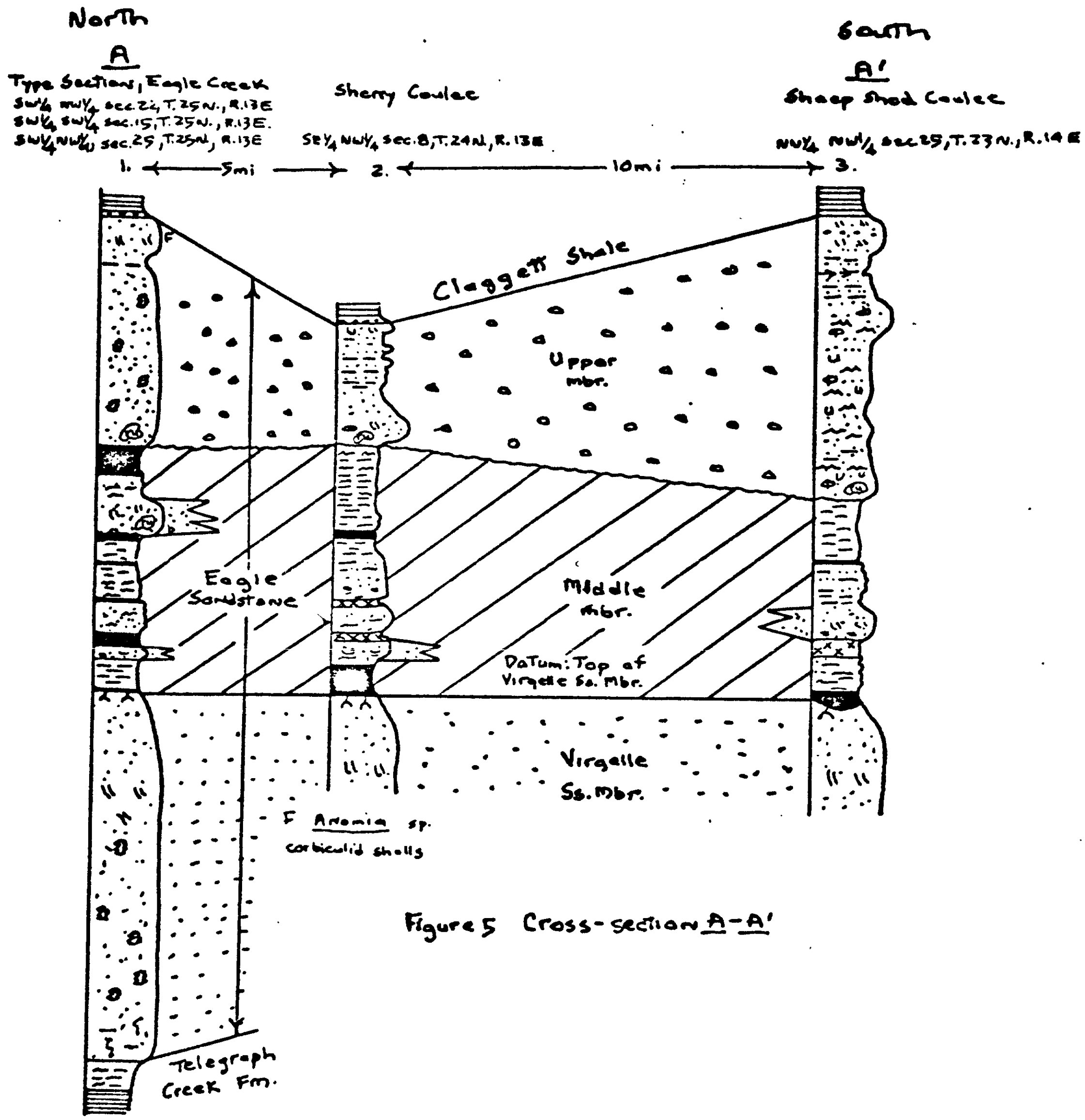

Figure 5 Cross-section A-A'

F *Ostrea* sp.
Anomia gryphorhynchus Meek
Brachiodontes sp.
Corbula subtrigonalis Meek & Hayden
Melania? *whiteavesi* Stanton

EXPLANATION
(for figures 5 and 6)

Columns

- Sandstone
- Shale
- Mudstone
- Siltstone
- Coal or carbonaceous shale
- Bentonite
- Igneous sill

- Root zone
- Chert pebbles
- Rip-up clasts
- Scour and fill
- b Bone
- F Fossils (listed below section)
- Carbonaceous or coal fragments
- Tabular crossbedding
- Trough crossbedding
- Ripple laminated
- Flaser bedding
- *Ophiomorpha*
- U *Arenicolites*
- Nondescript vertical burrows
- Nondescript horizontal burrows
- Bioturbated

Patterns

- Delta or coastal plain
- Delta-destructional
- Delta-front
- Prograding shoreline

- Disconformity
- Member
- Depositional unit

1mi = 1.6 Km

Metres Feet

0 — 0

5

25

10

15 — 50

(2) Flood basin--Sheet-like sandstones and siltstones, and variegated, bentonitic mudstone and shale are grouped in this facies. These sediments accumulated by suspension in a variety of environments including natural levees along channel systems, swamps, lakes, and bays.

(3) Coastal dunes--Isolated pods of eolian sandstone are occasionally preserved and are enclosed in finer grained flood basin deposits.

In the lower part of the coastal plain deposits, several widespread coals are present which indicate that extensive swamps evolved behind the prograding Virgelle shoreline. Although coals are present higher in the section, they are not as pure or as widespread.

The eastern exposures of the middle member, as illustrated in figure 6, are interpreted as being deposited in a deltaic setting, that is, the area along the coast where large volumes of land-derived sediments are deposited by a fluvial system. At the outcrops examined, the sequence consists of three main facies from base to top, delta plain and delta front capped by a thin delta plain.

The delta plain is the principal subaerial part of the delta system. In the middle member of the Eagle, two facies can be distinguished:

(1) Distributary channels--Channel sandstones as thick as 25 ft (8 m) are exposed in the Arrow Creek and Wolf Creek sections which have scoured into the underlying flood basin deposits. These sandstones were deposited in distributary channels which flowed across the delta plain and eventually fed the delta.

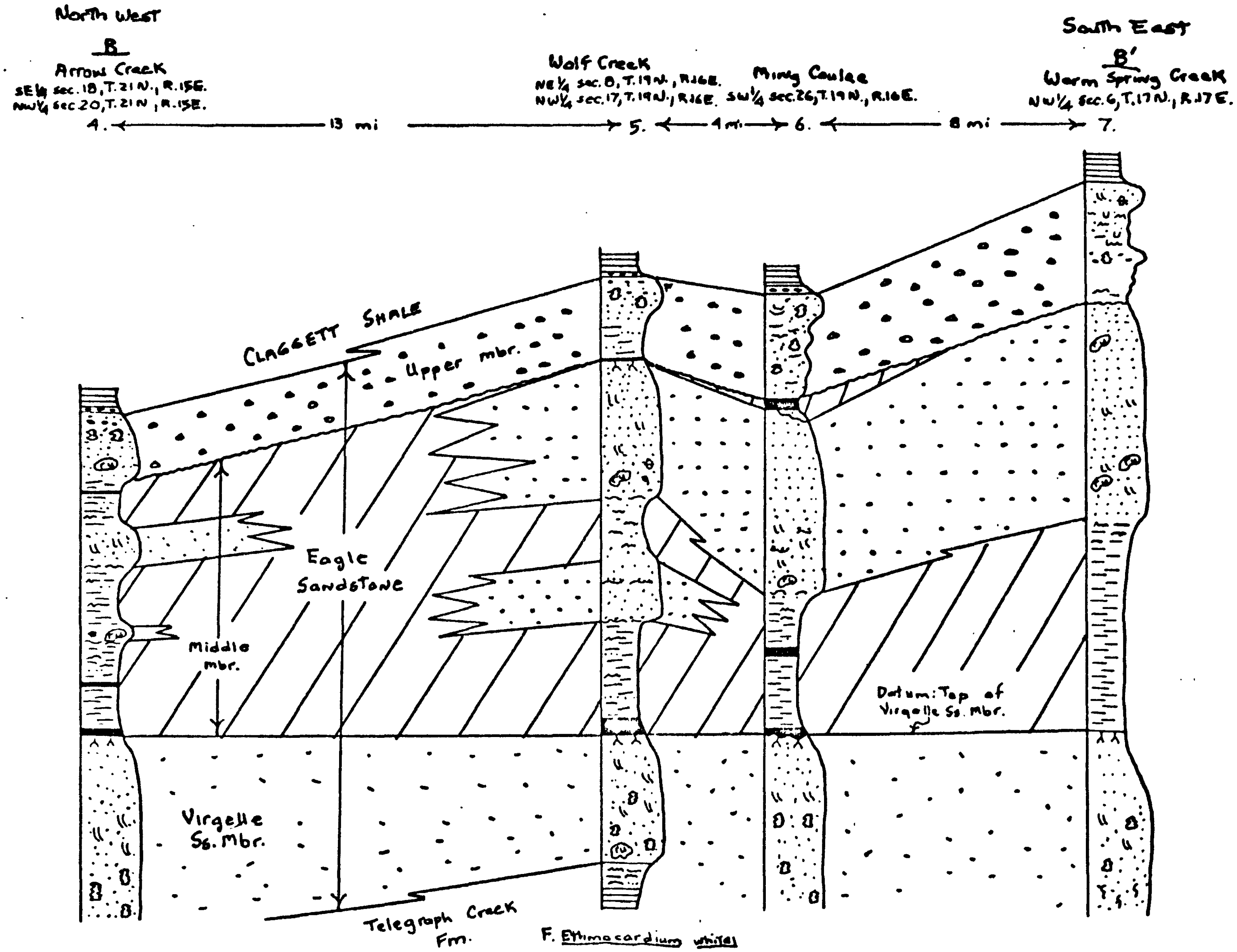

Figure 6 Cross-Section B-B'

(2) Flood basin--This facies is comprised of mudstones and shales with increasing interbeds of siltstone upward which are locally burrowed. These rocks accumulated in extensive bodies of water such as lakes, bays, and lagoons. These bodies indented the coast and probably changed from brackish to more marine upward which accounts for the burrowing.

The delta front is the subaqueous part of the delta which extends from the delta plain to the prodelta where sediments are deposited primarily by suspension. In the study area, sheet-like sandstones as much as 90 ft (29 m) thick overlie delta plain deposits and probably accumulated in a delta front environment. These sandstones form massive cliffs and are horizontal bedded to tabular crossbedded with some trough crossbedding and scour and fill features. Biogenic structures are rare.

The upper 25-30 ft (8-9 m) of this delta front unit are generally poorly exposed and different in character from the basal part. These light-gray to white sandstones are typically parallel bedded, a characteristic of the foreshore facies of the Virgelle Sandstone Member. Rill marks with Arenicolites burrows are occasionally preserved. The white color, which is in sharp contrast to the yellowish brown of the underlying ledge-forming sandstone, is the result of diagenetic bleaching caused by reduction of iron by biogenic hydrogen sulfide generated in the overlying delta plain deposits.

This delta front sandstone unit probably originated as river mouth bars. Because this environment was dominated by marine processes, these bars were reworked and moved along the coast. With progradation, the sand was built up and deposited in the foreshore zone in the upper part of the unit.

A thin delta plain facies is often preserved on top of the delta front unit. A root zone is usually developed which is in turn overlain by channel sandstones, carbonaceous mudstone, and (or) lignitic coal. Thus, with further progradation, the deltaic sequence built up to sea level and delta plain was established consisting of swamps, marshes, and meandering streams.

The termination of active progradation and processes of deltaic sedimentation usually results in the advancement of the marine environment. This process is referred to as the delta-destructional phase, or if the areal extent is widespread, as marine transgression. This delta-destructional phase took place in late Eagle time and is represented by deposits of the upper member. This member rests disconformably on delta plain and occasionally delta front deposits of the middle member and can be differentiated into the following two facies:

(1) Shoreface--This facies is represented by resistant sandstone ledges, as thick as 30 ft (9 m), characterized by parallel to low angle tabular crossbedding. Vertical *Ophiomorpha*, *Thalassinoides*, and small clay lined burrows are abundant, but do not destroy the bedding.

(2) Tidal flat--Interbedded sequences of sandstone, siltstone, and shale which exhibit alternating bedding types such as parallel, low angle tabular, ripple, lenticular, and flaser are assigned to this facies. Asymmetric ripple marks and interference ripple systems with *Arenicolites* burrows are often preserved. *Ophiomorpha* and *Thalassinoides* burrows are common, but are smaller in scale than the shoreface facies.

Chert gravel and pebbles are scattered, concentrated in laminae, or occur in conglomeratic beds in this upper member or at the base of the Claggett Shale. Robust, horizontal Ophiomorpha as much as 1.5 in (38.1mm) in diameter are often lined with these chert pebbles.

After termination of deltaic sedimentation during middle Eagle time, the late Eagle seaway encroached over the abandoned delta. Underlying deltaic deposits were eroded by marine processes and redeposited in a shoreface environment along the advancing shoreline. The interbedded facies accumulated in a tidal flat environment developed on a broad delta plain of late middle Eagle time. Chert gravel and pebbles were eroded from channels on the delta plain and often concentrated as lag deposits with the advancing sea.

The most favorable reservoir facies identified in the Eagle from this outcrop study are as follows:

(1) Shoreface sandstones of the upper member--The reservoir quality of this facies is greatly affected by the presence or absence of carbonate cement. This cement, which originated from the shell material restricted to this member, probably formed prior to gas generation.

(2) Delta front and distributary channel sandstones of the middle member.

(3) Upper shoreface and foreshore deposits of the Virgelle Sandstone Member.

These reservoir facies can be further limited by examining discoveries to date. One or more members of the Eagle may contain gas. The upper member is the primary producing reservoir in the Bearpaw Mountains area. Excellent reservoirs are present in the middle member, but they produce only where shoreface sandstones of the upper member are filled with gas or are not developed. The Virgelle Sandstone Member is also an excellent reservoir but only rarely contains gas where both the upper and middle members are filled. Thus, exploration for gas must be directed towards an understanding of the reservoir facies of primarily the upper and middle members.

Outcrop studies have shown the detailed aspects of depositional environments and are useful in determining the processes of sedimentation responsible for the deposition of the Eagle Sandstone. The end products of these depositional environments, in particular the reservoir facies, were identified in outcrop, and can be readily recognized in the subsurface as shown by the well in figure 7.

On a larger scale, subsurface data can then be combined with models of sedimentation developed from outcrop studies and a regional paleogeographic reconstruction is possible. This information can be used as an exploration tool by determining sandstone geometry, in predicting shoreline and reservoir facies trends, and eventually in defining the stratigraphic controls of Eagle gas entrapment.

The sedimentary history and paleogeography of the Eagle Sandstone in north-central Montana can be summarized as follows: The Eagle Sandstone accumulated along the western shoreline of a north-south trending epicontinental seaway which extended from the Gulf of Mexico to the Arctic Ocean. This seaway was separated from Pacific waters by a narrow, unstable Cordilleran highland in western Montana which was the source area for the Eagle sediments.

In the immediate study area, the sedimentary history of the Eagle can be divided into three stages:

(1) Virgelle progradation--The Virgelle Sandstone Member was deposited along a high-energy shoreline. This shoreline, which extended into western Montana during early Telegraph Creek time (fig. 8), prograded eastward at a rate of about 50 mi (81 km) per million years, laying down the most widespread member of the Eagle. The major part of the sand was probably brought to the coast by rivers, deposited in deltas, and transported along the coast. Although deltaic deposits were not recognized, the bulge in the strandline of _Scaphites hippocrepis_, which is Virgelle time, probably indicates the general site of a delta (fig. 8).

(2) Transgression and progradation of middle Eagle time--Progradation of the Virgelle resulted in subaerial exposure over most of the study area at the beginning of middle Eagle time. The lower part of coastal plain deposits, which make up the entire middle member in the western part of the study area, grade eastward into a delta plain facies. This facies grades from brackish to more marine upward indicating a transgression.

This delta plain sequence is in turn overlain by a sandstone unit which was deposited in a delta front environment. This extensive, sheet-like sandstone accumulated in a delta dominated by marine processes which is classified as a high destructional lobate or arcuate delta. Modern examples of this type are the Rhône, Niger, and shoal water lobes of the Mississippi. This delta is hereby referred to as the Judith River delta because this is the geographic area where its delta front deposits are best developed. The Judith

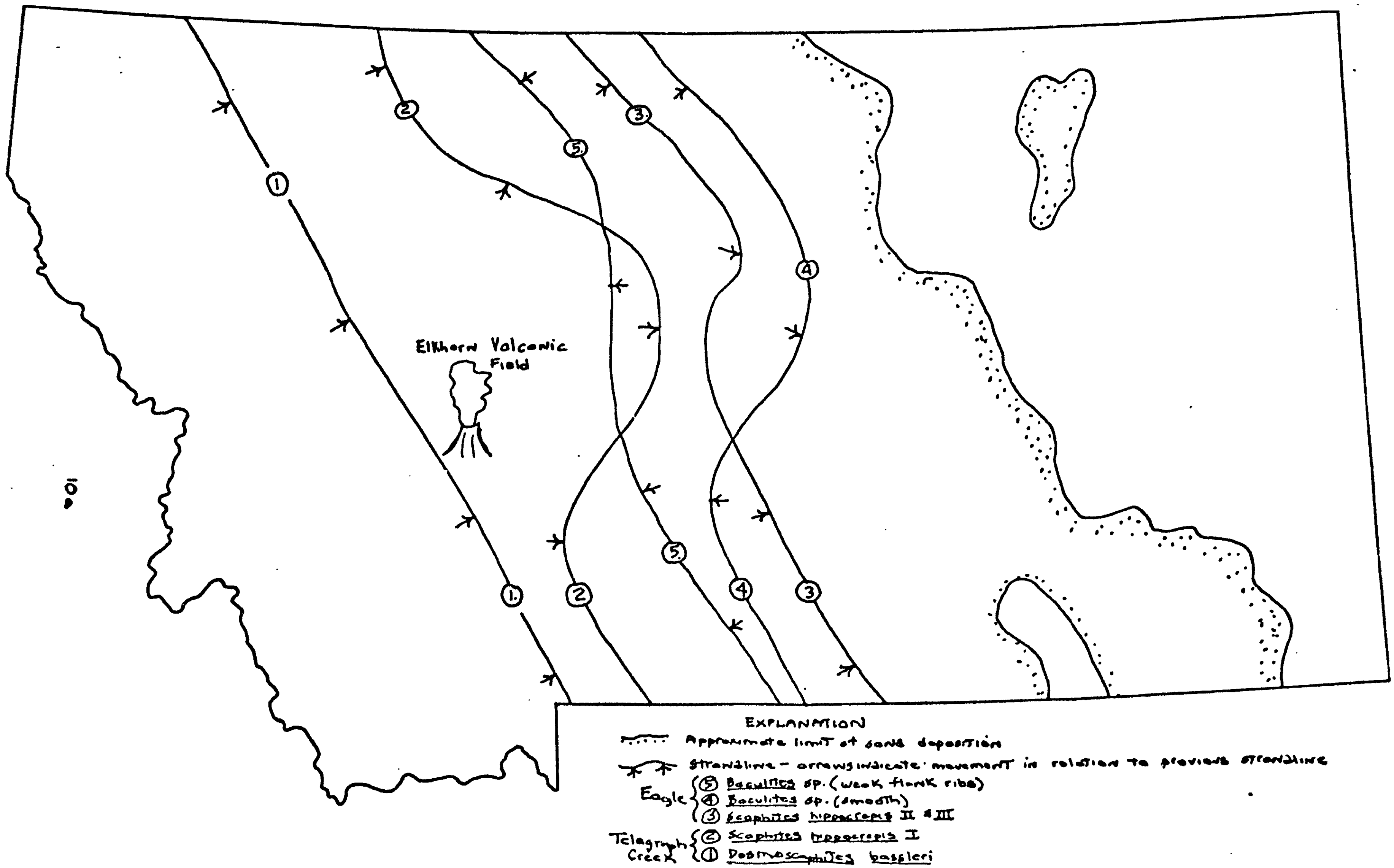

Figure 8 Map of Montana showing Upper Cretaceous Telegraph Creek and Eagle strandlines.

River delta prograded seaward and upward resulting in the developement of an extensive delta plain in late middle Eagle time.

(3) Transgression of late Eagle time--With termination of deltaic sedimentation and resulting compaction and subsidence, the late Eagle sea of Baculites sp. (weak flank ribs) time transgressed over the abandoned Judith River delta (fig. 8). Underlying deltaic deposits were reworked and redeposited under marine conditions. This widespread event, which was associated with concentrations of chert gravel and pebbles, makes a widespread marker over much of Montana and southern Canada. Later, the Claggett sea transgressed further to the west and resulted in widespread shale deposition.

The significance of applying information on the depositional environments of the Eagle Sandstone to future exploration is greatly amplified by understanding the processes of natural gas generation. Natural gas reservoired in the Eagle Sandstone from the Bearpaw Mountains area in north-central Montana occurs at relatively shallow depths and is characterized by a hydrocarbon fraction consisting of greater than 99 percent methane. In addition, the methane is enriched in the light isotope C^{12} with a δC^{13} value ranging from -66 to -70‰ . These characteristics are typical of gas generated during the immature stage of hydrocarbon generation which is referred to as biogenic gas. This methane-rich gas is formed by the breakdown of organic matter by anaerobic bacteria at shallow depths in accumulating sediments.

In north-central Montana, biogenic gas was generated in the marine shales enclosing the Eagle Sandstone and trapped in Eagle reservoirs prior to uplift, faulting, and associated volcanic activity of the Bearpaw Mountains during the Laramide Orogeny. Because of this early timing, the gas was probably stratigraphically trapped. These stratigraphic traps were later broken up by gravity faulting along the flanks of the Bearpaw Mountains. Thus, although structure is the primary trapping mechanism today, initial control was stratigraphic and an understanding of depositional environments of the Eagle is important for future exploration.

In conclusion, I believe that production from the Eagle Sandstone in north-central Montana can be greatly expanded by understanding depositional environments of the Eagle and applying this knowledge to future exploration efforts.