THE FRONTIER FORMATION IN NORTHWESTERN WYOMING AND ADJACENT AREAS

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ABSTRACT

A stratigraphic study of the Cretaceous Frontier Formation in the vicinity of Heart Mountain in the Big Horn Basin near Cody, Wyoming, and the Bridger Mountains on the western margin of the Crazy Mountains Basin in Montana has recently been completed. The formation is about 525 feet thick and consists of marine, deltaic, and lagoonal sediments. It overlies the Mowry Shale Formation and is overlain by the Cody Shale Formation. A basal marine sandstone unit and a carbonaceous shale and mudstone facies have been mapped.

The formation was deposited by progradation of sediment across south central Montana, southeastern Idaho, and northwestern Wyoming. Movement along major Precambrian fault systems may have displaced basement structures sufficiently to influence the progradation depositional process.

INTRODUCTION

The Frontier Formation is of early Upper Cretaceous age and is composed of sandstones, bentonites, coals and other clastic sedimentary units. The formation is found in Wyoming and in the adjacent areas of Montana, Idaho, Utah and Colorado. It is a good oil and gas target itself, and a knowledge of the formation is helpful to understanding the structural development of the overthrust exploration areas. The type area is near Kemmerer, Wyoming (Cobban and Reeside, 1952).

Field work was done to establish regional continuity trends for the highly diverse facies within the formation. The section was reviewed (Roberts, 1972) and new sections were measured in the Bridger Range area on the western margin of the Crazy Mountains Basin near Bozeman, Gallatin County, Montana (Tonnsen, 1975). These sections were compared with known outcrops in the vicinity of Heart Mountain in the Big Horn Basin north of Cody, Park County, Wyoming (Merewether et al, 1975 and Siemers, 175).

Cretaceous beds outcrop throughout the region (Fig. 1), but the Frontier part of the section is not everywhere well exposed. When all of the Bridger Range sections (x in Fig. 2) are plotted they form north-south and east-west lines centered over the whole Bridger Range area. The sections are referred to by name in the text. The Beasley, Slushman, Brackett, Troy, East Flank, County Line, Mandlow, Jensen, and Elkhorn sections are all Crazy Mountains Basin sections. The Two Dot and Hogan Reservoir sections are in the Big Horn Basin. Throughout the Crazy-Big Horn area the formation has been observed to have distinctive rock units and features and these are discussed in this paper. The units are not the same bed but their persistent appearance at about the same position each place is interesting.

REGIONAL CORRELATION

The bulk of the sediment comprising the Frontier was deposited during Cenomanian time when a delta prograded eastward into the late Albian Mowry sea (Fig. 3). By Turonian time a large delta had been established across Wyoming as sediment continued to be transported from the west across the delta plain and into the sea. This paper considers the stratigraphy along the northern margin of the delta.

In this area the Frontier sandstones overlie the dark-gray to black bentonitic marine Mowry Shale. A continued influx of mostly volcanic clastic material sustained deposition of Frontier sandstones until into the Coniacian stage. The transgressive marine shale of the Cody (or Hilliard) Formation overlies the Frontier but with variation in age from Cenomanian through Coniacian.

Extremity sandstones of the Frontier pinch out in southeastern Wyoming in shales and limestones. The Belle Fourche and Greenhorn Formations (F in Fig. 3) of the interior plains evidence marine shale and limestone deposition in the seaway contemporaneously with deposition of the main body of Frontier sandstones on the western shore (Kauffman, 1977).

LITHOLOGY AND PROVENANCE

The formation is divisible into a basal marine strandplain unit, an overlying fluvial-deltaic unit, successive pro-

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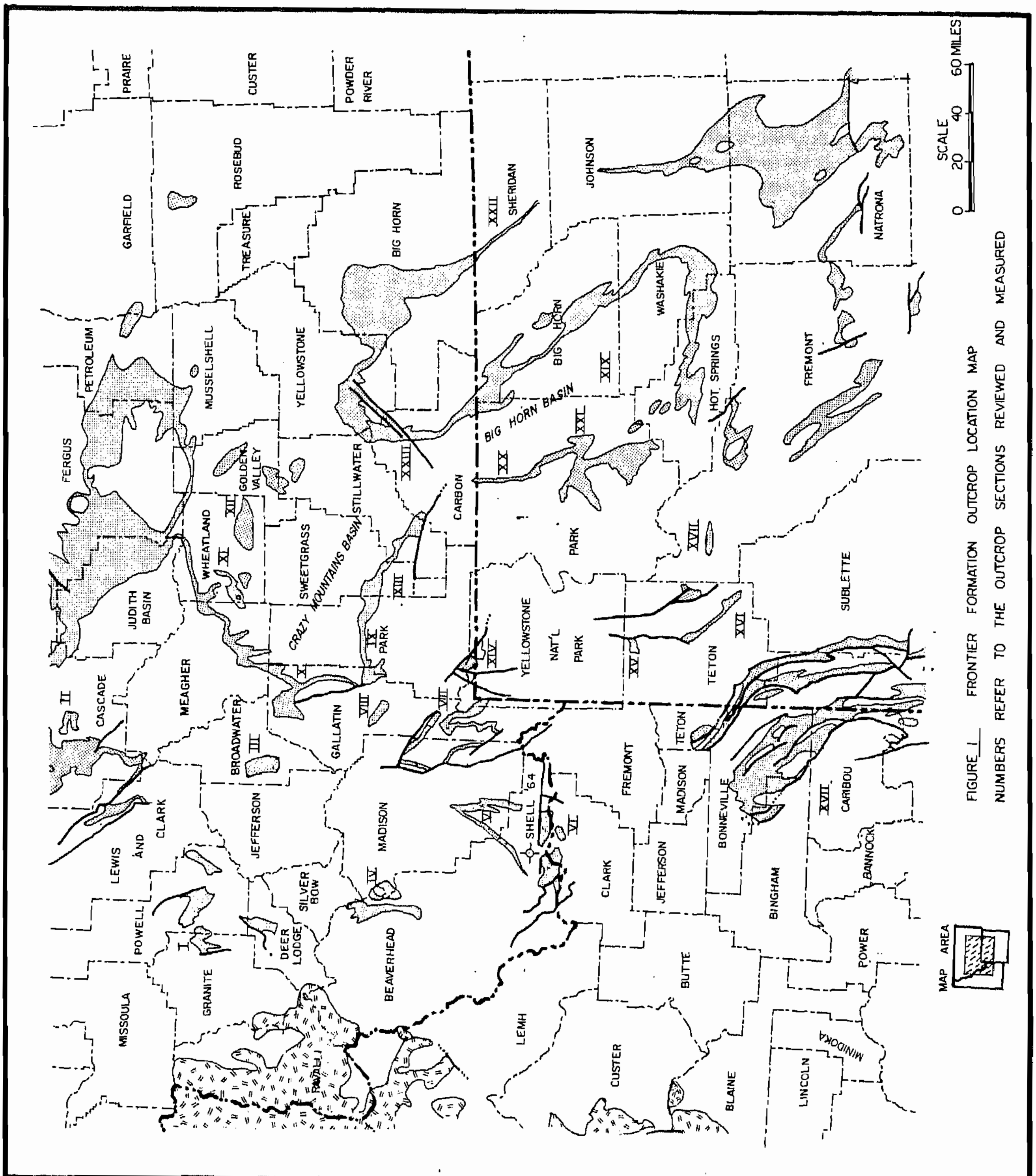


FIGURE 1 FRONTIER FORMATION OUTCROP LOCATION MAP
NUMBERS REFER TO THE OUTCROP SECTIONS REVIEWED AND MEASURED

gradational units, and a transgressive marine sandstone unit at the top.

The formation is consistently about 500 feet thick in the Crazy-Big Horn area, and where it thins (to about 300 ft) the variation is often due to an intraformational hiatus (see also Hale, 1962).

Bentonite beds in the lower part are nearly white with a few thin bright yellow or green beds near the base. The upper part of the formation contains one or more brown carbonaceous shale beds, some brownish-black coal seams, and some white and yellow-tan quartzose sandstones. Generally, however, the lithology is drab, greenish-gray, fine-grained quartz sand and dark chert grains with much gray volcanic ash matrix material. The grains are variably cemented with calcite and silica. Observations in the field and in thin section were made to determine the constituent components of the grains and matrix. The grain assemblages fall into four provenance categories thought to represent the terrestrial material being eroded from Utah, Idaho, Western Montana, and Western Canada.

A. Miscellaneous grains

Fine to very fine zircon, tourmaline and other heavy minerals (some coated with hermatite) are observed. Lithic fragments are seen as fine (.01 to .03 mm), oval shaped, opaque grains. Fibrous clay (dickite?) is thought to be an alteration product of heavy minerals. These have not been related to a specific provenance.

B. Sedimentary rocks

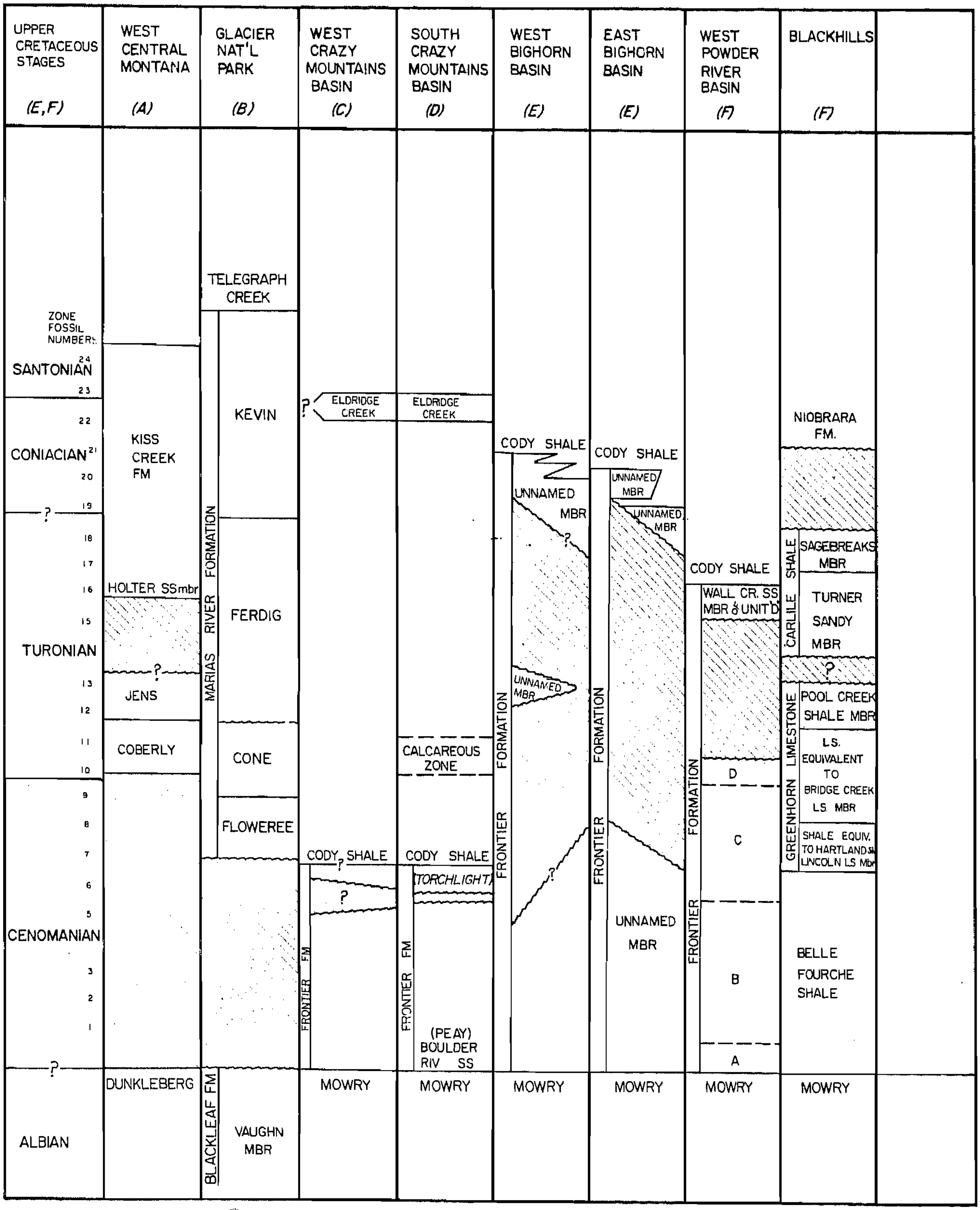
Green, brown, and tan glauconite and fine specks and patchy grains of shale and argillite may be from Precambrian, Paleozoic, and Mesozoic sediments. Medium to

	Number and Name	Location	Reference
I.	Drummond	Sec. 8, T. 10N, R. 11W	Gwinn, 1960.
II.	Great Falls	Sec. 1, T. 20N, R. 1W	Fox and Groff, 1966.
III.	Elkhorn Mts.	Sec. 4, T. 4N, R. 1W	Klepper et al, 1957.
IV.	McCartney Mt.	Sec. 16, T. 4S, R. 8W	Gwinn, 1960.
V.	Ruby River	Sec. 11, T. 9S, R. 3W	Mann, 1950.
VI.	Centennial	Sec. 36, T. 14S, R. 4W	Witkind, 1975.
VII.	South Gallatin	Sec. 7, T. 9S, R. 4E	M. Wilson, 1970.
VIII.	North Gallatin	Sec. 18, T. 4S, R. 4E	McMannis and Chadwick,1964.
IX.	Livingston	Sec. 26, T. 2S, R. 9E	Roberts, 1972.
X.	Bridger Range		Tonnsen, 1975.
	Beasley	Sec. 23, T. 1S, R. 6E	
	Slushman	Sec. 25, T. 1N, R. 6E	
	Brackett	Sec. 12, T. 1N, R. 6E	
	Troy	Sec. 4, T. 3N, R. 6E	
	East Flank	Sec. 11, T. 4N, R. 6E	
	County Line	Sec. 16, T. 5N, R. 7E	
	Mandlow	Sec. 14, T. 4N, R. 4E	
	Jensen	Sec. 6, T. 4N, R. 6E	
	Elkhorn	Sec. 3, T. 4N, R. 7E	
XI.	Castle Mts.	Sec. 16, T. 8N, R. 9E	Tanner, 1959.
XII.	Big Elk Dome	Sec. 21, T. 7N, R. 13E	Bowen, 1918.
XIII.	Boulder River	Sec. 11, T. 3S, R. 12E	Richards, 1957.
XIV.	Yellowstone Park	Sec. 36, T. 8S, R. 7E	Wilson, 1934.
XV.	Teton Range	Sec. 16, T. 48N, R. 116W	Tonnsen
XVI.	Jackson Hole	Sec. 36, T. 41N, R. 111W	Love, 1956.
XVII.	Dubois	Sec. 1, T. 42N, R. 107W	Keefer, 1957.
XVIII.	Wyoming Overthrust	Sec. 18, T. 35N, R. 115W	Rubey, 1973.
XIX.	Big Horn Basin		Cobban et al, 1975.
XX.	Heart Mt. Thrust		Tonnsen, this paper
	Bennett	Sec. 34, T. 58N, R. 103W	
	Singer	Sec. 5, T. 56N, R. 103W	
	Hogan	Sec. 34, T. 56N, R. 103W	
	Two Dot	Sec. 10, T. 54N, R. 103W	
	Rattlesnake	Sec. 24, T. 53N, R. 104W	
XXI.	Cody	Sec. 12, T. 51N, R. 102W	Siemers, 1975.
XXII.	Powder River Basin		Cobban et al, 1976.
XXIII.	Montana-Wyoming Line		Knappen and Moulton,1930.

Shell Oil Company #34X-113, Beaverhead County, Montana
SW¼SE¼ Sec. 13, T.13S R.5W D&A 1964

FIGURE 2 OUTCROP AND WELL DATA LOCATION CHART

FIGURE 3 FRONTIER FORMATION CORRELATION CHART



(A) GWINN (1960)
(B) RICE & COBBAN (1977)
(C) TONNSEN (1975)
(D) ROBERTS (1965, 1972)
(E) MEREWETHER, COBBAN, & RYDER (1975)
(F) MEREWETHER, COBBAN, & SPENCER (1976)

coarse (.1 to .3 mm) rounded grains and ¼ to over 3 inch pebbles are white, brown, gray and black chert material. These have an organic silica framework, and are probably from chert-rich Paleozoic carbonate units such as the Silurian Laketown Dolomite, the Mississippian Lodgepole Limestone, and the Permian Phosphoria Formation. Quartz grains in medium to coarse (to .3 mm) size are observed as clusters with interlocking texture and undulose extinction. This quartz is probably from Paleozoic sedimentary units such as the Ordovician Swan Peak Quartzite and the Pennsylvanian Tensleep Quartzite.

C. Crystalline rocks

Quartz, feldspar, and mica grains, probably from older igneous and metamorphic terrains, are observed. Well rounded fine quartz grains with strain shadow extinction are probably from old quartzites. Subangular to rounded potassic and perthitic textured feldspar grains may be from more recent pre-Cretaceous igneous intrusive rocks. Needle-shaped, very fine (.01 mm) sericite mica is possibly from schistose rocks, igneous rocks, or from alteration of chert and plagioclase grains.

D. Volcanic rocks

Volcanic material from contemporaneous, or nearly contemporaneous, Cretaceous volcanism comprises most of the sediment. Micro-fractured quartz, orthoclase, and plagioclase grains are common. The grains are large (medium, .03 mm or larger) and angular to subangular. Andesine and probably oligoclase plagioclase grains have been identified. Lithic fragments seen as angular and opaque material with ragged grain edges are probably scoria or other volcanic material. Plates, fibers and books of biotite are observed in up to coarse (1 mm) size. Much volcanic glass shard material (eyebrow and Y-shaped) is present.

BASAL MARINE STRANDPLAIN UNIT

A thick marine sandstone bed (often locally named) occurs at or near the base. The Big Elk Sandstone in the Crazy Mountains Basin is 248 feet thick and rests on Mowry Shale (Bowen, 1918, and Tanner, 1949), and may really be a part of the Mowry (Cobban and Reeside, 1952, p. 1961). The Boulder River Sandstone near Livingston is 119 feet thick (Roberts, 1972), and is a pebble and coarse sand basal Frontier sandstone unit. A 97-foot sandstone was measured at Troy Creek in the Bridger Range (Tonnsen, 1975). The Heart Mountain Sandstone north of Cody on the western side of the Big Horn Basin is over 125 feet thick (Siemers, 1975). These sandstones are all associated with the lowest parts of the formation but they probably are not contemporaneous. At the Hogan Reservoir section the thick sandstone has pinched out (Fig. 4). It occurs at the Two Dot section a few miles south, and it was drilled into in the Montana Power #16-14 Pat O'Hara, Section 14, T55N, R103W, Park County, Wyoming.

The unit is composed of variably bedded, coarsening-upward sequences of light-gray to bluish-dark-gray, fine-to medium-grained, glauconitic "salt and pepper" sandstones. The sandstones are intensely bioturbated and are interstratified with very dark-brown to black mudstone laminae at the base. The laminae grade upwards to thin (2 -8in.), medium (12 - 24in.), and thick to massive beds at the top. The sandstone is cemented with silica in the Bridger Range but in the Big Horn Basin it is commonly cemented by calcite and silica. Dessication cracks and calcareous iron oxides coat the bedding surfaces of many beds. The upper beds are friable and slightly crossbedded. These deposits are interpreted to be offshore marine strandplain sandstones. The sandstones were deposited by fluvial discharge into the tidal zone. The uniform bedding and laminae suggest deposition on a broad marine strandplain between the coastal environment to the west and the more open marine environment to the east. These sands seem to have been built up as sand "reefs" on the strandplain and an interpretation of the form of the buildups is suggested in Figure 5. The buildups seem to have an age sequence that may be related to tectonic shifting during deposition, and this is discussed at the end of this paper.

TRACE FOSSILS

Suspension-feeding and bottom-dwelling organisms were active during deposition. Horizontal bedding-plane track and trail forms presumably made by annelid worms, gastropods, and echinoderms occur in the thick marine sandstone and in the lower part of the formation. Other features perpendicular to the bedding planes are probably plug-shaped burrows of suspension-feeding crustaceans and vertical tubes of annelids. Some vertical tubes have a trumpet flare opening upwards through the bed to the bedding plane.

The forms observed in the Frontier resemble those discussed by Howard in the Cretaceous in Utah (1972, and personal communication). The similarity between the forms recognized by Howard and the forms observed in the Frontier are of assistance in relating various lithologies from the offshore to the foreshore or beach. Offshore sediments are reworked by suspension-feeding organisms such as *Ophiomorpha* (shrimp-like) and substrate burrowing organisms such as *Scolicia* and *Asterosoma* (worms). *Asterosoma* burrows are straight tubes vertical to the bedding in offshore sediments, but are trumpet-shaped holes in lower shoreface sediments. Studies of modern forms of these organisms indicate that they continually roll around the rim of the hole to keep it from filling up with sediment settling down the shoreface. The biogenic structures are lost on the upper shoreface by the turbulence of wave impingement. Nevertheless, tubular trails of *Ophiomorpha* are preserved where these crustaceans agitated the sediment while foraging for food.

The pattern suggested by the trace fossils in the lower Frontier in this area is restricted primarily to the offshore and lower shoreface facies. Some beds have vertical tubes of *Asterosoma* that suggest offshore facies but these are found erratically through the sections. Trumpet-shaped forms are common in the basal beds in the Big Horn Basin sections. This may mean that the shoreface was in the western Crazy Mountains Basin area and that a more open marine seafloor environment existed in the northern Big Horn Basin area.

Overall distribution of the trace fossils from the base to the top suggests a change in the environment from offshore to shallow water created by the buildup of sand. The progradation process not only shifts the shoreline seaward but also develops a progressively shallower water depth. A mixture of offshore and shoreface trace fossils and lithologies is observed. The strandplain sandstone is visualized as a sand "reef" that was only slightly above sea level and was nearly encircled by marine waters. The trace fossil faunal assemblages may have been duplicated on both the seaward and the landward sides of the strandplain sandstone. This observation is consistent with the notion that the Frontier lithology in southwestern Montana represents a ponded water environment that could rapidly be flooded by a shallow marine environment. (Mann, 1950; Wilson, 1970; and Shell Oil 34x-13, SWSE13, T13S, R5W Beaverhead County, Montana.)

COARSE GRAINED UNIT

Above the thick marine sandstone unit there is a lenticular sandstone unit 25 to 40 feet thick. The unit is not everywhere present. The sandstones are white, tan, or sooty gray and are coarse and quartzose with dark to colorful chert grains and volcanic rock fragments. Several chert pebbles (to about 5 in. across) and pieces of petrified wood were found in steeply crossbedded sandstones near the top of the unit at Two Dot in the Big Horn Basin where the unit measures 41 feet thick. A tan quartzose sandstone unit with coarse "salt and pepper" grains was found just north of Troy Creek and at Elkhorn in the Bridger Range abruptly above a siltstone and shale interval. This unit is interpreted to be a channel sandstone (Fig. 4) and it seems to reflect the process by which sediment was transported into the marine waters.

MAJOR VOLCANIC ASH UNIT

A distinctive zeolite unit found in the Bridger Range may correlate with a thick, nearly pure, bentonitic zone found in approximately the same position in the section in the Big Horn Basin. A thick bentonite, a zeolite, or a "porcelanite" zone is commonly observed above the channel sandstone zone in the formation here.

Zeolites are calcium, potassium, or sodium hydrous aluminum silicates. As with clay minerals, they are formed in a number of environments but commonly are associated with rapid deposition of silica-rich sediments in saline waters. Slow burial tends to hydrate the aluminosilicates too much and forms montmorillonite clay (Hay, 1966). Well-preserved "Y"-shaped and "eyebrow"-shaped shards are observed in thin section indicating that the volcanic glass was deposited as airborne ash. Subsequent alteration produced the zeolites and the silica cement. Some shards remain, but most of the materials were consumed.

In the East Flank section, zeolite is abundant. The matrix inclusions in the crystals indicate that the zeolite (analcite?) developed after burial, incorporating quartz silt material during crystal growth. The clusters appear as white specks against a black, gray or dark-green siliceous groundmass in the hand specimen, and are very distinctive at the outcrop.

In the Big Horn Basin the thick bentonite beds suggest both a greater distance from the ash fall and a larger, deeper body of water for the ash to fall into.

The unit is correlated (Fig. 4) between the two basins chiefly on the basis of the presumed great volume of ash deposited and its position in the section above the channel sandstone zone. In a deltaic-marine environment sediment is stripped from the delta and redeposited in the prodelta environment. Where the sedimentary processes are this active, it is difficult to rely on lithological correlation of even very thick bentonite beds.

PONDED WATER FACIES

In the northwestern Big Horn Basin there is a distinctive dark-brown to black carbonaceous and coaly shale unit about 250 to 300 feet above the base, and in the Bridger Range at this approximate position there is a fossiliferous black siliceous mudstone facies with carbonaceous and plant fibrous material matted into the sediment. At Elkhorn, the mudstone is interstratified with brown coal seams. The thickness, common position in the section, and the lateral persistence of this unit along strike supports correlation (Fig. 4).

The carbonaceous mudstone is found in the Bridger Range in a very distinctive unit that occurs about 50 feet above the zeolite unit and some 150 feet below the top of the formation. The fossils are pelecypods embedded in the black siliceous mudstone. A suite of specimens from Gallatin County, Montana (T4N, R6E) has been identified as the genus *Trigonarca*, an Upper Cretaceous shallow marine bivalve (W. A. Cobban, personal communication).

The unit forms a persistent zone a few feet thick across the northern part of the Crazy Mountains Basin and it gets thicker, to about 28 feet or more, in the central part of the Bridger Range area. It was not found in Yellowstone Park or in the Livingston area. A fossiliferous unit is found over a tuffaceous sandstone unit thought to be Frontier west of Yellowstone Park (Wilson, 1970 and VII in Fig. 1 and 2). There is a greater diversity of fossils there than in the Bridger Range area. That locality is not considered to have formed a part of the carbonaceous mudstone and coal unit mapped here (Fig. 6). However, paleontological correlations are not complete between the two areas. In Figure 6, the Big Horn Basin carbonaceous shale facies is interpreted to include the black mudstone facies in the Crazy Mountains Basin on the basis of the concentration of plant material at a common interval in the section. The coal seams are shown uncompacted (on a 10X basis) in order to isopach the coal facies with the relatively less compacted

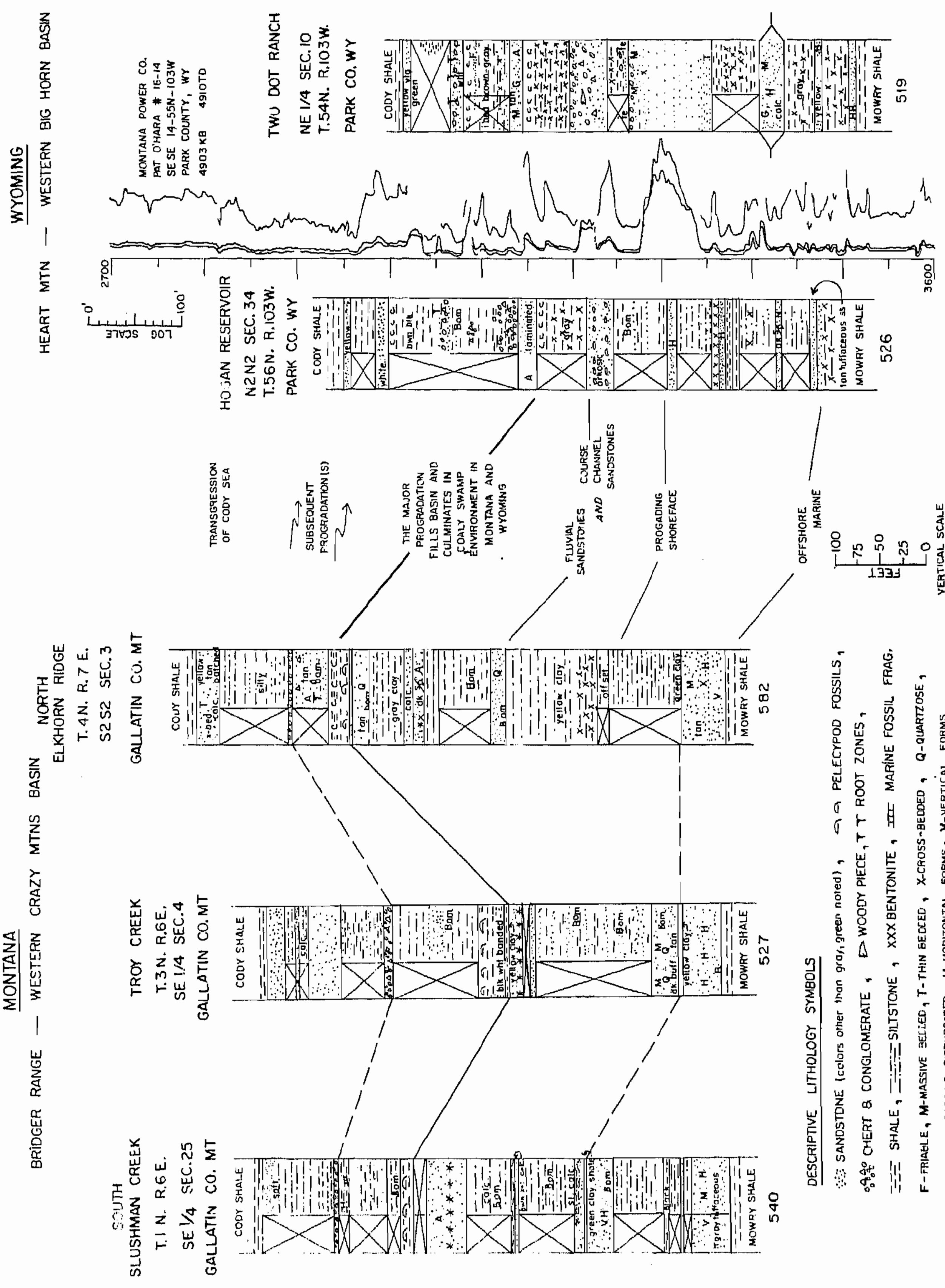


FIGURE 4 MEASURED SECTIONS OF FRONTIER FORMATION AND CORRELATIONS FROM MONTANA TO WYOMING

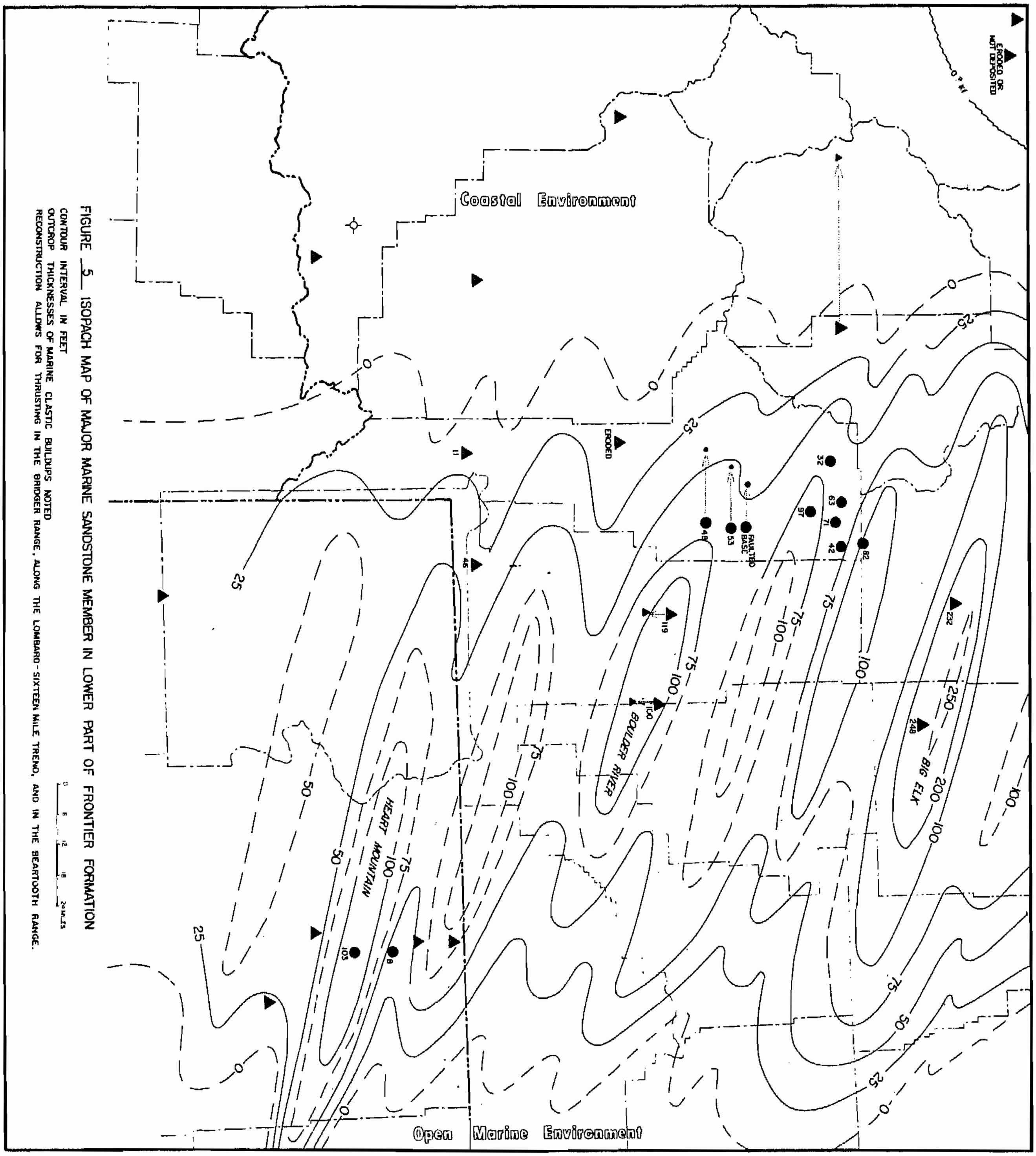


FIGURE 5 ISOPACH MAP OF MAJOR MARINE SANDSTONE MEMBER IN LOWER PART OF FRONTIER FORMATION

CONTOUR INTERVAL IN FEET
OUTCROP THICKNESSES OF MARINE CLASTIC BUILDUPS NOTED
RECONSTRUCTION ALLOWS FOR THRUSTING IN THE BRIDGER RANGE, ALONG THE LOMBARD-SIXTEEN MILE TREND, AND IN THE BEARTOOTH RANGE.

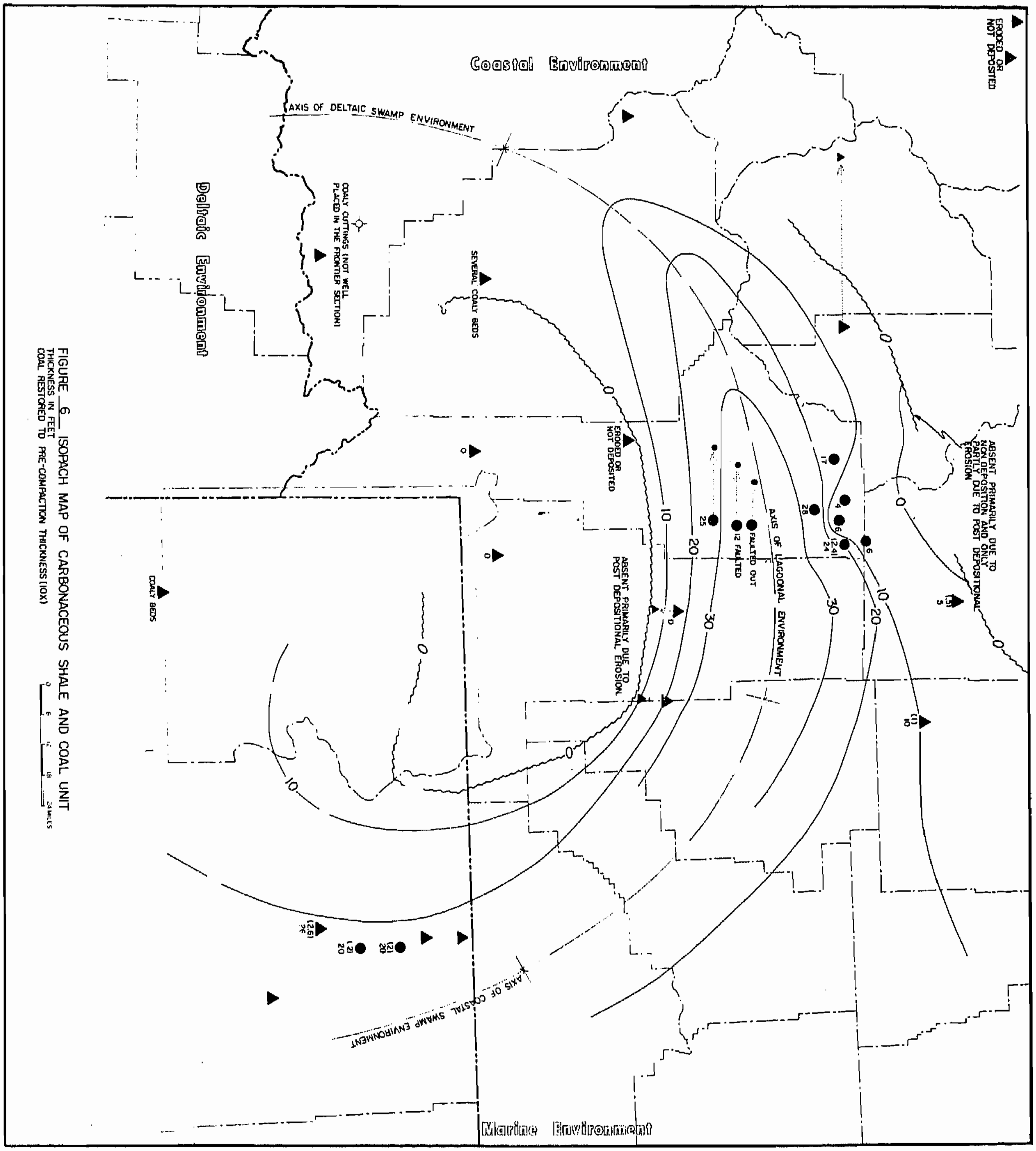


FIGURE 6 ISOPACH MAP OF CARBONACEOUS SHALE AND COAL UNIT
THICKNESS IN FEET
COAL RESTORED TO PRE-COMPACTION THICKNESS (10X)

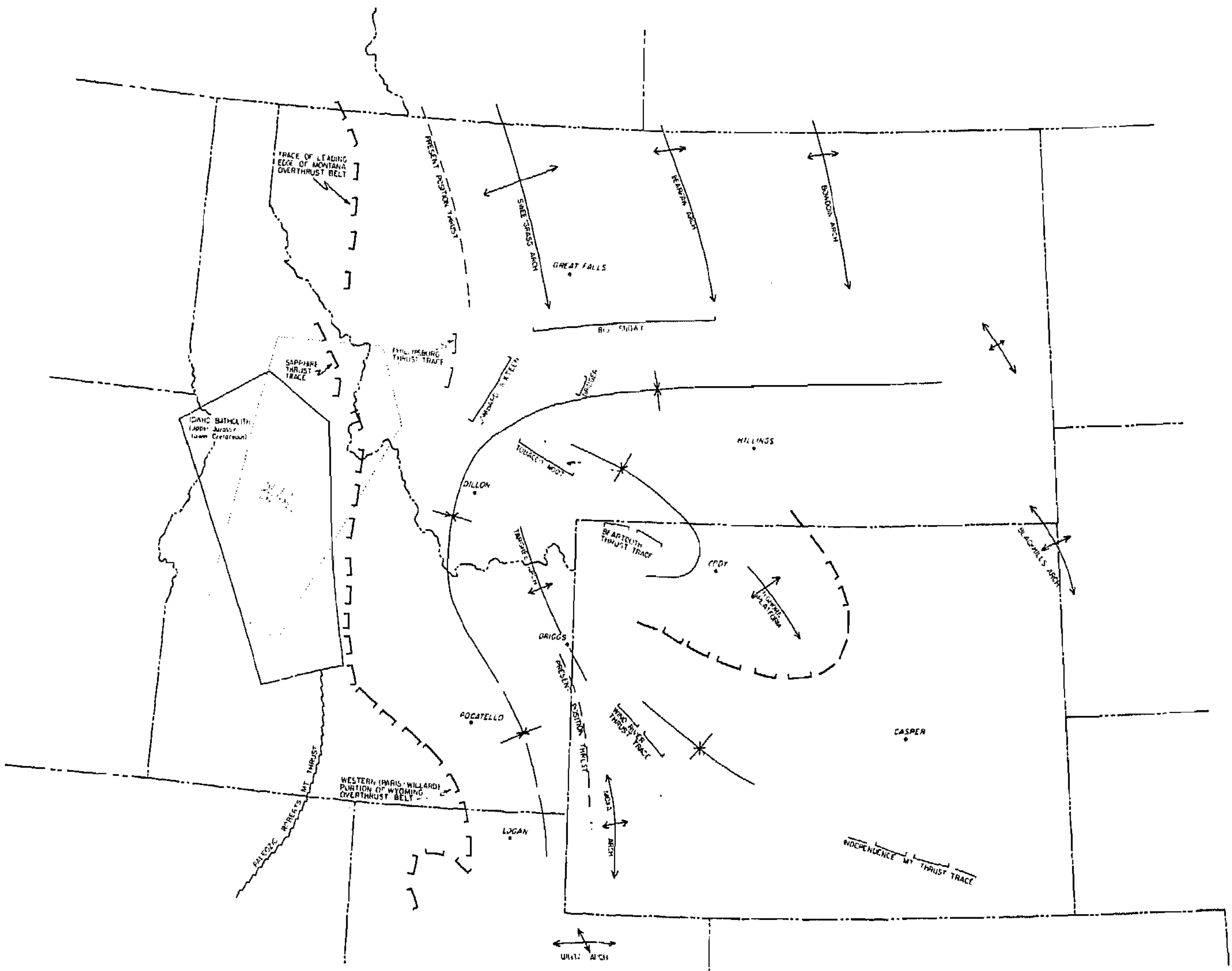


FIGURE 7 PALEOSTRUCTURE MAP

SOME TECTONIC FEATURES THAT INFLUENCED DEPOSITION OF THE FRONTIER FORMATION carbonaceous mudstone facies. The environment of deposition is segmented into a deltaic swamp in southwestern Montana, a coastal lagoon in the Bridger Range area, and a bay on the east near Cody. A hiatus existed during this time in western Montana (Fig. 3) and southward through Idaho (Cobban and Reeside, 1952) and into Utah (Hale, 1962). During progradation the depositional process moved eastward through time, and there was a loss of material in the source areas and an accumulation of it along the delta plain and at the strand zone. The ponded water facies in the Crazy-Big Horn area suggests that a progradational equilibrium was reached and sustained for a time.

CONGLOMERATE AND TOP SANDSTONE UNITS

Throughout the Bridger Range a thick (to about 12 feet), chert pebble conglomerate is associated with the upper part of the formation and several units containing thin conglomeratic lenses are found in the upper two-thirds of the section in the Big Horn Basin.

The conglomerate is composed of oval-shaped pebbles ranging in length from ¼ to nearly 3 inches and is in a matrix of coarse-grained quartz and chert sand. The pebble size averages ½ inch. The conglomerate contains brown, yellow, gray, and white chert pebbles covered with a red to black iron oxide rind. Chalcedony cements the pebbles together, although at various places along strike the unit is well indurated and tightly cemented. Conglomeratic lenses found in the Big Horn Basin contain pebbles up to 6 inches or more and are brown porphyritic andesite as well as chert (Goodell, 1962). The lenses are scattered through the section, more poorly sorted and ungraded, and are interbedded with dark shales. The iron oxide minerals indicate that the material may have been developed originally as a terrestrial "red beds" deposit. Sheet-like gravel trails can be left on beaches by a retreating sea. Thick conglomerates are thought to be best preserved by transgressing seas (Barrell, 1925). Transgression over a surface would bury conglomeratic material but gravels stranded by retreating seas are exposed to fluvial and marine energy and worn to sand-sized grains.

A fine-grained quartzose sandstone (eolian?), up to 22 feet thick, and an upper carbonaceous shale zone is found in the northwest Big Horn Basin. Some thin coarse sandstone beds were observed in the Bridger Range and at this general zone but no correlation could be made (Fig. 4). At the top of the formation is a very fine-grained, thin-bedded to laminar, yellow sandstone up to 25 feet thick. This unit represents the marine environment in a major transgression westward. The marine Cody Shale overlies this unit.

TECTONIC FACTORS

There are many tectonic implications to the stratigraphic relations and sedimentologic features mentioned here. The thick marine sandstone units may be structurally as well as hydrologically controlled as to length, width, thickness and position on the western shoreline (Fig. 5). An age progression is suspected and it, too, could be a product of some tectonic motion during the Cenomanian stage. Paleontological evidence is needed, but it seems that the thick sandstones are younger southward across the basinal area. The Big Elk, for example, is much lower in the Frontier section than the Heart Mountain is. It is suggested that uplift across central Montana caused a slight withdrawal of the sea southward into Wyoming and that these thick marine sandstones were deposited as regressive sedimentary bodies. The ponded water environment of fossil mudstone and coal seems well explained by tectonics (Fig. 6). This facies was bounded on the north by an emergent to partially erosional area and on the south by a broad developing uplift that probably caused erosional stripping. Between these two places a re-entrant from the sea developed.

Volcanism extending from British Columbia to Nevada and early thrusting in Utah, Idaho, and western Montana is thought to have generated the Frontier sediment. The sediment was moved to the coast and was prograded into the sea. The coastline migrated eastward as the Frontier delta developed. The strandplain (Fig. 5) was shifted eastward and a lagoonal facies (Fig. 6) was prograded into the area. Compressional tectonism probably affected certain ancient zones of weakness. The traces of some of the features are shown in Figure 7. The Big Horn Basin and Crazy Mountains Basin may have been related at this time as a crease on a broad, gentle feature called the Big Horn Platform in this paper. The crease was created by slight relative motion along the Tobacco Root and Beartooth thrust traces. The main deltaic mass is visualized as being steered across Wyoming by the Big Horn Platform. The result of subtle adjustment along these trends would be to control the direction of the delta growth and to produce a structural axis of deposition that coincides with the coal basin mapped in Figure 6. The movement implied may only have been slight and there may have been none at all at this time. The Frontier sediment is mostly volcanic in nature. Uplift might precede volcanism as a general rule but thrusting is not necessary.

Post-Frontier transgression in the Crazy-Big Horn area shifted the ponded water environment to the west. The Jens Formation near Drummond is a black mudstone facies similar to the Frontier mudstone unit in the Crazy Mountains Basin. Notice (Fig. 3) how a hiatus follows closely after deposition of the Jens just as a hiatus occurred in the Crazy-Big Horn area when the mudstone environment of the Frontier was sustained there.

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