Surficial geology of the Porcupine Drainage Basin, Gallatin County, southwest Montana
by Sherman Allan Sollid

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Earth Science (Geology)
Montana State University
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Abstract:
The Porcupine Drainage Basin lies east of the West Gallatin River in the Gallatin Range between Bozeman and West Yellowstone, Montana. It is a structural and topographic basin in the Northern Rocky Mountain Physiographic Province, It is bounded on the north by the crystalline upthrown block of the Spanish Peaks Fault. Cretaceous bedrock is exposed in the lower part of the basin and Tertiary volcanics dominate the upper reaches.

The Porcupine Drainage Basin is a semi-primitive area, rich in natural beauty and containing an abundance of wildlife. It is the winter range for the migratory Northern Yellowstone elk herd. It is also unique in that it contains part of the Gallatin Petrified Forest, a sequence of up to 27 buried forests of early Cenozoic age, in which many of the trees are standing upright in the position in which they grew.

Due to the characteristics of the underlying rock material, the abundance of steep slopes (over 30°), and the amount of available water, the basin is extremely prone to landsliding. Landslides and landslide debris cover more than one-third of the basin and have apparently obliterated most of the glacial deposits.

The surficial geology was studied and mapped in an attempt to relate geology to land management decisions for the Porcupine Drainage Basin and adjacent areas. The data obtained was ultimately used by planning personnel of the Gallatin National Forest to determine management alternatives for this area.

Development plans must focus on the high incidence of unstable slopes in the basin. Water is considered to be one of the major mechanisms for landslide release. Lubricated glide planes, increases in pore water pressure, and overloading through saturation are brought about by increased amounts of available water. Activities which increase the amount of available water, such as clearcutting, must be avoided in many areas. Ironically, many of the more desirable stands of commercial timber occur on old landslides, due to high water content and loose soil.

Due in part to the large number of geological hazards, the U.S. Forest Service has classified Porcupine Drainage Basin as an area to remain undeveloped. There will be no roads, and logging to control fire or disease threats will be by balloon or helicopter only.

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by

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A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

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June, 1973

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ABSTRACT

The Porcupine Drainage Basin lies east of the West Gallatin River in the Gallatin Range between Bozeman and West Yellowstone, Montana. It is a structural and topographic basin in the Northern Rocky Mountain Physiographic Province. It is bounded on the north by the crystalline upthrown block of the Spanish Peaks Fault. Cretaceous bedrock is exposed in the lower part of the basin and Tertiary volcanics dominate the upper reaches.

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The surficial geology was studied and mapped in an attempt to relate geology to land management decisions for the Porcupine Drainage Basin and adjacent areas. The data obtained was ultimately used by planning personnel of the Gallatin National Forest to determine management alternatives for this area.

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INTRODUCTION



Figure 1-Panoramic view looking east into the Porcupine Drainage Basin. Snow capped peaks in the distance are part of the Gallatin Range, the eastern boundary of the study area.

PURPOSE AND METHOD OF STUDY

The field work for this project was undertaken as part of an interdisciplinary study by the Montana State University RANN (Research Applied to National Need) project funded by the National Science Foundation. Geology represents only one of many disciplines which were involved in studying the physical and environmental aspects of a semi-primitive area. A large amount of the writer's research time was spent with planning personnel of the Gallatin National Forest because Porcupine Drainage Basin is part of a U.S. Forest Service Multiple-Use Planning Unit. Data obtained by members of the interdisciplinary team played a major role in the management alternatives developed for this area by the United States Forest Service. Information on Porcupine Creek high water sediment sources, locations of unstable slopes, percent of clay in soil types, and other physical factors aided the Forest Service personnel in making the necessary decisions.

This report represents the results of the study of surficial and environmental geology of the entire Porcupine Drainage Basin. As background, the general geological relationships such as stratigraphy, structure and geomorphology were also examined. I have included this information in the report to give the reader a brief overall geologic background of the area. Also an effort has been made to determine the

role that geology will play in man's projected use of the area.

Approximately ten weeks were spent in the field during the summer of 1972, plus several weekends during the fall of the same year. The geology was mapped on 1:20,000 scale airphotos obtained from the United States Forest Service and transferred by inspection to a 1:62,500 scale United States Geological Survey topographical map of the same area. An attempt was made to use a Saltzman vertical reflecting projector to transfer the data from the airphotos to the topographical sheet but minor errors in the base map made transferring by inspection the only alternative.

THE PORCUPINE PROBLEM

Early in 1970, it was announced that plans for a year-around large-scale resort were finalized for the West Fork drainage. It was to be named Big Sky of Montana and was to be funded by Chrysler Realty and other large corporations. The winter resort was to be located at the base of Lone Mountain to gain access to the skiable areas and the summer resort would be located in the broad valley between the West Gallatin River and the mountains.

The announcement of the resort plans in 1970 produced a flurry of concern and speculation among local citizens and others throughout the state and nation. The main concern was that the economic gains from such an enterprise would not offset the loss in environmental

quality.

For some time there has been a need to determine the impact that such a large-scale resort would have on the environment in a semi-pristine area. The announcement of the Big Sky plans in the West Fork basin provided an ideal opportunity to study the Gallatin Canyon as it was then, as it is now, and as it will be in the future. The objective is to construct guidelines for land use for future developments in similar areas.

To the above end a multi-disciplinary team of Montana State University scientists initiated a major study of the canyon in the summer of 1970, supported by funds from the National Science Foundation.

The data obtained in 1970 and 1971 were apparently significant and the National Science Foundation funded an additional year of study in 1972. At this time, Montana State University researchers proposed to determine what effects the Big Sky complex would have on the rest of the Gallatin Canyon.

One of the most obvious areas of impact and shifted open space interest was the Porcupine Drainage Basin east and slightly south of the West Fork basin. There were several reasons why it was thought that Porcupine Drainage Basin should be studied. First, its proximity to Big Sky makes it a natural overflow area for activities from Big Sky such as hunting and cross-country skiing. Secondly, it is the winter range for one of the world's largest elk herds. This is the

northern Yellowstone herd which forages high in the Gallatin Range near the park border in the summer and migrates into the Porcupine area in the winter. Thirdly, Porcupine Drainage Basin contains several sections of land that belong to Burlington Northern, Inc., and these are very rich in timber. Burlington Northern has a road application to gain access to their timber and must cross public domain to do so. It is possible that Burlington Northern could allow development on their lands in Porcupine in conjunction with the rapid development taking place in the canyon.

Several of the research team members, including the writer, commenced studies in Porcupine Drainage Basin during the 1972 field season and took an active part in the planning process that the U.S. Forest Service undertook to develop management decisions for this and adjacent areas.

LOCATION AND DESCRIPTION OF AREA

The Porcupine Drainage Basin study area covers approximately twenty-six square miles west of the West Gallatin River, on the west flank of the Gallatin Range, Gallatin County, Montana (Figure 2). It lies almost midway between Bozeman and West Yellowstone along Route 191 which follows the canyon formed by the West Gallatin River. Although the drainage is essentially a roadless area, very limited access by 4-wheel drive vehicle is provided by several unmaintained

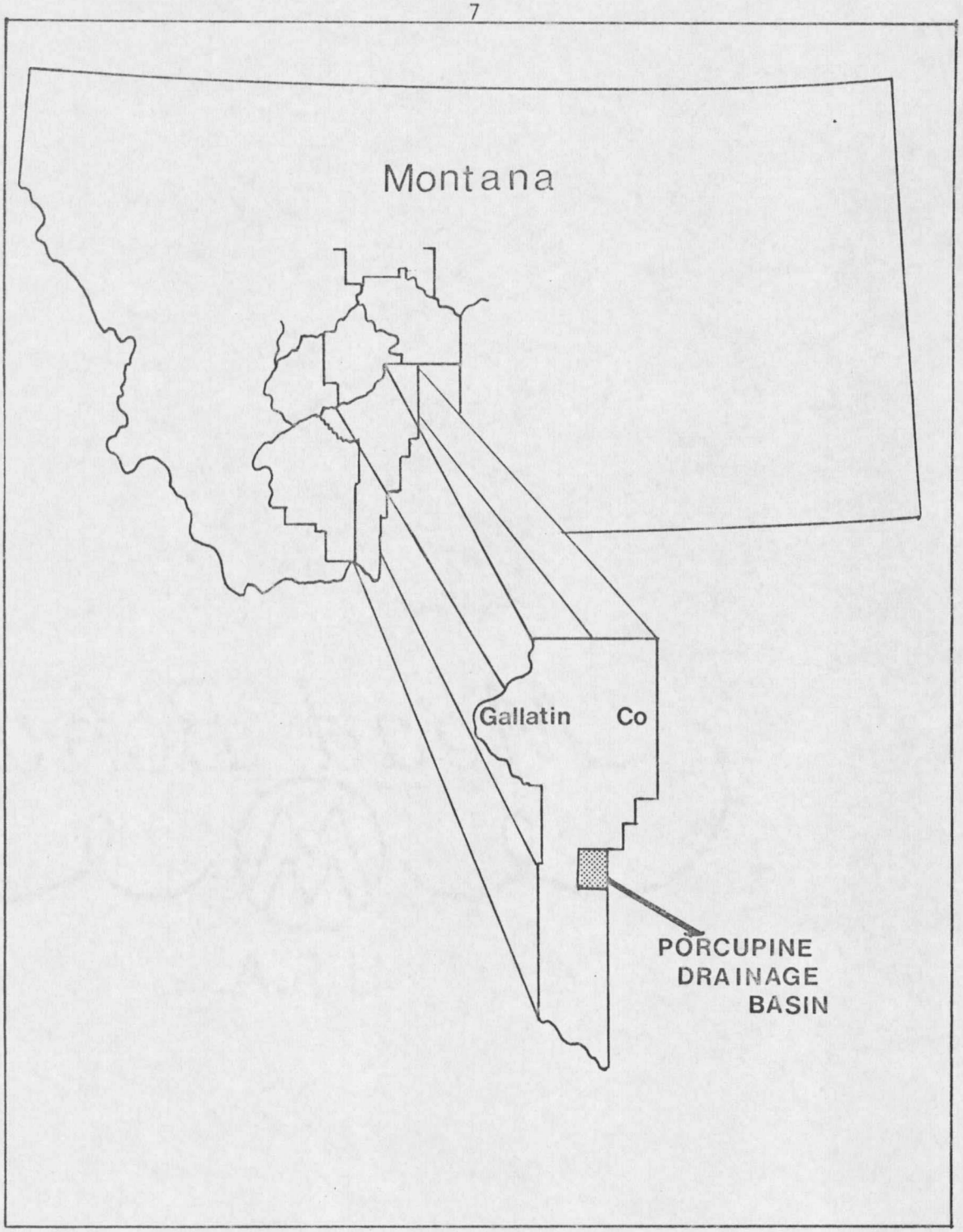


Figure 2-Location map of study area.

logging roads dating back to the early 1950's. The basin is used extensively in the winter by the migratory Northern Yellowstone Park elk herd for winter forage.

TOPOGRAPHIC-GEOGRAPHIC SETTING

The most impressive feature of the study area is the volcanic-capped mountain peaks along the crest of the Gallatin Range, which is the eastern boundary of the study area. Included is a portion of Fortress Mountain which rises to over 9800 feet, and Eaglehead Mountain which is the highest peak in the area at 9976 feet (Figure 3). Besides the highlands mentioned, the area also includes a structural and topographical basin which is an extension of the Lower Basin Syncline to the west. Levenski Ridge is an important landmark along the northern boundary and is the northern limb of the Lower Basin Syncline. The western boundary is the West Gallatin River which is incised in an alluvial floodplain having an elevation here of about 6100 feet. Total relief in the area is about 3900 feet. Several pediment surfaces emanate from midway up Levenski Ridge and are prominent features in the basin.

The eastern boundary of the drainage is the Elkhorn divide which is a tuff-capped ridge dividing the Porcupine and Elkhorn watersheds.

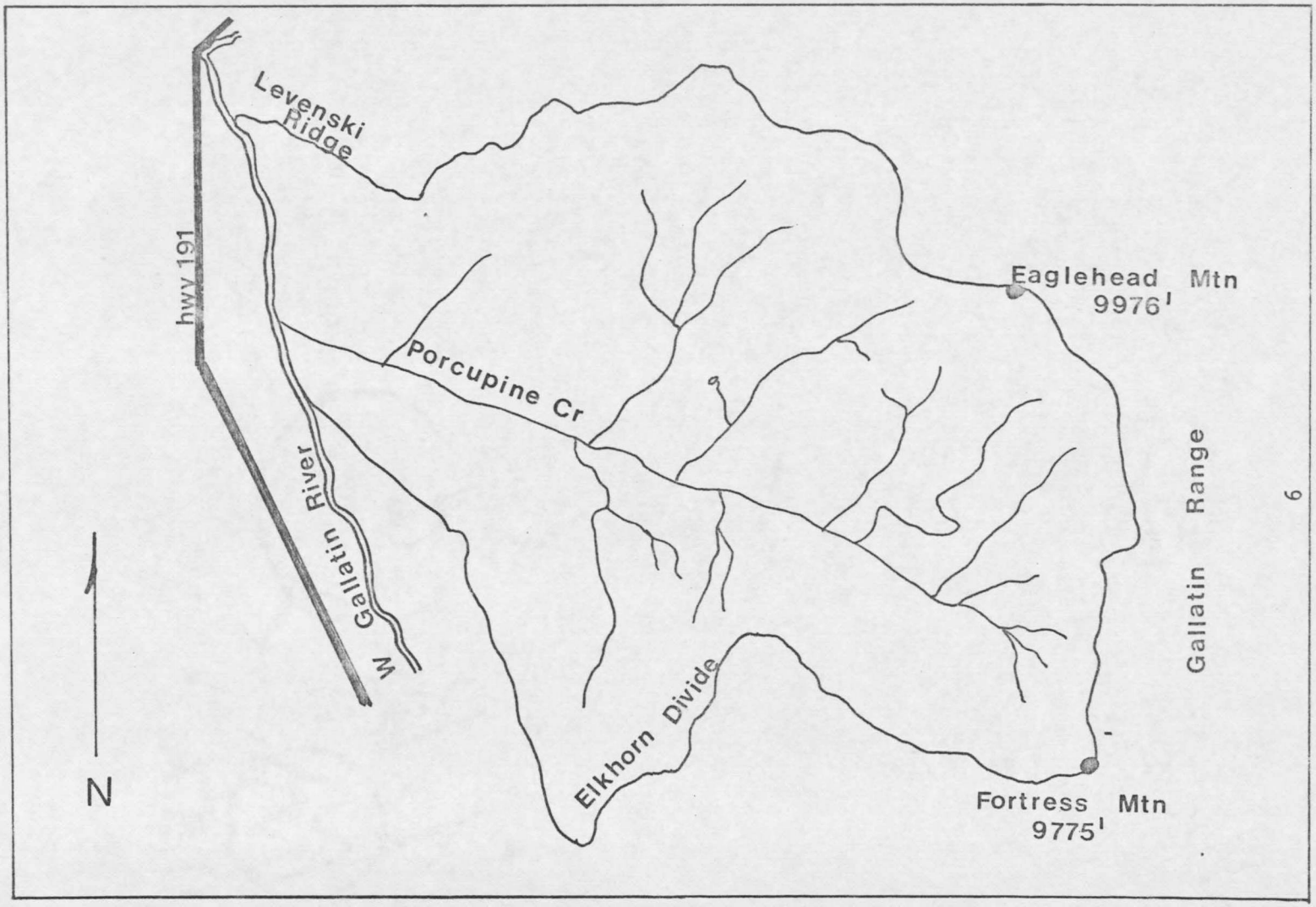


Figure 3-Map of prominent topographic features in study area.

PREVIOUS WORK

The Porcupine Drainage Basin has been included in Scientific studies since the Lewis and Clark Expedition of the early 1800's (DeVoto, 1953). Peale (1896) made the first important geological contribution when he mapped the Three Forks Quadrangle. Two rather recent works were relied upon extensively for the summer research and for this publication--W.B. Hall (1961) and W.J. McMannis and R.A. Chadwick (1964).

Hall's 1961 work covered some of the south part of the study area and his discussions of structure, stratigraphy, and surface features were invaluable.

McMannis and Chadwick (1964) mapped the geology of the Garnet Mountain Quadrangle which is directly north of the Porcupine Drainage Basin. Their area slightly overlapped into the study area in the northwest corner of the drainage basin. Many of their observations and measurements of stratigraphic units were made on the south flank of Levenski Ridge.

Other works in the area which proved to be helpful included Swanson's (1950) bedrock geology map, a Forest Service publication by Prinkki (1971), and four Montana State University theses on the West Fork area directly west of Porcupine: Kehew (1971), MOntagne (1971), Walsh (1971), and Goolsby (1972). Bailey's (1971) article on landslides was also helpful.

A BRIEF SKETCH OF GEOLOGICAL HISTORY AND SETTING

The Porcupine Drainage Basin is an extension of the Lower Basin Syncline, which begins to the northwest of the study area in the West Fork Basin. The syncline formed during the Laramide Orogeny, some 50-60 million years ago, from unidirectional compressional folding. Structural relationships are shown in Figure 4.

The syncline is bounded on the north by the Spanish Peaks Fault zone. Movement along the fault apparently took place towards the conclusion of compressional activity of the Laramide Orogeny. The Spanish Peaks Fault is a high-angle reverse fault in which the northerly block has been thrust upward and slid slightly southward. Because of the high relief, many of the sediments that were originally exposed north of the fault have now been stripped away, leaving the more resistant crystalline rocks exposed. The Spanish Peaks Fault can be traced westward to Ennis Lake and eastward to the head of Porcupine Creek where it is concealed by Tertiary volcanic flows. It is thought that it may be an extension of the Gardiner Fault (McMannis and Chadwick, 1964).

Shortly after folding and faulting ceased, major volcanism began to take place. This resulted in a series of lava flows which filled the topographically low areas first. Many of these lava flows solidified in place but others became broken and brecciated, and

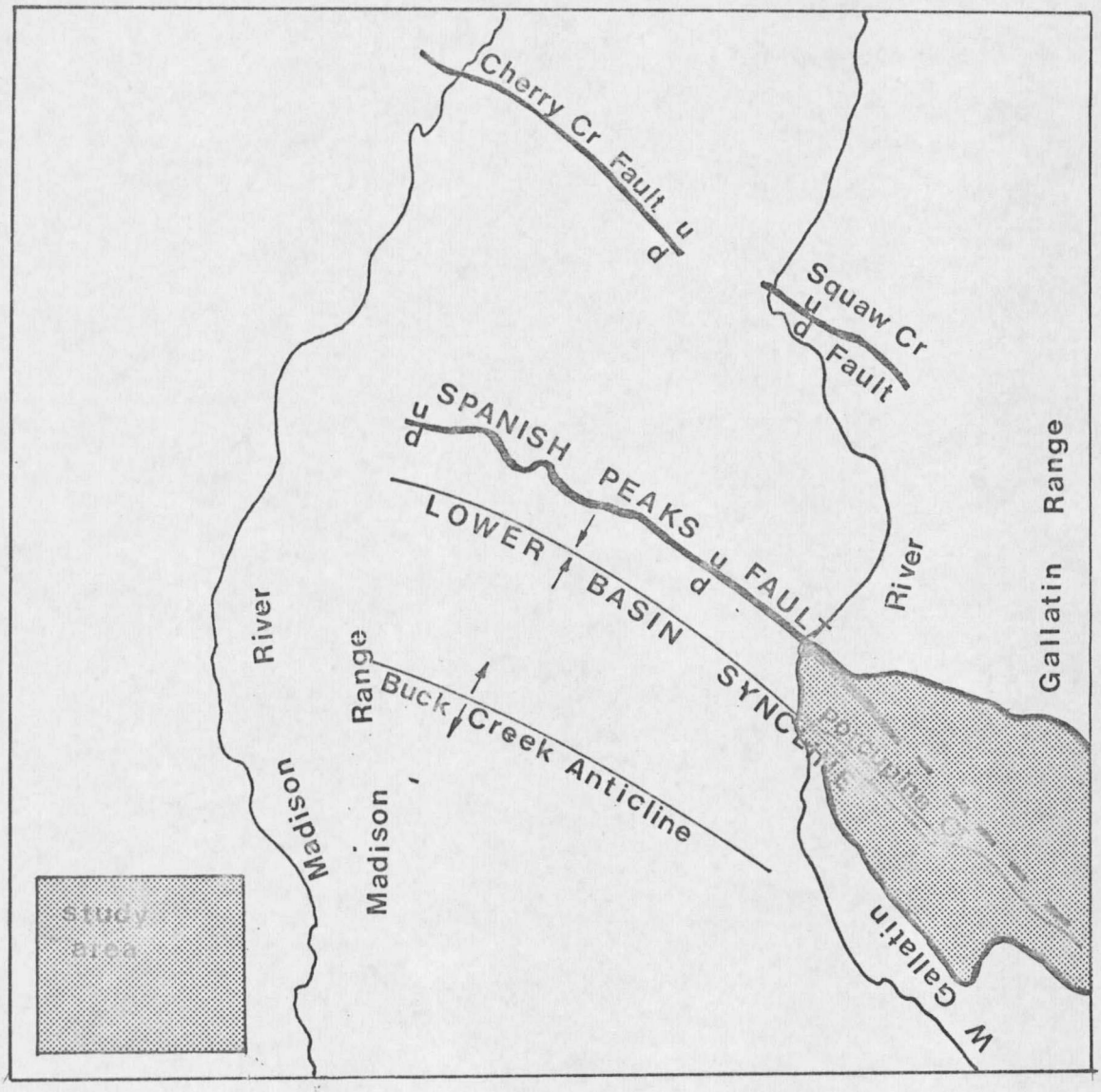


Figure 4-General structural map.

blocks of volcanic rocks were transported many miles by laharic mud-flows (McMannis and Chadwick, 1964). Volcanic rocks cap many of the higher ridges in the area today.

Since volcanism, the area has been tilted about 5 degrees to the east as indicated by the dipping volcanic rocks.

The destructive forces of erosion have shaped the drainage as we see it today. Streams have probably played the major role in shaping the landscape. For 40 million years they have cut down and laterally eroded the rock materials of the basin. In places, the streams have encountered hard crystalline rocks which have been relatively slow to erode. In other places, softer shales, sandstones, and poorly consolidated breccias have been deeply incised or rapidly reduced to the lowlands we see today.

Mass-gravity movements and glaciation have also shaped the drainage. It is estimated that over one-third of the basin is covered with landslide debris or has been involved with mass-gravity phenomena. These processes and others will be discussed further under the section on surface deposits.

STRATIGRAPHY

INTRODUCTION

The stratigraphy is discussed here as it applies to the problem of evaluating the surficial geology of the Porcupine Drainage Basin and the effects it has had on the physical environment. General lithological relationships are discussed to give the reader a background knowledge of the study area. A detailed stratigraphic interpretation can be obtained from McMannis and Chadwick (1964) and Hall (1961).

The lower part of the Porcupine Drainage Basin is an asymmetrical synclinal basin trending about S60°E (Figure 4). The syncline is characterized by steeply dipping to overturned beds on the northeast flank and gentle (15°N) dipping beds on the southwest flank (Plate I).

The basin contains more than 4,000 feet of sedimentary strata ranging in age from Cambrian through Cretaceous. The northeast flank of the syncline has Precambrian rocks thrust into contact with Paleozoic sediments as this lies along the thrust plane of the Spanish Creek Fault (McMannis and Chadwick, 1964). The upper reaches of the basin have been buried by Eocene and later volcanic flows and breccias (Hall, 1961).

The following discussion is a composite of the work of McMannis and Chadwick (1964) and Hall (1961). Many of the formations exposed

in the Porcupine Drainage Basin were measured by McMannis and Chadwick (1964) because the northwest part of the study area lies within the Garnet Mountain Quadrangle. Only in the area of Levenski Ridge are the Cenozoic and Mesozoic strata sufficiently exposed to facilitate measurement and observation.

PRECAMBRIAN METAMORPHIC ROCKS

Precambrian metamorphic rocks are exposed north of the Spanish Peaks Fault (Figure 3), and consist almost entirely of coarse gneiss, schist, and amphibolite with quartzite lenses. The metamorphic rocks are pre-Belt in age (McMannis and Chadwick, 1964) and Hall (1961) suggests that they are probably metasediments.

PALEOZOIC

Cambrian

Within the study area, there is only one outcrop of Cambrian strata. An uplifted block of Meagher Limestone is found in Sec. 32, R5E, T7S, near the upper end of the drainage where it forms a massive cliff several hundred feet high at its maximum point of relief. McMannis and Chadwick (1964) measured thicknesses of up to 449 feet at Garnet Mountain, some 13 miles north of the study area. It is a dense, medium-grey and yellow mottled thin-bedded to massive limestone. The mottle patches consist of fine-grained silty limestone contained in

a dense finely crystalline pure limestone. Glauconite is common in the upper beds.

Ordovician, Silurian, and Devonian

The Ordovician, Silurian, and Devonian strata are absent in the Porcupine Drainage Basin. Bighorn Dolomite (Ordovician) is present in the Madison Range to the southwest (Hall, 1961) and it also occurs at Mystic Lake, some 20 miles to the northeast at the northerly end of the Gallatin Range (McMannis and Chadwick, 1964). Silurian rocks are absent throughout western Montana (McMannis and Chadwick, 1964). Devonian strata (Maywood, Jefferson, Three Forks and Sappington formations) are present immediately adjacent to the northwestern boundary of the study area where they are brought into contact with the Precambrian crystalline rocks in a limited area along the Spanish Peaks Fault.

Mississippian

The Mission Canyon Formation of the Madison Group makes up the Mississippian strata exposed in the study area. This limestone is of late Early and early Late Mississippian age (McMannis and Chadwick, 1964). It is partially responsible for the prominent hogback, Levenski Ridge, along the northwestern boundary of the map area. It overlies the Lodgepole Formation, which is also part of the Madison Group. The Lodgepole Formation occurs north of the geographic limits of the map

area.

McMannis and Chadwick (1964) found that the Mission Canyon Formation averages about 675 feet in thickness in the Garnet Mountain Quadrangle immediately to the north and Hall (1961) found this unit to be 471 feet thick to the south of the map area. The outcrop in the study area has been overturned and dips about 85° to the northeast. The formation consists of a grey-brown, medium-bedded to massive, fine to coarsely crystalline dolomite, dolomitic limestone, and limestone. It weathers to rubbly outcrops with rather obscure bedding planes.

Mississippian-Pennsylvanian

The Amsden Formation of Late Mississippian and Early Pennsylvanian age overlies the Mission Canyon Formation in the Porcupine Drainage Basin, as is the case in most of the Gallatin Canyon. The Amsden Formation consists of a yellow-grey, thin-to thick-bedded, medium-to-coarse grained dolomite, pale-grey to white, dense, thin to medium-bedded dolomite; grey-brown, fine-grained, medium-bedded to massive, fossiliferous limestone; purplish-red, dense, dolomite, and minor amounts of green and red flaky dolomitic shale.

It ranges from 0 to about 225 feet in thickness in the Garnet Mountain Quadrangle (McMannis and Chadwick, 1964).

Although the Amsden is relatively non-resistant, it is very prominent in the Gallatin Canyon because of the brick-red soil band

which forms on the exposures from weathering of its red shale. It often contrasts to the buff colored limestone above and below it.

The Quadrant Formation ranges from 125 feet to 250 feet in thickness to the north in the Garnet Mountain Quadrangle (McMannis and Chadwick, 1964) and Hall (1961) found it to average 270 feet in the Madison Range. The Quadrant is taken to be all of the sandstone, limestone, and gradations between sandstone and limestone which overlie the Amsden Formation and underlie the Permian Phosphoria Formation. The Quadrant includes white to cream colored, medium-to-thickbedded, crossbedded, fine to medium-grained quartz sandstone. In the lower portion of the formation are medium-bedded light colored crystalline limestone and calcarenite. These tend to grade upward to sandy limestone, limy sandstone, and other quartzite. The top of the Quadrant Formation in much of the study area tends to be stained red from the Amsden Formation where it has been folded and thrust over the younger formation.

The Amsden-Quadrant contact is selected as the interval above the uppermost red beds of the Amsden. This tends to be more reliable than using relative amounts of sandstone and carbonate as a basis (McMannis and Chadwick, 1964).

Permian

The Phosphoria Formation, of Permian age, occurs throughout most of the Gallatin Canyon. It ranges from 105 feet to 119 feet

thick to the north as measured by McMannis and Chadwick (1964), and averages about 140 feet thick south of the study area (Hall, 1961). It consists of grey to yellow-brown nodular chert, grey-brown, medium-grained, thick-bedded quartzite and yellow-brown siltstone interbedded with chert. The phosphate content of this formation in the Upper Gallatin area is of no economic significance.

MESOZOIC

Triassic

The Dinwoody Formation of Early Triassic age is about 265 feet thick in the study area as estimated by McMannis and Chadwick (1964) on the basis of float. Hall (1961) found the formation to average some 80 feet in thickness to the south of Porcupine Basin.

It appears to rest conformably on the underlying Phosphoria Formation and consists of dark to light-brown, thick-bedded, sandy limestone and calcareous siltstone. Linguloid brachiopods are locally present.

Jurassic

The Ellis Group includes the Sawtooth, Rierdon, and Swift Formations, which are all of marine origin. The Ellis Group is about 570 feet thick in the map area (McMannis and Chadwick, 1964).

The Sawtooth Formation is of middle Jurassic age and composes

the basal unit of the Ellis Group. It is about 120 feet thick in the study area (McMannis and Chadwick, 1964), and rests disconformably on the Dinwoody Formation. The Sawtooth includes argillaceous limestone and calcareous shale in the lowermost unit which grade upward into yellow-brown, calcareous sandstone, sandy limestone, and silty shale. Neritic fossils are abundant in many of the beds.

The Rierdon Formation is Middle to Late Jurassic in age and rests conformably on the Sawtooth. It is approximately 28 feet thick in the study area (McMannis and Chadwick, 1964). The Rierdon outcrop in this area is a grey-brown, grey-weathering, densely oolitic limestone. Absence of an upper shale unit in this area is attributed to pre-Swift erosion (McMannis and Chadwick, 1964).

The Swift Formation, of Late Jurassic age, rests disconformably on the Rierdon. It consists of yellow-brown to greenish-grey, calcareous, thin-to medium-bedded, cross-bedded, ripplemarked, fine- to medium grained glauconitic sandstone and shale. Fossils are common throughout and there are some sporadic occurrences of chert bearing conglomerates. The Swift is 115 feet thick in the study area as measured by McMannis and Chadwick (1964).

The Morrison Formation overlies the Ellis Group and lies conformably on the Swift. It is of Late Jurassic age and is of non-marine origin. It consists of terrestrial mudstone, shale, siltstone, and sandstone and is 335 feet thick as measured by McMannis and

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Chadwick (1964). The mudstone, shale, and siltstone are red, green, grey, and olive and are generally noncalcareous. Some exposures contain thin zones of nodular silty limestone, and there are occurrences of yellow-brown cross-bedded coarse grained sandstone.

Cretaceous

The Cretaceous sequence consists of more than 9000 feet of predominantly non-marine sediments. The Lower Cretaceous is represented by the Kootenai and Thermopolis Formations while the Upper Cretaceous is a sequence of shale, claystone, and some sandstone that have not been studied in detail. The Cretaceous units vary greatly from one area to another due to the fact that they are non-marine in origin and therefore tend to show local influences determined by source areas. Not much work has been done on Cretaceous deposits near the general map area and the following discussion is taken from Hall (1961) except for that concerning the Kootenai Formation which was mapped by McMannis and Chadwick (1964) in the study area.

The Kootenai Formation (Early Cretaceous) consists of fresh water conglomerate, sandstone, claystone, and limestone, and lies uncomforably on the Morrison Formation. The formation has been divided into three units. The lowest unit is a conglomeratic sandstone which is grey, thick-bedded, crossbedded, and commonly coarse-grained and conglomeratic. This unit tends to grade upward to a fine-grained

sandstone.

The middle unit of the Kootenai is composed of yellow-brown to maroon mudstone and shale, limy siltstone, and fresh water limestone. The limestone occurs in two thin zones about 50 feet and 100 feet above the basal Kootenai.

The upper unit includes a fresh water limestone which contains gastropod and ostracod shells. This limestone is overlain by varying thicknesses of red, yellow, and grey mudstone.

The Kootenai Formation as measured by McMannis and Chadwick (1964), is 412 feet thick in the study area. The Kootenai Formation and the overlying Thermopolis Formation are the dominant surface units in the lower portions of the basin where they have not been covered by Tertiary volcanics. This makes them one of the key features in interpreting the Quaternary history of the area, as they have been involved in many mass-gravity movements.

The Thermopolis Formation apparently conformably overlies the Kootenai Formation in the lower part of the basin. The Thermopolis was measured by Bolm (1969) to be 195 feet thick in the West Fork Basin and Hall (1961) found it to be more than 150 feet thick in areas to the south. It consists of a medium to dark grey, very fissle carbonaceous shale and siltstone. This shale has been included by some in the lower member of the Colorado Shale, which includes both Early and Late Cretaceous rocks.

The Thermopolis grades conformably into a greenish-grey sandstone unit which is thought to be the equivalent of the Muddy Sandstone of Wyoming. It varies in thickness from 50 feet to 200 feet as measured by Hall (1961) to the south of the study area. In some places the sandstone grades upward into siltstone or shale similar to those of the underlying Thermopolis Formation. The Muddy Sandstone should be thought of as a unit member of the Thermopolis Formation.

The Albino Formation, of early Late Cretaceous age, consists of about 275 feet of non-marine volcanic clastic sediments and apparently rests conformably on the Muddy Sandstone. The Albino Formation is quite distinctive, consisting of claystone, bentonite, siliceous shale, siliceous ash, and tuff. The claystone, bentonite, and tuff are commonly pastel shades of brown, yellow, pink or green. The siliceous ash, tuff, and shale is almost white or pink. The ash and tuff beds are very rich in fossilized plant material, especially fern fronds and leaves.

Overlying the Albino Formation is about 8000 feet of undifferentiated sandstone and shale of Late Cretaceous age. The lower unit is a conglomerate composed of coarse sand and chert pebbles in a sandy matrix. The chert pebbles are stained red by iron oxide. Biotite is present in some sandstone units and there is some interstitial fine silt and clay.

CENOZOIC

The Cenozoic strata include more than 9000 feet of volcanic clastic rocks, welded tuffs, basaltic intrusives, alluvium, and till. Relatively little is known about these rocks due to the tectonic instability prevailing during their formation as compared to the stable shelf conditions which existed throughout most of the Paleozoic and Mesozoic. Stable shelf conditions deposit uniform strata over large areas, while reoccurring tectonic activity causes widespread variations in depositional units.

Tertiary

Resting unconformably upon the undifferentiated Upper Cretaceous sediments are tuff, breccia, agglomerate, sandstone, and shale of the Livingston Formation. The Livingston Formation, of Paleocene and Late Cretaceous age, ranges from 500 feet to 800 feet thick in the study area. The formation is an exceedingly complex unit consisting of green and brown tuffaceous sediments and pyroclastics, with some interbedded andesitic sills. Hall (1961) collected 19 different lithological samples, and thin sections indicated at least 10 different rock types. These undoutedly do not encompass all the rock types in the Livingston Formation.

The finer grained tuffs within the unit are very resistant in nature and form local topographic ridges in the map area.

Hall (1961) suggests that a local source area is strongly indicated by the presence of pyroclastic rocks and porphyritic sills and flows. This implies that these rocks may differ from other known occurrences of the Livingston Formation. There were probably many centers of volcanic activity during the Late Cretaceous and Early Tertiary.

The Specimen Creek Formation, which is thought to be Eocene and possibly Oligocene in age, consists of approximately 4000 feet of volcanically derived sedimentary rocks, tuffaceous sediments, tuffs, and minor amounts of felsic igneous rocks.

The formation has been broken into two lithological units and the following descriptions are taken from Hall (1961).

The lower unnamed member of variable thickness (0-2000 feet) consists of thin-bedded, grey to green, mudstone, bentonite, tuffaceous limestone and sandstone, tuff, and coarse andesitic-boulder conglomerate. It apparently was deposited on a surface of considerable relief as it is rather thick in former lows and thin or absent from topographical highs.

The upper member is called the Fortress Mountain Member, the name taken from a peak of that name on the Gallatin-Yellowstone divide. Fortress Mountain lies partially in the map area, forming the southern portion of the eastern boundary. (Sec 3, 4, T8S, R5E). This member rests with apparent conformity upon the lower unnamed member. It is

quite distinctive lithologically, consisting of stratified coarse volcanic conglomerates which are interlayered with volcanic ash and tuff. There are occassional breccia and tuff-breccia units, and some basalt sills.

The Fortress Mountain Member is impressive, forming steep cliffs, banded by layers of white ash and tuff and grey massive conglomerate layers up to 80 feet thick. They appear to be water deposited and the boulders are generally well-rounded. Sorting is apparent on a large scale but is less apparent on closer examination. Poorer sorting is evident in those layers thought to be of mudflow origin. The cobbles and boulders in the conglomerate are largely a andesitic. Occasional chunks of water-rounded fossilized wood indicate that the conglomeratic layers are not primary pyroclastic deposits. The conglomerate matrix is tuff or ash and is similar to the more consolidated ash or tuff layers except that the rock fragments are larger in the conglomerate matrix than in the ash or tuff beds.

The Fortress Mountain Member is unique in that it contains "fossil forests." Some exposures show as many as 20 or more horizons with still-erect fossil tree trunks or stumps. This petrified forest will be discussed in detail in the section entitled "Tertiary Fossil Forests."

Quaternary

Landslides and landslide debris, both Pleistocene and Recent, cover nearly one-third of the map area. Mass-gravity movements are discussed separately under the section on surficial deposits.

In the map area, glacial evidence has nearly been obliterated by mass-gravity flows. Investigations outside the map area show that nearly all the adjacent drainages have been glaciated. The Porcupine Drainage Basin contains U-shaped subdrainages and cirque-like features near the head of the drainage. The only till readily identifiable from morphological form is the small morainal feature which forms the Porcupine-Elkhorn divide in the upper reaches of the drainage. Some till-plastered ridges were observed several hundred feet above the present day Porcupine Creek. Glaciation is discussed separately under the section on surficial deposits.

Other Quaternary deposits can be classified as unconsolidated water deposits such as alluvium, terraces, and alluvial fans, and gravity deposits such as colluvium and rock fall debris. Each of these is mapped as a separate unit on Plate I as they are all important in understanding the geological history of the Porcupine Drainage Basin.

IGNEOUS ROCKS

INTRODUCTION

The previous section on stratigraphy has shown the close association of igneous activity to sedimentation since Late Cretaceous time. Water deposited sediments composed of volcanic clastics have already been discussed. The following sections on intrusive and extrusive rocks are taken from Hall (1961)

INTRUSIVES

The Livingston Formation, in addition to the tuffaceous sediments and pyroclastics, contains sills of diabase, andesite, and basalt. Hall (1961) believes the welded tuffs represent incandescent frothy flows and are truly igneous. The diabase and basalt sills are of unknown age and source. The andesite probably represents a sill from one of the nearby laccoliths. There are eight andesitic intrusive bodies which may have been the source for these sills. Five of these are near the headwaters of the Gallatin River in Yellowstone National Park. Hall (1961) discusses these somewhat in detail.

Two basaltic volcanic plugs are located in the basin in Secs. 29 and 32, T7S, R5E. Hall (1961) refers to them as the Porcupine necks. They are located about 1/4 mile apart and are less than a mile from the crest of the Gallatin Range. They are composed of black, microcrystalline basalt and stand several hundred feet higher than the

surrounding strata as they are more resistant. They apparently have been intruded along a fracture associated with the Spanish Peaks Fault, and may be contemporaneous with thick basalt flows which overlie the Fortress Mountain Member of the Specimen Creek Formation just east of the Gallatin-Yellowstone divide.

A small basalt plug is found on the southwestern boundary of the study area, and is known locally as Lemon Knob, as it stands higher than the surrounding area. It is located on the boundary between Secs. 22 and 27, T7S, R4E. Hall (1961) refers to this as the Lemon Drop dike-plug. (Figure 6). This intrusive apparently follows an E-W fracture and appears to be a local widening of a basalt dike (Hall, 1961). The basalt is very fine-grained and very black, and is surrounded by a mafic tuff-breccia. Hall (1961) included this tuff-breccia in the Specimen Creek Formation because of its lithological similarities, although it is unlike any other rocks in the area.

EXTRUSIVES

The Albino Formation is essentially all of volcanic origin although most of it was waterlaid as discussed previously.

The welded tuffs of both Livingston and Specimen Creek Formations have been classified as dacite by Hall (1961) on the basis of phenocrysts and larger fragments. As shown in hand samples, the



Figure 5-Lemon Knob in middle ground. This basalt plug is an extension of a dike and is associated with an E-W fracture. View is toward west with Spanish Peaks in background.

Livingston Formation contains two types of welded tuff while the Specimen Creek Formation has one very distinctive orange-brown welded tuff.

A Plio-Pleistocene tuff which occurs in the West Fork Basin (Walsh, 1971), in the adjacent Yellowstone drainage to the east (Todd, 1969) and to the south (Hall, 1961) of Porcupine, is not present in the study area. These tuffs are considered to be part of the 2 million year old Huckleberry Ridge Member of The Yellowstone Tuff sequence (Walsh, 1971). Since the tuff is a sheet like deposit present in adjacent areas, it is conspicuous in its absence in the Porcupine drainage. One can only speculate about the situation. For instance, the Porcupine area may have been higher during Plio-Pleistocene times, and therefore did not receive the tuff through gravity flow phenomena. Also, the flow in the West Fork Basin may represent only a meander of the flow that was deviated in that direction. It is also possible that it may have been removed from Porcupine by post-depositional erosion.

The reader is referred to Hall (1961) and McMannis and Chadwick (1964) for a complete description of the intrusive and extrusive rocks in the Porcupine Drainage Basin and adjacent areas.

SURFICIAL GEOLOGY

INTRODUCTION

The majority of time in the field was spent mapping and studying the surficial geology of the Porcupine Drainage Basin. When surficial geology deposits are keyed with other variables such as rock type, climate (past and present), and structure, the Quaternary history of the area may be determined.

The following section on surficial features includes a description of each deposit type as mapped on Plate 1 plus postulations of origin and development and other pertinent data deemed necessary. Also, where appropriate, environmental implications are discussed as they apply to man and his projected use of the study area.

COLLUVIUM

Colluvial deposits are made up of loose, incoherent materials which have been moved chiefly by gravity. This debris has been broken from the parent material and is the first product of weathering. Normal mechanical weathering processes are responsible for breaking up the bedrock and the fragments are transported downslope by either slopewash or other gravity phenomena such as solifluction. Flint (1961) proposed that previous colder climate processes, including frost-wedging, resulted in many of the thick colluvial deposits we see today in the Northern Rocky Mountains.

Colluvium has not been intensely studied and such factors as rate of formation or rates of movement are not known. Colluvial slopes in the lower Gallatin Canyon are presently being observed to see if it is possible to detect movement rates (J. Montagne, 1973 personal communication).

The colluvial deposits in Porcupine Drainage Basin range from 1 foot to over 12 feet thick. The fragments are very angular indicating their close proximity to the source area. No attempt was made to determine if thicker mantles of colluvium could be related to lithology. Many variables would have to be taken into account such as slope, aspect, water holding characteristics, structural weaknesses, diurnal temperature fluctuations, and many others.

It appeared that soil development on colluvium is limited to a thin A horizon developed on parent material. Many of these soils were mapped by soil scientists as miscellaneous mountain soils (see figure in Appendix), and would have to be classified as Entisols as the steeper slopes tend to lose the soil to erosional processes as soon as the soil develops.

In development plans, the percent of slope on colluvial material would probably be a limiting factor. Bailey (1971) suggests that often these slopes will exceed the internal angle of friction of natural soil materials. Therefore the balance between slope stability and slope failure is critical. Any slope under 34° should be below the

critical angle of slope stability (Terzaghi and Peck, 1967).

It also seems likely that if the amount of available water was increased so that the colluvial mantle became saturated, and pore water pressure was greatly increased, colluvial materials could become active.

Colluvial deposits are coarse textured and generally very permeable, making suitable construction sites. Very steep slopes (greater than 34°) should be avoided, and the amount of available water should not be greatly increased.

RESIDUAL SOILS

Soil is a natural material of the earth's surface, being characterized by layers parallel to the surface resulting from modification of parent materials by physical, chemical and biological processes operating under varying conditions during varying periods of time (Thornbury, 1966).

Soil formation takes place on all types of parent material and on all types of surface deposits. On steep hill sides, on alluvial deposits, on pediments, and on many other surface features, erosional processes remove soil almost as fast as it is formed.

A complete soil survey of this area was completed by Bruce Leeson and Ronald Aasheim in 1973. The results of their work can be seen in the soils map in the Appendix. All surficial deposits,

including bedrock, have some soil forming on them, through weathering processes. This is often only a very thin mantle of weathered material and is insignificant in a study of the surficial deposits. Usually these soils show only a very shallow A horizon over the parent material.

The areas represented as 'residual soils' on Plate 1 are areas where there is significant soil development to make soil the prime factor in studying the earth's surface. These generally are flat-bottomed valleys, mountain meadows, or flat-topped ridges. Areas so mapped had a well developed solum showing both an A and a B horizon overlying parent material.

Extensive areas in the study area have been mapped as soil units. These soil units would play a key role in development of alternatives. The reader is referred to the section entitled "Geology and Soils Correlations" for further discussion on this subject.

WATERLAID DEPOSITS

Water deposited features in the Porcupine Drainage Basin include alluvial terraces, alluvial fans, and alluvial plains. These have all been included under one heading because they are very similar in nature.

Alluvial terraces are relatively flat, horizontal or gently inclined surfaces which have been eroded from bedrock and are veneered with a surface deposit of well-rounded cobbles and boulders in a sandy

matrix. They generally mark former valley floor levels. Terraces may also be purely depositional in nature.

Alluvial fans are cone-shaped deposits located where a heavily loaded stream emerges from the mountains onto a lowland. The change in gradient causes the deposition of alluvium in a fan-like pattern, the apex being at the point of emergence. Dissection of the fan is common as the emerging stream erodes downward to keep up with changing base levels of master streams.

Alluvial plains are produced by the filling of a valley bottom with alluvium as the stream shifts about to reach equilibrium.

Alluvial plains are located along the West Gallatin River for its entire course through the map area. These plains also extend into the lower reaches of Porcupine Creek for a short distance. The only alluvial fans of any significant size are located near the northwest boundary of the study area where they apex immediately below Levenski Ridge and fan out onto the Gallatin River alluvial plain.

Only two minor terrace systems are located in the study area. One pair is located where an unnamed tributary discharges into Porcupine Creek in Secs. 22 and 23, T7S, R5W. The other terrace extends along the lower part of Porcupine Creek on the north side directly below the pediment surfaces.

The alluvial surfaces in Porcupine Creek are very favorable for construction in that they are very stable and extremely porous and

permeable. They contain excellent materials for foundation and road construction purposes. The Gallatin River alluvial plain and the lower portions of the alluvial plain which extends into Porcupine Creek are natural locations for home sites. Running water makes the sites more appealing. The trend for development in the Gallatin Canyon is along major drainages. The major concern would be whether the alluvial materials are too permeable and would allow effluent to directly enter the drainages. It is inevitable that continued growth will occur along the Gallatin River and provisions should be made to insure that residences and businesses are located far enough away from the river so that it does not become polluted.

ROCKFALL DEBRIS

According to Rapp (1961), the term rockfall is used to denote the free falling of rock particles of any size from steep walls or cliffs. It is a rapid and effective form of mass wasting as the retreat is usually not impeded by vegetation. Rockfall debris is material broken from steep walls and rolled or dropped by gravity into coarse conical piles known as talus slopes.

Many factors contribute to rockfall release but frostbursting and heavy rains are the most significant factors (Helm 1932, Rapp 1961). Earthquakes are also a contributing mechanism in rockfall release.

Rockfall debris in the Porcupine Drainage Basin occurs in

conjunction with resistant cliff forming rocks, mainly Precambrian gneiss and schist and the harder volcanic rocks. There are minor occurrences below ledge-forming Mississippian limestones on Levenski Ridge. The largest rockfall area in the basin is located in Sec. 36, T.7S., R.4E., directly below a tuffcapped landslide scarp ridge on the Porcupine-Elkhorn divide.

The rockfall debris is unconsolidated and very angular. It tends to be very unstable and the slightest disturbance, such as the weight of a man, will create small rock slides. Rockfall debris is located at the base of cliffs and very steep slopes, either of which are not good construction sites. Rockfall debris is abundant enough throughout the drainage to be used as subsurface road material and foundation material for construction sites. The limited occurrences of rockfall debris should create no problems to man's activities in the area except for the danger of rockfall in campgrounds and other areas where man will tend to congregate.

Rates on movements of rockfall slopes have not been determined, but current studies in the lower Gallatin Canyon should detect any perceptible movement (J. Montagne, personal communication). Movement rates are probably greatest when loading occurs from the weathered slopes above. This probably was during colder glacial climates when frost action was prevalent (Flint, 1961). Many of the talus slopes may be relict features from the Pleistocene.

BEDROCK

The portions of Plate I mapped as bedrock are areas where rock crops out on the surface. These are the more resistant rock types and form prominent ridges. Rock types found outcropping in the lower reaches of the drainage are sandstones and ledge-forming limestones. The exposed bedrock in the upper part of the drainage includes Tertiary volcanic sediments, especially volcanic conglomerates and breccias such as those capping the Gallatin Range. The rocks north of the Spanish Peaks Fault are mainly gneiss and schist. Only in fresh stream cuts and landslide scarps are the softer shales and mudstones exposed.

The exposed bedrock surfaces are generally not chosen as construction sites but may be encountered in the lower reaches if they lie in the path of road locations. Bedrock would also be encountered beneath the thin fluvial veneer on the pediment surfaces. These areas should present little difficulty as they contain softer shale, mudstone or poorly indurated sandstone.

Areas of public use should be planned so that there is no danger of outfall from exposed bedrock cliffs.

PEDIMENTS

One of the unique features in the Porcupine Drainage Basin is a south facing pediments system, now dissected, in Secs. 9, 10, 14, 15 and 16, T.7S., R.4E. Although this feature is more diagnostic of

erosional processes, it is veneered by thin fluvial deposits and may play a key role in Quaternary history interpretations. The pediment system is large enough in area to be considered in environmental considerations.

Very little is known of pediments in the Northern Rocky Mountains although they appear to be similar to those that form in the arid southwest. Pediments can best be described as gently inclined (2°-15°) planate erosion surfaces which are generally veneered with fluvial gravels. They rise from basin floors and abut against steeper mountain fronts. They are often extensive bedrock surfaces over which material from the retreating mountain front is transported to the basins below. Pediments, when viewed along their longitudinal axis, appear to be slightly concave in profile (see Figure 6).

The Porcupine pediments are well displayed on the south flank of Levenski Ridge, the steeply dipping limb of the Lower Basin Syncline. The pediments have truncated the steeply dipping Cretaceous sediments, and the Jurassic rocks, which have been folded and thrust upward to stratigraphically overlie the Cretaceous sediments, are only slightly truncated near the top of the pediments. The steeper flank of Levenski Ridge is composed of Mississippian and Pennsylvanian formations and has contributed much of the larger size material to the pediment veneer. Some older materials, including Precambrian rock types which occur just north of Levenski Ridge, are also included in

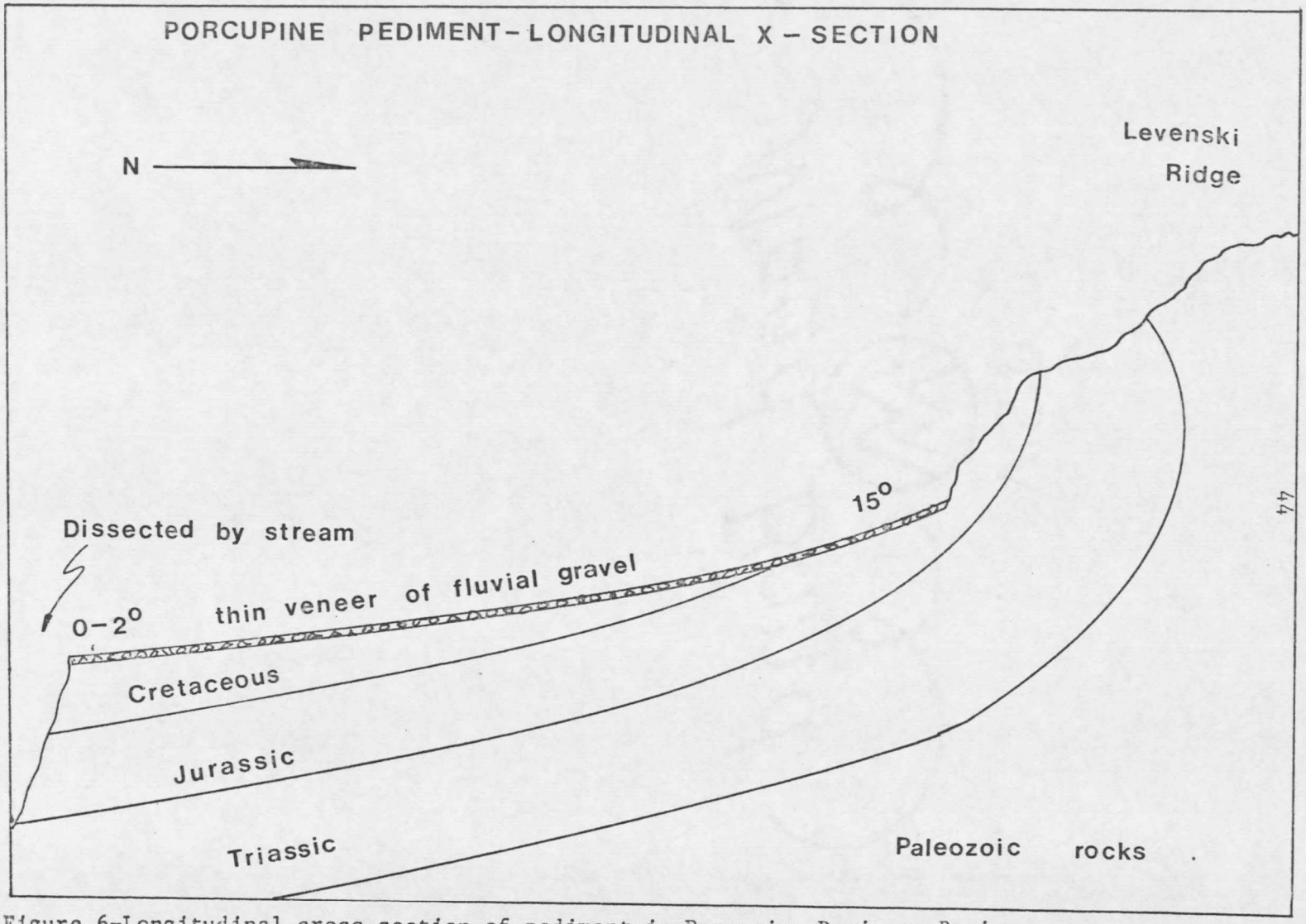


Figure 6-Longitudinal cross-section of pediment in Porcupine Drainage Basin.

the composite veneer. The veneer is roughly 15 to 35 centimeters thick and is composed mostly of unsorted subangular rock fragments. The veneer-bedrock interface is often difficult to determine because the bedrock is often composed of badly decomposed shaley material which tends to intergrade with the veneer. Many large cobble and boulder size rocks lie on the surface. These vary greatly in lithology and it is possible that they represent a thin sheet of till and outwash of late Wisconsin age. Observations on the Livingston pediments indicate that a number of the larger boulders are oriented with their long axis vertical, suggesting movement by solifluction processes (Bailey, et al., 1968).

It is apparent, when the pediment system is viewed in profile, that there are at least 6 levels or generations of pediments, each level representing a different era of base leveling. There is no apparent difference in profile or veneer between the older higher pediments and the younger lower pediments. Most of the higher pediments are dissected to a greater degree in response to lowering of base levels of master streams.

A study of pediments on north facing slopes near Livingston, Montana about 35 miles northeast of the study area shows that many of these surface possess microrelief features such as flow-terraces and bouldery flowage lobes (Bailey, et al., 1968). The Porcupine pediments are very flat and show little or no microrelief features.



Figure 7-Longitudinal view of Porcupine pediments. Different levels indicate different episodes of base leveling. Pediments have been dissected by Porcupine Creek.

It is postulated that, due to the wet conditions of north facing slopes, the pediment mantle in the Livingston area became saturated in the Spring and flowed downhill in response to gravity. In contrast, the south facing slopes containing the Porcupine pediments are much di drier and it is unlikely that the surface material would become saturated so that solifluction processes could operate.

Correlation of the pediment system near Livingston, Montana with Yellowstone River terrace levels indicates that they may be Illinoian (Early Wisconsin) in age (Bailey, et al., 1968). The Porcupine pediments grade to a base level between 40 and 100 feet above the present day drainage. Since Glacier Peak ash (ash deposited by the eruption of Glacier Peak, Washington about 12,000 years ago) lies on or near present day drainages in many areas of southwestern Montana, it is generally agreed that the present day drainage levels existed near the close of Pinedale time (Early Wisconsin) (J. Montagne, personal communication). This suggests that the pediments are at least older than Pinedale. By correlating the projected base level elevation of the pediments with elevations of dated glacial deposits in adjacent drainages, it may be possible to further refine the estimated date of the pediment formation.

Bailey, et al. (1968) suggests that glacial and periglacial processes may be partially responsible for northern latitude pediment formation. The Porcupine pediments may have begun to form during rapid mass-wasting of the mountain front from freeze-thaw phenomena

during colder glacial times. As the glacial front retreated, excess amounts of melt water could saturate the weathered mantle and successive mudflows and sheetfloods could then remove much of the weathered material. Permafrost activities would also be active long after the ice has retreated and the active layer could enhance solifluction processes, furthering the planation of the mountain front. It may also be possible that solifluction was operating on the pediment surfaces as a secondary process and had little or nothing to do with their formation. If the pediments are indeed relict features, solifluction may have operated on their surfaces during later glacial climates.

The pediment surfaces are natural construction sites and are very stable and should be rather permeable to at least a few feet beneath the surface. The fluvial veneer is rather thin, however, and the characteristics of the underlying bedrock must be considered. If a sequence of sandstone overlying shale is encountered, and this is subjected to an excess of water, a slide could occur as discussed under the section on Quaternary Landslides. However, the possibilities of mass failures on these surfaces is highly unlikely due to the southern exposure and the gentle slopes.

QUATERNARY LANDSLIDES

Landslides and landslide debris are the most prominent surficial features in the Porcupine Drainage Basin. Almost one-third of

the basin (nearly 10 square miles) is covered by landslide debris or has been involved in sliding.

Numerous attempts have been made to classify landslides and mass-gravity features. Sharpe (1938), recognized four classes of mass wasting which he designated as slow flowage, rapid flowage, landslides, and subsidence. Various types and subtypes were identified under each of the four classes. They are as follows:

1. Slow flowage types

   a. Creep: The slow movement downslope of soil and rock debris which is usually not perceptible except through extended observations.

   b. Soil Creep: Downslope movement of soil

   c. Talus Creep: Downslope movement of talus or scree

   d. Rock Creep: Downslope movement of individual rock blocks

   e. Rock-glacier Creep: Downslope movement of tongues of rock waste.

   f. Solifluction: The slow-flowing downslope of masses of rock debris which are saturated with water and not confined to definite channels.

2. Rapid flowage types

   a. Earthflow: The movement of water saturated clayey or silty earth material down low-angle terraces or hillsides.

   b. Mudflow: Slow to very rapid movement of water-saturated rock debris down definite channels.

   c. Debris avalanche: A flowing slide of rock debris in narrow tracks down steep slopes.

3. Landslides - Those types of movements that are perceptible and involve relatively dry masses of earth debris.

   a. Slump: The downward slipping of one or several units of rock debris usually with a backward rotation with respect to the slope over which the movement takes place.

   b. Debris slide: The rapid rolling or sliding of unconsolidated earth debris without backward rotation of the mass.

   c. Debris fall: The nearly free fall of earth debris from a vertical or overhanging face.

   d. Rockslide: The sliding or falling of individual rock masses down bedding, joint, or fault surfaces.

   e. Rockfall: The free falling of rock blocks over any steep slope.

4. Subsidence - Downward displacement of surficial earth material without a free surface and horizontal displacement.

The most common type of mass-gravity feature in the study area is the slump-earthflow, in which the upper part of the slide moves downward on a curved slip-surface, and the semi-saturated or saturated material in the lower part moves as an earthflow and forms a bulbous toe. Slump-earthflows commonly head in large basins where slope debris and weathering material is available. Excess water, such as a heavy rainfall, may trigger the movement of a part of this loose mass.

The slump-earthflows in the study area are often over a mile in length. Some appear to be stablized in their lower reaches but quite active near their sources as evidenced by fresh slump scarps.

Leaning trees or "drunken forests" are common on many of the flows, indicating recent movement. Several of the flows have infringed on streams in the past and are now being subjected to undercutting at their toe, which tends to keep them active, at least in the lower part of the slide. This also causes excessive siltation which is discussed in a following section.

Many of the larger slides or flows have coalesced (as is seen in Sec. 30, T.7S., R.5E.) forming huge masses of slide debris.

The rock type and relations in the drainage have had much to do with the large number of slides. In the lower reaches, permeable sandstones and mudstones and poorly consolidated debris of the Muddy Sandstone allows water to easily permeate downward to the impervious shale of the Thermopolis Formation. Water flowing along the sandstone-shale interface creates a lubricated glide plane which increases the sliding potential (Figure 8).

In the upper reaches of the drainage the slides consist predominantly of Tertiary volcanic tuffs, bentonitic clays, and poorly consolidated volcanic breccias and conglomerates. Much of this material has weathered to montmorillonitic-type clays which expand greatly in volume when wetted, contributing to the mechanics of sliding.

Besides slump-earthflows, mudflow-type movement is common in the Porcupine Drainage Basin. They lack the slump features in their

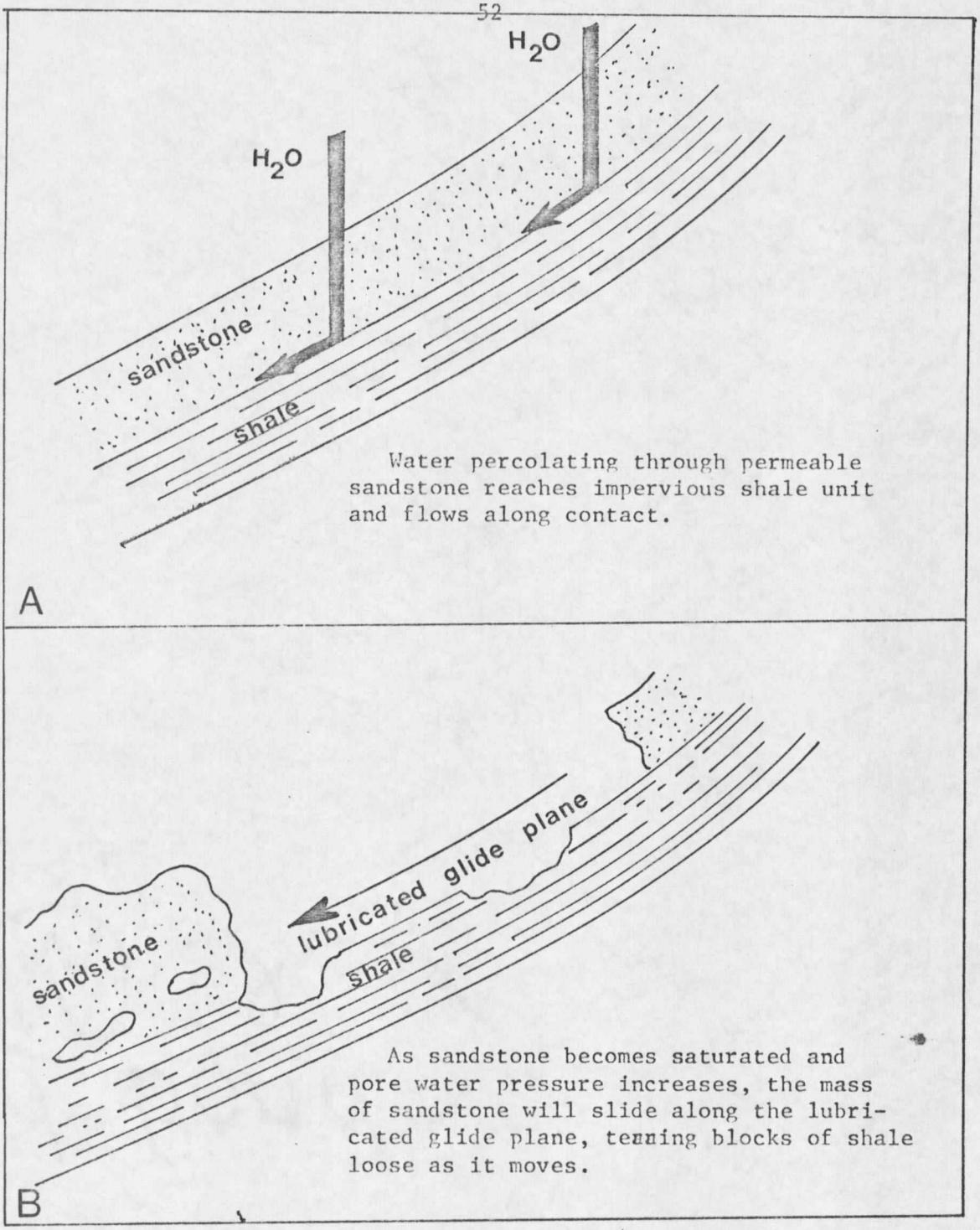


Figure 8- Diagram showing proposed mechanism for landsliding when sandstone overlies shale.

upper ends and apparently contain a higher degree of water and are therefore very fluid in their downslope movement.

Water is a controlling factor in the slide mechanism as evidenced by the high incidence of flows on the north slopes as opposed to the south slopes. North slope slide features outnumber south slope slide features by about five to one. Many of the slides have mature growths of aspen (Populus tremuloides) and willow (Salix) which appear to grow where there is an abundance of water. It is apparent that saturated conditions are more easily obtained on the north slopes. Ponded water is another feature on many of the slides which points to the high amounts of available water.

Increase in pore-water pressure is also thought to be a mechanism for sliding (Bailey, 1971). Excess amounts of water which will saturate the mantle material will increase the pore-water pressure and produce a net loss in cohesive forces.

Much of the debris derived by these gravity flow features is unsorted and nonstratified. It resembles glacial till except for the contained rock fragments that appear to be angular in shape. This is discussed further under the subsequent section on glaciation. The rock type found in the earthflows is derived from the source area. Some of the material undoubtedly is till-derived as glacial debris must have been abundant at one time.

It seems reasonable to assume that many of the landslides in the Porcupine Drainage Basin were caused by failure following an increase in the water content of the soil and underlying rock. Periods of increased moisture, both rainfall and meltwater, are commonly associated with glaciation, so a correlation between landslides and glacial periods seems reasonable. Watson and Wright (1963) concluded that landsliding in mountainous regions of New Mexico was related to greater available moisture and higher water tables during the Pleistocene. Pierce (1968) describes two separate periods of sliding near Cody, Wyoming between which there was an episode of terminal moraine deposition during the Wisconsin stage in the same valley.

The study of landslides in the Porcupine Drainage make it apparent that there was no one great epoch of landsliding. Some are relatively old, showing well developed soils and subdued morphology while others appear to be much more recent, with fresh scarps and poorly developed soils. Sliding is now actively taking place as evidenced by fresh tension cracks and "drunken forests". Many of these older slides are presently being rejuvenated through various processes. Others are new slides which are related to oversteepening of slopes, undercutting by streams, and expansion of saturated 2:1 lattice clays which have weathered from volcanic material. No glacial material was found on any of the slide surfaces although Bailey (1971) reports that most slides in the Teton National Forest occurred following Bull Lake

glaciation and are often overlain by Pinedale glacial deposits. It appears that most of the slides in the drainage are post-Pinedale, with sliding occurring intermittently from Pinedale glaciation to the present. Many of the slides probably cover older slides which were related to pre-Pinedale glaciation.

The significance of landflow features to development in the Porcupine Drainage Basin is very real. Removal of timber from forested slopes can increase the amount of available water as much as 40% (Prinkki, 1971). This is generally most critical during the first year before revegetation has occurred. A study by Bailey (1971) indicates that stabilized landflows have conditions conducive to forest growth such as loose deep soil and high moisture content. Accordingly, many of these flows are covered by dense growths of high quality timber. Disturbance of these areas by conventional logging methods may reactivate the slides.

A soil pit dug in the slump-earthflow in Sec. 22, T.7S., R.4E. reveals many burned wood fragments with random orientation, indicating that they were present when the slide took place. It is possible that this charred material represents the remains of a forest fire that denuded the slope and the consequential increase in available water may have triggered the slide.

The implication of land instability and development in the Porcupine Drainage Basin is discussed further under the section

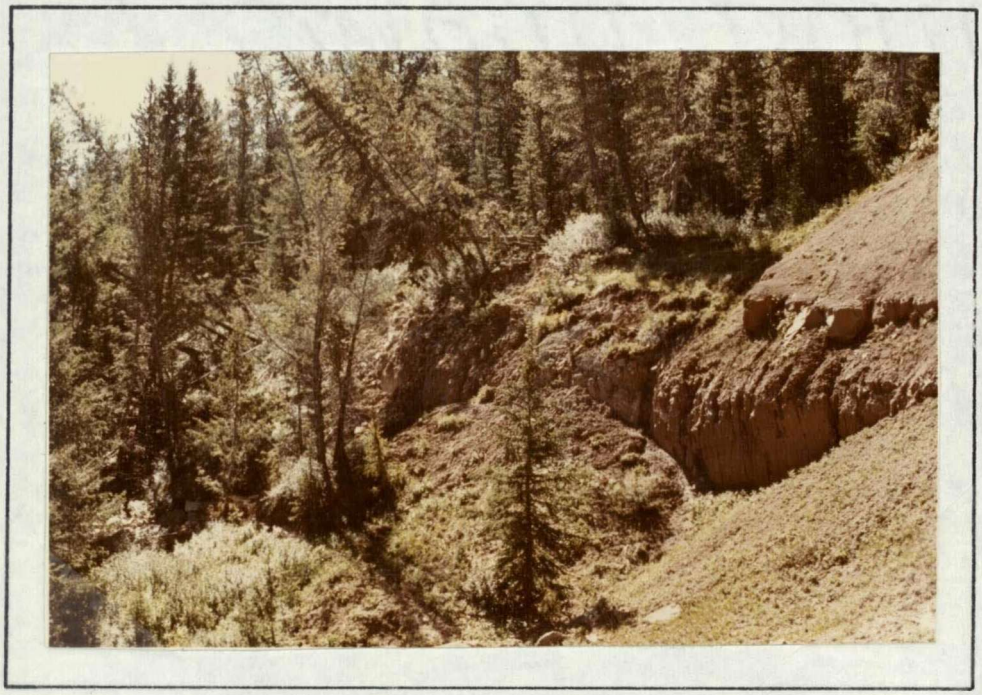


Figure 9-Slump scarp at top of large slide in sec. 23, 25, 26, and 36, T.7 S., R.4 E. Leaning trees and water percolating from scarp bank indicate recent activity

entitled Conclusions and Comments.

GLACIAL DEPOSITS

During Quaternary glaciation, much of the Northern Rocky Mountain region was strongly glaciated, first by local ice caps and secondly by individual valley glaciers. The Gallatin Range was no exception, and work by Blackwelder (1915) and later by Richmond (1965) points to five Pleistocene glaciations. Table 1 below is a summary of Quaternary geomorphology.

Table 1

Summary of Geomorphic History*

Years Before Present	Standard Glacial Sequence	Erosion Cycles	Glacial Stage	
800			Neo-Glaciation	Gannet Peak
4,000	Recent	Post-Glacial		Temple Lake
6,500		Altithermal		
	Classical Wisconsin			Pinedale II
25,000				Pinedale I
32,000		Lenore		
	Older Wisconsin			Bull Lake II
45,000				Bull Lake I
		Circle		
				Pre-Bull Lake III
				Pre-Bull Lake II
	Pre-Wisconsin			Pre-Bull Lake I
		Black Rock		
		Union Pass		
	Pliocene			

*Adapted from Bailey 1971, Blackwelder 1915, and Richmond 1965.

Bailey (1971) has summarized the works of Blackwelder (1915) and Richmond (1965) very well and much of the following discussion is taken from his article.

Pre-Bull Lake

Pre-Bull Lake glaciation is considered equivalent to Pre-Wisconsin. The great age of pre-Bull Lake deposits is indicated by (1) the absence of glacial topography, (2) the highly weathered condition of materials, and (3) the occurrences of the till as isolated remnants on intercanyon divides.

Pre-Bull Lake glaciation was followed by a period of considerable erosion when streams cut down as much as 200-1000 feet. This is why pre-Bull Lake glacial deposits show little relationship to present day drainages.

Bull Lake

Bull Lake glaciation, named for valley moraines on the northeast flank of the Wind River Range at Bull Lake, Wyoming, by Blackwelder (1915), have topographically well-defined moraines with outwash plains often a common feature. Boulders are generally numerous on the surface of the moraines but less so than those on the younger Pinedale moraines. Bull Lake moraines are deeply notched by tributary streams. Compared with the pre-Bull Lake till, the younger character of the Bull Lake deposits is revealed by (1) the lower topographic position,

(2) fresher morphological form, and (3) lesser degree of weathering in the exposed materials.

Following Bull Lake glaciation, a relatively short erosion cycle removed much of the accumulated materials from the valley floors and canyon mouths.

Pinedale

The Pinedale stage of glaciation was named by Blackwelder (1915) from moraines near Pinedale, Wyoming. Pinedale glaciers occupied the same valleys as the Bull Lake glaciers but in most cases did not extend as far down the valleys. Bull Lake end moraines are found typically near or at mouths of canyons while Pinedale deposits are usually low, fresh morainal forms on or near canyon floors in their middle or upper reaches.

Pinedale moraines are fresher and commonly in closer proximity to the source area than those of the preceding stage. The moraines are more bouldery than those of Bull Lake and less dissected. Pinedale features often include undrained depressions and morainal lakes. Minor moraines upstream from Pinedale terminal moraines suggest multiple advances of ice. Three stages of Pinedale glaciation are recognized by Richmond (1948). Pinedale glaciation is probably equivalent to midcontinental late Wisconsin (Richmond, 1965).

Neoglaciation

Following the Pinedale advance was a period of high temperatures known as the Altithermal. Following the Altithermal was a temporary return of a glacial climate, as evidenced by rock glaciers and talus flows in pre-existing cirques. Richmond (1965) has identified two minor advances in the Rocky Mountain ranges known as Temple Lake and Gannet Peak.

Glacial Deposits in Porcupine Drainage Basin

The excess amount of landslide topography in the Porcupine Drainage Basin complicates identification of glacial deposits. As early as 1909, it was realized that older landslides could be easily mistaken for glacial moraines unless the deposits could be examined internally (Howe, 1909). In parts of the Rocky Mountains, certain deposits originally identified as old tills have proved to be landslide derived (Bailey, 1971). Table 2 on page 61, taken from works of Bailey (1971) and Flint and Denney (1955), shows a comparison of landslide deposits and glacial features. This comparison proves to be very useful in mapping surficial deposits where landslide and glacial deposits coexist.

Table 2

Comparison of Landslide and Glacial Deposits*

Landslide Deposits	Glacial Deposits
External Position and Form	
Massive transverse ridges in headward part (slump blocks)	Sinuous transverse ridges in headward part (term. moraines)
May have longitudinal ridges upstream	Lack longitudinal ridges except at lateral margins (lat. moraines)
Coencentric transverse ridges are confined to toe and are not continuous with marginal ridges	Coencentric transverse ridges (terminal moraines) may be continuous with lateral ridges (moraines) and are not restricted to toe
Possess nearly straight transverse fractures and radial fractures at toe	Lack fractures
Lack outwash body beyond toe	Commonly have (small) outwash body beyond toe
Landslide valley may be irregularly blocked by landslides.	Glacial valley will generally have U-shaped form
Internal Composition	
Material derived only from rocks present on local slope	Materials may be derived from any or all rocks in glaciated areas upstream
Fragments include very large masses of weak bedrock and jointfaced boulders of strong rock	Fragments are comminuted and mixed; include fragments with abraded surfaces.
Loess and caliche absent, except as remnants of pre-slide surface. Some caliche present if parent material is calcareous	In places, material may be covered by loess. Rock fragments commonly have calache rinds. Soils with a calache horizon may cover the till

*Adapted from Bailey, 1971, and Flint and Denny, 1958.

Evidence of glaciation in the Porcupine Drainage Basin is very slight. Knowledge of the vast amounts of glacial deposits in adjacent drainages leads one to identify subtle hints of glaciation in the drainage which might otherwise be overlooked. The area was probably invaded by ice during each of the four ice advances as listed in Table 1. U-shaped subdrainages, cirque-like basins at the head of valleys, till-plastered ridges, glacial erratics, and outwash veneer are evident only after a very thorough investigation of the study area.

Hall (1961) has identified pre-Bull Lake deposits (which he relates to the Marble Point stage) on Blizzard Ridge which lies to the south of the study area at an elevation of 8,160 feet. This deposit consists mostly of metamorphic gneiss and schist, the nearest source being about five miles to the northeast of Blizzard Ridge. No deposits of this type or age were found on the intertributary divides in the Porcupine Drainage Basin. Hall (1959) states that the high level till deposits which cap stream divides in the Upper Gallatin Valley suggest that the entire drainage basin was glaciated and that during its greatest expansion, the ice was essentially continuous from the crest of the Madison Range on the west across the Gallatin Range to the Yellowstone-Absaroka ice fields. This implies that Porcupine Drainage Basin was, at least once, completely choked with ice.

The till-capped ridge in Sec. 23, T.7S., R.4E. appears to be Bull Lake in age as it lies about 200 feet above the present day

Porcupine drainage. It contains many Precambrian erratics (see Figure 10), some of which are over 6 feet in diameter. Soil pits dug on this ridge indicate heterogeneity in rock lithology. The soil profile shows a rather well-developed B_{2t} horizon about 29 inches thick. Pinedale soils in the West Fork drainage show little or no B horizon development (C. Montagne, 1971). Soil development on glacial features can often be used to chronologically age different glacial deposits.

A very fresh moraine is found near the head of Porcupine Creek and forms the Porcupine-Elkhorn divide. This moraine contains gneiss and schist which may be reworked material from a previous ice advance. This moraine is probably representative of the last advance of Pinedale ice as is suggested by its proximity to the source area and freshness of form.

In other areas glacial till forms a veneer over the bedrock. This is generally very thin and therefore was ignored in the mapping process. The thin veneer of till is hard to recognize from other fluvial deposits in the area. The fluvial gravels on the pediments could be partially glacial derived. The outwash material noted in the study area is probably a result of all the ice advances.

Onion Basin, located in Sec. 20, T.7S., R.5E., and the basin containing Ramshorn Lake, immediately south of the study area boundaries, appear cirque-like in shape and undoubtedly were catchment basins during ice advances.

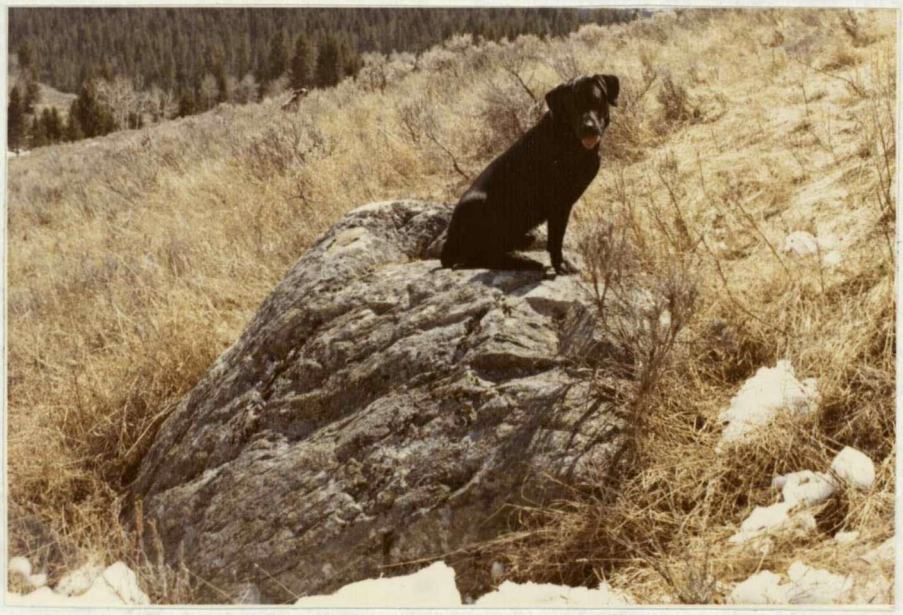


Figure 10-Large Precambrian glacial erratic found on till-plastered ridge in sec. 23, T.7 S.,R.4 E. The nearest occurrence of these crystalline rocks is over one mile to the northeast.

There would be more preserved glacial features if it had not been for the destructive forces of mass gravity movements. The excess amount of available water during the retreating phases of the ice occupation certainly was one of the major causes of these water-saturated flows.

The glacial deposits are not extensive enough to be significant in developmental plans. Unless the clay content is high, the material is fairly permeable and should be a good source of ground water. There should be no restrictions on these areas for foundation sites or drainage fields, unless they are very permeable and located next to a major stream.

TERTIARY FOSSIL FORESTS

GALLATIN PETRIFIED FOREST

The uniqueness of the Porcupine Drainage Basin is enhanced by the occurrence of a series of petrified forests. The fossil forests originate in Yellowstone National Park near its northern boundary. One of the most extensive and spectacular areas is located on Specimen Ridge, less than 7 miles south of the study area.

The fossil forests were discovered in the 1870's by W. H. Holmes (1879) and have since been the subject of many reports and publications. Erling Dorf (1960) undertook a revision and updating of the fossil flora plus a study of the stratigraphy and areal distribution of the fossil-bearing rocks. In addition to personal observations, the following discussion is largely from Dorf's 1960 article.

The fossil forest at the head of Porcupine Creek is limited to the crest of the Gallatin Range and possibly represents only a finger of the main petrified forest further south. The importance of the Porcupine petrified forest, although only one small part of the main fossil forest, cannot be overlooked as it is highly valuable from both a scientific and recreational aspect. It is currently very vulnerable to exploitation as it does not fall under the jurisdiction of Yellowstone National Park.

The Yellowstone Park fossil forest and its associated linear finger segments may be the most remarkable of their kind in the world

for several reasons:

1. They are very extensive in area, covering more than 40 square miles.

2. They consist of hundreds of petrified trees, many of which are standing upright as they grew.

3. Besides petrified trees, many preserved impressions of leaves, twigs, needles, cones, and seeds are present.

4. One locality in the Lamar Valley indicates a vertical succession of 27 separately buried forests.

The fossil forests occur in breccias, tuffs, and interbedded basalt flows near the base of the Tertiary volcanics. An estimate of the rate of deposition has been made in the Lamar Valley by Dorf (1960). Many of the stumps show up to 500 annual growth rings. Using these data and the fact that the 27 forests were buried in about 20,000 years by 1200 feet of volcanic sediments, Dorf (1960) calculated a rapid rate of deposition of 7.2 inches per year.

The pyroclastic rocks which contain the fossilized remains are believed to have been extruded from various vents and fissures east and northeast of the fossil forest area. Dorf (1960) found fossilized materials in well-bedded volcanic conglomerates of alluvial and laharic origin and in fine-grained tuffs deposited in lakes and sluggish streams or air deposited.



Figure 11-Petrified stump in-situ on Fortress Mountain
Many other stumps are found in this vicinity.

Studies by St. John (1927) indicate that the preserving material is silica derived from the silica rich volcanic rocks. In most instances, the mineral material fills the empty cavity cells in the wood. When this silica is dissolved in hydrofluoric acid, the remaining wood is almost perfectly preserved, retaining its shape to be studied exactly like modern wood.

For the interested reader, Dorf's 1960 article includes an extensive list of fossil plant species which occur in the Tertiary volcanics in the upper Gallatin Canyon.

Environmental aspects of the Porcupine petrified forest are discussed in the section entitled Conclusions and Comments.

GEOLOGY AND SOILS CORRELATIONS.

INTRODUCTION

Until rather recently, geologists and soil scientists have often worked in their own speciality without the benefit of the knowledge that the other discipline could provide. Geologists often referred to soil as 'loose surface deposits' and soil scientists did not always benefit from knowledge of parent material characteristics. Fortunately, the trend toward interdisciplinary studies has brought the two disciplines closer together and geologists are now using soils as geological indicators and soil scientists are paying more heed to parent material in soil studies.

As stated in the Introduction, the Porcupine Drainage Basin study was to be approached with an interdisciplinary attitude. Part of the field season was spent with soil scientists who mapped the soil associations in the study area. The following discussion considers the inter-disciplinary relationships between geology and soils in the study area.

The general soils map (see Appendix) shows 17 main groups of soils called soil associations. Each association consists of several different kinds of soils termed soil series. Soil series are selected on the basis of texture, natural drainage, depth, and certain physical and chemical properties. Therefore, the soils map does not show the specific kind of soil at any particular place but shows associations

of different soils that characteristically occur together. The soil associations have been named for the diagnostic soil series in them.

It was often possible, before direct sampling, to determine the soil association in the Porcupine Drainage Basin by knowing the surficial deposit present. The task of classifying the soils into their proper association was simplified if the surficial geology of the sample site was available.

SOIL ASSOCIATIONS AND GEOLOGY

The following discussion relates the soil associations as mapped by Aasheim and Leeson (1973) to the surficial geology. Only four of the major associations found in the drainage are discussed. The soil association descriptions are taken from Olsen, Leeson, and Nielsen (1971) and Aasheim (1973). Figure 12 shows the relationships discussed below.

Miscellaneous Steep Mountainous Lands Association

This association consists of miscellaneous lands, rocklands, rock outcrop and rock rubble on steep and very steep canyon sidewalls and ridges. The association consists of soils of variable textures and variable depths over bedrock. Content of rock fragments in these soils varies from those with only a few pebbles in them to those that are very cobbly and stony. The deeper soils are on fans and footslopes at lower elevations. About 25% of the association consists of rock outcrop and rock rubble. They occur at all levels in the landscape; however, rock outcrop is dominant on the upper slope. Much of the soil on the steep slopes has formed in materials moved down slope by gravitational creep.

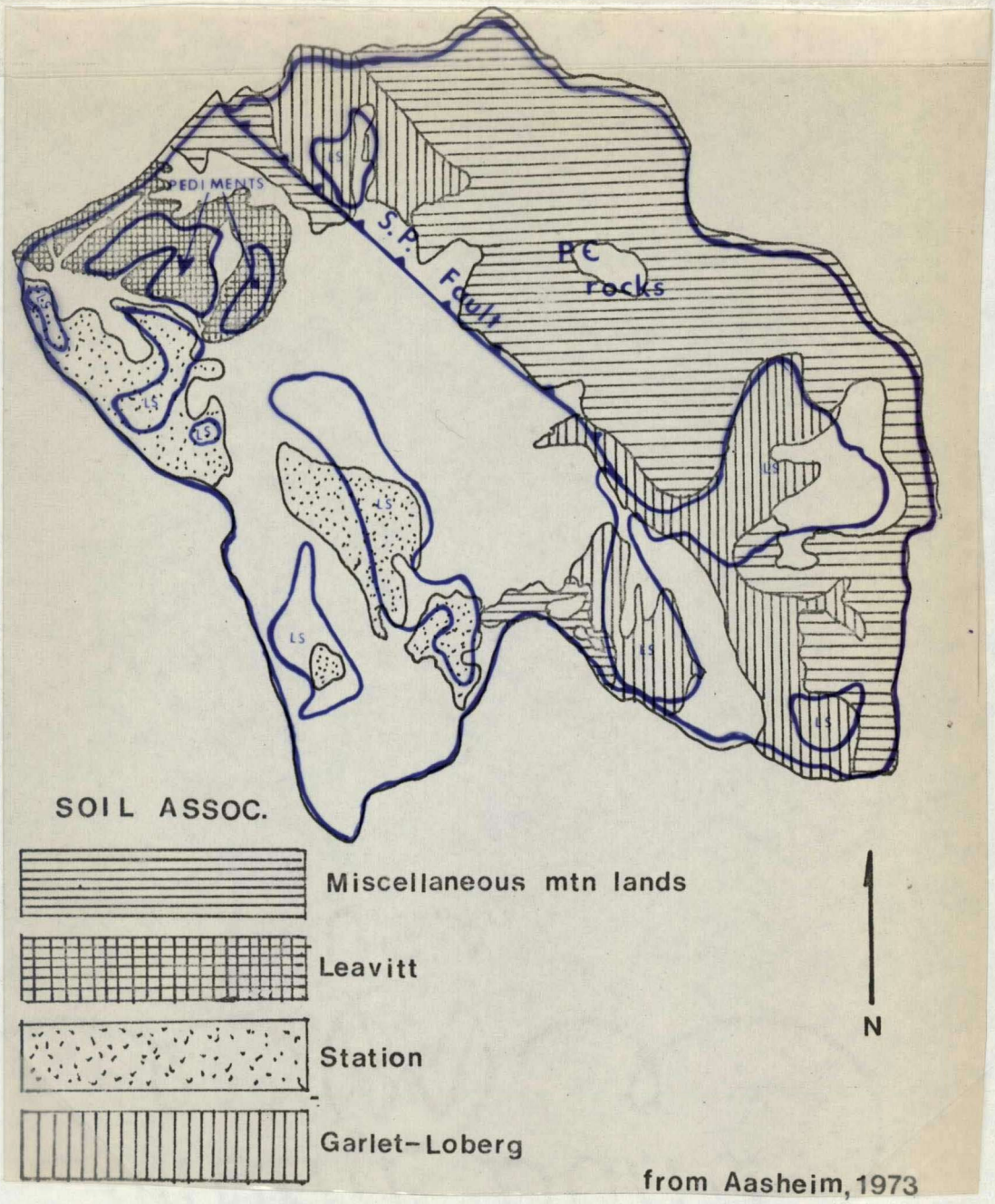


Figure 12-Map of soil associations with geology overlay. Surface deposits often influence the soil associations which form. White areas represent other soil associations not shown on this map.

This association, as expectable, occurs mainly north of the Spanish Peaks Fault in terrain of the very resistant Precambrian crystalline complex. The topography in this area is very rough with many steep slopes composed of bedrock, talus, and colluvium. Excluding the soils developed on the large Onion Basin slide, approximately eighty percent of the soils north of the fault are mapped as Miscellaneous Steep Mountainous Lands. The only other two occurrences of this association are along the entire crest of the Gallatin Range and a small portion of the Elkhorn divide. Both these latter areas are composed of very rugged terrain developed on volcanic rocks.

Garlet-Loberg Association

This soil association is on steep and very steep mountain slopes. Sharp ridges separated by deep cut canyons characterize the landscape. Rock outcrop, rock rubble, and landslide areas are common. This association is at elevations of 6,000 to 8,500 feet. Many of these are forested soils that develop in till at the head of drainage ways, immediately below steep mountain cirques. The soils in this association consist of rock outcrop and rock rubble, very shallow soils, landslide areas, and seep areas along drainageways.

This soil association occurs exclusively on the earthflows developed on volcanic rocks in the higher elevations of the drainage basin. The large earthflow in Onion Basin and the one that merges with it on the flank of the volcanic capped ridge along Elkhorn divide are both mapped almost entirely as Garlet-Loberg soils. The other major occurrence of this association is in the landslide terrain directly north of Levenski Ridge in Sec. 11 and 12 (implied), T.7S., R.4W.

This is also an area of volcanic rocks. All occurrences of this association in the Porcupine Drainage Basin are in earthflows developed on volcanic rocks and occur above 7000 feet.

Station Association (Teton-Brown Clay Complex)

These soils are contained typically on forested landscapes broken by mountain parks. The surface is commonly very dark grey to dark brown and usually is a clay loam. Clay in these profiles generally increases with depth and a B_{2t} horizon is present. The profile is essentially fragment-free and non-calcareous.

These two soil associations occur almost entirely on landslide slopes derived from Cretaceous sediments on the wetter north-facing slopes in the drainage. The elevation of these slopes is generally between 6400 and 7000 feet with one occurrence at an elevation slightly above 7600 feet. These soil associations occur on landslides which appear to have been very fluid during movement.

Leavitt Association

This is a grassland association of soils on undulating to steep glacial till uplands. Landscapes are complex and typically glacial till "kettle and kame" topography. Most of the slopes are between eight and thirty-five percent. This association commonly occurs between the forested till soil areas and the soils of the valley terraces below. It is at elevations of 5400 to 6700 feet. The Hanson Soils are well drained and cobbly and stony loam is dominant.

This soil association occurs exclusively on the pediment surfaces in the Porcupine Drainage Basin. The pediment soil is unusually shallow and it is pointed out by Aasheim (1973) that the Leavitt Stony Loam occurring on the north side of Porcupine Creek was exceptionally

shallow. The soil does not develop a very deep solum before it washed into the basin below. The stoniness is related to the fluvial gravels that are derived from the higher mountain sources.

BASIC GEOLOGY-SOILS RELATIONSHIPS

The interdisciplinary team working in the Porcupine Drainage Basin was fortunate to have access to a backhoe for several weeks toward the end of the summer field season. Soil pits were dug on several of the different surface deposits where studies of the soil would be advantageous to members of the team.

Basic soil relationships revealed in a soil pit can be used in geological interpretations in two ways. Analysis of the soil constituents, especially the larger separates, can help the geologist to determine the type of deposit (i.e. glacial till or landslide debris). Also, studies have shown that surface deposits, especially of glacial origin, can often be chronologically dated using soil development analysis (Sollid and Meyers, 1972). If the deposits being dated are limited to a small area, such as one drainage, other soil forming factors such as climate and topography should be essentially constant, making time the controlling variable. Therefore, the earliest deposits should show more advanced soil development than later deposits. Data from observations of depth of A horizon, depth of B horizon, percent of clay in each horizon, depth to lime and degree of structure



Figure 13-Digging a soil pit on the surface of the pediments with a backhoe furnished by the Plant and Soil Science Department. The pit was used by various members of the Porcupine study team.

development in B horizon, can be used to chronologically date soils, which in turn, dates the time of deposition of the surface feature. It is noted here that this method in itself is not reliable and must be used with other dating indicators such as freshness of morphological form, proximity to source areas, and elevation relationships to present day drainages. The many variables in soil formation--parent material, microclimate, aspect, and available water, among others--are too great to make soil development a reliable single criteria for dating surficial deposits.

Pediment Soil

The soil pit dug on the pediment surface revealed several things. Soil development on these surfaces is very limited as it is removed almost as rapidly as it forms. The lack of rounding and sorting in the pediment veneer was noticed, and deposition by natural stream processes was ruled out. The pediment veneer was measured in the soil pit and was between 15 and 35 cm. thick. Observations on the veneer indicated that it was rather angular and derived essentially from the immediate mountain flanks, ruling out glacial origin as originally proposed. There was no possibility of dating the pediments using the soil profile due to the continuing erosion of the surface layer and resulting modification of soil profile.

Landslide Soils

Soil pit analysis on the landslide in Sec. 22, T.7S., R.4W. provided additional information about the landslide that otherwise would not have been obtainable.

Charcoal fragments were found intermittently throughout the solum. These fragments, as suggested in the section on Quaternary Landslides, may be the key to the origin of this particular landslide. A very clayey substratum was observed and a large dessication crack formed on the bottom of the pit after it had been open for a short time. This indicated the probability that the clay observed in the profile was montmorillonitic, and shrank as it dried out.

The soil developed on this landslide (Station Association) is relatively advanced, with a highly developed B_{2t} horizon present, with clay content increasing with dept. Soils which have a highly developed B_{2t} horizon generally are older than Pinedale (C. Montagne, 1971; Sollid and Meyers, 1972). However, the large amount of clay present may be due in part to the occurrence of easily weathered Cretaceous sediments and also, the clay may have been present before the sliding took place. The freshness in morphology suggests a younger slide, perhaps related to the Pinedale glaciation.

Glacial Soil

The evidence for the till on the sandstone ridge in Sec. 23,

T.7S., R.4W., was obtained from observations made in a soil pit that was dug on the crest of the ridge. The ridge was previously mapped as sandstone (Hall, 1961). Initial observations indicated that it contained large Precambrian erratic boulders, pointing to the possibility of a glacial deposit. The soil pit indicated that it was veneered with a thin mantle of abraded rocks that represented every lithological type found in the drainage. Below this mantle of till is a zone of weathered sandstone from the underlying parent material.

Miscellaneous Soils

Soil pits were also dug on colluvial slopes to determine soil associations and to facilitate the problem of getting soil descriptions for the proper associations. It was possible to measure the depth of colluvium in these pits and to observe its angular characteristics. Often the pits did not reach bedrock and the depth of colluvium was estimated from the dip of rocks that outcropped above the site.

A soil pit was also dug on the face of a slump scarp at the head of the large earthflow beginning in Sec. 35, T.7S., R.4W. The sandstone-shale contract was observed and appeared to be the glide plane for the landslide. The amount of clay in this soil was also noted to be very high.

Additional information on soils, including soil descriptions from the various soil pits, is included in Aasheim's 1973 paper.

CONCLUSIONS AND COMMENTS

U.S. FOREST SERVICE PLANNING TEAM

As stated previously in the Introduction, the data gathered for this study was used extensively by the planning personnel of the Gallatin National Forest for developing several management alternatives for the Porcupine drainage and adjacent areas. Porcupine Drainage Basin makes up over one-third of the Porcupine-Buffalo Horn Planning Unit. This planning unit is on the Gallatin Ranger District which is part of the Gallatin National Forest. Planning units, by Forest Service definition, are geographical areas of land, characterized by particular patterns of topography, climate, and land use. The Porcupine-Buffalo Horn Planning Unit is presently undeveloped, except for a trail system and a few primitive roads. Due to its proximity to Yellowstone National Park, it becomes part of the Park's large natural ecosystem; a fact making this planning unit especially unique.

The management alternatives for the Porcupine-Buffalo Horn Planning Unit were developed by a team of interdisciplinary specialists, from both inside and outside the U.S. Forest Service. Disciplines represented were geology, hydrology, soils, forestry, engineering, landscape architecture, and wildlife biology. The approach the planning team took was as follows: (1) determined the ability of the land to produce resources and sustain uses, (2) made an inventory of existing resources and uses of the area, (3) recognized the peoples' needs and

demands, and (4) produced several management alternative plans for this area that would best meet the multi-objectives as set forth by the U.S. Forest Service. These multi-objectives are as follows:

1. To enhance the quality of the environment
2. To enhance National economic development
3. To enhance regional development

When the planning team had developed five alternatives for managing the Porcupine-Buffalo Horn Planning Unit, they were then presented to the public who were then allowed to accept, reject, or combine these alternatives by expression of popular opinions at open hearings and by written statements. The alternatives were considered by the planning team to be all within the capabilities of the land.

As a geologist on this planning team, representing the Gallatin Canyon Study Team and Montana State University, I was impressed by the importance of geology in developing the management alternatives for this area. The following discussion concerns the geological implications considered in the management decision made by the planning team. Where applicable, I have tried to relate geology to the other disciplines. Only the Porcupine portion of the planning unit will be discussed here. Geological interpretations of the remaining areas were derived from personal observations by other geologists on the planning team and from previous geological work in the area.

Land Instability

Landslides and landsliding are considered to be the major geological constraint for development in the Porcupine Drainage Basin. Figure 14 shows that over one-third of the basin has been involved in sliding or is covered by landslide debris. Any type of activity by man, if not carefully preplanned, has the potential for renewing landslide activity in the area. Any form of digging, such as for roads or buildings, could disturb the physical setting sufficiently to cause sliding.

Logging activities, especially clearcutting, can increase the amount of available water to a critical point, saturating mantle material, creating lubricated glide planes, and increasing pore-water pressure potential. This hydrological effect of forest cover on slope stability is due to the fact that trees transpire through their leaves, which in turn depletes soil moisture.

Clear cutting also influences slope hydrology by affecting snow accumulation and melt (Anderson, 1956). Maximum accumulation of snow is greater in the cut than uncut forest. Anderson (1956) found that clearcuts which create large open areas not only store more snow than a forest but also have much more rapid melt and runoff. It is apparent that clearcutting on pre-existing landslides or upslope from landslides should be avoided.

Ironically, the landslides on the wetter north slopes, with

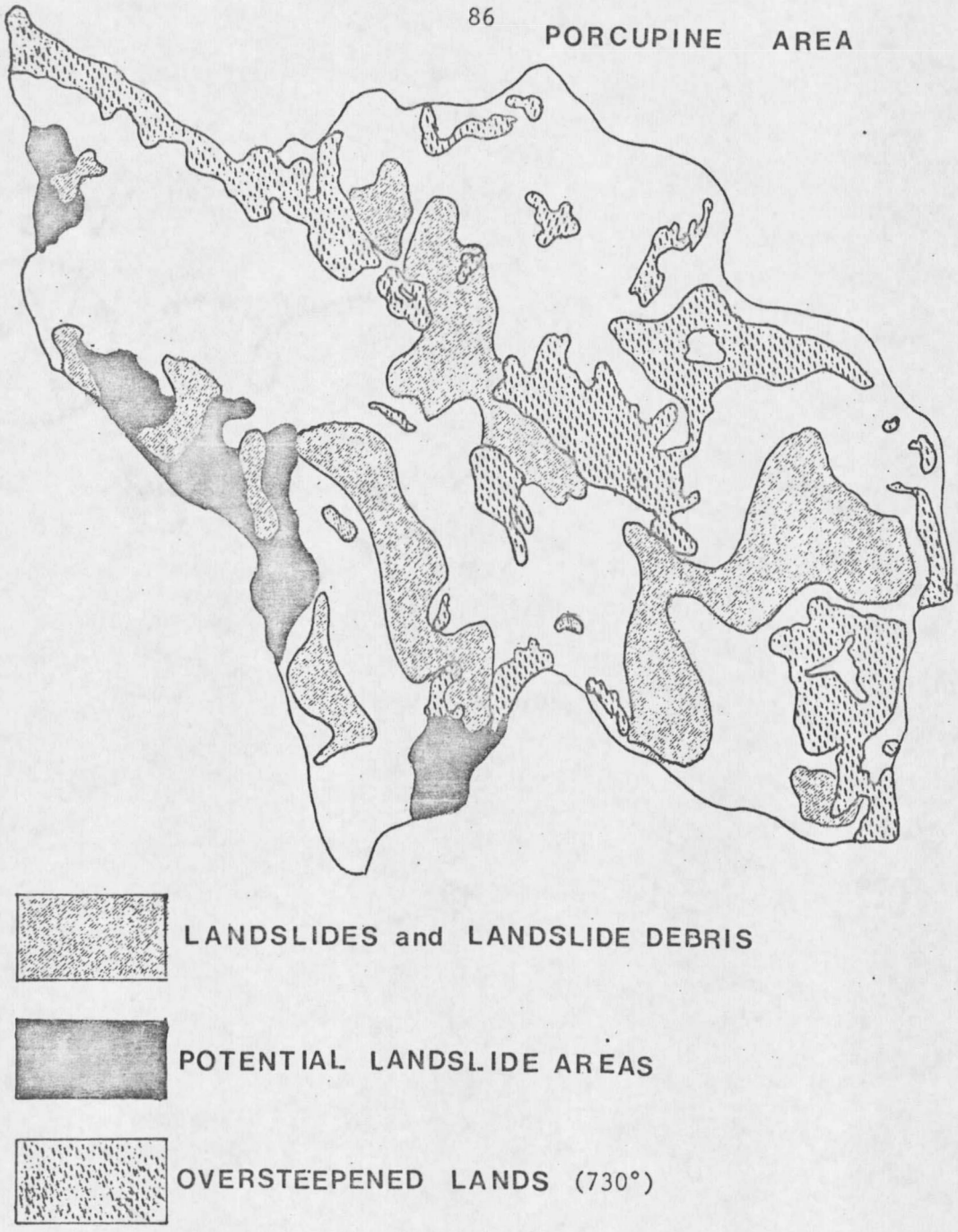


Figure 14-Map of Porcupine Drainage Basin showing areas of instability and potential instability which should be avoided in development plans.

characteristic loose soil and high moisture content produce the better stands of timber.

Roads and buildings can be constructed on unstable slopes only at very high construction costs. Engineering costs for road construction along the north facing slopes above Porcupine Creek were estimated at almost $1,000,000 per mile of road. This was attributed to the necessity for hauling in enormous amounts of subsurface rock material, for construction of downslope pilings, and for the construction of extensive drainage systems. Most of the slides are very high in clay, and would be very poor construction sites due to drainage problems.

Landsliding, besides being initially dangerous and destructive, can also be the major contributor of stream sediment. Many of the smaller tributaries in Porcupine Drainage Basin can be traced upstream to landslides which have effectively narrowed the channel. Here sediment is introduced into the stream by erosion of the landslide debris or erosion of the stream bank caused by diversion of the stream.

A smaller landslide on an unnamed south flowing tributary contributes a large percent of high water sediment in Porcupine Creek. Kojan (1967) found that soil creep and landslides account for some as much as 70 percent of the stream sediment along some slide-prone slopes in the coastal ranges of northern California. Bailey (1971) reports that runoff from the Eel River in northern California stripped away 320 million tons of soil and rock from a

3,000 sq. mile area in ten years. Apparently, most of the sediment was derived from widespread landslides and earthflows produced or accelerated by logging and road construction.

Potential Landslide Areas

Many slides were found that were too small to be practically mapped to scale. Also many areas are known to be prone to sliding and should be avoided in construction plans if possible. These areas are shown in Figure 14.

Most of the slopes on the south side of Porcupine Creek along its lower reaches may become unstable if the hydrologic regime is altered. The drier south facing slopes, such as the pediment surfaces, would provide good road and construction sites. Any type of construction in the upper reaches of the drainage should be preceded by on site investigation. Areas which have excessive subsurface moisture, clay-textured soils, easily weathered bedrock, and steep slopes are apt to have a high incidence of slope failure.

Oversteepened Slopes

Figure 14 also shows oversteepened slopes (over 30°) which are commonly characterized by numerous rock outcrops, shallow soils, avalanche paths, and talus and colluvium deposits. Roads which would be constructed in these areas would have high cut banks and long fill slopes. These cut and fill slopes are difficult to stabilize because

of the deeply incised drainage on the steep slope.

Other development problems associated with these oversteepened lands arise from the nature of surficial deposits which characterize these slopes. The slopes generally contain accumulation of unconsolidated debris which has been moved by gravity and is temporarily at rest. This debris is unstable, and when disturbed, large debris avalanches are likely to occur.

The lower limit of internal friction angles for soils commonly formed on these slopes is about 35° (Bailey, 1971). Slopes with gradients equal to or greater than this figure are highly susceptible to sliding if disturbed and should be avoided.

Petrified Forest

The petrified forest in the Porcupine area (Figure 15) is located along the crest of the Gallatin Range at the upper end of the Porcupine Drainage Basin. Although some of the better occurrences of petrified wood are southeast of the Porcupine Drainage Basin, the petrified forest in Porcupine is part of the overall Gallatin Petrified Forest which is in need of a management program.

Currently the portion of the petrified forest that lies outside Yellowstone National Park is open to unlimited collecting by anyone wishing to do so. Reports indicate that large quantities of the petrified wood leaves the area by helicopter and pack horse to be

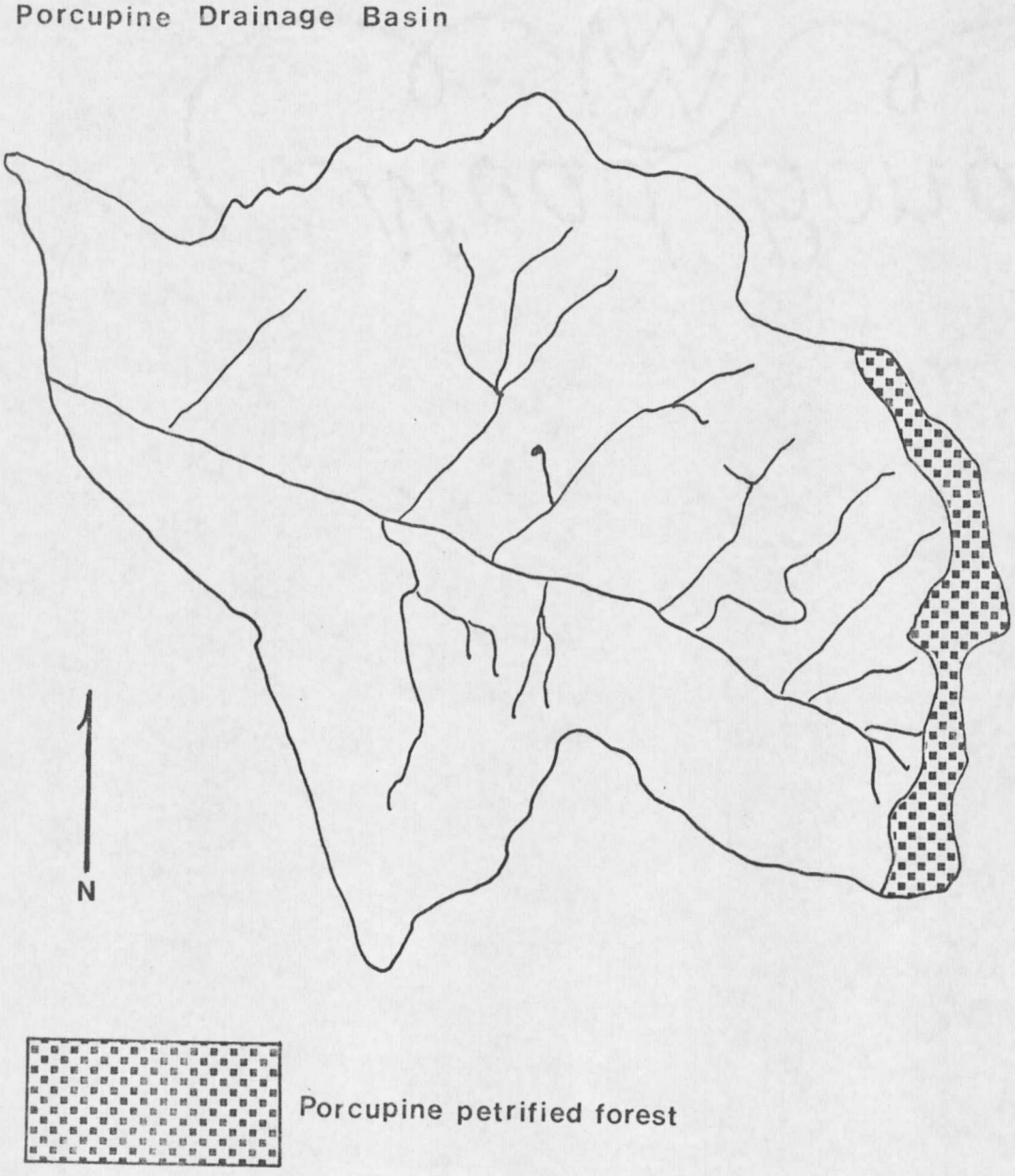


Figure 15-Map of Porcupine Drainage Basin showing approximate limits of petrified forest occurrence.

sold in rock shops throughout the nation. Collecting any type of samples in the park is forbidden by federal law.

Management of the petrified forest is a rather controversial subject but everyone agrees that some type of control is needed. Many people want the area to be limited to a specified amount of surface collecting by permit, leaving the in-situ trees and stumps for others to enjoy. Others believe that no type of collecting should be allowed.

The Gardiner Ranger District of the Gallatin National Forest has set up a program for management of the entire Gallatin Petrified Forest. The area is designated as a 'special management area' and will be protected by federal law. No commercial collecting will be allowed. Hobbyists will be able to collect 20 pounds per visit, with a maximum of 100 pounds per year allowed for each individual.

Porcupine As A Natural Area

People are becoming increasingly aware of their surroundings and there is a trend toward preserving natural or pristine areas. Porcupine is unique for several reasons; some, such as the petrified forest, already have been discussed.

From an aesthetic standpoint, Porcupine Drainage Basin deserves some special considerations. The natural beauty is unsurpassed. It is a very open area with many parks and stream valleys providing natural niches for wildlife.

The large landslide area in Secs. 23, 25, 26 and 36, T.7S., R.4W., known locally as the 'potholes', contains many moose, as the water ponded by landsliding makes ideal habitat. The large open faces on the north side of the creek remain bare throughout much of the winter months and provide much forage for the migratory elk herd which winters in the basin. Black bear are commonly seen in the drainage, and an occasional grizzly bear makes its way into the area from Yellowstone National Park. Mountain sheep and mountain goats inhabit the higher peaks on the crest of the Gallatin Range. An area such as this, with its abundance of wildlife and possessing natural beauty, needs carefully preplanned management policies.

The final management decision reached by the Gallatin National Forest for the Porcupine-Buffalo Horn Planning Unit excludes any development of the area. This decision was made after considerable public participation. The area will be left almost entirely in its present natural state. Logging, to reduce fire and disease potential, will only be allowed by balloon or helicopter methods, with prior planning to avoid any unnecessary destruction of the area.

CONCLUSIONS

It is readily apparent that the Porcupine Drainage Basin is a relatively sensitive area, existing in a natural state of equilibrium. Intrusion by man may upset this delicate state of balance resulting in severe consequences. The sensitivity of the area is the result of two factors: (1) The characteristics of the underlying rock material, and (2) The steepened slopes brought about by erosional forces.

Man's role in Porcupine must be well thought out. Presently, plans for Porcupine Drainage Basin exclude development. With the steady rise in cost of lumber, and the increase in demand for this type of environment, Porcupine and adjacent drainages may succumb to "progress."

As man moves into these areas, the physical factors must be considered. The geology of Porcupine and its relative significance has been discussed. Hopefully, the ideas and thoughts brought out by this discussion can be successfully applied elsewhere, when other pristine areas are being considered for development.

APPENDIX

Appendix A

FUTURE INVESTIGATIONS

Further studies in the Porcupine Drainage Basin are needed in order to provide a greater prospective of the area. The following suggestions on studies may be useful:

1. The monitoring of active landslides to determine rates and times of movement. This could include a grid system of reference points established and monitored with a transit.

2. The examination of older landslides to determine what factors contribute most to the mechanics of sliding.

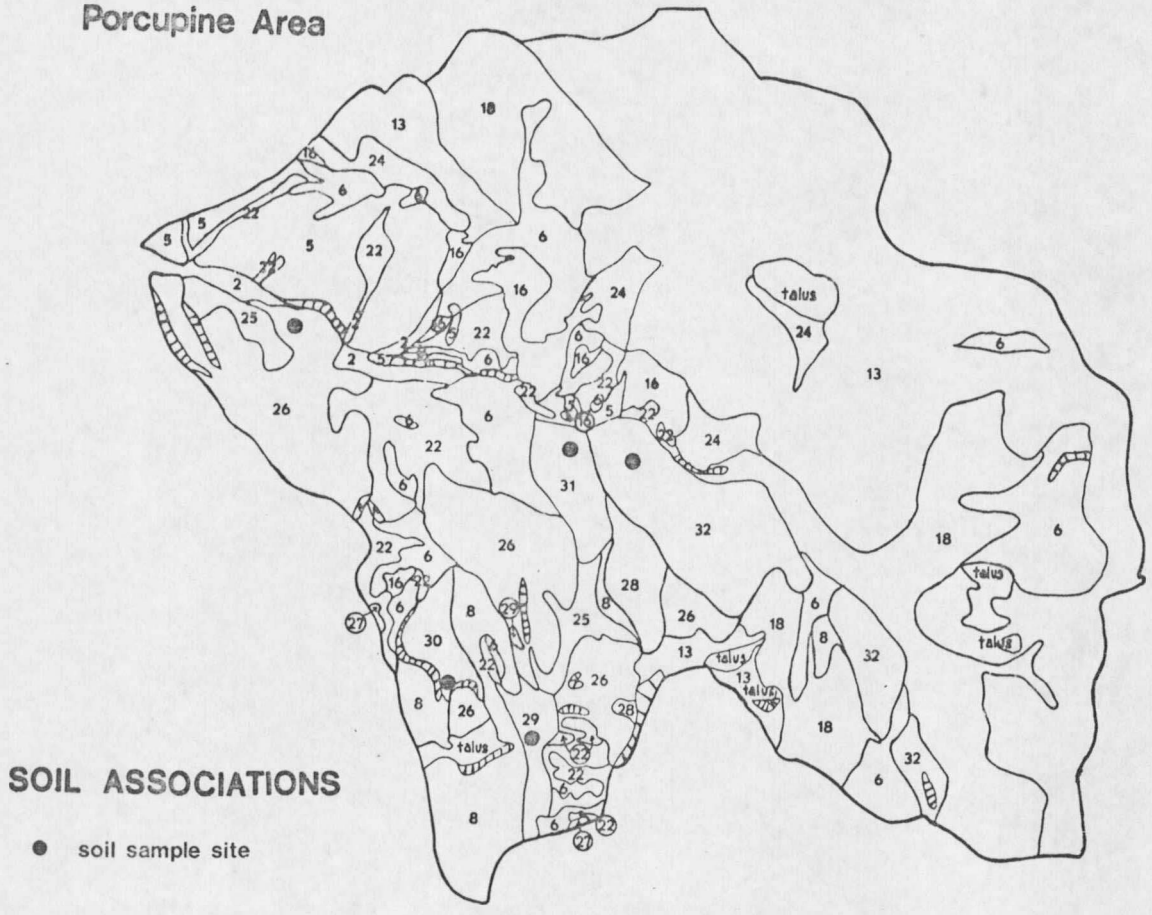
3. A thorough archaeology investigation of the area. The abundance of wildlife and the relatively milder winters makes this area a natural occupation site for early man.

4. A study of the vegetative pattern to determine if there is a correlation between vegetative occurrences and geology and soils.

5. An extensive search of the basin for more glacial evidence, as the small amount of glacial deposits found are inconsistent with adjacent areas.

6. If, for any reason, development is allowed in the drainage, a monitoring of geological hazards would benefit future land planning decisions.

Appendix B



(Figure taken from Aasheim, 1973)

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PLATE I

Surficial Geology Of The Porcupine Drainage Basin, Gallatin County, SW Montana

BY

SHERMAN ALLAN SOLLID

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE MASTER OF SCIENCE
AT
MONTANA STATE UNIVERSITY,
1973



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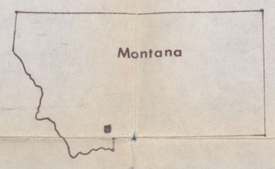
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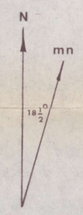
datum is mean sea level

Base map from 1955 U.S.G.S. Crown Butte and Garnet Mountain topographic maps

Geology partly taken from Hall (1961), McMannis and Chadwick (1964), and Prinkki (1971)



index map

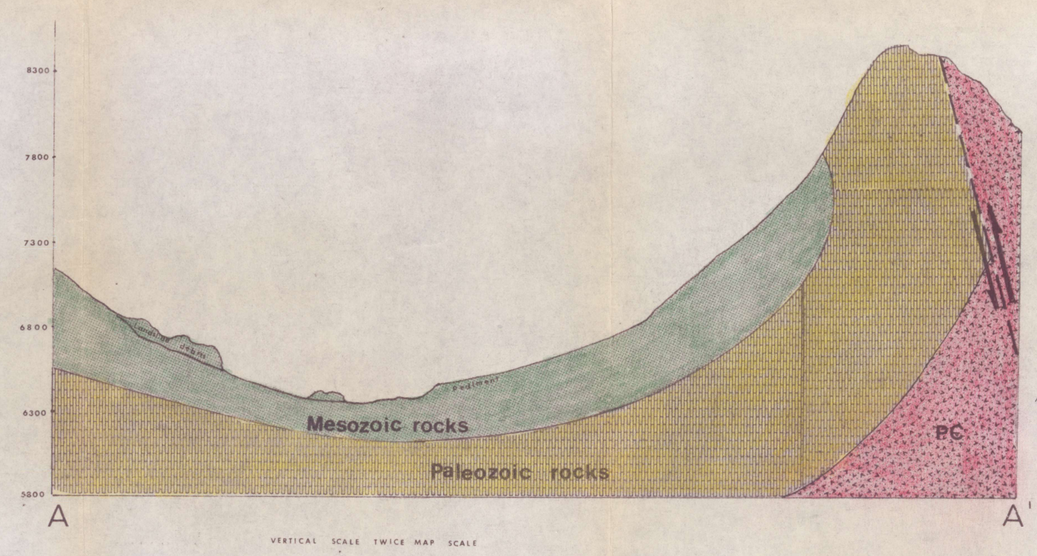


Explanation

- LANDSLIDE DEPOSIT
- ROCKFALL DEBRIS
- SOIL ON BEDROCK
- ALLUVIUM
- GLACIAL DEPOSIT
- COLLUVIUM
- BEDROCK AT SURFACE
- ALLUVIAL FAN
- STREAM TERRACE
- PEDIMENT

SYMBOLS

- Boundary of map area
- Fault (u / d)
- Contact
- Concealed fault
- A ——— A' Representative X-section



VERTICAL SCALE TWICE MAP SCALE

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