



Geology of the Spanish Creek Basin area, Madison and Gallatin Counties, Montana
by Craig William Tilley

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Earth Sciences

Montana State University

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Abstract:

The present geologic configuration of the Spanish Creek Basin Area has evolved through the interaction of structural and geomorphic processes on the basic stratigraphic framework.

The stratigraphic sequence in the map area is divisible into a basement complex of Precambrian metamorphic rocks, Paleozoic and Mesozoic marine sedimentary rocks, and a relatively thin discontinuous blanket of Cenozoic material.

The northern Madison Range is divided into at least three blocks by northwest trending high angle reverse faults. Fault displacement during the Laramide Orogeny was caused by a stress field with maximum compressive stress oriented SW-NE, horizontal, and minimum compressive stress oriented vertically. Paleozoic and Mesozoic sedimentary rocks were deformed by localized stress fields related to broad open drag folding along the margins of the moving blocks. In the map area the localized stress field was caused by the formation of the Cherry Creek Syncline. Maximum compressive stress paralleled the SW-NE trend of the short axes of the block uplifts, and minimum compressive stress paralleled the axial plane of the syncline and the SE-NW trend of the long axes of the blocks. Major compressive structural activity ceased in late early Eocene time. Post-Laramide structural activity involved normal faulting and epeirogenic uplift. The stress fields deduced from recent seismic disturbances near the Madison Range show a N-S trending tensional pattern.

The geomorphic history of the map area is as follows: 1. Early Eocene: consequent streams flowing down the northeast sides of the block uplifts joined subsequent trunk streams flowing southeast along the fault scarps. Drainage from the Tobacco Root Mountains and the southern fault block of the Madison Range passed through the map area and across the present Gallatin Range to join the ancient Yellowstone River.

2. Late early Eocene: volcanic rock was extruded in the Gallatin Range. This material buried the preexisting topography and caused a reversal in direction of streamflow in the map area. Drainage from the Tobacco Root Mountains and the Madison Range was concentrated in the Norris Hills and may have formed the Madison River.

3. Oligocene and Miocene: deposition of basin fill with minor episodes of erosion characterized this period.

4. Pliocene: basin filling and pedimentation in the high areas led to the development of a composite degradational-aggradational topographic surface. Remnants of this surface in the Spanish Creek Basin Area occur at elevations of 6600 feet and greater.

5. Pleistocene: changes in climate caused streams to downcut.

A pediment system in the map area was graded to Spanish Creek and the Gallatin River. At least three

main glaciations sharpened the relief of the Madison Range and contributed to the exhumation of early Tertiary landforms.

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Date

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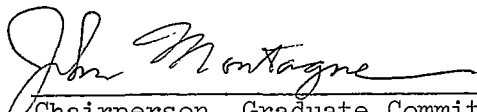
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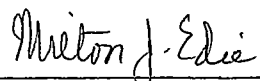
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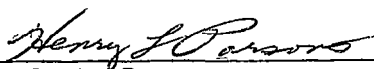
in

Earth Sciences

Approved:


Chairperson, Graduate Committee


Head, Major Department


Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

May, 1976

ACKNOWLEDGEMENTS

The writer wishes to thank the faculty and staff of the Earth Science Department at Montana State University and especially the members of his graduate committee; Prof. Charles Bradley, Prof. Robert Chadwick, and Prof. Gerald Nielsen (of the Plant and Soil Science Department). Special thanks are extended to Prof. John Montagne who served as chairman of the committee and faculty advisor.

Discussions with Verne Schrunck in the office and in the field helped clarify many obtuse relationships. Several field excursions with William Cullen Bryant IV and Ivan Bryant, in inclement weather, are also noted and appreciated. John Tonnsen deserves thanks for innovative suggestions. The unflagging enthusiasm of field assistants Tawny Fjeldahl and Jesse James was a great inspiration on hot and cold days. Prof. Robert Taylor generously provided cartographic equipment.

The writer thanks the Spanish Creek and Flying D ranches for allowing free access to the map area. Thanks go to Judy Fisher for manuscript typing.

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ABSTRACT

The present geologic configuration of the Spanish Creek Basin Area has evolved through the interaction of structural and geomorphic processes on the basic stratigraphic framework.

The stratigraphic sequence in the map area is divisible into a basement complex of Precambrian metamorphic rocks, Paleozoic and Mesozoic marine sedimentary rocks, and a relatively thin discontinuous blanket of Cenozoic material.

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3. Oligocene and Miocene: deposition of basin fill with minor episodes of erosion characterized this period.

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5. Pleistocene: changes in climate caused streams to downcut. A pediment system in the map area was graded to Spanish Creek and the Gallatin River. At least three main glaciations sharpened the relief of the Madison Range and contributed to the exhumation of early Tertiary landforms.

INTRODUCTION

Purpose

The purpose of this project was to map the geology of the Spanish Creek Basin Area. Major emphasis was focused on the geomorphology and glacial geology with the intent to unravel the Cenozoic, and particularly the Quaternary history of the area. Field work was carried on from the summer of 1974 to the spring of 1975. Mapping was done on enlargements of U.S.G.S. 15 minute quadrangle sheets (Anceney and Spanish Peaks, Montana) and on air photos of various scales.

Location and Access

The Spanish Creek Basin Area is an irregularly shaped tract encompassing approximately forty square miles at the northern edge of the Madison Range (Fig. 1). Most of the area lies within T4S, R3E, Gallatin and Madison Counties, Montana. The Gallatin River forms the eastern boundary while the area is framed on the north and south by the Spanish Breaks and the Spanish Peaks, respectively. The western boundary arbitrarily runs from the west edge of the Spanish Breaks southward to the North Fork of Spanish Creek. Spanish Creek and its tributaries drain the entire area except for a small part of section 24, T4S, R2E, which is drained by Cherry Creek.

Twenty miles southwest of Bozeman, near the junction of Spanish Creek and the Gallatin River, a private unimproved dirt road winds from

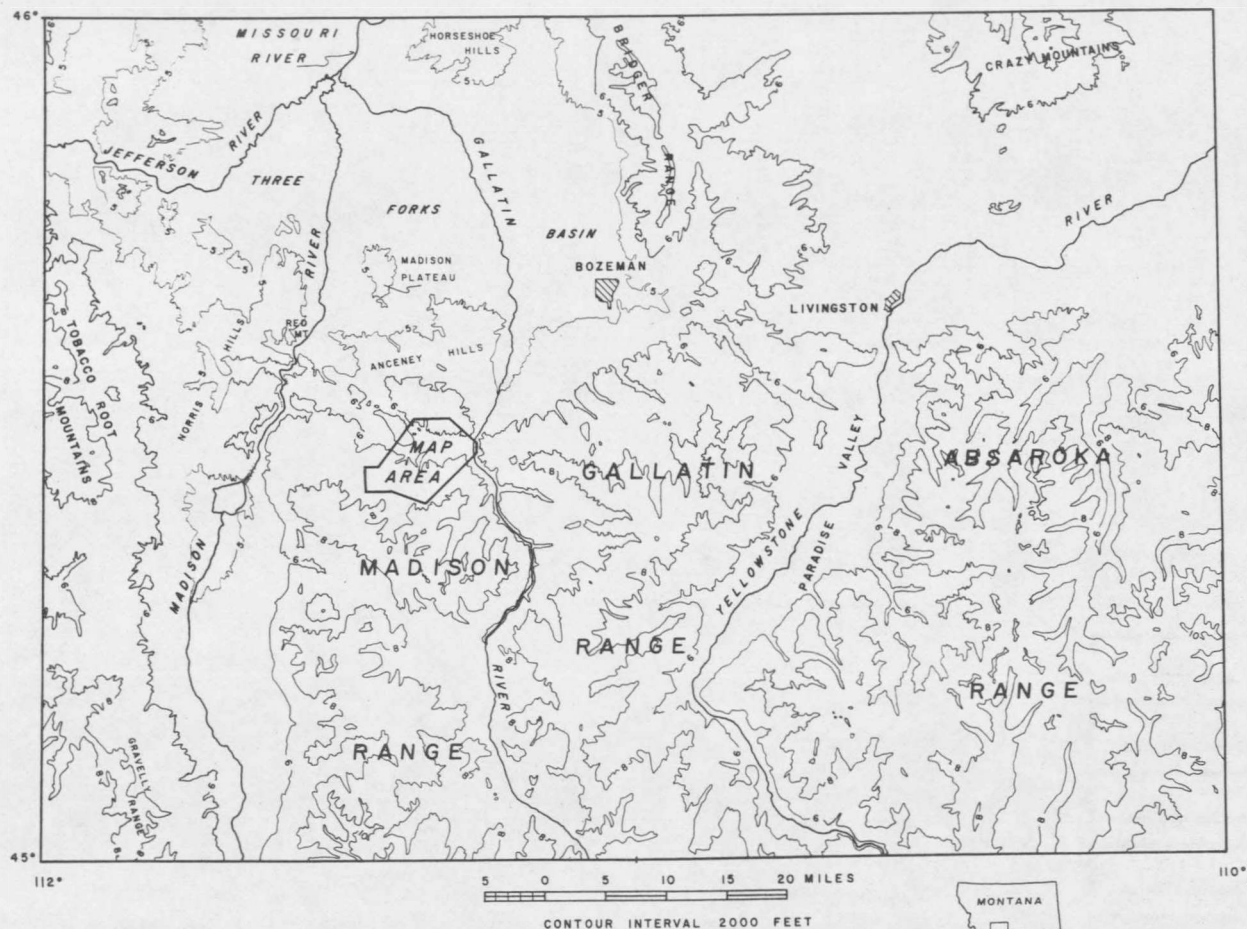


Fig. 1 LOCATION OF THE MAP AREA

U. S. Highway 191 into the Spanish Creek Basin Area, providing access throughout the year. Topographically diverse, the map area contains a variety of rounded hills, sharp ridges, deep canyons, and broad terraces, with some 3000 feet of total relief (Fig. 2).

Previous Work

The Spanish Creek Basin Area was included in the mapping study of the Three Forks 1 degree Quadrangle by Peale in 1896. Studies of mineral deposits in the Madison Range have been published by Hopkins and Taber (1947), Clabaugh and Armstrong (1950), and Becraft and others (1966). The map area was included in a regional study of Cenozoic block faulting by Pardee (1950). Alden (1953) made a cursory examination of the glacial geology near the South Fork of Spanish Creek. Kozak (1961) mapped most of the area as part of his study of the Cherry Creek Basin area. Mifflin (1963) compared the exhumed topography of the area with that of his own area. Several sections in the eastern part of the area were mapped by McMannis in conjunction with a study of the Garnet Mountain Quadrangle by McMannis and Chadwick (1964). Carl (1970) included the area in a study of the block faulting and drainage development of the northern Madison Range. Spencer and Kozak (1975) studied the Precambrian rocks of the northern Madison Range, including the map area.

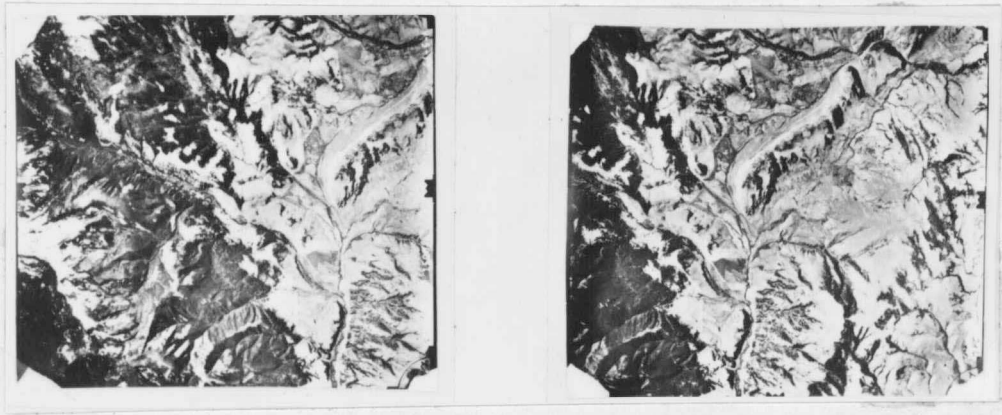


Fig. 2 Stereo pair of the Spanish Creek Basin Area.
North is to the right.

STRATIGRAPHY

The Spanish Creek Basin Area contains rocks and sediments ranging in age from Precambrian to Recent. Missing are the Precambrian Belt Supergroup, Ordovician, Silurian, and Triassic rocks. The section can be divided into three basic segments: a basement complex of Precambrian metamorphic rocks of unknown thickness, a Paleozoic-Mesozoic sequence of dominantly marine sedimentary rocks estimated to be over 4500 feet thick (McMannis and Chadwick, 1964), and a discontinuous blanket of late and post Laramide Cenozoic material deposited under continental conditions.

Due to the ubiquitous blanket of Tertiary and Quaternary sediments, exposures in the map area are generally restricted to canyons or valley sides where erosional agents have recently been active. For this reason, the stratigraphy was not studied in depth.

Precambrian

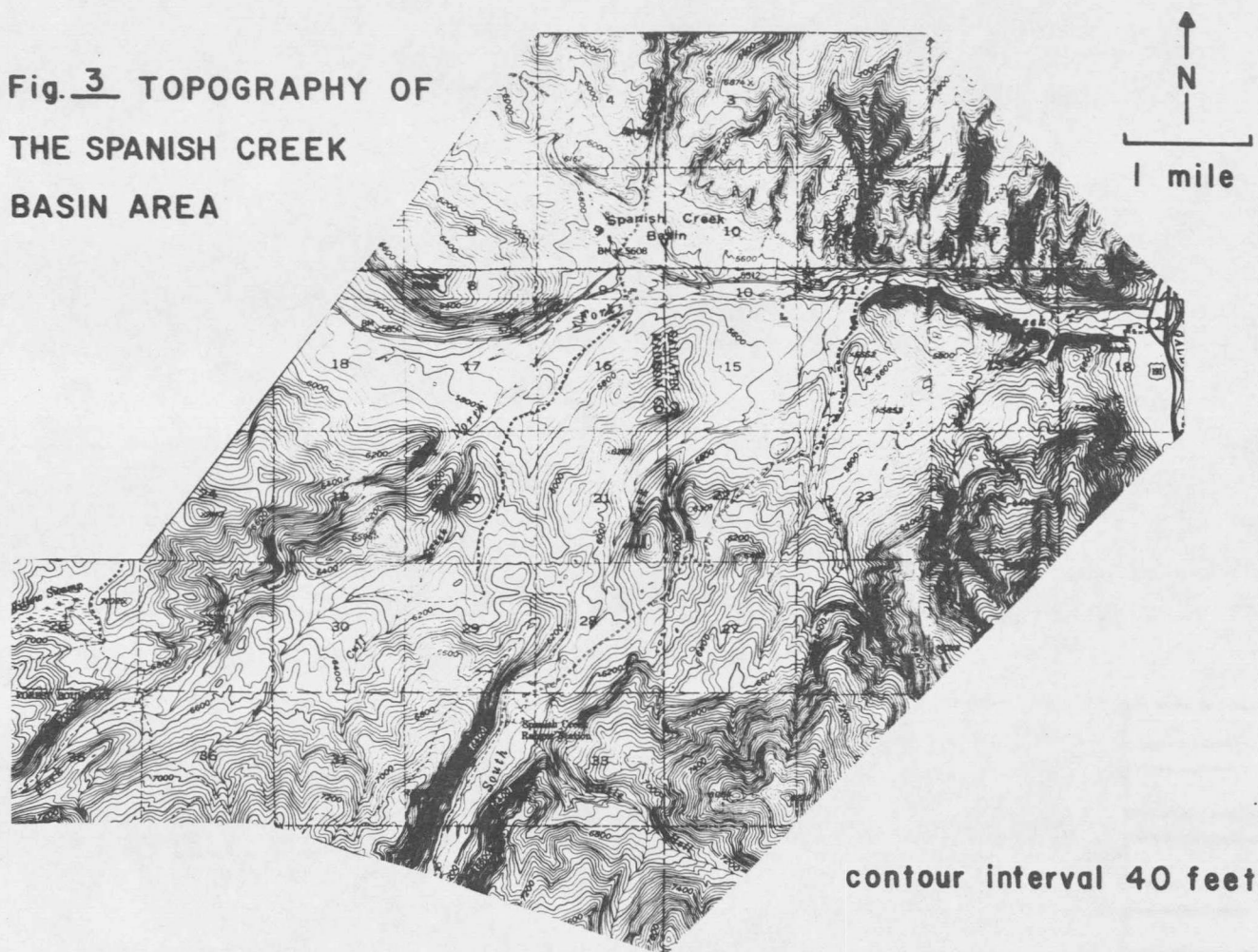
Precambrian metamorphic rocks underlie all deposits and crop out where the younger materials have been stripped off by erosion. The metamorphic rocks are exposed north of the Cherry Creek Fault, and from the southern margin of the Cherry Creek Syncline to the Spanish Peaks Fault (Fig. 8 and 12, pages 37 and 48 respectively). It is apparent that faulting has more than casually influenced the present areal distribution of Precambrian and younger materials (see STRUCTURAL GEOLOGY section, page 34).

The Precambrian metamorphic rocks include plagioclase-quartz gneiss, microcline-plagioclase-quartz gneiss, amphibolite, and mixtures of these with quartzite, sillimanite-quartz gneiss, biotite-kyanite-quartz schist, and marble present in less abundant amounts (Spencer and Kozak, 1975). Pegmatites are common in the gneisses. The pegmatite bodies, compositionally similar to the gneisses, vary from 1 inch thick lit-par-lit injections to 10 foot thick pods transverse to foliation (Kozak, 1961). On the northeast side of Willow Swamp a porphyritic rock with phenocrysts of olivine, augite, and plagioclase in a fine-grained hypohaline groundmass was mapped as "porphyritic ultrabasic rock" by Kozak (1961). Other igneous rocks of Precambrian age include amphibolized dikes and sills locally formed into boudins, and amphibolized foliated dikes and sills (Spencer and Kozak, 1975). Kozak (1961) examines the Precambrian rocks in much greater detail.

Spencer and Kozak (1975) cite evidence for two major Precambrian orogenic events: an early event which produced isoclinal folds, folded pegmatites, and amphibolite boudins, and a second event which produced large, open folds and a second generation of pegmatites. Emplacement of the Precambrian igneous rocks followed the second orogeny. These rocks were subsequently metamorphosed.

Quartz veins of nearly pure milky quartz exhibit concordant and discordant relations with the Precambrian rocks. The veins range in thickness from several centimeters to 1 meter. Their general

**Fig. 3 TOPOGRAPHY OF
THE SPANISH CREEK
BASIN AREA**



northwesterly trend subparallels the major faults of the northern Madison Range suggesting a close genetic relation with the faults. Therefore, a post-Precambrian (late Cretaceous to early Tertiary) age is suspected.

In the Spanish Creek Basin Area foliation in the Precambrian metamorphic rocks generally trends northeast, although there is great local variation.

The Belt Supergroup of late Precambrian age, which overlies the metamorphic complex in nearby areas, is not present in the map area. Metamorphic rocks are undifferentiated on the geologic map.

Cambrian

General. The Cambrian System is represented by six formations in the Spanish Creek Basin Area. Lower Cambrian strata are absent. The Middle Cambrian Flathead, Wolsey, Meagher, and Park Formations and the Upper Cambrian Pilgrim and Red Lion Formations make up a conformable sequence unconformably overlying the Precambrian metamorphic rocks. The top of the Red Lion Formation marks the boundary between Cambrian and Devonian strata.

In the map area Cambrian rocks are exposed along the southern edge of the Cherry Creek Syncline. The complete Cambrian section crops out in section 19, T4S, R3E, along the northern wall of the North Fork canyon. Cenozoic deposits obscure at least some part of the section in the surrounding area.

Flathead Formation. The Flathead Formation, resting unconformably on the Precambrian metamorphic complex, consists of buff to red, locally white to yellow, medium- to coarse-grained quartz sandstone containing occasional thin lenses of subround quartz pebble conglomerate. The degree of induration varies from moderately friable to quartzitic. The upper part of the unit is glauconitic and somewhat shaly with intercalations of micaceous shale becoming progressively more abundant toward the top. Cross-bedding and ripple marks are common sedimentary structures in the formation. Kozak (1961) determined a total thickness of 60 feet in the Cherry Creek Basin area. The Flathead Formation is quite resistant, forming low blocky ledges.

Wolsey Formation. Conformably and gradationally overlying the Flathead Formation, the Wolsey Formation is composed predominantly of green, grayish-green, and dark purple fissile micaceous shales containing numerous worm trails. The unit intercalates with the underlying Flathead Formation and the overlying Meagher Formation. The lower part of the Wolsey contains thin calcareous sandstone horizons with a few beds of impure quartz sandstone. Calcareous sandstone and sandy limestone beds occur near the top of the formation. In section 18, T3S, R2E, along Pole Creek, the Wolsey Formation is 233 feet thick (Kozak, 1961). In the map area the Wolsey Formation forms a pronounced topographic saddle between the Flathead and Meagher Formations due to its nonresistant nature.

Meagher Formation. In the Bridger Range, McMannis (1955) divides the Meagher Formation into three units: 1) a lower thin-bedded, fine-grained, dense gray limestone with intercalated greenish, calcareous shale; 2) dark gray, massive, fine-grained, dense limestone; 3) gray, fine-grained, dense limestone with interbedded shale. The contact between the Meagher and the Wolsey is obscure in most areas due to the nonresistance of the lower Meagher. Where exposures are good, the contact is placed at the base of the lowest ledge-forming limestone bed (McMannis, 1955). Gray and yellow-orange mottled, thin-bedded limestone with some limestone pebble conglomerate and thin oolitic beds near the top characterizes the Meagher Formation in the map area. The Meagher is 321 feet thick in section 18, T3S, R2E, along Pole Creek (Kozak, 1961), and 350 feet thick in T4S, R4E, near the junction of Squaw Creek and the Gallatin River (Hanson, 1952). Generally, the Meagher Formation is resistant and forms a prominent ledge.

Park Formation. The Park Formation is not exposed in the Spanish Creek Basin Area. In the Garnet Mountain Quadrangle the formation consists of gray-green and maroon fissile micaceous shale (McMannis and Chadwick, 1964). The Park overlies the Meagher Formation with apparent conformity, forming a topographic saddle between the Meagher Formation and the overlying Pilgrim Formation. Where measured in section 17 and 18, T3S, R2E (Kozak, 1961), and in T4S, R4E, near the mouth of Squaw Creek (Hanson, 1952), the Park Formation is 147 and 90 feet thick, respectively.

Pilgrim Formation. The conformable contact between the Park and overlying Pilgrim Formations approximately marks the Middle Cambrian-Upper Cambrian boundary (Hanson, 1952). Lithologically, the Pilgrim is divisible into two main units. The lower Pilgrim consists of gray-brown thin-bedded limestone with tan or yellow shaly partings, brown dolomite, massive, coarsely-mottled, sandy-weathering dolomite, and highly fossiliferous gray limestone with some limestone flatpebble conglomerate. The upper Pilgrim consists of massive, coarsely-mottled, sandy-weathering dolomite similar to that of the lower unit. In sections 17 and 18, T3S, R2E, the Pilgrim is 247 feet thick (Kozak, 1961). Hanson (1952) measured 215 feet of Pilgrim at the mouth of Squaw Creek. The Pilgrim Formation displays massive ledge-forming outcrops.

Red Lion Formation. The Red Lion Formation conformably overlies the Pilgrim Formation. The most conspicuous lithologic characteristic of the formation is the upper unit of interlaminated and wavy gray limestone and dark gray to brown siliceous limestone. Individual laminae are approximately $\frac{1}{2}$ inch in thickness. The more resistant siliceous laminae stand out with some relief on weathered surfaces. Chert stringers and nodules are also common. The lower Dry Creek Shale member is composed of gray-green fissile shale which forms a covered interval (McMannis and Chadwick, 1964). Thickness of the Red Lion Formation is 93 feet at the mouth of Squaw Creek (Hanson, 1952). The

top of the formation forms a subdued ridge that stands topographically higher than the overlying nonresistant Maywood Formation of Devonian age.

For mapping purposes, the Cambrian system was divided into four units: the Flathead and Wolsey Formations, the Meagher Formation, the Park Formation, and the Upper Cambrian Pilgrim and Red Lion Formations. Lithologic distinction and topographic expression served as the basis for these groupings.

Devonian

General. The Devonian System is represented by the Maywood, Jefferson, Three Forks, and Sappington Formations. These Upper Devonian units are a generally conformable sequence, although some evidence of a slight disconformity between the Three Forks and Sappington Formations exists (McMannis, 1962). Devonian strata at Squaw Creek are nearly 690 feet thick (McMannis and Chadwick, 1964). On the south side of Elk Mountain in sections 21, 22, 27 and 28, T3S, R2E, Kozak (1961) measured 620 feet of Devonian rocks. Kozak does not recognize the presence of the Maywood Formation in his map area, however. Thus, his measured thickness of 620 feet is understandably less than the thickness of Devonian rocks present in the Spanish Creek Basin Area.

Maywood Formation. The Maywood Formation rests unconformably on the Upper Cambrian Red Lion Formation. The Maywood marks the

resumption of sedimentation after a prolonged period of erosion and/or nondeposition in southwest Montana during the Ordovician and Silurian Periods (McMannis, 1965). The Maywood is exposed in section 20, T4S, R3E, east of Cuff Creek. Here the unit consists of approximately 50 feet of orange-yellow and red thin-bedded calcareous siltstone.

McMannis (1962) measured 61.5 feet of Maywood in section 28, T4S, R4E, at Squaw Creek. In a later publication (McMannis and Chadwick, 1964) this figure is amended to 34 feet in light of additional paleontologic and petrographic data. The Maywood Formation is nonresistant, forming a pronounced topographic saddle stratigraphically below the Jefferson Formation.

Jefferson Formation. Conformably overlying the Maywood Formation, the Jefferson Formation is composed of dark brownish-gray to brown, dense, sandy-weathering, medium- to fine-grained, medium- to thick-bedded dolomites and limestones containing numerous tetracoral and algal growths. Many of the beds emit a strong petroliferous odor. Solution breccias and gray-green shaly units intercalate with the dolomite strata. On the south side of Elk Mountain in T3S, R2E, Kozak (1961) measured 550 feet of Jefferson strata. The Jefferson Formation is resistant and ledge-forming throughout the area.

Three Forks Formation. The Three Forks Formation overlies the Jefferson Formation with apparent conformity. The sharp contact reported by McMannis and Chadwick (1964) is not exposed in the map

area. The formation can be subdivided into two members (McMannis, 1962). The lower Potlatch member consists of red, yellow, and greenish-orange argillaceous carbonate breccia, with a basal shale and a massive dolomite or limestone at the top (McMannis and Chadwick, 1964). This unit forms a covered interval in the map area. The upper unit, a medium- to thick-bedded, cream-colored, locally brecciated, dense limestone with innumerable calcite veinlets, is exposed near a glacial outwash channel in the NW $\frac{1}{4}$, SE $\frac{1}{4}$, sec 22, T4S, R3E. The position of the exposure is not included on the geologic map due to near total concealment by Tertiary deposits. The Three Forks Formation and the overlying Sappington Formation form a topographic saddle between the Jefferson Formation and the Mississippian Lodgepole Formation.

Sappington Formation. The Sappington Formation overlies the Three Forks Formation with apparent conformity, although the contact is not exposed in the map area. The formation is made up of a lower nonresistant covered interval of black shale (McMannis, 1962) and an upper more resistant yellow to white, coarse sandy limestone which grades upward into a fine-grained sandy limestone. Thickness of the upper unit is about 30 feet in the SW $\frac{1}{4}$, sec 22, T4S, R3E. Due to poor exposures, most workers combine the Three Forks and Sappington Formations for mapping purposes. In the map area of Mifflin (1963); the combined interval is approximately 140 feet in thickness. A 70

foot grass covered interval near Cowboy Canyon in section 27, T3S, R2E, corresponds with the Three Forks and Sappington Formations' (Kozak, 1961).

The four formations of the Devonian System are divided into two map units on the basis of topographic expression. The Maywood and Jefferson Formations constitute the first map unit, and the Three Forks and Sappington Formations constitute the second.

Mississippian

General. The Mississippian System is represented in the Spanish Creek Basin Area by two formations of the Madison Group; the Lodgepole Formation and the overlying Mission Canyon Formation. Thickness of these two formations totals about 1300 feet in the Garnet Mountain Quadrangle (McMannis and Chadwick, 1964), just east of the map area. The Madison Group forms Finnegan Ridge, an imposing linear homoclinal mountain spanning almost the entire Cherry Creek Syncline (Fig. 26, page 82).

Lodgepole Formation. The Early Mississippian Lodgepole Formation overlies the Devonian Sappington Formation disconformably (McMannis, 1962). Basal Lodgepole beds consist of black shale which is less than 10 feet in thickness. Above this shale lie the more characteristic brown-gray to gray, thin-bedded limestones with several beds containing abundant chert nodules. Highly fossiliferous beds, present at several levels, exhibit complete crinoids, crinoid

columnals, and fossil hash. More massive bedding prevails near the top of the formation.

Mission Canyon Formation. Conformably overlying the Lodgepole Formation, the late Early and early Late Mississippian Mission Canyon Formation (McMannis and Chadwick, 1964) consists of gray-brown to gray, thick-bedded and massive limestone and dolomitic limestone with abundant chert stringers and nodules. The formation is sparsely fossiliferous and contains solution breccias near the top. Both the Mission Canyon and the Lodgepole Formations are very resistant, forming the highest ridges of all Paleozoic and Mesozoic rocks.

The formations of the Madison Group are not differentiated on the geologic map due to their lithologic similarity and continuous topographic expression.

Pennsylvanian

General. The Amsden Formation straddles the Mississippian-Pennsylvanian boundary. Sloss and Moritz (1951) suggest that in many areas of southwest Montana where the Amsden is thin, it includes no beds older than the Pennsylvanian. In the Spanish Creek Basin Area, the Amsden Formation and the overlying Quadrant Formation are a conformable sequence resting unconformably on the Mississippian Madison Group. The Late Mississippian Big Snowy Group is absent from the map area due to nondeposition or erosion prior to Amsden deposition.

Amsden Formation. The Amsden Formation disconformably overlies the Mission Canyon Formation of the Madison Group. The formation is divisible into two units. The lower unit consists of bright red to purplish red, dolomitic siltstones and shales with occasional interbeds of purple, impure limestone. This unit forms a covered topographic saddle in the SE $\frac{1}{4}$, sec 16, T 4 S, R3E, between the Mission Canyon Formation and the second Amsden unit. Gray, thin- to thick-bedded limestone grading into light gray, medium- to thick-bedded dolomite with yellow to white dolarenite and quartzose sandstone near the top makes up the upper Amsden unit. The upper Amsden is exposed in the SE $\frac{1}{4}$, SE $\frac{1}{4}$, sec 16, T 4 S, R3E, and in the SE $\frac{1}{4}$, SW $\frac{1}{4}$, sec 4, T 4 S, R3E. At the latter location Kozak (1961) apparently confused the upper Amsden unit with the Mission Canyon Formation. Kozak bases his description of the Amsden Formation on an outcrop in the SW $\frac{1}{4}$, sec 10, T 4 S, R3E, which is obviously the Jurassic Morrison Formation since it lies stratigraphically above the Jurassic Ellis Group. Thickness of the Amsden Formation varies considerably. Where exposed in section 16, the formation is about 200 feet thick. Several miles east, in the Squaw Creek area, the formation is absent (McMannis and Chadwick, 1964).

Quadrant Formation. The Quadrant Formation conformably and gradationally overlies the upper Amsden unit. As each formation contains intercalations of the other's lithology, the position of the contact is arbitrarily placed at the base of the first thick bed of

sandstone (McMannis, 1955). The Quadrant consists of pale yellow to white, medium- to thick-bedded quartz sandstone and quartzite with intercalated dolomite in the lower part. The formation is exposed in the SE $\frac{1}{4}$, SE $\frac{1}{4}$, sec 16, T4S, R3E, and south of the Cherry Creek fault in sections 4, 5, and 9, T4S, R3E. In section 16, the Quadrant is about 150 feet thick. McMannis and Chadwick (1964) note the presence of 135 feet of the Quadrant Formation near Squaw Creek. Being quite resistant, the formation forms prominent ridges.

The interval between the Mississippian Madison Group and the Permian Phosphoria Formation is not differentiated on the geologic map. The saddle and ridge corresponding to the Amsden and Quadrant Formations are distinctive topographic features in the map area. Since the Pennsylvanian formations are intergradational, use of a single map unit avoids the strictly arbitrary contact location.

Permian

Phosphoria Formation. Only the Phosphoria Formation represents the Permian System in the Spanish Creek Basin Area. Overlying the Quadrant Formation conformably, the Phosphoria Formation consists of gray-brown to yellow-brown, thick-bedded quartzite and conglomeratic quartzite containing abundant fragments and nodules of chert and phosphate rock. The formation is exposed in the NE $\frac{1}{4}$, NE $\frac{1}{4}$, sec 9, T4S, R3E, and in the SE $\frac{1}{4}$, SE $\frac{1}{4}$, sec 16, T4S, R3E. At these locations the Phosphoria Formation forms a resistant capping ledge on the

Pennsylvanian Quadrant Formation. The formation is 105 feet thick on Squaw Creek (McMannis and Chadwick, 1964), but is apparently much thinner in the Spanish Creek Basin Area.

The Phosphoria Formation could logically be mapped with the Pennsylvanian strata because of its minor thickness and its lithologic and topographic continuity with the Quadrant Formation. The formation is delineated from the underlying formations on the geologic map only to maintain the identity of the separate systems.

Jurassic

General. Four Jurassic Formations are present in the Spanish Creek Basin Area; the Sawtooth, Rierdon, and Swift Formations of the marine Ellis Group, and the nonmarine Morrison Formation. These formations crop out along a subdued ridge-like interfluvium in the southern portions of sections 9 and 10, T4S, R3E.

Sawtooth Formation. In the absence of Triassic rocks, due to erosion or nondeposition, the Sawtooth Formation unconformably overlies the Permian Phosphoria Formation. The Sawtooth is composed of basal gray and gray-green calcareous shales, and an upper part consisting of yellow-brown argillaceous limestones (Moritz, 1951). In the map area, the formation is not exposed, as a result of its nonresistance and burial in Quaternary alluvial fan deposits. The gap between exposures of the Phosphoria and Rierdon Formations suggests its presence. The Sawtooth is about 160 feet thick near Squaw Creek (McMannis and Chadwick, 1964). ✓

Rierdon Formation. The Rierdon Formation overlies the Sawtooth Formation. In areas of better exposure the contact is thought to be conformable (Moritz, 1951). Where exposed, the Rierdon consists of massive gray oolitic limestone. A less resistant covered interval between the oolitic limestone and the overlying Swift Formation probably corresponds to the upper Rierdon, which consists of yellow-brown calcareous shale (McMannis and Chadwick, 1964). In the Garnet Mountain Quadrangle, thickness of the Rierdon Formation ranges from 28 to 63 feet (McMannis and Chadwick, 1964). Greatest thicknesses occur where the upper calcareous shale unit is present.

Swift Formation. An unconformity separates the Swift Formation from the underlying Rierdon Formation. Although not obvious in the map area, a period of erosion, in which the upper Rierdon unit was partially or completely removed, is well documented in other areas (Imlay, 1956; McMannis and Chadwick, 1964). The Swift Formation consists of red-brown to yellow-brown, fine- to medium-grained, calcareous, glauconitic sandstone with some chert grains and chert pebble conglomerate. The Swift Formation is 25 feet thick on Squaw Creek (McMannis and Chadwick, 1964). ✓

Morrison Formation. Conformably overlying the Swift Formation, the nonmarine Morrison Formation is composed of variegated red, purple, and green calcareous mudstones and shales, with occasional reddish, sandy and sandy limestone beds. The base of the Morrison is marked by

a 2 foot gray-brown limestone bed in the Little Sheep Creek section of Moritz (1951), and in the Spanish Creek Basin Area. The upper part of the formation lies under alluvium. On Squaw Creek the Morrison Formation is 450 feet thick (McMannis and Chadwick, 1964).

The four Jurassic formations are divided into two map units. The Sawtooth, Rierdon, and Swift Formations are mapped together as the Ellis Group, since exposures are generally poor and contact relations questionable. The Morrison Formation constitutes the second Jurassic map unit.

Cretaceous

Kootenai Formation. The Early Cretaceous Kootenai Formation unconformably overlies the Morrison Formation (McMannis, 1965). The contact is not exposed in the map area. In the Garnet Mountain Quadrangle (McMannis and Chadwick, 1964) the Kootenai may be divided into: 1) a basal gray, thick-bedded, cross-bedded, coarse-grained, conglomeratic sandstone containing pebbles of light- to dark-gray chert, quartzite and limestone; 2) variegated reddish shales and mudstones; 3) gastropod- and ostracod-bearing fresh-water limestone overlain by variegated red, yellow-brown, and gray mudstone. Thickness of the units are: 1) 75 to 85 feet; 2) 250 to 260 feet; 3) 35 to 50 feet. On Squaw Creek the Kootenai Formation is 360 feet thick (McMannis and Chadwick, 1964). In the Spanish Creek Basin Area only the basal Kootenai unit is exposed, forming a block strewn ledge.

Spatial and topographic relations between the basal Kootenai sandstone and the Cherry Creek fault indicate that the upper units of the Kootenai Formation, and perhaps even part of the Cretaceous Colorado Group, may be present in the SE $\frac{1}{4}$, sec 10, T4S, R3E. Alluvial fans cover the $\frac{1}{4}$ to $\frac{1}{2}$ mile distance between the basal Kootenai and the fault.

Tertiary

General. Tertiary strata unconformably overlie all older deposits in the map area. The Tertiary deposits overlap the irregular topography of the post-Laramide Eocene. Peale (1896) describes the Tertiary sediments of the region as the "Bozeman lake beds." He concluded that volcanic dust, carried to the region by winds, settled in and around the many coexisting lakes of southwest Montana before the Pleistocene Epoch. Matthew (1899) and all later workers have avoided the term, believing that fluvial and eolian processes also contributed to the genesis of the Tertiary deposits. Robinson (1963) adopts the term "Bozeman Group" to include the Tertiary deposits of the Three Forks Basin. He subdivides the Bozeman Group into three formations. In ascending order these are: 1) the Milligan Creek Formation, mainly fresh-water limestone, of Eocene age; 2) the late (and middle?) Eocene and early Oligocene Climbing Arrow Formation composed mainly of bentonitic clay and sand; 3) the Dunbar Creek Formation, of Oligocene age, composed mainly of tuffaceous siltstone. Also included in the

Bozeman Group are the Sphinx conglomerate of (pre-Milligan Creek Formation) Eocene age, and Miocene and Pliocene gravel called the Madison Valley Formation by Douglass (1907).

In the Spanish Creek Basin Area, Tertiary strata of the Bozeman Group are widely (yet poorly) exposed between elevations of 5500 and 6200 feet. A much thicker section is thought to have been present prior to Late Tertiary and Quaternary erosion (these and other relations are discussed in the section on CENOZOIC GEOMORPHIC HISTORY, page 68).

Milligan Creek Formation. In the Three Forks Quadrangle the Milligan Creek Formation consists of "light-colored fine-grained tuffaceous lake deposits, mainly limestone but ranging from limestone through marlstone to calcareous mudstones, and interfingering stream-channel sandstone and conglomerate" (Robinson, 1963). Although Feichtinger (1970) finds no evidence of the formation in her map area (northwest of the Spanish Creek Basin Area), lithologically similar deposits are exposed in the SW $\frac{1}{4}$, NW $\frac{1}{4}$, sec 21, T4S, R3E. Discontinuous exposures hinder attempts at positive identification of all Tertiary strata, because similar lithologies occur throughout the Tertiary section. Thickness determinations are accordingly nebulous.

Climbing Arrow Formation. The Climbing Arrow Formation of late (middle?) Eocene and early Oligocene age consists of stream-deposited yellow-hued quartzose sand, sandstone, and conglomerate, and massive

olive to reddish-brown clay (Robinson, 1963). This poorly indurated formation overlies the Milligan Creek Formation. The unit is exposed in roadcuts in the NE¹/₄, SW¹/₄, sec 21, T⁴S, R3E. The Climbing Arrow Formation may also be exposed in the SE¹/₄, sec 9, T⁴S, R3E. Stream-rounded pebbles and cobbles of rhyolite (from Red Mountain?) make up a large portion of the deposit here. The Climbing Arrow Formation, except for Quaternary alluvium, is more widely exposed than any other unit in the Three Forks Quadrangle (Robinson, 1963).

Dunbar Creek Formation. The Dunbar Creek Formation of Oligocene age may be the most widely exposed Tertiary formation in the Spanish Creek Basin Area. It is composed of white and gray tuffaceous siltstone, quartzose sandstone, and minor amounts of tuffaceous limestone (Robinson, 1963). The formation is poorly exposed in sections 5, 13, 14, 17, 18, 22, and 23, T⁴S, R3E. Broad benches have been carved in the formation at most areas of exposure. Pebbles and cobbles of Gallatin Range volcanics sparingly mantle the benches in the eastern half of the map area. The derivation of these clastic particles is not clear. They could represent a lag deposit, set free from the underlying beds. Feichtinger (1970) traces the Dunbar Creek Formation from the Three Forks Quadrangle southward to the Cherry Creek fault in her area of study.

The uncertain identification of the Tertiary formations in the map area, resulting from incomplete exposures and lithologic similarity of units, has led to the adoption of a generalized map unit.

Quaternary

General. Quaternary deposits overlie at least some parts of all older strata in the Spanish Creek Basin Area. The thickness of these nonindurated sediments varies considerably due to original depositional differences and the dynamic erosional conditions of the Pleistocene. In contrast with Precambrian, Paleozoic, Mesozoic, and (most) Tertiary strata, Quaternary sediments are very locally derived. These deposits are roughly divided into four general categories (although the transitional relationship of each to the others is demonstrable). All relate in some way to the Pleistocene glaciations of the Madison Range. No formational divisions are employed.

Glacial Drift. According to Flint (1971), glacial drift:

embraces all rock material in transport by glacier ice, all deposits made by glacier ice, and all deposits predominantly of glacial origin made in the sea or in bodies of glacial meltwater, whether rafted in icebergs or transported in the water itself. It includes till, stratified drift, and scattered clasts that lack an enclosing matrix.

Criteria for identification of deposits of glacial origin are:

1) abraded surfaces of bedrock beneath the deposits; 2) streamline forms in the deposit or underlying bedrock; 3) poor sorting and wide range in grain size; 4) pentagonal, faceted, striated, or angular coarse fragments; 5) presence of a characteristic fabric; 6) variable thickness, lateral extent, and lithology; 7) constructional features; (Flint, 1971).

Throughout the Rocky Mountains the glacial sequence described by Blackwelder (1915) in the Wind River Mountains, Wyoming is widely used as the standard for correlation (Fig. 4).

1. Pre-Bull Lake Glaciation(s): Deposits of deeply weathered drift lacking morainal topography and resting on divides, isolated hills, and spurs along valley slopes are called "Buffalo drift" by Blackwelder (1915), from their occurrence along the Buffalo Fork of the Snake River. The deposits rest on and grade to Blackwelder's Black Rock erosional surface (Fig. 29, page 89). More recent study (Richmond, 1948, 1957) reveals multiple glaciations associated with the Buffalo stage. For this reason, correlative deposits are referred to as pre-Bull Lake (Richmond, 1960).

In the Spanish Creek Basin Area, pre-Bull Lake drift has a flat to gently rolling surface with scattered boulders. The deposits lie beyond the outer limits of the younger Bull Lake and Pinedale moraines (for a description of the location and relations of moraines and drift remnants see the CENOZOIC GEOMORPHIC HISTORY section, page 68), and up to 900 feet above the present drainages. The physiographic position of drift remnants suggests a pre-canyon origin, although some deposits occur near the valley floors. The lower deposits could represent a subsequent pre-Bull Lake glaciation, but are more likely resting in low positions as a result of mass wasting and solifluction.

	Central North America Flint (1971)	Wind River Mountains Blackwelder (1915)	Richmond (1948)	Yellowstone Park Pierce (1970)	Richmond (1970)	Wasatch Mountains Morrison and Frye (1965)	Spanish Creek Basin Area (This Paper)	Termination Date in Years B.P. Richmond (1970)
Pleistocene	Wisconsin Stage	Recent Ice	Recent Ice	Gannett Peak Stage	Temple Lake Stage	Younger Deposits and Soils	Younger Deposits	
		Interglacial	Interglacial	Interglacial	Post-Pinedale Soil	Interglacial		
		Pinedale Stage	Pinedale 3	Pinedale Glaciation	Late Stage	Late Stage	Pinedale 2	11800
			Interstade		Interstade	Soil	Interstade	
			Pinedale 2		Middle Stage	Middle Stage	Middle Pinedale Stage ?	
			Interstade		Interstade	?	Interstade	
			Pinedale 1		Early Stage	Early Stage	Pinedale 1	
		Interglacial	Interglacial	Interglacial	Post-Bull Lake Soil	Interglacial		25000
		Bull Lake Stage	Bull Lake 2	Bull Lake Glaciation	Late Stage	Late Stage	Late Stage	70000
			Interstade		Inter-glacial	Middle Stage Soil	Interstade	80000
			Bull Lake 1		Early Stage	Early Stage	Early ? Stage ?	112000
	Sangamon Stage	Interglacial	Interglacial (canyon cutting)	Interglacial	Pre-Bull Lake Soil	Interglacial (canyon cutting)		130000
	Illinoian Stage	Buffalo Stage	Buffalo Stage	Sacagawea Ridge Glaciation	Sacagawea Ridge Glaciation	Pre-Bull Lake Stage(s)		180000
	Yarmouth Stage			Interglacial	Soil			290000
	Kansan Stage			Cedar Ridge Glaciation	Cedar Ridge Glaciation			700000
	Aftonian Stage			Interglacial	?			
	Nebraskan Stage			Washakie Point Glaciation				1200000
	Pre-Continental Glaciation	?	?	?	?	?		
Pliocene								

Fig. 4 Correlation of Quaternary Stratigraphy

Pre-Bull Lake drift is composed of cobbles and boulders of Precambrian metamorphic rocks, Paleozoic limestones and sandstones, and occasional clasts of volcanic rock. In the map area, the volcanics are not present in post pre-Bull Lake deposits[?]. The source of these rocks in the Spanish Peaks was apparently completely eroded by pre-Bull Lake ice or other pre-Bull Lake erosional agents.

In the Spanish Creek Basin Area pre-Bull Lake drift is not divisible into lithologically distinct units. In the southern Madison Range, T. H. Walsh (personal communication through John Montagne, 1976) finds evidence for three pre-Bull Lake glaciations. The oldest of these is overlain by the 1.9 million year old Huckleberry Ridge Tuff. Three pre-Bull Lake glaciations probably did occur in the map area. Their differentiation awaits further study, however,

2. Bull Lake Glaciation: Glacial drift overlying pre-Bull Lake (Buffalo) deposits at Bull Lake on the east flank of the Wind River Mountains is related to the Circle erosion surface and called "Bull Lake drift" by Blackwelder (1915). In the map area, moraines of the Bull Lake glaciation are large with slopes strewn with boulders. The moraines were breeched by the younger Pinedale ice and presently exist as broad arcuate remnants. Kettles are filled and hummocks are much reduced so that the surface of Bull Lake till is rougher than pre-Bull Lake till but smoother than Pinedale till.

Bull Lake deposits of the Spanish Creek Basin Area consist of Precambrian metamorphic rock fragments of all sizes. The deposits are differentiable from pre-Bull Lake deposits by: 1) the presence of an extensive outwash plain emanating from the Bull Lake ice terminal position (the pre-Bull Lake ice was so extensive that outwash was transported almost directly to the Gallatin River. Erosion has removed most if not all pre-Bull Lake outwash in the map area); 2) the lower topographic position; 3) the preservation of constructional features; 4) the slight degree of weathering in the exposed materials; 5) the presence of only metamorphic rocks in the drift.

3. Pinedale Glaciation: The Pinedale Glaciation was named from moraines around several glacial lakes near the town of Pinedale, Wyoming (Blackwelder, 1915). In the map area, Pinedale moraines are steep and hummocky with a profusion of fresh, relatively unweathered boulders at the surface. Kettles contain water at least seasonally. Erosion has had little effect on the Pinedale deposits. Terminal moraines are intact and streams flow through them via sharp, narrow incisions. Outwash from Pinedale ice lies below the much more extensive Bull Lake outwash plain. At least two separate Pinedale advances took place in the map area (the possibility of a third middle Pinedale advance is discussed in the CENOZOIC GEOMORPHIC HISTORY section, page 68).

In many areas of the Rocky Mountains, the soils in Quaternary deposits of successive ages show a corresponding succession in

development; the greatest development in the oldest deposits, the least in the youngest (Birkeland, 1974). In the Spanish Creek Basin Area an attempt was made to distinguish the deposits of pre-Bull Lake, Bull Lake, and Pinedale age by the degree of soil development. Several pits were dug and roadcuts examined in sections 21, 28, and 29, T4S, R3E. Mechanical analyses and x-ray diffraction of the clays were performed on selected samples of these soils. Figure 5 summarizes the characteristics of pre-Bull Lake (oldest) and Pinedale (youngest) soils at these locations. Greater clay content and horizonation mark the pre-Bull Lake soils. In other aspects, these oldest soils remarkably resemble the younger soils. Disintegration of metamorphic rock clasts is as great in Pinedale soils as in pre-Bull Lake soils. The predominant clay mineral present in all samples is smectite.

Soil genesis in the tills of the area apparently proceeds quite rapidly (geologically speaking) after deposition. A steady state is probably achieved early in the history of the developing soils so that additional changes in the character of the soils are slow. Since the pre-Bull Lake, Bull Lake, and Pinedale deposits are made of the same parent materials and have been subject to the same climate, organisms, and topography, the similarity in their development is not surprising.

Alluvium. Alluvium is material transported and deposited by running water. It generally exhibits better sorting and greater rounding of clasts than ice deposited materials (Fig. 6). In the

PRE-BULL LAKE SOIL		PINEDALE I SOIL *	
A ₁	0-15 cm Loam (40% sand, 40% silt, 20% clay), 10YR 2/1, granular - subangular blocky	A	0-28 cm Silt loam (35% sand, 50% silt, 15% clay), 10YR 3/2, medium-coarse granular
B ₂	15-30 cm Clay loam (45% sand, 25% silt, 30% clay), 10YR 5/4, granular - subangular blocky		
B ₃	30-45 cm Loam (40% sand, 34% silt, 26% clay), 10YR 6/6, granular - subangular blocky	B	28-60 cm Sandy clay loam (55% sand, 18% silt, 27% clay), 7.5YR 4/3 Weak subangular blocky
C	> 45 cm Sandy loam (60% sand, 20% silt, 20% clay), 2.5Y 7/4, granular - angular blocky	C	> 60 cm Sandy gravel, 10YR 4/4, granular - massive

* after V.K. Schrunk

Fig. 5 Comparison of Soils in the Spanish Creek Basin Area

A



B



Fig. 6 Comparison of deposits of till (A) and outwash (B). Hammer shows scale. Note the greater rounding and sorting of clasts in the outwash.

Spanish Creek Basin Area alluvium is mapped according to apparent age. Three assumptions facilitate age determination: 1) streams aggrade during glaciation and degrade during ice-free intervals; 2) the separate glacial intervals were of sufficient duration for streams to achieve graded conditions; 3) each successive glaciation has been of lesser magnitude (pre-Bull Lake greater than Bull Lake greater than Pinedale). Ideally, a stairstep succession of matched alluvial terraces, each graded from a specific meltwater outlet at a particular glacier terminus, should be encountered. The age of a terrace is thus determined by tracing or projecting it to its origin. Unfortunately, the actual record of alluvial aggradation and degradation lacks such fine order. The oldest deposits lie in thin scattered patches, as much as 450 feet above present streams. Only the Bull Lake glaciation produced a widely recognizable outwash level in the map area. Pinedale outwash occupies a level nearly coincident with the modern streams.

Two ages of alluvial fans are present in the Spanish Creek Basin Area. Bull Lake age fans grade from their apexes along the edge of the Spanish Breaks to the level of Bull Lake outwash. Incised and developed below them are Pinedale age fans which grade to Pinedale outwash. An alluvial fan in sec 32, T4S, R3E, developed after the withdrawal of Pinedale ice up-valley from the mouth of Little Hell Roaring Creek.

Colluvium. Colluvium consists of unconsolidated debris associated with gravitative transfer down slopes. Included in this category are talus and slope wash. Colluvial fragments are usually angular and composed of the same material as the bedrock. In some cases, the fragments are subrounded and of exotic lithology. These occur in areas of pre-Bull Lake drift. Ridges of Paleozoic limestone and glacially steepened canyons show a strong propensity for these deposits. Age assignments are not employed because most of the exposed colluvium was deposited during or after the Pinedale glaciation.

Landslide Masses. Landslides are not common in the Spanish Creek Basin Area due to the resistant and competent nature of most of the rocks. They occur in an area just south of the great Bull Lake and Pinedale 1 meltwater canyon (now abandoned) in sec 22, T4S, R3E. The combination of the shaly Three Forks and Sappington Formations, and oversteepened slopes leading into the canyon produced unstable conditions resulting in earth movement. The landslide masses are primarily slumps and debris flows.

Some slumping may have occurred in pre-Bull Lake drift near the border of sections 20 and 21, T4S, R3E. Here, a Pinedale 1 (and Bull Lake?) proglacial stream cut through the older drift causing instability. Slumping is suggested by the forms present on aerial photographs. The slumps are not well developed. Rather, they resemble the product of massive slow creep.

STRUCTURAL GEOLOGY

Regional Structure

The Spanish Creek Basin Area is part of a broad tract in southwest Montana where Precambrian metamorphic rocks are widely exposed. McMannis (1965) calls this portion of the state the "Basement province" (Fig. 7). The province is bounded on the north by the zero isopach of the Precambrian Belt Supergroup, which marks the ancient shoreline of the east-west trending Belt Embayment. In this area the zero isopach is suspected to be fault controlled. This fault or fault zone, called the "Perry Line" by Harris (1957), coincides with the Willow Creek Fault of the western Three Forks Basin (Robinson, 1963) and the Pass Fault of the Bridger Range (McMannis, 1955), as both faults mark the southern edge of Belt sediments (Fig. 8). The occurrence of an abnormally coarse facies of the Belt Series, the Lahood Formation, along the Willow Creek-Pass Fault zone is indicative of Precambrian structural movements (McMannis, 1955, 1963). On the western border of the Basement province, the zero isopach of the Belt Supergroup roughly follows the north-south trending Armstead-Melrose thrust zone. The eastern edge of the province coincides with the eastern limit of severe deformation associated with the Laramide Orogeny (McMannis, 1965). The southern boundary is obscured by the Yellowstone-Absaroka volcanic complex. ✓

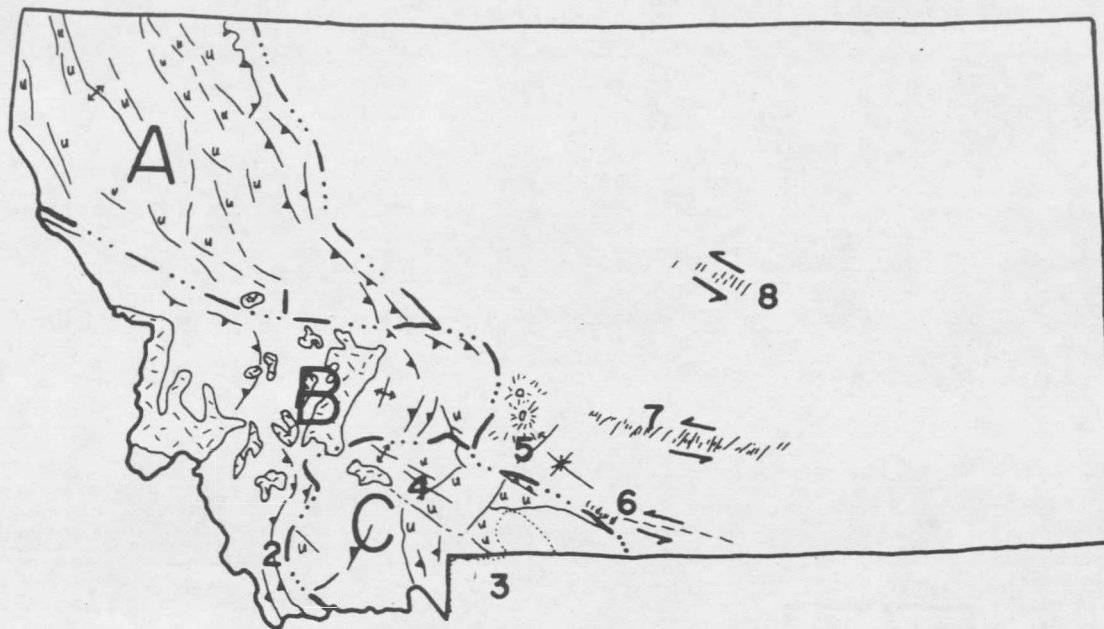


Fig. 7 TECTONIC MAP OF WESTERN MONTANA *

<u>A</u> BELT PROVINCE	1 Osburn Fault Zone	Thrust Fault
	2 Melrose-Armstead Thrust Zone	
<u>B</u> BATHOLITH PROVINCE	3 Yellowstone-Absaroka Volcanics	Steep Fault
	4 Spanish Creek Basin Area	
<u>C</u> BASEMENT PROVINCE	5 Crazy Mountain Basin	Syncline
	6 Nye-Bowler Zone	
	7 Lake Basin Zone	Anticline
	8 Cat Creek Zone	Monocline

* after McMannis, 1965

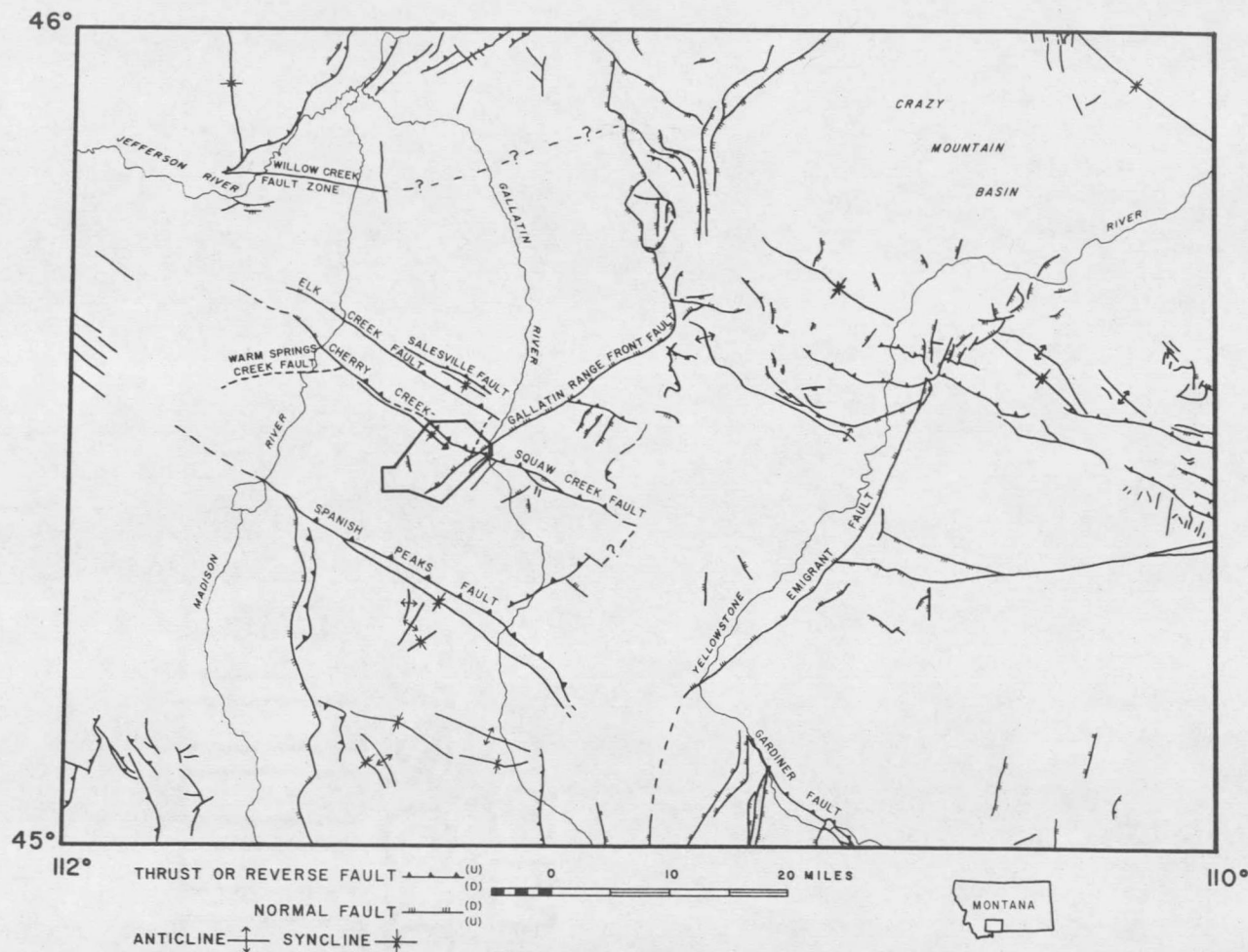


Fig. 8 GENERALIZED STRUCTURES

The Basement province displays a unique structural style of block uplifts, which are not expressed in adjacent areas. The absence of the thick Belt sedimentary sequence in the Basement province is largely responsible for this (Harris, 1957).

The thinner the cover, the more does block faulting dominate over folding in deformed areas. Furthermore, where thick cover is deformed and where observation is possible over a large stratigraphic range from high in the cover to or near the basement, deformation of the lower strata tends to resemble that in areas where the original cover was thin; block faulting dominates over folding and the folds tend to be gentle, broad open arches. The faults are mainly high angle. Going up in the cover, folding is intensified--the folds overturned in a dominant direction, and the faults flatten in dip (Wisser, 1957).

To the north, in the Batholith and Belt provinces, north-northwest trending, westerly dipping thrust sheets were peeled from and imbricated in the thick cover of Belt and younger sediments in reaction to Laramide forces. The shallowly buried metamorphic rocks of the Basement province formed a buttress against these forces, deforming rigidly through block jostling and strike-slip faulting (Robinson, 1963). The thin sedimentary cover passively draped, arched, and slid in response to movements of the blocks (Fig. 9). Northeast and northwest trending high angle faults dominated the Laramide structural scene of the Basement province, although many of the faults may have followed preexisting lines of weakness in the metamorphic rocks. The northeast trending faults are generally subparallel to Precambrian foliation. The northwest trending faults are generally parallel to the Montana Lineament, Nye-Bowler Zone, Lake Basin Zone, and the Cat Creek Zone

(Fig. 9). All of these major structural elements trend N50-75W and exhibit some evidence of pre-Laramide strike-slip faulting. The exact timing and nature of structural movements of the region are incompletely understood, yet the superposition of late Cretaceous-early Tertiary deformation on Precambrian trends is widely accepted.

Local Structure

In the northern Madison Range three northwest trending high angle faults divide the Precambrian metamorphic basement into three distinct fault blocks (Carl, 1970): the Spanish Peaks Fault forms the southern boundary of the southern block, the Cherry Creek Fault separates the southern and central blocks, and the Salesville Fault divides the central and northern blocks (Fig. 9). Boundary relations of the northern block are obscured by Tertiary deposits, but several other northwest trending faults mapped by Mifflin (1963) north of Elk Creek indicate continued block faulting of possibly diminishing magnitude to the north. Initial Laramide movement on all three boundary faults was reverse (some strike-slip?) with the south sides down. Feichtinger (1970) cites evidence for Oligocene and Pleistocene normal slip on the Cherry Creek Fault near the Madison River in opposition to the original reverse movements. The Elk Creek Fault(s), within the central block, has also experienced a reversal of displacement near the Madison River.

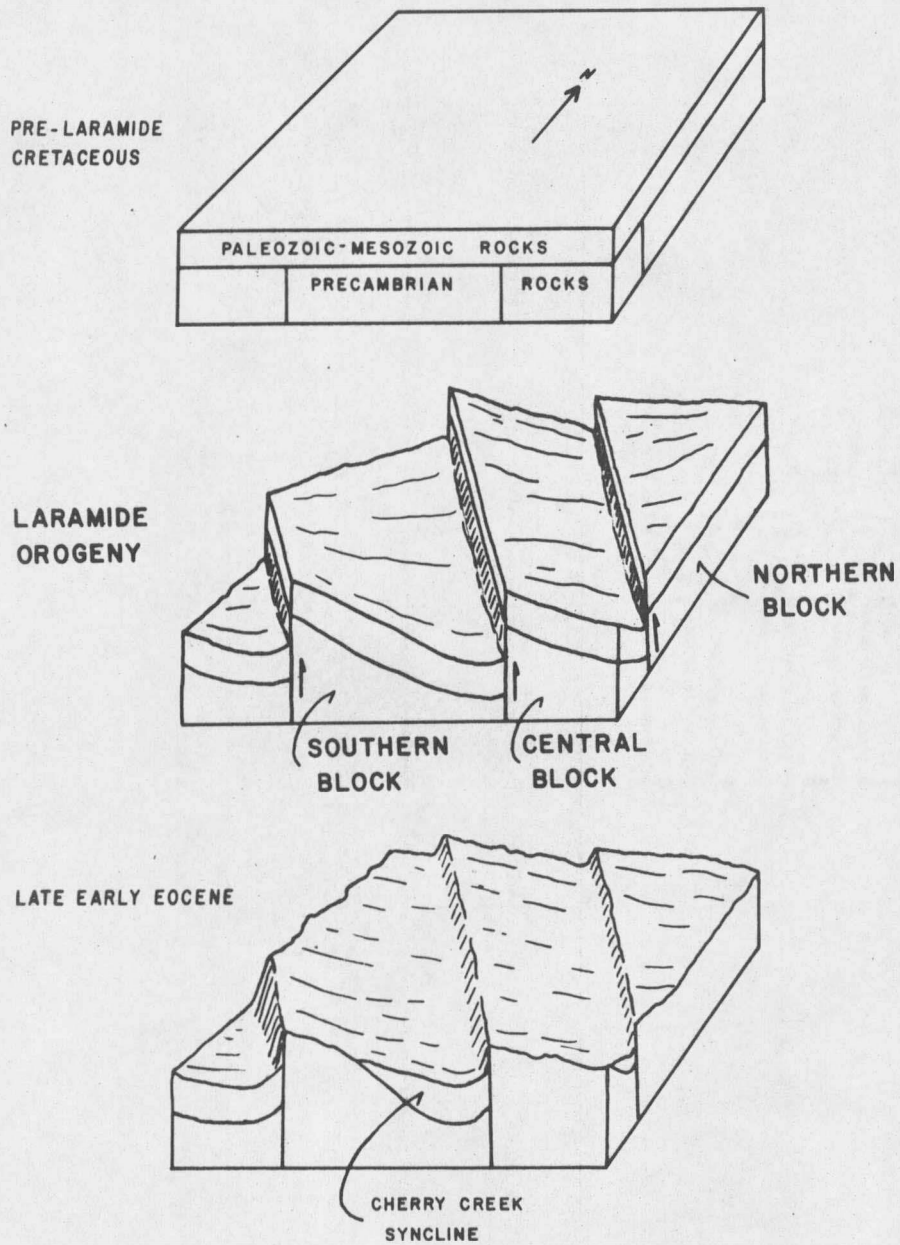


Fig. 9 STRUCTURAL DEVELOPMENT OF THE NORTHERN
MADISON RANGE (adapted from CARL, 1970)

Cherry Creek Fault. The Cherry Creek Fault is traceable from the Willow Creek Reservoir (Feichtinger, 1970) to the Gallatin Range Front Fault. The latter fault divides the Cherry Creek Fault from its southeast continuation, the Squaw Creek Fault (Fig. 8, page 37). The Squaw Creek segment is buried by a late early Eocene siltstone and Gallatin Range volcanics near the center of the Garnet Mountain Quadrangle (McMannis and Chadwick, 1964). Since the Cherry Creek-Squaw Creek Fault offsets Precambrian metamorphic rock to a position opposite the Cretaceous Colorado Group, with a dip-slip component of movement possibly exceeding 6500 feet (McMannis and Chadwick, 1964), displacement must have occurred between deposition of the Colorado Group and the late early Eocene siltstone.

The sense of Laramide displacement on the Cherry Creek Fault was reverse with the north side up. Evidence for dip-slip movement is displayed in section 4, T4S, R3E. Here the upper Amsden carbonate unit is warped from beneath the overlying Quadrant Formation by drag on the Cherry Creek Fault.

In the Tobacco Root Mountains, Reid (1957) finds anomalies in the trends of foliation and folds in the Precambrian metamorphic rocks on opposite sides of the Pony Fault, and ascribes the observed trends to major strike-slip fault motion.

Such differences in foliation trend are not apparent on the northwest trending faults which outline the basement blocks of the

northern Madison Range. This fact does not eliminate the possibility of strike-slip movements, however, for as Mifflin (1963) observes, the faults meet the foliation at an acute angle, so that strike-slip displacement would not markedly affect the basic foliation trend on opposite sides of the faults.

Several en echelon northeast trending faults along the south side of the Squaw Creek Fault (Fig. 8, page 37) may have been generated by a stress couple produced by a left-lateral strike-slip component of movement on the main fault (McMannis and Chadwick, 1964).

The nature of displacement on the Cherry Creek Fault in the map area, whether composite or simple, is subject to debate. The only hard evidence supports reverse motion on the fault which juxtaposed the metamorphic rocks on the north and Cretaceous rocks on the south (Fig. 12, page 48). The reversal of movement on the fault documented by Feichtinger (1970) near the Madison River is not indicated in the Spanish Creek Basin Area or the Garnet Mountain Quadrangle (McMannis and Chadwick, 1964). A possible end point of Feichtinger's Oligocene and Pleistocene displacement reversal may be located at the intersection of the Cherry Creek Fault and a northeast trending fault mapped by Kozak (1961) near Pole Creek. This fault is directly in line with a fault mapped by Andretta and Alsup (1960) trending northeastward from the Tobacco Root Mountains along Warm Springs Creek to the Madison River (Fig. 8m page 37). In Kozak's area the fault strikes N80E and

CHERRY CREEK FAULT



Fig. 10 View to the NW from the SE $\frac{1}{4}$, sec 14, T4S, R3E showing the location of the Cherry Creek Fault. The fault trends N50W and is nearly vertical. Precambrian rocks, in the upper right, have been uplifted against Cambrian to Cretaceous rocks, on the left. Tertiary deposits, in the foreground, were deposited after fault displacement ceased.

dips 83S. Tertiary sediments found directly southeast of the fault junction in the valley of Cherry Creek are not present northwest of it (Kozak, 1961), reflecting possible downdropping of the Tertiary sediments (or simple erosion). Physiographic evidence suggests that the reversal of movement on the Cherry Creek Fault continued farther southeast, however. Profile 1 (Fig. 24, page 79) shows the Paleozoic rocks of the Cherry Creek Syncline towering above Precambrian rocks on the opposite side of the Cherry Creek Fault. These Precambrian rocks once stood higher than the syncline (as they do along profile 2 of Fig. 24, page 79). The end point of the post-Laramide normal slip on the Cherry Creek Fault apparently lies near Cowboy Canyon.

North Fork Fault. In sections 18, 19, and 30, T4S, R3E, a fault striking N15W has displaced Precambrian through Middle Cambrian rocks. This fault is observable from just north of Cuff Creek to the SW $\frac{1}{4}$ of section 18. Since the fault is easily traced near the canyon of the North Fork of Spanish Creek, it is hereby designated the North Fork Fault (Fig. 12, page 48). Stratigraphic displacement on the order of 300 feet occurs at the southeasternmost exposure of the fault where Precambrian metamorphic rock on the northeast lies relatively uplifted against the Meagher Formation on the southwest. The straight trace of the fault across the North Fork Canyon suggests a vertical or very steeply dipping fault plane.

Movement on the North Fork Fault is inferred to be dip-slip in nature. This displacement cannot be dated with any precision, although topographic and stratigraphic relations may be casually invoked for a hypothetical overview. The drainage divide between Spanish Creek and Cherry Creek in the exhumed valley south of Finnegan Ridge lies directly in line with the trace of the North Fork Fault. The role played by fault movement in the development of the drainage is moot. If a relation exists between the North Fork Fault and the drainage of the valley, a late Tertiary or early Pleistocene age displacement is supported, as exhumation of the area from a cover mass of Tertiary sediments vigorously began at this time. In any event, fault displacement ceased before Wisconsin age glaciation of the Madison Range since glacial drift of that age buries the fault in section 30, T4S, R3E.

Gallatin Range Front Fault. The Gallatin Range Front Fault extends from southeast of Bozeman to the Spanish Creek Basin Area, marking the boundary between the Gallatin Range and the downdropped Three Forks Basin throughout most of its length. At the eastern edge of the map area the fault structurally divides the Gallatin Range from the Spanish Breaks (central fault block), although the most obvious topographic disjunction lies slightly west, in the Gallatin River canyon (Fig. 11).

In the Spanish Creek Basin Area the Gallatin Range Front Fault exhibits normal dip-slip movement along a roughly parallel surface

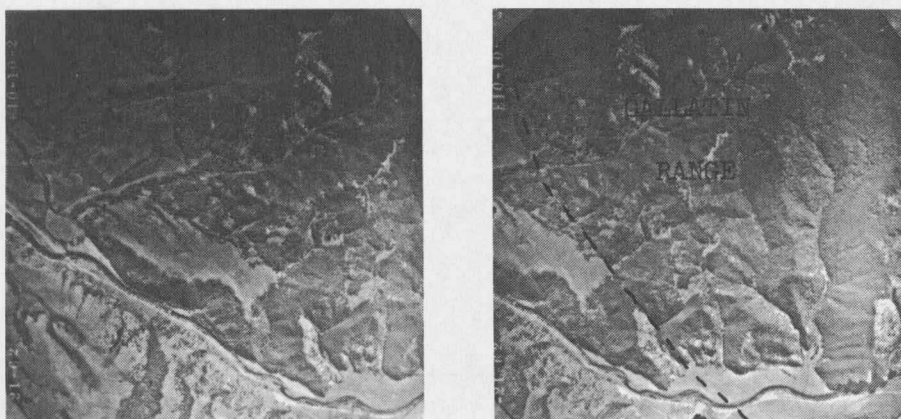


Fig. 11 Stereo pair showing the location of the Gallatin Range Front Fault relative to the canyon of the Gallatin River (T4S,R4E). The Gallatin Range Front Fault marks the boundary between the Gallatin Range and the Central Fault Block. at this location.

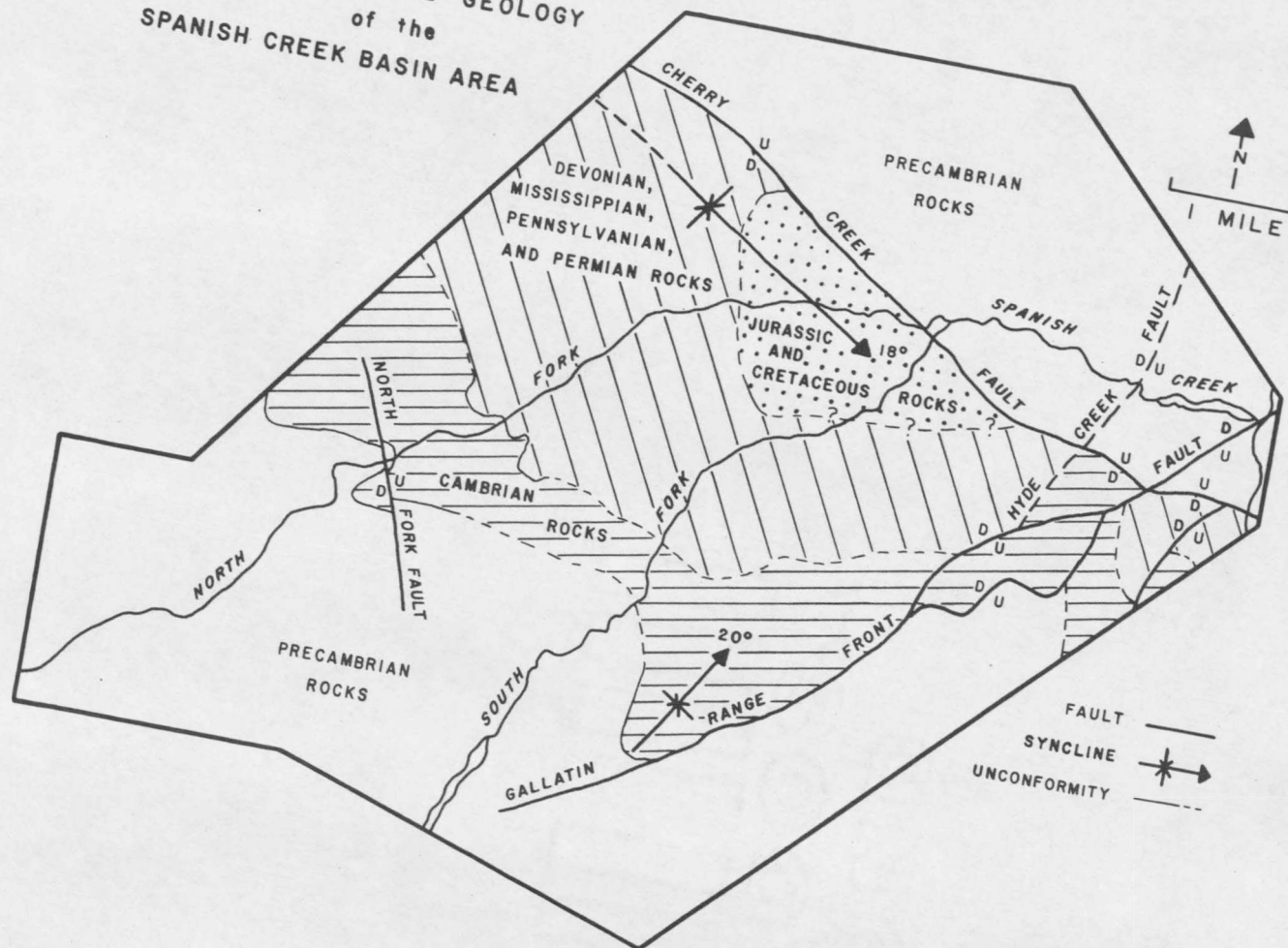
striking N50E (Fig. 12). The fault bifurcates just southwest of the Cherry Creek Fault intersection and rejoins at Twin Creek. Solution of a three point problem in the vicinity of Twin Creek shows a north-westerly dip of about 30 degrees on the southern element. Analysis of the surface trace of the Gallatin Range Front Fault southwest of Twin Creek also suggests a dip of 30 degrees to the northwest.

The southern bifurcated segment of the fault places the Park Formation, on the north side, opposite the Flathead Formation on the south, reflecting an apparent stratigraphic displacement of approximately 700 feet.

A pronounced north-facing scarp marks the trace of the northern segment of the bifurcation. Tertiary sediments dip gently toward the scarp and obscure stratigraphic relations on the northwest side of the fault. However, an exposure east of Twin Creek shows the Meagher Formation on both sides of the fault, indicating only small stratigraphic displacement. Thus, the northern fault represents a subsidiary offshoot from the main Gallatin Range Front Fault which coincides with the southern segment.

The Gallatin Range Front Fault is traceable from Twin Creek southwest to the glacial valley of the South Fork of Spanish Creek. In section 33, T4S, R3E, the fault cuts the northeast limb of a small synclinal flexure in Middle Cambrian rocks. The fault places the Flathead, Wolsey, and Meagher Formations against Precambrian metamorphic

Fig. 12 STRUCTURAL GEOLOGY
of the
SPANISH CREEK BASIN AREA



rock. The fold axis plunges 20 degrees to the northeast. The fold could have developed from drag coincident with left lateral strike-slip fault movement. The Middle Cambrian sequence on the southeast side of the fault occurs approximately $3\frac{1}{2}$ miles northeast of the sequence on the northwest side of the fault. These positions could also result from left lateral fault slip. Radical changes of orientation in foliation of Precambrian rocks juxtaposed by the Gallatin Range Front Fault (Mifflin, 1963) suggest strike-slip movement of large magnitude, yet the displacement of Paleozoic rocks is not in accordance with such movement. Precambrian strike-slip movement may have occurred (Mifflin, 1963). A combination of normal dip-slip displacement with concomitant drag folding of the Cambrian beds on the downdropped side, and subsequent erosion of the corresponding beds on the upthrown side could as easily account for the present form and distribution of strata near the fault.

Several remnants of volcanic rock on the northwest side of the Gallatin Range Front Fault must have been continuous with the main body of volcanic rocks southeast of the fault in the Gallatin Range. A vertical distance of 1500 to 2500 feet separates these formerly continuous units just northeast of the map area (Mifflin, 1963). The relation between these remnants and the rest of the Gallatin Range volcanics tends to add credence to normal dip-slip motion on the fault. The displacement on the Gallatin Range Front Fault probably follows the

close of the Laramide Orogeny since the displaced volcanic rocks overlies a late early Eocene siltstone which overlies the Laramide age Squaw Creek Fault in the Garnet Mountain Quadrangle (McMannis and Chadwick, 1964).

Physiographic and stratigraphic evidence suggests post-Laramide dip-slip movement on the Gallatin Range Front Fault. In actuality, displacement on the fault seems to have involved a component of rotation, with movement greatest in the vicinity of Bozeman. Apparent movement diminishes to the southwest and becomes nil at the glaciated valley of the South Fork of Spanish Creek.

Hyde Creek Fault. In section 13, T4S, R3E, just east of Hyde Creek, Upper Cambrian strata block the probable Eocene (and Oligocene?) drainage outlet of the Spanish Creek Basin Area. The Cambrian rocks are devoid of the Tertiary strata so ubiquitous immediately west. Along the trend of the block, Hyde Creek has incised a canyon through Precambrian rock to reach Spanish Creek. Pediments along the southern margin of the Spanish Breaks are offset noticeably along this same line. Mifflin (1963) maps a fault on the crest of the Spanish Breaks which probably continues southward into the Spanish Creek Basin Area (Fig. 8, page 37). Thus, the fault extends from section 32, T3S, R4E, where it intersects the southern Elk Creek Fault, to the northern border of section 24, T4S, R3E, where it intersects the northern bifurcated segment of the Gallatin Range Front Fault (Fig. 12). The

fault is hereby named the Hyde Creek Fault, since its trace runs parallel to Hyde Creek for some distance.

Solution of a three point problem reveals a strike of approximately N25E, and a dip of 30 to 40 degrees to the east. The Hyde Creek Fault thus exhibits reverse dip-slip displacement with the east side uplifted.

The Hyde Creek Fault slightly offsets the Cherry Creek Fault and must post-date movement on the latter (Fig. 12). The age of movement is very late or post-Laramide, and probably coincides with displacement on the Gallatin Range Front Fault. In fact, the movement on the Gallatin Range Front Fault may have initiated local stresses at the edge of the central basement block which were relieved through rotation of a relatively small portion of the block, down on the Gallatin Range Front Fault and up on the Hyde Creek Fault (Fig. 8, page 37, Fig. 12, page 48). The segment of the southern Elk Creek Fault which lies southeast of the intersection with the Hyde Creek Fault displays a sense of displacement compatible with a rotational movement of the small central block segment. This displacement sense is opposite to the original movement on the Elk Creek Fault.

Cherry Creek Syncline. The greatest structural feature of the Spanish Creek Basin Area is the Cherry Creek Syncline. This asymmetric, conical, southeast plunging fold extends from an apex near the Madison River southeastward to the Gallatin Front Fault (Fig. 8, page 37).

In the map area the fold axis trends N55W and plunges 18 degrees to the southeast (Fig. 12, page 48). The axial plane strikes N50W and dips approximately 75 degrees to the northeast (Fig. 15). The Cherry Creek Fault, whose trend subparallels the axis of the syncline, slices the fold, placing successively younger strata, from Middle Cambrian to Cretaceous, against the Precambrian metamorphics of the central basement block.

The syncline seems to have developed from the relatively passive draping of Flathead to Colorado sediments at the boundary of the southern and central basement blocks, as these blocks shifted position along the Cherry Creek Fault (Fig. 9, page 40). The conical geometry of the syncline suggests that the greatest structural displacement between the southern and central blocks occurred at the southeastern end of the Cherry Creek Syncline. Very similar relations exist along the Salesville Fault, although lesser structural displacement of the northern block may be indicated by the smaller extent of the draped syncline south of the fault.

Fractures. Kozak (1961) shows three main fracture trends in the Paleozoic rocks of the Cherry Creek Syncline; N75E, N6W, N51E, all vertical. He determined these trends by plotting the poles to fractures on an equal area net, and contouring these poles on the basis of percent per 1 percent area to show the distribution of maximum concentrations (for plotting and contouring methods see Billings, 1972). In similar

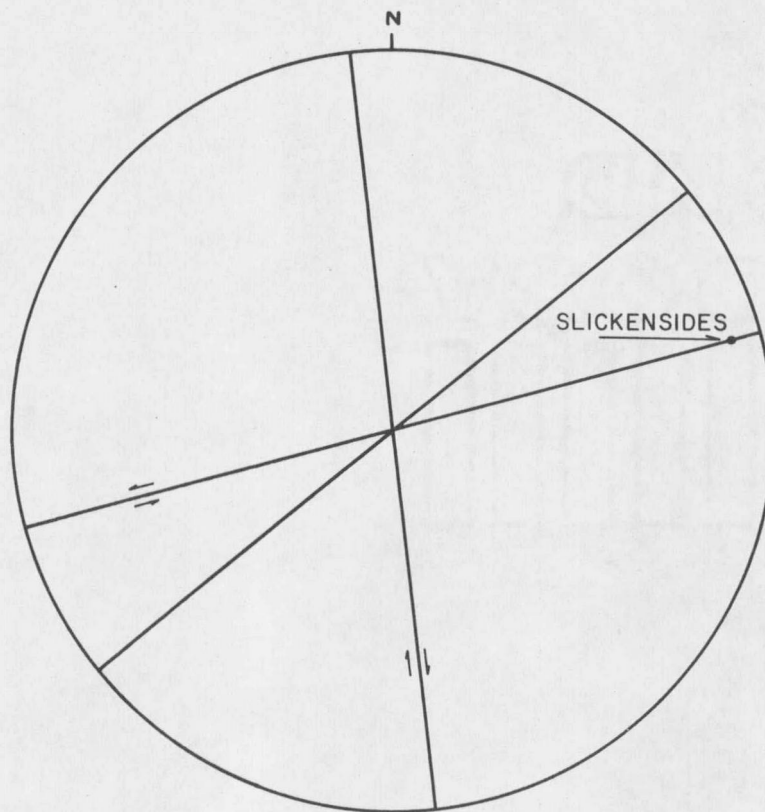


Fig. 13 EQUAL AREA PROJECTION OF
FRACTURES IN PALEOZOIC ROCKS
(AFTER KOZAK, 1961)

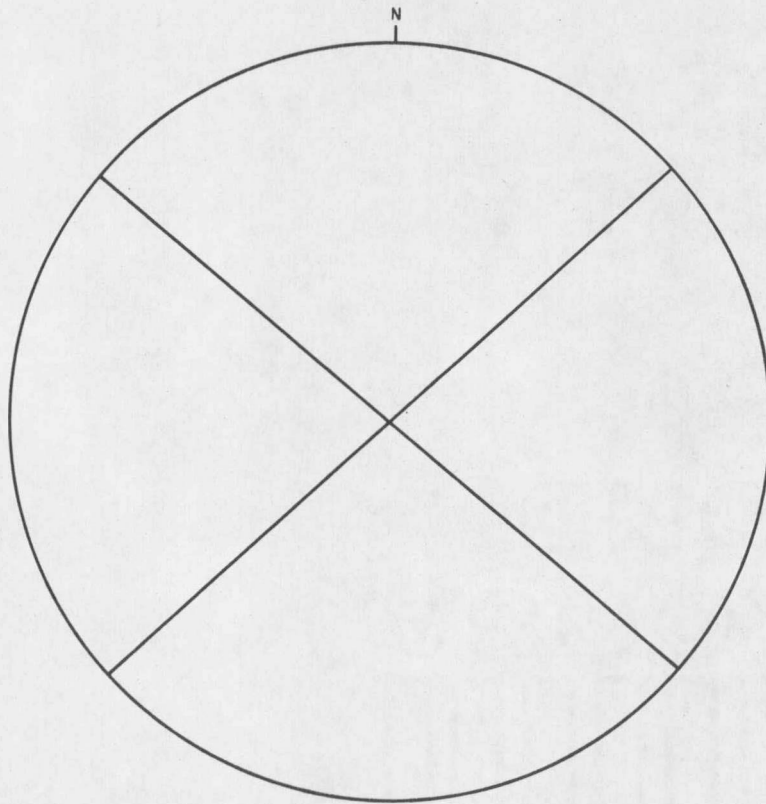


Fig. 14 EQUAL AREA PROJECTION OF
FRACTURES IN PRECAMBRIAN ROCKS
(AFTER KOZAK, 1961)

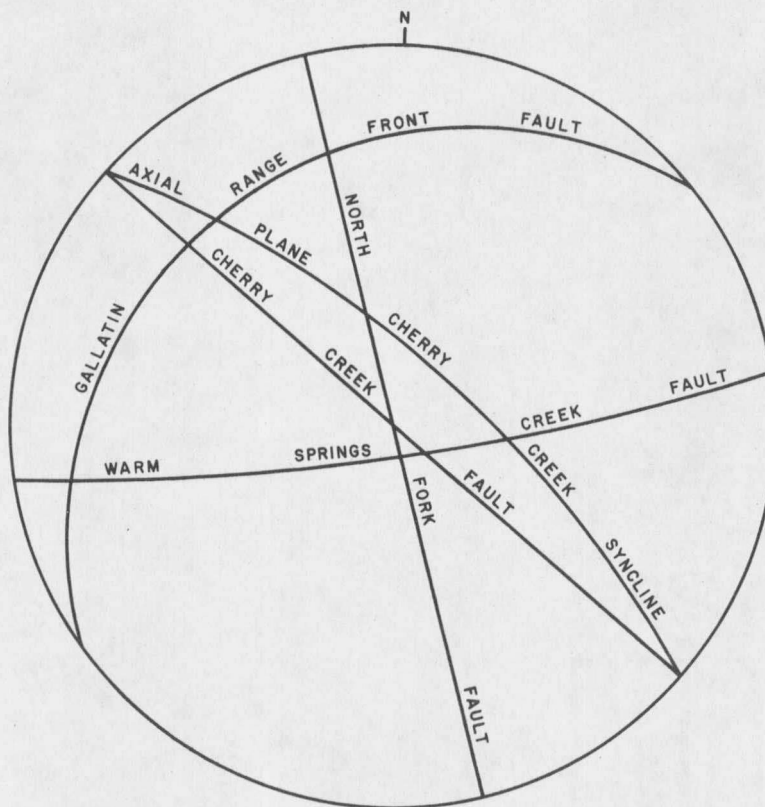
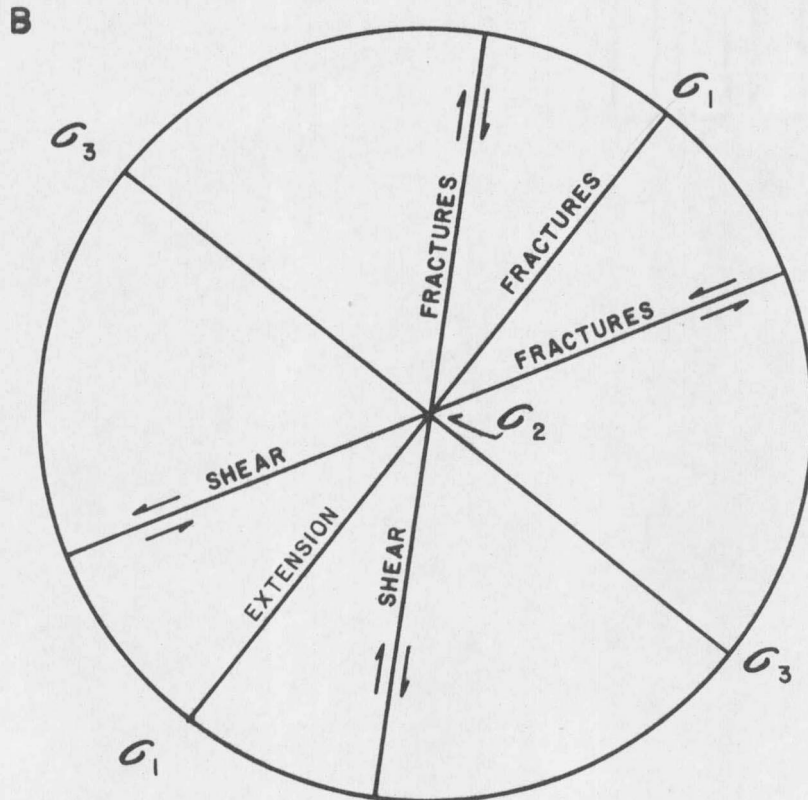
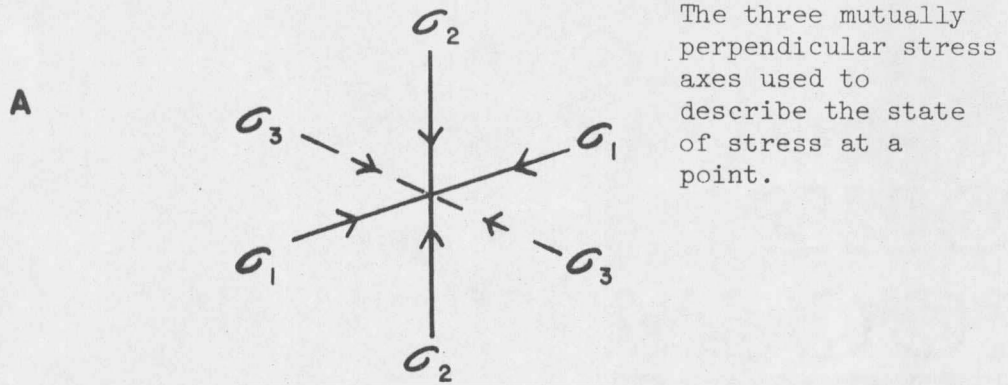


Fig. 15 EQUAL AREA PROJECTION OF
STRUCTURES IN THE VICINITY OF THE
SPANISH CREEK BASIN AREA



Lower hemisphere equal area projection showing the geometry of the stress axes and resultant theoretical fracture sets.

Fig. 16

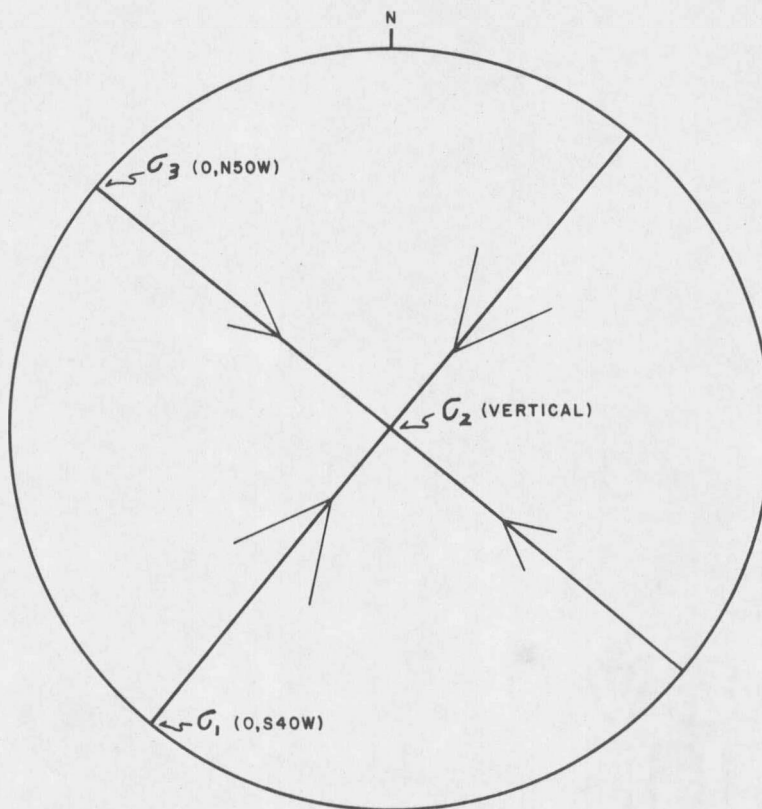


Fig. 17 EQUAL AREA PROJECTION OF THE
LARAMIDE STRESS FIELD IN THE SPANISH
CREEK BASIN AREA

fashion, Kozak determined two major fracture trends in the Precambrian rocks of the southern and central fault blocks; N50W, N47E, both vertical. These fracture sets cut all folds and structures of Precambrian vintage, and are therefore considered to be coeval with the structures of the Laramide Orogeny (Kozak, 1961). Kozak's data is summarized on lower hemisphere equal area projections in Figures 13 and 14, pages 53 and 54 respectively.

When the main structural features of the Spanish Creek Basin Area are plotted on a lower hemisphere equal area projection (Fig. 15) and compared with Figures 13 and 14, several interesting patterns stand out: 1) The strike of the Gallatin Range Front Fault parallels a fracture set in the Paleozoic rocks and a fracture set in the Precambrian rocks. 2) The orientation of the Cherry Creek Fault, the axial surface of the Cherry Creek Syncline, and the other fracture set in the Precambrian rocks are subparallel. 3) The North Fork Fault and a fracture trend in the Paleozoic rocks are subparallel. The geometric arrangement of these structural elements is not random or coincidental. Rather, a definite relation exists between the observed structural geometry of the area and the geometry of stress during the Laramide Orogeny, although some imprinting of Laramide structures on Precambrian trends, and post-Laramide structures on Laramide trends is observed.

Stress Determinations

The orientation of the stress field responsible for the genesis of structures in the Spanish Creek Basin Area can be determined from the orientation and angular relationships of the structures. Laboratory and field studies indicate that four fracture orientations are commonly associated with brittle deformation (Billings, 1972). These consist of two conjugate shear fracture sets and an extension fracture set which bisects the acute dihedral angle of the shear fractures. The fourth fracture set, which is more common in experimentally fractured rocks, is perpendicular to the extension fracture set. The direction of maximum compressive stress (σ_1) parallels the extension fracture set and is perpendicular to the intermediate compressive stress (σ_2), which is defined by the intersection of the four fracture sets. The direction of minimum compressive stress (σ_3) is perpendicular to the other stress axes (and the extension fracture set) and bisects the obtuse dihedral angle of the shear fracture sets. Figure 16 visually summarizes the geometry of the stress axes and resultant fractures.

Comparison of the theoretical fracture geometry (Fig. 16) and actual fractures in the map area (Fig. 13 and 14, pages 53 and 54 respectively) reveals a startling though expectable match. When the major structures of the area (Fig. 15, page 55) are also considered, the significance of the match is cemented.

Analysis of the local structure indicates that maximum compressive stress (σ_1) in the map area during the Laramide Orogeny trended about N40E, horizontal, perpendicular to the strike of the axial plane of the Cherry Creek Syncline and parallel to the short axes of the basement blocks. The intermediate stress axis (σ_2) was vertical, whereas the minimum compressive stress axis (σ_3) trended N50W, horizontal, parallel to the axial plane of the Cherry Creek Syncline and the long axes of the basement blocks (Fig. 15 and 17, pages 55 and 57 respectively).

This orientation of triaxial stress should have developed left lateral strike-slip shearing on the Warm Springs Creek Fault and on the fracture set in the Paleozoic rocks which strikes N75E, Kozak (1961) reports the presence of slickensides plunging 5-10 degrees northeast on the N75E fracture set, substantiating a shear origin (Fig. 13, page 53). Right lateral strike-slip shearing should have occurred on the North Fork Fault and on the fracture set in the Paleozoic rocks which strikes N6W. Since the displacement sense on the North Fork Fault does not reflect such movements, the North Fork Fault may be a later structural development. The fracture set in the Paleozoic rocks striking N51E and the fracture set in the Precambrian rocks striking N47E are subparallel to the suspected trend of maximum compressive stress, and therefore should have developed as extension fractures. The strike of the Gallatin Range Front Fault is also subparallel to this trend. Although

the Gallatin Range Front Fault displays post-Laramide movement, active tension along this trend was well established concomitantly with other Laramide structures so that later Tertiary (and Quaternary?) displacement on the northeast trend may have been initiated earlier. The lack of fractures in Paleozoic rocks parallel to the N50W trend of one of the fracture sets in Precambrian rocks (and the Cherry Creek Fault) suggests that this northwest trend was established prior to deposition of the Cambrian Flathead Formation (Kozak, 1961).

The reverse displacement on the Cherry Creek Fault complicates the orderly and expected relation between structure and stress hitherto described. The near vertical Cherry Creek Fault lies perpendicular to the postulated maximum compressive stress trend. Displacement on the fault during active compression should have been inhibited by the summation of frictional and normal forces which would serve to hold the opposite walls stationary. Movement would only ensue abatement and termination of horizontally directed compressive stress. Since large Laramide reverse displacement did occur on the Cherry Creek Fault (McMannis and Chadwick, 1964), two different stress systems, one deep seated and the other shallow, are hereby suggested to have operated in the area. The shallow stress system and the resulting structures are described above. It is proposed that these structures resulted from a local compressive state developed near the surface by tilting of the basement blocks in response to deep seated forces, Mathews, Callahan,

and Work (1975) describe a similar situation in the northern Front Range of Colorado. In the map area, both stress fields were oriented with the maximum compressive stress (σ_1) trending southwest-northeast. In the deep stress field the direction of easiest relief (minimum compressive stress axis σ_3), was vertical, while the direction of easiest relief in the shallow zone was horizontal, trending northwest.

Post-Laramide stress. The period following the Laramide Orogeny is widely characterized by epeirogenic uplift and the predominance of tensile over compressive forces. The record of normal faulting in southwest Montana begins in the post-Laramide early Tertiary and continues at present, as evidenced by the 1959 Hebgen Lake earthquake (Myers and Hamilton, 1964).

Sbar and others (1972) and Smith and Sbar (1974) show composite fault plane solutions compiled from seismic data related to earthquakes and microearthquakes throughout the intermountain western United States. From the fault plane solutions they derive the orientation of the stress field associated with each seismic disturbance and indicate the probable sense of displacement responsible for the disturbance. Of particular interest to this study are the fault plane solutions near the Madison Range in southwest Montana.

In chronological order, the recent seismic events centered around the map area are: 1) the Montana earthquake of June 27, 1925, whose epicenter lies approximately 30 miles due north of the map area

near Clarkston (Pardee, 1926); 2) the Hebgen Lake earthquake of August 18, 1959, approximately 40 miles south of the map area (Myers and Hamilton, 1964); 3) the October 1964 earthquake in the Madison Valley just southwest of the map area; 4) microearthquakes in the Three Forks area measured in 1969 by Sbar and others.

The stress axes of these events are plotted on a lower hemisphere equal area net (Fig. 18). The general accordance of axes of the 1925, 1964, and 1969 events suggests a common genetic relationship. These seismic incidents were produced by suspected left lateral strike-slip displacement on an unidentified northwest striking fault in the Three Forks area (Sbar and others, 1972), right lateral strike-slip displacement on an unidentified northeast striking fault near Clarkston (Smith and Sbar, 1974), and strike-slip faulting of unidentifiable trend in the Madison Valley (Smith and Sbar, 1974). The Hebgen Lake quake was, on the otherhand, surficially expressed as a fault with dip-slip displacement. The orientation of the stress field was significantly different from the other three events (Fig. 18). The unifying thread of all the recent seismic disturbances is tension oriented in an approximate north-south direction (Fig. 19). The mechanism responsible for this regional tension, whether related to simple expansion upon epeirogenic uplift, crustal rifting along the Snake River Plane, or shifting of the North American crustal plate over the East Pacific Rise, remains unknown. The indication of strike-slip movements at depth

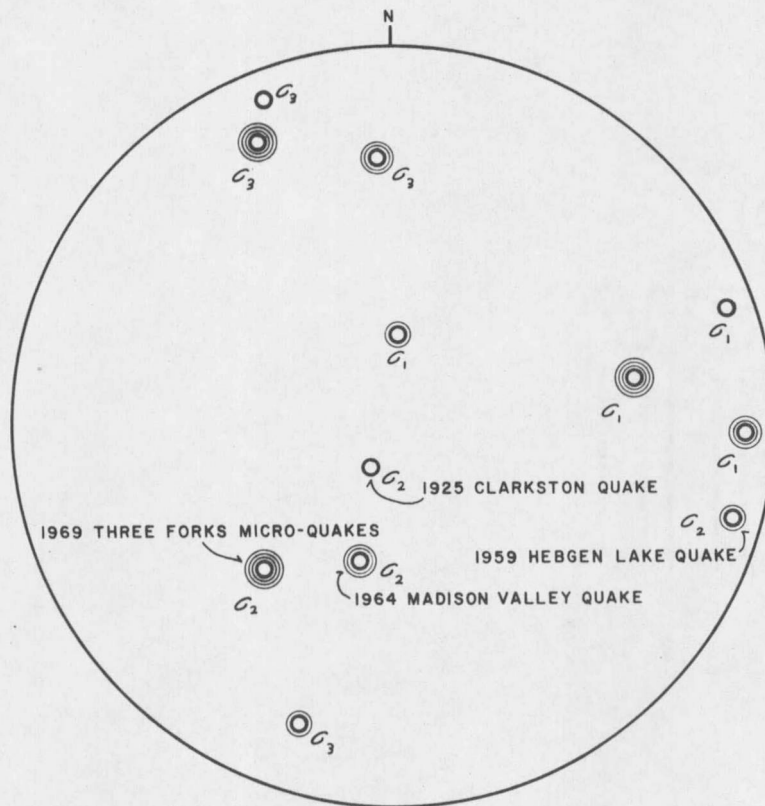


Fig. 18 EQUAL AREA PROJECTION OF STRESS AXES OF RECENT EARTHQUAKES (adapted from SMITH and SBAR, 1974)

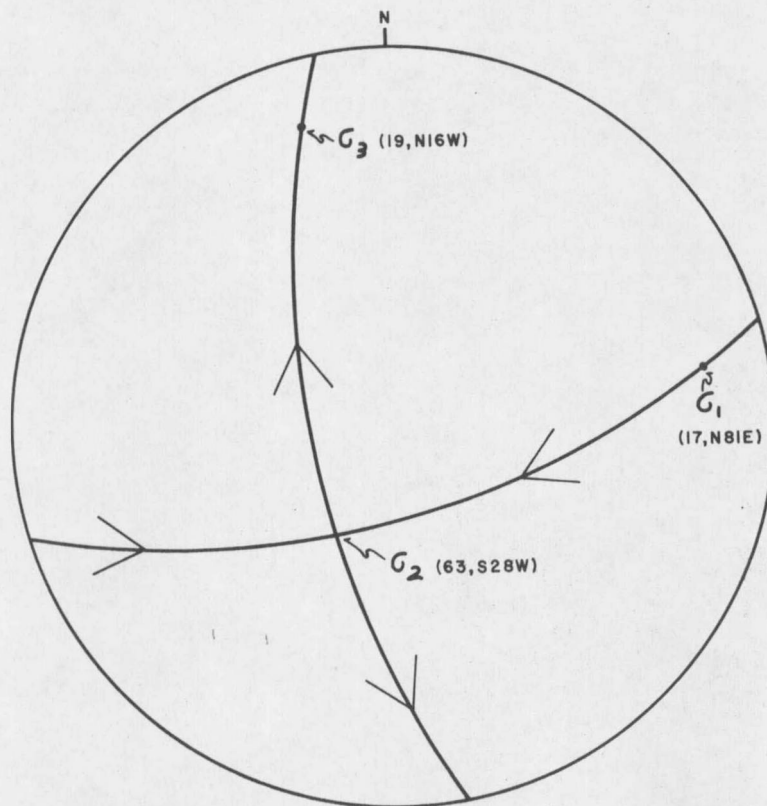


Fig. 19 EQUAL AREA PROJECTION OF THE
AVERAGE STRESS FIELD OF RECENT QUAKEs

(Smith and Sbar, 1974, Sbar and others, 1972) suggests a continuation of orogenesis in southwest Montana.

Summary

Laramide structures in the Spanish Creek Basin Area resulted from differential movements of large basement blocks in the northern Madison Range. Displacement of the blocks was caused by a stress field with maximum compressive stress oriented SW-NE, horizontal, and minimum compressive stress (direction of easiest relief) oriented vertically. The parallelism of the northwest trending long axes of the blocks with major tectonic zones of postulated Precambrian movement (Lake Basin Zone, Cat Creek Zone, Nye-Bowler Zone) suggests a reactivation of faults of Precambrian vintage in the northern Madison Range. The presence of a fracture set in Precambrian rocks (but absent in the Paleozoic rocks) parallel to this northwest trend lends further support to this conclusion.

Paleozoic and Mesozoic sedimentary rocks were deformed in response to localized stress fields related to broad open drag folding along the margins of the moving basement blocks. In the Spanish Creek Basin Area the localized and relatively shallow stress field was oriented with maximum compressive stress trending SW-NE and minimum compressive stress trending SE-NW, both horizontal.

Post-Laramide faulting in the map area has been restricted to SW-NE trends. The Gallatin Range Front Fault is the only major

structure in the map area exhibiting post-Laramide activity. The normal dip-slip displacement on the fault reflects a state of active tension. The fault parallels the direction of Laramide extension fractures in the basement blocks and in the Paleozoic and Mesozoic rocks, suggesting the reactivation of a Laramide trend.

Analysis of the stress fields associated with recent seismic disturbances near the northern Madison Range reveals a general state of active tension oriented approximately NS. The seismic disturbances and regional post-Laramide normal faulting and epierogenic uplift exemplify the extant crustal dynamics of southwest Montana. Although the driving mechanism responsible for the compressional and subsequent tensional stresses is moot, it is surely related to plate tectonics.

CENOZOIC GEOMORPHIC HISTORY

Initiation of presently recognizable geomorphic features in the Spanish Creek Basin Area followed the last pulses of the Laramide Orogeny in the early Eocene. At this time the primary topographic and structural components of the northern Madison Range were essentially fixed in the form of three parallel northwest trending basement fault blocks (Carl, 1970) with relatively thin veneers of Paleozoic and Mesozoic rocks draped into synclinal form at the bounding edges (Fig. 9, page 40). Consequent streams flowed on the northeast dipping surfaces of the blocks. These streams were subsequently shunted in northwest or southeast directions as they encountered the formidable scarp of the next block. Differential erosion of the Paleozoic-Mesozoic cover produced the prominent homoclinal Finnegan Ridge of Mississippian limestone near the center of the Cherry Creek Syncline. Streams originating on the southern fault block succeeded in breaching the barrier only in section 16, T4S, R3E. The relative sizes of the valleys cut in the syncline north and south of Finnegan Ridge indicate the possible progressive domination of drainage by the southern valley through the interception and diversion of water by the Finnegan Ridge barrier. The acute angle made at the confluence of the two valleys suggests a southeast direction of flow. Stream-rounded pebbles and cobbles of rhyolite similar to the rhyolite of Eocene age at Red Mountain (Kavanagh, 1965) are exposed in a cut near the present valley bottom in section 9, T4S, R3E. Feldspathic sediment derived from the

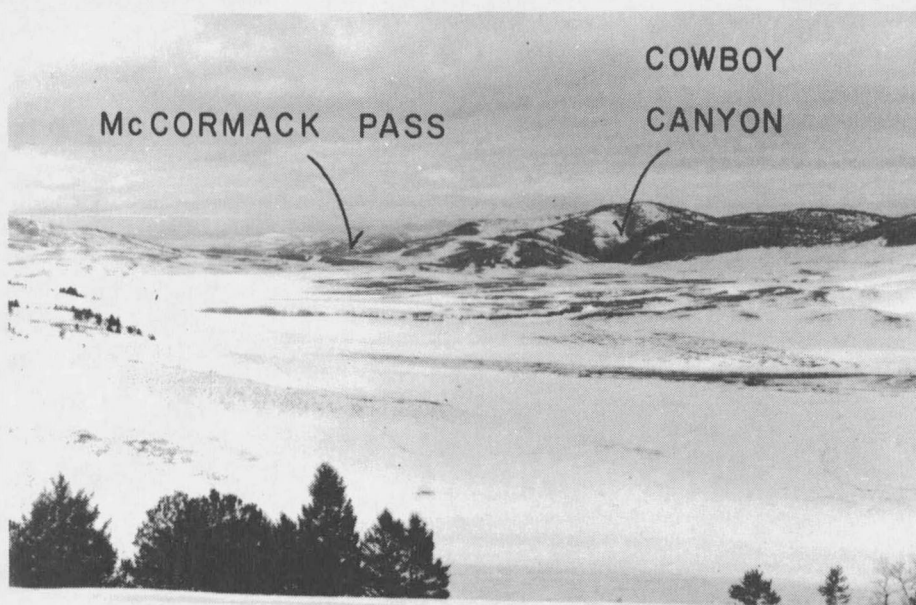


Fig. 20 View to the northwest from the NE $\frac{1}{4}$, sec 19, T4S, R3E. Cherry Creek flows through Cowboy Canyon. The exhumed valley in the foreground served as the main drainageway from the Tobacco Root Mountains to the ancient Yellowstone River during Eocene time.

Tobacco Root Stock has been traced by Montagne (personal communication) along valley shoulders above Warm Springs Creek, across the Madison River Canyon, to a position near the northwestern border of the Cherry Creek Syncline. The provenance of these sediments indicates a southeast direction of streamflow. Mifflin (1963) postulates a southeast flowing Eocene stream system north of the Cherry Creek Fault. McMannis (1955) and Robinson (1961, 1963) cite evidence for a regional east flowing drainage system during Eocene time. Thus, a strong implication exists that the Madison River was not present in the early Tertiary. If present at all, the Madison or proto-Madison River probably flowed northward on the southern fault block as a consequent tributary to a subsequent trunk stream which was flowing southeast along the Cherry Creek Syncline (Fig. 21).

The destination of southeast flowing water in the ancient Spanish Creek Basin remains speculative. Surely the stream reached the present position of the Gallatin River. Its channel did not occupy the present canyon of Spanish Creek (in sections 11, 12, 13, and 18), however, as this canyon originated at a later date. The ancient stream probably flowed somewhat to the south along the Cherry Creek Fault scarp and across the present position of the Gallatin Range Front Fault. The fault had yet to undergo displacement and did not interfere with drainage. If the ancient stream continued to flow southeastward along the Cherry Creek-Squaw Creek Fault it should have encountered the high

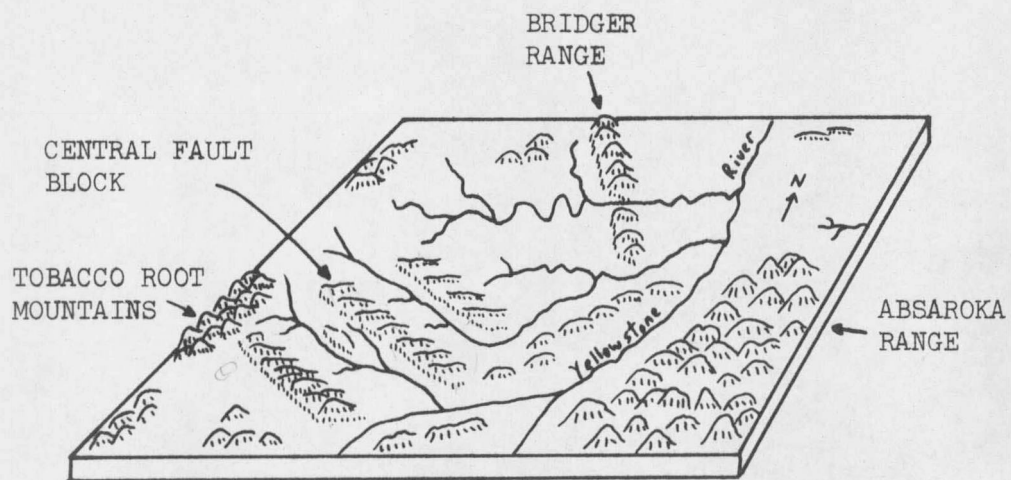
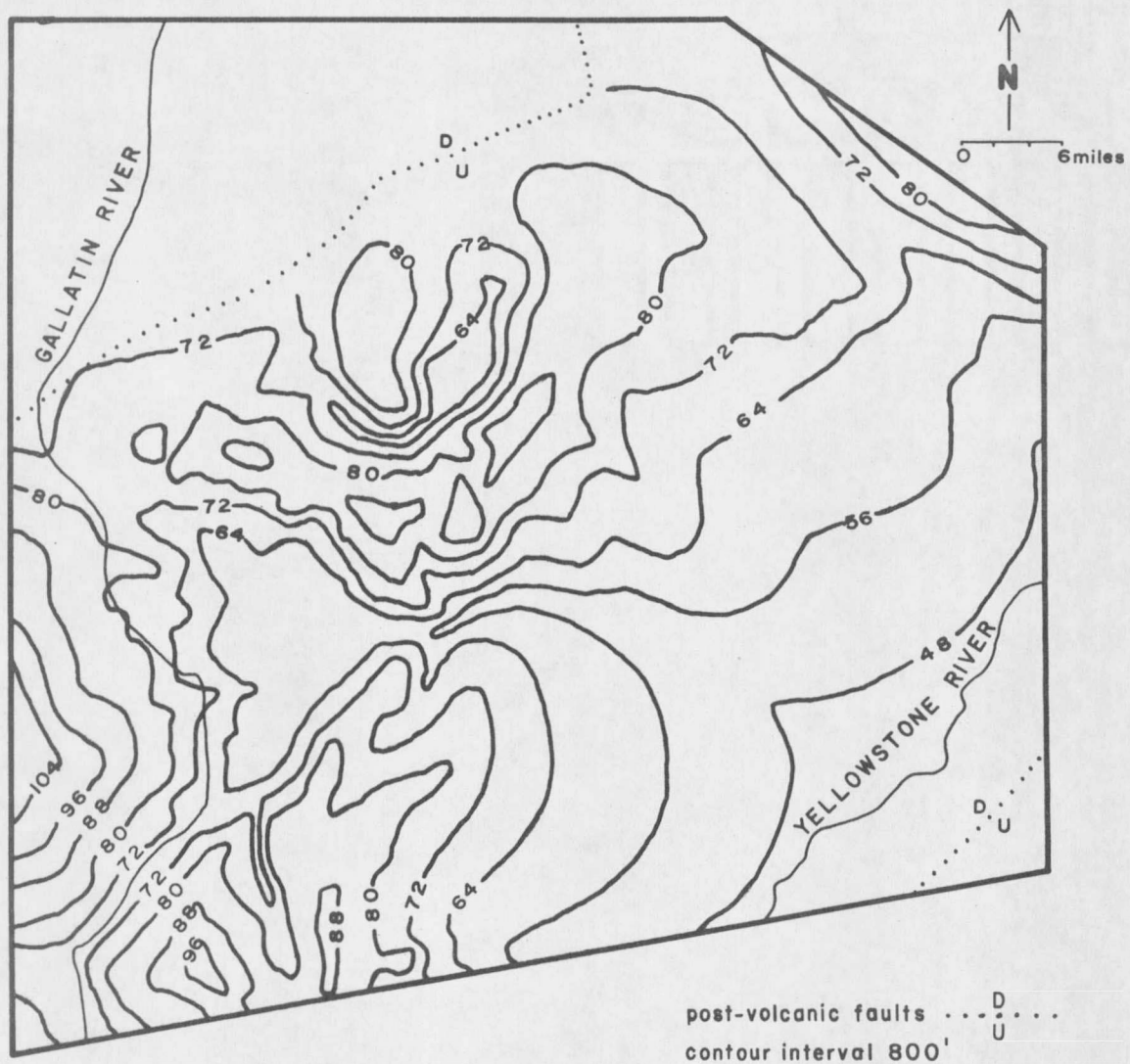


Fig. 21 Pre-volcanic early Eocene drainage

topography of the present Gallatin Range. The amount of post-Eocene movement on the Gallatin Range Front Fault is deemed insufficient to allow for pre-fault drainage across the range (Mifflin, 1963), yet Mifflin finds no evidence of an early Tertiary north flowing river near the present junction of Spanish Creek and the Gallatin River. Contour maps of the sub-volcanic surface of the Gallatin Range (McMannis, 1964, McMannis and Chadwick, 1964) show a definite low area south of the Squaw Creek Fault extending southeastward to an ancient Gallatin River valley (Fig. 22). This valley connected with Paradise Valley. Although the maps show a small drainage divide near the Squaw Creek sill swarm, it is not outside the realm of possibility that ancient Spanish Creek drainage traversed this area. Later Tertiary movement on the numerous northeast trending faults in the vicinity (Fig. 8, page 37) could account for the apparent drainage divide.

Volcanic rock from the Gallatin Range was extruded northwestward for some unknown distance onto the Eocene topography of the fault blocks, filling valleys and disrupting drainage. Evidence for some thickness of volcanic rock along at least the southeastern portion of the fault blocks includes: 1) remnants of volcanic rock along the downdropped north side of the Gallatin Range Front Fault in section 9, T4S, R4E (Mifflin, 1963) and section 24, T4S, R3E in the Spanish Creek Basin Area; 2) remnants of volcanic rock at elevations above 9000 feet on the southern fault block in the Garnet Mountain Quadrangle (McMannis



**Fig. 22 PRE-VOLCANIC TOPOGRAPHY IN THE
 GALLATIN RANGE (after McMannis, 1964)**

and Chadwick, 1964); 3) cobbles and boulders of volcanics in early Pleistocene glacial deposits of the Spanish Creek Basin Area; 4) volcanic debris in pediment gravels on the north side of the Spanish Breaks (central fault block) (Mifflin, 1963).

In the Gallatin Range the volcanic pile effectively buried the scarp lines of the fault blocks, resulting in drainage development above them. The Gallatin River established a course across this relatively flat volcanic terrain to the Three Forks Basin (McMannis and Chadwick, 1964). After considerable erosion of the volcanics and underlying rocks, the Gallatin River became superposed in its present day canyon.

The southeasterly flow of water through the Spanish Creek Basin probably reversed direction as a result of the damming effect of the volcanic pile. A well indurated stream-deposited conglomerate, probably belonging to the late Eocene Milligan Creek Formation, forms an isolated hill at the center of the broad valley south of Finnegan Ridge in the NW $\frac{1}{4}$, SW $\frac{1}{4}$, sec 16, T 4 S, R3E. The beds of this remnant dip 30 degrees northwest, subparallel to the broad valley axis. If the northwest dip is initial, and there is no available evidence to contradict this assumption, a northwest direction of streamflow is suggested. Today, greatest structural and topographic relief of the fault blocks exists at their southeast ends. There is no reason to suspect significant differences in this pattern in the post-Laramide Eocene. Streams

dammed by the volcanics in the Spanish Creek Basin would find easiest outlet over the fault blocks near the present Norris Hills. Thus, drainage from the Tobacco Root Mountains and the northern Madison Range would have been concentrated near the present position of the Madison River (Fig. 23). The impetus of this concentrated drainage may have led to the capture of drainage in the Madison Valley, south of the Spanish Peaks Fault, to form the Madison River.

Contemporaneous with or shortly after extrusion of the Gallatin Range volcanics, copious amounts of airborne volcanic ejecta began clogging drainages throughout the region. Coupled with the initial rise of the Bridger Range, which ponded the east flowing streams in the Three Forks Basin (McMannis, 1955; Robinson, 1961, 1963), the glut of tuffaceous sediments caused the inception of a general period of aggradation lasting until the Pliocene. During this interval the "Bozeman Lake Beds" of Peale (1896) were deposited. Although numerous lacustrine deposits punctuate the Tertiary stratigraphic column, alluvial deposits are by far more common. Therefore, the term "Bozeman Lake Beds" has been replaced by the more general Bozeman Group (Robinson, 1963) which is comprised of the Sphinx Conglomerate, Milligan Creek Formation, Climbing Arrow Formation, and the Dunbar Creek Formation.

The Oligocene and Miocene of the Three Forks Basin was characterized by recurrent uplift of the Bridger Range, ponding of the east

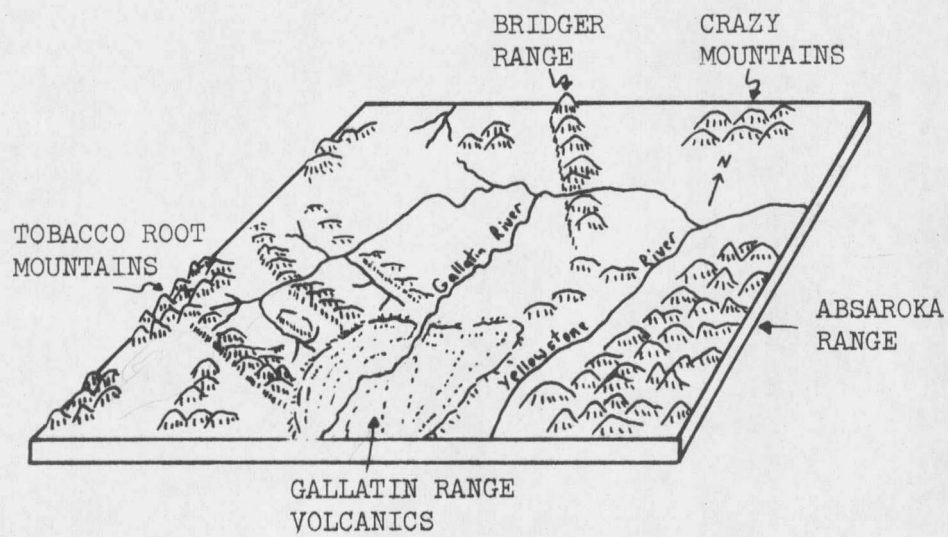


Fig. 23 Post-volcanic late Eocene-early Oligocene drainage.

flowing drainage, and reestablishment of eastward drainage through the Bridger Range barrier (Robinson, 1961). In the Spanish Creek Basin Area little can be ascertained of the events of this period. No significant differences between the Oligocene and Miocene history of the map area and the Three Forks Basin are apparent.

By Pliocene time the region was reduced to low relief by the development of a composite degradational-aggradational topographic surface extending from isolated inselbergs in the ranges out onto the deeply filled basins. Such a surface characterized most of the Rocky Mountains in the late Tertiary (Thornbury, 1965). Atwood and Atwood, (1938), Pardee (1950), and Wolfe (1964) consider this surface a peneplain, while Alden (1953), Robinson (1961, 1963), and Carl (1970) refer to it as a gravelled or alluvial plain. Mackin (1947) suggests that pedimentation more logically explains the origin of the degradational-aggradational surface in light of the late Tertiary semi-arid climate. Thus, the mountain ranges of the region were attacked through the processes of pedimentation and encircled by the graded surfaces of coalescing bajadas. The alluvial plain of Robinson (1961, 1963) corresponding to this bajada surface is preserved along the west side of the Madison River north of Red Mountain, and east of the Madison River, north of Elk Creek, on the Madison Plateau. At these locales the Oligocene and Miocene sediments are capped with up to 100 feet of stream deposited cobbles and boulders (of Pleistocene age?).

Many workers have projected these surfaces southward to the Tobacco Root and Madison Ranges in an attempt to establish the Pliocene transition point between degradation and aggradation, or, more simply, the pediment edges. Alden (1953) assumes a gradual increase in the gradient of the surface approaching the mountains, and projects the gravelled plain to a broad bench north of Ward Peak in the Tobacco Roots at a present elevation of approximately 7000 feet. Pardee (1950) projects the "late Tertiary peneplain" across the crest of the Spanish Breaks (7000 feet) to a 7000-8000 foot level in the Spanish Peaks, Mifflin (1963) expresses some skepticism in a late Tertiary origin for the flattish crestal surface of the Spanish Breaks. He believes this area to be a Eocene erosion surface which was buried by Gallatin Range volcanics and later exhumed in late Pliocene or early Pleistocene time. Carl (1970) notes the presence of Tertiary strata up to the 6000 foot level on the southern fault block and identifies this elevation along the Spanish Peaks as the border of the late Tertiary alluvial plain. His own north-south profile from the Madison Plateau to the Spanish Peaks clearly shows the projected alluvial plain intersection the Spanish Peaks at an elevation of approximately 7000 feet, however. Profiles drawn perpendicular to the Cherry Creek Syncline show many different matched and unmatched bench levels (Fig. 24). The most prominent bench occurs at 6600 feet on both the southern and central fault blocks. Although much dissected by streams, the 6600 foot level

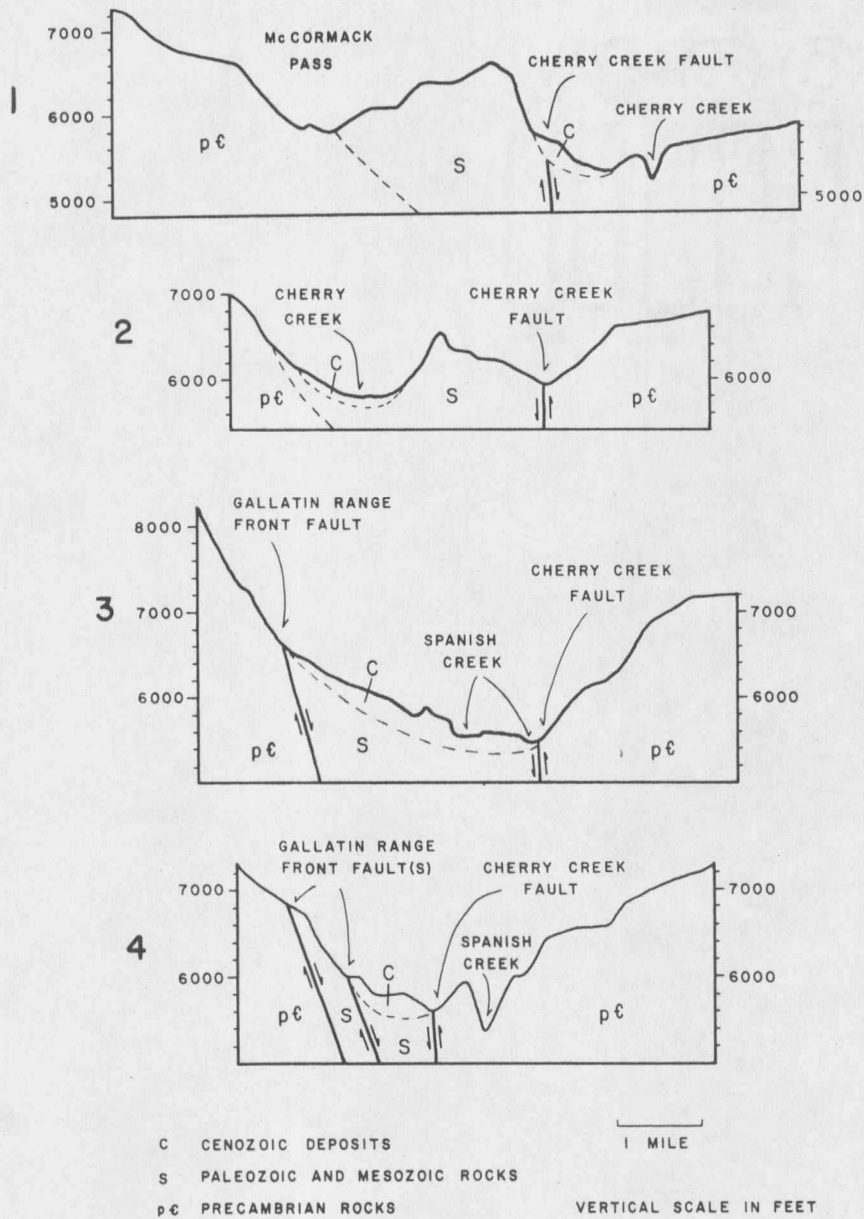


Fig. 24 TRANSVERSE PROFILES

still retains the gross form of a broad pediment system carved in the rocks of the fault blocks. These pediments resulted from a stable period of lateral planation by streams descending from the mountains onto a vast alluvial apron approximately 1000 feet above the present drainages. It is logical to assume the aggradational Tertiary sediments accumulated in the Cherry Creek Syncline to levels higher than the preserved remnant deposits, now 600 feet below the pediments. The pediment surfaces slope toward the center of the Cherry Creek Syncline and subtly grade northwestward to the Norris Hills suggesting the presence of a roughly integrated Madison River system during the Pliocene Epoch with Cherry Creek Basin drainage included as a northwest flowing tributary. The location of the Gallatin River during this period probably coincided quite closely with its present position. Several benches of small areal extent are present along the sides of the Gallatin River canyon, north of the intersection of Spanish Creek, up to 1000 feet higher than the present river (Mifflin, 1963). Some drainage from the Spanish Creek Basin Area might have joined the Pliocene Gallatin River, but the northwest slope of the pediment system suggests that most of the streams from the southern block were flowing toward the Madison River (Fig. 27).

Near the close of the Pliocene Epoch the stable conditions which permitted formation of the great alluvial plain and associated pediment system were disrupted. Regional uplift of at least 1000 feet and

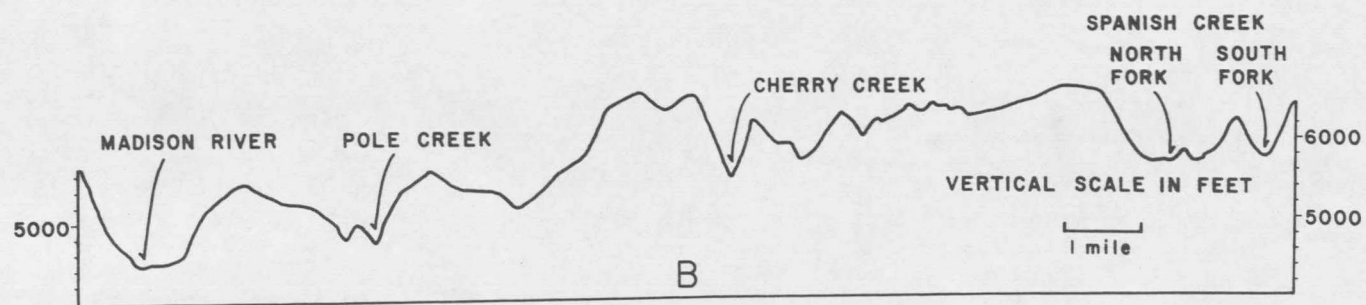
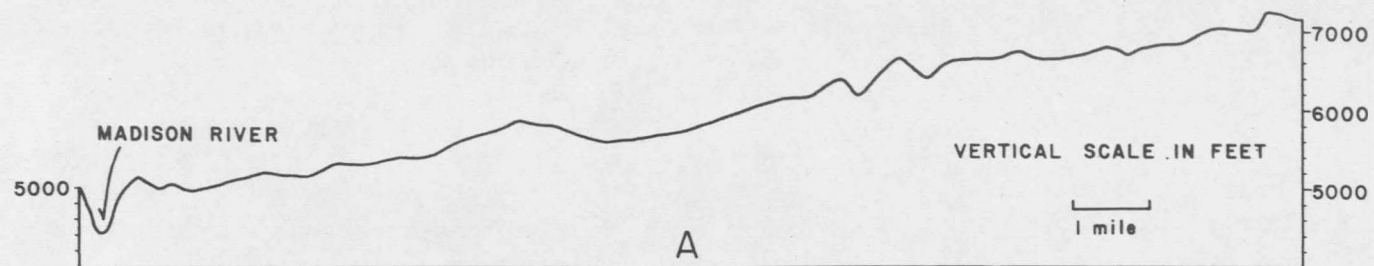


Fig. 25 LONGITUDINAL PROFILES



Fig. 26 Location of transverse profiles 1, 2, 3, and 4, and longitudinal profiles A and B. The contour interval is 200 feet.

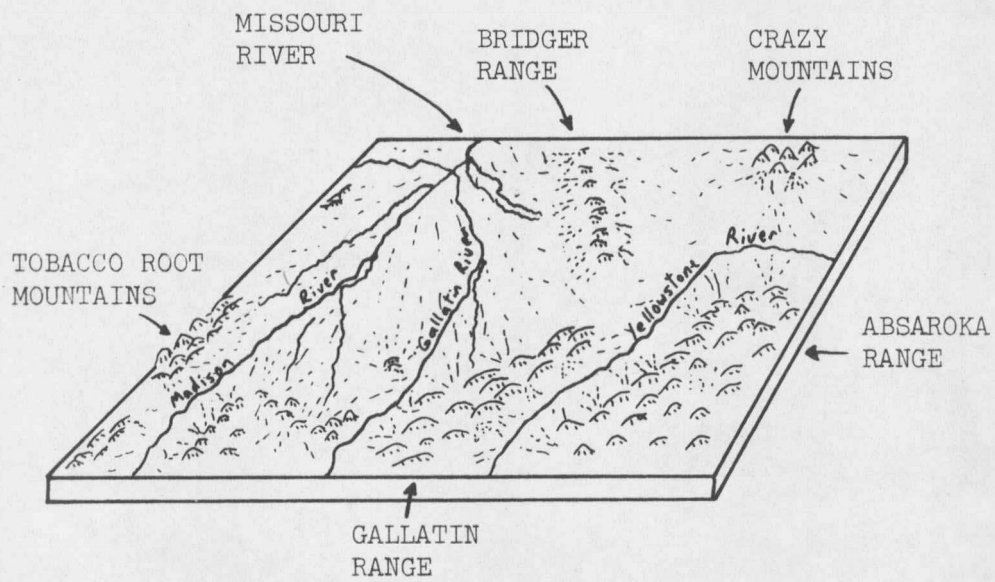


Fig. 27 Pliocene drainage.

northwestward tilting provided impetus for headward erosion of the Missouri River and led to the eventual capture of the sluggish east-flowing streams of the Three Forks Basin (Robinson, 1961). The rejuvenated streams of the region were now capable of carrying larger loads. Downcutting on a massive scale ensued, with streams incised through the Tertiary cover in seemingly anomolous positions.

Rather than follow the lower central part of the Norris Hills, which probably served as an aerlier drainage route, the Madison River excavated a canyon in Precambrian metamorphic rock, along the high eastern border of the Norris Hills and the northern Madison Range, at elevations up to 6500 feet (Fig. 26). The Gallatin River probably began canyon cutting at an earlier date as it eroded through the relatively flat volcanic terrain of the Gallatin Range. Miocene and later movement on the Gallatin Range Front Fault, which uplifted the Gallatin Range, probably played an important role in the development of the superposed-antecedent Gallatin Canyon.

Carl (1970) proposes two possible modes of origin for the great notch (Cowboy Canyon) cut through Finnegan Ridge by Cherry Creek (Fig. 26). He presupposes that Finnegan Ridge, at an elevation of 6600 feet, projected far above the Pliocene alluvial plain, and thus, he eliminated superposition as a possibility. Carl first suggests that a preexisting windgap in Finnegan Ridge may have served as a Pliocene channel for Cherry Creek. He alternately suggests that a stream on the north side of

Finnegan Ridge captured the originally southeast flowing Cherry Creek by headward erosion through Cowboy Canyon.

After integration in the Missouri River system, the Gallatin and Madison Rivers competed for the drainage of the southern fault block of the northern Madison Range. Presently, the Cherry Creek Syncline is intersected by the Madison River almost 1000 feet below the level of the intersection with the Gallatin River. The Madison River obviously possesses greater attraction for tributaries in the syncline, as a result. If a similar difference in local baselevel existed between the two rivers in the late Tertiary, some credence is lent to Carl's second hypothesis for the origin of Cowboy Canyon. The reversal of movement (north side down) on the Cherry Creek Fault near the Madison River (Feichtinger, 1970) would have increased stream gradients along the fault and promoted stream capture. In light of the pediment remnants along the southern and central basement blocks (Fig. 24 and 25, pages 70 and 81 respectively) and high shoulders along the Madison Canyon at or near 6600 feet, superposition should perhaps be given further consideration in the development of Cowboy Canyon.

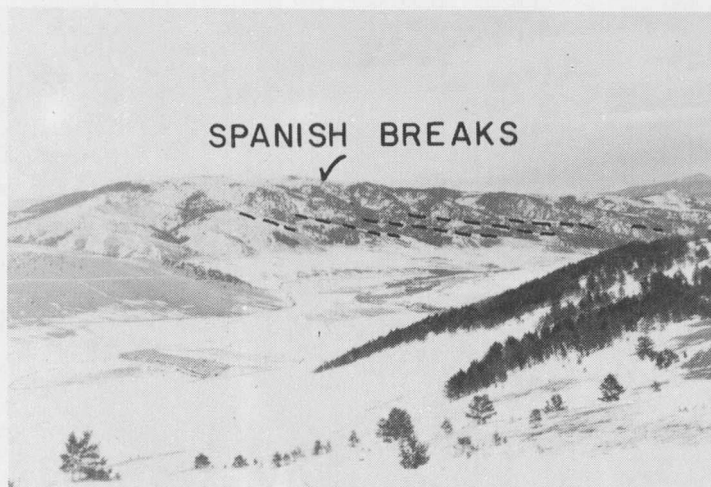
Little is known of the Pliocene-Pleistocene transition. In most areas, late Pliocene and early Pleistocene deposits are undifferentiable (Flint, 1965). The boundary is loosely fixed by observed changes in the faunal and floral record by some workers and by indicated changes in climate by others. Considerable overlap occurs.

Locally, the base of the first obvious glacial deposit may serve to stratigraphically delineate the Pleistocene from the Pliocene, although the actual time-stratigraphic boundary may be somewhat different (Flint, 1965).

After Pliocene-Pleistocene uplift and dissection of the gravelled plain, with the associated superposition of the Madison and Gallatin Rivers and Cherry Creek, conditions again stabilized and a broad surface evolved in the Spanish Creek Basin Area. A lower pediment system on the south side of the Spanish Breaks graded to laterally planed Tertiary sediments in the partially exhumed valley (Fig. 28). Numerous accordant shoulders along the Cherry Creek Syncline at elevations near 6000 feet also attest the presence of this surface (Fig. 24, page 79). Thus, by early Pleistocene time, some 600 feet of Tertiary basin fill had been stripped from the area. The pediment remnants on the south side of the Spanish Breaks decrease in elevation towards the southeast, indicating that the early Pleistocene surface in the Spanish Creek Basin Area graded to the Gallatin River.

The drainage divide between the Madison and Gallatin Rivers continued to shift to the southeast. Cherry Creek was, at this time, well established in its course through Cowboy Canyon, although the East Fork of Cherry Creek probably remained part of the Spanish Creek drainage. Headward erosion through the Tertiary sediments of the Cherry Creek Basin later in the Pleistocene led to the eventual capture

A



B

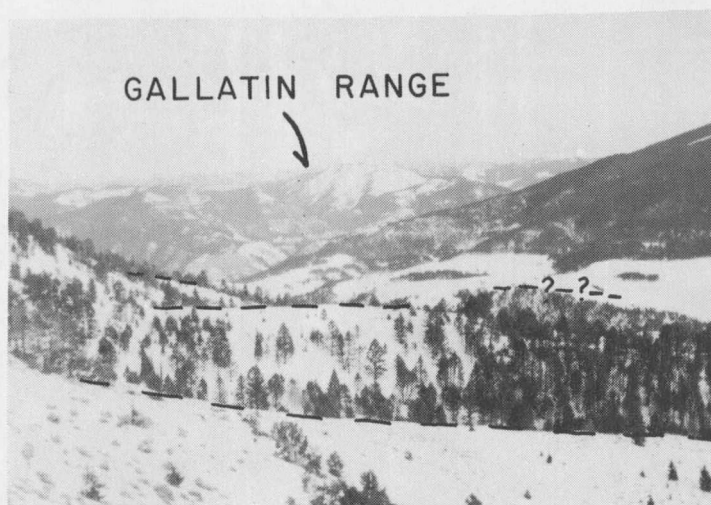


Fig. 28 (A) View to the northeast from the NW $\frac{1}{4}$, sec 19, T4S, R3E, showing remnants of the 6000 foot pediment system on the south side of the Spanish Breaks. The exhumed Eocene drainageway is in the left foreground. (B) View to the southeast from the SW $\frac{1}{4}$, sec 3, T4S, R3E. The pediment remnants appear to project across the present canyon of Spanish Creek. The Eocene and early Pleistocene (?) drainage route lies south of the modern stream.

of the East Fork of Cherry Creek and further southeastward translocation of the drainage divide.

Changes in climate and possible renewed uplift of the region resulted in snow accumulation in the orographic traps of the high peaks and led to the subsequent development of glacial ice. In view of the worldwide isochronous occurrence of glaciation (Flint, 1971), it seems logical to assume that climate, rather than uplift, played the major role in glacier formation in the Rocky Mountains. The underlying causes for climatic change are subject to much speculation. Flint (1971) explores several possibilities.

Evidence exists for at least one pre-Bull Lake glaciation in the Spanish Creek Basin Area (STRATIGRAPHY section, page 5). The ice accumulated in the Spanish Peaks and flowed down broad stream valleys to coalesce into a large piedmont glacier. The most abundant pre-Bull Lake drift rests on the 6000 foot surface. This relationship suggests a correlation between the 6000 foot surface in the map area and the Black Rock terrace of the Wind River Mountains, Wyoming (Blackwelder, 1915) (Fig. 29). If a relation does exist, it follows that the 6600 foot surface in the map area may be contemporaneous with Blackwelder's Union Pass surface. Remnants of the pre-Bull Lake drift are found along a ridge just west of the South Fork of Spanish Creek in section 21, in the SE $\frac{1}{4}$ of section 16, on Finnegan Ridge in the NE $\frac{1}{4}$ of section 17, in sections 4, 5, and 9 and in the NE $\frac{1}{4}$ of section 23 (all in T4S,

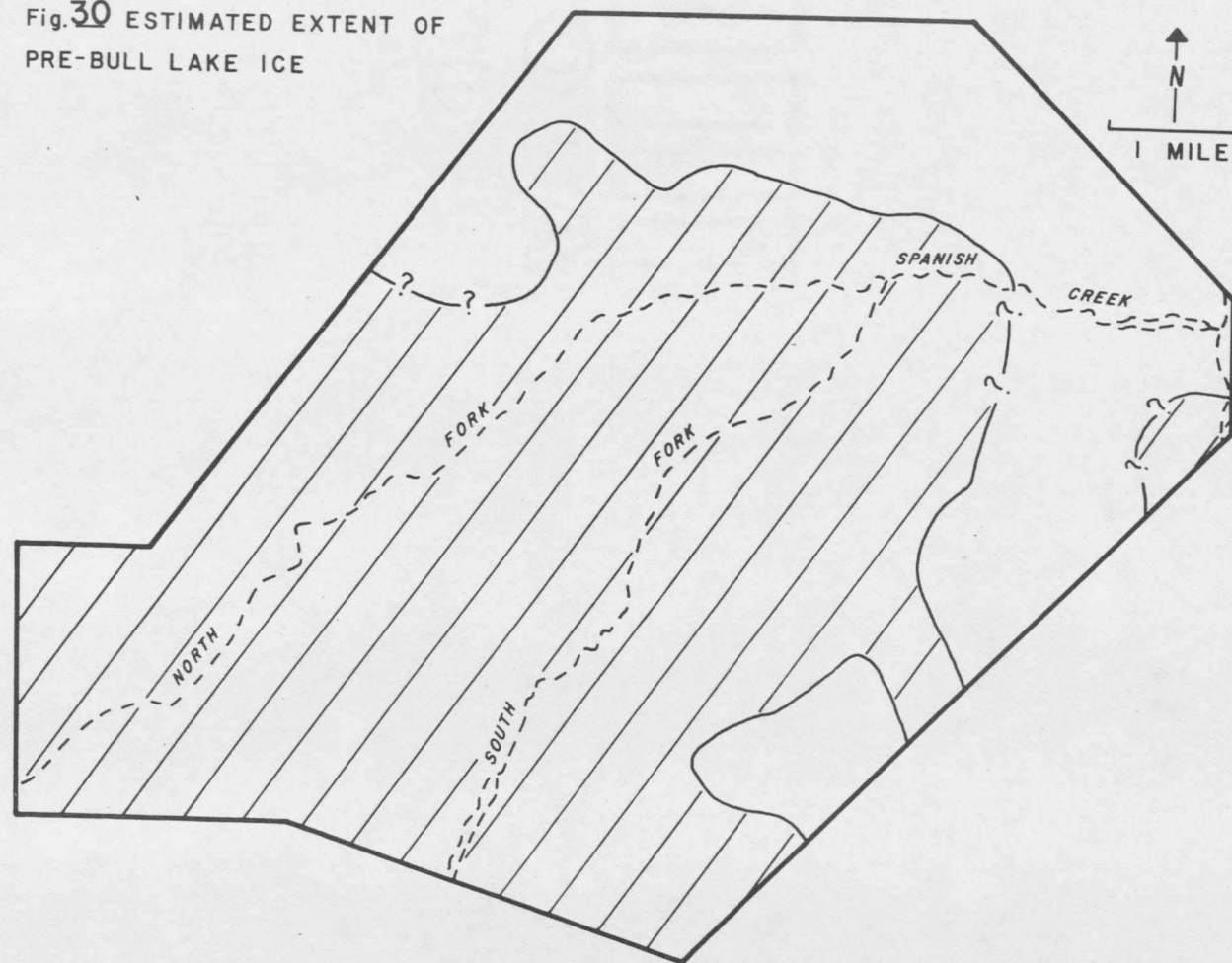
WIND RIVER MOUNTAINS BLACKWELDER (1915)		CENTRAL WESTERN MONTANA WOLFE (1964)		SPANISH CREEK BASIN AREA THIS PAPER	
GLACIAL STAGE	ASSOCIATED TERRACE	GLACIAL STAGE	ASSOCIATED SURFACE	GLACIAL STAGE	ASSOCIATED SURFACE
RECENT ICE	PRESENT STREAMS	RECENT ICE	PRESENT STREAMS	RECENT ICE	PRESENT STREAMS
INTERGLACIAL		INTERGLACIAL		INTERGLACIAL	
PINEDALE	LENORE	PINEDALE	#4 BENCH	PINEDALE	5-20 FEET
INTERGLACIAL		INTERGLACIAL		INTERGLACIAL	
BULL LAKE	CIRCLE	BULL LAKE	#3 BENCH	BULL LAKE	40-80 FEET
					5800 FOOT SURFACE
INTERGLACIAL	CANYON CUTTING	INTERGLACIAL		INTERGLACIAL	CANYON CUTTING
BUFFALO	BLACK ROCK	PRE-BULL LAKE	#2 BENCH	PRE-BULL LAKE	6000 FOOT SURFACE
	UNION PASS		#1 BENCH		6600 FOOT SURFACE

Fig. 29 CORRELATION OF SURFACES

R3E). On the border of sections 22 and 27, T4S, R3E, pre-Bull Lake glacial drift completely mantles a whaleback shaped hill high above Wisconsin age deposits. The smooth streamlined form of the southwest segment of the hill rises gradually to an elevation of 6482 feet and contrasts markedly with the steep glacially plucked (?) northeast side. Flint (1971) states that the long axis of such whaleback or stoss and lee forms offers the best indication of the direction of ice movement. The orientation of the hill axis in sections 22 and 27 suggests a northeast direction of movement for the pre-Bull Lake ice in this area. If the hill was inundated by the same ice which advanced over the 6000 foot surface, a minimum of 500 feet of ice was present near the hill.

The upper valley of Twin Creek exhibits a vague valley in valley profile. The sharp V-shaped inner valley is incised in remnants of a broad parabolic valley, suggesting that glacial ice formerly flowed in the Twin Creek drainage. At the head of Twin Creek the broad upper valley merges with a great semi-circular amphitheater which probably developed as a glacial cirque during the pre-Bull Lake glaciation. The only glacial drift observed near Twin Creek is of pre-Bull Lake age. Twin Creek was apparently glaciated only during the very extensive pre-Bull Lake glaciation (Fig. 30). Perhaps the Twin Creek cirque failed to develop glacial ice in later glaciations due to a continuing rise of snowline.

Fig. 30 ESTIMATED EXTENT OF
PRE-BULL LAKE ICE



In sections 20 and 29, T⁴S., R³E.; a great body of formless drift blocks the abandoned valley of the North Fork of Spanish Creek. This drift was apparently derived from ice originating in both the North and South Forks of Spanish Creek. In fact, in the waxing and waning of pre-Bull Lake glaciation the position of this drift marked the point of coalescence of the two valley glaciers into a piedmont glacier. During the pre-Bull Lake maximum, the ice was probably of sufficient thickness to override most of the topography of the Spanish Creek Basin Area.

Large angular erratics, consisting of Paleozoic limestones and sandstones, rest on and drape over the edge of a pediment remnant (cut in Precambrian rock at 5800 feet) in the SW¹/₄, sec 11, T⁴S., R³E. This deposit is probably contemporaneous with the other pre-Bull Lake drift bodies. Its anomalously low position could have resulted from later solifluction from a higher level,

After the pre-Bull Lake glaciation, a long interval of ameliorated climate with associated diminution of stream loads led to canyon cutting in the area. Spanish Creek began accelerated excavation of its canyon at this time,

The location of Spanish Creek in the Precambrian metamorphic rock of the central fault block rather than the easily erodable Tertiary sediments to the south can be explained in several ways:

- 1) With northward tilting of the region in the late Pliocene, Spanish Creek shifted to the north side of the 6600 foot gravelled plain in the

Spanish Creek Basin Area. Uplift caused rejuvenation and superposition of the stream in the Precambrian rock; 2) Spanish Creek flowed on the 6000 foot surface south of its present canyon along the partially exhumed Eocene valley (Fig. 21, page 71). Pre-Bull Lake glacial ice, flowing northeastward from the Spanish Peaks, filled the Spanish Creek Basin and forced the stream out of its channel. Canyon cutting began during the maximum aerial extent of ice through the work of the debris-charged ice-marginal Spanish Creek.

The first hypothesis is the simpler and as such is rather appealing. The second hypothesis is not without support, however. The shoulder on the south side of the present canyon lies at an altitude of slightly less than 6000 feet and appears to project directly northward to pediment remnants on the north canyon rim. The south canyon shoulder may have been part of the 6000 foot pediment system (Fig. 24 and 28, pages 79 and 87, respectively) which graded to Spanish Creek and the Gallatin River. If so, Spanish Creek must have been flowing south of the present canyon. Patches of pre-Bull Lake drift, to the south and west of the canyon, indicate the close proximity and tremendous extent of ice (Fig. 30). Hall (1959) suspects that pre-Bull Lake ice formed a great mountain ice sheet extending from the southern Madison Range, Gallatin Range, and Yellowstone Plateau northward to the junction of the Gallatin River and Spanish Creek (Fig. 30).

The origin of other canyons in the Spanish Creek Basin Area can be related to similar hypotheses.

The North Fork of Spanish Creek exits the north side of its broad glacial valley via a right angle bend to rush through a deep shear-walled canyon cut in Precambrian and Paleozoic rocks. The canyon threshold is between 6400 and 6600 feet, so that superposition from the 6600 foot surface is a possibility. An ice-marginal origin for the canyon is supported by the ubiquitous glacial drift in the abandoned valley. If this canyon was created before pre-Bull Lake glaciation, modification in form should have resulted from erosion by ice. The canyon shows no sign of glaciation.

Cuff Creek flows across the old North Fork valley and through a small canyon on the north side of the valley to join the North Fork (Plate 2 or Fig. 3, page 7). Pre-Bull Lake drift blocks the old valley outlet. The Cuff Creek canyon could have originated in the following ways: 1) Pre-Bull Lake drift filled the old North Fork to a depth greater than the 6200 foot threshold of the canyon. Cuff Creek became superposed from the drift cover to form the canyon after déglaciation. Meltwater from subsequent glaciers in the North Fork removed most of the pre-Bull Lake drift upstream from the canyon; 2) An ice-marginal stream cut the canyon during the waning stages of pre-Bull Lake glaciation as ice was confined within the old North Fork valley. Cuff Creek flowed along the opposite valley side as an ice-marginal stream. After deglaciation, Cuff Creek shifted its course across the valley and used the canyon; 3) Wastage of pre-Bull Lake ice in the old North Fork

valley proceeded more rapidly than in the South Fork. Meltwater from the retreating North Fork ice and meltwater from the still present South Fork ice became concentrated, and perhaps ponded, in the lower part of the old North Fork valley. Incision of the canyon resulted.

The South Fork of Spanish Creek cut a canyon through Paleozoic rocks in section 21, T4S, R3E, during the interglacial which followed the pre-Wisconsin ice.

A steep sided canyon in section 22, T4S, R3E, subparallel to the South Fork, is now occupied by a grossly underfit stream (Plate 2 or Fig 3, page 7). Although the canyon served as an outlet for Bull Lake and Pinedale 1 meltwater, it apparently originated in the period following the pre-Bull Lake glaciation. The canyon threshold lies at an elevation between 6300 and 6443 feet. The canyon could have developed from superposition from the 6600 foot surface, but this is not likely. Pre-Bull Lake ice is known to have advanced north of the canyon yet no evidence of glacial modification is present in the canyon.

In the Spanish Creek Basin Area the amount of canyon cutting following the pre-Bull Lake glaciation was about 200 feet. After this incision, an extensive surface developed in the basin. Remnants of the surface, at or near 5800 feet, are located between the South Fork of Spanish Creek and Twin Creek in sections 14, 15, and 22, in the NW $\frac{1}{4}$ of section 15, in the SW $\frac{1}{4}$ of section 16, and in the NW $\frac{1}{4}$ of section 21 (all

in T4S, R3E). Most of the remnants consist of bevelled Tertiary strata with a thin gravel cap. The exact age of the surface is not clear.

The surface post-dates interglacial canyon cutting and pre-dates deposition of the extensive outwash plain associated with the Bull Lake glaciation (Fig. 31). If the 6000 foot surface described earlier is correlative with the Black Rock surface in the Wind River Mountains, Wyoming (Blackwelder, 1915), the surface at 5800 feet in the map area may correlate with Blackwelder's Circle surface (Fig. 29, page 89). In the Smith River drainage along the east side of the Big Belt Mountains, Wolfe (1964) notes a similar bench level (#2 bench) and roughly correlates it with the early and late Pleistocene (pre-Wisconsin-Wisconsin, pre-Bull Lake-Bull Lake) transition. These surfaces definitely developed during a period of climatic and structural stability which was of apparent regional scope.

Streams resumed downcutting as cool and wet climatic conditions began to prevail at the inception of the Bull Lake glaciation. Ice descended from cirques in the high peaks (some cirques formed during pre-Bull Lake glaciation were not reoccupied) excavating and widening the stream valleys. Debris from Bull Lake ice was carried by meltwater through the canyons at the mountain front. As these streams debouched onto the wide flat bottom land, their competence radically diminished, resulting in deposition of an outwash plain. This plain is well preserved in section 15, 16, and 17, T4S, R3E (Fig. 31). The

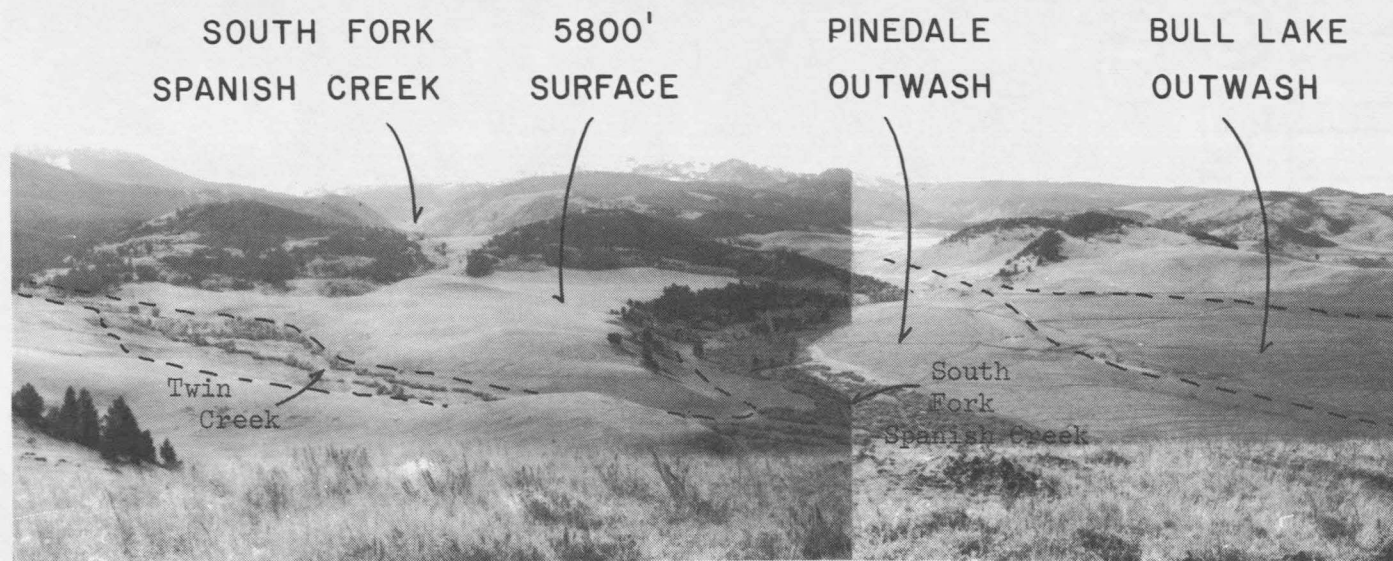


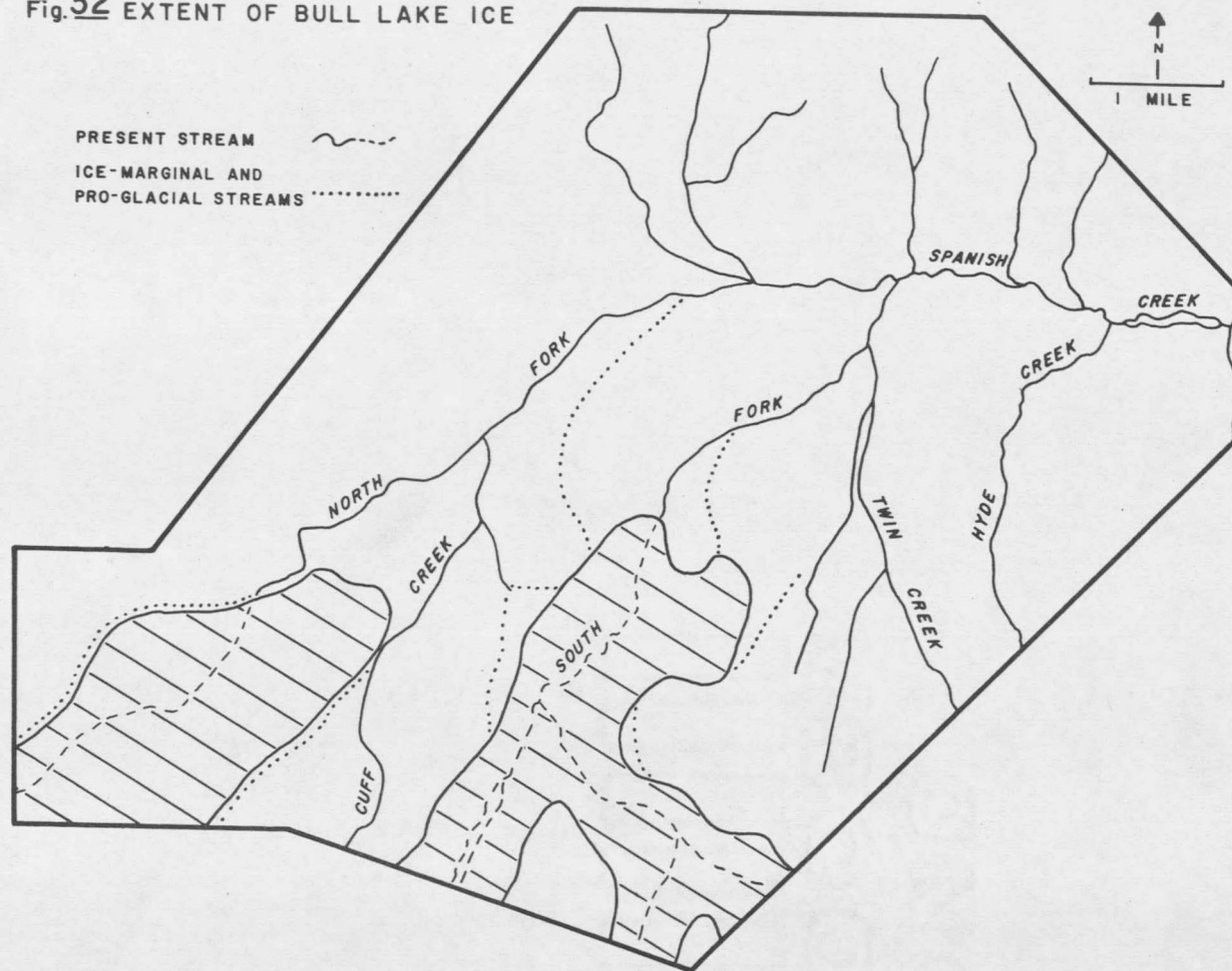
Fig. 31 View to the southwest from the NE $\frac{1}{4}$, sec 14, T 4 S, R3E, showing the relation between the 5800 foot surface and later glacial outwash.

topographic position of remnants of Bull Lake end moraines along the South Fork of Spanish Creek suggest that Bull Lake ice was confined to the South Fork valley and was far less extensive than pre-Bull Lake ice (Fig. 30 and 32, pages 91 and 99, respectively). Two advances of Bull Lake ice may have occurred, although evidence is scanty. A boulder strewn Bull Lake lateral moraine rests astride the west side of the Spanish Creek valley in sections 28 and 29, T4S, R3E. The other portions of contemporaneous end moraine have been removed by erosion. A subdued knob of moraine lies beyond and downstream from the projected continuation of the prominent Bull Lake lateral. This remnant could represent an earlier Bull Lake stade, although only one level of Bull Lake outwash is present in the Spanish Creek Basin Area. If two Bull Lake glaciations occurred, their associated outwash deposits must be superimposed; the younger on the older.

The record of Bull Lake glaciation in the North Fork of Spanish Creek consists of one small segment of end moraine which projects through Pinedale 1 moraine on the north side of the North Fork valley. In both the North and South Forks of Spanish Creek, Bull Lake end moraines were breeched and nearly obliterated by later ice and melt-water.

During the Bull Lake glaciation large alluvial fans developed along the south side of the Spanish Breaks in sections 9, 10, and 11, T4S, R3E. These fans graded to the Bull Lake outwash plain in section 15, T4S, R3E.

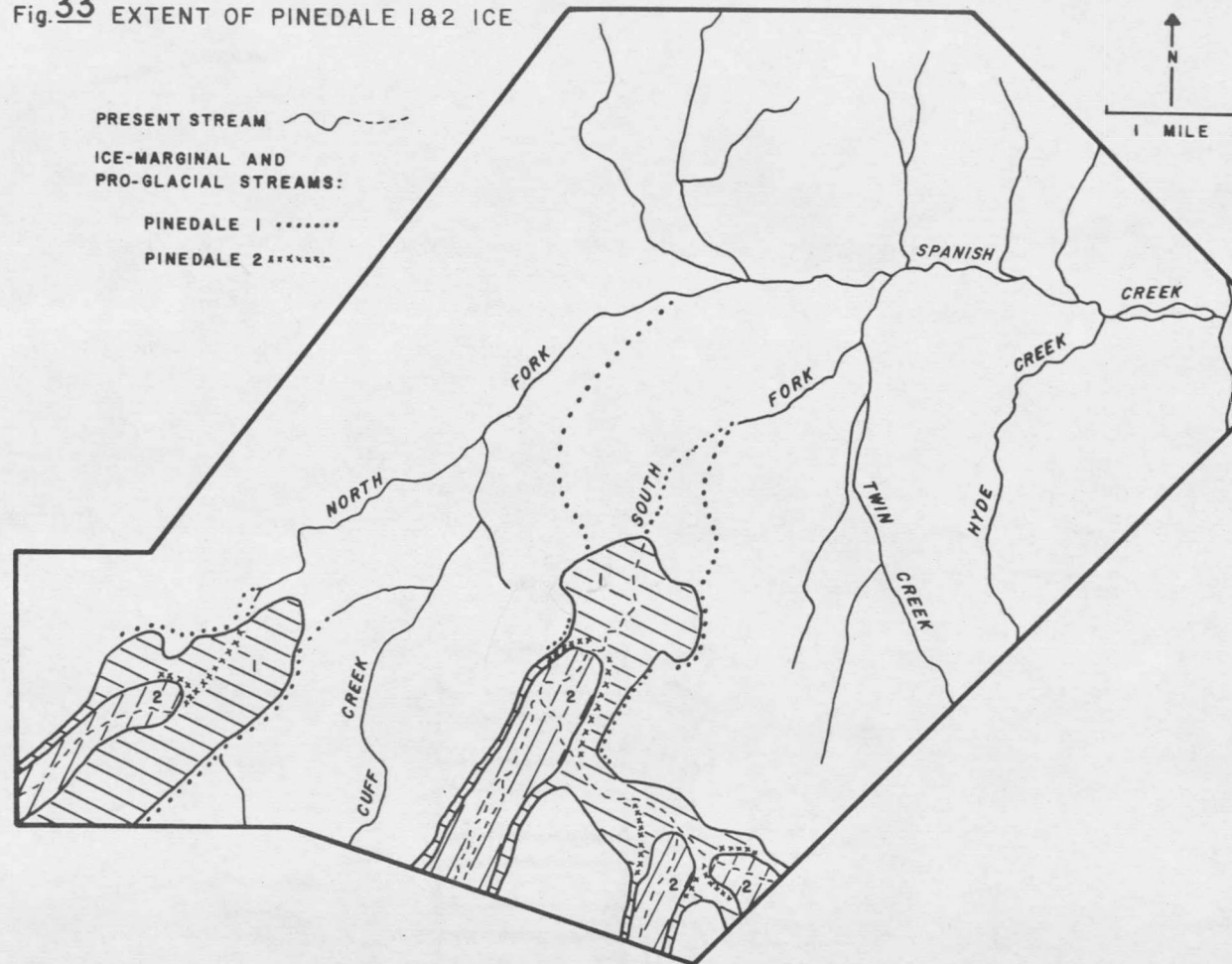
Fig. 32 EXTENT OF BULL LAKE ICE



A shift in climate caused the final wastage of Bull Lake ice and the incision of streams in the Bull Lake deposits. Some minor amounts of canyon cutting may have taken place during the Bull Lake-Pinedale interglaciation.

A return to glacial climate induced ice formation in most of the high cirques of the Spanish Breaks. This glaciation has been correlated with the Pinedale glaciation of the Wind River Mountains, Wyoming (Blackwelder, 1915; Richmond, 1948) (STRATIGRAPHY section, page 5). Pinedale ice flowed in the valleys formerly occupied by Bull Lake ice (Fig. 32 and 33, pages 99 and 101, respectively), although the thickness of the Pinedale ice was apparently not as great. In the North and South Forks of Spanish Creek, Pinedale ice and meltwater destroyed most of the Bull Lake end moraines. In the South Fork the ice terminated just beyond the (late?) Bull Lake lateral moraine remnant. Kame terraces high on the valley side of this remnant grade to the Pinedale 1 terminus suggesting that the majority of the boulders which litter the Bull Lake moraine are Pinedale in age. The early Pinedale ice produced a large arcuate terminal moraine in section 28, T4S, R3E, and a terminal moraine of equal proportions in the valley of the North Fork of Spanish Creek in section 25, T4S, R2E. Willow Swamp drainage was dammed by Pinedale ice and moraine and forced to join the North Fork almost a mile east of the original junction (Plate 2 or Fig. 3, page 7). The West Fork of Cuff Creek was likewise shunted eastward along the ice

Fig. 33 EXTENT OF PINEDALE 1&2 ICE



terminus. This stream formerly joined the North Fork in section 36, T4S, R2E. The stream still follows its ice-marginal route around the Pinedale terminal moraine while a slight cut in the moraine would send its waters cascading down the valley side.

Meltwater from early Pinedale ice careened through all the major canyons of the mountain front. In addition, a proglacial stream ran from the Pinedale terminus in the SW $\frac{1}{4}$ of section 21, T4S, R3E, to the North Fork of Spanish Creek near the Flying D Ranch. After the early Pinedale glaciation, this proglacial channel, incised in pre-Wisconsin and Bull Lake deposits, was abandoned. Outwash emanating from Pinedale ice was deposited in channels cut in Bull Lake outwash.

Ice melted back from the early Pinedale moraine in the South Fork of Spanish Creek. Of the three main proglacial channels only one was maintained during and after the retreat. The sluiceway in section 21 and the steep canyon in section 22 (both in T4S, R3E) were abandoned as meltwater was diverted by the moraine to the present position of the South Fork (Plate 2 or Fig. 3, page 7).

The ice terminus retreated at least one half mile and formed a low arcuate end moraine. The subdued form of the moraine suggests that the ice front did not long occupy this position. The moraine was probably built in a minor period of equilibrium during the overall recession of ice.

The ice terminus continued to retreat. The Little Hell Roaring Creek glacier melted back from ice in the Spanish Creek valley and separated into two tongues of ice. A readvance (Pinedale 2) or prolonged period of equilibrium resulted in the construction of end moraines at the two ice tongue termini in Little Hell Roaring Creek and in the South Fork valley (Fig. 33). Outwash from the Little Hell Roaring Creek ice piled up against South Fork ice at the junction of the two valleys. Debris charged Little Hell Roaring Creek meltwater swept along the east margin of South Fork ice and out onto the valley floor. The combined outwash of Little Hell Roaring Creek and the South Fork nearly buried the (middle Pinedale?) recessional moraine in the valley.

Undrained depressions on the South Fork valley floor between the early and late Pinedale moraines could indicate that the Pinedale events transpired within the period of longevity of stagnant ice. Preservation of the depressions could have resulted from the fortuitous routing of outwash to other areas, however.

In the North Fork of Spanish Creek the retreat of ice from the early Pinedale terminus apparently continued until development of a late Pinedale moraine about one mile upstream. As in the South Fork, late Pinedale meltwater was directed by the early Pinedale moraine to the master stream.

The late Pinedale moraine in the South Fork exhibits an asymmetric pattern resulting from the deflection of late Pinedale ice by a bedrock bastion near the mouth of Little Hell Roaring Creek. Interaction of early Pinedale ice from the main and tributary valleys, with subsequent reduction in flow and erosive capacity at the junction (Flint, 1971), apparently spared the old (Bull Lake?) valley floor remnant from destruction.

As the ice in the South Fork valley melted back past the mouth of Little Hell Roaring Creek, this stream began to deposit an alluvial fan on the floor of the main valley. The South Fork has had some difficulty maintaining its channel through the glut of alluvium supplied by Little Hell Roaring Creek as evidence by the sluggish, swampy, and braided drainage just upstream. The fan has succeeded in diverting the South Fork to the extreme western side of the valley.

On the south side of the Spanish Breaks, alluvial fans developed between and beyond the trenched and dissected remnants of larger Bull Lake age fans. These younger fans graded to the Pinedale outwash in Spanish Creek.

At the close of the Pinedale glaciation the geomorphology of the Spanish Creek Basin Area was essentially that of the present. Some minor trenching of streams and development of talus and colluvium have occurred; but the general landforms are relatively unchanged.

SUMMARY AND CONCLUSIONS

The Spanish Creek Basin Area has undergone a continuum of environmental changes which have profoundly affected the geometry and surficial expression of the rocks and sediments. Over short periods, such as the lifetime of a man or even several thousand years, the increments of change are almost imperceptible. The summation of these gradual changes over large spans of time does result in major modifications, however.

In Early Precambrian time a thick sedimentary sequence was deposited in southwest Montana and adjacent areas. The sediments were deformed and metamorphosed during at least two separate orogenies (Spencer and Kozak, 1975). These rocks now form the basement complex of southwest Montana.

About 1 billion years ago the Belt Supergroup accumulated above the basement in a north-south trending geosyncline and in an eastward trending embayment north of the Willow Creek-Pass Fault Zone (McMannis, 1965). The Spanish Creek Basin Area was part of a broad tract south of this fault zone which remained positive during Belt sedimentation. Thus, during Middle Cambrian marine transgression, sediments were deposited on the eroded surface of Early Precambrian metamorphic rocks in the map area. ✓

Early Paleozoic to early Mesozoic time was generally characterized by continued marine sedimentation, although several noteworthy episodes of nondeposition and erosion did occur during the Ordovician, Silurian, and Triassic Periods.

After deposition of the Cretaceous Colorado Group, the relative quiescence was interrupted by the Laramide Orogeny. In the northern Madison Range, large blocks of the basement were differentially uplifted along possible zones of Precambrian weakness. The Paleozoic and Mesozoic rocks were folded, fractured, and faulted in response to movements of the blocks.

At the close of the compressive phase of the Laramide Orogeny in late early Eocene time, alluvial, lacustrine, and eolian sediments began to accumulate in the map area. Tension associated with epeirogenic uplift caused the development of normal faults throughout the region. A great many of these faults followed pre-existing trends. By the end of the Pliocene Epoch the combination of basin sedimentation and normal faulting led to the development of choked drainage and near burial of many of the ranges.

During the Pleistocene Epoch numerous glaciations markedly sharpened the relief of the mountain ranges and directly or indirectly contributed to the exhumation of early Tertiary topographic forms.

The present physical setting of the Spanish Creek Basin Area consists of the Precambrian basement complex, Paleozoic and Mesozoic sedimentary rocks, and a relatively thin mantle of Cenozoic deposits. This environment has evolved through time under the influence of natural processes. The effects of alterations in the rate of operation and focus of existing processes on the basic environmental framework should

receive careful consideration prior to development of the area for residential, commercial, or recreational purposes.

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GEOLOGIC MAP OF THE SPANISH CREEK BASIN AREA

LEGEND

Qal2 Recent Alluvium and Pinedale Outwash
Qal1 Bull Lake Outwash and Alluvium
Qal Undifferentiated Higher Level Alluvium

Qc Colluvium

Qls Landslide Masses

QUATERNARY

Qm2 Pinedale 2 Moraine
Qm1 Pinedale 1 Moraine
Qmb Bull Lake Moraine
Qgd Undifferentiated Glacial Drift
Qg Undifferentiated pre-Bull Lake Deposits

TERTIARY

Ts Tertiary Strata of the Bozeman Group

Ti Igneous Rocks

CRETACEOUS

Kk Kootenai Formation

JURASSIC

Jm Morrison Formation

Je Ellis Group

PERMIAN

Pp Phosphoria Formation

PENNSYLVANIAN

IPaq Amsden and Quadrant Formations

MISSISSIPPIAN

Mm Madison Group

DEVONIAN

Dts Three Forks and Sappington Formations

Dmj Maywood and Jefferson Formations

€pr Pilgrim and Red Lion Formations

CAMBRIAN

€p Park Formation

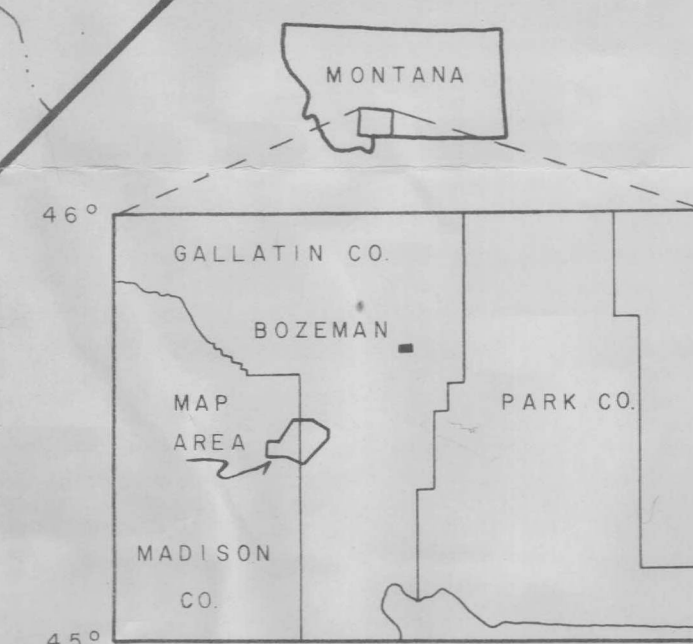
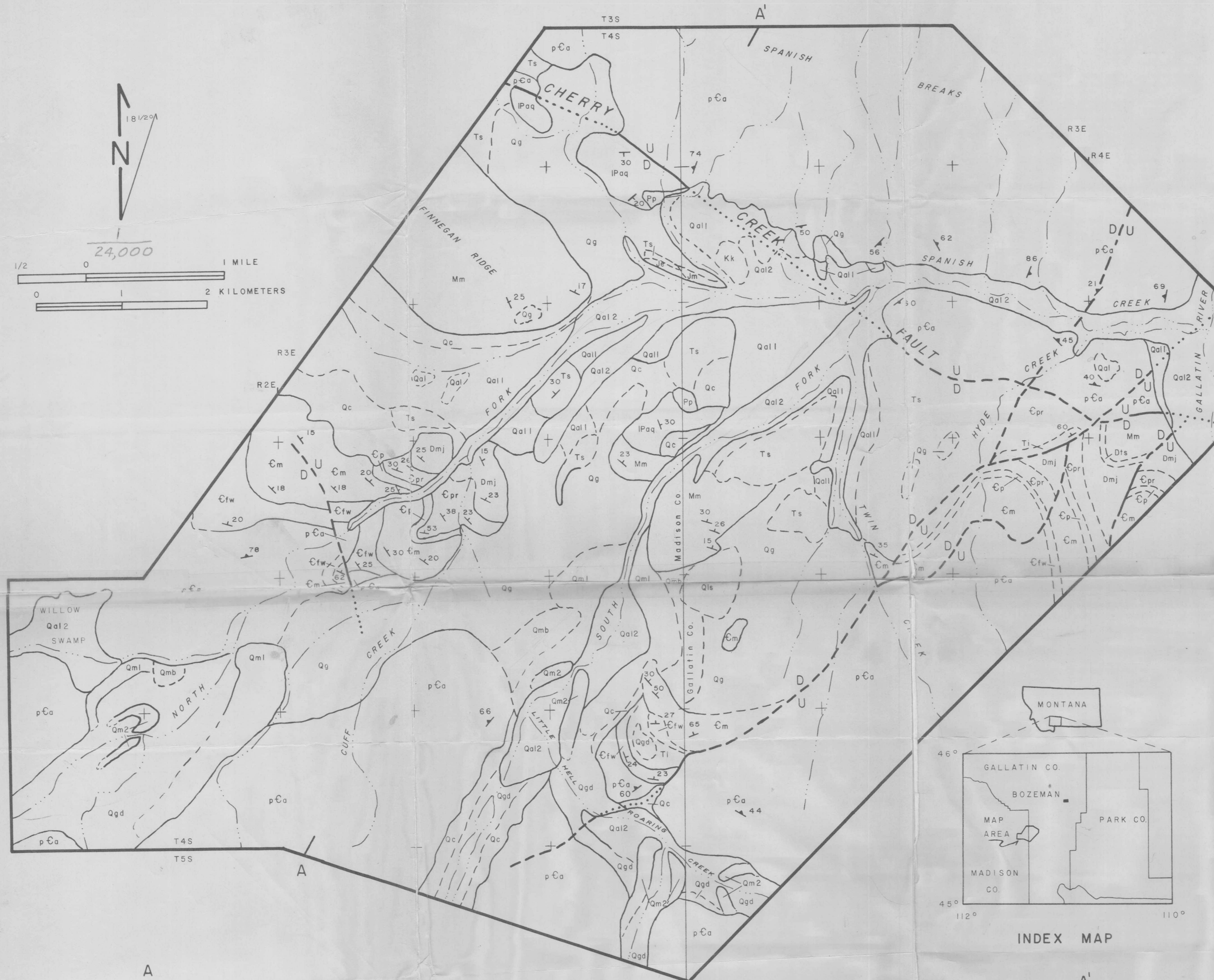
€m Meagher Formation

€fw Flathead and Wolsey Formations

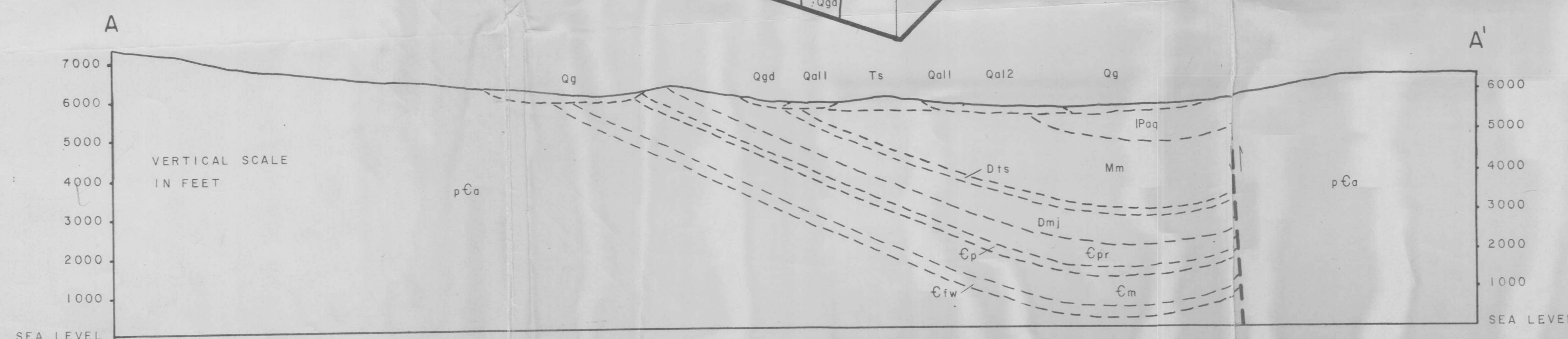
PRECAMBRIAN

pCa Archean Metamorphic Rocks

--- Geologic Contact, Dashed Where Approximate
--- Fault, Dashed Where Approximate, Dotted Where Concealed
--- Strike and Dip of Beds
--- Strike and Dip of Foliation (AFTER KOZAK 1961)
--- Stream



INDEX MAP



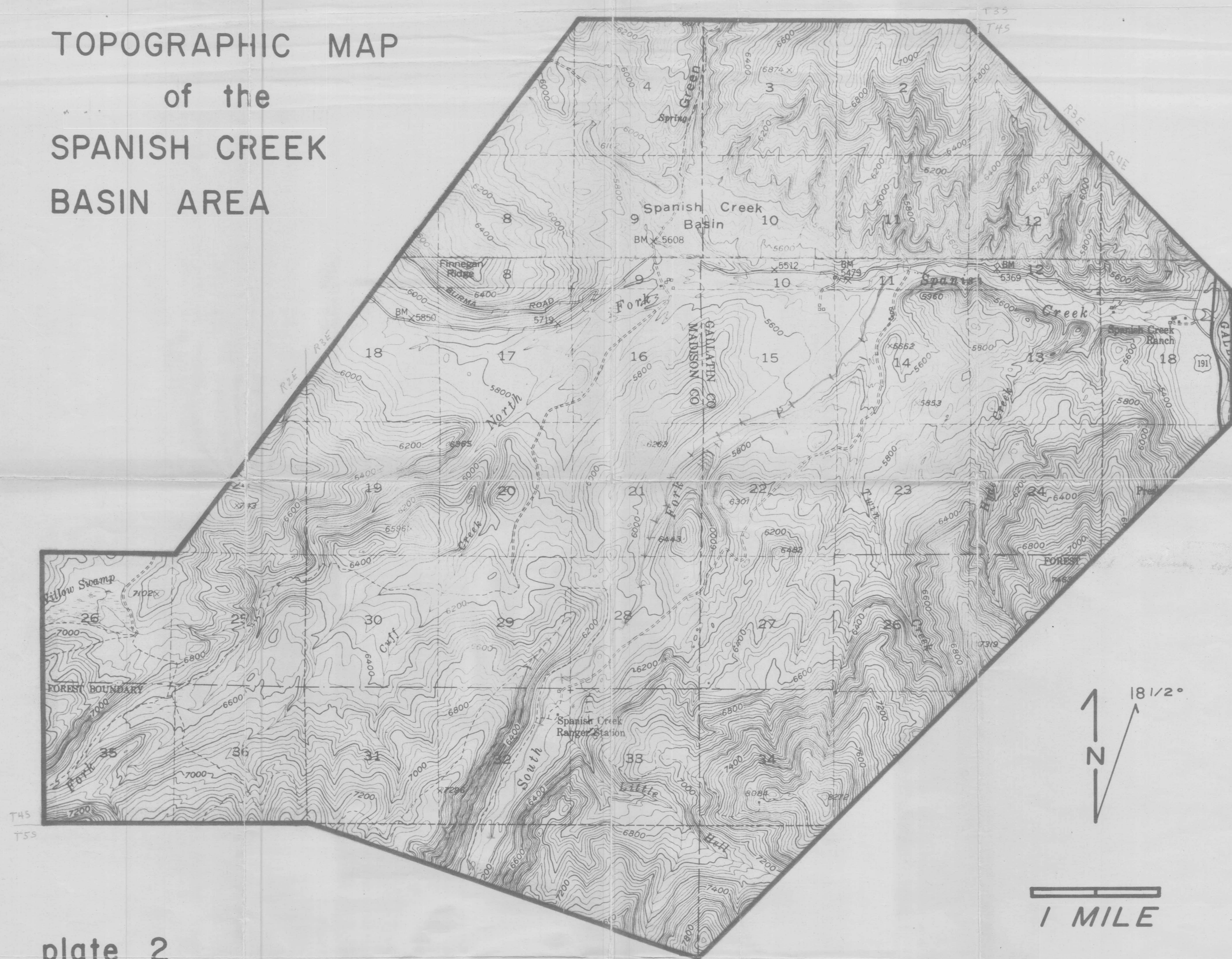
CROSS SECTION A-A'

GEOLOGY BY CRAIG W. TILLEY
SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN EARTH SCIENCES
AT MONTANA STATE UNIVERSITY 1976

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TOPOGRAPHIC MAP
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