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

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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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.

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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 encompasing 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

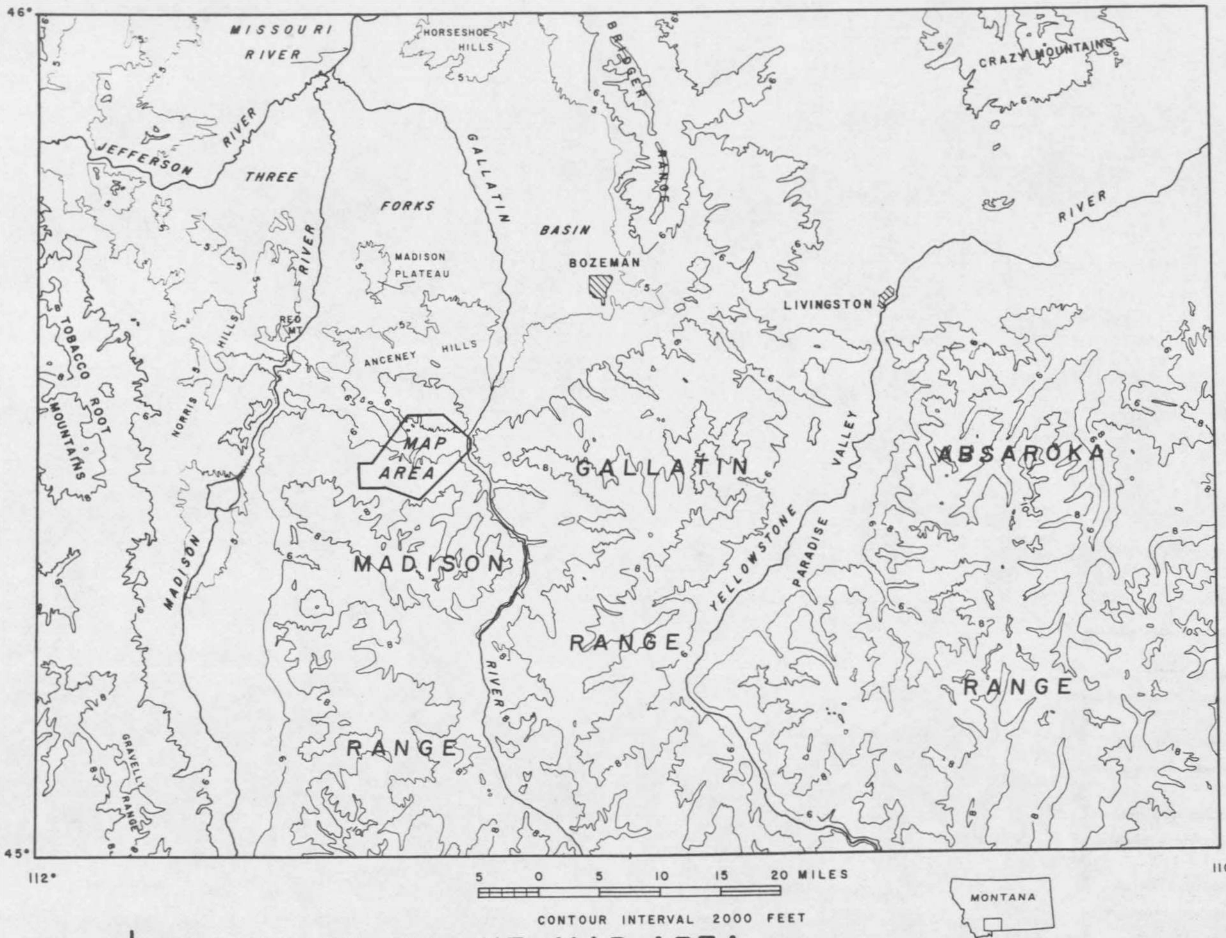


Fig. 1 LOCATION OF THE MAP AREA

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.

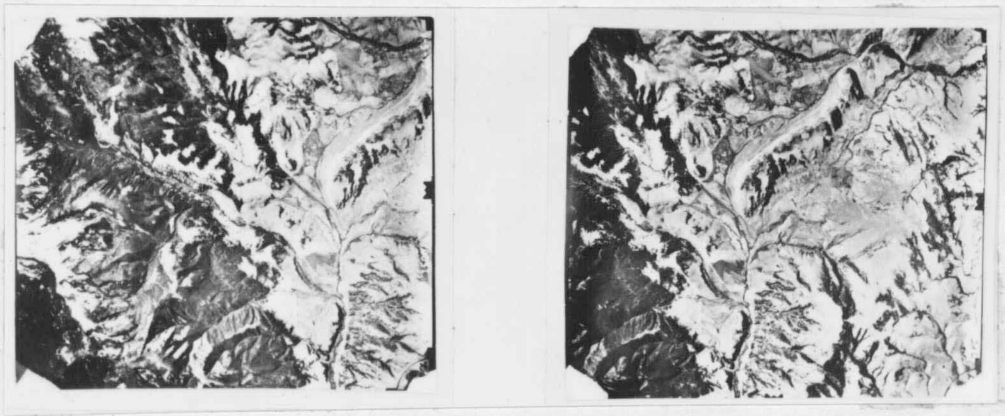


Fig. 2 Stereo pair of the Spanish Creek Basin Area. North is to the right.

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

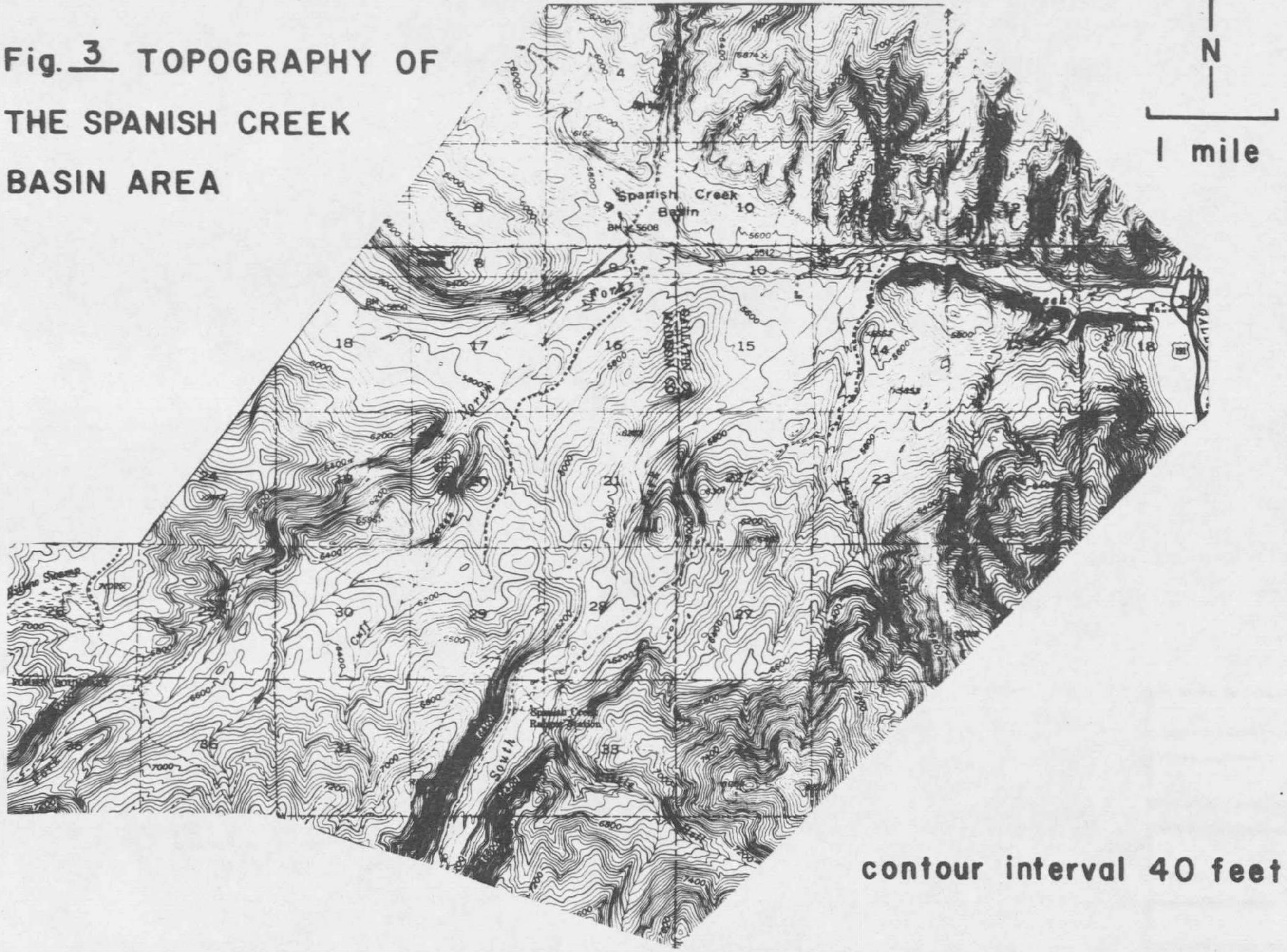
Precambrian metamorphic rocks underlie all deposits and crop out where the younger materials have been stripped off by erosion. The metamorphic rocks are exposed north of the Cherry Creek Fault, and from the southern margin of the Cherry Creek Syncline to the Spanish Peaks Fault (Fig. 8 and 12, pages 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 plagioclass-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 Foramtion 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 fissle 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 ½ 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 fissle 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 NW¼, SE¼, 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 SW¼, 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 sparesely 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 Mississipian 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 occassional interbeds of purple, impure limestone. This unit forms a covered topographic saddle in the SE¼, sec 16, T4S, 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 SE¼, SE¼, sec 16, T4S, R3E, and in the SE¼, SW¼, sec 4, T4S, 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 SW¼, sec 10, T4S, 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 SE¼, SE¼, 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 NE¼, NE¼, sec 9, T4S, R3E, and in the SE¼, SE¼, 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 interfluve 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 Foramtion 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 SE¼, sec 10, T4S, R3E. Alluvial fans cover the ¼ to ½ 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 fluviatile 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 SW¼, NW¼, 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 NE¼, SW¼, sec 21, T4S, R3E. The Climbing Arrow Formation may also be exposed in the SE¼, 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)	Wind River Mountains 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 Stade Temple Lake Stade	Younger Deposits and Soils	Younger Deposits	
		Interglacial	Interglacial	Interglacial	Post-Pinedale Soil	Interglacial	
		Pinedale Stage	Pinedale 3	Pinedale Glaciation: Late Stade	Pinedale Glaciation: Late Stade	Pinedale 2	11800
			Interstade	Interstade	Soil	Interstade	
			Pinedale 2	middle Stade	Middle Stade	middle Pinedale stade ?	
			Interstade	Interstade	?	Interstade	
			Pinedale 1	Early Stade	Early Stade	Pinedale 1	
		Interglacial	Interglacial	Interglacial	Post-Bull Lake Soil	Interglacial	25000
		Bull Lake Stage	Bull Lake 2	Bull Lake Glaciation: Late Stade	Bull Lake Glaciation: Late Stade	Bull Lake Glaciation: Late Stade	70000
			Interstade	Inter-glacial	middle Stade Soil	Interstade	80000
			Bull Lake 1	Early Stade	Early Stade	Early Stade ?	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 sourthern 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

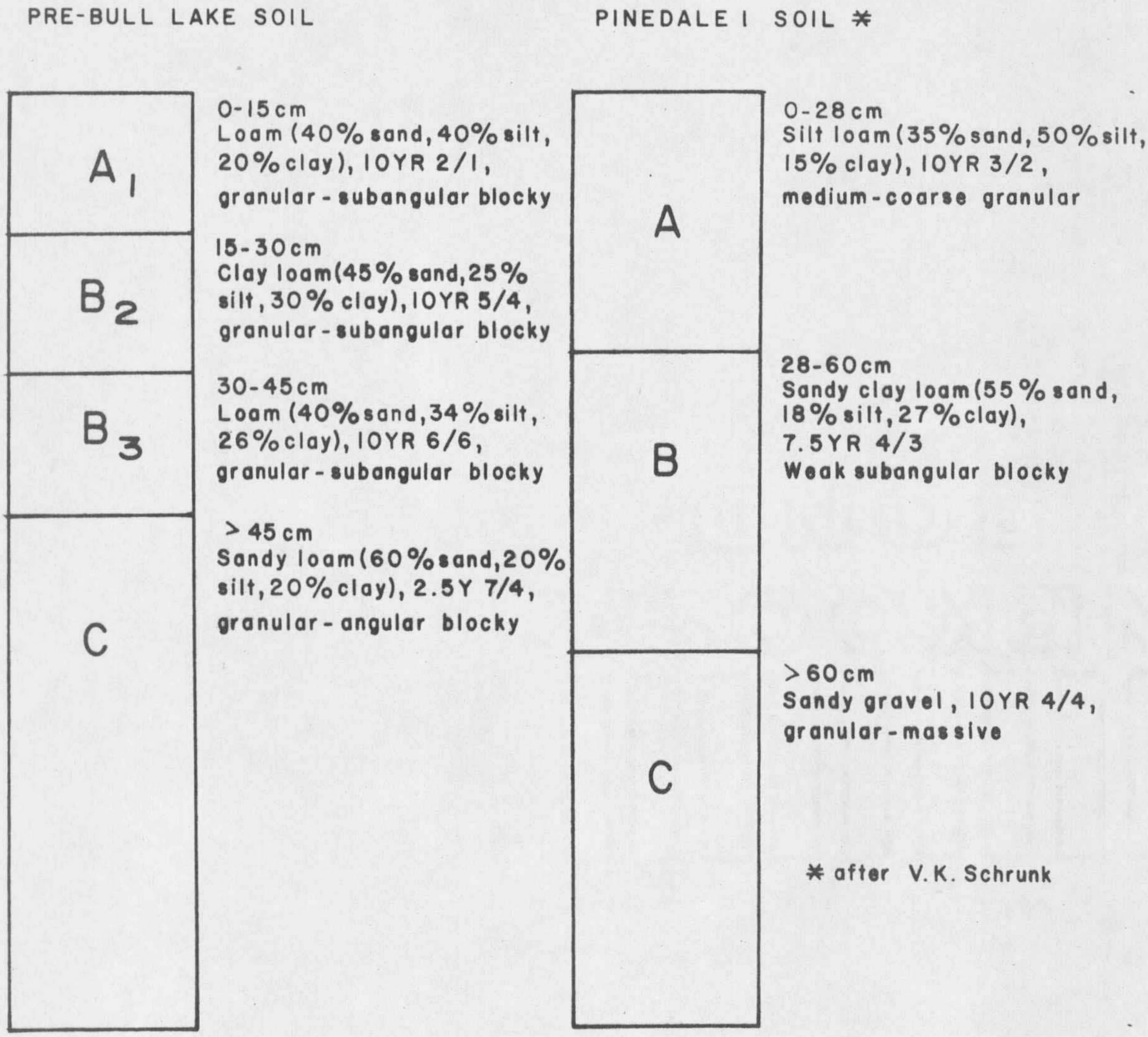


Fig. 5 Comparison of Soils in the Spanish Creek Basin Area

A

B

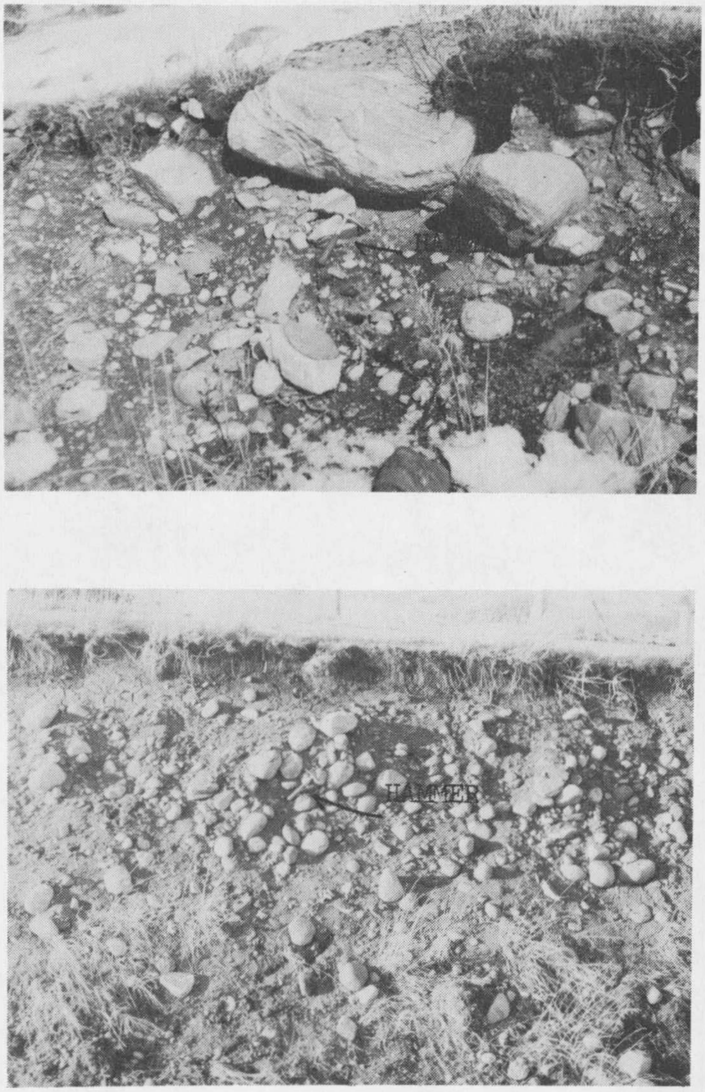


Fig. 6 Comparison of deposits of till (A) and outwash (B). Hammer shows scale. Note the greater rounding and sorting of clasts in the outwash.

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.

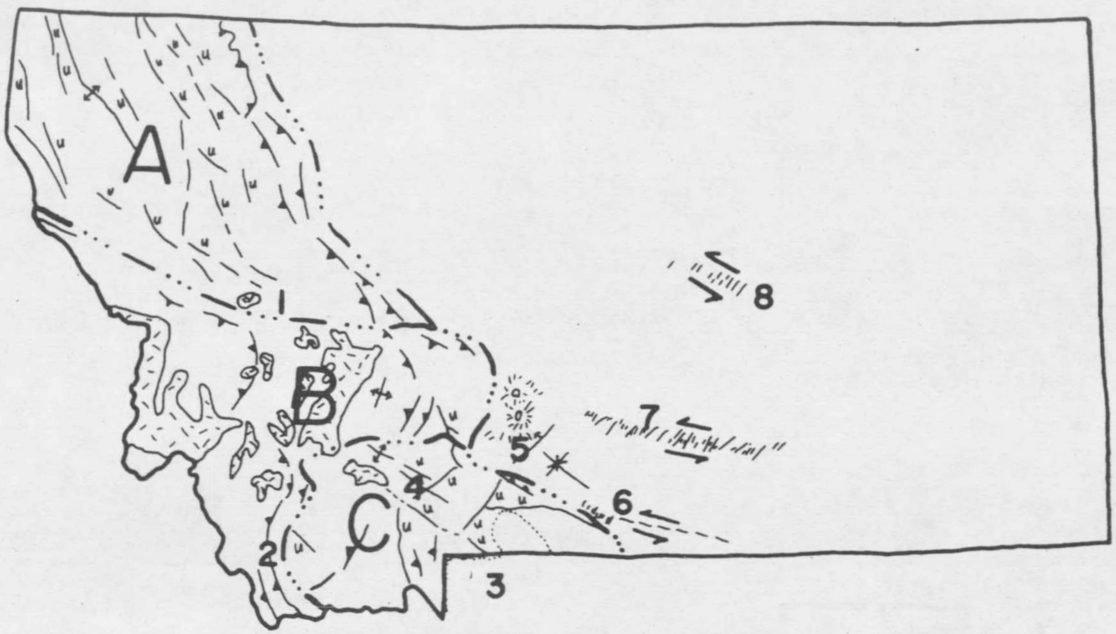


Fig. 7 TECTONIC MAP OF WESTERN MONTANA *

A BELT PROVINCE

B BATHOLITH PROVINCE

C BASEMENT PROVINCE

1 Osburn Fault Zone
2 Melrose-Armstead Thrust Zone
3 Yellowstone-Absaroka Volcanics
4 Spanish Creek Basin Area
5 Crazy Mountain Basin
6 Nye-Bowler Zone
7 Lake Basin Zone
8 Cat Creek Zone

Thrust Fault

Steep Fault

Syncline

Anticline

Monocline

* after McMannis, 1965

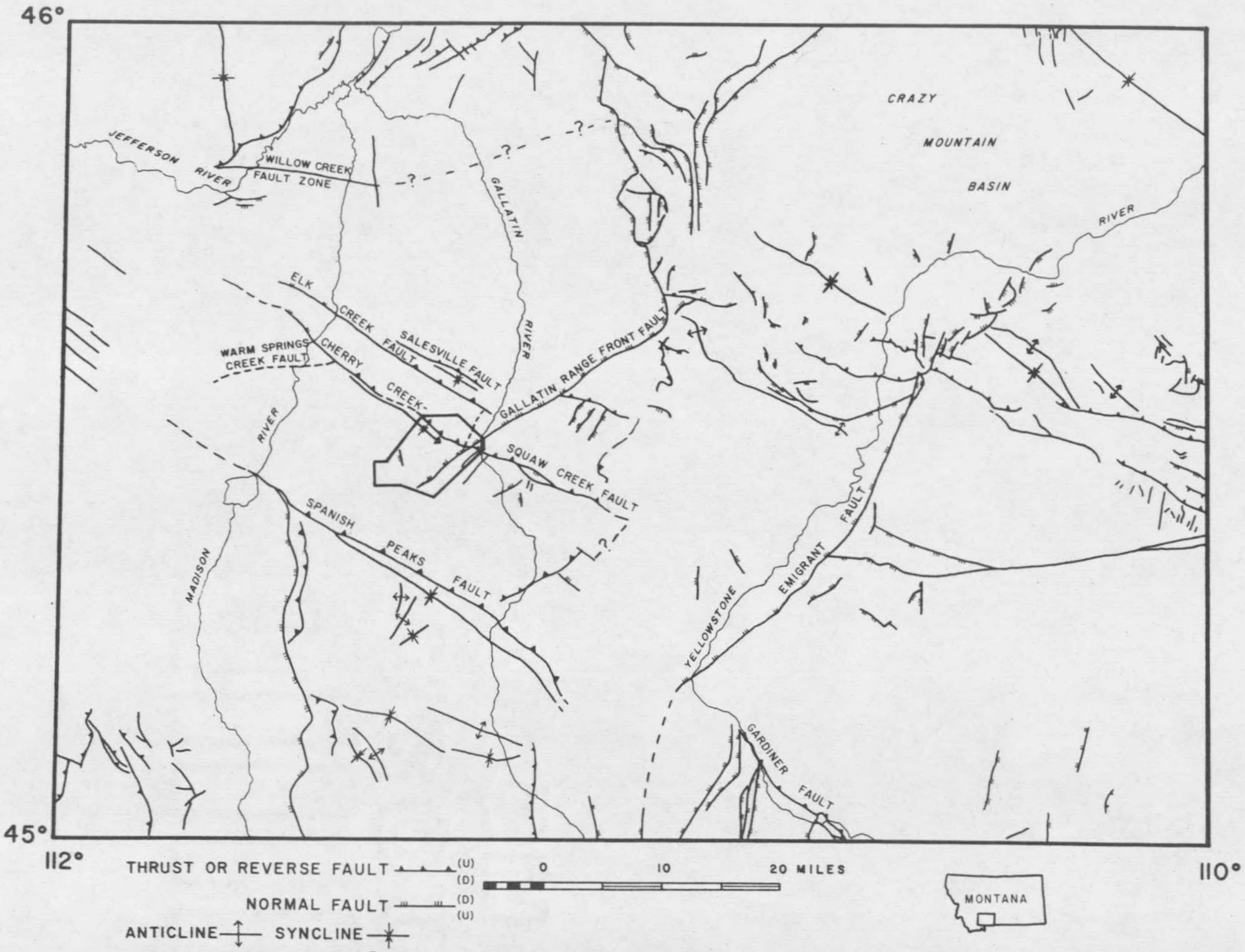


Fig. 8 GENERALIZED STRUCTURES

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.

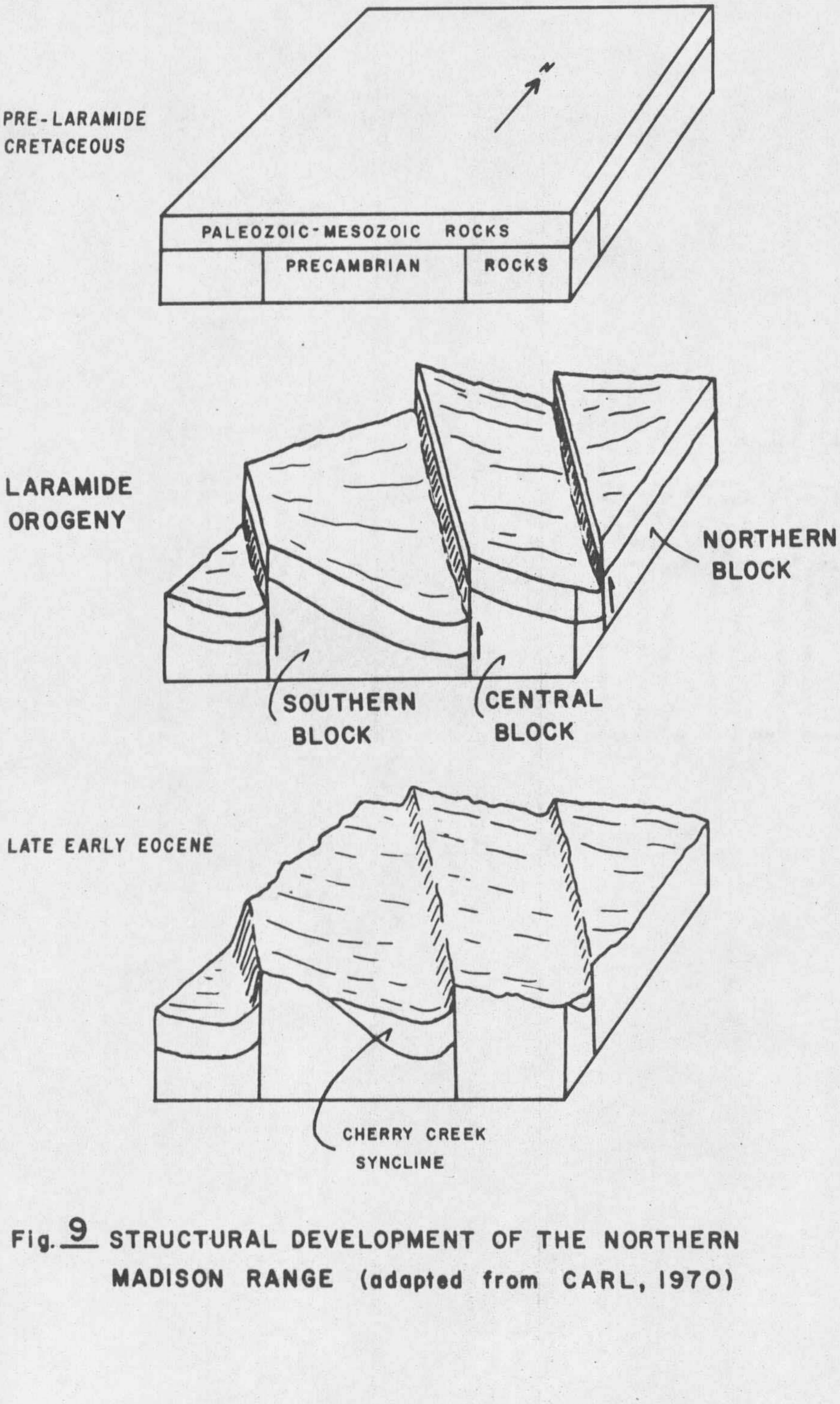


Fig. 9 STRUCTURAL DEVELOPMENT OF THE NORTHERN MADISON RANGE (adapted from CARL, 1970)

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

Fig. 10 View to the NW from the SE¼,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 SW¼ 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