THE GEOLOGICAL SURVEY OF WYOMING

DANIEL N. MILLER, JR., State Geologist

PRELIMINARY REPORT NO. 13

Structural Geology of the Eastern Half of the Morgan Quadrangle, the Strouss Hill Quadrangle, And the James Lake Quadrangle, Albany and Carbon Counties, Wyoming.

BY

D. L. BLACKSTONE, JR.

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by

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OCTOBER, 1973

STATE OF WYOMING

1933

GEOLOGICAL SURVEY

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View northwest across south end of Seven Mile anticline.
Lewis shale in foreground, Rock Creek Ridge on skyline in background.

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STRUCTURAL GEOLOGY OF THE EASTERN HALF OF THE MORGAN QUADRANGLE,

THE STROUSS HILL QUADRANGLE, AND THE JAMES LAKE QUADRANGLE,

ALBANY AND CARBON COUNTIES, WYOMING

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D. L. Blackstone, Jr.*

INTRODUCTION

The writer has been engaged in a continuing study of the geologic structure and the structural evolution of the Laramie Basin since 1955. The geologic map here presented fills a void (see Fig.2) in the existing published data dealing with the eastern flank of the Medicine Bow Mountains north of the Centennial Valley. Mapping has been carried on in the eastern third of the Morgan quadrangle so that the trace of the Arlington thrust complex could be included and related to the adjacent structures to the east. Rocks lying above the Arlington fault plane are Precambrian in age and have been mapped in reconnaissance by Houston (1968). The present mapping included the western one-third of the James Lake quadrangle in order that the structural geology here presented can provide adequate data for cross sections extending from the Precambrian rocks of the Medicine Bow Mountains across the flank of the Laramie Basin.

Geologic mapping in these quadrangles has been carried on intermittently since 1962. Intensive field work in the area was done in the summer and fall of 1969. All mapping was done on vertical aerial photographs at a scale of approximately 1:42,240, and was plotted almost simultaneously upon the $7\frac{1}{2}$ minute topographic series of the U. S. Geological Survey, scale 1:24,000.

The writer wishes to acknowledge the support of the Geological Survey of Wyoming in this project. Numerous discussions concerning the geology have been held with James A. Barlow, Jr., Arnold C. Cunningham, R. S. Houston, John S. King, S. H. Knight, J. D. Love, Malcolm McCallum, Brainerd Mears, Jr., Frank Royse, Jr., and W. H. Wilson. The ideas expressed are however those of the writer, and are his responsibility.

The basic mapping of the Precambrian rocks which crop out in the Morgan quadrangle has been done by John S. King (1963) and by R. S. Houston (1968). The mapping of the Precambrian rocks was sponsored and funded by the Wyoming Geological Survey as a part of a regional study of the Medicine Bow Mountains in Wyoming. The inclusion of this mapping in the present project has been done with the permission and cooperation of the individuals responsible.

The writer wishes to acknowledge subsurface well data provided by Chevron Oil Company, Pan American Petroleum Corporation, and A. C. Cunningham.

Particular thanks should be extended to Mr. Robert Tschudy, U. S. Geological Survey for examination and identification of palynological material.

The cooperation of ranchers in the area is gratefully acknowledged.

PREVIOUS INVESTIGATIONS

No geologic mapping on this scale has been published for the quadrangles in question. Generalized mapping from several sources was presented by Houston and others (1968) at a scale of 1:63,360. Adjacent mapping includes that by Hyden and others in the Arlington quadrangle (1967) and Hyden in the Bengough Hill quadrangle published in 1966. The mapping of the Rex Lake Quadrangle to the south by Blackstone was published in 1970. Two producing oil fields lie within the map area - Seven Mile and Quealy Dome. Summaries of the geology of these fields are presented by Espach and Biggs (1960), West (1953), and in the Wyoming Geological Association Symposium on Wyoming oil fields.

Other investigations dealing with the geology of the region include those by Siebenthal and Darton (1909), Darton (1910), Beckwith (1933), Houston and others (1968), Knight (1953) and Mears (1953), and de la Montagne (1953).

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Compilations of published and unpublished data for Albany County and Carbon County are found on the county geological maps by Love and Weitz (1953) and Weitz and Love (1952). Other sources less directly related are listed under References.

LOCATION

The area mapped is shown on Fig. 1 and lies in T.'s 16, 17, and 18 N., R.'s 76, 77, and 78 W., 6th P. M. in Albany and Carbon Counties, Wyoming. The area is accessible by either Interstate Highway No. 80 or Wyoming State Highway No. 0104, and lies approximately 26 miles in a northwesterly direction from Laramie, Wyoming.

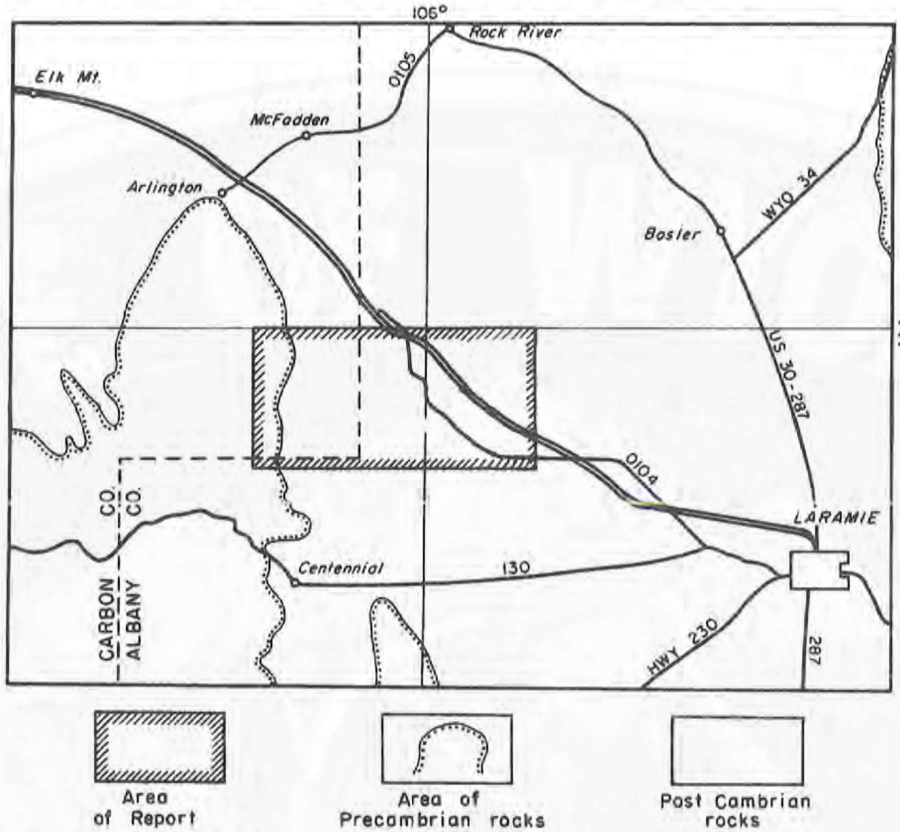

FIG. 1 INDEX MAP - Preliminary Report No. 13

The base map consists of the east half of the Morgan quadrangle, the Strouss Hill quadrangle, and the James Lake quadrangle. The quadrangle sheets are from the $7\frac{1}{2}$ minute topographic map series of the U. S. Geological Survey at a scale of 1:24,000. An index to adjacent quadrangles and areas mapped is presented in Fig. 2.

GENERAL GEOLOGY

The area mapped lies on the eastern flank of the northern Medicine Bow Mountains and includes the overthrust faults related to that uplift, as well as major anticlines which are subsidiary to the mountains. The eastern part of the area includes the gently dipping strata that descend into the Laramie Basin. Rocks exposed range in age from Precambrian to Recent but no rocks are present of Lower Paleozoic age since the Pennsylvanian Fountain-Casper Formation overlies the basement.

Exposures in the area are for the most part poor because of either extensive forest cover at higher elevations or wide spread erosion surfaces and alluviated areas east of the mountain front. Distribution of rock units has in some cases been interpreted from drill records.

Special problems exist relative to the Late Pleistocene history and will be treated in a cursory fashion under stratigraphy. Emphasis has been placed on bedrock rather than surficial geology, and the map reflects an attempt to indicate what bedrock is present throughout the area despite the cover. Photo interpretation has been used extensively.

STRATIGRAPHY

General

The exposed core of the Medicine Bow Mountains consists of rocks of Precambrian age which have been discussed in some detail by Houston and others (1968). The distribution of such rocks in the area covered by

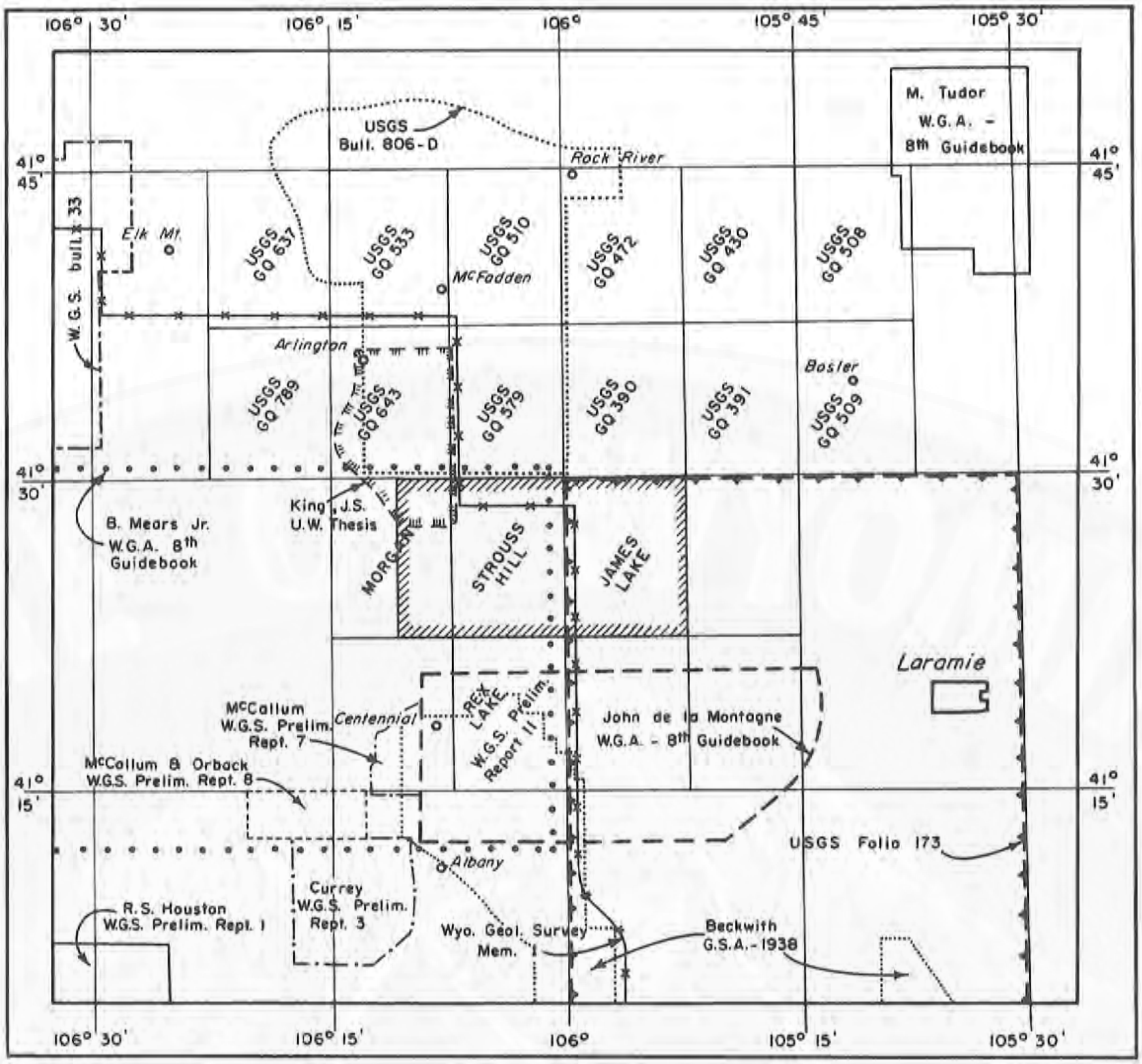

FIG. 2

Index to Geologic Mapping

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this report is taken from Houston and others (1968) and from King (1963), and only brief descriptions of the rock types present will be presented here.

The Precambrian basement rocks are overlain by sedimentary rocks of Pennsylvanian age which are in turn overlain by a rather complete succession of late Paleozoic and Mesozoic rocks. Only the Paleocene, Eocene, and Quaternary epochs of the Cenozoic Era are definitely represented. Quaternary deposits are widespread and blanket large areas.

No detailed measured sections are presented because the succession is so poorly exposed as to make detailed stratigraphic studies almost impossible. The formations contain enough units of distinctive lithology to make mapping possible with reasonable confidence. Considerable attention has been given to mechanical logs of tests drilled for oil and gas within the area in order to establish proper thickness of stratigraphic units to be used in structural interpretation.

Table I presents pertinent information as to the formations present, their lithologic characteristics and thickness, and significant features. For further details the reader should consult papers dealing with specific stratigraphic units.

Stratigraphic evidence concerning the age and development of the geologic structure is of utmost importance. For this reason the Late Cretaceous and Cenozoic formations will be discussed more fully. Information concerning the Pleistocene history is new and warrants elaboration beyond the information given in Table I.

Table I. Stratigraphic units present in the Morgan, Strouss Hill, and James Lake quadrangles, exclusive of rocks of Precambrian age.

Age			General Lithology	Thickness
CENOZOIC	Quaternary	Recent	Alluvium, colluvium and landslide deposits, eolian deposits, and stream gravels.	
		Pleistocene	High level boulder deposits, pediment gravels, glacial till(?), mass gravity deposits, and boulder terrace deposits.	
	Tertiary	Olig. (?), Mio. (?) Plio. (?)	Tertiary undivided - Tuffaceous siltstone, sandstone, and conglomerate.	200'+
			Major unconformity	
		Eocene	Wind River Formation - Variegated claystone, sandstones, conglomerates.	400'+
			Major unconformity	
		Paleocene	Hanna Formation - Basal conglomerate with quartzite boulders, arkosic sandstones, fossil wood.	800'+
			Major unconformity	
MESOZOIC		Cretaceous	Medicine Bow Formation - Sandstones, shales, carbonaceous shale, coals, ironstones. Pelecypod fauna. Only basal part present.	400'+
			Fox Hills Sandstone - Sandstone, gray, fine grained. Mapped with Lewis shale.	2200-2600'
			Lewis Shale - Shale, gray, marine, containing sandstone, fine grained, soft, local concretion zones.	
			Mesaverde Formation - Pine Ridge Sandstone Member at top (coal bearing). Sandstones brown, siltstones, and gray shales. Thick, yellow weathering sandstones near base.	1200-1300'
			Steele Shale - Shale, gray, marine. Persistent sandstone 1300' above base has been locally called "Shannon" sandstone.	2600'+
			Niobrara Formation - Calcareous shale with three well defined marlstone units.	500'
			Frontier Formation - Wall Creek Sandstone Member at top, "salt and pepper", sandstone, chert pebbles and shark teeth (at base). Shale gray, changing to black at base. Septarian concretions in basal shale.	10' 450'
			Mowry Shale - Shale, siliceous, weathers silver gray. Fish scales common. Numerous bentonite layers.	150'
			Muddy Sandstone - Sandstone, medium grained.	20'
			Thermopolis Shale - Shale, black, marine containing thin lenticular olive green sandstone layers.	110'

Cretaceous

Medicine Bow Formation (Foote Creek of Hyden and others, 1965)*

The youngest exposed rocks of Cretaceous age within the mapped quadrangles is a sequence which has been assigned by the writer to the Medicine Bow Formation. The unit crops out around the margins of the Mill Creek syncline, conformably overlies the Lewis Shale, and is characterized by light colored clay stones, light yellow concretionary calcareous sandstones, coals and carbonaceous shales, and a brackish water fauna containing abundant pelecypods and oysters of Late Cretaceous age.

The most complete sequence of the Upper Cretaceous rocks in the area crops out on the South Fork of Mill Creek in sections 6 and 7, T.16 N., R.77 W., and section 12, T.16 N., R.78 W. At this locality it is possible to observe a rather complete section of Cretaceous rocks ranging upward from the Mowry shale through the lower part of the Medicine Bow Formation. Davidson (1966) described the Lewis Shale at this locality and reported a thickness of 2600+ feet, and established the Late Cretaceous age of the strata on the basis of marine invertebrate fossils.

Overlying the Lewis Shale conformably is a sequence 576 feet thick which has been assigned to the Medicine Bow Formation by Houston and others (1968, p.96) and described in detail. The geologic age of these rocks was established on the basis of palynological material identified by Robert H. Tschudy of the U.S. Geological Survey (Houston and others, 1968, p.97).

Justification for applying the name Medicine Bow Formation to these rocks which are 50 miles southeast of the type locality of the formation, must be based on the usual indirect stratigraphic criteria. Unfortunately the application of a new stratigraphic name - Foote Creek Formation to rocks of Late Cretaceous age by Hyden, McAndrews, and Tschudy (Hyden and others, 1965) has compounded the problem.

The name Medicine Bow Formation was applied by Bowen (1918, p.280) to a sequence of rocks 6,200 feet thick, conformably overlying the Lewis Shale at a locality in T.'s 22 and 23 N., R.'s 84 and 85 W. along the North Platte River above the mouth of the Little Medicine Bow River. The lower part of the formation is composed of claystones, ironstone concretions, and several coals. The age of the formation was established as Cretaceous on the basis of invertebrate fossils, vertebrate remains, and plant remains.

The Medicine Bow Formation subsequently was recognized and mapped in the Hanna and Carbon Basins (Dobbin Bowen and Hoots, 1929); in the Elk Mountain district (Beckwith, 1941); but was not recognized in the Rock River district (Dobbin, Hoots, Dane, and Hancock, 1929). Knight (1954) correlated strata on the south flank of the Mill Creek syncline in secs. 28 and 29, T.16 N., R.77 W., with the Medicine Bow Formation on the basis of stratigraphic position and the presence of a brackish water fauna and coals. Blackstone (1970) continued this usage. Love and Weitz (1953) indicated the existence of the formation as far south as T.16 N., R.77 W. near the Rex Lake oil field.

The strata herein described and mapped as Medicine Bow Formation bear the same relationship to the marine Lewis Shale as exists at the type locality of the Medicine Bow - to wit, a conformable relationship reflecting a change in environment from marine to brackish water and non-marine coal swamp. Material collected from coals and carbonaceous shales in section 7, T.16 N., R.77 W., cropping out on the South Fork of Mill Creek were submitted to Mr. Robert H. Tschudy, U.S. Geological Survey, to be examined for palynological specimens. Mr. Tschudy reported as follows: (Houston and others, 1968, p.97)

> Both samples yielded Late Cretaceous pollen and spore assemblages. The dominant taxon was a monosulcate pollen with characteristic reticulate sculpture. This taxon is common to abundant in the Cretaceous Medicine Bow Formation near its type locality. In both

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* Subsequent to the completion of this report Gill, Merewether and Cobban (June 1970) recommended changes in nomenclature for certain Upper Cretaceous and Lower Tertiary rock units in south-central Wyoming. Specifically the abandonment of the names Foote Creek and Dutton Creek was recommended. The writer had independently reached the same conclusions and had incorporated the evidence in this report.

The writer has discussed specific situations in regard to the problem of nomenclature and has therefore retained in this report the evidence for his conclusions, though part of the argument parallels that of the workers noted above.

samples this taxon exceeded 25% of the total pollen and spore flora. Other pollen species characteristically limited to the Upper Cretaceous were found. These include species of Proteacidites and Aquilapollenites and a new genus we have coded as C3-rt30. More than 25 distinct taxa were recognized in each of the two samples. No fossils characteristically limited to the post-Cretaceous were seen.

There seems no doubt that a mappable unit characterized by coals and dated as Late Cretaceous overlies the Lewis Shale in the area. The equivalency of these rocks with the Medicine Bow Formation is considered by the writer to be adequately established.

Unfortunately the late Harold Hyden and his co-workers, over the objections of geologists working in the area, proposed a new formation name - Foote Creek - for rocks previously mapped as Medicine Bow Formation.

The reasons advanced by Hyden (Hyden and others, 1965) in defense of the new formation name are listed below:

1. Beds cannot be traced from basin to basin to establish definite correlation.
2. The great difference in thickness (as much as 20,000 feet in the Hanna Basin versus about 800 feet in the north part of the Laramie Basin).
3. Probable difference in source areas.
4. An indicated slight age difference in specific units.

The points will be discussed in order.

(1) The Medicine Bow Formation cannot be directly traced by continuous outcrop to the Laramie Basin. The same may be said of hundreds of isolated outcrops of any formation, and cannot be considered a valid criticism against equivalency.

(2) The great difference in thickness is due to the fact that only the basal few hundred feet of the Medicine Bow are present, and that the upper contact is one of regional unconformity with the Hanna Formation so that the overlying unit frequently rests on Lewis Shale or older rocks with no intervening Medicine Bow.

(3) Difference in source areas for the Medicine Bow Formation and the proposed Foote Creek Formation was not demonstrated since only the source of the Foote Creek is mentioned.

(4) The variance in the age of the proposed formation is perhaps the most invalid of his arguments and must be discussed at some length.

The variance in age is based on samples collected by Hyden (and others) and identified by W. A. Cobban and R. H. Tschudy. The samples are from widely separated surface outcrops, and from one core hole.

The type section of the proposed Foote Creek Formation is located in NE $\frac{1}{4}$ sec. 13, T. 20 N., R. 79 W., and the NW $\frac{1}{4}$ sec. 18, T. 20 N., R. 78 W., Carbon County, Wyoming, on the east flank of the Rock River anticline. Both macrofossils and palynological material establish a Late Cretaceous age (Hyden and others, 1965, p. K 4 and K 5).

A core hole was drilled to a total depth of 450 feet in the SE $\frac{1}{4}$ sec. 32, T. 19 N., R. 77 W. (Hyden, 1966), and the location is shown on the U. S. Geological Survey Map GQ-479 - Bengough Hill. The core descriptions are presented in U. S. Geological Survey Bulletin 1194-K, pages K 7 and K 8. The description of rocks assigned to the Foote Creek Formation begin at Unit 33, depth 249.0 feet and continue to Unit 4 at a depth of 444.5 feet where the hole is reported to have entered the Lewis Shale.

In the text (p. K 5) reference is made to the U. S. Geological Survey Paleobotanical location D3194, and in the core descriptions collections are reported as follows:

Units	U. S. G. S. Paleobot. location	Depth	Thickness
18	D3194A	328.0	3.8
17	D3194B	332	6.1
12	D3194C	351.0	2.1
7	D3194D	396.0	7.0
6	D3194E	403.5	3.3

All samples are reported to have yielded excellent palynological specimens. Hyden (Hyden and others,

1965) states:

"These genera indicate a Paleocene age for the Foote Creek Formation at this locality."

At all other localities where the Foote Creek Formation was mapped on the surface the age was established to be Late Cretaceous. Locality numbers and locations are found on U.S. Geological Survey GQ Maps in this area. (See index map - Fig. 2 this paper). One exception to the Late Cretaceous age of the Foote Creek Formation in surface exposures was reported. At the Terry Mine in sec. 18, T. 19 N., R. 77 W., Pierce Reservoir quadrangle, U.S.G.S. GQ Map 510, plant leaves indicated a Paleocene age.

The writer has no reason to dispute the determination of the geologic age at the localities in question. He does however seriously challenge the mapping of units which are dated. The confusion as to age results from poor mapping in the field, and incorrect identification of the rocks from which the fossils were collected. The incorrect mapping exists in the Bengough Hill and Pierce Reservoir quadrangles and the reader is referred to U.S. Geological Survey Map GQ Nos. 510 and 579 (See Fig. 2) to review the mapping which has been presented.

About one and one-half miles south of the U.S. Geological Survey core hole, (sec. 32, T. 19 N., R. 77 W.) in the SE $\frac{1}{4}$ sec. 8, T. 18 N., R. 78 W., a coal bed four feet thick and the abandoned adit of a coal mine are shown as occurring in the Foote Creek Formation, and as being the correlative of rocks of the same formation lying about one-half mile northwest of the core hole. Other outcrops of the Foote Creek Formation are mapped north of King Reservoir at the site of the Fry and Terry Mines.

The strata mapped as Foote Creek Formation in sec. 8, T. 18 N., R. 78 W., are actually a coal bearing unit in the Lewis Shale and lie about 1,500 feet above the base of the Lewis Shale which is approximately 2,200 feet thick in this area. At Cooper Creek just south of the outcrops under discussion, the coal bearing unit in the Lewis Shale is overlapped unconformably by the basal conglomerate of a unit considered by the writer to be the Hanna Formation. Northward from section 8 the coal bearing unit in the Lewis can be traced on aerial photographs northward and can be plainly seen to pass through the east half of sec. 31, T. 19 N., R. 77 W., at a point about a mile west of the core hole. The map relationships are shown on Fig. 3.

Since the Lewis Shale is approximately 2,200 feet thick in this area the outcrops mapped as Foote Creek Formation along the Albany-Carbon County line in sec. 32, T. 19 N., R. 77 W., are probably upper Lewis which would agree with the information presented in Cross Section A - A', U.S.G.S. GQ 579 (Bengough Hill quadrangle) and with the structure contours shown on that map.

The writer believes that the map evidence warrants the conclusion that the strata drilled in the U.S. Geological Survey core hole were not Foote Creek Formation. The upper 203 feet drilled consisting of coarse sandstones and conglomerates is part of the Hanna Formation, and the rocks encountered in the lower part of the hole are a fine grained facies of the Paleocene Hanna Formation. The interpretation simply is that there is <u>no Foote Creek Formation at this locality</u>, and therefore there cannot be a part of the unit which is of different age than the Late Cretaceous rocks as reported at the type locality.

The coal bearing strata at the Fry Mine and continuing north eastward as depicted on the U.S. Geological Survey Pierce Reservoir quadrangle Map GQ 510 are probably improperly identified as Foote Creek, since the only fossil collection from the coal beds yielded material indicating a Paleocene age. The strata probably are equivalent to the coals drilled in the core hole, and belong to the Hanna.

If there is no variation in the age of the unit proposed by Hyden then point four of his reasons for a new formation is also invalid.

In conclusion the writer has seen fit to correlate the coal bearing sequence of Late Cretaceous age lying above the marine Lewis Shale and unconformably overlain by a sequence of Paleocene age with the Medicine Bow Formation.

Furthermore, the writer recommends that the stratigraphic term Foote Creek be abandoned as unnecessary.

Cenozoic Era

<u>Paleocene</u>

Hanna Formation (Dutton Creek Formation of Hyden and others, 1965)

A distinctive sequence of strata occupies the deeper part of the Mill Creek syncline, and two narrow synclines lying east and west of the Dutton Creek - Cooper Cove - Seven Mile anticlinal trend. The dominant lithology is arkosic sandstone, much of which is coarse grained. Limonitic concretionary zones are present locally and siltstones are also present. A rather persistent carbonaceous shale unit occurs above the prominent basal

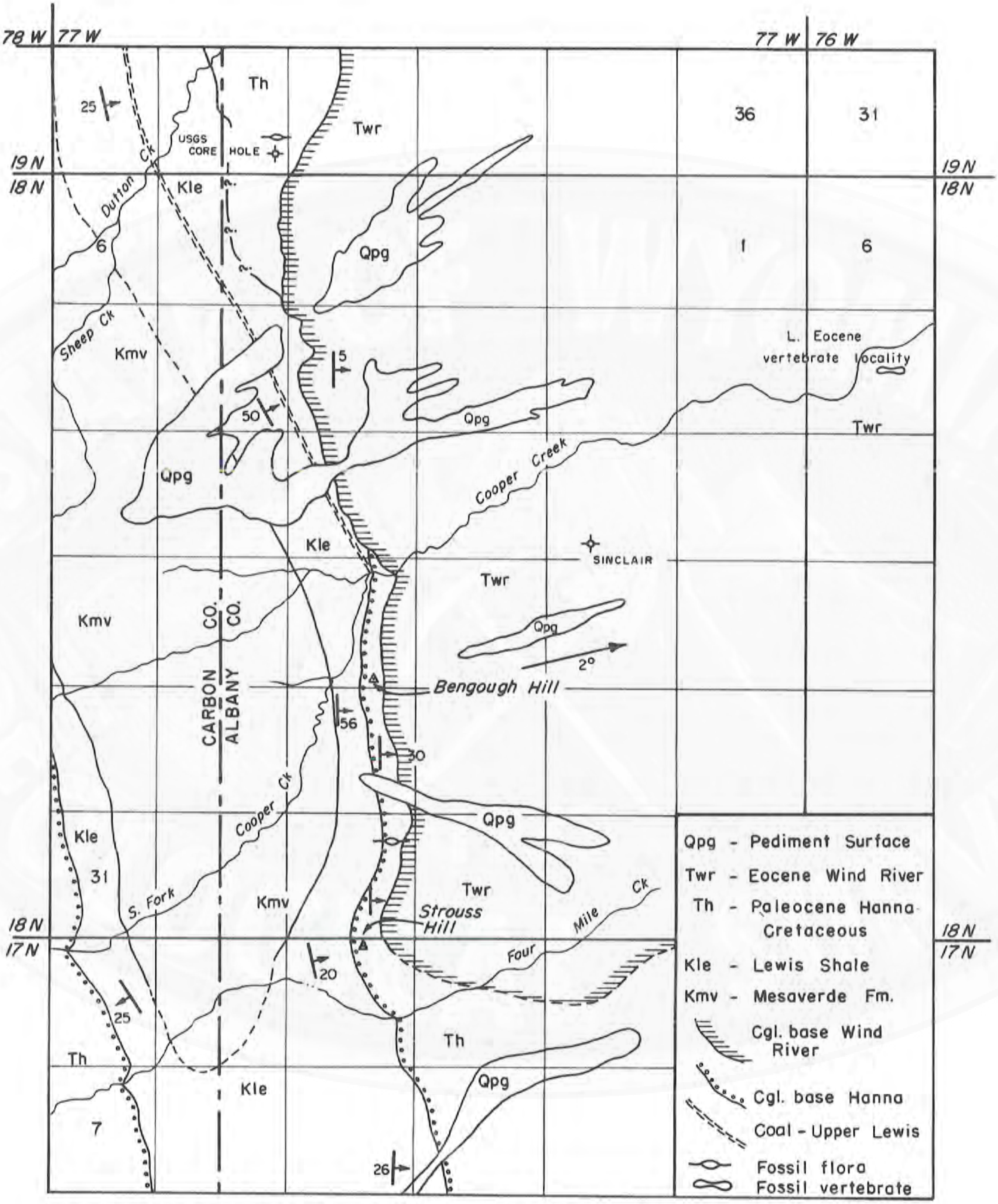


FIG. 3 RELATIONSHIP of HANNA FORMATION and WIND RIVER FORMATION, COOPER LAKE AREA.

conglomerate.

A very striking and at times confusing aspect of this sequence is the presence of conglomerates at the base. The conglomerates appear upon aerial photographs as well defined strike ridges, but on the ground cobbles and boulders derived from the conglomerates strew the slopes and obscure the relationships.

The conglomerates consist of pebbles, cobbles and boulders predominately of quartzite. Cobbles up to 18" in diameter have been observed in place, but much larger boulders up to five feet in length have been observed on the slopes but could not be definitely proven to derive from the conglomerates. The cobbles and boulders in place are well rounded, with many having an almost spherical shape. Pebbles and smaller clasts are subangular in shape in contrast to the more rounded large fragments. The basal phase is usually well cemented with limonitic stained sand forming the rock matrix.

This sequence characterized by a prominent basal conglomerate has been assigned to the Hanna Formation. Reasons for so designating these strata as Hanna rather than using the name Dutton Creek as proposed by Hyden, McAndrews and Tschudy (Hyden and others, 1965, p. K 8) will be developed.

The name Hanna Formation was applied by Bowen (1918) to about 7,000 feet of strata in the vicinity of the coal mining community of Hanna, Carbon County, Wyoming. The formation unconformably overlies the Ferris Formation and was assigned a Paleocene (Fort Union) age on the basis of plant remains (leaves) and invertebrate fossils though Bowen (p. 231) states that some invertebrates near the top resemble a Wasatch fauna.

The Hanna Formation has been stated to be Eocene in age and equivalent to the Greybullian by Wilson, Keroher and Hansen (1959) in Index to the geologic names of North America, but no substantiating evidence for this age is provided. Apparently the assignment of an Eocene age is based on the earlier report of Bowen (1918) which applies only to the uppermost few hundred feet of the original unit. Gill, Merewether and Cobban (1970) consider the formation to be entirely Paleocene in age with some doubt as to the exact part of that time interval that is represented.

The underlying Ferris Formation as defined by Bowen (1918) is in part Late Cretaceous in age and in part Paleocene (Fort Union) thus indicating marked tectonic activity in Paleocene time.

Within the quadrangles mapped there exists an angular unconformity between the conglomeratic series described earlier in this section and the underlying rocks of Late Cretaceous age - Steele Shale, Mesaverde Formation, Lewis Shale and Medicine Bow Formation. It seems appropriate to correlate these rocks with the type Hanna Formation, but several problems must be resolved to justify this usage.

Hyden, McAndrews and Tschudy in 1965 in the process of mapping several $7\frac{1}{2}$ minute quadrangles in the Laramie Basin area, namely the TL Ranch, White Rock, Arlington, McFadden, Bengough Hill and Pierce Reservoirs quadrangles (see Fig. 2), were faced with a choice of names for rocks of similar physical character and stratigraphic position to those here considered as Hanna Formation. These investigators (Hyden and others, 1965) proposed a new formation name - Dutton Creek - for such rocks. The type locality was established along Dutton Creek in secs. 32 and 33, T. 19 N., R. 77 W., Albany-Carbon County, Wyoming. The section is poorly exposed and the authors state:

> The surface section of the Dutton Creek could not be measured at the type locality because of surficial cover, but its thickness is estimated to range from 200 to 500 feet in the mapped area.

No definite base nor top was established on the surface nor is a detailed description provided. A partial section is given on the basis of cores from a U.S. Geological Survey core hole drilled in the SE $\frac{1}{4}$, sec. 32, T. 19 N., R. 77 W. No fossil evidence for age of the formation as reported in this core hole is given. The rocks underlying the Dutton Creek and assigned to the Foote Creek Formation are Late Paleocene in age.

A second core hole drilled by the U.S. Geological Survey in SE $\frac{1}{4}$, sec. 26, T. 20 N., R. 75 W. (Paleobot. loc. D3199), in rocks which were considered to be Dutton Creek Formation yielded palynological material on the basis of which Tschudy (Hyden and others, 1965) assigned a Late Paleocene age to the rocks.

Houston and others (1968) compiled a map of the Medicine Bow Mountains of Wyoming on which rocks lying above the widespread regional unconformity and below the Wind River were designated as Hanna-Ferris Formation undivided. This choice of map units does not adequately handle the situation since it is doubtful on the basis of present work whether any rocks equivalent to the Ferris Formation are present on the east flank of the Medicine Bow Mountains.

Knight (1953) considered the lower conglomeratic sequence of rocks along the flank of the northern Medicine Bow Mountains to be the equivalent of the Hanna Formation and of Paleocene (?) age. Knight did not consider any of the strata to be equivalent to the Ferris Formation of the Hanna Basin.

The present writer's reasons for correlating rocks called Dutton Creek with the Hanna Formation are as follows:

(a) The rocks are marked by a basal conglomerate and lie with angular unconformity upon strata as young as the Late Cretaceous Medicine Bow Formation, and at least as old as the Steele Shale of Late Cretaceous age.

(b) Palynological material collected immediately above the basal conglomerate and identified by Robert Tschudy indicates a Latest Paleocene age for the rocks. Collections were made at:

South Fork Mill Creek - sec. 7, T. 16 N., R. 77 W. (Houston and others, 1968, p. 96)

South end Bengough Hill - $NE\frac{1}{4}$ $E\frac{1}{4}$ sec. 33, T. 15 N., R. 77 W., U.S. Geological Survey Paleobot. Numbers DB-A, DB-B, D4286-A, and D4286-B

Concerning the collection made by the writer at Bengough Hill, Robert Tschudy states (personal communication):

> The presence of <u>Carya</u>, <u>Pistillipollenites</u> (P3-pl), <u>Momipites</u> <u>tenuipolis</u>, (p3-sml B), and BCP3-rllB indicates that these samples are from the upper part of the Hanna Formation of Late Paleocene age. I could find no clear evidence of Eocene age, although I examined the samples carefully with this possibility in mind. I am convinced that these samples are from the uppermost part of the Paleocene. The assemblages resemble most closely assemblages from the Tongue River Member of the Fort Union Formation.

(c) The rocks occupy the same stratigraphic position, and overlie the underlying strata with angular unconformity, and can be traced almost continuously to the type locality of the Hanna Formation.

In conclusion the writer believes that the name Dutton Creek Formation is unnecessary and should be abandoned for the following reasons:

1. No adequate type section has been established.

2. The basal contact is described as "an irregularly channelled surface" (Hyden and others, 1965, p. K 11) which is only a half truth. The regional character of the angular unconformity below the formation is not mentioned, and appears to be misunderstood.

3. The formation is everywhere of Late Paleocene age which places it as at least the time equivalent of part of the Hanna Formation.

4. The physical relationship of the overlying Wind River Formation in the vicinity of the type locality of the Dutton Creek Formation is not properly mapped, or described, with the result that the proposed formation has no defined upper limit.

<u>Eocene</u>

Wind River Formation (?)

The existence of rocks of Tertiary age in the area around Cooper Lake, in a broadly synclinal structural setting, was first recognized by Darton and Siebenthal (1909, p. 43) who suggested that the units might be of either Bridgerian or Wasatchian age. Knight (Nace, 1936, p. 167-68) later described a partial section on Cooper Creek and reported diagnostic Eocene vertebrate fossils. Subsequently additional collections have been made in an area of badlands south of Cooper Creek in sections 7 and 8, T. 18 N., R. 76 W., and a study of this fauna by Prichinello (1970) indicates that these rocks are Greybullian of Early Eocene age.

No other collections of vertebrate fossils have been made in the area, but a carbonaceous shale has yielded plant remains in the same locality where the vertebrate fossils have been collected and these indicate an Eocene age (Knight, personal communication).

Inasmuch as the rocks containing the vertebrate remains lie well above the base of the formation and in a sequence of distinctively reddish-maroon siltstones and claystones,it has become a common practice to consider as Wind River Formation only those strata that exhibit a red color. Because of this usage no consistent base of the formation has been established in the Cooper Lake Basin.

The base of the Wind River Formation within the map area has been placed at the base of a well defined conglomerate or conglomeratic sandstone that crops out in sections 27, 28, and 34, T. 18 N., R. 77 W. and for several miles to the north in the Bengough Hill quadrangle. The matrix is a coarse grained sandstone grading to conglomerate. Visible clasts range upward in size from one fourth inch to over six inches in diameter. The smaller clasts include quartz, fresh feldspar, gneiss, amphibolite and chert. Larger clasts include quartz, much gray chert, red quartzite, white quartzite and occasional crystalline metamorphic rock types. The larger clasts are generally better rounded than the material in the matrix. It is overlain by arkosic, conglomeratic sandstones of yellowish color, and contains occasional large masses of red and green claystone. These arkosic beds are in turn overlain by sandy siltstones with the characteristic red-maroon color reported by Knight (Nace, 1936). There are no continuous exposures of the rocks assigned to the Wind River Formation so a detailed section cannot be obtained. On the basis of surface outcrops, dips, and the record of the Sinclair Oil and Gas Co. Federal 8-Albany No. 1 well in SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 14, T. 18 N., R. 77 W. the thickness of the formation must be at least 400 feet.

In the deeper part of the Mill Creek syncline on the east side of Bunker Hill located in sec. 6, T. 16 N., R. 77 W. there are strata that possibly should be assigned to the Wind River Formation. No Eocene fossils have been reported at this locality,and the exposures are poor.

The physical reasons for establishing the base of the Wind River Formation in this area are shown on Fig. 3. The map is compiled from the current mapping of the writer, mapping by S. H. Knight (personal communication), and modification of previous mapping by the U. S. Geological Survey (Hyden, 1966).

In a belt of outcrops extending in a north-south strip about six miles long and about equally divided north and south of Cooper Creek the critical relationships are well displayed. On the west side of the strip the Mesaverde Formation and the Lewis Shale crop out on the east flank of the Cooper Creek-Seven Mile anticline, and dip to the east at 15° to 45°.

Just south of Cooper Creek there are two prominent north-south trending ridges which are the topographic expression of two conglomerates in the stratigraphic section that are likewise dipping to the east. The lower of these two conglomerates is the base of the Hanna Formation and lies on the marine Lewis Shale, and when traced northward can be seen to truncate a carbonaceous shale section in the middle of the Lewis Shale. Palynological material collected immediately above the conglomerate establishes the age of the rocks as Latest Paleocene.

The upper conglomerate can be traced northward for over nine miles in rather straight-forward fashion. The conglomerate is expressed topographically as a low cuesta with a well defined dip-slope drainage to the east. About one-half mile north of Cooper Creek the upper conglomerate truncates the basal Hanna conglomerate and rests on the strata of the upper Lewis Formation. Approximately two miles further north the Hanna Formation reappears from beneath the upper conglomerate and the outcrop pattern widens to the northwest.

The writer has placed the base of the Wind River Formation at the base of the upper conglomerate shown on Fig. 3 because the physical relationship of an angular unconformity provides a mappable boundary; because it is compatible with the relationship of the Lower Eocene rocks in many parts of Wyoming; and because the section appears to be continuous upward to dated Eocene rocks.

Oligocene, Miocene and Pliocene

Any discussion of the stratigraphy of the area must take into account the rather scattered occurrences of rocks of Late Tertiary (?) age in and around the northern Medicine Bow Mountains. The limited extent of these rocks and the limited amount of vertebrate material for dating the rocks leaves room for a good deal of speculation concerning the Late Tertiary history.

Beckwith (1938) documented the existence of rocks of Oligocene age (Chadronian) at the south end of the Centennial Valley lying with strong angular unconformity upon rocks of Paleozoic, Mesozoic and Precambrian age, post-dating the major structural deformation.

No dated rocks of Miocene or Pliocene age exist in the northern Medicine Bow Mountains,though some inferences regarding possible correlation have been made by McCallum (1968) and Houston and others (1968).

Rocks of possible Late Tertiary age occur in Rock Creek valley in fault contact with Precambrian rocks in sec. 17, T. 17 N., R. 78 W. as originally reported by Knight (1953), and later mapped by King (1963) and

Houston and others (1968). The rocks consist of light colored tuffaceous sediments with conglomerates of locally derived rocks. No fossils have been found in these strata to establish their age. King (1963) considered the rocks to be Miocene (?) in age,and Houston and others (1968) assigned them to the Miocene-Pliocene North Park Formation.

The writer has indicated these deposits as Tertiary undivided, with the belief that they are Miocene or younger in age.

Quaternary

General

The geological history of this period of time warrants intensive study, but the writer has mapped only such Quaternary features as are prominent and rather self evident, and has made no effort to present a map which would fully delineate all the features of the Pleistocene and Recent history. The distribution of the rock units beneath the Quaternary and Recent deposits has been emphasized. There are extensive areas covered by a thin veneer of debris which might be mapped as colluvium, but extensive use of such a map symbol would obscure the basic structural relationships and therefore has been avoided.

Pleistocene

Pre-Wisconsin pediments

Prominent geomorphic features of the area are the surfaces of low relief sloping away from the mountain front capped by coarse to fine grained, partially cemented gravels, and lying at relatively high elevations. The surfaces truncate steeply dipping sedimentary strata, but do not extend onto the Precambrian rocks. Such surfaces have been considered as pediments and the gravels have been mapped as pediment gravels (Qpg.-Plate 1). De la Montagne (1953) described comparable erosion surfaces a few miles to the south near Big Hollow and considered them to be pre-Wisconsin in age. No radiometric dates nor age determinations based on fossil remains are available for these surfaces,so their probable age is based on general stratigraphic considerations and more critically on topographic considerations. The pediment at the highest elevation on the east flank of the Medicine Bow Mountains is that described by Dobbin, Hoots, Dane, and Hancock (1929) as the Arlington terrace and considered by them to be of Pliocene or Pleistocene age. The surface can be traced north-eastward from the mountains for a distance in excess of 15 miles.

Wisconsin (?) glacial deposits

The area surrounding Medicine Bow Peak in the northern Medicine Bow Mountains was severely glaciated during Wisconsin time. An ice cap accumulated there, and valley glaciers extended outward radially from this center down all major drainages. The age and distribution of ice has been discussed by Atwood (1937), Mears (1953), de la Montagne (1953) and McCallum (1962). The eastward limit of this glacial ice cap has long been considered to have been the Rock Creek Valley west of Rock Creek Ridge (Atwood, 1937).

On the basis of geomorphic phenomenon lying east of Rock Creek Ridge the writer believes that glacial ice moving eastward from the Medicine Bow Peak area overrode the ridge and flowed down the east flank into the existing valleys. The evidence for such a distribution pattern of ice consists of both depositional and erosional features which are described in the sections immediately following.

Wisconsin moraines (?)

Three irregular deposits of material that may be till have been mapped by the writer. The best defined of the deposits extends southward in a broad arc from Four Mile Creek, across the valley of Seven Mile Creek and into the headwaters of the North Fork of Mill Creek (Plate I). Lost Lake lies west of, and behind the crest of the ridge underlain by the most continuous deposit. The material appears to be poorly sorted, bouldery debris of Precambrian rock types, resting on tilted older sedimentary rocks. The topographic form is a well defined ridge and suggests a terminal moraine of an ice lobe. The area lying west of the ridge is topographically rather smooth, heavily timbered, and the surface is covered with large quartzite boulders. In the valley of Seven Mile Creek at and west of the topographic ridge there are scattered outcrops of sedimentary strata down to and including the Casper Formation.

A second much less well defined ridge is present in secs. 1 and 2, T.16 N., R.78 W. between the Middle and South Forks of Mill Creek. Here a fairly well defined topographic ridge extends from an elevation of 9,400 feet down to 8,900 feet, is arcuate in form, and is composed of bouldery debris.

A third area of what may be till is found in a series of landslide scars at the headwaters of Seven Mile Creek at an elevation of 10,000 feet. (Figs. 4A - 4B) The deposit is light colored with a fine sandy matrix containing boulders of quartzite, and has an unsorted appearance.

On the basis of topographic form, and the bouldery composition of the material the writer has classified these deposits as till (?), and has so indicated them on the geologic map.

Fig. 4 A. View north across Seven Mile burn toward Rock Creek Ridge. Camera located near NE SE sec 21, T. 17 N., R. 78 W. Slump scar in bouldery deposit, possibly morainal, right center.

Fig. 4 B. View north, close up of bouldery deposit shown in Fig. 4 A

Mass gravity deposits

The geologic map indicates an extensive area in which the bed rock has been involved in mass gravity movement and/or solifluction. The topographic evidence for such movement includes sag ponds, hummocky topography, scroll ridges, and lobate tongues of displaced material, and almost complete lack of bed rock outcrops. The area of such deposits extends from Four Mile Creek southward to beyond the southern boundary of the map area up onto the ridge south of the South Fork of Mill Creek. That part of the area lying west of the morainal (?) ridges exhibits less evidence for mass gravity movement than that lying to the east. Within the area of rather pervasive mass movement there are later distinct individual landslides than can be defined by use of aerial photographs.

Boulder covered terraces

In the major stream valleys leading eastward from Rock Creek Ridge there are broad terrace like surfaces lying above present stream level which are strewn with quartzite boulders up to six feet in diameter. The concentration of these boulders near the mountain front within existing valleys and reflecting rather rapid downcutting suggest that they resulted from large volumes of melt water flowing away from glacial ice. A particularly good example of this type of deposit is found on Four Mile Creek just northwest of the Seven Mile oil field. Dobbin and others (1929) report similar deposits on Rock Creek and Three Mile Creek to the north. A definite outwash plain exists east of the terminal moraine on Libby Creek (Blackstone, 1970, de la Montagne, 1953, and McCallum, 1962).

High level boulder deposits

In addition to the above described features there are puzzling boulder deposits which may be of glacial origin. On the summit of Rock Creek Ridge at an elevation of over 10,000 feet, at Rock Creek Point, and at the ridge crest a mile further south there are deposits of large quartzite boulders. There are no exposures known to the writer where the internal character of the deposit may be determined but on the surface there is a range in size of boulders from a few inches to over six feet. The upper surface of the deposit is relatively smooth and shows little local relief. Many boulders are frost riven into angular fragments and others show extensive wind blasted surfaces. A search for boulders showing striae was unsuccessful.

In the past these deposits have been considered to be of Tertiary age, and were assigned to the basal phase of the Hanna Formation (Knight 1953, Weitz and Love 1952, and Love and Weitz 1953). The writer suggests that the boulders are a glacial deposit, modified by later erosion or even by slow moving, near stagnant ice. The distribution of the deposits agrees with the inferred position of ice based on the moraines (?),and similar boulder deposits exist south of the map area on Centennial Ridge and to the west of that ridge.

Conclusions on Pleistocene history

In conclusion the writer believes that at the time of maximum ice accumulation during the Pinedale Stade of the Wisconsin epoch Rock Creek Valley was filled by ice which was moving northward and eastward. Profiles of the valley of Rock Creek indicate that the lower course of the valley near Arlington was not modified by a valley glacier and therefore the terminus of the ice was probably just below the mouth of Deep Creek. The thickness of ice accumulating west of Rock Creek eventually became great enough to create positive movement of the ice to the east overtopping Rock Creek Ridge and moving down the east slope of the mountain.

Ice on the east slope of Rock Creek Ridge modified and smoothed the topography, left a terminal moraine and supplied a source for the water which saturated the sedimentary rocks causing mass gravity movement. The melt water from the ice flowed down the valleys and deposited extensive boulder deposits along the major stream courses.

Recent

Landslides

Well defined landslides are prevalent in many parts of the area and have been mapped both by ground observation and from vertical aerial photographs. The shales of the Upper Cretaceous Lewis Formation and the Steele Shale are susceptible to this type of surficial mass movement because of the high clay content of the rocks. In the area of mass gravity movement (Qmg-Plate I) there are individual slides which must be later than the general movement because they appear to lie upon it, and to have very definite form. The landslides here exhibit scrolls, lobate tongues, and the toe of the slide is well defined as a topographic ridge.

Eolian deposits

Deposits which have the topographic form of dunes are found east of James Lake, and on the eastern and leeside of several small deflation depressions in the James Lake quadrangle. The deposits at the surface appear to be composed of clays or silts derived from the floor of the depression. The clays and silts would be derived from the sediment carried into the lake by local streams, and later blown out during periods of dessication.

The history and nature of these deposits is more complex than the surface form suggests. At the northeast corner of James Lake in a deep cut excavated in connection with a now long abandoned water diversion project, Lewis sandstones crop out and dip gently to the northwest. Overlying the Lewis strata are well exposed, nearly horizontal strata in the dune complex. In excess of fifteen feet of strata are exposed in the partial section. The layers consist of alternating dark colored clays and light colored sands in layers up to 15 inches in thickness. The sands are in part quite coarse grained and contain pebbles up to one-half inch in length including some that appear to be ventifacts.

The wind deposited material must be younger than the actual excavation of the deflation depression in which James Lake lies. The alternation of coarse and fine grained material reflects severe changes in the climate from moist periods reflected in the fine grained material from the lake deposits and periods of extreme aridity reflected in the coarse sands derived from the same locality. No dates for the eolian deposits are available,

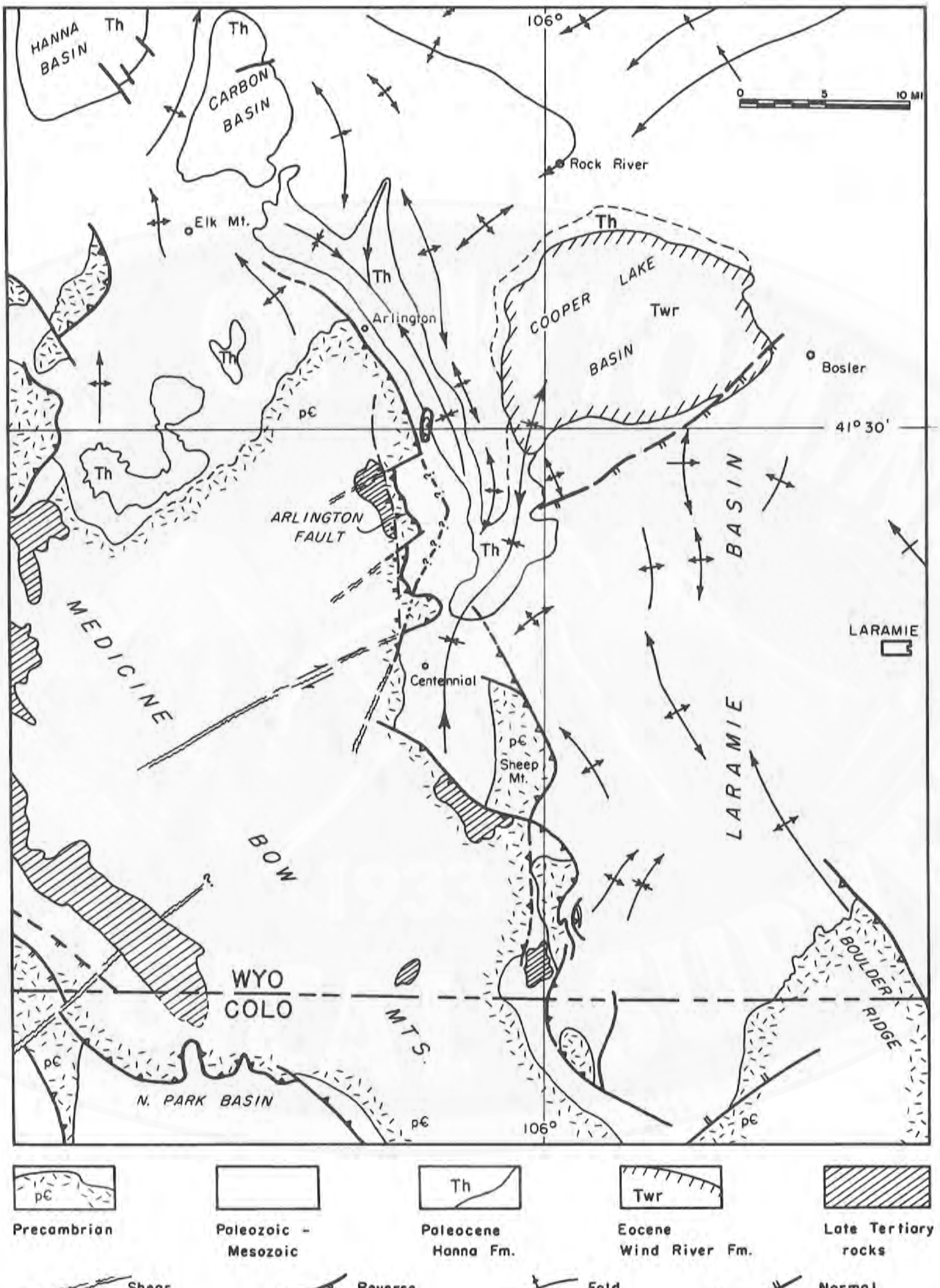


FIG. 5 TECTONIC MAP of REPORT AREA

but on the basis of topographic considerations they must be quite recent.

Gravels

Throughout the three quadrangles there are ridge summits at varying elevations that are capped by unconsolidated gravels. The clasts in these gravels range up to boulder size but are generally in the pebble and cobble size range. The clasts are rounded to subrounded and consist of Precambrian rock types known in the Medicine Bow Mountains. Quartzite is by far the most abundant rock type making up 80% to 90% of the deposits.

The gravels appear to be lag gravels from several sources. Some are derived from the wide spread pediment gravels; some may be residuals of basal channels of the Eocene Wind River Formation; some are derived from conglomerates in either the Paleocene Hanna Formation or the Eocene Wind River Formation; and some have no readily discernible source.

Colluvium

The term denotes ill-defined deposits which lie on slopes at varying elevation and which consist of weathered material, soil, slope wash, etc. In the map area there is a great deal of such material but the writer has used the designation very sparingly as a map unit. Some material mapped as colluvium may actually be terrace gravels but could not be readily distinguished as such.

Alluvium

All major stream valleys contain alluvial deposits essentially at the level of the present stream which appear to be normal flood plain deposits. At present most streams appear to be degrading,and bed rock frequently appears in the stream bed. The alluvial deposits are only a few feet or tens of feet in thickness.

STRUCTURAL GEOLOGY

General

The area described in this report is located on the western side of the Laramie Basin, an intermontane structural depression lying between the Laramie Mountains on the east and the Medicine Bow Mountains on the west. The basin is moderately complex structurally and includes several large folds some of which are faulted at depth. The tectonic setting is presented on Fig. 5.

Specific Features

Arlington thrust fault

The eastern margin of the Medicine Bow Mountains is ruptured by a thrust fault named by Siebenthal and Darton(1909) the Arlington fault. Subsequent work by Dobbin and others (1929, p. 144), King (1964), Hyden and others (1967), Houston and others (1968) and Blackstone (1970) has provided further information concerning the nature of the fault.

The trace of the Arlington thrust fault lies at an elevation of approximately 10,100 feet, but it is poorly exposed. The trace of the fault has been established on the basis of topographic expression and the areal distribution of the Precambrian rocks which make up the hanging wall plate.

The southern termination of the Arlington fault is located just north of the community of Centennial, Wyoming, about 3.5 miles south of the area mapped. At this locality Precambrian rocks have been tectonically transported eastward over the west limb of the Centennial-Mill Creek syncline (Blackstone, 1970). The trace of the fault plane is readily apparent along the south flank of Corner Mountain (Fig. 6) but is very poorly exposed throughout the northwest part of the Centennial quadrangle, and is not well defined until it appears in sec. 27, T. 17 N., R. 78 W. in the southeastern part of the Morgan quadrangle near Rock Creek Point.

Near Rock Creek Point the trace of the Arlington may be offset to the northeast by the apparent continuation of a shear zone mapped in the SW$\frac{1}{4}$ sec. 5, T. 16 N., R. 78 W. (Houston and others 1968). The shear zone in section 33 is marked by a wide band of silicified and brecciated dolomites of the Nash Formation and therefore stands out as a ridge. The Arlington fault plate north of this shear zone has moved farther to the east but is also relatively downthrown to the north.

The general trend of the Arlington thrust fault trace is north; the fault plane dips west at 20° or less at the surface; and the sense of tectonic transport is to the east in the hanging wall plate. The amount of slip has not

Fig. 6. View north from near center of sec. 35, T. 16 N., R. 78 W. showing trace of the Arlington thrust fault on the south slope of Corner Mountain with Precambrian gneiss in fault contact with Upper Cretaceous sediments.

been determined,but on the basis of cross sections constructed across the fault zone it appears to be several thousand feet.

From Rock Creek Point northward the trace of the thrust lies just east of and below the crest of Rock Creek Ridge and continues northward to the headwaters of Four Mile Creek at which point the trace is again displaced by a northeast trending shear zone which may be the continuation of a shear zone mapped in the Precambrian rocks at Rock Creek Knoll (sec. 35, T. 17 N., R. 79 W.) by Houston and others (1968). The displacement of the trace is about one and one-half miles eastward, and again the northern segment is relatively down. The fault trace continues northward beyond the map boundary, and joins with the trace as mapped by Hyden and others (1967) in the Arlington quadrangle.

Allochthonous masses related to the Arlington thrust fault

Four allochthonous masses of Precambrian rock lie east of the trace of the Arlington fault in the vicinity of the old community of Morgan. The largest of these masses is a bald ridge, devoid of vegetation,known as Cooper Hill; one smaller mass lies to the south across Four Mile Creek and has no local name; and a third much smaller mass lies north of Cooper Hill; and the fourth lies southeast of Cooper Hill. The geology of Cooper Hill has been discussed by Schoen (1953), King (1963) and Hyden and others (1967) in terms of the rocks that comprise the masses. In addition King (1964) concluded that these masses had been emplaced by movement downslope under the influence of gravity, and onto the east dipping Hanna Formation. The present writer concurs in this explanation.

Folding parallel to the Medicine Bow Mountains

A major line of folding that trends N. 15° W. parallels the east flank of the Medicine Bow Mountains from Foote Creek at the north end of the Rock Creek anticline southward for a distance of 22 miles to Seven Mile Creek at the south end of the Seven Mile anticline. Several distinct closures along this trend have produced commercial amounts of oil and gas. The largest producing field is Rock Creek,but production has also been obtained at Dutton Creek, Cooper Cove and Seven Mile fields.

Arlington Syncline

A rather narrow, deep syncline trending N. 25° W. parallels the Seven Mile-Cooper Cove-Dutton Creek anticlinal fold on the west side. The syncline is outlined at the surface by well defined hogbacks developed upon the conglomeratic basal beds of the Hanna Formation. The syncline plunges to the northwest at a low angle and reaches the greatest depth a short distance northeast of Arlington. Exposures of strata underlying the Hanna Formation in the west limb of the syncline are essentially non-existent, but the position of the syncline is affirmed by records from the Belco Petroleum Corp. No. 1 Arlington, sec. 10, T. 18 N., R. 78 W. The syncline becomes very narrow and tight in sections 19 and 20, T. 17 N., R. 77 W. on the southwest flank of the Seven Mile anticline along Seven Mile Creek. At this point the plunge of the syncline is reversed to the southeast and the southern extension becomes a minor fold on the flank of the Mill Creek syncline.

Cooper Cove Anticline

The south plunging termination of the Cooper Cove anticlinal closure extends into the Strouss Hill quadrangle (Cross section A-A'-Plate 2). The fold is expressed in the Mesaverde Formation and the Lewis Shale and is slightly asymmetrical to the east on the basis of observed surface dips. Dips on the flanks of the fold range from 11° to 52°, and the surface position of the fold hinge can be well established in the Mesaverde in the SW¼ sec. 32, T. 18 N., R. 77 W. At and near this locality the south plunge of the fold is approximately 10°. In the producing area of the Cooper Cove field the subsurface structure at the level of the Cloverly Formation is complex and controlled by east dipping faults. Production from the Cretaceous Muddy sandstone is limited to the upthrown and eastern blocks relative to such faults. Not enough wells have been drilled to deeper horizons to fully explore the nature of the structure on the top of the Casper Formation.

Seven Mile Anticline

The Seven Mile fold is quite complex, and the major surface axis appears to be the direct continuation of the Cooper Cove surface axis. Twelve tests for oil and gas have been drilled on this feature, of which four are currently producing oil from the Muddy Sandstone Member of the Thermopolis Shale. Data concerning the drilled wells is summarized in Table II. A structure contour map of the fold has been prepared using the top of the Cloverly Formation as a datum, Figure 7.

The anticline is expressed for the most part in the Lewis Shale in which the observed dips on the flanks of the fold range from 15° to 55°, and the fold in the producing area at the depth of the Cloverly Formation is asymmetrical to the west.

A tight south plunging minor fold with a very steep west flank is present on the southwest flank of the structure. The east flank of the major fold is disrupted by two faults. The western one is reverse in nature, trends N. 10° E. and has a displacement of about 800 feet which places Mesaverde Formation upon Lewis Shale. (Cross section C-C', Plate 2). The easternmost fault is normal in character, and downthrown to the east, and is well expressed in offsets of the concretionary zones in the Lewis Shale. The displacement is approximately 700 feet.

Only two wells have reached the Pennsylvanian-Permian Casper Formation within this anticline, and they offer little help in the interpretation of the complex subsurface structure below the Cloverly Formation. The only published reports on the structure of the field to date are a brief resume by Espach and Biggs (1960) and a structure contour map in the Wyoming Oil and Gas Fields Symposium (1957).

Structure contours on top of the Cloverly Formation indicate about 600 feet of effective closure on the basis of existing wells. The saddle between Cooper Cove field and the Seven Mile local closure may have a greater depth than 600 feet but there is no positive evidence. The structure is asymmetric to the west, and at least one well encountered dips in excess of 45° at the level of the Cloverly Formation on the west flank. Faults are common in the relatively brittle marlstones of the Niobrara Formation and are reverse in nature with the east side upthrown.

Two wells reached the Casper Formation on the southeast flank of the field, but do not provide enough information to define the form of the fold at that stratigraphic level. The relationship of the Seven Mile anticline to the surrounding structure is shown on cross section B-B', Plate I.

The producing area as depicted at the level of the Cloverly Formation is a subsidiary faulted feature on the east flank of the Cooper Cove-Seven Mile anticlinal fold. The faults which offset the Cloverly Formation dip to the east and may merge into the bedding at the level of the Triassic Chugwater Formation or below.

Quealy Dome

Quealy Dome is a discrete fold located about four miles east of the Seven Mile field and separated from it by a well-defined syncline. The fold trends essentially north-south and is asymmetric to the west. The fold is analogous in position to Bull Mt., Ring Mt., and Jelm Mt. structures to the south (Beckwith, 1935).

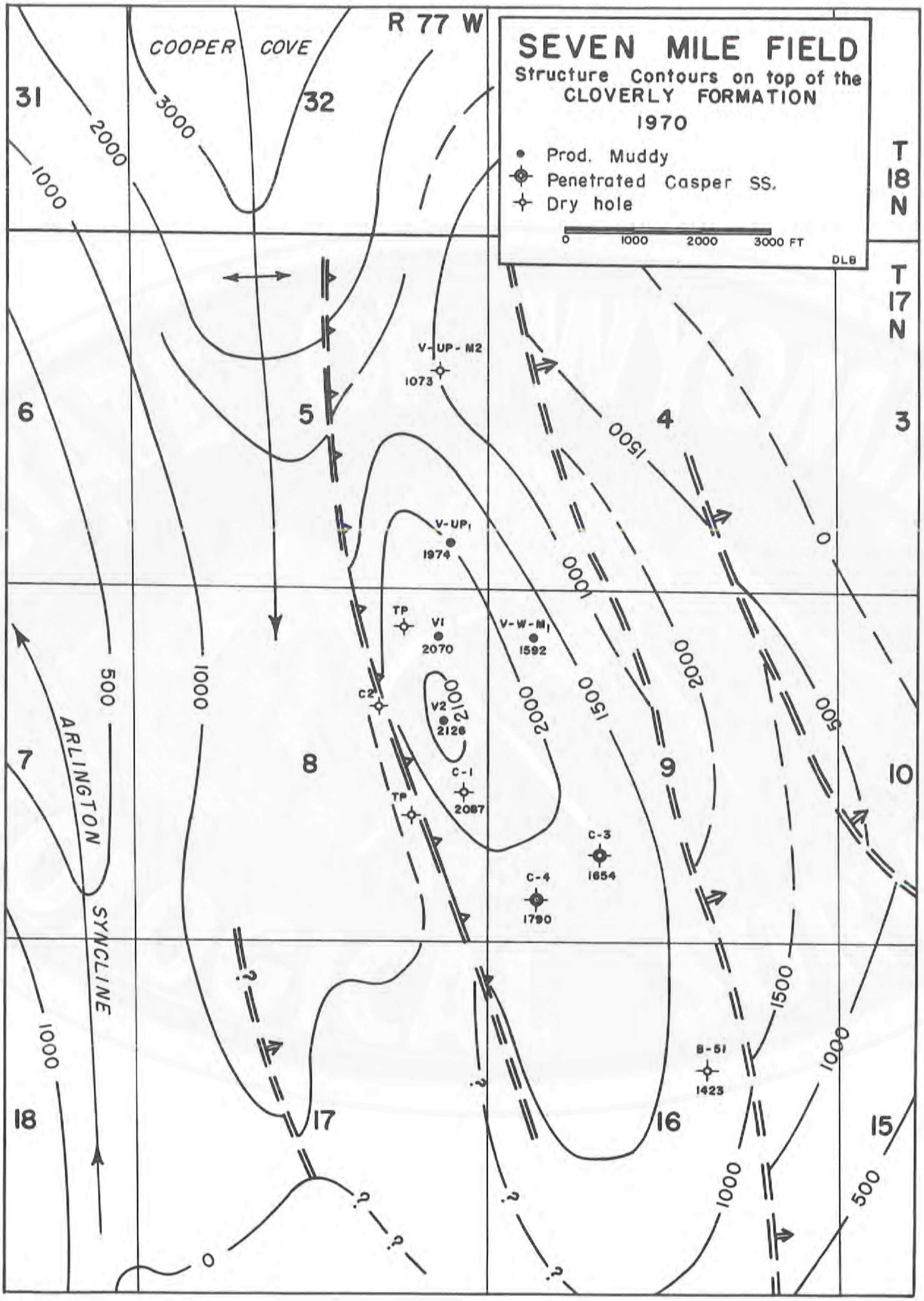
Steele Shale is exposed at the surface in the crestal region surrounded by poorly exposed Mesaverde Formation. Outcrops in the central area are very limited because of a surficial mantle of bouldery debris associated with poorly defined erosion surfaces.

A summary of the information relative to productive history of the field by Espach and Nichols (1941) and by Espach and Biggs (1960), a short discussion of the structure of the field by West (1954); and a structure contour map in the Wyoming Oil and Gas Fields Symposium (1957) constitute the published data concerning the

SUMMARY OF WELL DATA
SEVEN MILE FIELD - January, 1970
T. 17N., R. 77W
Albany County, Wyoming

Operator	Location	Elevation K.B.	Total Depth	Status	Ridge	Steele	Nio-brara	Muddy	Cloverly	Chug-water	Casper
Vessels-UPPR Miller #2	SE NE 5	7878	6643 Morrison	D. & A.	320	1650	5370	6710	6800		
Vessels-UPPR Miller #1	SE SE 5 610 FSL 660 FEL	7934	6015 Morrison	Prod. Muddy	180	1360	4390	5850	5960		
Vessels-Miller Gov't. #1 (Orig. Sharples)	C NE NE 8	7970	6001 Morrison	Prod. Muddy	230	1440	4330	5760	5900		
Vessels-Miller Federal #2	C SE NE 8	8006	5985 Morrison		310	1500	4362	5740	5880		
California Co. #2 Unit	NE SW NE 8	8015	6782 Morrison	P. & A.	350	1500	4490	(?)	6540		
California Co. #1 Christiana	NE NE SE 8	8005	6774 Red beds	P. & A.	250	1540	4342	5820	5918 6085	6770(?)	
Vessels Miller #1	C NW NW 9	7962	6481 Morrison	Prod. Muddy	350	1550	4665	6280	6370		
California Co. #4 Unit	C SW SW 9	7920	8262 Casper ss.	P. & A.	450	1550	4600	6010	6130	7090	8110
California Co. #3 Unit	SW NE SW 9	7927	8189 Casper ss.	P. & A.	420	1590	4730	6180	6273	6980	8075
Skinner & Burns #1 State-Miller	SW NE 16 1880 FEL 1960 FNL	8103	6790 Morrison	D. & A.	930	2100	5080	6570	6680		
Texas Prod. #1	600 FNL 1240 FEL 8	7975(?)	1615	D. & A.	Spud. in Kmv	no data					
Texas Prod. #2	1740 FNL 1600 FEL 8	8015(?)	2857	D. & A.	Spud. in Kmv	no data					

Table 2



SEVEN MILE FIELD
Structure Contours on top of the
CLOVERLY FORMATION
1970
Prod. Muddy
Penetrated Casper SS.
Dry hole
0
1000
2000
3000 FT
DLB
R 77 W
T 18 N
T 17 N
COOPER COVE
ARLINGTON SYNCLINE
31
32
6
5
4
3
7
8
9
10
18
17
16
15
V-UP-M2
1073
V-UP1
1974
TP
V1
2070
V-W-M1
1592
C2
V2
2126
C-1
2087
TP
C-3
1654
C-4
1790
B-51
1423
3000
2000
1000
500
1500
2100
0

FIG. 7

SUMMARY OF WELL DATA
QUEALY DOME FIELD - January, 1970
T. 17 N., R.'s 76 and 77 W.
Albany County, Wyoming

Lease Name & Well No.	Location	Elevation K. B.	Total Depth	Prod. Data	Depths to Formation from Electric logs: Steele	Nio-brara	Muddy ss.	Cloverly	Sun-dance	Chug-water	Casper	Pre-cambrian
Texas Prod. #1	NE NE NW 13	7475(?)	3210	D. & A.				no data				
Texas Prod. #1-A	NE NE NW 13 Skidded rig.	7475(?)	3574	Junked				no data				
Matador-Roxana	NE NW NE 13 125 FNL 1600 FEL	7455(?)	3694	D. & A.				in Kcv(?)				
The California Co. (Predecessor to Chevron) drilled all wells listed below.												
Holst (F. G.) #1	NW NW SE 12	7458	5470	D. & A.		3588	5168	5292				
Holst #1	NE SE SE 13	7514(?)	(?)				3146	3231				
Holst #2	SW NE SE 13	7481	OWWD5653	Prod. Kcv IPc				3165	4167	4545	5355	
Holst #3	NE SW SE 13	7515(?)	3420	D. & A.				no data				
Holst #4	SE SE SE 13	7511	3452	Prod. Kcv		2237	3287					
Holst #5	SE NE SE 13	7428(?)	3760	Prod. Js	---no log----		3111	3192	3675			
Holst #6	NW NE NE 13	7473	3961	Prod. Kcv	---no log----		3045	3130	3804			
Holst #7	NE NE SE 13	7455(?)	3793	Prod. K	---no log----		3155	3230	3670			
Holst #8	SW SE NW 13	7455(?)	3875	Prod. Kcv	---no log----		3098	3179	3775(?)			
Holst #9	NW SE NE 13	7406	3490	Prod. Kmd	---no log----		3232	3324				
Holst #10	SE SE NE 13	7442	3487	Prod. Kcv	---no log----		3290	3380				
Holst #11	NE SW NE 13	7438	OWDD3357 5872	Prod. IPc	---no log----		3165	3260	(?)	4261	5500	
Holst #12	SE NW NE 13	7440	3465	Prod. K P. & A.		2150	3306	3392				
Holst #13	SE SW NE 13	7467	3356	Prod. K		1994	3135	3245				
Holst #14	CSL SE NE 13	7452	5602	Prod. IPc		2050	3175	3260	3707	3987	5320	
Holst #15	SW NE SE 13	7450	5511			2015	3135	3218	3633	3890	5250	
Wilson #1	NW SW SW 18	7498	3398	Prod. Kcv				3364				
Wilson #2	SE SE SE 18	7505(?)	(?)	Prod. Kcv				+4062				
Wilson #3	SW NW SW 18	7470	4010	Prod. Kcv			3311	3397	3818	penetrated ?		
Wilson #4	NW NW SW 18	7428	3570	Prod. Kcv			3375	3451				
Wilson #5	660 FWL 1320 FSL 18	7485	5593	Prod. IPc		2285	3409	3492	3910	4155	5220	
Wilson #6	NW SW 18	7428	5421	Prod. IPc		2250	3444	3530	3980	4245	5235	
Wilson #7	SE SW SW 18	7499	5502	Prod. IPc		2430	3448	3552	3868	4115	5240	6135
Wilson #8	NW SW SW 18	7504	6165	Prod. IPc		2248	3225	3315	3752	3960	5260	
Wilson #9	NW SE SW 18	7466	5465	Prod. IPc		2640	3721	3800	4178	4440	5345	
Wilson #10	NW NE SW 18	7434	5815	P. & A.	190(?)	2845	4059	4140	4560	4832	5685	
Wilson #11	NE SE 24	7494	Bottom 1379N 764W 9588	D. & A.	2600	5585	6930	7030	7503	7840	8835	
Holst-Woolf #1	NW NW NW 19	7494	4067	P. & A.			3520	3578	3975			
Holst-Woolf #2	NE NW NW 19	7488	3650	D. & A.		2842						
Holst #2-2	NW NE NW 19	7464	6195	D. & A.	1970	3290	4390	4500	4883	5089	omitted	5982

Note: Wells in secs. 7, 18 & 19 - R. 76 W.
Wells in secs. 12, 13 & 24 - R. 77 W.

Table 3

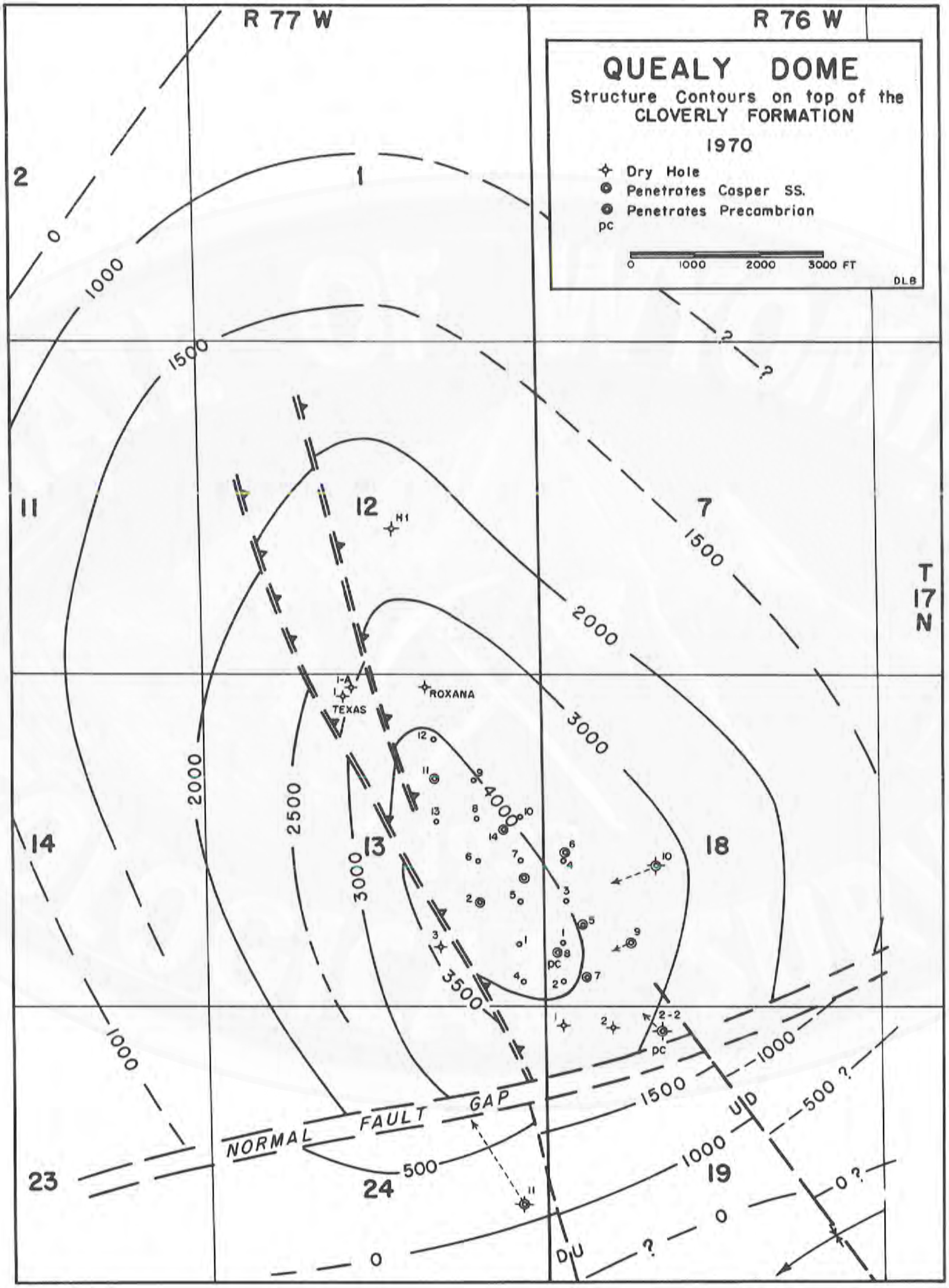

R 77 W
R 76 W
QUEALY DOME
Structure Contours on top of the
CLOVERLY FORMATION
1970
Dry Hole
Penetrates Casper SS.
Penetrates Precambrian
pc
0 1000 2000 3000 FT
DLB
T
17
N
2
1
11
12
7
14
13
18
23
24
19
ROXANA
TEXAS
NORMAL FAULT GAP
0
500
1000
1500
2000
2500
3000
3500
4000
U D
D U
?

FIG. 8

field. To date 33 wells have been drilled, nine of which produce from the Pennsylvanian Casper Formation, the major producing zone, but production has also been obtained from the Sundance Formation, the Muddy Sandstone, and the Cloverly Formation. Data concerning wells drilled is summarized in Table III.

A structure contour map on the top of the Cloverly Formation is presented as Fig. 8.

The subsurface structure of the field is more easily understood when viewed as three separate intervals:

(a) surface down to the Chugwater Formation;
(b) Chugwater Formation to Casper Sandstone;
(c) Casper Sandstone and configuration of the top of the Precambrian basement.

Two major faults that trend N. 70° E., dip about 80° south, and are downthrown to the south set off a half-dome from the Quealy producing area. The dip slip on the southern fault is approximately 1,200 feet and is readily apparent in well records. The slip on the northerly fault is about 750 feet. The fault system is here referred to as the South Quealy fault and is considered to delimit the South Quealy structure.

The structure of the fold from the surface to the Chugwater Formation is asymmetrical to the west with dips increasing with depth on the west flank of the fold. Several reverse faults dip to the east and repeat parts of the Niobrara to Chugwater interval. Steep dips were reported in cores taken from the Jurassic Sundance Formation. The anticline has over 3,500 feet of structural relief and closure when contoured on top of the Cloverly Formation, and the crest of the fold is 2,000 feet higher structurally than the crest of the Seven Mile producing area contoured on the same datum.

The structure from the Chugwater Formation down is dissimilar to that above in that steep faults offsetting beds in the west limb of the fold dip eastward and in the east limb coincide with, or are subparallel to the bedding in the Chugwater Formation and lower strata on the east flank of the fold. The form of the fold as expressed on top of the Casper sandstone is simple and has a lower dip than that expressed by the Cloverly Formation.

The deeper anticlinal structure in the Quealy field proper is defined on the basis of twelve wells which penetrate the Casper Formation. As defined by the top of the Casper the anticline is quite regular, is essentially symmetrical, and the axis trends N. 15° W. The plunge of the fold in the producing area of the Casper cannot be more than a few degrees to the north, and the structure is still rising to the south when it is terminated by the South Quealy normal fault system. Two wells reached the Precambrian basement at essentially the same datum elevation and provide little information as to the configuration of the subsedimentary surface.

The South Quealy half-dome can be partially defined by surface geology and use of vertical aerial photographs. Exposures are extremely poor, and difficult to decipher. Aerial photographs reveal a very marked linear feature trending N. 15° W. across sections 19 and 30, T. 17 N., R. 76 W. along which there are groundwater seeps indicative of a fault trace.

The writer has used surface data, the dip meter survey of the Chevron Oil Company No. 11 Wilson test in sec. 24, T. 17 N., R. 77 W., and projected dips encountered in the California Company No. 2 - 2 Holst, sec. 17, T. 17 N., R. 76 W. to construct the structure contours for the South Quealy half-dome. The areal distribution of the Lewis Shale and its surface dips south of the field have also been utilized.

The writer's interpretation of these data is that the South Quealy half-dome is ruptured by two north-south normal faults of unknown dip. The fault movement has been relatively up on the central segment with an indicated displacement of approximately 900 feet.

The low angle faults which parallel the bedding in the Chugwater Formation in the producing area of the field were not recognized in the area south of the major normal faults. It appears that the Chevron Oil Co. No. 11 Wilson test did not cut such faults for the reason that it is probably in the footwall relative to such displacements.

Mill Creek Syncline

The syncline underlying Centennial Valley between Sheep Mountain and Centennial Ridge extends northeastward across the Rex Lake quadrangle (Blackstone, 1970) into the Strouss Hill and James Lake quadrangles. The deeper part of the syncline lies approximately in sec. 33 and 34, T. 17 N., R. 77 W. with Hanna Formation overlying Medicine Bow Formation. Several core holes have completely penetrated the Hanna Formation at depths of less than 900 feet.

The syn-line as outlined at the surface by the basal contact of the Hanna Formation exhibits several minor folds along the flanks with plunge to the south. The most sharply defined part of the major syncline lies just south of Quealy Dome where the strike of the strata makes a 90° bend from north-south to east-west, and the fold plunges S. 70° W. At the south end of the Seven Mile fold the Hanna Formation unconformably overlies the

Lewis Shale. In this area Seven Mile anticline flares out into a number of small folds that in turn merge into the flank of the Mill Creek syncline.

The Mill Creek syncline extends in a northeasterly direction along the southeast and east flanks of the Quealy anticline, but the plunge reverses and is to the northeast at a low angle. The syncline is poorly defined because of low dips, and limited outcrops.

Seven Mile Syncline

Seven Mile anticline is separated from Quealy Dome by a well defined syncline outlined by the basal beds of the Hanna Formation in the southern end and along the west flank. The east limb is poorly defined north of Seven Mile Creek because of the unconformable overlap of very low dipping strata of the Wind River Formation. The syncline probably continues northward with an almost north-south strike into the Bengough Hill quadrangle. The plunge of the syncline is very low, probably under five degrees.

Centennial Ridge fault and fold extension

West of the Arlington syncline along the east flank of the Medicine Bow Mountains there are very few outcrops of sedimentary rocks which can be used for structural control. The area is one of timbered slopes developed on either glacial deposits or on extensive areas that have undergone mass gravity movement. Such exposures as do exist are largely in the upper reaches of Seven Mile Creek and in the headwaters of the South Fork of Mill Creek. In the Seven Mile drainage, outcrops of Mowry Shale, Cloverly Formation, Morrison Formation, probable Chugwater red beds, and Casper Formation are present from east to west over a distance of two miles. The most westerly outcrops are a limited area of Casper Formation at an elevation of 10,000 feet, immediately below and east of the trace of the Arlington thrust fault.

The distribution of these units over a distance of two miles necessitates some folding to account for the width of outcrop. The Upper Cretaceous strata exposed on the west flank of the Arlington and Mill Creek syncline dip steeply eastward, and are locally overturned. If the strata continued to dip at the high angles observed, the basement should appear at a distance of about 6,000 feet west of the contact between the Mesaverde Formation and the Lewis Shale. Such is not the case, and therefore the dip must change due to either folding or faulting.

To adequately explain the steep dips on the west flank of the syncline, as well as the outcrop width the writer has postulated a fault-fold situation (Blackstone, 1970). At the north end of Centennial Ridge (Fig. 9) there is a reverse fault which trends N. 20° E. and that appears to have originated in a shear zone located in the valley of the Middle Fork - Little Laramie River. The fault has been reported by Beckwith (1938) and McCallum (1968). Movement on the Centennial Ridge fault has placed Precambrian rocks in the western block in fault contact with the upper Casper Formation in the eastern block. The dip in the Casper increases to the north. The writer has projected this fault northeastward into the Morgan and Strouss Hill quadrangles as a logical explanation for the distribution of formations discussed above.

The Centennial Ridge fault is interpreted to be a high angle, west dipping, reverse fault, upthrown on the west side. The inferred relationships are indicated in cross sections accompanying Plate 2. The strata in the hanging wall block are postulated to be rather broadly folded, and in turn overriden by the Arlington thrust plate. The strike of the Centennial Ridge fault is considered to change direction from N. 20° E. to N. 30° W. in the vicinity of sec. 25, T. 17 N., R. 78 W. Such a change in trend is compatible with the regional pattern of deformation.

Rock Creek normal fault

Rock Creek is a north flowing drainage that probably is fault controlled. Knight (personal communication) has reported undated tuffaceous rocks believed to be of Tertiary age in fault contact with the Precambrian in sec. 17, T. 17 N., R. 78 W., and illustrated the situation in a series of blocks diagrams (1954). The tuffaceous sediments were considered by King (1963) to be Miocene in age, and by Houston and others (1968) to be Miocene-Pliocene Northpark Formation.

The Rock Creek fault is postulated to continue southward from the outcrop area of Tertiary rocks on the basis of a very well defined north-south photo lineation in secs. 4 and 5 T. 16 N., R. 77 W. No offset of Precambrian units could be demonstrated.

South Quealy normal faults

The Quealy anticline is ruptured by a group of normal faults which dip to the south and are downthrown to the south. The western termination of the fault system appears to be in sec. 22 T. 17 N., R. 77 W. just south of Seven Mile Creek where the fault appears to pass into a southwest plunging anticline in the Lewis Shale that is also reflected in the overlying Hanna Formation.

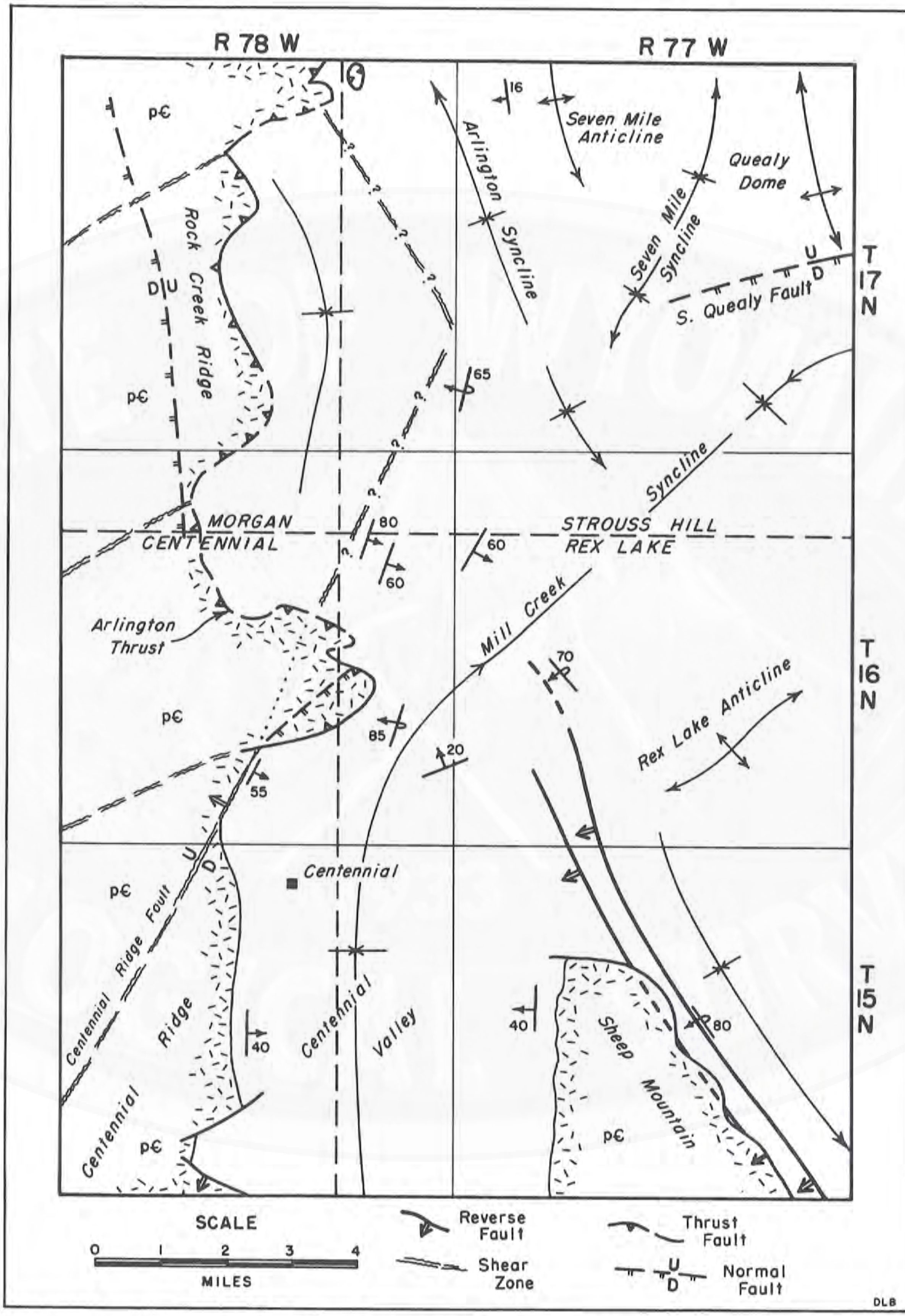


FIG. 9 MAP SHOWING LOCATION of CENTENNIAL RIDGE FAULT

Eastward along the fault trace there is a large spring controlled by the fault. Further evidence of the fault is found in well records. The surface trace of the fault is believed to lie very close (south of) the California Co. No. 2 and No. 7 Wilson wells, and probably does not extend more than a half mile east of the No. 7 Wilson. Well locations are shown on Plate I and Fig. 8.

The second fault in this group crosses the range line just south of the southeast corner of sec. 18, T. 17 N., R. 77 W. and was penetrated by the bore of the California Company No. 2-2 Holst well. Near this well the strike of the fault trace changes from N. 75° E. to N. 60° E. and places Lewis Shale in fault contact with Mesaverde Formation. The combined displacement in the two normal faults is in excess of 1,500 feet.

The continuation of this fault to the northeast is suggested but cannot be definitely demonstrated on surface geology because of the lack of good marker beds in the Lewis Shale. It appears that the fault passes near the extreme north end of James Lake and continues to the northeast corner of the James Lake quadrangle. The displacement on the fault in the vicinity of James Lake is not known but an estimate of approximately 500 feet is suggested.

Northeast-trending normal faults

Southeast of Quealy Dome two marked linear features can be observed on vertical aerial photographs. The lines on the photographs are defined by changes in vegetation and alignment of wet ground and active seeping springs. The positive physical evidence as to the nature of the geological control for the springs could not be established on the ground. The lines are interpreted to be the trace of near vertical normal faults.

The westerly fault trends N. 14° W. and roughly parallels the northeast margin of the Mill Creek syncline, passes through the Lewis Shale and may be responsible for the west dips in the Lewis Shale, Medicine Bow Formation and the Hanna Formation. The structure contour map of the Quealy Dome (Fig. 8) indicates that the fault is downthrown to the southwest and has a displacement of approximately 900 feet.

The easterly fault extends further to the south and can be observed continuing almost to the flood plain of the Little Laramie River. The trend of the trace is N. 30° W. which is roughly the trend of the Quealy anticline. The fault was not recognized in the log of the California Co. No. 2-2 Holst well and it is therefore concluded that the dip of the fault plane is vertical or that it dips steeply to the east. The relative movement on the fault plane is believed to be downthrown to the northeast. The amount of displacement is conjectural but may be as great as that on the western fault.

The segment bounded by the two faults is displaced upward relative to the surrounding rocks, and is horst-like in character.

Analysis of Geologic Structure

The best appreciation of the structural geology of an area is obtained from serial cross sections normal to the structural strike. Such sections provide a clear visualization of the continuity of individual structural elements that make up the whole. The correctness of such cross sections depends upon the accuracy of the surface mapping; the amount of subsurface control available; and the accuracy of the stratigraphic thicknesses used. The reconstruction must reflect the structural thinking of the individual who makes the interpretation.

Five cross sections A - A' through E - E' are presented on Plate 2. The sections are oriented in an east-west direction, and pass through two producing oil fields and reflect intensive study of the subsurface geology of the fields. The cross sections are self-explanatory and illustrate the geological structures described under Specific Features.

The reconstructions shown in the western third of the sections and which involve the postulated position of the Centennial Ridge Fault are problematical. The surface exposures in this area are very poor and widely separated and provide only minimum control for the cross sections. The sections as drawn are internally consistent and provide a reasonable though probably simplified interpretation of the actual situation. All constructions are based on constant thickness of stratigraphic units and parallel folding.

Crustal shortening

The cross sections discussed have been used to evaluate the amount of horizontal shortening that can be demonstrated in the sedimentary rocks. The thickness of the stratigraphic interval from the top of the exposed Late Cretaceous Medicine Bow Formation to the top of the Precambrian crystalline basement is approximately 11,000 feet.

The original length of the stratigraphic units was determined by using a simple map distance measuring device tracked along the contacts as drawn in the cross sections. The base of the Cretaceous Mesaverde

Formation was used where convenient. In some instances the base of the Cretaceous Cloverly Formation was used, and in one instance the top of the Casper sandstone was used. Shortening due to faults has been included insofar as possible. The amount of lateral displacement on the Arlington thrust cannot be determined since all the sedimentary cover normally present above the Precambrian basement on the hanging wall block has been removed by erosion. A minimum value of 5,000 feet has been assigned to the shortening that can be attributed to this fault. Table IV is a summary of the data relative to the shortening as calculated from the cross sections.

Table IV. The values relative to crustal shortening as exhibited in the cross sections are tabulated below.

Section	Stratigraphic boundary measured	Original Length	Present Length	% Shortening
A - A'	Top of Mesaverde Fm. Including Arlington Fault	37,600	30,400	19.2
B - B'	Partial section Top of Mesaverde Fm.	33,400	31,000	7.2
	Base of Cloverly Fm. Entire section excluding Arlington Fault	52,000	46,400	10.8
C - C'	Base of Mesaverde Fm. Excluding Arlington Fault	43,000	39,400	8.4
	Base of Cloverly Fm. Excluding Arlington Fault	43,000	39,400	8.4
D - D'	Partial Section Base of Mesaverde Fm.	31,200	30,400	2.6
	Partial Section Top of Casper ss.	20,000	18,450	7.8
	Combined values including faults	51,200	48,850	4.6
E - E'	Base of Mesaverde Fm. East of Centennial Ridge Fault	21,200	16,600	21.7
	Top of Casper Formation West of Centennial Ridge Fault	21,400	15,600	27.1
	Combined values including faults	42,600	32,200	24.4

Note: A value of 5,000 feet was assigned to the Arlington fault, and 1,000 feet to the Centennial Ridge fault.

The percentage shortening varies from 2.6% to 27.1%. The lesser values were obtained from the eastern parts of the sections where the dips are low and there is little deformation. The higher values reflect the increasing deformation as the Medicine Bow Mountains are approached.

If the sedimentary section is in normal contact with the Precambrian basement, and no detachment or decollement exists, the above figures may be interpreted to mean that crustal shortening in the order of 12.9% has taken place within the strip covered by the cross sections.

Differential vertical uplift

The top of the Precambrian basement provides a convenient structural datum for determining major crustal movement. Several wells penetrate the Casper Formation, and since the stratigraphic thickness to the basement is reasonably well established it is possible to predict the sea level elevation of the sedimentary-Precambrian interface at a number of points in the basin east of the Medicine Bow Mountains. Datum values for the crest of the Medicine Bow Mountains and the Laramie Mountains are minimal since the amount of material removed by erosion is unknown. A map with selected datum points, and two cross sections have been prepared at a scale of 1:500,000 (Figs. 10 and 11). These may readily be compared with Fig. 5 which indicates the major structural elements.

The minimum vertical structural relief from the crest of the northern Medicine Bow Mountains to the deepest part of the Laramie Basin is 15,000 feet. The control points are 27 miles apart as shown by the map. The amount of vertical structural relief using this data varies considerably from that shown by Knight (1953) on a structure contour map of the top of the Precambrian surface. The difference in values for the Laramie Basin results from new data derived from wells. Knight has estimated that the sub-sedimentary surface on the crest of the Medicine Bow Mountains was 16,000 feet above sea level, which may be a reasonable figure. If this value is used the structural relief is about 19,500 feet.

Using the datum points shown on Fig. 10 and the accompanying cross sections which reflect the major faults and folds the crustal shortening across the basin was calculated graphically and found to be 3.7% to 4.0% for a total length of section of 57 miles, this amount to a maximum value of about 12,400 feet, or a little over two miles. Considering the entire basin and its margins the amount of relative vertical movement is not a great deal larger than the horizontal component (15,000 vs. 12,400). Such values are not particularly significant in estab-the stress field causing the deformation. This value is considerably less than the values shown in Table IV for the area adjacent to the mountain front, indicating that the deformation is quite localized.

Localization of deformation

The regional trends in the broad area in which the mapped quadrangles lie are shown on Fig. 5 and at least two of the principal structural trends are well represented in the area detailed.

The major structural element is the Medicine Bow uplift which in gross structure is a Laramide feature trending N. 15° W., and which plunges in a northerly direction into the Hanna basin. A series of faulted blocks and elongate folds roughly parallel the Medicine Bow Mountains on the east flank and are also Laramide in age. These features partake of the general northwest trend of the majority of the structural elements in Wyoming and northern Colorado.

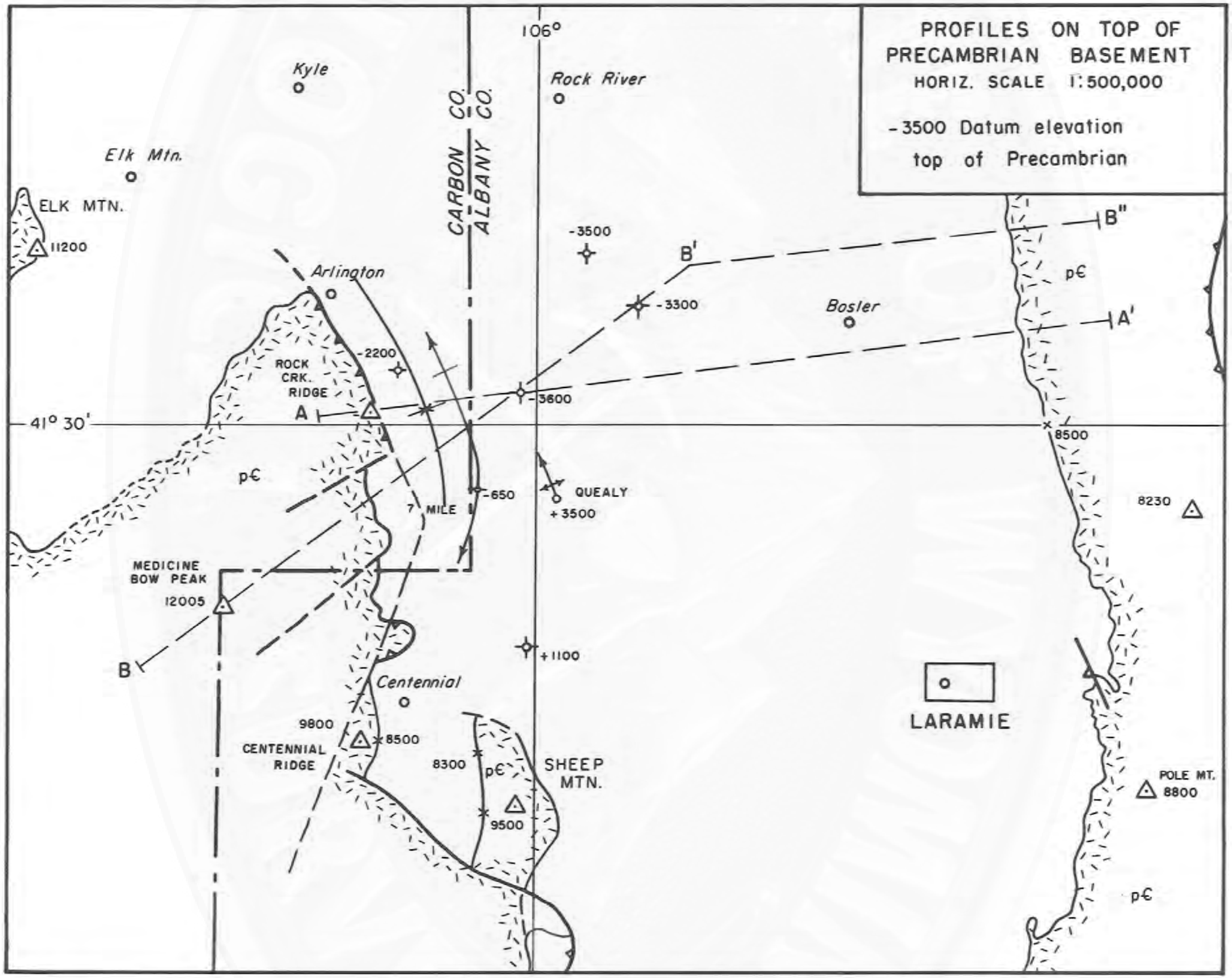
No investigations to date have found any systematic distribution of rock types in the Precambrian basement which would account for the structural alignment. Local coincidence of the present northwest deformational trends with either basement rock type or local structural grain in the Precambrian have been observed but there is no regional correlation of the two. The northwest trends therefore must be controlled by something other than heterogeneity of basement rocks.

A northeast trending structural grain of approximately N. 65° E. is very well developed in southeastern Wyoming and is well portrayed by such features as Flat Top anticline, Como Bluff anticline, McGill anticline, and similar folds. Ransome (1913) called attention to this fact and described the situation as the Wyoming lineament.

Within the Precambrian rocks exposed in the core of the Medicine Bow Mountains (Houston and others,1968) have described several shear zones characterized by mylonite and rocks with cataclastic textures. The principal one is the Nash Fork-Mullen Creek shear zone which splays at the eastern end into several minor shear zones.

The Arlington thrust fault terminates against a part of the Nash Fork - Mullen Creek shear zone near Centennial, Wyoming, and the fault has its maximum displacement adjacent to the shear. The overthrust plate is offset at two places by faults which may be the northeastward extension of shear zones mapped by Houston and others (1968).

In the east half of the Morgan quadrangle the trace of the Arlington fault changes direction from northwest to northeast suggesting offset of the trace along a northeasterly trending tear fault. The southerly of the changes in strike is located about a mile south and southwest of Rock Creek Point (sec. 28, T. 17 N., R. 78 W.). The elevation of the Arlington fault trace at the points of inflection is essentially identical though they are separated by a distance of two miles. The fault plane may be horizontal with the northwest segment having moved eastward relative to southeast segment, on a tear fault which represents a reactivated shear zone in the Precambrian rocks.



PROFILES ON TOP OF
PRECAMBRIAN BASEMENT
HORIZ. SCALE 1:500,000
-3500 Datum elevation
top of Precambrian
106°
41° 30'
Kyle
Rock River
Elk Mtn.
ELK MTN.
11200
CARBON CO.
ALBANY CO.
-3500
B'
B"
-3300
Bosler
A'
Arlington
-2200
ROCK
CRK.
RIDGE
A
-3600
8500
pЄ
-650
7 MILE
QUEALY
+3500
8230
MEDICINE
BOW PEAK
12005
B
+1100
Centennial
LARAMIE
9800
8500
CENTENNIAL
RIDGE
8300
SHEEP
MTN.
9500
POLE MT.
8800

FIG. 10

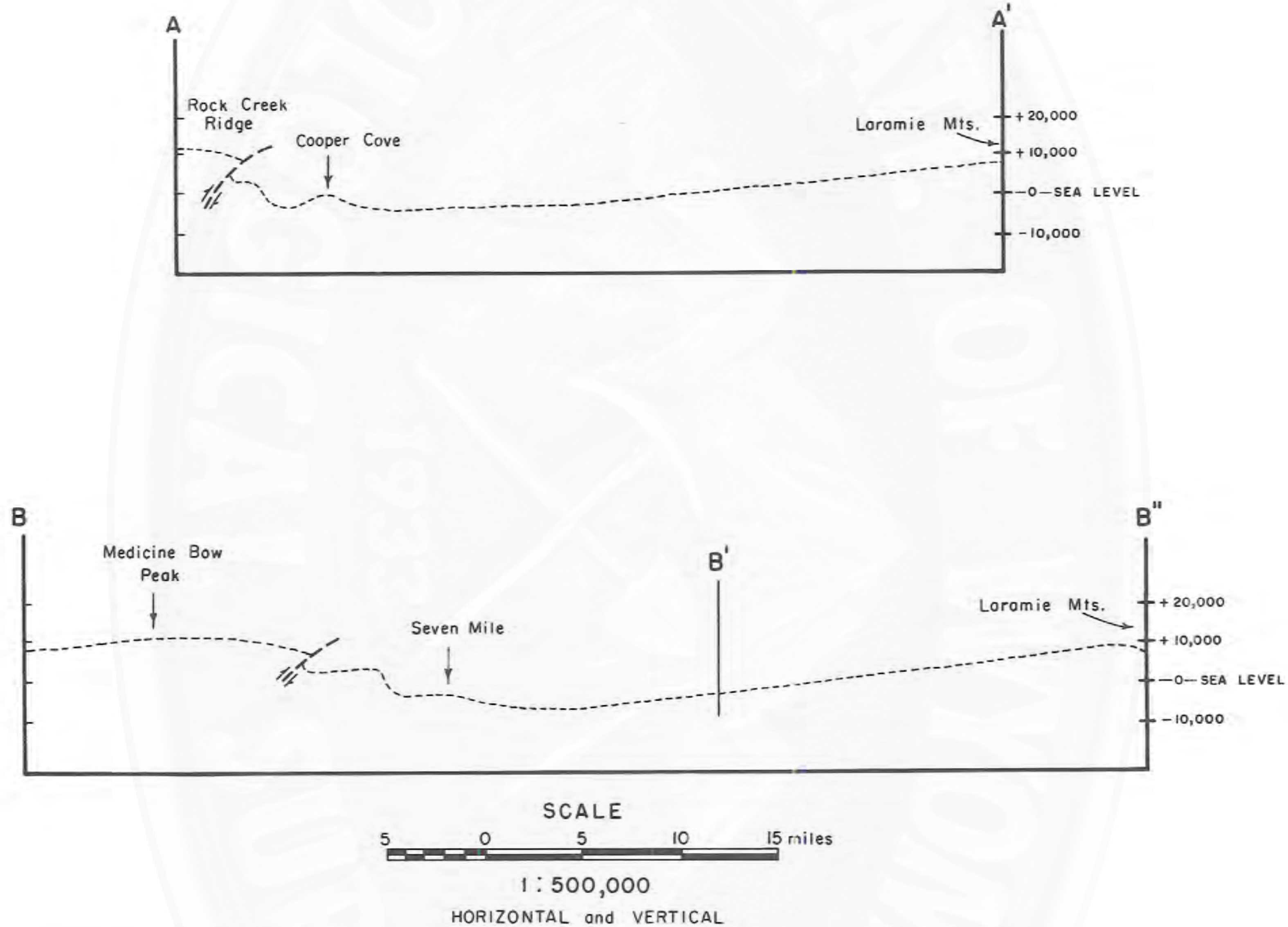


FIG. 11 CROSS SECTIONS of PRECAMBRIAN SURFACE ACROSS LARAMIE BASIN

An equally satisfactory explanation of the map relationships, and the one preferred by the writer, is that erosion of the hanging wall plate causing westward recession of the fault trace was controlled by the silicified and brecciated Precambrian Nash Fork Formation in the hanging wall. No movement would have occurred, and inflection in the direction of the trace is entirely erosional.

The second marked change in trend of the Arlington fault trace roughly coincides with the valley of the south tributary of Cooper Creek about a mile south of the summer community of Morgan. The trace of the thrust plane along the east face of Rock Creek Ridge lies at an elevation of 10,000 feet and essentially follows the contour. .

About two miles to the northeast the trace lies at an elevation of 8,700 feet and continues northward at about the same elevation to the quadrangle boundary. If the Precambrian rocks lying northwest of the offset have moved to the northeast along a reactivated Precambrian shear zone, and if the thrust plane has a reasonably constant dip, then the displaced trace of the Arlington fault north of the shear should lie at a higher elevation.

Since the offset part of the trace lies at a much lower elevation the writer concludes it is displaced by a transverse fault which offsets both the hanging wall and the footwall, and cannot be directly related to a Precambrian shear zone. This fault may be essentially vertical and the north block is relatively down.

The strata lying east of the trace of the Arlington thrust fault and in the footwall relative to that fault plane show no evidence of northeast trending deformation. The larger folds trend northwest and have excellent continuity in that direction.

Stone (1969) has presented a series of maps upon which are depicted several northeast trending strike slip faults in the central Laramie Basin. The only <u>bonafide</u> evidence of northeast trending structures in the area under consideration are the Rex Lake anticline, and a group of normal faults at the south end of Quealy Dome. The Rex Lake anticline is ruptured by a northeast trending, south dipping reverse fault at the level of the Forelle Limestone, and there is no evidence of strike slip movement associated with this fold. The normal fault at Quealy is a late feature, tensional in nature, south dipping, with relative movement down to the south. Again there is no evidence of strike slip movement.

The writer believes that the postulated strike slip faults shown by Stone (1969) have not been established in fact, either by mapping on the surface or in the subsurface and thus a false impression of the nature of the deformation has been created.

Structural Analysis

The major problem in analyzing the deformation of rocks in any episode of orogeny is to define the stress field which was effective at the time in question. It is often more difficult to establish the temporal relationship than to ascertain the facts of the deformation itself. In this part of the Rocky Mountain system the question may be simply stated by asking -- "Was the stress field during Laramide deformation predominately a vertically directed one or predominately a horizontally directed one?"

In recent years there have been exponents of both viewpoints and these have been reviewed by Keefer and Love (1963), Hodgson (1965), Prucha, Graham and Nickelsen (1965), Malahoff and Moberly (1968), Sales (1968), Shelton (1968), and Stone (1969). This list is not complete but these writers present the major viewpoints.

The data gathered in this investigation and in the adjacent Rex Lake quadrangle (Blackstone, 1970) suggest that horizontal stresses were responsible for at least part of the deformation. The horizontal shortening as revealed by the present configuration of the sub-sedimentary plane seems to require a horizontally directed stress field. The major buckling and eastward overriding of the basement rocks suggests that they have been folded, then ruptured, and crowded eastward. Differential vertical elevation of the basement would be accomplished by this means. If the movement were vertical only and the stress field vertical it would appear that no folding would occur, and that high angle faults with little overriding would be present.

Further evidence for a horizontally directed stress field can be found in the lateral displacement eastward of the Precambrian basement rocks over the recumbent western limb of the Mill Creek syncline in the vicinity of Corner Mountain. The development of strongly recumbent limbs of folds is difficult to achieve without at least a significant component of horizontal stress.

The normal faults such as Rock Creek fault, and the South Quealy fault reflect a change in structural regimen in which extension of the crust is necessary and vertical movements took place.

It should be kept clearly in mind that these two sequences of events are separated in time, and comprise separate episodes.

Structural Development in Time

The evaluation of geologic structural development is usually best documented by the sediments which derived from the deformed and uplifted rock sequences. Conglomerates are especially useful in this sense because the clasts are large enough to allow the observer to directly identify the source formation.

S. H. Knight (1953) admirably demonstrated in a series of block diagrams the methodology of reconstructing structural evolution on the basis of the sequences of rocks developed marginal to an uplifted area. Some modification of Knight's interpretation may be in order in view of the data found in this investigation. Love (1960) and Love, McGrew and Thomas (1963) have reviewed the Late Cretaceous and Cenozoic tectonic history of Wyoming in a regional sense. McCallum (1968) has reviewed the Cenozoic history of the east-central Medicine Bow Mountains, and Houston (1968) presented his views on the evolution of the northern Medicine Bow Mountains. The writer's ideas on the structural evolution follow.

Cretaceous

Rocks of Late Cretaceous age assigned to the Medicine Bow Formation contain a local lens of conglomerate in sec. 29, T. 16 N., R. 77 W. near an abandoned coal prospect known as Citizen's Mine (Knight, 1953; Blackstone, 1970; Houston and others, 1968). These conglomerates contain cobble and pebble size, poorly rounded clasts which Houston and others (1968, Table 60) described as follows:

> Conglomerate, light brown to dark reddish brown; matrix; arkosic, gravelly, sandstone; gravel consists of fragments of feldspar, quartz, and small fragments of silicified sandstone (Cloverly Formation), silicified wood (Morrison Formation), silicified pebble conglomerate (Cloverly Formation), siliceous shale (Mowry Formation), silicified fossil bone (Morrison Formation), chert (Morrison and Cloverly Formations), quartzo-feldspathic gneiss and granite (Precambrian), some cobbles are present that are largely fragments of silicified sandstone and conglomerate from the Cloverly Formation and Precambrian quartzo-feldspathic gneiss; gravel and cobble sized clasts are subrounded.

The conglomerates reflect an early pulse of tectonic activity in Late Cretaceous time which sufficiently elevated a land area to allow deep erosion and subsequent transport. The conglomerate lies less than 500 feet above the upper contact of the marine Lewis Shale in beds considered to be the equivalent of the lower part of the Medicine Bow Formation at the type locality (Bowen, 1918) which contains no conglomerates.

The source of the conglomerates exposed at Citizen's Coal Mine is problematical. Houston and others (1968) considered the cobbles of quartzo-feldspathic gneiss to have been derived from the Precambrian rocks of the Medicine Bow Mountains immediately to the west. The writer does not believe this was the source for the following reasons.

If the conglomerate was derived from the immediately adjacent Medicine Bow Mountains there should be a greater volume of debris than one thin local lens. No conglomerates have been reported from the Medicine Bow Formation around the northern end of the mountains, and the limited amount of debris suggests that the source was considerably more remote.

The association of clasts of Precambrian rocks with clasts of Cretaceous rocks suggests a source at some distance to allow for mixing in the course of transport. At many localities in Wyoming the locally derived early tectonic conglomerates contain only clasts of sedimentary rocks derived from the stripping of the sedimentary cover prior to the exposure of the basement. Later conglomerates, particularly those of Eocene age contain abundant clasts of Precambrian rock types almost to the exclusion of sedimentary debris. Here the wide variety of rock types suggests a more complex, and remote source.

Lovering (1929) pointed out that the northern Front Range of Colorado was elevated in Late Cretaceous time and may have been a source of sediment before the close of Pierre shale deposition east of the Front Range. Hale (1965, pp. 62, 116) reported that pre-Tertiary erosion had removed the upper part of the Pierre Shale in North Park, and he assumed -- "that Laramide tectonic activity began during latest Cretaceous (post-Pierre) time."

The writer believes that the source of conglomerate in the Medicine Bow Formation at Citizen's Coal Mine was either in the Front Range - southern Medicine Bow region of Colorado or in the Park Range but not in the northern Medicine Bow Mountains of Wyoming immediately adjacent to the present location of the conglomerate lens. Uplift of the northern Medicine Bow Mountains may have begun but had not elevated the area enough to provide coarse clastics of Precambrian rock fragments. The bulk of the Medicine Bow Formation in the area to the north of the mountains is fine to medium grained, and characterized by numerous coals and carbonaceous shales in the lower part.

The Medicine Bow Formation at the type locality in the Hanna Basin is overlain by the Ferris Formation (Bowen, 1918). The boundary between the two units in the western part of the Hanna Basin is characterized by the appearance of conglomerates. Dobbin and others (1929, p. 24) state:

> The lower 300 feet of the Ferris Formation consists of dark shale and coarse, friable massive buff to yellow sandstone containing small scattered pebbles and irregular thin beds of conglomerate. Overlying this lithologic unit is one about 800 feet thick, made up largely of conglomerate, which occurs as pockets, lenses, and thin beds irregularly distributed throughout the sandstone that constitutes the remainder of the unit. The pebbles of the conglomerate are usually less than 1 inch in diameter, are well rounded, and consist of quartzite, black, gray, and yellow chert, jasper, rhyolite, and porphyry. The remaining 5,400 feet of the formation consists of gray, brown, and yellow sandstones interstratified with numerous thick beds of coal.

The writers do not discuss the possible source of the conglomerate, nor the possible source beds of the individual clasts. The volume of material suggests a local source and may reflect the first major uplift of the northern Medicine Bow Mountains, as well as the Sweetwater Arch to the north.

Knight (1951) describes the first pebbles in the conglomeratic sequence on the north flank of the Hanna Basin as having a maximum diameter of two inches, and to consist of chert, quartzite, and Mowry shale fragments. He does not mention any crystalline metamorphic rocks.

The age of the basal conglomeratic part of the Ferris Formation containing Triceratops as mapped by Dobbin and others (1929, Plate 27) is currently believed to be Lancian. The conglomerates may be locally derived and represent the first uplift in the Wyoming part of the Medicine Bow Mountains.

In the Hanna Basin the Medicine Bow Formation is in excess of 6,000 feet thick but only the lower 500+ feet are present along the west margin of the Laramie Basin. The conclusion is that the Laramie Basin area, and the northern Medicine Bow Mountains were a positive area that was elevated during the period when the upper Medicine Bow Formation and lower Ferris Formation were deposited in the Hanna Basin trough.

Paleocene

Bowen (1918) defined the Hanna Formation and designated the type area to be near the town of Hanna, Wyoming. The formation was described as unconformably overlying the Ferris Formation, and the lower part was assigned a Fort Union (Paleocene) age although the upper part was tentatively considered to be Wasatchian (early Eocene) in age.

Knight (1951) on the basis of mapping on the north flank of the Hanna Basin came to the conclusion that the Ferris and Hanna Formations were conformable in the area which he examined and could not satisfactorily be divided into units. He therefore described the rocks under the name Ferris-Hanna undivided.

Currently the age relationships of the sequence established by Bowen (1918) and mapped by Dobbin and others (1929) are as described below, and shown in Fig. 12.

1. The basal sand and conglomeratic sequence of the Ferris Formation in the southwestern part of the Hanna Basin is Late Cretaceous in age and may be correlative with the Lance Formation of other areas.

2. The boundary between the Cretaceous and the Paleocene is placed above the conglomeratic phase of the Ferris and below the Dana No. 1 and No. 2 coals. These coals are equivalent in age to the lower part of the Fort Union Formation of the Wind River Basin.

3. The boundary between the Paleocene and Eocene lies between the No. 1 Hanna coal and the 83-A coal near the town of Hanna. The No. 1 Hanna coal is the time equivalent of the upper part of the Waltman Shale Member of the Fort Union Formation in the Wind River basin and the No. 2 Hanna coal is the time equivalent of the middle part of the Waltman Shale Member.

4. Coal 83-A is Wasatchian in age, therefore the upper Hanna as mapped is Eocene in age.

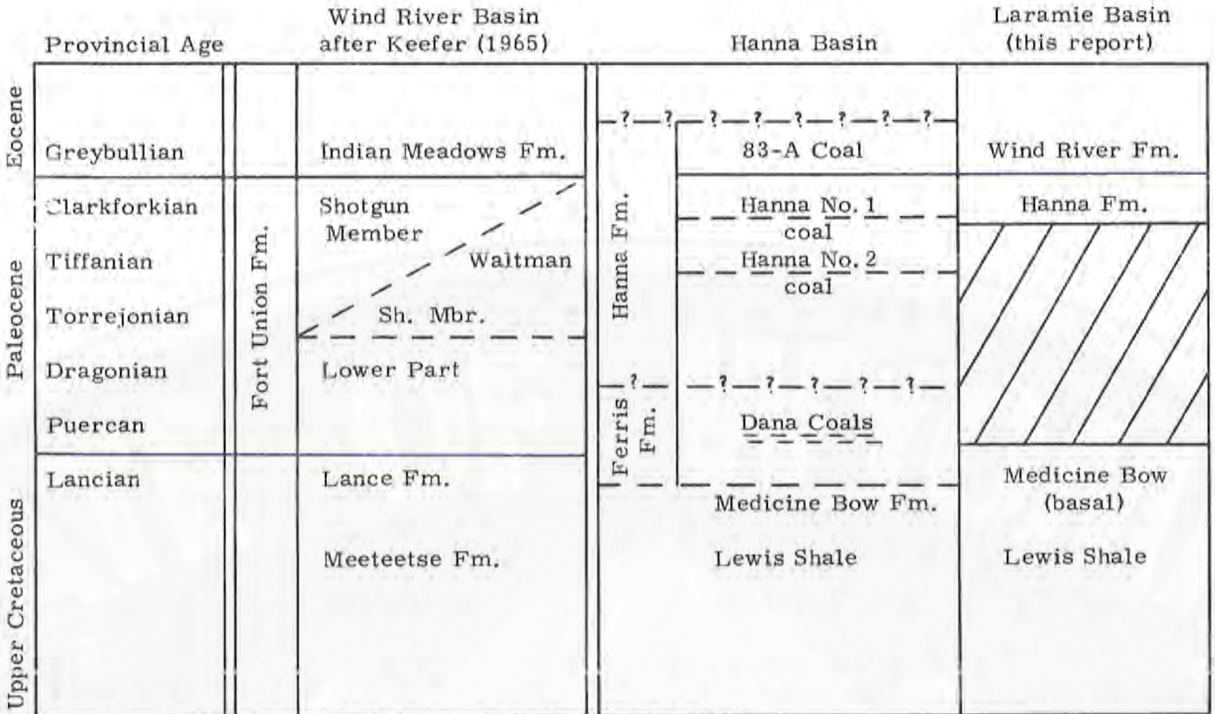


Fig. 12 Age relationship of Paleocene rocks in Laramie Basin

The structural development of the Strouss Hill quadrangle area is closely related to that of the nearby Hanna Basin. In the Strouss Hill area the basal conglomerates of the rocks mapped as Hanna Formation represent very latest Paleocene time and unconformably overlie Medicine Bow Formation, Lewis Shale, Mesaverde Formation, and Steele Shale. In terms of rock units a thickness of about 500+ feet of Medicine Bow Formation is succeeded by about 600+ of latest Paleocene Hanna Formation. In the Hanna Basin the same time interval is represented by approximately 18,000 feet of strata.

The conclusion drawn from these data is that the general area south of the east-west trending axis of the Hanna Basin and including the southern Laramie Basin, the northern Medicine Bow Mountains, and part of the Laramie Mountains was elevated after the deposition of the lower Medicine Bow Formation and continued to undergo erosion until late Paleocene time when the conglomerates of the latest Paleocene part of the Hanna Formation overlapped the older rock units toward the source of the conglomerates.

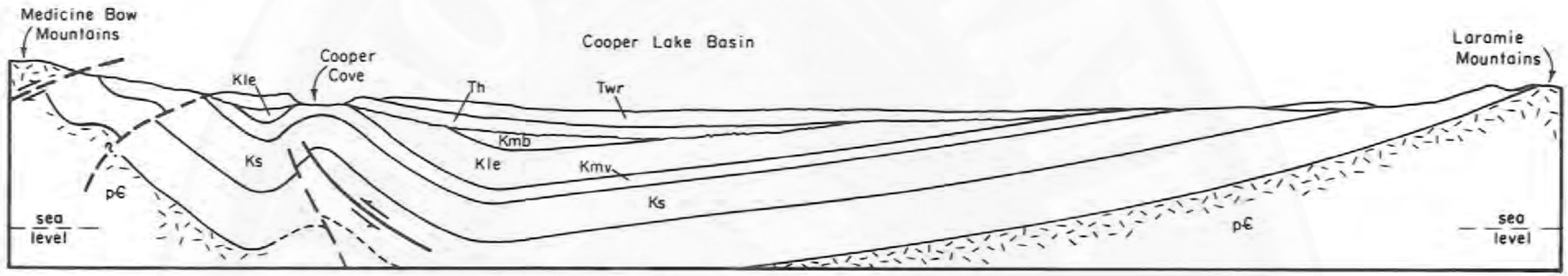
In this interval of time -- latest Cretaceous to latest Paleocene -- the east flank of the Medicine Bow Mountains was deformed largely by movement related to the Centennial Ridge line of folding and faulting, and by development of the major line of folding from Rock Creek anticline south to Seven Mile. Folds related to this deformation were truncated by erosion and overlapped by the basal conglomerates of the Hanna. Some elevation of the Laramie Mountains also took place since the Hanna appears to overlap the Medicine Bow Formation on the east side of the Cooper Lake Basin.

Deposition was continuous in deeper parts of the Hanna Basin from Lancian through early Wasatchian time. Marginal to the trough the younger formations overlap toward the sources of supply and lie with angular unconformity on older rock units that were elevated by deformation along the adjacent mountain flanks.

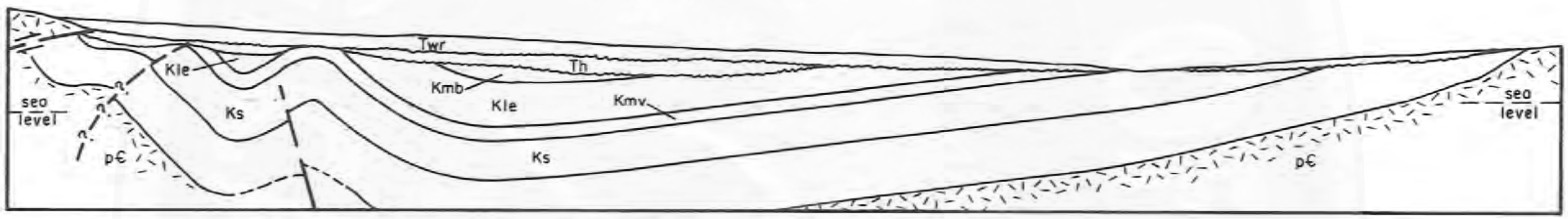
Eocene

Strata of earliest Eocene age (Greybullian, see above) occupy the structurally lower part of the Laramie Basin in an area centering around Cooper Lake in T. 19 N., R. 75 W. The upper part of this succession is a sequence of claystones, siltstones, and sandstones characterized by variegated coloring with red and maroon colors predominant. The lower part of the succession contains arkosic debris of coarse sand to pebble size which is strongly cross-laminated, but poorly bedded. Nace (1936) applied the name Wind River Formation to these rocks and considered them to be the direct equivalent of the type Wind River.

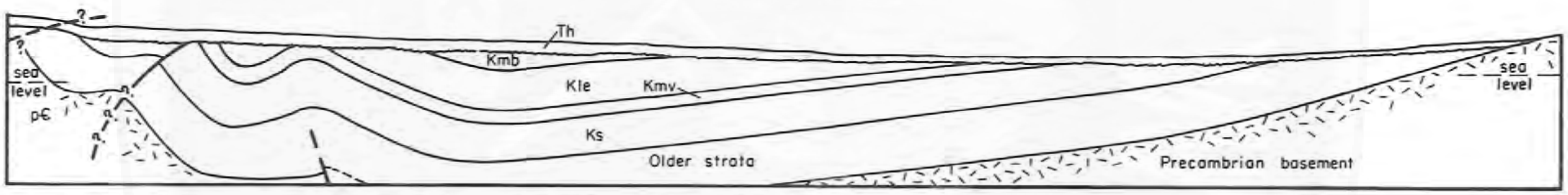
The Wind River Formation unconformably overlies the Hanna Formation and overlaps that formation on both the east and west flanks of the Cooper Lake Basin as shown in Fig. 3. The angularity of the unconformity is low in the basin center but appears to increase on the east flank of the Cooper Cove-Seven Mile anticline.



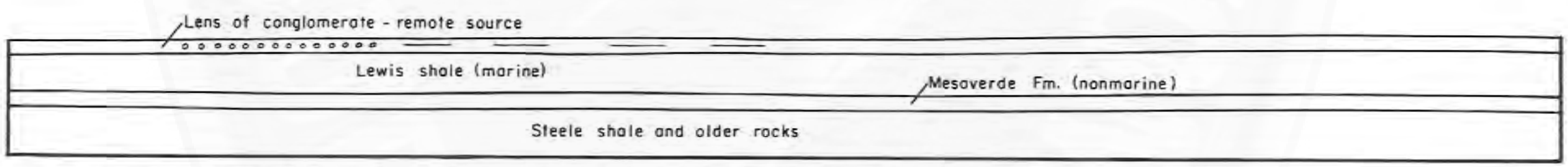
Present structure - Regional uplift relative to sea level since Oligocene



Early Eocene - Deposition of Wind River Formation (Greybullian)



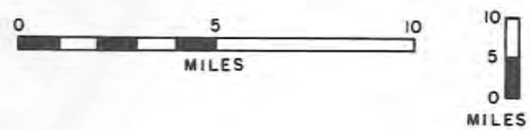
Latest Paleocene - Deposition of local, basal conglomerate of Hanna Formation



Near sea level after deposition of basal Medicine Bow Formation (Lancian)

FIG. 13

Diagrammatic cross sections illustrating structural development of the northern Medicine Bow Mts. – Cooper Lake Basin area. Line trends northeast from northern Medicine Bow Mts. to Laramie Mts.



No definite occurrence of the Wind River Formation has been reported in or west of the Arlington syncline. A few occurrences of reddish to pink mudstone have been noted by the writer east of Cooper Hill and north of Deer Mountain (Arlington quadrangle) that suggest Wind River lithology but are not conclusive enough to warrant mapping the unit in those localities.

A strong pulse of deformation further deformed the Strouss Hill area after the deposition of the Hanna Formation, and prior to the deposition of the Wind River Formation. The Paleocene strata were folded by renewed movement along the Rock Creek-Seven Mile anticlinal axis and by further deformation of the Arlington and Mill Creek synclines. The writer believes that it was this pulse of deformation which resulted in the emplacement of the Arlington thrust plate.

After deposition of the Wind River Formation broad folding further depressed the Cooper Lake area and deepened the syncline wherein the Eocene rocks are preserved. The Wind River Formation is offset by normal faults the age of which is indeterminate at this time. Blackstone (1970) mapped one such fault on the south flank of the Mill Creek syncline in the Rex Lake quadrangle. Current mapping has added details concerning the major normal fault at the south end of the Quealy anticline and the northeast continuation of this fault beyond the James Lake quadrangle.

McAndrews (1964, a, b) did not recognize the existence of the South Quealy normal fault in the Big Judson and Cooper Lake South quadrangles. Present mapping indicates that the Wind River Formation is markedly displaced by the South Quealy fault in these quadrangles, and therefore dating the fault as post-Wind River Formation, but it may be much younger.

The South Quealy fault system aligns with the extensive series of normal faults mapped by McGrew (1963, p. F 34) east of the Laramie Mountains and considered by her to be post-middle Miocene in age. It is possible that the South Quealy fault system is also post-Miocene in age.

In conclusion the region was deformed strongly in early Eocene time and achieved elevation and relief of considerable magnitude. Erosion was the dominant activity during middle and late Eocene time.

Oligocene

The rocks of Oligocene age in the Laramie Basin area are fine grained claystones derived from pyroclastic materials in which there are channels of locally derived gravels. The deposits rest with strong angular unconformity, upon a surface of major relief and upon all older rocks down to and including the Precambrian. The Oligocene rocks have been mapped as the White River Formation and assigned a Chadronian (early Oligocene) age on the basis of vertebrate fauna (Beckwith, 1938; McGrew, 1953).

The Oligocene rocks at the south end of the Centennial Valley are essentially flat lying and indicate that the period was one of structural quiescence (Beckwith, 1938).

Miocene and Pliocene

No rocks of these ages have been positively dated on the east flank of the Medicine Bow Mountains, but rocks of Miocene age (Barstovian) have been identified in the Saratoga valley on the west flank of the mountains (de la Montagne, 1957).

McCallum (1968) has reconstructed the Cenozoic history of a section of the Medicine Bow Mountains on the basis of lithologic correlation of scattered occurrences of rocks that can be inferred to be Tertiary in age. The lack of faunal or radiometric dates makes the reconstruction tenuous, but probably provides an adequate relative chronology of the Cenozoic events.

In the area studied the normal faulting present in Rock Creek valley is believed to be post-Miocene, but may be younger. Certainly on the basis of lithologic similarity the faulted strata would be considered as late Tertiary in age.

Widespread normal faulting took place in the Rocky Mountain region after middle Miocene. In the Laramie Basin area this period of faulting is inadequately known, and conjecture as to its extent and significance is beyond the scope of this study.

Summary

The development of the geologic structures based on data gathered in this study are shown diagrammatically in Figure 13.

ECONOMIC GEOLOGY

Oil and Gas

The oil and gas possibilities of the area have not been fully explored. The major structural traps have been tested and production established. It is possible that there are still drillable locations on the known structural traps because the subsurface structure is complex.

In view of the widespread interest in stratigraphically trapped oil in the Lower Cretaceous Muddy Sandstone attention should be given to this formation in this area.

Uranium

Uranium prospecting has been carried out by several groups through the method of airborne scintillometers followed by drilling. Effort has been concentrated on the Paleocene Hanna Formation and Eocene Wind River Formations. To date no ore bodies have been reported.

Bentonite

No rocks bearing significant bentonite beds crop out at the surface within the mapped area. There appears to be little likelihood of deposits worthy of investigation existing at the surface.

Coal

Coal and/or carbonaceous shales have been observed in several formations. Old coal prospects and shallow mines occur in most of these,but no coal is currently being mined. The oldest of the coal bearing units is the Mesaverde Formation with about 20 feet of carbonaceous shale with stringers of coal present in the basal part of the Pine Ridge Sandstone Member of the Mesaverde.

A thin carbonaceous shale with coal stringers is present about 1,300 feet above base of the Lewis Shale. In times past attempts were made to mine this coal in the Bengough Hill quadrangle. The basal Medicine Bow Formation which has limited outcrop contains several coal beds of low grade, none of which appear to be commercial.

New highway cuts on U.S. Interstate Highway 80 reveal carbonaceous shale 4 to 5 feet thick with coal stringers up to a few inches thick. They lie about 50 feet stratigraphically above the base of the Hanna Formation in the northern part of the Strouss Hill quadrangle.

No detailed measurement of coal beds have been made. A general appraisal of the coals on outcrop and the refuse on numerous old mine dumps indicates that these coals have neither the thickness nor the rank to warrant serious economic consideration at this time.

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