Solid waste disposal site suitability evaluation in Montana
by David Wayne Bowen

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


Abstract:
Solid waste disposal site suitability studies are needed for understanding potential environmental hazards and for licensing. The Montana Solid Waste Management Bureau identified twenty-one operating sites needing evaluation for solid waste disposal suitability. The sites were evaluated by on-site reconnaissance of soil and hydrogeologic factors. The primary criteria evaluated were permeability of surficial materials, groundwater flow, connection of shallow groundwater with deeper aquifers, and proximity to surface water. In general, a suitable site should be located in materials of low permeability with a deep water table, have no connection of shallow groundwater with deeper aquifers, and should be far from surface water. Fourteen of the twenty-one sites evaluated were unsuitable. Inadequate site suitability assessments were made prior to locating many solid waste disposal sites in Montana. Suitable sites exist within a five mile radius of each of the unsuitable sites. A small amount of data coupled with soil and hydrogeologic planning would lead to better siting.

The site specific studies emphasize the need for generalized soil and hydrogeologic information. Local authorities responsible for solid waste disposal site location must be aware of the constraints which control site suitability in their area. Important soil and hydrogeologic parameters which control site suitability can be categorized on a regional basis for Montana by dividing the state into five physiographic provinces. These five provinces are the Mountains and Valleys, the Unglaciated Plains and Mountains, the Glaciated Plains and Mountains, the Unglaciated Plains, and the Glaciated Plains. In general, unsuitable sites for solid waste disposal in the unglaciated provinces are underlain by alluvium, sandstone, limestone, igneous rocks, or metamorphic rocks; suitable sites are generally underlain by siltstone, claystone, or shale. In the glaciated provinces, unsuitable sites are generally underlain by glacial outwash sands and suitable sites are generally underlain by glacial till.

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Signature David W. Bowen

Date August 20, 1980

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DAVID WAYNE BOWEN

A thesis submitted in partial fulfillment
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Earth Science

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## ABSTRACT

Solid waste disposal site suitability studies are needed for understanding potential environmental hazards and for licensing. The Montana Solid Waste Management Bureau identified twenty-one operating sites needing evaluation for solid waste disposal suitability. The sites were evaluated by on-site reconnaissance of soil and hydrogeologic factors. The primary criteria evaluated were permeability of surficial materials, groundwater flow, connection of shallow groundwater with deeper aquifers, and proximity to surface water. In general, a suitable site should be located in materials of low permeability with a deep water table, have no connection of shallow groundwater with deeper aquifers, and should be far from surface water. Fourteen of the twenty-one sites evaluated were unsuitable. Inadequate site suitability assessments were made prior to locating many solid waste disposal sites in Montana. Suitable sites exist within a five mile radius of each of the unsuitable sites. A small amount of data coupled with soil and hydrogeologic planning would lead to better siting.

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# INTRODUCTION

Many solid waste disposal sites exist in the State of Montana. Relatively few have been assessed for suitability as disposal locations. Isolated site-specific studies at Butte and West Yellowstone, Montana show that contamination of ground and surface water takes place due to the location of solid waste sites in materials which are ill-suited for effective disposal (Kringler, 1979; Jones, 1979). There is a need to evaluate other sites in Montana to assess materials in which they are located for suitability as disposal mediums.

Sites evaluated in the past were evaluated on the basis of the soil at the site and the depth to the water table. These are important parameters which need to be evaluated, however, they are only a part of the integrated hydrogeologic system which controls the suitability of a site. In order to adequately evaluate the suitability for use in solid waste disposal, all parts of the soil and hydrogeologic system must be considered.

To determine a site's suitability for solid waste disposal, it is first necessary to be aware of those parameters which control suitability. With this awareness, a small amount of soil and hydrogeologic data coupled with minimal planning will lead to better siting of solid waste disposal operations.

Often, local people responsible for siting solid waste disposal operations for their communities are not familiar with those parameters which control a site's suitability, and, are not aware of soil and hydrogeologic relationships in their areas. With this in mind, three main objectives will be met:

1. summarize those parameters which control solid waste disposal site suitability,

2. present the relationship between the soils and hydrogeology at a site and the usefulness of that site for solid waste disposal, and

3. generalize soils and hydrogeologic information pertinent to solid waste disposal for the State of Montana.

These objectives are met by discussing the relationship between soils and hydrogeologic settings and solid waste disposal site suitability. Two sections discuss this relationship. The first section deals with 21 site specific studies in Montana, and conclusions drawn from these studies. The approach to the first section is to provide background information on parameters which control solid waste disposal site suitability, to summarize the results of 21 site specific studies, and to discuss the significance of the results and the associated need for generalized information.

The purpose of the second section is to provide general information useful for directing future site suitability assessments in Montana. This section also generates an awareness of problems related to locating solid waste disposal sites in Montana. The approach to this section is to divide the state into five physiographic provinces and to relate soil and hydrogeologic settings with suitability for solid waste disposal in each of the provinces.

## SECTION ONE: SITE SPECIFIC STUDIES

### Introduction

The Montana Department of Health and the Environmental Protection Agency recognized that many small landfills exist in the State of Montana for which no site suitability studies have been done. There may be degradation of ground and surface water quality if landfills are located in materials which should not be used for solid waste disposal. Twenty-one disposal sites in Montana were chosen for site specific evaluation by the Montana Department of Health and Environmental Sciences (Figure 1) (Bowen, Custer, and Miller, 1979). The section on site specific studies demonstrates patterns of solid waste disposal site suitability.

The site specific section defines parameters that control suitability. This section uses these parameters to demonstrate the kinds of site suitability problems that exist in Montana. It then shows that hydrogeologic planning is necessary before locating a disposal site, and that only a small amount of general information can lead to much better siting.

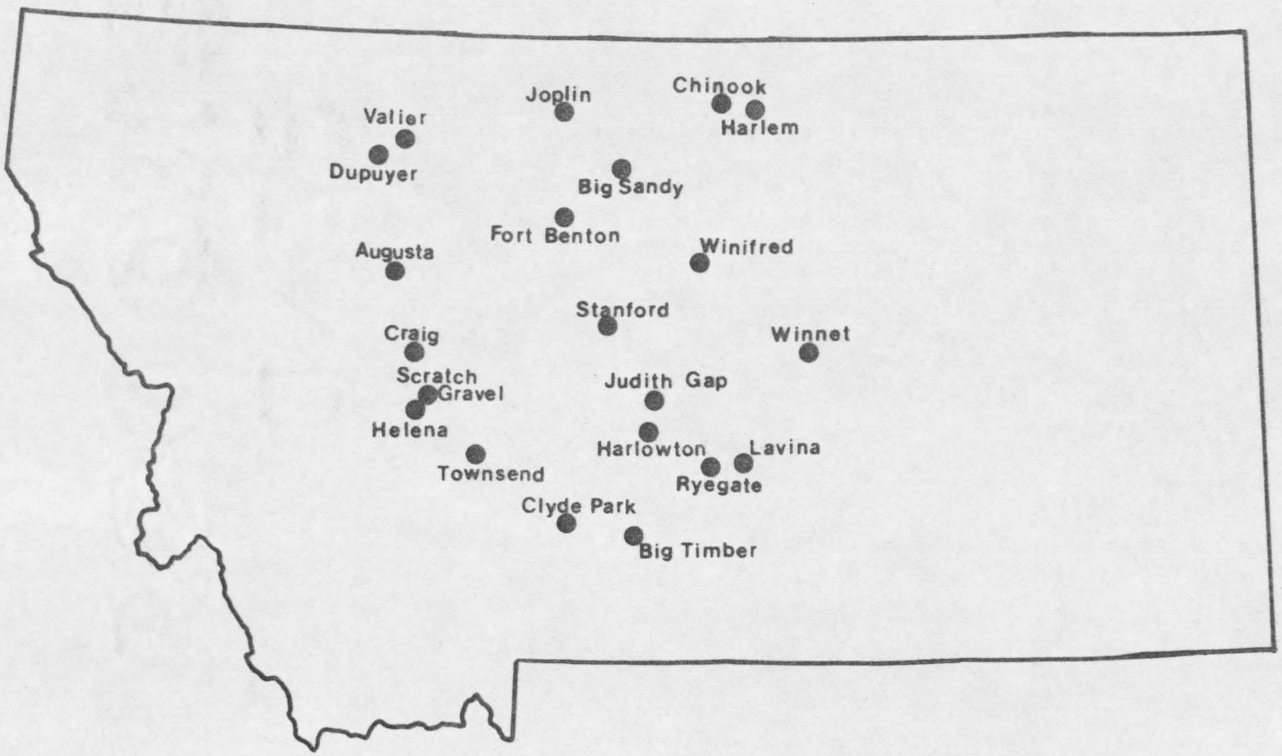



Figure 1: Location map of the 21 site specific studies.

Background Information

Suitability of a site for use as a solid waste disposal site is determined by political, social, economic, climatological, workability, and environmental parameters (Bergstrom, 1968). The study of political, social, economic, and climatological factors is beyond the scope of this study. All of the 21 sites evaluated are in operation. Therefore, workability factors, which include soil texture, soil consistence, stoniness, rockiness, and depth to bedrock (U. S. Soil Conservation Service, 1971), will not be considered further in the site specific section. The evaluated parameters for the 21 chosen sites are all environmental.

The environmental suitability of a solid waste disposal site is dependent upon the ability of the materials in which a site is located to prohibit the production of leachate, or isolate any leachate which is produced at the site (Bergstrom, 1968). Since this is a reconnaissance study, no wells were drilled for monitoring the production and movement of leachate. Thus, several assumptions are necessary. These assumptions are that leachate is produced in a semi-arid climate, and that this leachate is capable of contaminating ground and surface water. Leachate is produced at the West Yellowstone, Montana, and Butte, Montana landfill sites. This leachate is contaminating ground and surface water (Kringler, 1979; Jones, 1979). Assuming leachate production at landfill sites in Montana, and the capability for contamination of ground and surface water by this leachate, the suitability of a landfill site is controlled by the integrated soil and hydrogeologic system of that site. In general, a suitable site will have impermeable soils and surficial deposits, a deep water table, no connection of shallow groundwater with deeper aquifers, and will be far from surface water (Figure 2). Impermeable soil, when used as a cover material for waste, limits water infiltration and thus the production of leachate. Impermeable surficial deposits help contain leachate to the disposal site. A deep water table lessens the potential for shallow groundwater contamination by leachate. With no connection of shallow groundwater to deeper aquifers the potential for contamination of regional aquifers is eliminated. Finally, a large distance between a disposal site and surface water reduces the potential for contamination of surface water.

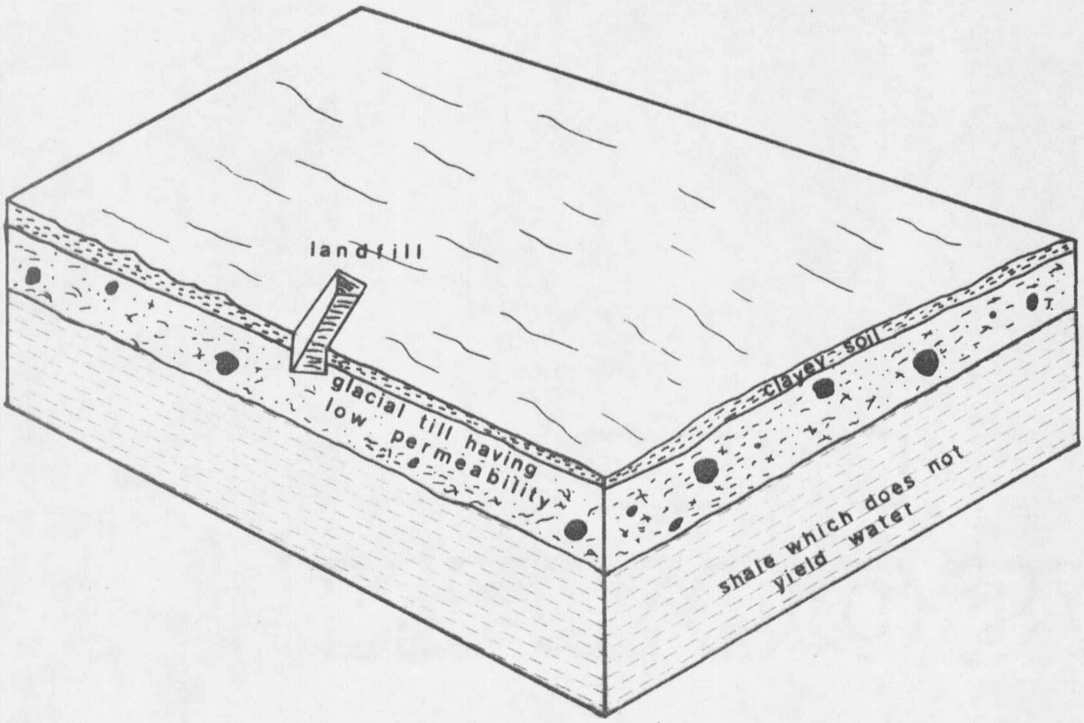



Figure 2: Soils and hydrogeology at a hypothetical suitable, landfill site.

Solid waste disposal sites may be unsuitable for a variety of reasons. A site will not be suitable if it has highly permeable soils and surficial deposits which allow water to infiltrate refuse producing a leachate, and allow this leachate which is produced to escape through the base of the site (Figure 3). A shallow water table beneath the site, which can easily be contaminated by leachate, causes the site to be unsuitable. A site will also be unsuitable if there is a connection between shallow groundwater and deeper aquifers which could lead to contamination from leachate, since, leachate contaminating shallow groundwater could then contaminate deeper aquifers. The other factor which could cause a site to be unsuitable is proximity to surface water, which could lead to contamination of that surface water by leachate.

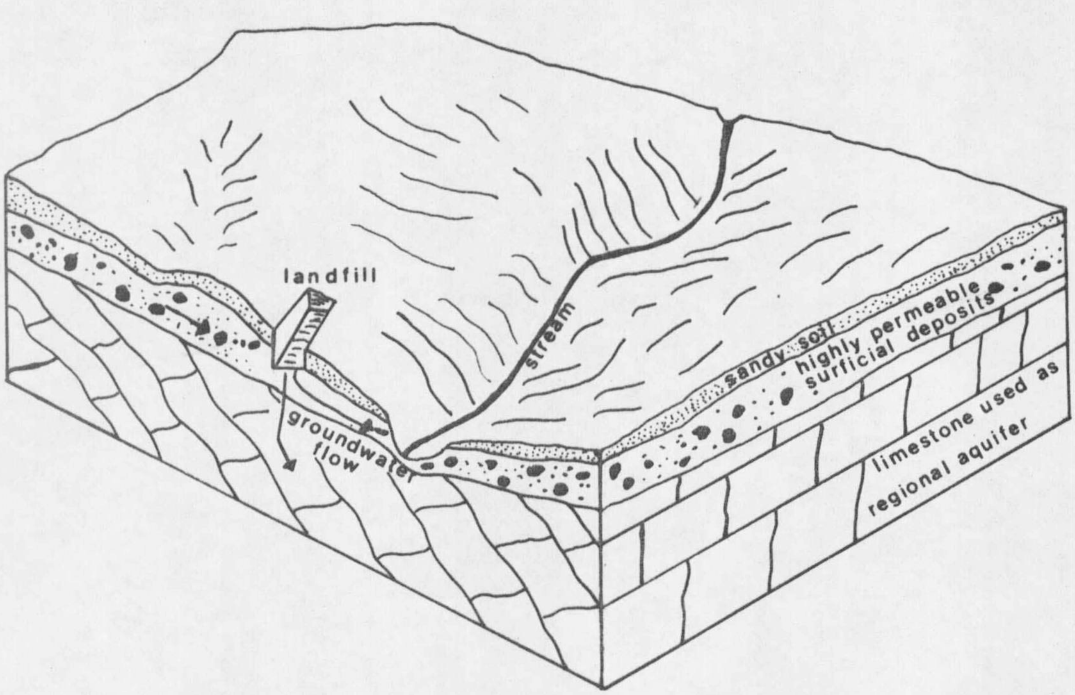



Figure 3: Soils and hydrogeology at a hypothetical, unsuitable landfill site.

In summary, four general criteria are useful for evaluating the environmental suitability of a site:

1. permeability of soils and surficial deposits,
2. depth to shallow groundwater,
3. connection of shallow groundwater with deeper aquifers, and
4. proximity to surface water.

Methods

Field:

soils Operational trenches or backhoe pits were used at each site for soil evaluation. Texture was determined in the field by hand texturing. A field description of the soil included horizonation and thickness. A soil sample from each horizon was collected for lab analysis. Depth to bedrock was measured where exposed.

geology Surficial geologic deposits were determined and described through field observation. Local stratigraphy was described when surface outcrops were present.

hydrology Depth to water table was estimated from vegetative, topographic, and surface water associations. Water table contours were estimated on the basis of topography. Permeabiity was estimated on the basis of soil texture (U.S. Soil Conservation Service, 1971).

Lab:

soils Soil samples were analyzed by hydrometer to determine their texture (Day, 1965). This work was done by the Montana State Soil Testing Lab.

Literature:

geology Available literature was used to determine local stratigraphy and structure, and the aquifer characteristics of stratigraphic units.

<u>hydrology</u> Regional groundwater flow was found from available literature.

Well Logs:

<u>geology</u> Depth to bedrock and local stratigraphy was found through well logs when applicable logs existed.

<u>hydrology</u> Depth to water table was found through well logs when applicable logs existed.

## Results

Limitations of sites for use as sanitary landfills were determined on the basis of the soils and hydrogeologic parameters evaluated at each individual site (Bowen, Custer, and Miller, 1979). The results of the study are summarized in Table 1. The results are discussed following the table.

| SITE | TEXTURE | PERMEABILITY | SLOPE | SURFICIAL DEPOSIT | ROCK UNIT | AQUIFER CHARACTERISTICS | DEPTH TO WATER TABLE | POTENTIAL FOR GROUND-WATER CONTAMINATION | POTENTIAL FOR SURFACE WATER CONTAMINATION | LIMITATION |
|---|---|---|---|---|---|---|---|---|---|---|
| Augusta | loam<br>clay loam | slow to mod. slow | 5% | glacial till | Two Medicine Fm | sand units produce water | +100' | slight | slight | slight |
| Big Sandy | sand<br>loamy sand | rapid | 7% | glacial outwash | Claggett Fm | sand units produce water | 4' | severe | moderate | severe |
| Big Timber | loam<br>loamy sand | mod. rapid to rapid | 2% | alluvium | unknown | unknown | 10-30' | severe | severe | severe |
| Chinook | sandy loam<br>loamy sand | very rapid | 5% | glacial outwash | Judith River Fm | sand units produce water | 20' | severe | severe | severe |
| Clyde Park | loam<br>loamy sand | <84cm slow to<br>+84cm rapid | 8% | alluvial fan | Livingston Fm | sand units prod. some water | 80' | severe | severe | severe |
| Craig | loam<br>sandy loam | mod. to mod. rapid | 8% | alluvial | volcanics | poor unless fractured | 30' | moderate | moderate | moderate |
| Dupuyer | clay loam<br>sandy loam | <100cm slow<br>+100cm rapid | 3% | glacial till, outwash | Two Medicine Fm | good in the Dupuyer area | 8.5' | severe | severe | severe |
| Fort Benton | clay loam<br>sandy loam | <100cm slow<br>+100cm rapid | 10-25% | colluvium | Colorado shale | very poor | 200' | slight | mod. to severe | severe |
| Harlem | clay loam | slow | 2% | glacial till | Bearpaw shale | poor | +100' | slight | slight | slight |
| Harlowton | clay loam<br>sandy clay | slow to mod. slow | 10-15% | alluvium | Judith River Fm | mod., sand units produce water | 30-40' | slight | slight | slight |
| Helena | silt loam<br>sandy loam | rapid | 3% | alluvial fan | Tert. basin fill | channel deposits prod. water | 30' | severe | severe | severe |
| Joplin | clay loam<br>silty clay | mod. slow to mod. | 2% | glacial till | Colorado shale | very poor | 4' | moderate | slight | moderate |
| Judith Gap | sandy clay<br>sandy loam<br>clay loam | slow, mod. rapid | 3.5% | alluvium | Judith River Fm | good in this part of Montana | 6' | severe | slight | severe |
| Lavina | loam<br>sandy loam | mod. | 3% | alluvium | Claggett Fm | poor | 20' | slight | moderate | moderate |
| Ryegate | sandy<br>loam | mod. rapid to rapid | 2% | absent | Eagle Fm | very good | +50' | moderate | slight | moderate |
| Scratch Gravel | loam, sandy<br>loam, gravel | slow, rapid | 4% | alluvial fan | intrusive igneous | poor unless fractured | 35-60' | severe | slight | severe |
| Stanford | loam, clay<br>loam, sandy<br>loam & clay | slow to very slow | 7% | alluvial | Colorado shale | very poor | 20' | slight | slight | slight |
| Townsend | silt loam<br>sandy loam<br>sand | slow<85cm, rapid 85+ | 8% | alluvial fan | Madison ls. | very good | 30-150' | severe | moderate | severe |
| Valier | clay loam<br>clay | very slow | 2% | glacial till | Two Medicine Fm | sand units produce water | +50' | slight | slight | slight |
| Winifred | sandy loam<br>clay loam | <70cm mod.<br>+70cm slow | 1% | alluvium | Judith River Fm | sand units produce water | 15' | slight | severe | severe |
| Winnet | clay loam<br>sandy clay<br>loam | mod. | 3% | alluvium | Colorado shale | very poor | +50' | slight | slight | slight |

Table 1: Summary of environmental parameters evaluated and suitability results for 21 evaluated landfill sites.

Discussion of Results

Evaluated sites were given suitability limitation ratings on the basis of potential for ground or surface water contamination by leachate from the sites. Since the studies did not include actual measurements of leachate production or movement, suitability limitation ratings were designated on the probability of contamination based on the soil and hydrogeologic parameters evaluated at each site. A site has a slight limitation if the soil and surficial deposit is of low permeability, the groundwater table is deep, shallow groundwater beneath the site is not connected with deeper aquifers, and the site is far from surface water. A site has a severe limitation if it is likely to cause contamination of ground or surface water. This contamination problem can be due to high permeability of soil and surficial deposits, a shallow groundwater table, a connection of shallow groundwater with deeper aquifers, or the site being close to surface water. A site has a moderate limitation if the site is less than ideal, but, is not clearly seen to be a potential source for contamination of ground or surface water. An example of this situation would be a site that is close to surface water, which would normally cause a severe limitation, but has soil and surficial deposits of very low permeabilities mitigating the contamination problem.

Seven of the 21 sites evaluated were determined suitable for solid waste disposal. The Augusta solid waste disposal site is an example (Table 1). The Augusta disposal site is in sandy-clay-loam and loam soil. The soil is developed from clayey glacial till and has low permeability. Groundwater is first encountered 100' below the landfill in a sand unit of the Two Medicine Formation (Figure 4). Relatively impermeable till and shale separate the disposal site from groundwater so there is little chance of groundwater contamination by leachate. The site is far from surface water, separated by gently rolling topography; there is little potential for surface water contamination.

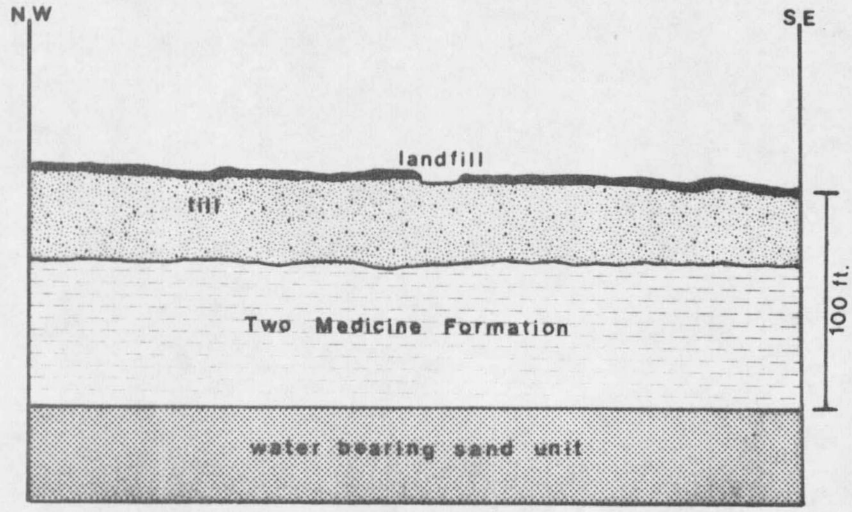



Figure 4: Generalized cross-section through the Augusta solid waste disposal site.

Fourteen of the sites were unsuitable for use as sanitary landfills. Sites were unsuitable for four reasons.

1. high permeability of soils and surficial deposits,
2. shallow groundwater flow through, or near, the base of a site,
3. connection of shallow groundwater beneath the site, with deeper aquifers,
4. proximity to surface water.

Examples of each type of problem are presented in the following paragraphs.

The Helena, Montana landfill site is an unsuitable disposal site due to the high permeability of surficial materials (Figure 5). Helena's landfill site is in sand and sandy loam soils having rapid permeability (Table 1). The surficial deposits at the Helena landfill site are alluvial fan deposits consisting of sands, gravels, and cobbles. This material has rapid permeability below the soil zone. The highly permeable nature of the surficial materials allows water to readily infiltrate refuse producing a leachate, and allows this leachate to leave the site through the base. The water table is 30' below the surface and a small stream discharges from the landfill through a culvert at the northeast end of the landfill site. The high permeability of surficial materials leads to a severe potential for ground and surface water contamination.

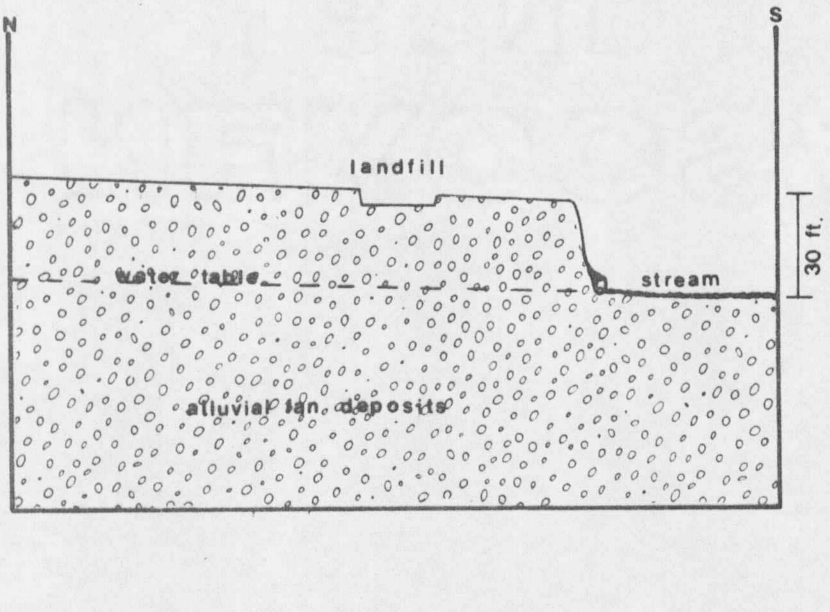



Figure 5: Generalized cross-section through the
Helena solid waste disposal site.

The landfill at Big Sandy, Montana is unsuitable because shallow groundwater flows through the base of the site (Figure 6). The Big Sandy landfill site is in sand and sandy loam soil (Table 1). The surface is veneered with 7 feet of glacial outwash sands overlying glacial till. Shallow groundwater is ponded above the glacial till and flows down the hydrologic (topographic) gradient through the sands. Refuse floats on water at the landfill site producing leachate. This leachate is transmitted away from the site in the shallow groundwater. Due to the severe potential for groundwater contamination the Big Sandy landfill site is unsuitable for use.

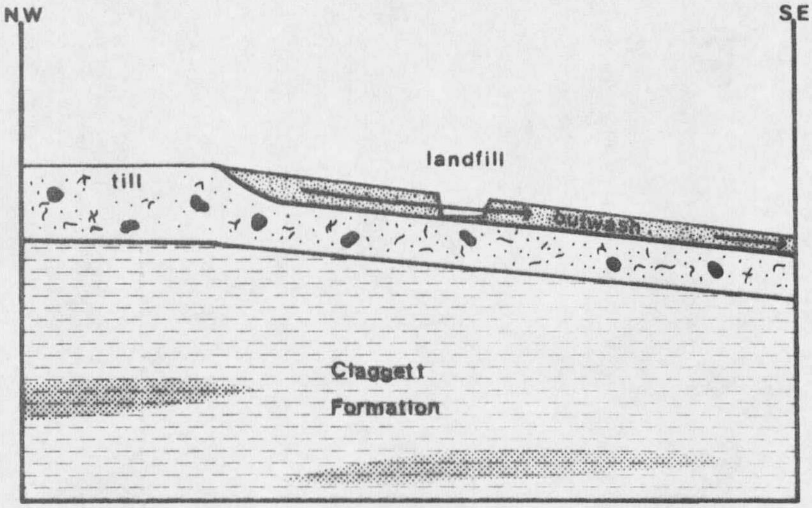



Figure 6: Generalized cross-section through the Big Sandy solid waste disposal site.

The landfill site at Judith Gap, Montana is unsuitable because of the connection between shallow groundwater and deeper aquifers under the site. (Figure 7). Field observation at the Judith Gap site shows a water table 6 feet below the surface and the Judith River Formation 7 feet below the surface. In the Judith Gap area the Judith River Formation is a sandstone which acts as a good aquifer (Groff, 1962). Shallow groundwater flowing through the base of the landfill will produce a leachate. This leachate will flow down gradient with the shallow groundwater and flow into the Judith River Formation, leading to a severe potential for contamination of that aquifer.

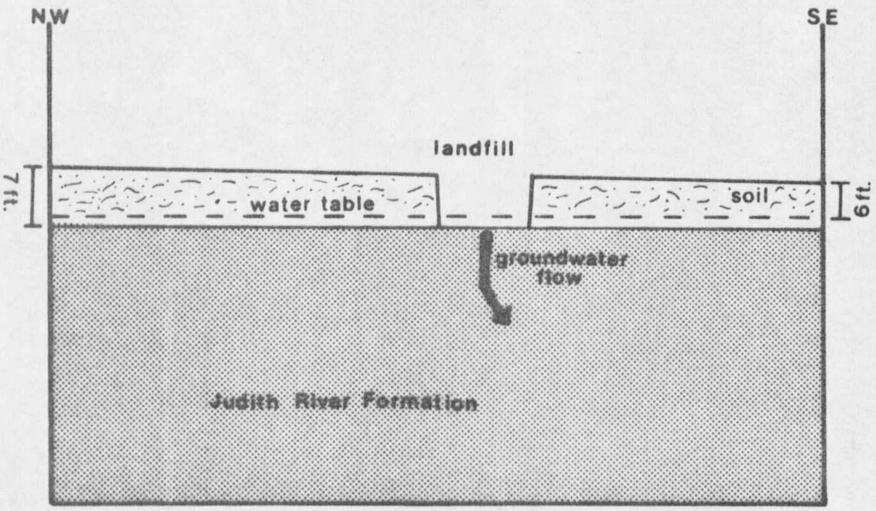



Figure 7: Generalized cross-section through the Judith Gap solid waste disposal site.

The Dupuyer, Montana landfill site is unsuitable due to a severe potential for contamination of surface water (Figure 8). The Dupuyer landfill site is in clay loam soil (Table 1). The surface is veneered with 5' of glacial till underlain by glacial outwash sands. The water table at the landfill site is 8.5 feet below the surface with the base of the landfill trench below the water table. Shallow groundwater flowing through the refuse leaches out contaminants and carries them down the hydrologic (topographic) gradient into Dupuyer Creek where shallow groundwater is discharged. Due to the severe potential for surface water contamination the Dupuyer site is unsuitable.

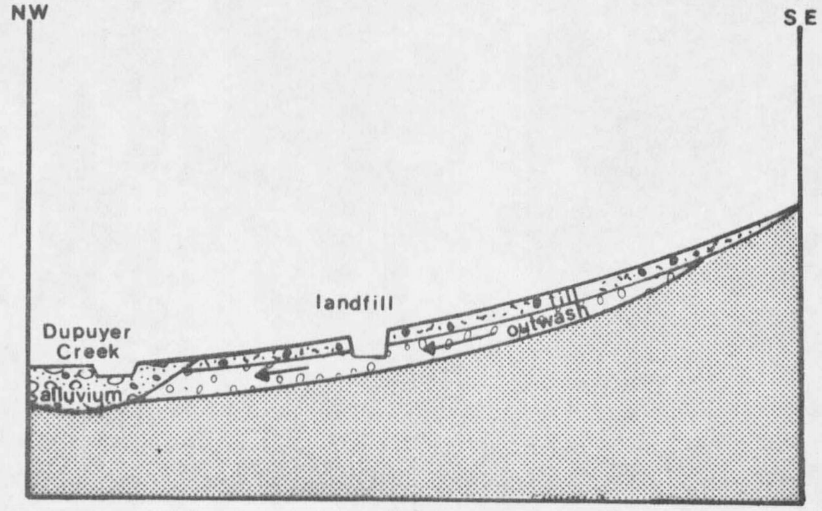



Figure 8: Generalized cross-section through the Dupuyer solid waste disposal site.

A site-suitability pattern emerged from these studies (Table 2). Suitability is strongly related to the geologic medium into which refuse is disposed. Those sites using a similar geologic medium for disposal generally have similar suitabilities.

Alluvium is usually unsuitable as in general it has high permeabilities, is close to surface water, and is found in association with shallow groundwater. Glacial outwash sands are usually unsuitable. Glacial outwash sands have rapid permeabilities and are associated with shallow groundwater. Sandstone is also generally unsuitable, as sandstone units are aquifers over much of Montana. Disposal sites located over sandstone units could easily transmit leachate into the associated aquifers.

Sites located in glacial till are generally suitable. Glacial till has low permeabilities which tend to contain leachate at the site area. Till fracturing may increase the permeability (Grisak and others, 1976) and could lead to severe limitations for sites located in the fractured till.

| Disposal Medium | Limitations Severe | Moderate | Slight |
|---|---|---|---|
| alluvium | 7 | 2 | 3 |
| glacial outwash | 3 | 0 | 0 |
| sandstone | 1 | 1 | 0 |
| glacial till | 0 | 0 | 4 |

Table 2: Site suitability patterns. The disposal mediums are listed on the left. The three columns represent the three limitation ratings. The numbers in these columns signify the number of sites having an assigned limitation for that disposal medium.

Inadequate site suitability assessments were made in the past. Fourteen out of the twenty-one sites evaluated were unsuitable. Only a small amount of data and minimal hydrogeologic planning would have been necessary to place these sites in suitable locations. All fourteen of the unsuitable sites had suitable locations within a 5 mile radius of the unsuitable site.

The landfill at Judith Gap, Montana is an example which shows the necessity for hydrogeologic planning before disposal site location. The landfill site at Judith Gap is unsuitable due to a potential for connection of shallow groundwater with deeper aquifers as previously discussed. The geologic units of concern at the Judith Gap landfill site are the Judith River Formation, the Claggett Formation, the Eagle Sandstone, and the Colorado Shale (Figure 9).

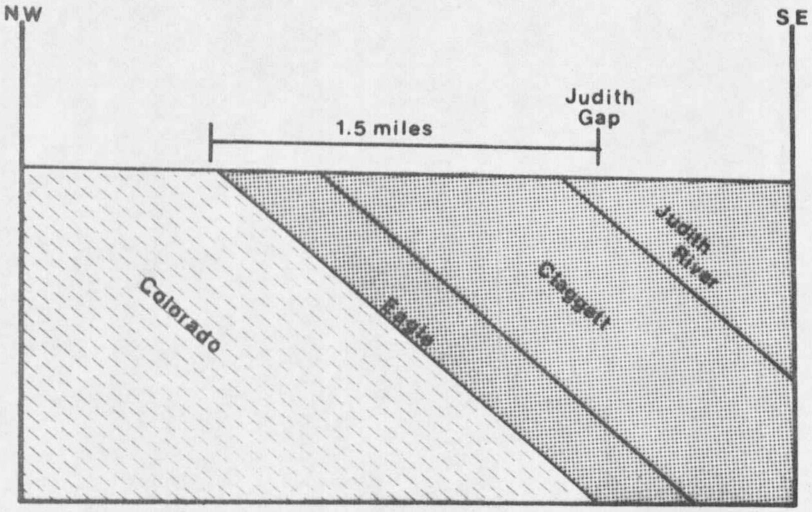



Figure 9: Generalized NW-SE cross-section in the Judith Gap area.

All four of these units trend northeast-southwest and dip to the southeast (Groff, 1962). The Judith River Formation, Claggett Formation, and Eagle Sandstone are all sandstone units and act as good aquifers in this part of Montana (Groff, 1962). The Colorado Shale has very poor water bearing characteristics (Groff, 1962). Solid waste disposal sites should avoid any of the three sandstone units because of the potential for contamination of their associated aquifers. The Colorado Shale, however, is a good geologic unit on which to place disposal sites as the soils developed on the Colorado Shale are generally deep and impermeable (Veseth, 1980), and the unit is not an aquifer. The Colorado Shale is found at the surface 1.5 miles to the northwest of the existing Judith Gap landfill site (Figure 9). A site located over the Colorado Shale would most likely be suitable.

Conclusions

Inadequate site suitability assessments were made before locating many solid waste disposal sites in Montana. Fourteen out of twenty-one sites evaluated were unsuitable. Only a small amount of data and minimal hydrogeologic planning would have been necessary to place these sites in suitable locations. Suitable locations exist within a five mile radius of each of the unsuitable sites. A general knowledge of soils and hydrogeology in an area coupled with a small amount of planning would lead to better placement of solid waste disposal sites. The following section will generalize soil and hydrogeologic information helpful in planning future solid waste disposal sites in Montana.

## SECTION TWO: RELATIONS OF SOIL AND HYDROGEOLOGIC SETTINGS TO SOLID WASTE DISPOSAL SITE SUITABILITY IN MONTANA

### Introduction

The site studies show that inadequate site suitability assessments were made before locating many existing solid waste disposal sites in Montana. Generalized information on Montana's soils and hydrogeology will help direct future siting in specific ways. The information creates an awareness of how local materials relate to the location of suitable solid waste disposal sites. The information also helps to identify disposal problems which might be expected in a given area. The following section will provide this generalized information on soils and hydrogeology as it relates to solid waste disposal in Montana.

The suitability of a site for the disposal of solid wastes is controlled by the integrated system of the soils and hydrogeology at the site. The soils and hydrogeology in a given area are determined by the geologic history of an area and the resultant geologic relationships. These geologic relationships will determine the physiography of the area. Areas with similar physiographies have comparable soil and hydrogeologic properties, and therefore have similar suitability characteristics for solid waste disposal.

Montana can be divided into five physiographic provinces

(Figure 10).

1. Mountains and Valleys
2. Plains and Mountains Unglaciated
3. Plains and Mountains Glaciated
4. Plains Unglaciated
5. Plains Glaciated

Each of these provinces have characteristic soil and hydrogeologic relationships resulting from the geologic history within the province. Suitability for solid waste disposal is dependent upon the soil and hydrogeologic relationships. It may be noted that Fenneman's (1931) classification of physiographic provinces is not used. This is because Fenneman's classification deals with the western United States as a whole and is not specific enough for the purpose of this paper.

This section develops each of the five physiographic provinces according to the following format:

1. <u>geographic setting</u> The geographic setting describes general physical characteristics and the boundary of the province.

2. <u>general geologic setting</u> The general geologic setting provides generalized background information on the geologic history of the province and the resultant geologic relationships.

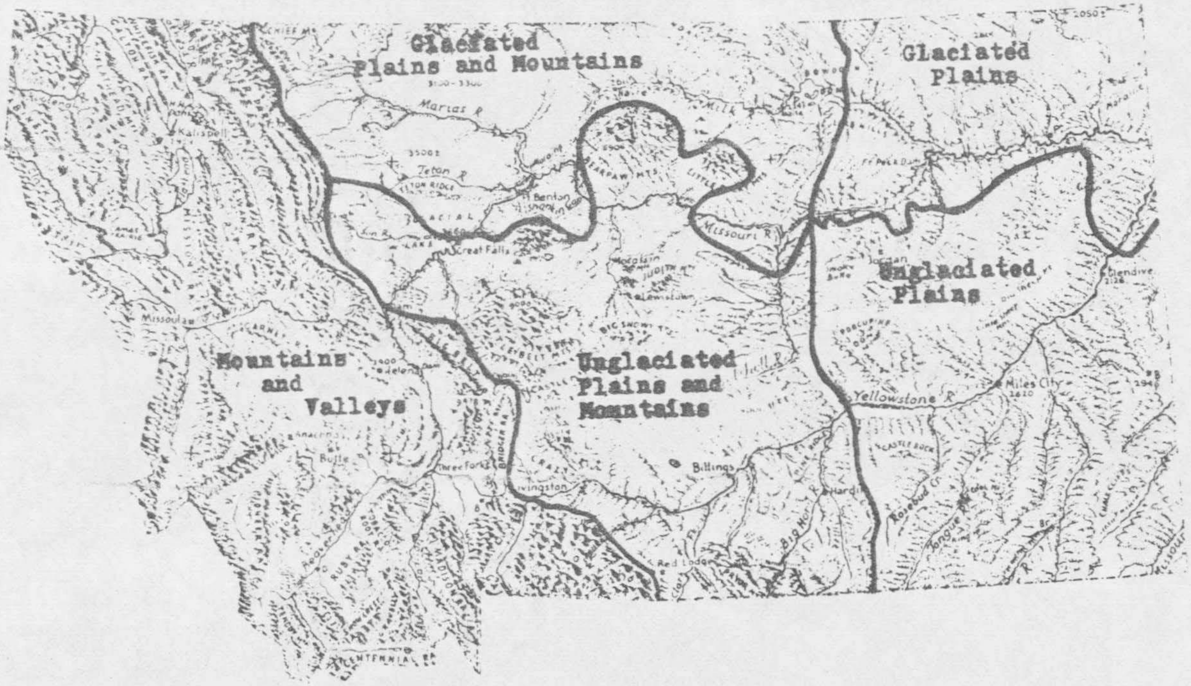



Figure 10: Physiographic map of Montana.
(modified from Raisz, 1952)

3. hydrogeologic units and water bearing characteristics The section discusses the hydrogeologic units found in the province and the water bearing characteristics of these units.

4. soils The soils section discusses the soils developed on the hydrogeologic units and the properties of these soils as related to the disposal of solid wastes.

5. suitability patterns The section on suitability patterns discusses those properties associated with each hydrogeologic unit in the province which relates to suitability for solid waste disposal.

6. summary This section summarizes disposal mediums which should be avoided and disposal mediums which are generally suitable in the province.

There is some redundancy of information between physiographic province chapters. This is intentional as each chapter is written as a complete unit which can be read without reference to other chapters, to aid readers interested only in a specific region.

## Mountains and Valleys Province

### Geographic Setting

The Mountains and Valleys Province consists of a linear group of northwest-southeast mountains separated by broad intermontane basins (Figure 11). The boundary of the province is the Montana-Canada border to the north, the Montana-Idaho border to the west, the Montana-Wyoming border to the south, and the change in relief associated with the Plains and Mountains Province to the east.

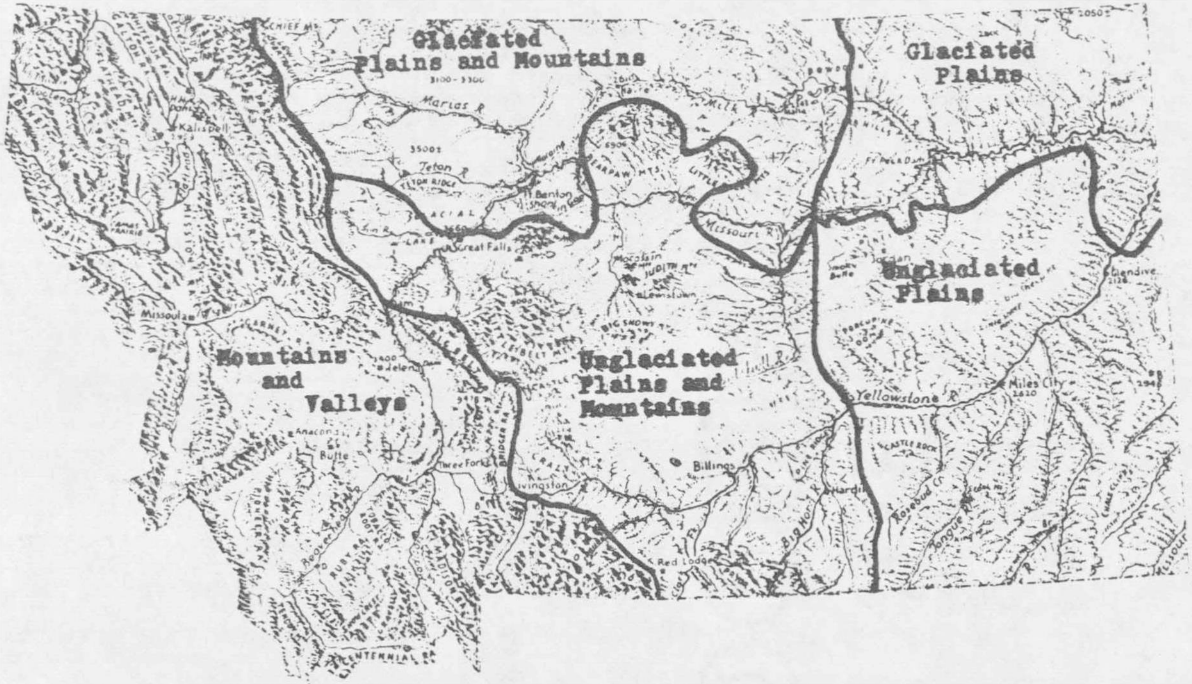



Figure 11: Location map of the Mountains and Valleys Province. (modified from Raisz, 1952)

General Geologic Setting

The Mountains and Valleys Province has a long geologic history. Compression during the Laramide Orogeny folded and faulted the Rocky Mountains in late Cretaceous and early Tertiary time. Erosion during early Tertiary time modified these mountains and filled the valleys with sediment. Tertiary/Cretaceous igneous rocks (Figure 12; Tkv, Tki) are sporadically dispersed throughout the Mountains and Valleys Province, the result of igneous activity associated with the Laramide Orogeny. Tensional block faulting began to lift mountains and drop valleys in middle Tertiary time and continues today. These movements temporarily blocked river drainages and the valleys filled with sediments from the erosion of adjacent mountains (TQu; Figure 12). At times, rivers flowed across the basins leaving channel sand and gravel deposits interbedded with the silt and clay deposits of blocked drainages (Hughes, 1980; Kuenzi and Fields, 1971; Robinson, 1963, 1961). Quaternary fluvial and eolian processes resulted in the deposition of alluvial fan, river, terrace, and loess deposits (TQu) over the Tertiary basin fill deposits. Mesozoic and Paleozoic sedimentary rocks (Km, Kc, KJTr, MP, D€) are found on the flanks and on the tops of uplifted blocks in southwest Montana. Precambrian metasediments (p€b, p€bl, p€bu) are widespread in north-

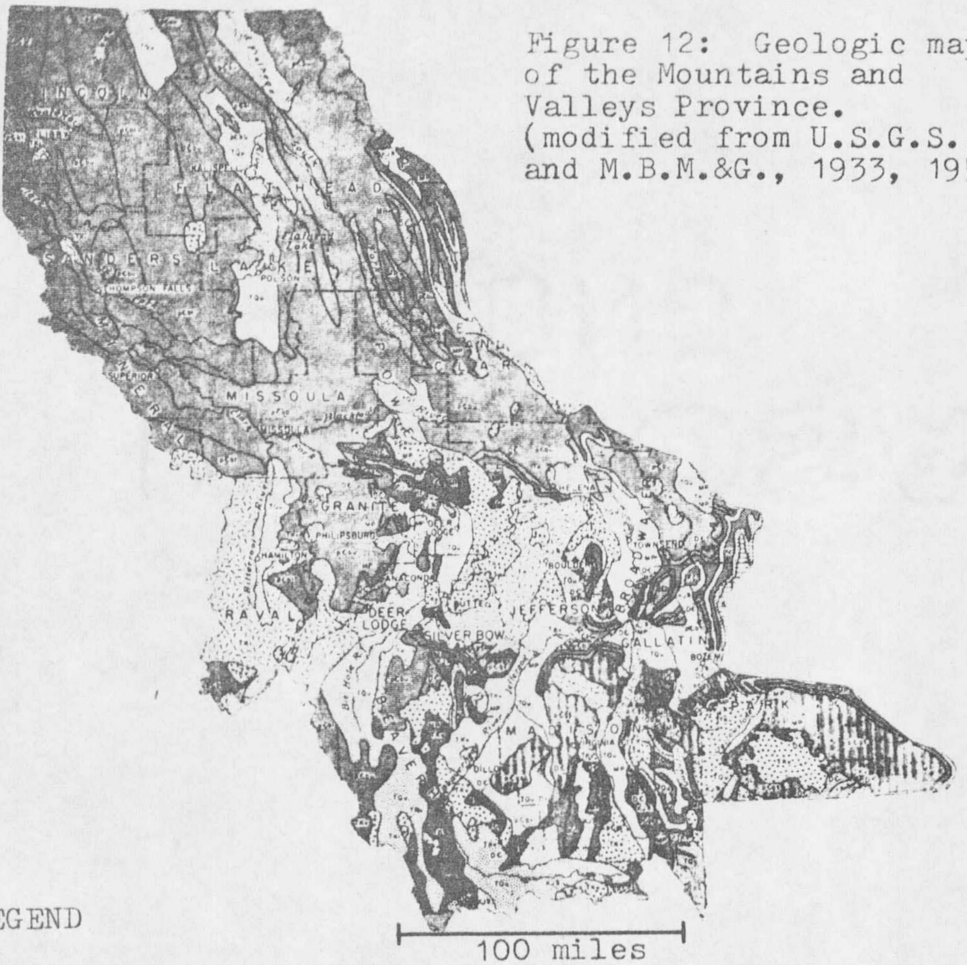



Figure 12: Geologic map of the Mountains and Valleys Province. (modified from U.S.G.S., and M.B.M.&G., 1933, 1955)

LEGEND

TQu Quaternary/Tertiary sediments

TKv, Volcanic Rocks
TKi, Intrusive Rocks
Tertiary/Cretaceous igneous rocks

Km KJR Dc Kc MP
Mesozoic and Paleozoic sedimentary rocks

p€b p€bu p€bl undifferentiated p€gs
Precambrian metasediments and metamorphic rocks

western Montana. Precambrian crystalline metamorphic rocks (pꞒgs) are exposed in the cores of some uplifted blocks in southwestern Montana.

Hydrogeologic Units and Water Bearing Characteristics

Rocks in the Mountains and Valleys Province are divided into four hydrogeologic units based on similar map distribution, occurrence, and water yielding properties (Table 3). The major aquifers are located in sand and gravel units in the unconsolidated alluvial valley deposits (TQu). The Tertiary/Cretaceous igneous rocks act as aquifers only if fractured. The Mesozoic and Paleozoic sedimentary rocks are not used as major aquifers in the Mountains and Valleys Province at the present time, but, Mississippian limestones and Cretaceous sandstones produce abundant water in other regions. None of the Mesozoic or Paleozoic shales produce water. The water bearing characteristics of the Paleozoic hard sandstones are also poor. Precambrian crystalline metamorphic rocks and metasediments produce water only if enriched by fractures.

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY | WATER BEARING CHARACTERISTICS |
|---|---|---|---|
| Quaternary/Tertiary Sediments | TQu | gravels, cobbles | good |
| | | sand, silt | poor to moderate |
| | | clay | poor |
| Tertiary/Cretaceous Igneous Rocks | TKi | igneous intrusive | poor unless fractured |
| | TKv | igneous extrusive | poor unless fractured |
| Mesozoic and Paleozoic Sedimentary Rocks | Km | mod. hard sandstone | good |
| | | soft gray shale | poor |
| | Kc | soft gray-black shale | poor |
| | KJTr | hard sandstones | poor to moderate |
| | | soft red varicolored shales | poor |
| | | limestone | poor |
| | MP, D€ | hard sandstones | poor |
| | | green-gray shales | poor |
| | | limestones and dolomites | good |
| Precambrian Metasediments and Metamorphic Rocks | p€b, p€bl, p€bu | metasediments | poor |
| | | crystalline metamorphic rocks | poor unless fractured |

TABLE 3: Hydrogeologic units and water bearing characteristics in the Mountains and Valleys Province.

Soils

Soils in the Mountains and Valleys Province have been grouped into four major units corresponding to the hydrogeologic units on which they develop (Table 4). These four groups are further sub-divided according to dominant lithologies. The classification system presented is based on the premise that certain soil properties are inherited from the parent material (Veseth, 1980). Thus, soils of a given parent material have similar soil properties. The soil properties outlined in Table 4 are not the only possible soil properties that may be encountered given each of the parent materials, but are the dominant types to be expected.

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY OF SOIL PARENT MATERIAL | TEXTURE OF SOIL | PERMEABILITY | CONSISTENCE | STONINESS CLASS | SOIL DEPTH |
|---|---|---|---|---|---|---|---|
| Quaternary/ | | gravels, cobbles | sand, loamy sand | moderate to rapid | sl. sticky to sticky sl. plastic | class 3 | deep |
| Tertiary | TQu | sand and silt | loam, silty loam | mod. to mod. slow | sticky, sl. plastic | class 0 - 1 | mod. to deep |
| Sediments | | clay | clay loam | slow | sticky, plastic | class 0 | mod. to deep |
| Tertiary/ | TKi | igneous intrusive | loamy sand, sand | rapid | sl. sticky, sl. plastic to non-plastic | class 0 - 3 | shallow to mod. |
| Cretaceous | TKv | extrusive igneous | loam | mod. to mod. slow | sl. sticky, sl. plastic | class 0 - 1 | shallow to deep |
| Igneous Rocks | | | | | | | |
| Mesozoic | Km | mod. hard sandstone | sand, loam, silt loam, sandy loam | mod. rapid to very rapid | non-sticky, non-plastic | class 0 - 2 | shallow |
| and | | | | | | | |
| Paleozoic | | soft gray shale | clay loam, silty clay loam, sandy clay loam | slow to very slow | sticky, plastic to very plastic | class 0 | mod. deep to deep |
| Sedimentary | | | | | | | |
| Rocks | Kc | soft gray black shale | clay loam, silty clay loam, sandy clay loam | slow to very slow | sticky, plastic to very plastic | class 0 | mod. deep to deep |
| | KJTr | hard sandstones | sand, sandy loam, loamy sand | mod. to mod. rapid | non-sticky to sl. sticky, non-plastic to sl. plastic | class 1 - 2 | shallow to mod. |
| | | soft red varicolored shales | clay, clay loam | mod. slow to very slow | sticky, plastic to very plastic | class 0 | mod. deep |
| | MP, D€ | hard sandstones | sand, loamy sand, sandy loam | mod. to mod. rapid | non-sticky to sl. sticky, non-plastic to sl. plastic | class 1 - 2 | shallow to mod. |
| | | mod. hard green-gray shale | clay, clay loam | mod. slow | sl. sticky to sticky, sl. plastic to plastic | class 0 | mod. |
| | | limestones & dolomite | loam, silt, silt loam | mod. | sl. sticky, sl. plastic | class 1 - 3 | shallow to deep |
| Precambrian | p€b, p€bl, p€bu | metasediments | fine sandy and loamy | mod. to mod. rapid | non-sticky to sl. sticky non-plastic to sl. plastic | class 1 - 3 | shallow to mod. |
| Metasediments and | | | | | | | |
| Metamorphic Rocks | p€gs | crystalline metamorphic rocks | sand, loam | mod. rapid | non-sticky to sl. sticky non-plastic to sl. plastic | class 1 - 3 | shallow to mod. |

TABLE 4: Characteristic soil properties in the Mountains and Valleys Province. (Data for this table was obtained from Veseth, 1980)

(see Appendix for explanation of soil parameters)

## Suitability Patterns

### Quaternary/Tertiary Sediments

Quaternary alluvial deposits are generally unsuitable for solid waste disposal because of high permeability, good water bearing characteristics, and association with surface water and shallow groundwater. The large number of cobbles in soils developed from Quaternary alluvium causes workability problems as well. Quaternary loess deposits are not a function of the underlying geology, therefore, suitability for solid waste disposal cannot be determined on the basis of the presence of loess only. Loess does act as suitable cover material, since it consists of silt loam and has moderate permeability, and is slightly sticky, and slightly plastic when wet. Loess is desirable cover material from both an environmental and workability viewpoint.

Suitability of Tertiary deposits is dependent upon texture, as the lithology of these deposits is highly variable. Tertiary gravel deposits are undesirable for use as a disposal medium due to the high permeability, rapid infiltration, good water bearing characteristics, and poor workability. Tertiary sand and silt deposits may or may not be suitable. The suitability of this material is dependent upon the permeability and water bearing characteristics in a given location. A high silt content leads to low permeability and poor water bearing characteristics, while a high sand content leads to high permeability and good water bearing characteristics. Site specific information is especially important before considering the location of a disposal site in Tertiary sand and silt deposits. Tertiary clay deposits are generally suitable because they have low permeabilities, fair ratings for use as a cover material, moderate to deep soil development, and stoniness classes of 0. (U.S. Soil Conservation Service, 1971). The only problem which may be anticipated with sites located in these clay deposits is workability during wet weather due to the sticky, plastic wet consistence of the clay.

Tertiary/Cretaceous Igneous Rocks

Suitability of extrusive igneous rocks for solid waste disposal depends upon the depth and type of soil development on the igneous rocks, and fracturing in the rock. These units are suitable only if there has been deep soil development, clay formation from weathering of the feldspar minerals in the rock, and no fracturing of the rock to allow water movement out of the base of the landfill and into the rock. Some workability problems are anticipated when soil development is shallow. Usually igneous extrusives are unsuitable.

Intrusive igneous rocks are generally unsuitable because the soils developed on intrusive igneous rocks are highly permeable with workability problems common due to shallow soil development and high stoniness. If fractured, intrusive igneous rocks will transmit water rapidly from the base of the landfill and cause high potentials for contamination of groundwater.

## Mesozoic and Paleozoic Sedimentary Rocks

Mesozoic and Paleozoic sedimentary rocks will generally be unsuitable because they occur on steep slopes in the mountains. If exposures are found in the foothills where steep slopes and lack of soil development are not prohibitive, suitability will be dependent upon the lithology below the landfill site. Sandstones are generally unsuitable. Soils developed on sandstones have high permeabilities, Cretaceous sandstones have good water bearing characteristics, and workability problems are anticipated on some sites located above sandstone. Limestones and dolomites are unsuitable for use as disposal mediums. Mississippian carbonates have good water bearing characteristics which connect to regionally important aquifers. Carbonates also have workability limitations because of shallow soil development and high stoniness classes.

Shales are usually suitable for use as disposal mediums. Shales and the soils which develop on the shale, have low permeabilities with moderate to deep soil development. The only problem which may be anticipated with sites located on shales is workability when wet due to the sticky, plastic wet consistence of the clay soils.

## Precambrian Metasediments and Metamorphic Rocks

Precambrian metasediments and metamorphic rocks are usually unsuitable for use as disposal mediums for solid wastes. Soils developed on these rock types have moderate to moderately rapid permeabilities. Workability problems are severe due to shallow soil depths and stoniness hazards. The operation of disposal sites on these rock types would be extremely difficult.

## Summary

In general, sandstones, limestones, igneous rocks, metasediments, metamorphic rocks, coarse alluvium, and sites proximal to surface water should be avoided when locating sites in the Mountains and Valleys Province. Suitable sites include Tertiary clay deposits, possibly Tertiary silt deposits, and Mesozoic and Paleozoic shale units in the foothills. Use of this paper does not preclude the use of site specific studies, as it is intended only as a guide for directing future work.

## Unglaciated Plains and Mountains Province

### Geographic Setting

The Unglaciated Plains and Mountains Province is a series of dissected plains interspersed with domal shaped mountains (Figure 13). The boundary of the province is the Montana-Wyoming border to the south, the southern limit of continental glaciation to the north, the change in relief associated with the Mountains and Valleys Province to the west, and the change in relief associated with the Plains Province to the east.

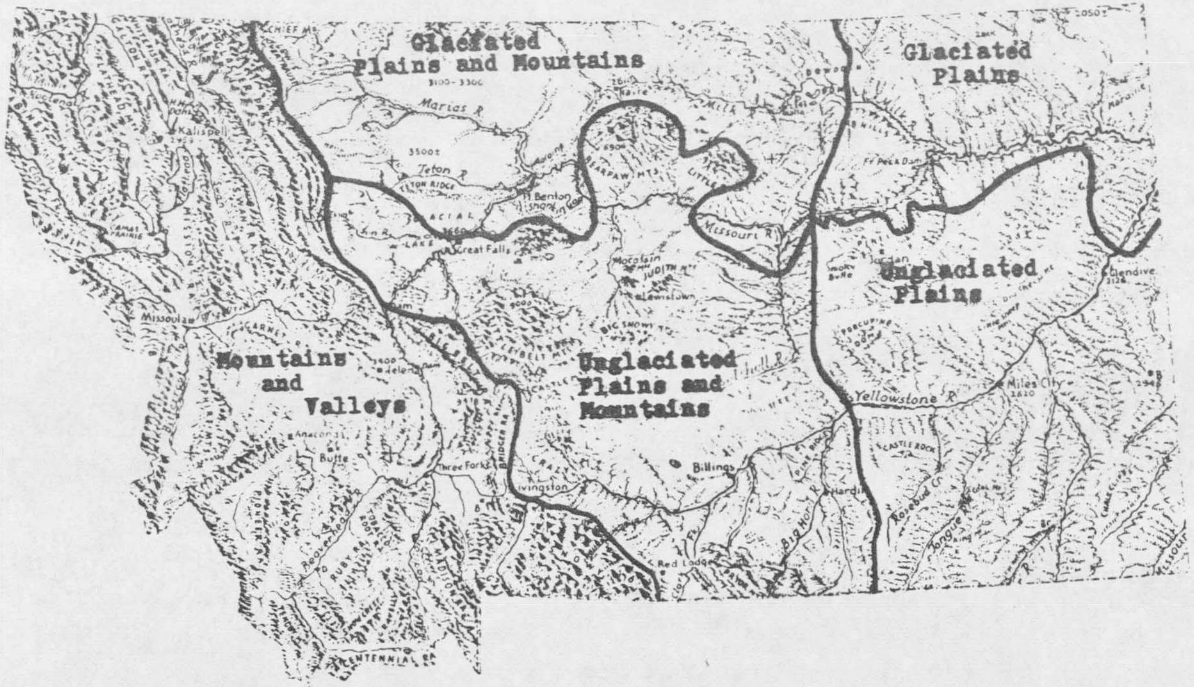
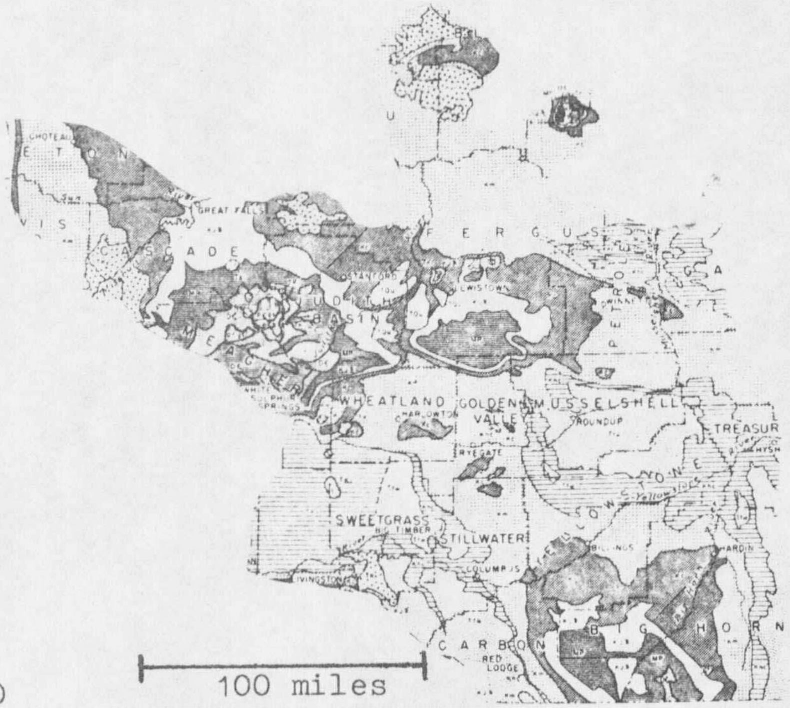



Figure 13: Location map of the Unglaciated Plains and Mountains Province. (modified from Raisz, 1952)

General Geologic Setting

The major structures in the Unglaciated Plains and Mountains Province are domes and monoclinal flexures formed during the Laramide Orogeny. Other, smaller, subcircular mountain groups evolved about igneous centers which were active in Late Cretaceous and Early Tertiary time. Reverse faults accompanied the compressional event associated with the Laramide Orogeny, and normal faulting occurred with a post-Laramide tensional event. Some en echelon faults are also present (Eardley, 1955).

There are five main geologic associations in the Unglaciated Plains and Mountains Province (Figure 14). The Tertiary and Quaternary deposits (TQu) occur in the valleys of the province. The Tertiary deposits are basin fill deposits in limited areas where they have not been stripped away by erosion. The Quaternary deposits are alluvial fans, terraces, and modern river alluvium. Lower Tertiary and Mesozoic sedimentary rocks (TKl, Tfw, Khc, Km, Kc, KJTr) make up the majority of the outcropping rock package in this province. Lower Tertiary sedimentary rocks are generally exposed at the centers of basins. Mesozoic sedimentary rocks are brought to the surface at the uplifts and dip into the basins between them. Paleozoic sedimentary rocks (MP, D€) are exposed on the immediate flanks of uplifts where




LEGEND

TQu Tfw — Quaternary/Tertiary sediments

TKv, Volcanic Rocks; TKi, Intrusive Rocks — Tertiary/Cretaceous igneous rocks

TKl, Km, KJR, Khc, Kc — Tertiary and Mesozoic sedimentary rocks

MP, Dc — Paleozoic sedimentary rocks

pCgs — Precambrian sedimentary rocks

Figure 14: Geologic map of the Unglaciated Plains and Mountains Province. (modified from U.S.G.S. and M.B.M.&G., 1933, 1955)

erosion has removed younger rocks. Tertiary/Cretaceous intrusive and volcanic igneous rocks (TKi, TKv) are associated with many mountain groups in this province. Pre-cambrian metamorphic rocks (p€gs) are exposed only in those limited areas where they have been faulted to the surface in the centers of uplifts.

Hydrogeologic Units and Water Bearing Characteristics

The Plains and Mountains Unglaciated Province is divided into five hydrogeologic units based on similarities in geologic occurrence and water bearing characteristics (Table 5). These hydrogeologic units correspond to the five main rock associations discussed in the general geologic setting section.

Quaternary/Tertiary sediments act as aquifers when composed of sands and gravels. The water yielding characteristics of lower Tertiary and Mesozoic sedimentary rocks are dependent upon lithology. The shale units do not produce potable water, while the lower Tertiary and Mesozoic sandstone units yield water for stock and domestic wells (Groff, 1962; Perry, 1933, Zimmerman, 1962, Zimmerman, 1956). Water bearing characteristics of the Tertiary/Cretaceous igneous rocks are not well known. No wells are known to be producing water from these units, but, the water yielding characteristics of these igneous rocks are probably poor unless they have been fractured. Paleozoic sedimentary rocks are not notable aquifers on a local scale in the Plains and Mountains Unglaciated Province. However, Paleozoic carbonate units are major targets for high capacity water wells regionally (Lorenz and McMurtrey, 1956). Precambrian crystalline metamorphic rocks are not known to yield water.

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY | WATER BEARING CHARACTERISTICS |
|---|---|---|---|
| Quaternary and Tertiary Sediments | TQu | gravel and cobbles | good |
| | | sand and silt | moderate to poor |
| | | clay | poor |
| Tertiary and Cretaceous Igneous Rocks | Tki | Igneous Intrusives | poor unless fractured to yield secondary porosity |
| | Tkv | Igneous Extrusives | poor unless fractured to yield secondary porosity |
| Tertiary Sedimentary Rocks & Masozoic Sedimentary Rock | Tkl, Tfw | soft sandstone | moderate to good |
| | | soft siltstone | poor |
| | | soft claystone | poor |
| | Khc | soft sandstone | good |
| | | soft siltstone | poor |
| | | soft claystone | poor |
| | Km | moderately hard sandstone | Eaglé is excellent aquifer: Judith River good: Claggett good |
| | | soft gray shale | poor |
| | Kc | soft gray black shale | poor |
| | KJTr | hard sandstone | poor to moderate |
| | | soft red varicolored shale | poor |
| Paleozoic Sedimentary Rocks | MP | hard sandstone | poor |
| | D€ | limestone & dolomite | good: however not a major aquifer due to struct.position |
| | | moderately hard green/gray shale | poor |

(Table 5: continued next page)

Table 5 continued:

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY | WATER BEARING CHARACTERISTICS |
|---|---|---|---|
| Precambriam Metamorphic Rocks | p€gs | medium to course grained hard metamorphic rocks | poor |

TABLE 5: Hydrogeologic units and water bearing characteristics in the Plains and Mountains Unglaciated Province.

## Soils

Soils in the Plains and Mountains Unglaciated Province have been grouped into five major units corresponding to the hydrogeologic units on which they develop (Table 6). These five groups are further sub-divided according to dominant lithologies. The classification system presented is based on the premise that certain soil properties are inherited from the parent material (Veseth, 1980). Thus, soils of a given parent material have similar soil properties. The soil properties outlined in Table 6 are not the only possible soil properties that may be encountered given each of the parent materials, but are the dominant types to be expected.

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY OF SOIL PARENT MATERIAL | TEXTURE | PERMEABILITY | WET CONSISTENCE | STONINESS | SOIL DEPTH |
|---|---|---|---|---|---|---|---|
| Quaternary | TQu | gravels & cobbles | sand to loamy sand | mod. rapid to rapid | slightly sticky, slightly plastic | class 3 | deep |
| & Tertiary | | sand and silt | loam to silty loam | mod. to moderately slow | sticky and slightly plastic | class 0 - 1 | moderate to deep |
| Sediments | | clay | clay loam | slow | sticky and plastic | class 0 | moderate to deep |
| Tertiary | TKl, | soft sandstone | sands and sand loams | rapid to very rapid | non-sticky, non-plastic | class 0 | moderate |
| Sedimentary | | soft siltstone | loams and silt loams | moderate | slightly sticky, slightly plastic | class 0 | moderate to deep |
| Rocks | Tfw | soft claystone | clay loams | slow to very slow | sticky plastic | class 0 | mod. deep to deep |
| & | | soft sandstone | sands and sand loams | rapid to very rapid | slightly sticky, slightly plastic | class 0 - 2 | shallow to moderate |
| Mesozoic | Khc | soft siltstone | loams and silt loams | moderate | slightly sticky, slightly plastic to non-plastic | class 0 - 3 | shallow to deep |
| | | soft claystone | clay loams | slow to very slow | non-sticky, non-plastic | class 0 | moderate |
| Sedimentary | Km | mod. hard sandstone | sand loams, silt loams & loams | very rapid to mod. rapid | slightly sticky, slightly plastic | class 0 | moderate to deep |
| Rocks | | soft gray shale | clay loams | slow to very slow | sticky, plastic | class 0 | mod. deep to deep |
| | Kc | soft gr/bl. shale | clay loams | slow to very slow | non-sticky, non-plastic | class 0 | shallow |
| | KJTr | hard sandstone | sands and loamy sands | mod. to mod. rapid | sticky, plastic to very plastic | class 0 | deep to mod. deep |
| | | soft red vari-colored shale | clays and clay loams | mod. slow to very slow | sticky, plastic to very plastic | class 0 | deep to mod. deep |
| Paleozoic | | hard sandstone | sands and loamy sands | very rapid to mod. rapid | non-sticky to slightly sticky, non-plas. to slightly plas. | class 1 - 2 | shallow |
| Sedimentary | MP | limestone & dolomite | loam, silt, silt loam | moderate | slightly sticky, slightly plastic | class 1 - 3 | shallow to moderate |
| Rocks | DЄ | mod. hard gr/gy shale | clays and clay loams | moderately slow | slightly sticky to sticky, slightly plas. to plastic | class 0 | moderate |
| Precambrian Metamorphic Rocks | pЄgs | hard, coarse grained metamorphic rocks | sands and loams | moderately rapid | non-sticky to slightly sticky, non-plastic to slightly plastic | class 1 - 3 | shallow to deep |

Table 6: Characteristic soil properties in the Unglaciated Plains and Mountains Province. (data for this table was obtained from Veseth, 1980)

(see Appendix for explanation of soil parameters)

## Suitability Patterns

### Quaternary and Tertiary Sediments

Quaternary deposits are generally unsuitable for solid waste disposal. The high permeability, good water-bearing characteristics, and association of Quaternary alluvium with ground and surface water cause these deposits to be environmentally unsuitable. The large number of cobbles in the soil causes workability problems as well. Suitability of unconsolidated Tertiary deposits is dependent upon texture as the lithology of these deposits is highly variable. Tertiary gravel deposits are undesirable for use as a disposal medium due to the high permeability, good water bearing characteristics, and poor workability characteristics of these deposits. Tertiary sand and silt deposits may or may not be suitable. The suitability of this material is dependent upon the permeability and water bearing characteristics in a given location. A high silt content leads to low permeability and poor water bearing characteristics, while a high sand content leads to high permeability and good water bearing characteristics. Site specific information is necessary before considering the location of a disposal site in Tertiary sand and silt deposits. Tertiary clay deposits are generally suitable. These deposits have low permeabilities, fair suitability ratings for use as a cover material (U.S.D.A. Soil Conservation Service, 1971), moderate to deep soil development, and stoniness classes of 0. The only problem which may be anticipated with sites located in Tertiary clays is workability during wet weather due to sticky, plastic wet consistence.

Lower Tertiary and Mesozoic Sedimentary Rocks

The site suitabilities for solid waste disposal of this group of sedimentary rocks is dependent upon the lithologies of the rock units. Sandstones are unsuitable for use in disposing of solid wastes because they are highly permeable and are aquifers, which result in environmental problems. The hard sandstones have shallow soil development resulting in workability problems as well.

Soft siltstones, soft claystones and shales are generally suitable for use as disposal mediums. These units have very poor water bearing characteristics; the associated soils are deep and of low permeability. The only problem which may be anticipated is workability during wet weather due to sticky, plastic wet consistence of clay soils.

Tertiary/Cretaceous Igneous Rocks

Extrusive igneous rocks are generally unsuitable for use as disposal mediums. Igneous extrusives generally have shallow soils, poor workability because of the shallow soils and, fracturing, which could lead to groundwater contamination problems if used as a disposal medium.

Intrusive igneous rocks generally are unsuitable. The soils developed on igneous intrusives are highly permeable and workability problems are prevalent as a result of shallow soil development and high stoniness. If fractured, igneous intrusive rocks transmit water rapidly.

Paleozoic Sedimentary Rocks

Paleozoic sedimentary rocks will generally be unsuitable for use as disposal mediums in the Unglaciated Plains and Mountains Province. The steep slopes associated with the uplifts exposing Paleozoic rocks, and the lack of soil development due to these steep slopes, will limit usefulness for solid waste disposal. Paleozoic sandstones and conbon-ates have prohibitive workability problems, and function as regional aquifers. If Paleozoic shales can be found in the foothills of the mountains where they are accessible and where soil erosion would not limit the profile depth, then Paleozoic shales could be used as a disposal medium. The deep, slowly permeable soils would tend to contain leachate at the site.

## Precambrian Metamorphic Rocks

Precambrian metamorphic rocks are usually unsuitable for use as a disposal medium. Soils developed on these rock types have rapid permeabilities. Workability problems are severe due to shallow soil depths and stoniness hazards. The operation of disposal sites in this rock type would be extremely difficult.

## Summary

In general, locations to be avoided when siting a solid waste disposal site in the Unglaciated Plains and Mountains Province are coarse alluvium, sites close to surface water, igneous rocks, sandstones, limestones, and metamorphic rocks. Suitable sites include fine textured alluvium, soft siltstone, soft claystone, and shale. Use of this paper does not preclude site specific studies. It is intended only as a guide for directing future work.

## Glaciated Plains and Mountains Province

### Geographic Setting

Topographically, the Glaciated Plains and Mountains Province is a dissected plain with domal uplifts. Glaciers, which covered the province during Quaternary time, modified the landscape. The boundary of the province is the Montana-Canada border to the north, the limit of continental glaciation to the south, the change in relief associated with the Mountains and Valleys Province to the west, and the change in relief associated with the Plains Province to the east (Figure 15).

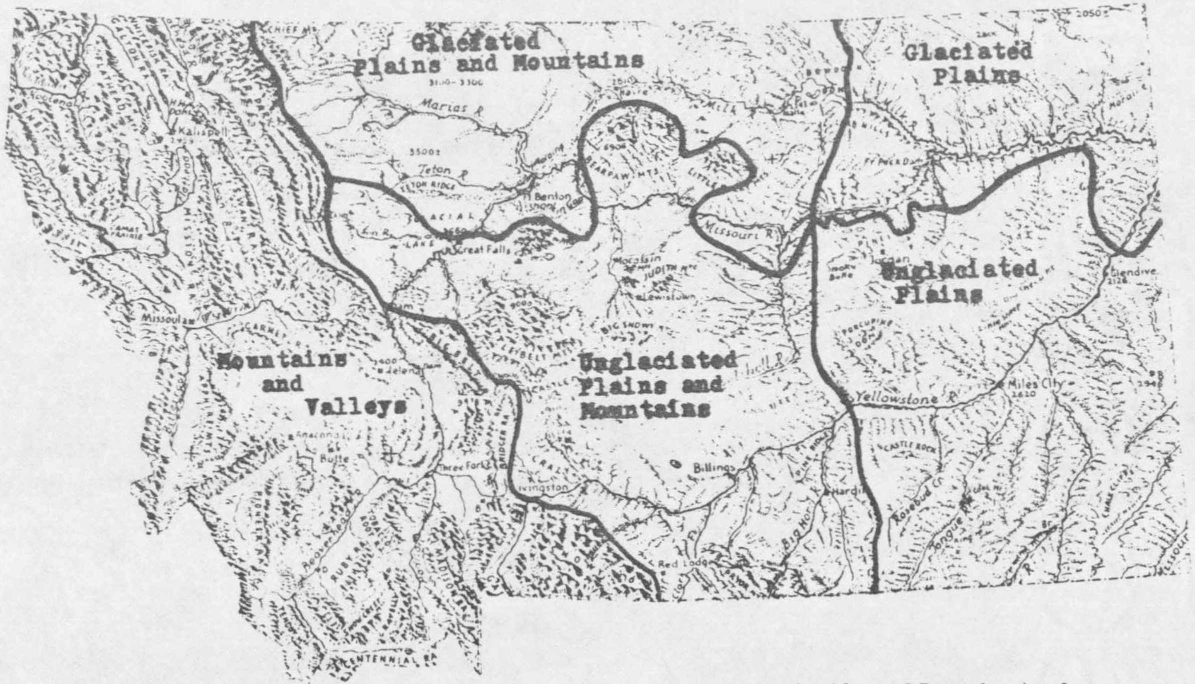



Figure 15: Location map of the Glaciated Plains and Mountains Province. (modified from Raisz, 1952)

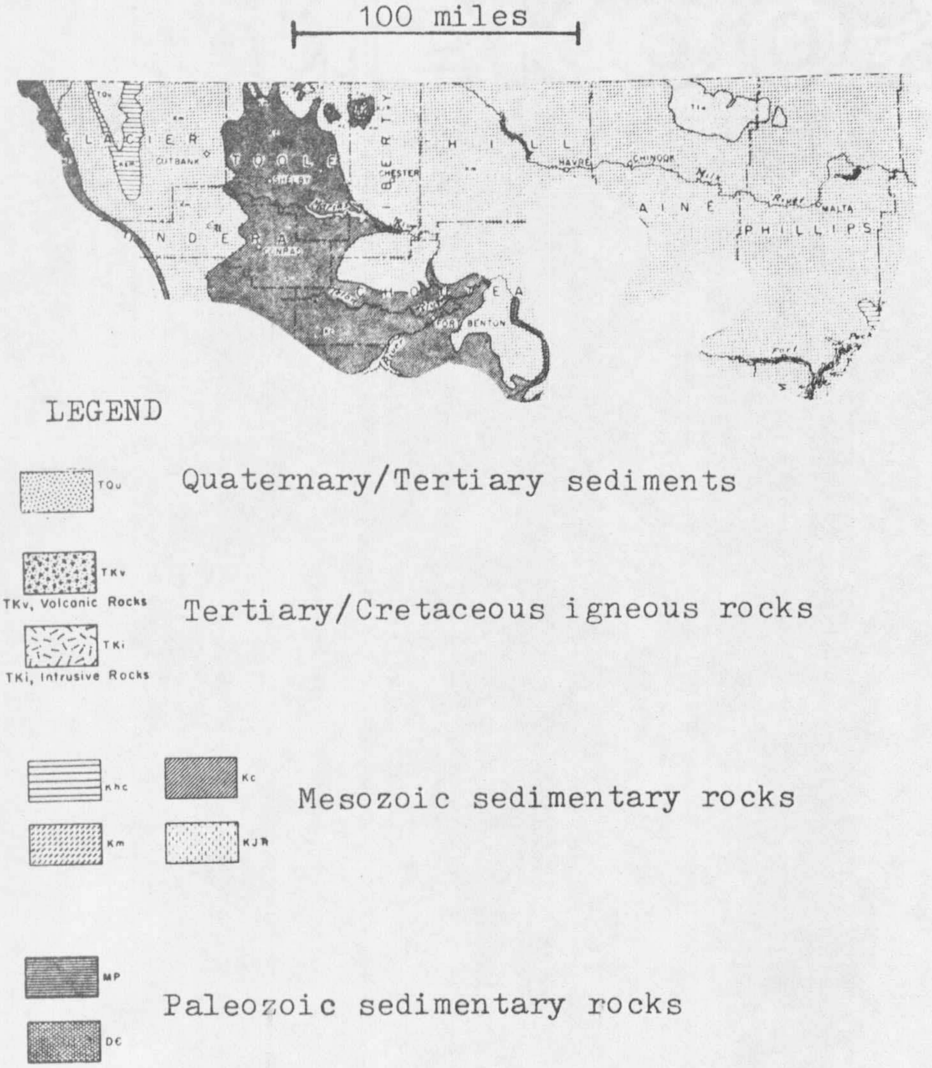
General Geologic Setting

The major structures in the Plains and Mountains Glaciated Province are domes and monoclinal flexures formed in an east-west trend during the Laramide Orogeny. Other smaller sub-circular mountain groups evolved about igneous centers which were active during late Cretaceous and early Tertiary time. Some en echelon faults are also present (Eardly, 1955).

There are five main geologic associations in this province (Figure 16). Tertiary/Quaternary sediments (TQu) are found as alluvium related to present drainages, alluvial fans, and remnant terraces. Tertiary/Cretaceous igneous rocks (TKi, Tkv) are found associated with many of the mountain groups in this province and occur as cores of many domes. Most of the province is underlain by Mesozoic sedimentary rocks (Ksm, Km, Kc, KJTr) which are uplifted at the domes and dip gently into the basins between uplifts. Paleozoic sedimentary rocks (MP, D€) are exposed only where doming is severe. The outcrop patterns of the Paleozoic units are confined to the immediate flanks of the domes and dip below younger rock units.

Quaternary glacial deposits cover the bedrock (Lemke and others, 1965) (Figure 17). Two main types of glacial deposits are found in the Plains and Mountains Glaciated Province:

Figure 16: Geologic map of the Glaciated Plains and Mountains Province. (modified from U.S.G.S., and M.B.M.&G., 1933, 1955)



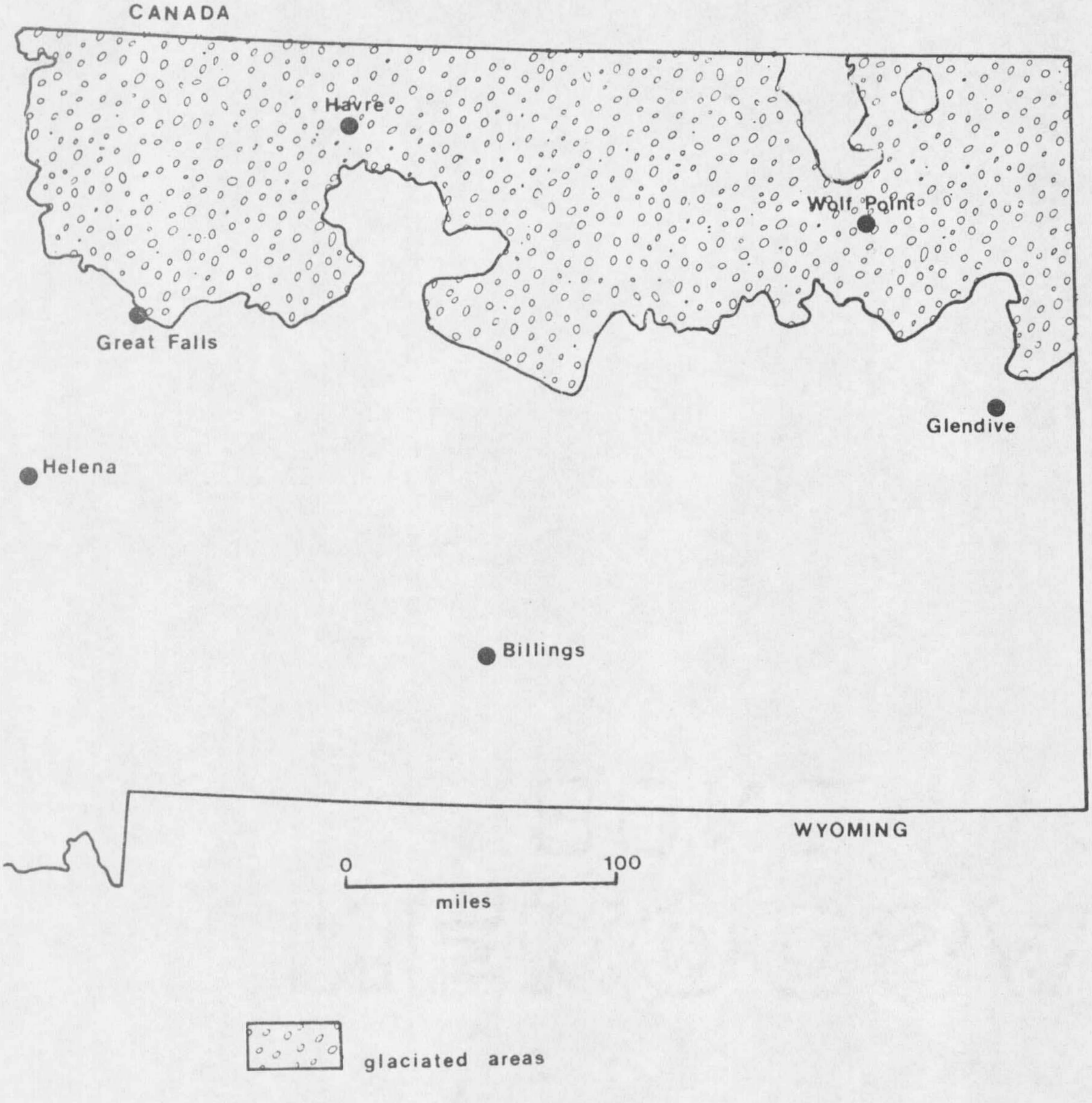



Figure 17: Extent of continental glaciation east of the Northern Rocky Mountains. (modified from Lemke and others, 1965)

glacial till and glacial outwash. Glacial till usually ranges from 10 to 50 feet thick. In some areas, however, it is over 100 feet in thickness. Till is usually poorly sorted, clayey, and compacted at depth (Veseth, 1980). Glacial outwash deposits are well sorted sands which vary in volume and configuration depending upon the nature of the outwash streams. Till and outwash can not be mapped separately given the scale of this study.

Hydrogeologic Units and Water Bearing Characteristics

The Plains and Mountains Glaciated Province is divided into five hydrogeologic units based on similarities in geologic occurrence and water yielding properties (Table 7). These hydrogeologic units correspond to the five geologic associations discussed in the general geologic setting section.

Quaternary/Tertiary sediments act as local sources of water when they are composed of sand and gravel. They are used to supply water to domestic and stock wells when they occur near abundant surface water.

Water bearing characteristics of glacial deposits are dependent upon lithology. Glacial till does not yield potable water in sufficient quantities to be useful as a water source. If fractured, glacial till can transmit water (Grisak and others, 1976). Glacial outwash sands bear significant volumes of water and are used to supply water in some areas.

Water bearing characteristics of the Tertiary/Cretaceous igneous rocks are not well known. No wells are known to produce water from these units, but the water yielding characteristics of these igneous rocks are probably poor unless they are fractured.

The water yielding characteristics of the Mesozoic

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY | WATER BEARING CHARACTERISTICS |
|---|---|---|---|
| Quaternary and Tertiary Sediments | TQu | gravels/cobbles | good |
| | | sand/silt | moderate to poor |
| | | clay | poor |
| Quaternary Glacial Deposits | | till | poor (may transfer water when fractured) |
| | | outwash | good |
| Tertiary-Cretaceous Igneous Rocks | Tki | igneous intrusives | poor unless fractured |
| | Tkv | igneous intrusives | poor unless fractured |
| Mesozoic Sedimentary Rocks | Khc | soft sandstone | good |
| | | soft siltstone | poor |
| | | soft claystone | poor |
| | Km | mod. hard sandstone | good |
| | | soft gray shale | poor |
| | Kc | soft gr/bl shale | poor |
| | KJTr | hard sandstone | poor to moderate |
| | | soft red vari-colored shale | poor |
| Paleozoic Sedimentary Rocks | MP, DЄ | hard sandstone | poor |
| | | limestone and dolomite | good |
| | | hard sandstone | moderate to poor |

Table 7: Hydrogeologic units and water bearing characteristics in the Glaciated Plains and Mountains Province.

sedimentary rocks are dependent upon lithology. Mesozoic shale units do not produce water. Mesozoic sandstone units are major aquifers in this province. Paleozoic sedimentary rocks are not notable aquifers on a local level in the Plains and Mountains Glaciated Province. The Paleozoic units dip too steeply from the uplifted regions, and plunge too quickly beneath the surface to be practical for use as local aquifers, but, Paleozoic carbonate units are major aquifers on a regional scale (Lorenz and McMurtrey, 1956).

## Soils

Soils in the Plains and Mountains Province have been grouped into two major units corresponding to the parent material from which they develop (Table 8). These two units include those soils on Quaternary sediments and those soils on glacial deposits. The glacial grouping is further divided into soils which develop from glacial till and soils which develop from glacial outwash. The classification system presented is based on the premise that certain soil properties are inherited from the parent material (Veseth, 1980). Thus, soils of a given parent material have similar soil properties. The soil properties outlined in Table 8 are not the only possible soil properties that may be encountered given each of the parent materials, but are the dominant types to be expected.

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY OF SOIL PARENT MATERIAL | TEXTURE | PERMEABILITY | CONSISTENCE | STONINESS | SOIL DEPTH |
|---|---|---|---|---|---|---|---|
| Quaternary and Tertiary Sediments | TQu | gravels & cobbles | sand to loamy sand | mod. rapid to rapid | slightly sticky, slightly plastic | class 1 - 3 | deep |
| | | sand and silt | loam to silty loam | mod. to moderately slow | sticky, slightly plastic | class 0 - 1 | moderate to deep |
| | | clay | clay loams | slow | sticky, plastic | class 0 | moderate to deep |
| Quaternary Glacial Deposits | | till: clay | clay loams | slow to very slow | sticky, plastic | class 0 - 1 | deep |
| | | outwash: sand | sand to loamy sand | rapid to very rapid | non-sticky non-plastic | class 0 | moderate |

Table 8: Characteristic soil properties in the Glaciated Plains and Mountains Province. (data for this table was obtained from Veseth, 1980)

(see Appendix for explanation of soil parameters)

## Suitability Patterns

### Quaternary Alluvial Deposits

Quaternary alluvial deposits are generally unsuitable for use as a disposal medium due to high permeability, good water bearing characteristics, and association of Quaternary alluvium with ground and surface water.

### Glacial Deposits

Suitability patterns in the Glaciated Plains and Mountains Province are complicated by the overprint of glacial deposits on the underlying bedrock geology. Suitability can be related to the type of glacial deposit or to the bedrock geology. Generally, sites on glacial till are suitable, unless the till is fractured, and sites on glacial outwash sands are unsuitable. However, if till deposits are thin, fractured, or glacial outwash deposits are thin, then underlying geologic associations become the determining factor for suitability. The following suitability patterns are for geologic units which underlie the glacial deposits.

Tertiary/Cretaceous Igneous Rocks

Extrusive igneous rocks are generally unsuitable for use as disposal mediums. Igneous extrusives generally have shallow soils, poor workability, and fracturing, which could lead to contamination problems if used as a disposal medium.

Intrusive igneous rocks are also generally unsuitable. The soils developed on igneous intrusives are highly permeable and workability problems are prevalent because of shallow soil development and high stoniness. If fractured, igneous intrusive rocks transmit water rapidly.

Mesozoic Sedimentary Rocks

The site suitability for solid waste disposal on Mesozoic sedimentary rocks is dependent upon the lithologies of the rock units. Sandstones are unsuitable for disposal of solid wastes because they are highly permeable and are aquifers, which results in environmental problems. The hard sandstones have shallow soil development upon them resulting in workability problems as well. Soft claystones, soft siltstones, and shales are generally suitable for use as disposal mediums. These deposits and the soils developed upon them have low permeabilities, poor water bearing characteristics, and good workability characteristics. The only problem which may be anticipated is workability during wet weather due to the sticky, plastic wet consistence of clay soils.

Paleozoic Sedimentary Rocks

Paleozoic sedimentary rocks will generally be unsuitable for use as disposal mediums in the Glaciated Plains and Mountains Province. The steep slopes associated with the uplifts exposing Paleozoic rocks, and the lack of soil development due to these steep slopes, will limit their usefulness for solid waste disposal. Paleozoic sandstones and carbonates have prohibitive workability problems and function as regional aquifers. If Paleozoic shales can be found in the foothills of the mountains where they are accessible and where soil erosion would not limit the profile depth, they could be used for waste disposal. The deep, slowly permeable soils would tend to contain leachate at the site area.

## Summary

In general, sites on glacial outwash and Quaternary alluvium are unsuitable; and, sites on glacial till are suitable. If the till is thin or fractured, and the outwash is thin, then suitability is a function of the underlying bedrock geology. Sites on igneous rocks, sandstones, and carbonates are unsuitable. Sites on soft siltstones, claystones, and shales are usually suitable. Use of this paper does not preclude site specific study, as it is intended only as a guide for directing future work.

## Unglaciated Plains Province

### Geographic Setting

The Unglaciated Plains Province is a relatively flat lying topographic surface which is dissected by through-flowing drainages. The boundary of the province is the Montana-South Dakota-North Dakota border to the east, the Montana-Wyoming border to the south, the change in relief associated with the Plains and Mountains Province to the west, and the southern limit of continental glaciation to the north (Figure 18).

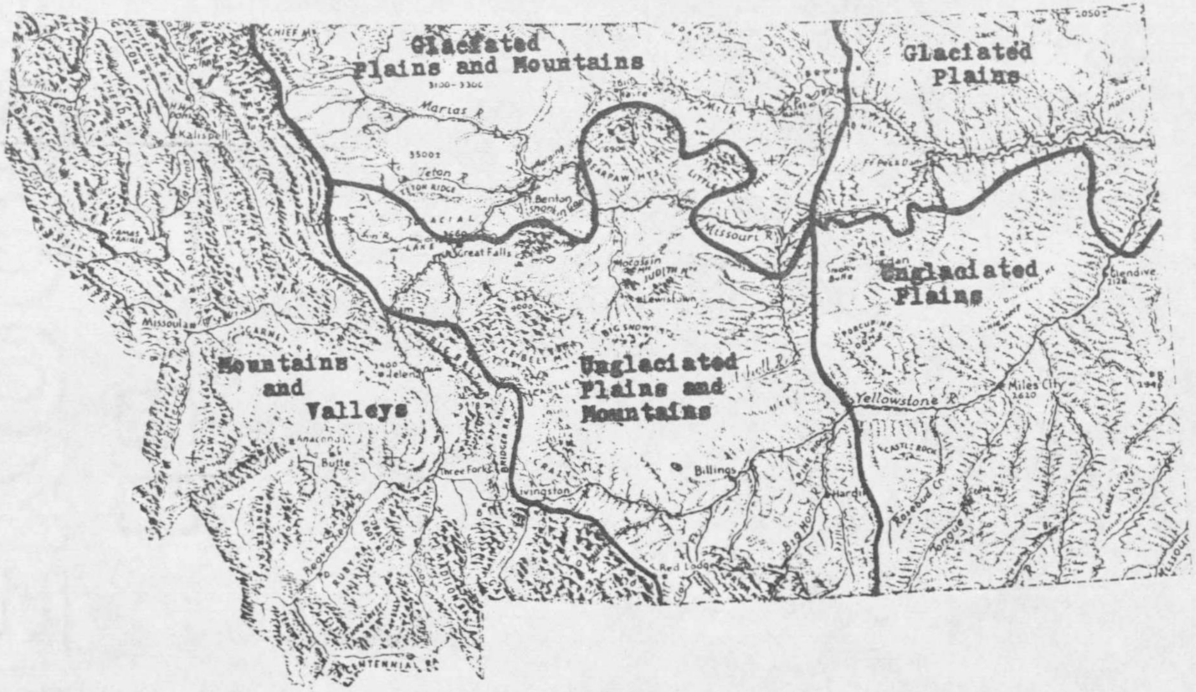



Figure 18: Location map of the Unglaciated Plains Province. (modified from Raisz, 1952)

## General Geologic Setting

There are four main structural features in the Unglaciated Plains Province (Figure 19). These features are the Cedar Creek anticline, the Sheep Mountain syncline, the north-western extension of the Black Hills, and the Porcupine Dome (Eardley, 1955). The domes and anticlines bring Mesozoic sedimentary rocks (Khc, Km, Kc; Figure 20) to the surface. Gently folded Tertiary sedimentary rocks cover the remaining area of the province except where Quaternary streams have deposited alluvial sediments. These deposits are associated with streams shown on Figure 20, although they are not depicted on the geologic map.

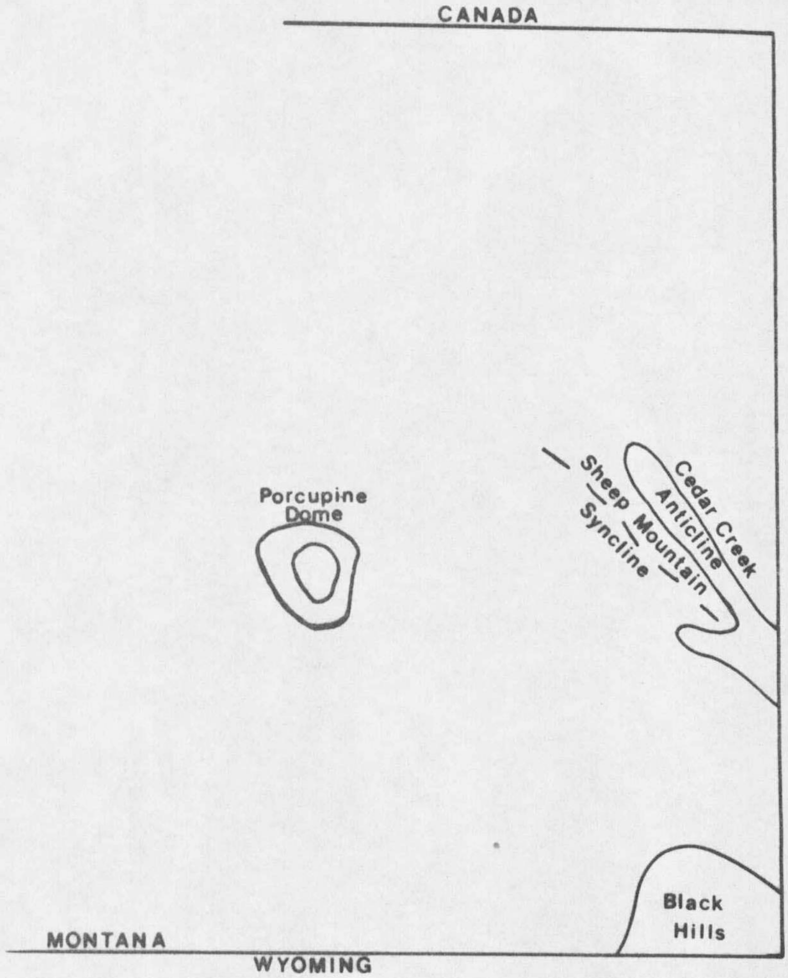
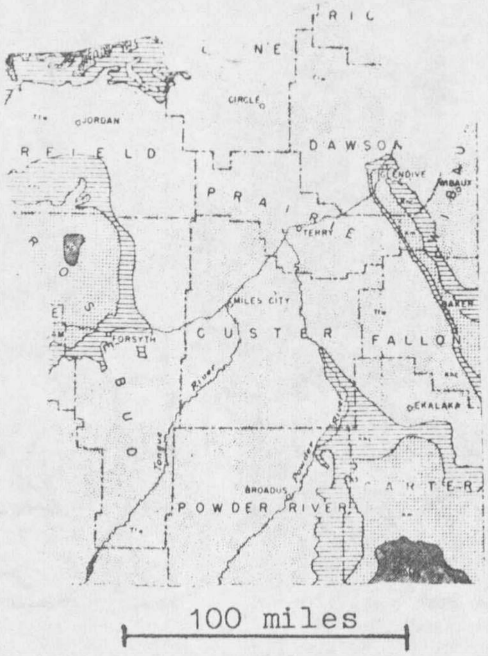



Figure 19: Structural features in the Unglaciated Plains Province. (modified from Eardley, 1955)




LEGEND

Tertiary sedimentary rocks

Mesozoic sedimentary rocks

Figure 20: Geologic map of the Unglaciated Plains Province. (modified from U.S.G.S.,and M.B.M.&G., 1933, 1955)

## Hydrogeologic Units and Water Bearing Characteristics

The Unglaciated Plains Province is divided into three hydrogeologic units which correspond to the three main rock associations discussed under the general geologic setting section (Table 9). Sandy alluvial aquifers are used as local sources of water when recharged with surface water. Silty and clayey alluvial sediments have poor water yielding characteristics.

Water bearing characteristics of Tertiary and Mesozoic rocks depend on lithology. Sandstones, coal, and clinker are important local water sources. Siltstones, claystones, and shales have poor water yielding characteristics and are not water sources in this province.

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY | WATER BEARING CHARACTERISTICS |
|---|---|---|---|
| Quaternary Deposits | Qal (not mapped) | sand | good |
| | | clay | poor |
| Tertiary Sedimentary Rocks | Tfw | soft sandstone | good |
| | | soft siltstone | poor |
| | | soft claystone | poor |
| | | coal | good |
| | | clinker | good |
| | | shale | poor |
| Mesozoic Sedimentary Rocks | Khc | soft sandstone | good - excellent |
| | | soft siltstone | poor |
| | | soft claystone | poor |
| | Km | mod. hard sandstone | good |
| | | soft gray shale | poor |
| | Kc | soft gray black shale | poor |

Table 9: Hydrogeologic units and water bearing characteristics in the Unglaciated Plains Province.

## Soils

Soils in the Plains Unglaciated Province have been grouped into three major units corresponding to the hydrogeologic units on which they develop (Table 10). These three groups are further sub-divided according to dominant lithologies. The classification system presented is based on the premise that certain soil properties are inherited from the parent material (Veseth, 1980). Thus, soils of a given parent material have similar soil properties. The soil properties outlined in Table 11 are not the only possible soil properties that may be encountered given each of the parent materials, but are the dominant types to be expected.

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY OF SOIL PARENT MATERIAL | TEXTURE | PERMEABILITY | CONSISTENCE | STONINESS | SOIL DEPTH |
|---|---|---|---|---|---|---|---|
| Quaternary | | sand | sand to sandy loam | rapid | slightly sticky to non-sticky, slightly plastic to non-plastic | class 0 - 1 | deep |
| Deposits | | clay | clay loams | slow to very slow | sticky and plastic | class 0 | moderate to deep |
| | | soft sandstone | sands and sand loams | very rapid to rapid | non-sticky, non-plastic | class 0 | moderate |
| Tertiary | | soft siltstone | loams and silt loams | moderate | slightly sticky, slightly plastic | class 0 | moderate to deep |
| Sedimentary | Tfw | soft claystone | clay loams | slow to very slow | sticky, plastic | class 0 | deep to mod. deep |
| Rocks | | coal | loams | moderate to rapid | slightly sticky, slightly pastic | class 0 | deep to mod. deep |
| | | clinker | sand loams, silt loams | moderate | slightly sticky, slightly plastic | class 0 - 2 | moderate |
| | | shale | clay loams | slow to very slow | sticky, plastic to very plastic | class 0 | deep to mod. deep |
| Mesozoic | Khc | soft sandstone | sands and sand loams | very rapid to rapid | non-sticky, non-plastic | class 0 | moderate |
| | | soft siltstone | loams and silt loams | moderate | slightly sticky, slightly plastic | class 0 | moderate to deep |
| | | soft claystone | clay loams | slow to very slow | sticky, plastic | class 0 | deep to mod deep |
| Sedimentary | Km | mod. hard sandstone | sand loams, silt loams, and loam | very rapid to mod. rapid | non-sticky, non-plastic | class 0 | shallow |
| Rocks | | soft gray shale | clay loams | slow to very slow | sticky, plastic to very plastic | class 0 | deep to mod. deep |
| | Kc | soft gray/bl. shale | clay loams | slow to very slow | sticky, plastic to very plastic | class 0 | deep to mod. deep |

Table 10: Characteristic soil properties in the Unglaciated Plains Province. (data for this table was obtained from Veseth, 1980)

(see Appendix for explanation of soil parameters)

## Suitability Patterns

### Quaternary Sediments

Quaternary sediments in the Unglaciated Plains Province are generally unsuitable for use as a disposal medium. Streams in this province generally deposit fine channel sands interbedded with flood plain clays. Sand deposits are unsuitable for use due to the high permeability of the sands and the good water bearing characteristics which provide water for domestic wells (Perry, 1933). Sites located on alluvial clays are also unsuitable. The unsuitability of the clays is due to proximity to surface water, association with shallow groundwater, and possible poor workability when wet due to sticky, plastic wet consistence of clay soils.

### Tertiary Sedimentary Rocks

Site suitabilities in areas underlain by Tertiary sedimentary rocks depend on the lithologies of the underlying rock. Sandstone, coal, and clinker are all good aquifers in this province, and solid waste disposal sites should not be located in them. Shale units have very poor water bearing characteristics, deep, slowly permeable soils, good workability except when wet, and, should provide suitable disposal sites. When wet, the sticky, plastic wet consistence of the soils developed on shale may cause workability problems.

## Mesozoic Sedimentary Rocks

Suitabilities of areas underlain by Mesozoic sedimentary rocks are also dependent upon lithologies of the underlying rocks. Sandstone units will generally be unsuitable due to the high permeabilities of the sandstones and the soils developed upon them, and the good water bearing characteristics of the sandstone units. Shale units will generally be suitable as a result of deep, slowly permeable soils, poor water bearing characteristics of the shale and good workability, except when wet. During wet weather the sticky, plastic wet consistence of the clay soils may cause workability problems.

## Summary

Sandstones, coal, clinker, and alluvial deposits are generally unsuitable for use as disposal mediums in the Plains Unglaciated Province. Shale units are generally suitable. Use of this paper does not preclude the use of site specific study. It is intended only as a guide for directing future work.

## Glaciated Plains Province

### Geographic Setting

The Glaciated Plains Province is a relatively low relief series of surfaces which have been dissected by streams. A veneer of glacial debris modifies these surfaces. The boundary of the province is the Montana-Canada border to the north, the Montana-North Dakota border to the east, the limit of continental glaciation to the south, and the change in relief associated with the Plains and Mountains Province to the west (Figure 21).

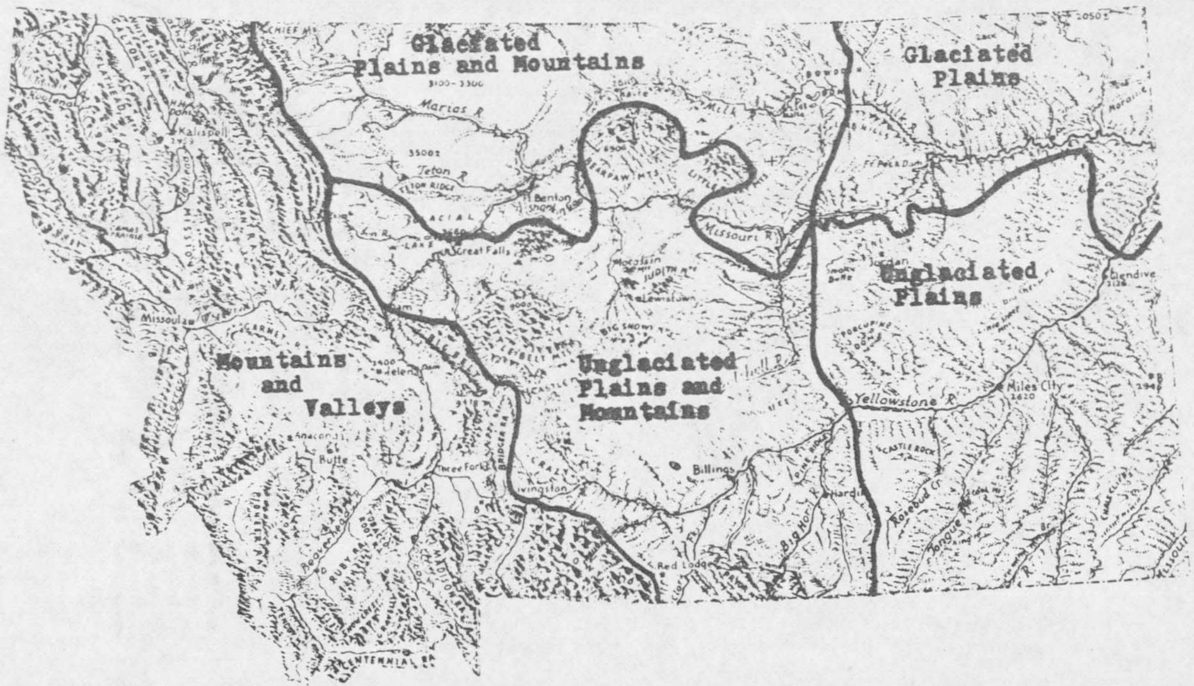
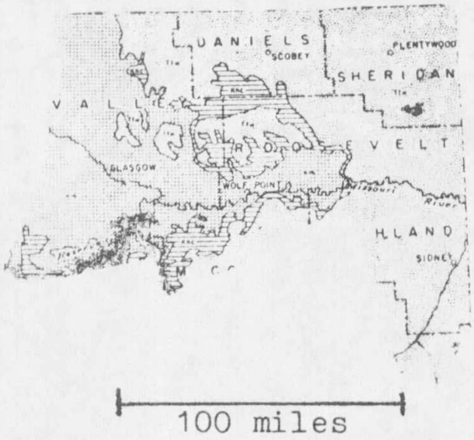



Figure 21: Location map of the Glaciated Plains Province. (modified from Raisz, 1952)

General Geologic Setting

This province consists of gently folded Tertiary and Mesozoic sedimentary rocks which are veneered with unconsolidated Quaternary alluvium, Quaternary glacial deposits, and Tertiary remnant terrace gravels. The Mesozoic sedimentary rocks (Km, Khc; Figure 22) are exposed in gently folded areas in the western part of the province and in deeply eroded areas of the central region. The Tertiary deposits (Tfw) are represented by soft sedimentary rocks and by remnant gravels. These two Tertiary deposits are not separated on the geologic map, however, the terrace deposits are found on two high level unglaciated terraces (Figure 23), while the soft sedimentary rocks are represented by all other areas on the geologic map (Figure 22) designated as Tfw. Imprinted over this geologic setting are the Quaternary glacial deposits. Approximately 2-3 million years ago fluctuations in climate brought glaciers which modified the northern Montana landscape and surficial deposits (Lemke and others, 1965). Two main types of glacial deposits are found in the Plains Glaciated Province; glacial till and glacial outwash. Glacial till usually ranges from 10-50 feet thick. In some areas, however, it is over 100 feet in thickness. Till is usually poorly sorted, clayey, and compacted at depth (Veseth, 1980). Glacial outwash deposits are well




LEGEND

Tertiary sedimentary rocks

Mesozoic sedimentary rocks

Figure 23: Geologic map of the Glaciated Plains Province. (modified from U.S.G.S., and M.B.M.&G., 1933, 1955)

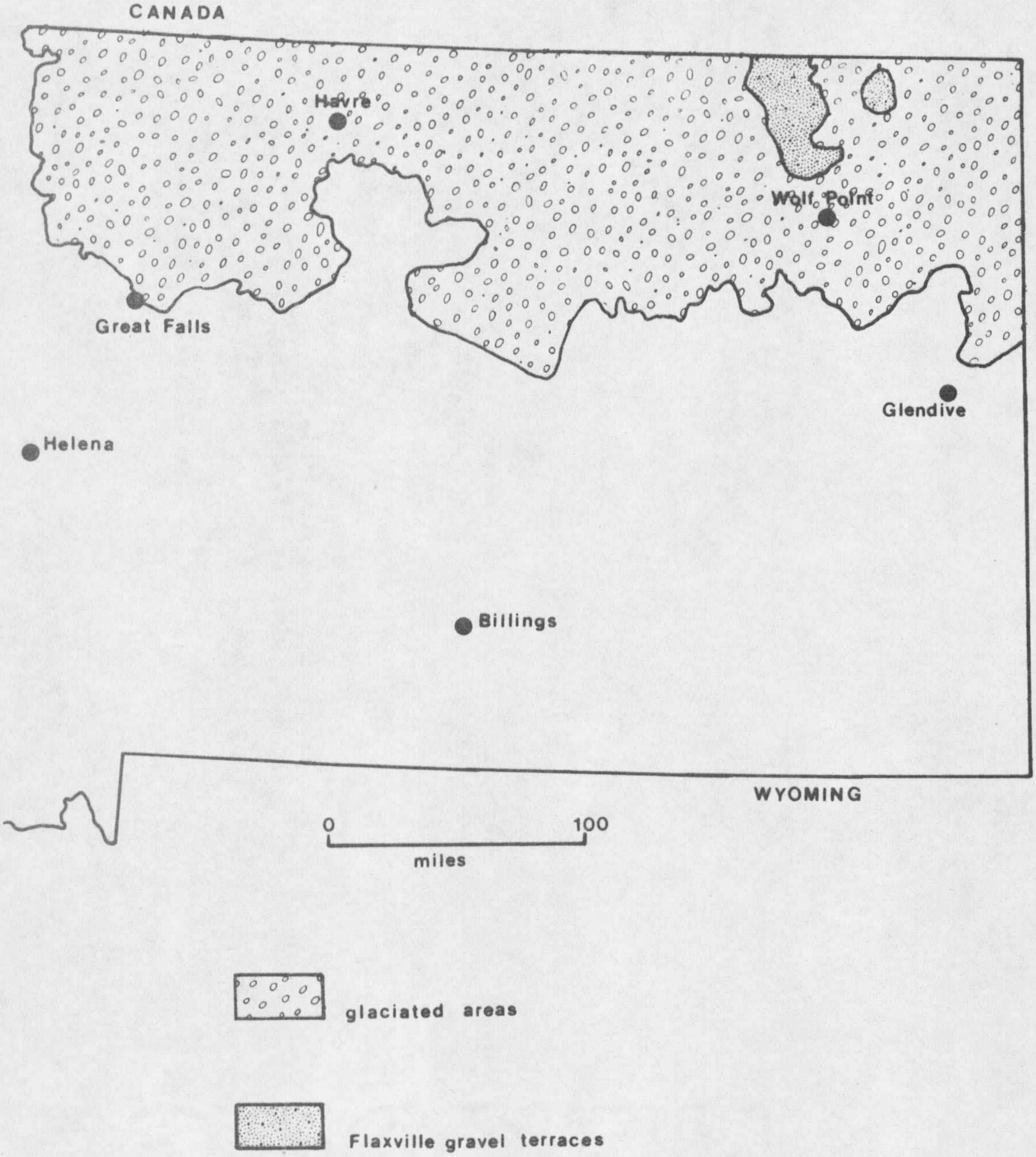



Figure 22: Map of continental glaciation east of the Northern Rocky Mountains and of Tertiary remnant terrace gravels. (modified from Lemke and others, 1965)

sorted sand which vary in volume and configuration depending upon the nature of the outwash streams. Till and outwash deposits may be interbedded. Quaternary alluvial deposits are associated with modern drainages.

Hydrogeologic Units and Water Bearing Characteristics

The Glaciated Plains Province is divided into five hydrogeologic units based on similarities in geologic occurrence and water yielding characteristics (Table 11). Sandy Quaternary alluvial sediments are used as aquifers when they are associated with surface water, while alluvial silt and clay have poor water yielding characteristics. High level Tertiary gravel deposits, known as the Flaxville gravels, are one of the major aquifers in this province (Perry, 1933). Soft sandstone, coal, and clinker are all important water sources, while, soft siltstone, soft claystone, and shale have poor water yielding characteristics.

Water bearing characteristics of the Mesozoic sedimentary rocks also depend on lithology. Soft to moderately hard sandstones have good to excellent water bearing characteristics and are important aquifers. Shales, siltstones, and claystone have poor water yielding characteristics and do not act as sources of water in this province.

Water bearing characteristics of glacial deposits depend on origin. Glacial till does not yield potable water in sufficient quantities to be useful as a water source, but, if fractured, glacial till can transmit water (Grisak and others, 1967). Glacial outwash sands can bear significant

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY | WATER BEARING CHARACTERISTICS |
|---|---|---|---|
| Quaternary Alluvium | | sand and silt | moderate to good |
| Quaternary Glacial Deposits | | fill | poor |
| | | outwash | good |
| Tertiary Gravel Deposits | Tfw | gravel | excellent |
| Tertiary Sedimentary Rocks | Tfw | soft sandstone | good |
| | | soft siltstone | poor |
| | | soft claystone | poor |
| | | coal | good |
| | | clinker | good |
| | | shale | poor |
| Mesozoic Sedimentary Rocks | Khc | soft sandstone | good |
| | | soft siltstone | poor |
| | | soft claystone | poor |
| | Km | moderately hard sandstone | good |
| | | soft gray shale | poor |

Table 11: Hydrogeologic units and water bearing characteristics in the Glaciated Plains Province.

quantities of water and are used as a water source for domestic and municipal wells in some areas.

## Soils

Soils in the Plains glaciated province have been grouped into three major units corresponding to the parent material from which they develop (Table 12). These three units include those soils on Quaternary sediments, sub-divided into those on sand and those on clay; those soils on glacial deposits, sub-divided into those on till and those on outwash; and those solid developed on Tertiary gravels. Soils are not developed on other parent materials because of a lack of exposure of the geologic strata due to blanketing by glacial deposits. The classification system presented is based on the premise that certain soil properties are inherited from the parent material (Veseth, 1980). Thus, soils of a given parent material have similar soil properties. The soil properties outlined in Table 12 are not the only possible soil properties that may be encountered given each of the parent materials, but are the dominant types to be expected.

| HYDROGEOLOGIC UNIT | STRATIGRAPHIC UNITS | LITHOLOGY OF SOIL PARENT MATERIAL | TEXTURE | PERMEABILITY | CONSISTENCE | STONINESS | SOIL DEPTH |
|---|---|---|---|---|---|---|---|
| Quaternary Alluvium | | gravel and sands | sand to loamy sand | rapid to very rapid | non-sticky, non-plastic | class 1 - 3 | moderate |
| Quaternary Glacial Deposits | | till: clay | clay loams | slow to very slow | sticky, plastic | class 0 - 1 | moderate deep to deep |
| | | outwash sands | sand to loamy sand | rapid to very rapid | non-sticky, non-plastic | | moderate |
| Teritary Gravel Deposits | Tfw | gravel and cobbles | sand to loamy sand | rapid.to very rapid | non-sticky, non-plastic | class 1 - 3 | moderate |

Table 12: Characteristic soil properties in the Glaciated Plains Province. (data for this table was obtained from Veseth, 1980)

(see Appendix for explanation of soil parameters)

## Suitability Patterns

### Quaternary Alluvial Deposits

Quaternary alluvial deposits are generally unsuitable for use as a disposal medium. These deposits are unsuitable because of high permeability, good water bearing characteristics, and association of Quaternary alluvium with ground and surface water.

### Glacial Deposits

Suitability patterns in the Glaciated Plains Province are complicated by the overprint of glacial deposits on the underlying bedrock geology. Suitability can be related to the type of glacial deposit or to the bedrock geology. Generally, sites on glacial till are suitable unless the till is fractured, and, sites on glacial outwash are unsuitable. However, if till deposits are thin, fractured, or glacial outwash deposits are thin, then the underlying geologic associations become the determining factor for suitability. The following suitability patterns are for geologic units which underlie the glacial deposits.

Tertiary Gravel Deposits

High level Tertiary gravel deposits are not suitable for solid waste disposal. Soils developed on Tertiary gravels have high permeabilities and are stony. The Tertiary gravels themselves have excellent water bearing characteristics and are one of the major aquifers in this province. Because of the high potential for environmental contamination, the Tertiary gravels should not be used for solid waste disposal.

Tertiary Sedimentary Rocks

Suitabilities of areas underlain by Tertiary sedimentary rocks are dependent upon the lithologies of the underlying rocks. Sandstone, coal seams, and clinker all act as very good aquifers in this province, and as such should not have solid waste disposal sites located on them. Shale units have very poor water bearing characteristics, deep slowly permeable soils, and good workability characteristics except when wet, and generally should be suitable disposal mediums. When wet, the sticky, plastic wet consistence of the clay soils developed on shale may cause workability problems.

## Mesozoic Sedimentary Rocks

Suitabilities of areas underlain by Mesozoic sedimentary rocks also depends on the lithologies of the underlying rocks. Sandstone units are generally unsuitable because of high permeabilities and good water bearing characteristics. Mesozoic shale units are usually suitable due to deep slowly permeable soils, poor water bearing characteristics, and good workability characteristics except when wet. During wet weather the sticky, plastic wet consistence of the clay soils may cause some workability problems.

## Summary

In general, Quaternary alluvial deposits, Quaternary glacial outwash deposits, Tertiary gravel deposits, sandstone, clinker, and coal are not suitable for use in disposal. Shale units are generally suitable. Use of this paper does not preclude the use of site specific studies, and is intended only as a guide for directing future studies.

## CONCLUSION

Site specific evaluations were made for 21 existing solid waste disposal sites in Montana. The suitability of these sites as found to be a function of:

1. permeability of soils and surficial deposits,
2. depth to shallow groundwater,
3. connection of shallow groundwater with deeper aquifers, and
4. proximity to surface water.

A suitable site has slowly permeable soils and surficial deposits, a deep water table, no connection of shallow groundwater with deeper aquifers, and is far from surface water.

Fourteen out of twenty-one of the evaluated sites were unsuitable. For all unsuitable sites, suitable sites exist nearby. The use of a small amount of soil and hydrogeologic data, and minimal planning, could have resulted in better placement of sites. Generally, the people responsible for locating solid waste disposal sites on a local level are not aware of the soil and hydrogeologic factors which control site suitability in their area.

Simple generalizations concerning the soils and hydrogeology create a greater awareness of the constraints for solid waste disposal in a given area. To achieve this end, the state of Montana was sub-divided into five physiographic provinces. Soil and hydrogeologic information pertinent to solid waste disposal site suitability was generalized for each province. In general, it was found that in glaciated provinces, sites on glacial till would be suitable unless the till is fractured, or shallow, while site on glacial outwash and alluvium would be unsuitable. In non-glaciated provinces sites on shales and clays are generally suitable and sites on sandstone, limestone, coal, clinker, and alluvium are generally unsuitable.

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# REFERENCES CITED

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APPENDIX

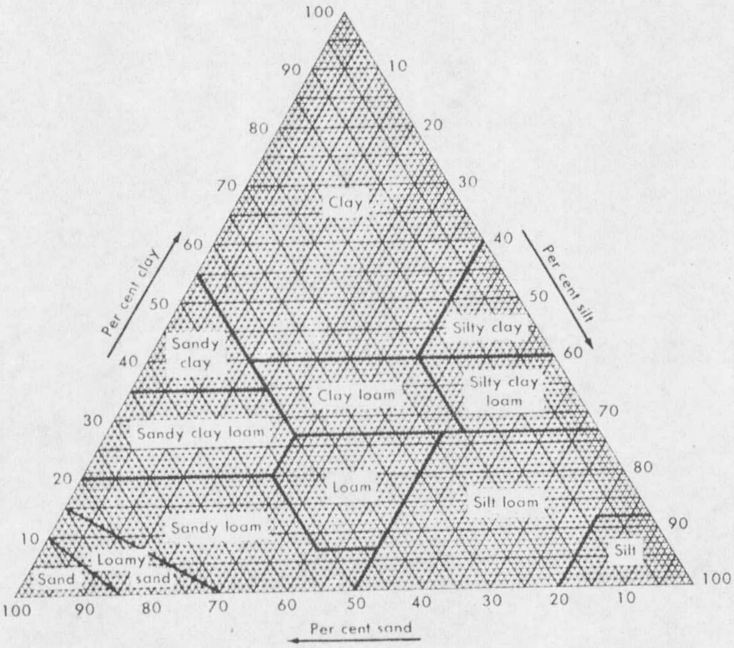


Chart showing the percentages of clay (below 0.002 mm.), silt (0.002 to 0.05 mm.), and sand (0.05 to 2.0 mm.) in the basic soil textural classes.

(from Soil Survey Staff, 1952, p. 209)

SOIL PERMEABILITY

| | Possible rates in inches per hour |
|---|---|
| Slow: | |
| 1. Very slow | less than 0.05 |
| 2. Slow | 0.05 to 0.20 |
| Moderate: | |
| 3. Moderately slow | 0.20 to 0.80 |
| 4. Moderate | 0.80 to 2.50 |
| 5. Moderately rapid | 2.50 to 5.00 |
| Rapid: | |
| 6. Rapid | 5.00 to 10.00 |
| 7. Very rapid | over 10.00 |

(from Soil Survey Staff, 1952, p. 168)

## CONSISTENCE WHEN WET

A. Stickiness - Stickiness is the quality of adhesion to other objects. For field evaluation of stickiness, soil material is pressed between thumb and finger and its adherence noted. Degrees of stickiness are described as follows:

0. Nonsticky: After release of pressure, practically no soil material adheres to thumb or finger.
1. Slightly sticky: After pressure, soil material adheres to both thumb and finger but comes off one or the other rather cleanly. It is not appreciably stretched when the digits are separated.
2. Sticky: After pressure, soil material adheres to both thumb and finger and tends to stretch somewhat and pull apart rather than pulling free from either digit.
3. Very sticky: After pressure, soil material adheres strongly to both thumb and forefinger and is decidedly stretched when they are separated.

B. Plasticity - Plasticity is the ability to change shape continuously under the influence of an applied stress and to retain the impressed shape on removal of the stress. For field determination of plasticity, roll the soil material between thumb and finger and observe whether or not a wire or thin rod of soil can be formed. If helpful to the reader of particular descriptions, state the range of moisture content within which plasticity continues, as plastic when slightly moist or wetter, plastic when moderately moist or wetter, and plastic only when wet, or as plastic within a wide, medium, or narrow range of moisture content. Express degree of resistance to de-formation at or slightly above field capacity as follows:

0. Nonplastic: No wire is formable.
1. Slightly plastic: Wire formable but soil mass easily deformable.
2. Plastic: Wire formable and moderate pressure required for deformation of the soil mass.
3. Very plastic: Wire formable and much pressure required for deformation of the soil mass.

(from Soil Survey Staff, 1952, p. 232)

## STONINESS

Class 0:

No stones or too few to interfere with tillage. Stones cover less than 0.01 percent of the area.

Class 1:

Sufficient stones to interfere with tillage but not to make inter-tilled crops impracticable. (If stones are 1 foot in diameter and about 30 to 100 feet apart, they occupy about 0.01 to 0.1 percent of the surface, and there are about 0.15 to 1.5 cubic yards per acre-foot.)

Class 2:

Sufficient stones to make tillage of intertilled crops impracticable, but the soil can be worked for hay crops or improved pasture if other soil characteristics are favorable. (If stones are 1 foot in diameter and about 5 to 30 feet apart, they occupy about 0.1 to 3 percent of the surface, and there are about 1.5 to 50 cubic yards per acre-foot.)

Class 3:

Sufficient stones to make all use of machinery impracticable, except for very light machinery or hand tools where other soil characteristics are especially favorable for improved pasture. Soils with this class of stoniness may have some use for wild pasture or forests, depending on other soil characteristics. (If stones are 1 foot in diameter and about 2.5 to 5 feet apart, they occupy about 3 to 15 percent of the surface, and there are about 50 to 240 cubic yards per acre-foot.)

Class 4:

Sufficient stones to make all use of machinery impracticable; the land may have some value for poor pasture or for forestry. (If stones are 1 foot in diameter and are about 2.5 feet or less apart, they occupy 15 to 90 percent of the surface, and there are more than about 240 cubic yards per acre-foot.)

Class 5:

Land essentially paved with stones that occupy more than 90 percent of the exposed surface (Rubble).

(from Soil Survey Staff, 1952, p. 217-219)

# DEPTH CLASSES

| | Ranges in limits: Upper (inches) | | Ranges in limits: Lower (inches) |
|---|---|---|---|
| 1. Very shallow | 0 | | 5-10 |
| 2. Shallow | 5-10 | | 20-30 |
| 3. Moderately deep (or moderately shallow[1]) | 20-30 | | 30-50 |
| 4. Deep[2] | 30-50<br>30-50 | or | 50-60<br>60+ |
| 5. Very deep[2] | 50-60 | | 60+ |

[1] "Moderately shallow" is used where the contrasting layer is nearer the surface than typical for the kind of soil.

[2] The very deep class is rarely required. Where it is needed, the deep class has a lower limit somewhere between 50 and 60 inches.

(from Soil Survey Staff, 1952, p. 285)