Environmental geology of the southeast margin of the Gallatin Valley, Gallatin County, Montana
by Earl Francis Griffith

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Earth Science
Montana State University

Abstract:
Bozeman's attraction as an outdoor recreation area and community with a high quality of life has resulted in significant development of former agricultural land. Most of the area studied is privately owned and within the boundary of the Bozeman City-County Planning area.

This corner of the Gallatin Valley is part of a downdropped block bounded on the south by the Gallatin Range and on the northeast by the Story Hills and the south end of the Bridger- range. Tertiary (Bozeman Group)' rocks comprise the major portion of rocks in the area. Various thicknesses of Quaternary colluvial material and fan deposits veneer the Tertiary near the mountain fronts.' More recent Quaternary alluvium dominates the alluvial valleys. Two major faults border the study area; the northwest trending Bridger Creek-Bear Canyon fault along the eastern edge, and1 the Gallatin Range front fault along the southern edge.

Frequently encountered hazards are rockfall, rock-slides , small local landslides, seismic hazards of ground shaking and potential fault displacement and flooding along all major streams. Geologic constraints include unstable and potentially unstable slopes, creep, solifluction, very steep slopes over 30%, north aspect slopes greater than 15%, problematic soils and high ground water.

Overturned and thrust-faulted Paleozoic and. Mesozoic rocks in Bridger Canyon are very susceptible to rock-fall and rockslides. Active landslides have developed on overturned Cretaceous rocks east of the Bridger Creek-Bear Canyon fault in the Story Hills. These rocks are characterized by bentonite clays, low permeability, low shear strength and a dip slope attitude. Flooding along the major streams is a frequent problem, especially in the East Gallatin drainage north of Interstate 90 and along Bozeman (Sourdough) Creek where existing conduits cannot handle peak flood flows.

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Date 28 April 1982

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by

EARL FRANCIS GRIFFITH

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ABSTRACT

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CHAPTER I

INTRODUCTION

Purpose

Land use planning within Bozeman's City-county planning area requires a physical constraint assessment to make rational land use decisions. This thesis, with the accompanying maps, should be the first in a series of efforts to describe to planners, land developers, contractors, and prospective home buyers the geologic constraints in the planning area. The need for this kind of information is underscored by the present effort to update the Bozeman Area Master Plan.

Legislated guidelines regarding land use planning in Colorado (Shelton, 1979), and legal trends toward emphasizing comprehensive plans as a tool in land planning in Oregon (Bela, 1979), are two examples where states now are mandating a physical data base prior to land development.

Document Use

General

The map and thesis information is a compilation of existing data and field reconnaissance, subject to change as additional information becomes available. The maps represent average conditions as they existed at the time of investigation, and in no way preclude the need for more specific on-site investigations. The information base and resulting recommendations are intended as an aid to the decision-making process.

The thesis text is structured around the maps where possible. Major thesis headings usually correlate with specific maps to help the reader find data. A glossary and appendixes are provided to clarify technical language and supply additional information to the reader.

Site Evaluation

The maps and text provide constraint information which can be compared with a project's site requirements to assess compatibility and viability. A map scale of 1:24,000 or approximately 1 inch to 2000 feet is used on all the accompanying plates. Major projects may require more specific on-site surveys at a scale of 1 inch to 200 feet.

Land Capability

Land capability maps can be derived from the six available maps and thesis information using the overlay method if desired. This has been partially addressed on the Construction Constraints map. All the maps, thesis data, and recommendations are based on the premise that future development will be primarily residential or light industrial/commercial, in keeping with past growth patterns and projected future development.

Policy Determination

Comprehensive planning requires at the outset a physical data inventory to augment sound decision making. Not only does sound planning provide a direction to decision makers, it makes the prospective land buyer/developer aware of the constraints present on a given site and protects the well-being and safety of the general public (Bela, 1979).

Map Scale and Detail

Numerous geologic, hydrologic and soil maps have been prepared for portions of the study area, but not at a common scale. I have attempted to include all pertinent map data whenever possible. Some of the map data required a scale change to accommodate the 1:24,000 base scale.

The only area where more detailed maps were used was in the Story Hills. Mayfield and Associates provided the maps for the site-specific study of Subdivision 3 in June 1980 and Survco, Inc. furnished the maps for a preliminary site assessment of Story Hills Subdivisions 2 and 3 in June 1979.

CHAPTER II

GEOGRAPHY

Location and Extent

Rapid residential development has taken place and is expected to continue in the 36 square mile study area. Boundaries were established by natural topographical barriers and within simple political borders which included those areas of rapid development. (Figure 1 -- Location Map). The six base maps were generated from four 1:24,000 scale Upper Missouri River Basin Survey Maps numbered 87, 88, 97, and 98.

Topography

Figure 1 shows the physiographic regions of the study area. Land divisions are based on present form, modifying processes and materials. The four major land forms discussed include alluvial stream valleys, alluvial fans, remnant surfaces and mountainous uplands.

The alluvial stream valleys of Bridger Creek, the East Gallatin River and Bozeman Creek overlie thick deposits of Tertiary sedimentary rocks (Hackett, 1960). Flood plain slopes range from 0-2% except on the upper reaches of Bozeman Creek.

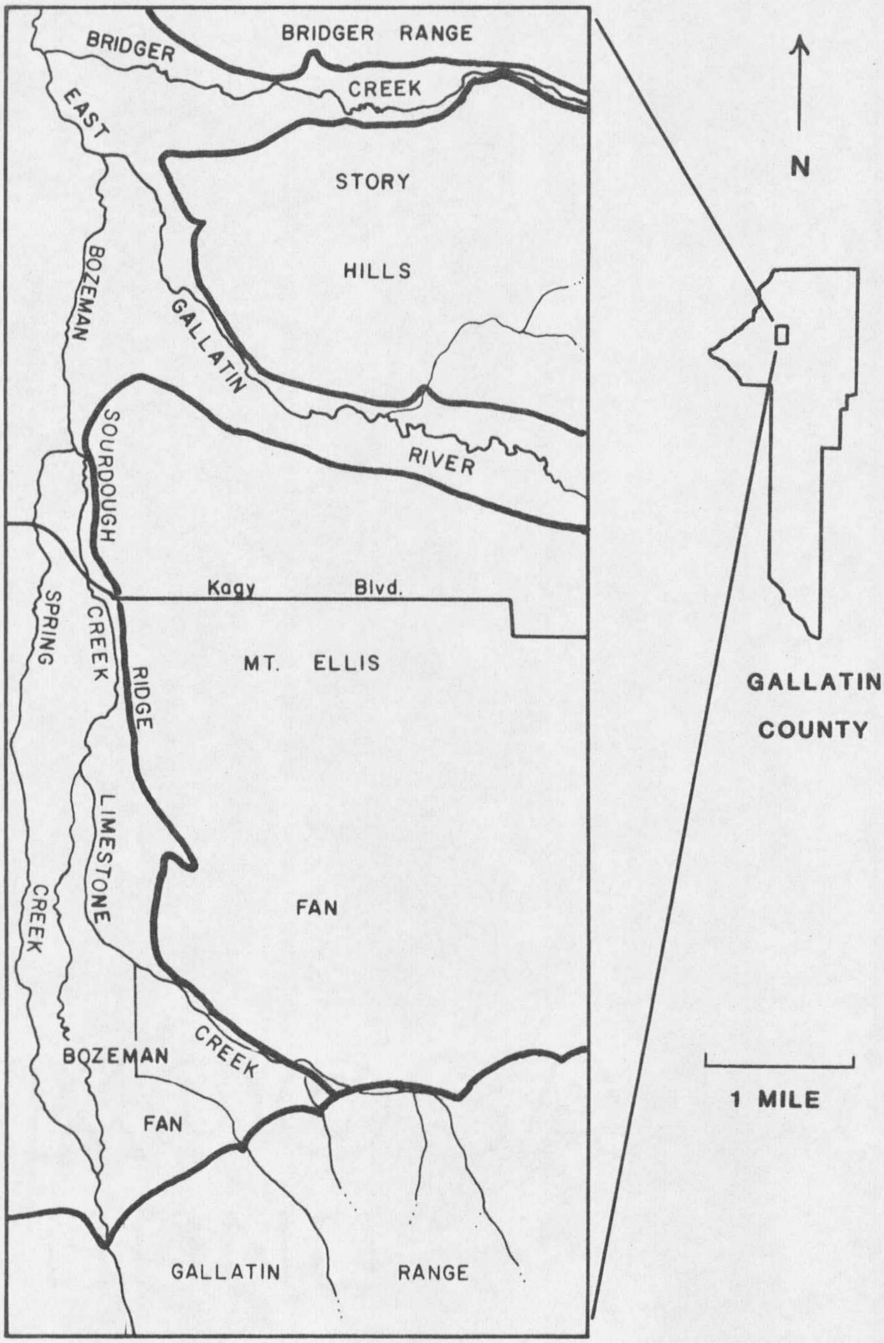

Figure 1. Study area location map.

The Bozeman and Mount Ellis alluvial fans dominate the south-central portion of the study area. Quaternary slope-wash and alluvial sediments 'thin' rapidly away from the Gallatin Range front to an east-west line just south of Kagy Boulevard on the Mount Ellis fan. Fan materials of a later depositional period comprise the dissected Bozeman fan in the study area (Hackett, 1960). The western edge of the Mount Ellis fan is established by Sourdough Ridge. Thick deposits of silt loam soils overlie the entire Mount Ellis fan area from Sourdough Ridge to the edge of the study area and from the mountainous uplands to the East Gallatin River alluvial valley. Slopes generally range from 0-10% except along Sourdough Ridge and in established drainageways where slopes range from 15-30%.

Between the East Gallatin River and Bridger Creek an erosion remnant of Tertiary sedimentary rocks, down-faulted against overturned Devonian through Cretaceous units, comprises the bulk of the Story Hills. Slopes range from 5% to well over 30% in the drainageways and on slopes adjacent to major streams. Aspect ranges from south to north, with much of the developable land facing west-southwesterly.

The steep mountainous areas of the south end of the

Bridger Range and the north flank of the Gallatin Range are generally under public stewardship. Very steep slopes dominate both areas and the Gallatin Range front has the additional problem of a north aspect.

Population and Land Use

Regional recreational amenities and efforts to attract light industry are expected to maintain the present rapid population growth through the 80's. Increasing energy and transportation costs will encourage development closer to Bozeman. The flood plains of Bozeman Creek, the East Gallatin River, and Bridger Creek, the western portion of the Story Hills, Sourdough Ridge and the Mount Ellis alluvial fan areas will receive moderate development pressures.

Problems associated with this expected change in land use are greatest on the surface drainage systems. For instance, urban growth reduces available infiltration areas and speeds up surface runoff to existing channels (Dunne and Leopold, 1978). Downstream flooding will increase, soil erosion will increase, and the 100-year flood plain will expand over time.

CHAPTER III

GEOLOGY

Structural Setting

The Gallatin Valley is part of the Three Forks structural basin, a high intermontane basin, characteristic of the northern Rocky Mountain Physiographic Province (Hackett, 1960).

Formation of the Three Forks structural basin in pre-Oligocene (Eocene?) time was probably due to a late phase of Laramide compression which obstructed the eastward drainage system and promoted aggradation in the closed basin (Robinson, 1961). The advent of tensional faulting (post-Oligocene?) caused recurrent eastward tilting of the basin and shifted the depositional center, accounting for the Miocene and Pliocene sediments in the basin's eastern half (Glancy, 1964). Subsequent uplift to the south caused the Tertiary beds to develop a northwesterly slope, consequently the master drainage changed from an east flowing system to a west and north flowing one (Robinson, 1961).

Major Tectonic elements in the area include the overturned and thrust-faulted Paleozoic and Mesozoic rocks at the south end of the Bridgers; the northwest-trending Bridger Creek-Bear Canyon normal fault (McMannis, 1955; Overturf, 1974); and the east-northeast-trending normal fault along the Gallatin Range front as indicated by aeromagnetic data (Davis, and others, 1965). East-trending normal faults in Tertiary deposits are found along South Church Avenue (Hackett, 1960) and are suspected in both the Story Hills and Bridger Canyon from gravity, structural, and geomorphological data (Plate 1).

Geomorphic Setting

Alteration of the master drainage from an east to a west and north flowing system set the stage for all depositional and erosional activity since the late Pliocene or early Pleistocene. Erosion dominated this period but some deposition took place adjacent to the Bridger and Gallatin Ranges (Hackett, 1960). The net result of all these processes is clearly indicated by the valley landforms. Quaternary deposits become thinner away from the mountain front on Sourdough Ridge, the Mount Ellis and Bozeman fans, and the small fans on the west side of the Bridgers. Remnants of Tertiary (Miocene-Pliocene) sedimentary rocks are present in the Story Hills and the northern portion of the Mount Ellis Fan (Plate 1).

The youngest natural geologic materials are the

Quaternary clay, silt, sand, and gravel in the flood plains of all the creeks of the study area. Erosion in both the Bozeman Creek and Limestone Creek drainages has obliterated any of the alluvial fan form most writers believe was present prior to a change in water and/or material balance.

Loess from both the Madison and Gallatin River flood plains deposited during interglacial periods of the Quaternary is the final overprint to the area's land forms (Bourne, 1960). The resulting Bozeman and Bridger silt loam soils are dominant on the relatively flat surfaces of the Mount Ellis Fan. The soils are discussed further in the section entitled Geologic Hazards and Constraints. Flood-plain soils are delineated and explained on Plate 4.

Surficial Geologic Units

The complex history of Tertiary and Quaternary erosion and sedimentation has resulted in an abundance of surficial geologic units consisting of unconsolidated and semiconsolidated deposits of gravel, sand, silt, and clay of varying extent and thickness. Man's contribution to surficial geology is noted along the flood plain and channel reaches of the East Gallatin River and Bozeman Creek and at various other locations. These units are described in the text below.

Holocene-Manmade Deposits (Hm). These unconsolidated and uncompacted deposits consist of excavation material, construction waste, and demolition rubble; and in older (pre 1940?) sites, variable thicknesses of solid waste. The deposits are located along the channels and flood plains of the East Gallatin River and Bozeman Creek in low-lying areas zoned commercial/industrial and at other sites as noted on Plate 4. Thickness varies from 2 feet to well over 25 feet.

Holocene-Landslides (Hls). These geomorphic features have resulted from slope failure within the last 15 years. The small landslides are located in the eastern portion of the Story Hills and consist of unconsolidated surficial soil materials, Tertiary sedimentary rocks and the underlying fractured Cretaceous bedrock (Plates 4 and 5). A prominent headscarp, dip-slope attitude, large amount of available groundwater, hummocky topography and a lobate terminus characterize these small slides (Figures 3 and 4). Thickness is probably less than 25 feet.

Holocene Rockslide (Hrs). The Bridger Canyon rockslide consists of various sized blocks derived from Big Snowy-Amsden siltstone, dolomite and limestone and possibly some overlying Madison Limestone to the west. The slope angle exceeds 50% and the entire north slope area is unstable and undergoing continuous downslope movement (Plates 4 and 5).

Quaternary Young Alluvium (Qya). According to Roberts (1964), the material consists of unconsolidated, interbedded clay, silt, sand, and gravel along stream channels and on flood plains (Plate 1). The alluvium varies in thickness and generally overlies older Quaternary and Tertiary deposits. Relief is from 0 to 2% along the major drainages and may increase to 10%(+) along streams near the mountains. The materials are characterized by a high groundwater table and are regularly subject to flooding and bank erosion (Plates 3 and 6).

Quaternary Fan Deposits (Qf). Fan deposits consist of a heterogeneous mixture of coarse- and fine-grained sediments deposited by Pleistocene streams which cut higher older (Qac) deposits (Hackett, 1960). The unit is found in the Bozeman Creek drainage near the mountain front and along the eastern margin of the study area as a remnant of the Bozeman alluvial fan.

Quaternary Alluvium-Colluvium (Qac). Unconsolidated slope wash and alluvial fan deposits of mixed silt, sand, pebbles, cobbles and boulders characterize the Qac (Roberts, 1964). The unit is located adjacent to and thins rapidly away from the Gallatin and Bridger ranges.

Quaternary Landslide (Qls). A major feature on the north slope of the Story Hills is a large (1.5 miles E-W by 0.6 miles N-S) ancient landslide (Plate 1). It is an unconsolidated, unstratified, heterogeneous mixture of soil and Tertiary (Bozeman Group) materials, which slid off the highlands of the Story Hills to the north and west during the Pleistocene. Hummocky terrain, north slope, steep variable slope angle, soil creep, and springs on the north slope distinguish this feature (Plate 5). The combination of constraints supports classifying the approximate slide area as an unstable slope (See Chapter III, Mass Movement-Constraints).

Tertiary-Bozeman Group (Tb). The Bozeman Group is comprised of poorly stratified, variously consolidated tuffaceous siltstone, sandstone, claystone, and conglomerate (Roberts, 1964). Most of the Story Hills presently considered for development and the northern portion of the Mount Ellis Fan consist of these materials (Plate 1).

Bedrock Geologic Units

Bedrock exposures are limited to the Bridger Canyon area and the Gallatin Range front portion of the study area. The rocks in the Bridger Canyon area have been severely thrusted and the more resistant rocks show complex jointing. The more resistant rocks maintain steep slopes whereas the shale and silty units become covered topographic swales. Gneiss, schist and granite dominate bedrock exposures along the Gallatin Range front except in sections 3 and 10, T.3 S., R.6 E., where Paleozoic and Mesozoic limestone, sandstone, and shale rest on the Precambrian rocks.

Because geologic constraints are closely related to rock unit competency and erodibility, the brief discussion which follows is in two parts: resistant and non-resistant units. A more detailed description of all rock units is listed on Plate 1.

Resistant Units

Resistant units are generally the limestone, dolomite, cemented sandstone, and gneiss, schist, and granitic rocks which maintain steep slopes and are relatively resistant to erosion. Geologic constraints in resistant rocks usually involve the steep slopes. The overturned and fractured rocks in the Bridger Canyon area are inherently unstable and the hazards from rockslides and rockfall are very severe (See Chapter 4 -- Mass Movement-Hazards and Plate 5).

Non-Resistant Units

Nearly all the non-resistant rocks are mixtures of interbedded shale, siltstone, sandstone, and limestone. These easily erodible units are almost always concealed. Serious mass movement constraints are encountered on these units in the Story Hills east of the Bridger Creek-Bear Canyon Fault (Plates 1 and 4). Here, the dip slope attitude and impermeable shale layers of the Colorado Group rocks are the controlling elements of slope failure.

Structural Elements

Faults

The geologic maps accompanying this text show the major known or suspected faults in the study area (Plate 1). Location is as precise as field evidence or gravity data allow, and any fault location on the maps should be viewed as approximate. Any reader wishing a more detailed discussion of the valley structure is referred to McMannis (1955), Robinson (1961, 1963), Glancy (1964), and Tysdal (1966).

Bridger Creek-Bear Canyon Fault

The Bridger Creek-Bear Canyon fault is the major and most critical fault in the study area. Tertiary rocks on the west side of the fault have been dropped relative to the Paleozoic-Mesozoic rocks on the east side. Displacement of the fault east of Belgrade is about 2,500 feet, but is unknown in the study area (Davis and others, 1965).

The fault is identified and located by: (1) two deep coulees along the fault trace; (2) well data which indicates a definite change in rock types at depth; (3) recent road-cut exposures of Cretaceous bedrock; and (4) the existence of springs along the fault trace.

A fault trace is normally a weak zone and erosion will exploit this weakness. The existence of the deep coulees infers the presence of the faults. A number of wells were drilled in 1974 in the Story Hills in an attempt to locate an adequate water supply. Well logs from two of these wells indicate the presence of a major fault in the area. One well, located 1300 feet southwest of the center of section 3, T.2 S., R.6 E., penetrated 318 feet through Tertiary rocks. From 318 to 400 feet, clay and "blue" shale were encountered. This thickness of clay and shale is very unlikely in the Tertiary fluvial rocks and probably marks the fault plane of the Bridger Creek-Bear Canyon fault (Overturf, 1974). The second well, located ¼ mile south of the northwest corner of section 3 penetrated 440 feet of gravel and conglomerate. A comparison of the well log data indicates a west dipping fault plane with a surface expression very likely at or near the deep coulees. Road excavations at the topographic saddle between the two coulees exposed a sandstone unit. Slightly east of this location, another road cut exposes a lignite unit and a bentonite clay layer. Tertiary rocks are present on the surface east of the deep coulees and rest on the sandstone, lignite and clay units. The sandstone, lignite and clay units are not found in shallow excavations or well holes west of the deep coulees. This evidence supports post-Pliocene faulting along the Bridger Creek-Bear Canyon fault. Finally, faults often act as ground-water barriers by disrupting ground-water flow along the fault plane. Springs at the surface are indicators of such a fault barrier. Both coulees have springs originating in their upper reaches which may indicate a fault contact.

Gallatin Range Front Fault

Field evidence for the Gallatin Range front fault is locally rather general. The linear contact between the mountain front and valley fill implies faulting of some sort. The best evidence is based on a gravity study conducted by Davis and others (1965, p. 3).

> An analysis of the gradients and of a gravity profile crossing the center of the southernmost negative anomaly indicates that a bedrock trough occurs beneath the southeastern margin of the basin. Near South Cottonwood Creek the bottom of the trough is computed to be about 2 miles wide and approximately 6,000 feet beneath the surface. Northeastward the trough broadens slightly, then narrows, and becomes shallower southeast of Bozeman. The subsidiary low in the eastern part of the anomaly coincides with a large alluvial fan and may be caused in part by the low density of the fan material. The high southeastern gradient of the main anomaly probably is the expression of a concealed steep fault zone that lies along the base of the Gallatin Range. The fault zone is inferred to extend northeastward from the mouth of Gallatin River canyon to Bear Creek and to have at least 4,000 feet of throw beneath South Cottonwood Creek.

In addition to this gravity data, Tysdal (1966, p. 79) listed numerous lines of evidence for the fault's existence in the Hyalite (Middle) Creek, South Cottonwood Creek and Big Bear Creek drainages. The data include: (1) the linear expression of the mountain front; (2) concentration of landslide debris at the mountain front; (3) absence of pre-Tertiary outcrops in the basin proper; (4) a steep contact plane locally where Tertiary strata abut the mountain front; (5) pre-Tertiary strata dip toward the proposed fault near the range front (sections 32, 35, and 36, T.3 S., R.4 E.); (6) horizontal offset of the Squaw Creek-Cherry

Creek fault along the range front trends (McMannis and Chadwick, 1964); and (7) shearing of metamorphic rocks in sections 14, 15, and 22, T.3 S., R.5 E. The estimated minimum length of the fault is 23 miles (Tysdal, 1966, p. 80). Tertiary rocks in the SE¼, sec 21, T.3 S., R.5 E., are disturbed where they abut the Precambrian metamorphic rocks, but a Quaternary alluvial fan has not been disturbed. This evidence dates the latest fault activity as post Miocene-Pliocene (Tysdal, 1966, p. 81).

Bridger Creek -- Story Hills E-W Linear Faults

Structural control along east-west linear axes in Bridger Canyon and the Story Hills is inferred from geomorphic, stratigraphic and gravity data. Offset of the two Story Hills erosion surfaces (Plate 1, contour map) suggests a post-Pliocene adjustment along an east-trending fault coincident with the main coulee through the hills (Overturf, 1974). The south surface appears structurally lower than the north and topographically higher surface. Vertical displacement is estimated at 150 to 200 feet, assuming equivalent erosion rates for both surfaces. Addtional evidence for faulting is implied by the deep linear coulee separating the erosion surfaces. The linear character suggests exploitation of an underlying weakness by a tributary stream in the Story Hills. Finally, gravity data show a trough trending east-northeasterly through the Story Hills at this point, possibly indicating a fault at depth (Davis and others, 1965).

The Bridger Creek east-west fault is a more complex and difficult problem. A preliminary structural assessment of the area at a scale of 1:8,000 conducted by the author and Adrienne Bonnet in 1976 disclosed sufficient stratigraphic offset and structural discrepancies from one side to the other to imply offset along a fault plane (Plate 1).

The following inferences suggest a fault with an east-west trend through Bridger Canyon in Section 34, T.1 S., R.6 E.: (1) strata north of Bridger Creek are overturned, have a general northeast strike and dip northwestward, while strata south of Bridger Creek are also overturned but strike northwest and dip southwestward; and (2) a lack of stratigraphic continuity across the narrow canyon implies some kind of structural control which offsets the units along an east-west fault plane.

More pronounced thrusting on the south side of Bridger Canyon (Plate 1) supports McMannis' (1955) suggestion that a second phase of Paleocene compression occurred in the canyon area. This evidence and the structural and stratigraphic inferences noted above support the existence of a tear-fault coincident with Bridger Creek resulting from the second phase of Paleocene thrust faulting.

CHAPTER IV

GEOLOGIC HAZARDS AND CONSTRAINTS

General

The limits which natural processes and conditions impose on any given land use are called geologic constraints (e.g. creep, steep slopes). When these conditions and processes conflict with human activity, they become known as geologic hazards (Hansen and others, 1975). Human interaction with geologic constraints dates from the earliest civilization (Hansen and others, 1975). The costs to society of this confrontation have increased markedly with the advent of technology. Not all costs are measured in dollars however, as the quality of living is reduced as a result of the conflict (Hansen and others, 1975). The special place accorded Geology in the planning process comes from the unique guidelines and insights it provides the scientist to better evaluate and predict the consequences of the interaction of human land use and natural processes (Hansen and others, 1975).

Constraints addressed in this report include mass movement phenomena and the associated factors of slope steepness and aspect, creep, solifluction and unstable and potentially unstable slopes (Plate 5). Hydrologic con-