Wyoming State Geological Survey
Gary B. Glass, State Geologist

# Evaluation of Bentonite and Gold Resources on the Wind River Indian Reservation, Wyoming

by Clark A. Roberts, June B. Worthington, and Lewis G. Nonini

Reprinted from: Administrative Report to the Bureau of
Indian Affairs and Shoshone - Arapahoe Tribes
Report BIA 8-II, Part 1 (Wind River)
1983
United States Department of the Interior
Bureau of Mines

**Reprint No. 58 • 1995**

Laramie, Wyoming

---

People with disabilities who require an alternative form of communication in order to use this publication should contact the Editor, Wyoming State Geological Survey at (307) 766-2286. TDD Relay Operator 1(800) 877-9975.

This and other publications available from: Wyoming State Geological Survey
P.O. Box 3008, University Station
Laramie, Wyoming 82071-3008
(307) 766-2286 • FAX (307) 766-2605

---

This report is released to the Public by authority of the Joint Business Council (JBC 6-7-93) of the Shoshone and Arapahoe Tribes of the Wind River Reservation.

---



---

STATE OF WYOMING

1933

GEOLOGICAL SURVEY

# Evaluation of Bentonite and Gold Resources on the Wind River Indian Reservation, Wyoming

By Clark A. Roberts, June B. Worthington, and Lewis G. Nonini

Report BIA No. 8-II, Part 1 (Wind River)

*June 1983*

*United States*
*Department of the Interior*
*Bureau of Mines*

# EVALUATION OF BENTONITE AND GOLD RESOURCES ON THE WIND RIVER INDIAN RESERVATION, WYOMING

By Clark A. Roberts, June B. Worthington, and Lewis G. Nonini

Report BIA No. 8-II, Part 1 (Wind River)

June 1983

United States Department of the Interior

Bureau of Mines

Prepared under the authority of the Wind River Tribal Council Resolution No. 4767, as passed on June 10, 1981, and the Interagency Agreement No. 23, Supplement No. 1 between the Bureau of Indian Affairs and the Bureau of Mines.

CONTENTS

## ILLUSTRATIONS

Plates

TABLES

# EVALUATION OF THE BENTONITE AND GOLD RESOURCES ON THE WIND RIVER INDIAN RESERVATION, WYOMING

by

Clark A. Roberts[1], June B. Worthington[1], and Lewis G. Nonini[2]

## SUMMARY AND CONCLUSIONS

At the Joint Arapahoe-Shoshone Tribal Council's request, and the Bureau of Indian Affairs acceptance of recommendations made by the Bureau of Mines and Geological Survey in a Phase I Study (93),[3] the Wind River Indian Reservation was examined for bentonite and gold deposits.

Bentonite beds in the Frontier, Mowry, and Thermopolis Formations crop out on the Wind River Indian Reservation along the eastern flank of the Wind River Range and along the northern and southern slopes of the Owl Creek Mountains. All three varieties of swelling bentonite occur on the reservation. Three areas have mining potential. Samples, which were collected in each area by trenching, augering, and rotary drilling, have physical properties approximating or surpassing certain industrial specifications. Chemical enhancement enables selected samples to surpass American Petroleum Institute specifications for drilling mud. Chemical treatment and reanalyses of samples collected in one area are recommended in order to evaluate the bentonite's suitability for use in manufacturing drilling mud. In addition, several bentonite beds require further drilling, sampling, and testing to determine their extent, attitude, and quality.

Small amounts of gold are widespread in gravels throughout the Wind River Indian Reservation. Most, if not all, of the gravels from the Wind River Formation and younger sediments contain at least some gold, but the terrace, pediment, and tributary stream gravels appear to be even lower in gold content than the gravels of the main streams, which are submarginal. Any attempts at future gold mining on the Wind River Indian Reservation should be preceded by detailed, exploratory testing and thorough metallurgical testing. Although the gold-bearing gravels are widespread and occur in great volume, they are much too low in grade to justify further effort at this time.

[1]Geologist. Both authors are with the Intermountain Field Operations Center, Bureau of Mines, Denver, Colo.

[2]Physical Scientist. Intermountain Field Operations Center, Bureau of Mines, Denver, Colo.

[3]Underlined numbers in parentheses refer to items in the list of selected references at the end of this report.

# INTRODUCTION

This report was prepared for the U.S. Bureau of Indian Affairs (BIA) by the U.S. Bureau of Mines (BuMines) under an interagency agreement to investigate the potential for economic development of mineral resources located on certain Indian lands. The agreement specifies that a Phase II study (a field examination and evaluation report) be made on the Wind River Indian Reservation. Such a project was suggested in a Phase I mineral literature study that was prepared jointly by the BuMines and the U.S. Geological Survey (USGS) (93). In the initial (Phase I) report, suggestions for additional work included a reconnaissance geologic study of the bentonite-bearing Thermopolis, Mowry, and Frontier Formations to provide data to assess more accurately the value of this potential resource, and an investigation of the placer gold potential in recent alluvial deposits, particularly in the western part of the reservation. At the request of the Joint Business Council of the Shoshone and Arapahoe Tribes of the Wind River Indian Reservation, only tribal land was evaluated for bentonite and gold; private and allotted lands were not investigated. Location of tribal land is shown in figure 1.

The present study carries out the recommendations made in the Phase I report. Information sources included published and unpublished reports, personal communications, field examinations, field sampling, and laboratory testing. Fieldwork was conducted primarily during the 1982 field season, which lasted from June into September, but the reservation also was visited during a 2-week period in September 1981.

## Location and Access

The areas studied are scattered throughout the Wind River Indian Reservation, a rectangular area of 2,948 square miles in Fremont and southern Hot Springs Counties, Wyo. (pl. 1). The reservation lies just east of the Continental Divide in west-central Wyoming between Townships 2 S and 9 N, measured from the Wind River Base Line, and ranges 6 E and 6 W, measured from the Wind River Principal Meridian.

Portions of the Owl Creek and Absaroka Mountains lie in the northern part of the reservation; the rugged Wind River Range crosses the southwest corner. Except for a small area on the northern flank of the Owl Creek Mountains, which extends into the Bighorn Basin, the remainder of the reservation is located in the topographic Wind River Basin (fig. 2). The major drainage, the Wind River, flows diagonally from the northwestern part of the reservation to the town of Riverton, turns northward along the eastern edge of the reservation, and leaves the basin through the Wind River Canyon, which cuts northward through the Owl Creek Mountains.

The reservation covers a large area, only small sections of which are accessible by hard-surfaced roads. U.S. Highway 287 enters the reservation along the south-central border near Lander, heads northward and then westward, and exits the reservation along the northern portion of the western boundary. Federal Highway 26 follows the same route as State Highway 789 between Shoshoni and Riverton and then turns to the northwest to join U.S. Highway 287 (pl. 1). Several other improved roads connect the major

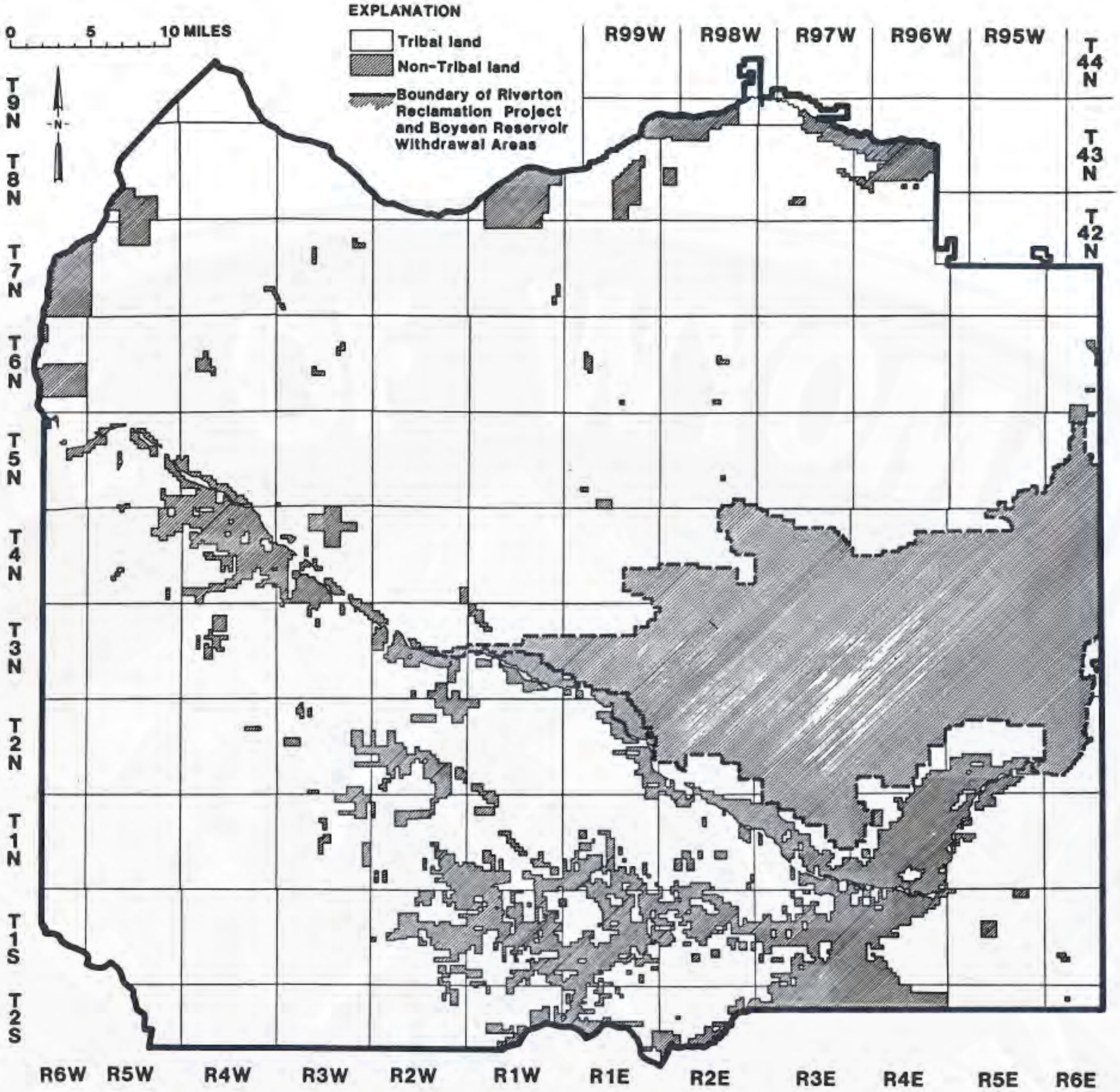



FIGURE 1.—Location of tribal land and withdrawal areas, Wind River Indian Reservation, Wyoming (modified from BIA (15)).

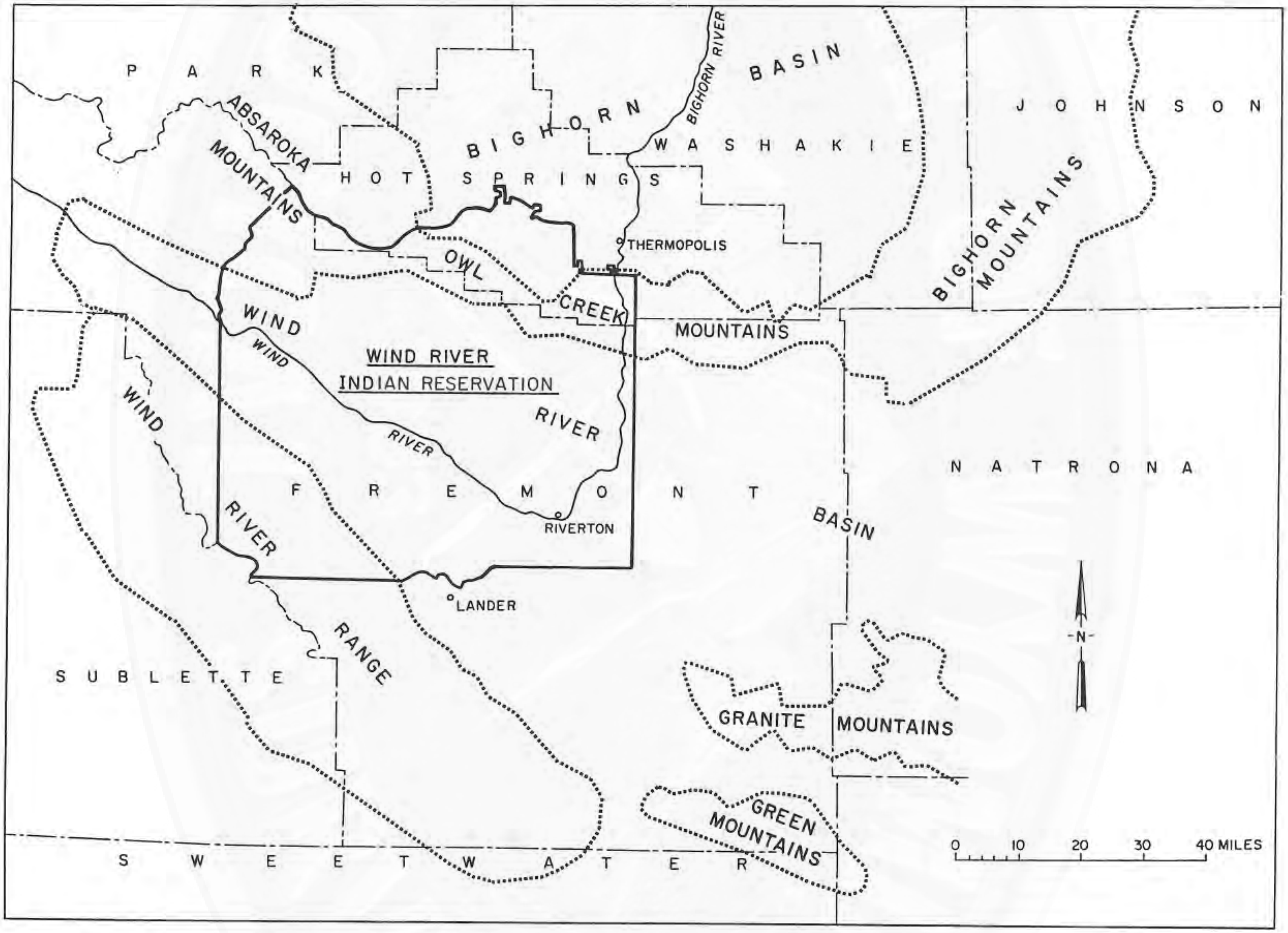



FIGURE 2.—Physiographic features of the Wind River Indian Reservation and adjacent areas, Wyoming (Bolmer and Biggs (13)).

population centers. Numerous additional routes, ranging from gravel roads to very rough 4-wheel-drive jeep trails, give access to within a few miles of most places within the reservation except in mountainous areas. Many of these routes are unmaintained and often are impassable in wet weather.

Population centers within and near the reservation include Riverton (population 9562), Shoshoni (population 879), Thermopolis (population 3853), and Lander (population 7867), (oral comm., U.S. Census Bureau, Nov. 30, 1982). Unincorporated towns include Fort Washakie, Ethete, Pavillion, Kinnear, and Crowheart.

## Physiography and Climate (16)

Elevations range from about 4,700 feet in the Wind River Valley northeast of Riverton to greater than 12,700 feet along the Continental Divide in the Wind River Range. Most of the Wind River Basin consists of subdued (5,200- to 7,000-foot) topography interrupted by cliff-forming mesas and eroded structural features. Broad plains extend across the reservation, fanning out from alluvium-filled valleys and glacial moraines along the mountain fronts. They are dissected by numerous permanent and intermittent streams that flow predominantly to the southeast or northeast away from the mountainous areas and drain into the Wind River. The Wind River, Little Wind River, and their tributaries drain most of the Wind River Basin, and Owl Creek drains most of the reservation north of the Owl Creek Mountains. These mountains form a divide between the topographic Wind River Basin and the Bighorn Basin.

The climate of the reservation exhibits wide local variations, ranging from temperate and arid in the lowest altitudes to frigid and humid at the highest. Except for the higher mountainous areas, the climate is characterized by light rainfall, hot summers and cold winters, abundant sunshine, low relative humidity, and wide variations in wind movement and temperature.

Both the amount and distribution of precipitation are highly variable from year to year. Over a major portion of the Wind River Basin, annual precipitation ranges from 1 to 8 inches. It increases to about 15 inches along the foothills at the base of the mountains, reaches 20 to 30 inches in the Owl Creek and Absaroka Mountains, and exceeds 40 inches along the Wind River Range.

Temperatures in the central part of the plains belt range from -42 to 102 degrees Fahrenheit, averaging 17.6 and 72.1 degrees Fahrenheit, respectively, during January and July. The average frost-free season comprises 127 days, between May 12 and September 23.

## Previous Work

### Geology

The geology of Wyoming in general, and the Wind River Indian Reservation in particular, have been studied intensely, and numerous reports and maps are available. General geology is shown on the 1:500,000 scale Geologic Map of Wyoming (66), and energy resources as shown on the 1:500,000 scale Energy Resources Map of Wyoming (32). The locations of other mineral resources, including bentonite and gold, are shown roughly on the 1979 Wyoming Mines and Minerals Map (39). Numerous regional and quadrangle maps and reports are available; most important of these are two USGS hydrologic atlas maps (67, 106), portions of which together cover the entire Wind River Indian Reservation, and the USGS Water Supply Paper 1576-I (70), which includes a 1:125,000 scale geologic map of the reservation. Useful geologic maps are included in several quadrangle and regional geologic reports that cover areas such as Shotgun Butte (52), Bull Lake East and West Quadrangles (75, 87), southern Bighorn Basin (105), Sage Creek Dome (94), Little Dome (74), Maverick Springs Quadrangle (5), Bargee area (110), Blue Holes Quadrangle (44-45), Lander and vicinity (99, 103), and other areas (42, 58-59, 68). Studies made of the oilfields on and near the reservation give detailed geology for several areas (10, 53, 63, 76, 100-101).

Many geologists have added to the knowledge of Wyoming stratigraphy. Authors such as Thompson and others (98), Mills (73), Love and others (65), Lee (60), and Haun and Barlow (38) measured and correlated geologic formations throughout all or part of Wyoming. Papers by Reeside and Cobban (81), Cobban and Reeside (21), and Eicher (26) concentrate on the Thermopolis, Mowry, and/or Frontier Formations over large portions of Wyoming and adjacent states.

Structure in Wyoming also is discussed in most of the aforementioned papers. In addition, Keefer discusses the structural history of the Wind River Basin (49); Bartram and Hupp (8), Keefer (50-51), and Paape (78) describe the structural history and anticlinal growth in central Wyoming during the late Cretaceous Epoch; and Collier (22) discusses the structure and origin of folds within the Wind River Basin near Maverick Springs Anticline.

Numerous other geologic studies, specifically concerning the geology of the Wind River Basin or the Wind River Indian Reservation, also are available. In addition to the Water Resource papers, the Hydrologic Atlas sheets, and the quadrangle and regional reports, Case and Keefer (18) produced a regional gravity survey, and Love (62), Keefer (48, 50), and Burk (17), among others, produced stratigraphic works on those portions of formations within the Wind River Indian Reservation. In 1956, the nomenclature committee of the Wyoming Geological Association presented a correlation and summary of the stratigraphy of Wyoming and the Reservation that contains useful summaries of the stratigraphy of the Wind River and Bighorn Basins (17, 73). Glacial tills in the Wind River Range are discussed by Richmond (85-86).

The small portion of the reservation north of the Owl Creek Mountains is included in most studies of the Bighorn Basin. Formations of Cretaceous age and younger in the southern Bighorn Basin are examined by Merewether and others (72), Hunter (46), Keefer (48), Fisher (30), Weitz (105), and Berry and Littleton (10). The southern portion of the Bighorn Basin is similar in many stratigraphic and structural aspects to the Wind River Basin, and most of the geologic information pertaining to the Wind River Basin also is pertinent to this area.

## Bentonite

The origin and occurrence of bentonites in rocks of Cretaceous age in Wyoming have been topics of general interest for many years, and because of their importance for industrial uses, bentonites have been studied in many areas of Wyoming. Despite this, only limited work is available on the bentonites of the Wind River Indian Reservation.

Information concerning the general characteristics or origins of various bentonite deposits is given in Rosenkrans (88), Heathman (40), Gruner (37), Brindley (14), Hewett (41), and Patterson and Murray (80). Recent studies concerning physical characteristics and laboratory testing of Wyoming bentonites are found in papers by Regis (82), Bleifuss (11-12), Slaughter and Earley (95), Everett (27), Williams, Elsley, and Weintritt (108), and Williams, Neznagko, and Weintritt (109). Davis and Vachner (24), Patterson and Murray (80), Ampian and Polk (4), and Ampian (3) give information on mining procedures, commercial preparation, and industrial uses of bentonite.

Although information on bentonite occurrences specifically within the Wind River Indian Reservation is limited, the presence of bentonite is mentioned in many geologic and stratigraphic studies. Tentative ideas and theories about the origin and stratigraphy of the Wind River Indian Reservation bentonites can be drawn from information available from commercially mined deposits located in the Bighorn Basin, the Black Hills, and other areas of Wyoming (25, 54-56, 111). Most of these deposits are in formations of the same age as those on the reservation, and they also are similar in many other respects.

Several large-scale bentonite studies include the reservation area. In 1965, Slaughter and Earley described and measured sections of bentonite beds in the Mowry and the lower part of Frontier Formations over a 40,000-square-mile area of north-central Wyoming, which included the Wind River Indian Reservation (95). They attempted to correlate and explain the lobe-shaped bentonite deposits in this area and to suggest a relationship between the sedimentational and tectonic history of beds of Cretaceous age. Other bentonite studies covering the Wind River Indian Reservation include several unpublished BuMines administrative reports. In 1949, Everett (28) discussed the mineral resources of the Wind River Basin. He mentioned only that bentonite was present on the reservation, and that it was considered to be of inferior quality to deposits currently being mined in other areas of Wyoming. Bolmer and Biggs (13) briefly discussed the bentonite resource on the reservation, and Seeland and Brauch (93) included bentonite in their report on the status of mineral resource informaton for the reservation. These last two studies include much of what is known about reservation bentonite deposits. Much of the background information in this report was obtained from these two sources.

## Gold

In 1913, relative to land classification work on the Shoshone Indian Reservation (now the Wind River Indian Reservation), Frank C. Schrader of the USGS investigated gold deposits. Subsequent workers, such as Bolmer and Biggs (13), Osterwald (77), and Seeland and Brauch (93), relied heavily on the work of Schrader. The major portion of his work involved collecting and evaluating one vein sample and 98 placer samples. The samples were collected along about 200 linear miles of the Wind, Little Wind, Popo Agie, and North Fork of Popo Agie Rivers. Although he touched upon known lode deposits and made mention of bench and terrace gravels far removed from existing streambeds, Schrader dealt principally with gravels in and adjacent to principal streambeds. He found that the gravels are of great areal extent, generally range from 15 to 20 feet in thickness, rest on sandstone bedrock, and, therefore, are well adapted for dredging operations. He also determined that the values were not concentrated on bedrock but were scattered throughout the thickness of the gravel beds and that very high values, which were reported by various mine operators, were of limited extent and erratically distributed within the gravel beds.

Pertinent to this study because of information on probable source areas for placer gold are the works of Spencer (96) on the Atlantic Gold District and Antweiler (6-7) on the widespread gold mineralization in northwestern Wyoming.

## General Geology

The Wind River Indian Reservation is located in the western one-half of the Wind River Basin and the southwestern portion of the Bighorn Basin. Both basins are structural and topographic depressions that have complex geologic histories. The Wind River Mountains border the western edge of the Wind River Basin. Portions of the Absaroka and Owl Creek Mountains separate the Wind River Basin from the Bighorn Basin. Plate 2 is a generalized geologic map of the Wind River Indian Reservation and adjacent areas. Appendix A includes information on the stratigraphy and structure of those portions of the basins within the Wind River Indian Reservation and those portions of the mountain ranges along the reservation's northern and western margins. Table A-1[4] gives the nomenclature of the rocks on the Wind River Indian Reservation, and tables A-2, A-3, and A-4 relate the generalized stratigraphy for formations of Paleozoic, Mesozoic, and Cenozoic ages. Although this information generally concerns the Wind River Basin, it also is usually applicable to the portion of the Bighorn Basin within the reservation.

---

[4]Tables A-1, A-2, etc., refer to tables included within appendix A; table B-1, etc., refer to tables within appendix B; and so on.

Information on the geology of the area, in addition to those references given in the section on previous work in this paper, is given in Thomas (97), Reynolds (84), Merewether and Cobban (71), and Goodell (33).

## BENTONITE RESOURCE

Far from being a simple clay that always possesses valuable properties, the material commonly referred to as "bentonite" is an extremely complex and often misunderstood earth material whose properties and usefulness can vary greatly from occurrence to occurrence and even within the same bed. In order to assist the reader in understanding the nature of the material, this section begins with a brief explanation of what is meant by the term "bentonite." Information concerning the chemical and physical properties, varieties, and origin of bentonite is included in appendix B. Several of the beds that were sampled during the study are described in appendix C, and appendix D contains geologic descriptions of the reservation's bentonite-bearing formations. Results of various tests used to assess potential industrial applications are shown in appendix E.

### Introduction

The clay-like material that today is recognized by most mineralogists and geologists as bentonite has had other names, and the term "bentonite" has been defined in a variety of ways since its first use in 1898 (57). Knight proposed the name for a yellow-green, clay-like material possessing unusual properties that had been mined commercially since 1888 on the Taylor Ranch near Rock River, Wyo., and sold under the name "Taylorite" (19). "Soap Clay" and "Mineral Soap" are previously used terms that reflect an early application of the material as a cleansing agent. Knight used the term "bentonite" because he believed the material occurred in the Fort Benton "group" of Cretaceous age; the name "Taylorite" could not be used because it previously had been reserved for another mineral. Hewett (41) in 1917 and Ross and Shannon in 1926 (90) demonstrated that the material Knight called "bentonite" was formed by the alteration of volcanic ash. Ross and Shannon also proposed the following redefinition of the term:

> "Bentonite is a rock composed essentially of a crystalline clay-like mineral formed by devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash; and it often contains variable proportions of accessory crystal grains that were originally phenocrysts in the volcanic glass."

Additional definitions have since been proposed by Davis and Vacher (24), Dana (23), Grim (35), and Ross (91). Some of these definitions also are based on mode of origin, but others emphasize the unique swelling properties of the material, the mineralogical composition, or a combination of these factors. This large number of formally proposed definitions, along with several informal ones commonly used by laymen, has created confusion over usage of the term "bentonite" within scientific and popular literature and in those industries associated with mining and utilizing the material. During the last 30 years, clay-bearing materials possessing properties generally associated with commercial-grade bentonite, but having a variety of origins, have been mined from several occurrences throughout the world. As a result, most mineralogists and geologists today agree that the term "bentonite" should be used to refer to a particular type of rock, which, like other rock types, must be defined solely by its constituent minerals and not by its mode of origin, place of occurrence, or properties (36, 80, 91). Accordingly, the term "bentonite" is used in this paper to refer to a rock composed essentially of one or more minerals belonging to the smectite group of clay minerals; accessory minerals include quartz, cristobalite, other clay minerals, feldspars, calcite, gypsum, and zeolites.

Bentonites frequently are classified according to their behavior when mixed with water. Those that increase in volume or swell only slightly more than other clay minerals are referred to as "nonswelling bentonites." Varieties that swell many times their original volume are known as "swelling bentonites." The nonswelling variety is relatively rich in calcium cations and also is known as "calcium-rich bentonite," whereas the swelling variety is relatively rich in sodium cations and commonly is referred to as "sodium-rich bentonite." Appendix B includes a discussion of the origins of the swelling and nonswelling varieties and an explanation of how bentonites are classified into these groups.

## Uses

A detailed discussion of the numerous uses of bentonite is beyond the scope of this paper. Ross (91), Grim (35), and Clem and Doehler (20) discuss scores of uses for the swelling and nonswelling varieties of bentonite. (The low-, intermediate-, and high-swelling types of bentonite, as described in appendix B, will be referred to as swelling bentonite in the remainder of this report, unless otherwise noted.) The following few paragraphs summarize the work of these authors.

Most uses of swelling bentonite depend upon its behavior in water. Because physical properties of bentonite-water mixtures vary with the ratios of the two materials, many bonding, plasticizing, and suspending applications are possible. When a relatively small amount of water is mixed with a swelling bentonite, a sticky mass having adhesive properties results. The amount of water must be inadequate to meet the oriented-water requirements of the molecular sheets comprising the bentonite (20). Apparently, the available water is shared by adjacent molecular sheets, producing rigidity rather than plasticity. If materials bonded by swelling bentonite are air-dried or fired in an oven, their rigidity increases considerably. This is referred to as dry-bond strength. High dry-bond strength is important in binding foundry sand and in pelletizing taconite ore. Brake linings, animal feed, and insulating materials also are bonded by mixtures having low ratios of water to bentonite. If an amount of water sufficient to meet the oriented-water requirements of the molecular sheets is mixed with a swelling bentonite, the molecular sheets become lubricated by the excess water (20). A highly plastic mixture capable of allowing raw materials to be easily shaped or molded into the form of a finished product results. Such properties are useful as plasticizing agents in certain ceramic, mortar, grout, and concrete products. Relatively small amounts of swelling bentonite, generally less than 10 percent by weight, form suspensions when mixed with water. In such mixtures, the molecular sheets are dispersed by the water molecules, producing a large number of extremely small, uniform particles known as colloids. These suspensions possess useful properties, such as viscosity and gel-forming ability. Largest and best known application of bentonite suspensions is in production of drilling mud. Suspensions also are used in fire retardants and as media for suspending paints, insecticides, and medicines.

Numerous other applications of swelling bentonite result from its use as a filling material. Seepage of water from disposal sites, reservoirs, and canals can be controlled with linings made of swelling bentonite. The bentonite adsorbs water upon contact and swells to seal openings. In civil engineering uses, foundations of buildings and other structures similarly can be protected from ground water damage. Swelling bentonite improves the capacity, smoothness, softness, and adsorption of paper products. It serves as a dilutant and carrier for pesticides and herbicides. In cosmetics, creams, medicines, soaps, detergents, and polishing compounds, it serves as an extender; some soaps may contain as much as 40 percent bentonite. Swelling bentonite also is used to clarify wine, beers, syrups, and other liquids.

Properties exhibited by mixtures of nonswelling bentonite and water also account for some of this material's industrial applications. Nonswelling bentonite will orient only a few layers of water molecules between the molecular sheets comprising its structure; accordingly, its molecular sheets are more strongly attached to each other than those in similar mixtures of swelling bentonite and water (20). The result is a highly rigid form that is stronger than those produced by using a swelling bentonite. This property, known as high green strength, accounts for the widespread use of nonswelling bentonite as a binding agent. A major use is in binding foundry sand. When mixed with large amounts of water, nonswelling bentonite commonly crumbles into numerous, irregularly shaped granules, because it is unable to orient enough water layers for the molecular sheets to be dispersed. Many oils and waxes are clarified either by filtering or mixing them with nonswelling bentonite granules or powder. Highly adsorbent, nonswelling bentonite is sometimes known as fuller's earth. The adsorptive properties of some nonswelling bentonites can be enhanced by activation with acids. These activated bentonites are widely used in decolorizing fluids and in refining mineral oils. Some nonswelling bentonites are used to soften water, treat sewage, stabilize colors in inks and dyes, and adsorb ink from paper during repulping. Calcined granules of nonswelling bentonite are used to adsorb animal waste, grease, oil, and other liquids from floors and other surfaces.

Despite the many industrial applications of bentonite, only a few are significant with respect to the amount consumed. Of the 4.2 million short tons sold or used in 1980, more than 3.6 million were the swelling variety (4). Percentages of the total domestic consumption of bentonite required for principal uses are cited in the following figures: Major uses for swelling bentonite include production of drilling mud (46), pelletizing taconite ore (29), binding foundry sand (14), binding animal feeds (4), and water proofing and sealing (3). Primary uses for nonswelling bentonite include binding foundry sand (50); filtering, clarifying, and decolorizing oils and greases (19); and production of drilling mud (10). More than 634 thousand short tons of bentonite was exported in 1980. All but 20 thousand short tons was the swelling variety. Main uses of exported swelling bentonite were in producing drilling muds (54) and foundry sand binders (36). Major uses of exported nonswelling bentonite were in producing foundry sand binders (64) and drilling muds (9).

## Geology

Major bentonite beds on the Wind River Indian Reservation are present in the Mowry and Frontier Formations; lesser amounts occur in the underlying Thermopolis Formation (pl. 3). Minor beds also are reported in the Wind River Formation and Jurassic strata (13). Only bentonite beds within the Thermopolis, Mowry, and Frontier Formations were examined during this study.

Bentonite beds are well to poorly exposed in various areas depending upon structural and topographic factors. Soil and slopewash cover many areas where beds may be present. Because the purpose of this study was to review and study known deposits, no attempt was made to delineate hidden or suspected bentonite beds. Large areas of the formations of interest, therefore, were not sampled; only outcrops were examined, and sampling was concentrated at or near these outcrops.

The general physical appearance of the bentonite on the Wind River Indian Reservation differs widely among beds and to a lesser degree, within beds. Information from field and laboratory data show that color and most other physical features seen in the field cannot be used as a key to bentonite quality. Physical features depend on weathering, depth, initial source and composition of volcanic material, types and amounts of clay minerals present, degree of oxidation, the calcium-sodium exchangeable cation ratio, presence of impurities (such as biotite, quartz, or rock fragments), and surface contamination. The bentonite grades from waxy, unlaminated beds having blocky conchoidal fracturing; to laminated, gritty or sandy beds that often have shaley cleavage; and to bentonitic shale. These various textures and compositions of bentonite often occur in irregular layers or lenses within a bed. Several authors have studied the physical properties of bentonite beds and discerned a layering or pattern of texture and other physical properties within the beds (11, 82, 95, 108). Because this is an economic, rather than a geologic study of the bentonite, no attempt was made to duplicate or extend the work of these authors.

Weathering produces several changes in bentonite and bentonitic shale units. These include physical and chemical effects at or near the surface, such as a "popcorn" texture, iron staining, and development of gypsum; and chemical effects that extend to greater depths, such as changes in the exchangeable cation ratio and oxidation of the iron in the smectite structure. Generally, as beds containing an appreciable amount of swelling bentonite weather, they develop an unvegetated, 0.1- to 0.3-foot-thick surface layer having a loose, popcorn-like texture. The greater the percentage of bentonite within the beds, and the greater its swelling capacity, the more extensively developed will be this phenomenon. In many places, the bentonite in a 1- to 2-foot-thick zone below the loose material is disturbed because of the shrinking and swelling of the clay and is slightly to moderately iron stained. Gypsum, as a white coating or as small crystals, is visible in the upper several feet of many bentonite beds.

Intervals of bentonitic shale occur throughout the studied formations but are particularly common in the Frontier and Thermopolis Formations. Superficially, they are mistaken for "pure" bentonite in many places because of their popcorn-like texture, an observation that is disproven upon closer examination. Thin beds of bentonite interbedded with bentonitic shale accentuate this effect, owing to the downslope washing of loose "popcorn" material over underlying shale units. Some earlier authors probably overestimated the true thickness of the bentonite beds because of this phenomenon.

Orientation of the bentonite beds is related to local structure. Strata comprising domes and anticlines in the western and northern parts of the Wind River Indian Reservation have dips of approximately 15 degrees to vertical; some beds are overturned. Inclined beds along the mountain fronts may dip up to 45 degrees. The amount of material overlying a specific bentonite bed varies according to the geologic structure, local topography, and orientation of the bed in relationship to other strata.

Thickness of the individual bentonite beds within the formations of interest range from less than 0.1 foot to 17 feet; most are less than one foot thick. In many cases, thickness does not appear to be consistent. The one known area having a 17-foot thickness is believed to be a local thickening of a bed. According to the bentonite producers, only beds which have less than 50 feet of overburden and a stripping ratio (overburden-to-bentonite-thickness ratio) of a maximum of 15 to 1 are considered minable; these figures depend on the bentonite quality and the ease of overburden removal. Only those beds which might meet these criteria are considered in this study.

Specific information concerning the geology of each of the studied formations--the Thermopolis, Mowry, and Frontier--is given in appendix D, Geology of the Bentonite-Bearing Formations. Geologists disagree concerning contact locations, lithologies, and thicknesses of these formations making correlations between areas within and outside the reservation difficult.

## Minable Beds

Based on preliminary laboratory results and observations made in the field, three areas were chosen in which to concentrate further investigations, particularly drilling, during the remainder of the field season. These areas are the eastern side of Bighorn Ridge and the eastern and northern flanks of Winkleman Dome; the area 2 miles north of Arapahoe Reservoir, where the Frontier, Mowry, and Thermopolis Formations crop out; and the northern slope of Blue Ridge (pl. 3). Bentonite beds that were sampled in these areas are described in appendix C.

### Eastern Side of Bighorn Ridge

The area of interest along the eastern side of Bighorn Ridge and the eastern and northern flanks of Winkleman Dome lies on the eastern and northern sides of the Sage Creek Anticline (pl. 3). No significant beds of bentonite were observed on the anticline south of the Little Wind River or along its steeply dipping western edge. Although all three formations of interest are exposed in this area, only the Mowry and Frontier Formations contain bentonite beds of possible economic potential.

The orientation of the Mowry and Frontier Formations on the eastern side of Bighorn Ridge positions bentonite beds in a manner favorable for possible economic recovery. A dip of 10 to 30 degrees, along with a slightly sloping ground surface, could allow stripping of these beds into the basin east of Bighorn Ridge; the distance of economic mining would depend on the rate of deepening of the beds and the lithology of the overlying material.

North of Bighorn Ridge, the eastern side of Winkleman Dome might be stripped for a length of about 2.5 miles along its flank and for a width of 0.25 mile eastward into the basin. Overlying sandstone ridges probably would prevent further bentonite recovery. Additionally, the dip of strata increases to the north along Winkleman Dome increasing the amount of overburden that would need to be removed during stripping. Winkleman Dome also is an area of active oilfield leases and may be unavailable for bentonite recovery in the foreseeable future.

Numerous bentonite beds are reported in the Mowry and Frontier Formations in the Bighorn Ridge-Winkleman Dome Area, but fieldwork and laboratory data reveal that only two or three known beds have possible economic potential. These are within a prominent 5- to 17-foot-thick, white, bentonite-porcellanite interval located at the Mowry-Frontier contact (figs. 3 and 4). In most places the interval contains two bentonite beds, but in some areas these appear to join and become one bed. Some authors believe this interval may be the same as or equivalent to the heavily mined "Clay Spur Bentonite Bed" in northern Wyoming (<u>17</u>, <u>73</u>). Fresh exposures of the bentonite beds are buff, greenish gray, or bluish gray. Surface exposures of the bentonite-porcellanite interval are usually white or buff and have an intense "popcorn" texture; however, the white or buff coloration is produced by the porcellanite beds in many places, rather than by the bentonite beds. Thin beds, lenses, and intervals of disrupted, fragmented porcellanite and white, siliceous shale, having irregular distribution, are common within these beds. These beds are covered in many areas and average thickness can be estimated only from outcrops and drill-hole data.

Thicknesses of the upper and lower bentonite beds are approximately 2 feet and 5.5 to 9.5 feet, respectively. In one area, where the two beds appear to merge into a single bed and crop out, the bentonite is 17 feet thick (fig. 3). About 900 feet away, however, a drill hole (site 3) intersecting the same interval shows two bentonite beds having thicknesses of 2.0 and 9.5 feet. Although the beds vary in thickness and crop out intermittently, they appear to be present along the eastern side of Bighorn Ridge from the Little Wind River to the northern end of Winkleman Dome, a distance of about 10 miles.

Characteristically, the upper bentonite bed includes up to several feet of white to gray, blocky, porcellanite and siliceous shale that overlies and often interfingers with the upper few inches of bentonite. In addition, there is as much as 2 feet of porcellanite between the two bentonite beds. In places, the porcellanite is so fragmented and intermixed with the bentonite beds that the bentonite probably is useless for most industrial applications. Thickness measurements of beds in such areas may include large amounts of porcellanite.

FIGURE 3.—The 17-foot-thick bentonite-porcellanite interval (light-colored material) that crops out on the eastern side of Bighorn Ridge.

FIGURE 4.—The bentonite-porcellanite interval (light-colored material) where it crops out near sample site 3.

In one area (site 7), 11 feet of black shale occurs between the two bentonite beds. These two beds may be equivalent to the two bentonite beds found in other areas along Bighorn Ridge, or one bed at site 7 may be a third bed or lens of unknown dimensions. If so, the two beds present in other areas along Bighorn Ridge may have merged into a single bed in the vicinity of site 7.

The basal contact of the lower bentonite bed consists of an abrupt, distinctive change from bentonite to shale and sandy shale in the south. Northward in the Winkleman Dome area, the shale changes to a siliceous sandstone. This sandstone is very hard and provides a good "floor" for dip-slope exposures of the bentonite.

In addition to several preliminary samples taken in this area, the bentonite-porcellanite interval was drilled or trenched at sites 2, 3, 6, 7, and 13. Site 2 is near the southern end of the ridge about 0.5 mile north of the Little Wind River. Site 3, about 4 miles farther north, is approximately midway along the eastern side of the ridge. Site 6 is about 1 mile north of site 3. Site 7 is on the eastern side of the southern part of Winkleman Dome, and site 13 is at the northern end of Winkleman Dome. All except site 6 were sampled with a rotary drilling rig.

Stratigraphically above the bentonite-porcellanite interval and farther away from Bighorn Ridge are numerous other bentonite beds and lenses in the Frontier Formation. These are exposed in drainages and crop out in some areas to the northeast of Bighorn Ridge. Because of the scarcity of outcrops, their continuity and thickness are difficult to predict without additional fieldwork, but most appear to be too thin or discontinuous to be of economic value. Generally, this bentonite is greenish-buff and has a light-gray or greenish-gray "popcorn" texture where exposed.

Test holes were drilled in two of these beds at sites 4 and 5. Site 4 is a flat area along the projected strike of a bentonite bed. It is about 100 feet north of where the bed crops out in a drainage. No clean bentonite was encountered in the drill hole, only bentonitic shale. This may indicate that the outcrop was part of a lens, rather than a bed. The rock was sampled, however, in order to determine the properties of the bentonitic shale. Site 5 was drilled farther north, perhaps into the same interval and 7.25 feet of clean bentonite was found. These meager data indicate that additional beds of minable bentonite may be present in the Frontier Formation, but their continuity and thickness are unknown and would need to be tested by additional drilling.

## North of Arapahoe Reservoir

Numerous bentonite beds or lenses are present in the Mowry and Thermopolis Formations, and a few are present in the Frontier Formation in the area of Cretaceous outcrops 2 miles north of Arapahoe Reservoir. Structurally, this area consists of several folds. The formations dip approximately 9 to 18 degrees to the southeast along the eastern limb of an anticline and extend approximately 1 mile to where the structure abuts the Owl Creek Mountains. The formations then bend to the southeast in an adjacent syncline. If not too thickly covered with overburden, beds in this area could be stripped for up to 600 feet along the dip; actual distance would depend upon the dip of the bentonite beds and the type of overburden. Because these folds were formed by the uplift of the Owl Creek Mountains, the bentonite-bearing formations may decrease in dip and level out under the adjacent alluvium as the distance increases from the mountains. If so, the amount of strippable bentonite would be greater. This possibility can be tested only by additional drilling. The nose and western limb of this anticline are very steeply dipping and have very rough topography, factors which probably would make mining uneconomical.

One bed in the Mowry Formation near the crest of the major north-south ridge in the area was sampled at several sites, including preliminary site 9P and sites 8 and 9. Site 8 was sampled using the drilling rig, and site 9 was sampled using the hand auger.

This bed consists of clean, soft, greenish-gray bentonite, having a maximum measured thickness of 4.8 feet; no shale or porcellanite impurities were observed within the bed. Overlying this bed are several feet of light- to medium-gray, ridge-forming, siliceous shales and blocky mudstones that weather silvery gray. The mudstone is softer and less siliceous than the porcellanite found along Bighorn Ridge. This bentonite is placed in the Mowry Formation because the immediately overlying strata contain abundant fish scales, a characteristic of the Mowry Formation.

A second bed stratigraphically lies approximately 40 feet above the Mowry Formation in the Frontier Formation and crops out only near the nose of the anticline. Although it has limited exposure, it contains clean bentonite and possibly is strippable under the alluvium for a short distance. It is 2.7 feet thick and crops out near the nose of the anticline approximately 50 feet below a ridge surface, and thus, may be covered with too much overburden to be economically mined.

Stratigraphically below the major ridge-forming bed in the region, and having limited exposure, are numerous additional beds or lenses of bentonite in the Mowry and Thermopolis Formations. These range from 0.3 foot up to 4 feet in thickness and are separated by different thicknesses of shale, which grades from white, siliceous shale to soft, fissile, black shale. Many of the beds are covered with slopewash and are visible only in stream cuts. One of these beds sampled at site 10P contains clean bentonite, but the quantity available is unknown. One sampled area, site 12P, lies near a water gap in a sandstone ridge approximately 1.5 miles west of the above described area. At this site, a 10-foot bed of yellow, waxy to gritty, gypsum-rich bentonite lies along the southern base of the ridge and is inclined 60° from the horizontal. It may be continuous for approximately 4 to 9 miles along the ridge, but it is covered in many areas, so its continuity is uncertain. The relationship of this bed to the above-mentioned beds also is uncertain. Because of the steep dip and the uncertain continuity, the minability of this bed is questionable.

Northern Slope of Blue Ridge

Along the northern slope of Blue Ridge, an area north of the Owl Creek Mountains and west of Thermopolis, one possibly economic bentonite bed lies at the contact between the Mowry and Frontier Formations. Because the ridge slopes at approximately the same angle as the bentonite bed, and because the overburden ranges from 10 to 50 feet (estimated), the area possibly is suitable for stripping. The major impediment may be a blocky sandstone bed which upholds the ridge. The continuity, thickness, and hardness of this bed need further investigation.

Bentonite in this bed consists of up to 4.5 feet of greenish-gray to yellowish-buff, slightly damp, gritty to waxy bentonite that has varying amounts of red to orange weathering along fractures. It is overlain by an interval of white siliceous shale (porcellanite at site 12) that contains soft, bentonitic shale and thin bentonite beds, and underlain by dark-gray mudstone and shale. The ridge-forming sandstone lies about 10 to 20 feet above the white shale and is separated from it by another soft, gray, shale interval.

One preliminary sample and three trench or auger samples were obtained from this bed. Sites 13P and 10 are close to one another and are located approximately in the center of the 6-mile-long outcrop near a prominent sheepherder's monument that is constructed of rocks. Site 11 is approximately 2 miles to the east, and site 12 is near the western end of the outcrop. The bed sampled at site 12 may be at a different horizon.

## Sampling Procedures

During September 1981 and much of the 1982 field season, personnel of the BuMines sampled and studied bentonite deposits on the reservation. Fieldwork in 1981 consisted of a two-week reconnaissance trip through the area. The 1982 field season lasted from late May through mid-September.

In all, 63 samples were obtained. Twenty-six samples were taken by trenching at 17 sites; seven samples were taken by hand augering at two sites; and 30 samples were obtained by rotary drilling at 7 sites. Samples from all methods were bagged and labeled, and a numbered tag was placed inside each bag. The goal of the preliminary sampling was to sample the bentonite as widely as possible, and locations were chosen appropriately. Fifteen samples were collected from 13 sites (1P through 13P, pl. 3) during the September 1981 trip and early in the 1982 field season. These samples were numbered 201 through 215 and were considered preliminary samples. Laboratory data from these were used in selecting later sampling sites.

Later sampling took advantage of preliminary laboratory data and other factors affecting the minability of the bentonite. These later samples were numbered 300 through 347, and the sites were numbered from 1 through 13. Sample sites and sample numbers are shown on plate 3, and selected sites are described in appendix C.

After the preliminary samples were obtained, numerous criteria were used to determine areas that needed further sampling and to select the most appropriate sampling method for each location. In general, later samples were collected in areas that might have economic bentonite deposits, as shown by field and laboratory data. Only tribal land was sampled at the request of the Joint Business Council of the Shoshone and Arapahoe Tribes. Major criteria were the quality of the bentonite present in an area and its potential for economic development. Only those areas having outcrops suitable for mining were studied. This eliminated large areas where the Frontier, Mowry, and Thermopolis Formations crop out, particularly the area immediately east of the Wind River Range. Factors used to determine suitability for mining included inclination of beds, type and thickness of overburden, topography extent of outcrop, and impurities within the bed. Specific conditions often precluded one or more sampling methods. Rotary drilling was the preferred technique because the sample could be taken farther away from the outcrop and, therefore, would have minimal surface contamination. In general, the other two techniques were used during the initial reconnaissance when the rotary drill was unavailable and during later sampling where topographic or stratigraphic conditions prevented its use. Some criteria considered in determining the appropriate sampling method included accessibility of the sample site, slope of the ground surface at the site, adequate area in which to maneuver the drilling equipment, presence of hard stratigraphic layers that produce difficult or very slow drilling, and dip of the beds.

### Trench Samples

Trench samples were taken in areas where rough topography or other factors prevented the use of the rotary drill (fig. 5). Trenches often were cut into hillsides, and true thicknesses were measured. These trenches were dug 1 to 1.5 feet wide and 3 to 4 feet into the hillside; exact depths depended on the attitude of the bentonite bed and slope of the hill. Samples collected from trenches often were taken at intervals of less than 2 feet because the trench walls were visible and variations in the bentonite were easily seen.

### Hand Auger Samples

Auger samples were obtained from two sites using the DR-90 Acker Soil Sampling Kit.[5] Hand auger samples were taken only in areas where the top of the bentonite bed was at or very near the surface and where the bed was believed to be free of shale, porcellanite lenses, and other impurities. A chopping bit was available to physically break hard units but was rarely used.

Auger samples were taken on 1-foot intervals or where changes in the appearance of the bentonite occurred. In both areas augered, the bentonite forms a bench and is overlain by 1 to 2 feet of loose, siliceous, white to light-gray shale and mudstone.

---

[5]Use of specific product or brand names does not constitute an endorsement by the Bureau of Mines or the authors of this paper.

FIGURE 5.—Trench cut into a bentonite bed for sampling.

## Rotary Drill Samples

Major equipment used for rotary drill sampling consisted of a CFD-2 Holemaster Failing portable rotary drilling rig, a 375-cubic-feet-per-minute air compressor, and an all-wheel drive, 2.5-ton, flatbed truck (fig. 6).

The CFD-2 Failing drill is a self-contained, truck-mounted, drilling rig requiring a minimum of auxiliary equipment for operation. It is designed for mobility and operation in rough terrain. Drill locations were limited, however, because of the need to level the drilling rig and air compressor, the inability of the tricone drilling bits to cut through siliceous sandstone, and the need for the air compressor to be located close to the drilling rig. Air was used during drilling rather than water, owing to the distance of most sample locations from a water source and to the tendency of bentonite to form a tightly squeezing gel when mixed with water.

Samples obtained with the drilling rig were recovered as small chips or balls. These were caught in a wire screen, which was placed around the drill hole, and then placed into a labeled, plastic bag (fig. 7).

## Testing

A variety of laboratory tests were utilized to evaluate the bentonite resource. The initial phase involved identifying the primary and accessory minerals present in the preliminary samples (sites 1P to 13P, pl. 3) by using X-ray diffraction analysis. Each mineral has a characteristic structure that can be determined by X-ray diffraction methods. This phase was necessary to ascertain whether the sampled beds consist principally of smectite minerals, making them identifiable as bentonite, and to ascertain the types and relative amounts of other minerals present. Bentonite beds can contain large amounts of nonsmectite materials, such as quartz and zeolite minerals. These can contaminate the bentonite and make it unsatisfactory for many industrial uses. In addition, zeolites are valuable industrial minerals, and discovery of a rather pure deposit would be commercially important.

Bentonites are used more for their physical properties than for their chemical ones (20). Accordingly, the second phase of testing evaluated the physical properties of the samples. Several laboratory tests have been devised to measure the physical properties of bentonite-water mixtures. Although many of the laboratory procedures are standardized by organizations, such as the American Society for Testing Materials (ASTM) and the American Petroleum Institute (API), individual laboratories sometimes make small modifications. As a result, different values on a particular test are sometimes reported for the same sample by different laboratories.

Despite the several tests that are available, no single test is accepted for evaluating both the swelling and nonswelling varieties of bentonite over a wide range of uses. Regis (82) suggested in 1978 that the physical properties most useful in assessing the commercial potential of swelling bentonites are viscosity or yield, filtration rate or water loss, and water-holding capacity or liquid limit. These are defined briefly in this report in appendix B. Procedures and equipment for performing tests to evaluate the first two properties are included in API publication RP 13, "Standard Field Procedure for Testing Drilling Fluids" (1). These procedures were followed, except as noted in table E-4. The test evaluating the last property was not utilized in this study because it is difficult to conduct on high-swelling bentonites, owing to their high degree of water adsorption, plasticity, and thixotropic nature (35, p. 211). In 1981, a procedure for the plate-water absorption or Enslin test, as used by the Bentonite Users Committee, was proposed to the ASTM for consideration as a standard test for evaluating the water-sorption capacity of swelling bentonites (Kenneth Tanner, Consulting Geologist, Ten Sleep, Wyo., written communication, June 8, 1982; and Kenneth Liles, Research Chemist, BuMines Tuscaloosa Research Center, oral communication, August 17, 1982). The test measures in weight percent the amount of water a sample of bentonite can absorb and adsorb in 18 hours under specified conditions. The test currently is being used by some producers and consumers to evaluate the suitability of bentonites for use in pelletizing taconite ore (43, 47). Water-sorption capacity also is important in evaluating bentonites for use as foundry-sand binders, pond sealants, and animal-feed binders. The plate-water absorption test was used to evaluate the water-sorption capacity of most of the samples collected during the study.

Another method commonly employed to evaluate the suitability of swelling bentonites for use in binding foundry-sand is the dry compressive strength test (61). The test measures the dry-bond strength of a bentonite-sand mixture. In the test, a specific amount of bentonite is mixed with foundry sand and water and then rammed into a standard cylinder until a plug of required size is formed. Each plug is then dried by following a standard procedure. The dry compressive strength is determined by subjecting each of the plugs to an increasing load on an H. W. Oietert High-Strength Universal Sand-Testing device (61). Dry compressive strength is the force, measured in pounds per square inch, required to cause failure in a plug. A dry compressive strength value was obtained for all samples collected during the study.

Some physical properties useful in determining the commercial potential of nonswelling bentonites are green compressive strength, water or oil absorption capacity, and bleaching capacity. Green compressive strength, measured in pounds per square inch, indicates the mechanical strength of foundry molds after they have been shaped but before they have been dried or fired. The test is conducted in the same manner as the dry compressive strength test, except the plugs are not dried (61). A green compressive strength value was determined for each of the samples collected during the study. Because initial tests indicated that the Wind River Indian Reservation bentonites are the swelling variety, other laboratory tests normally used to evaluate the nonswelling type were not included as part of this study.

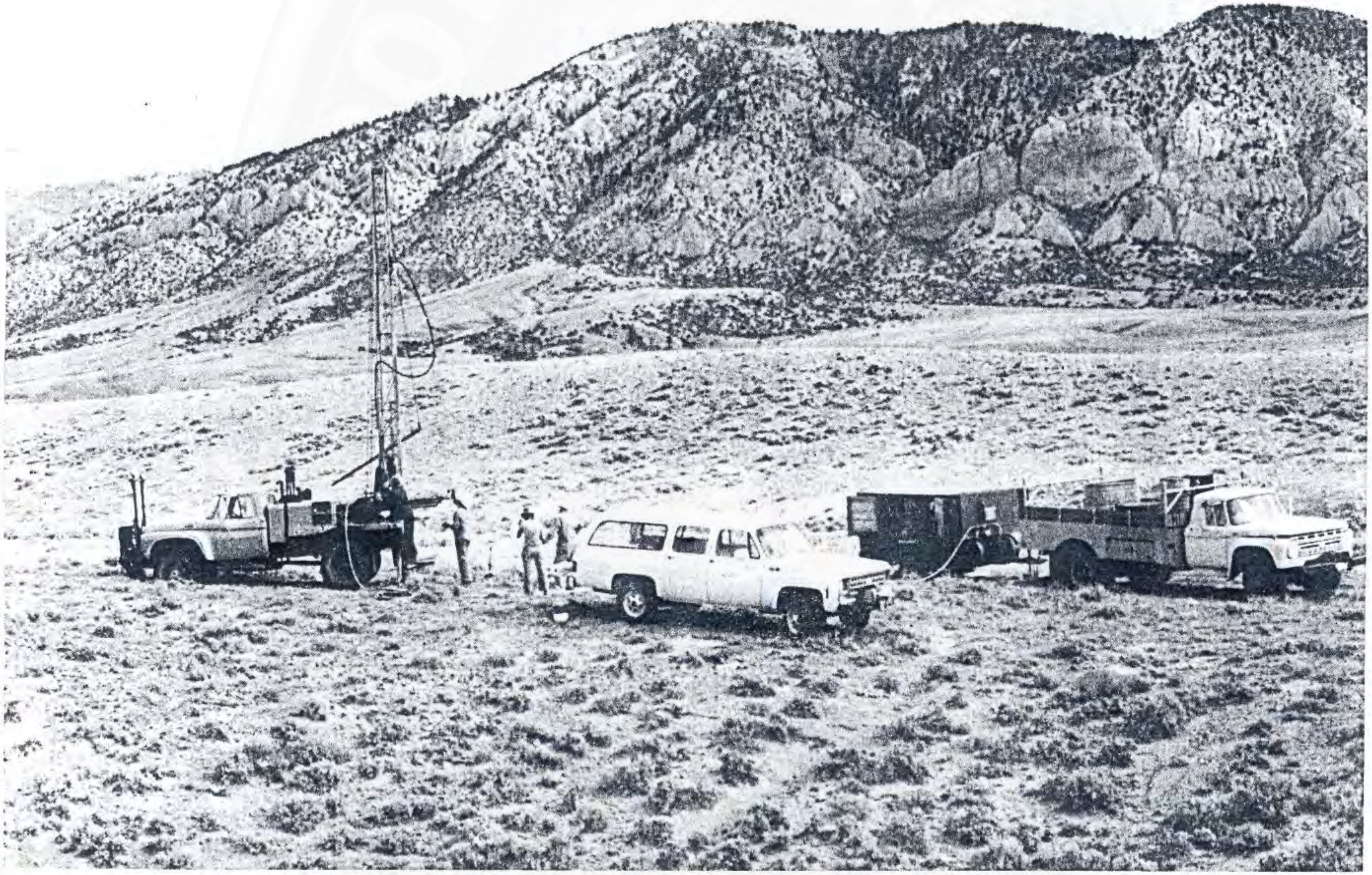


FIGURE 6.—Equipment used for obtaining rotary drill samples.

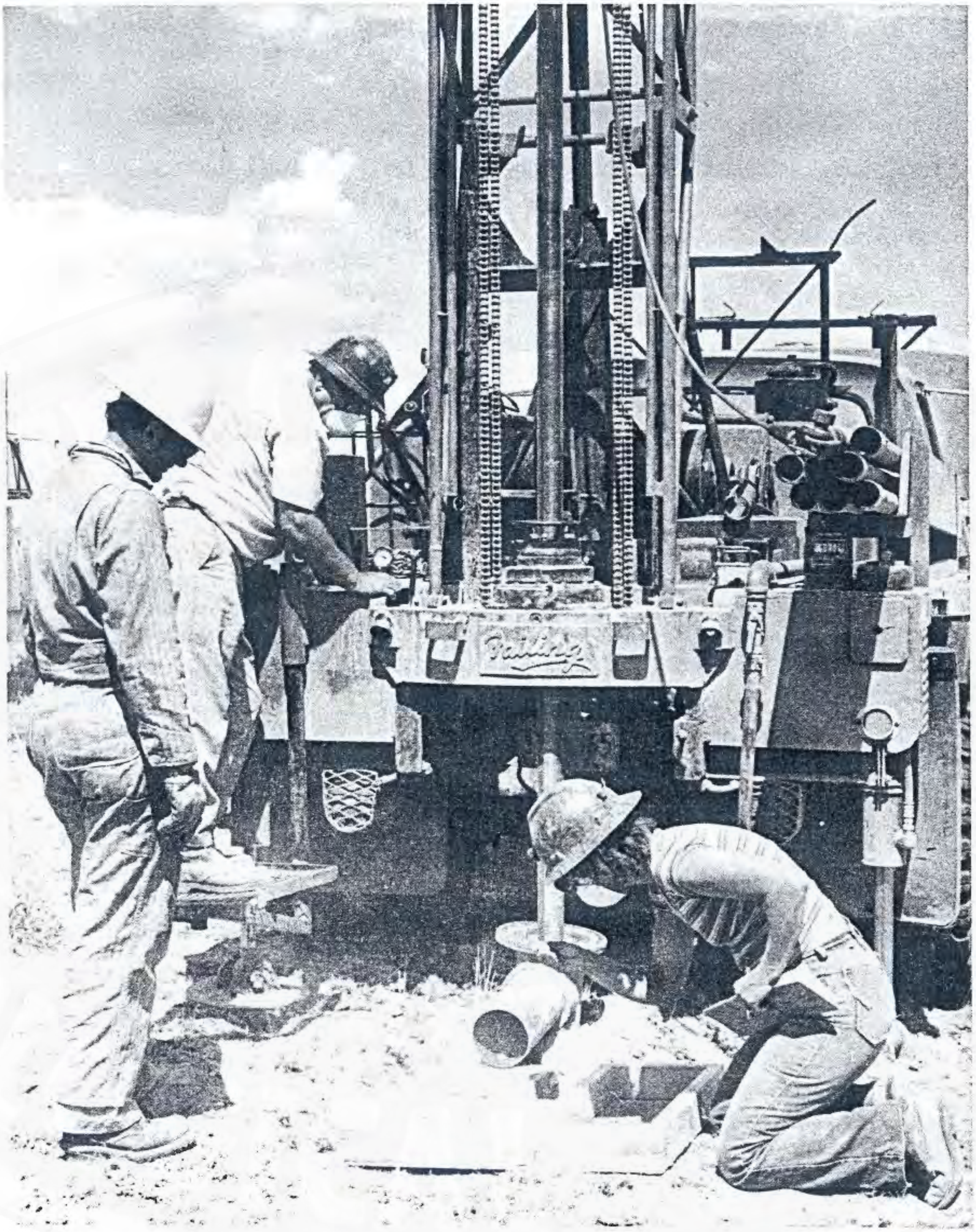


FIGURE 7.—Close-up view of rotary drilling rig and wire screen used for collecting bentonite samples.

Most of the tests used to evaluate the physical properties of the bentonite samples were conducted at the BuMines Tuscaloosa Research Center. In addition, Kenneth Tanner, a consulting geologist in Ten Sleep, Wyo., assessed the potential of selected samples for use in manufacturing drilling mud.

The third and final phase of the testing program involved treating selected bentonite samples with soda ash ($Na_2CO_3$) and a commercially prepared polymer, FR-76. Producers commonly treat bentonite with soda ash prior to or during milling (43, 111). Sodium cations derived from the soda ash, owing to their relatively high concentration, replace some of the exchangeable calcium cations on the molecular sheets comprising the bentonite structure (see appendix B for a discussion of exchangeable cations). The resulting increase in exchangeable sodium cations causes a decrease in the rate of water loss from most bentonite-water suspensions; it also may cause an increase in the viscosity or yield of the suspension. Producers also commonly use one or more commercially available polymers to enhance their products (Kenneth Tanner, oral communication, November 10, 1982). The long-chain, organic polymers attach themselves to exchange sites on the molecular sheets of the smectite minerals and cause a marked increase in the viscosity or yield of most bentonite-water suspensions (Kenneth Liles, oral communication, November 18, 1982). Less high-swelling bentonite, therefore, is necessary to meet API specifications in manufacturing drilling mud (47). In addition, such treatments may allow the use of intermediate-swelling bentonites for manufacturing drilling mud. Recent tests, conducted at the Worland, Wyo., laboratory of the U.S. Bureau of Land Management (BLM), have demonstrated that blending and chemical enhancement permits bentonite with a yield of at least 55 barrels per ton and a water loss not exceeding 24 milliliters to surpass API specifications for drilling mud (Steven Barrell, Geologist, BLM, Worland, Wyo., oral communication, December 7, 1982). API specifications require a minimum yield of approximately 91 barrels of 15-centipoise drilling mud and a water loss not exceeding 15 milliliters (2). Ten samples not meeting API specifications for drilling mud were treated with soda ash in amounts ranging from 0.5 to 3.0 weight percent and a polymer in amounts equivalent to 0.5 to 1.5 pounds per ton of bentonite. These tests also were conducted by Tanner.

## Specifications

Specifications used to evaluate the suitability of bentonite for industrial applications are not uniform. Bentonite consumers, even those manufacturing the same product, often have their own set of tests and specifications (82). Differences in plant technology, sources and types of raw materials, and use of the product are factors contributing to the highly variable nature of specifications currently in use for grading bentonites. Previous experience with a bentonite possessing certain physical properties also plays a major role in a consumer's requirements. In many instances, suitability of a bentonite for a particular application can be assessed only after it has been used in a full-scale plant test. Such tests are, of course, not possible during the exploration phase of evaluating bentonite deposits, when relatively small samples are collected.

Methods that use small samples to estimate the potential of a bentonite deposit include comparing properties of the samples with properties of untreated bentonite collected from producer's pits, with properties of commercially prepared bentonite products, and with specifications that appear in the literature. Each method has advantages and disadvantages. The advantage for the first two methods is that all samples can be compared by using the same tests and procedures. The third method enables the properties of a bentonite to be compared with specifications required for diverse applications. A disadvantage of the first method is that producers frequently mine a particular bentonite deposit for a specific use; higher grades of swelling bentonite usually are destined for use in manufacturing drilling mud, whereas lower grades generally are mined for other applications (82, 91, 111). With the second method, the principal disadvantage is that producers often tailor a bentonite for a particular use or consumer by blending different grades of bentonite and by enhancing with chemical additives (111); such products should not be compared with a bentonite sample when evaluating the sample for other applications. The third method's disadvantage, which often is major, is that the tests and procedures utilized to determine the specifications usually are not discussed. When this occurs, comparisons must be made only in a general manner.

Each of these methods is used in this report to estimate the potential of the Wind River Indian Reservation bentonite deposits. Mineralogical composition and physical properties of five untreated bentonite samples collected from producer's pits near Greybull and Lovell, Wyo., were determined in the same manner as used to test the bentonite samples collected on the reservation. Results of these tests are shown in table 1. The same tests also were used to determine the physical properties of a commercially produced, swelling bentonite product intended for use in manufacturing drilling mud and a commercially produced, nonswelling bentonite product intended for use in binding foundry sand (table 2).

Several examples of specifications for major uses of swelling bentonite are given by Regis (82). According to him, water loss is the single most important physical property in grading swelling bentonites. If the water loss exceeds 16 milliliters, he rates the bentonite unacceptable for manufacturing drilling mud, pelletizing taconite ore, and binding foundry sand. He also lists yield and water loss specifications considered acceptable for commercial use on the basis of data from 20 companies (82).

Manufacturing drilling mud (6 companies)

yield = 76 to 95 barrels per ton
water loss = $<15$ milliliters

Pelletizing taconite ore (18 companies)

yield = 60 to 105 barrels per ton (average 89 barrels per ton)
water loss = $<15$ milliliters

Civil engineering uses (3 companies)

yield = $80 \pm 5$ barrels per ton
water loss = $<15$ milliliters

Binding foundry sand (10 companies)

Steel foundry:
yield = 70 to 90 barrels per ton
water loss = <15 milliliters

Gray iron foundry (also see below)
yield - no specification reported
water loss - no specification reported

Pond sealants, reservoir liners, etc.

yield - no specifications reported
water loss = <30 milliliters

Animal feed binders (also see below)

yield - no specification reported
water loss - no specification reported

Pet absorbents (3 companies; also see below)

yield - no specifications reported
water loss - no specifications reported

Lacking examples of specifications from companies processing bentonite for use as cat litter, Regis (82) obtained and tested samples of bentonite being used to manufacture this product by two companies. The yields for these samples ranged from 0 to 55 barrels per ton and the water losses ranged from 35 milliliters to greater than 80 milliliters.

Regis (82) also reports that nearly all swelling bentonites are suitable for use in binding animal feed and gray-iron foundry sand. One company accepts bentonite for both uses that has a yield of less than 30 barrels per ton and a water loss exceeding 35 milliliters.

Examples of specifications for grading bentonites also are discussed by Grim (35) and Rose (91). Grim (35) reports that green compressive strengths of bentonites used in binding foundry sand commonly range from 5 to 7.5 pounds per square inch. A range of 70 to 100 pounds per square inch is given by the same author as acceptable dry compressive strength values in the same industry. Ross (91) states that requirements for bentonites used in manufacturing drilling mud generally range from 60 to 100 barrels per ton; however, a minimum of 90 barrels per ton is preferred. He also reports that a bentonite used in binding foundry sand has a green compressive strength of about 8.5 pounds per square inch and a dry compressive strength of about 95 pounds per square inch.

TABLE 1. - Mineralogical composition and physical properties of bentonite samples collected from producers' pits near Greybull and Lovell, Wyo.

(mont = montmorillonite; qtz = quartz; cli = clinoptilolite; cris = cristobalite; gyp = gypsum; cal = calcite; rpm = rotations per minute; bbl/ton = barrels per ton; pct = percent; and psi = pounds per square inch)

| Sample | Mineralogical composition[1] | | | Fann viscometer reading, 600 rpm[2, 3] | Yield, bbl/ton[2] | Plate-water absorption, pct[2] | Compressive strengths[2] | |
|---|---|---|---|---|---|---|---|---|
| | Major | Minor | Trace | | | | Green, psi | Dry, psi |
| A..... | mont | none | qtz, cli, cris | 24 | 86 | 816 | 6.80 | 30.3 |
| B..... | -do- | cris | cli, qtz, gyp | 5 | 46 | 171 | 5.55 | 71.8 |
| C..... | -do- | none | cli, cris | 23 | 85 | 676 | 6.10 | 51.8 |
| D..... | -do- | none | cli, qtz, cal | 12 | 68 | 681 | 5.10 | 44.5 |
| E..... | -do- | cris | cli, qtz | 25 | 87 | 734 | 3.4 | 67.0 |

[1]Analyses performed by BuMines Reno Research Center.
[2]Analyses performed by BuMines Tuscaloosa Research Center.
[3]Test conducted using 20.25 grams of dry bentonite; equivalent to 22.5 grams of bentonite containing 10 percent moisture content (see note in table E-3).

TABLE 2. - Physical properties of commercially prepared bentonite products[1]

(rpm = rotations per minute; NAp = not applicable; bbl/ton = barrels per ton; ml = milliliters; pct = percent; and psi = pounds per square inch)

| Bentonite type | Fann viscometer reading[2] | | Yield, bbl/ton | Water loss, ml | Water-sorption capacity, pct | Compressive strengths | |
|---|---|---|---|---|---|---|---|
| | 600rpm | 300rpm | | | | Green, psi | Dry, psi |
| swelling........ | 34 | 22 | 96 | 12 | 894 | 5.6 | 80.2 |
| nonswelling..... | NAp | NAp | NAp | NAp | 130 | 6.4 | 46.2 |

[1]Analyses performed by BuMines Tuscaloosa Research Center.
[2]Tests conducted using 20.25 grams of dry bentonite; equivalent to 22.5 grams of bentonite containing 10 percent moisture content.

The plate-water absorption or Enslin test is not discussed widely in the literature, and examples of requirements for many applications are unavailable. As proposed to the ASTM, a bentonite should have a water-sorption capacity of of at least 600 percent to be acceptable for binding taconite ores; a value of 800 percent is preferred (Kenneth Liles, oral communication, November 18, 1982). Hofstadt and Fahn (43), however, report that acceptable taconite pellets also may be made from bentonites having water-sorption capacities around 500 percent.

Most of the authors referred to above do not discuss the implications of chemically enhancing bentonites upon grading, owing probably to the relatively recent advances in this technology. As reported by the BLM, such enhancement can markedly increase the yield and significantly decrease the water loss of a swelling bentonite. (Yield and water loss values for grading bentonite, as determined by the BLM, are included elsewhere in this report in the section discussing testing.) Tests evaluating the suitability of chemically enhanced, swelling bentonites for use in binding taconite ore and foundry sand are scheduled to be conducted in 1983 by the BLM (Steven Barrell, oral communication, December 7, 1982). Specifications for grading bentonites for these applications likely will result from the studies.

## Discussion of Results

Tables listing the mineralogical composition and physical properties of the Wind River Indian Reservation bentonite occurrences, as determined in this study, are included in appendix E. Data collected by testing a single sample must not be considered typical of the entire bed or area from which the sample was taken. Lateral and vertical variations in mineralogical composition and physical properties are especially commmon within bentonite beds and result from the manner in which they form and from the effects of weathering upon near-surface occurrences; producers commonly sample a bed at 50-foot intervals before beginning mining operations.

Considerable information about the bentonite-bearing Frontier, Mowry, and Thermopolis Formations was collected during the preliminary or reconnaissance phase of the study. Most of the bentonite occurrences within these formations, including several described in the literature (13, 95), are too thin, too impure, or too steeply dipping to be considered minable. Many consist of thin, interlayed units of bentonite, siliceous shale, and porcellanite. In general, such occurrences were not sampled.

X-ray analyses indicate that the smectite mineral montmorillonite is the major component of each bentonite sampled during the field reconnaissance (sites 1P through 13P; pl. 3). Minor and trace amounts of other materials present in the samples include quartz, cristobalite, gypsum, and clinoptilolite (table E-1). Each of the beds sampled, therefore, meets the definition of bentonite as used in this study. A number of the beds are highly fissile and, therefore, were described as "bentonitic shales" during the fieldwork. This term also is used in this report when referring to such beds.

Yields of the preliminary samples range from less than 30 to 85 barrels per ton (table E-1). Based on Regis' (82) classification (appendix B), all three varieties of swelling bentonite are present on the reservation. Sample 211 (site 9P), having a yield of 85 barrels per ton and a water loss of 16.4 milliliters, is the only sample collected during the field reconnaissance that surpasses Regis' (82) yield and water loss values for high-swelling bentonite. Two other samples (210 and 212), collected at sites 8P and 10P, have yields slightly less than Regis' requirement for high-swelling bentonite, but their water loss values are, respectively, 12.1 and 14.5 milliliters. Because water loss is the more important property (Andrew Regis, former BLM Industrial Minerals Specialist, oral communication, December 6, 1982), these samples also are considered as high-swelling bentonites. Analyses of samples collected at sites 1P through 7P and 13P indicate that they are low-swelling bentonites. These samples, however, were collected from shallow channels or trenches made across bentonite outcrops and may have been contaminated with non-bentonitic materials. Weathering of such near-surface occurrences may have reduced their swelling capacity by sufficiently altering the ratio of exchangeable sodium to calcium cations (11). Accordingly, additional samples were collected in two areas considered minable. These areas are along the eastern side of Bighorn Ridge, including the eastern and northern flanks of Winkleman Dome, and along the northern slope of Blue Ridge (pl. 3). Results of the additional work in these areas and in the area north of Arapahoe Reservoir, where preliminary sampling showed the highest yield and lowest water loss values, are individually discussed below. Additional work was not done near sites 8P (sample 210) and 11P (sample 213), owing to the small areal extent of the bentonite beds that crop out in these areas.

### Eastern Side of Bighorn Ridge

Table E-2 shows the results obtained from laboratory analyses of additional samples collected at seven sites along the eastern side of Bighorn Ridge and the eastern and northern flanks of Winkleman Dome. Most of the samples were collected at sites 2, 3, 6, 7, and 13 (pl. 3) from the bentonite bed or beds occurring in the bentonite-porcellanite interval located along the contact between the Frontier and Mowry Formations. (The bentonite bed or beds in this interval are described elsewhere in this report in the section discussing minable beds.) Yield and water loss values for these samples range, respectively, from 40 to 76 barrels per ton and from 14.3 to 92.5 milliliters. In general, they are low- and intermediate-swelling bentonites, and several do not appear to have potential for use in manufacturing drilling mud or pelletizing taconite ore. Samples 345 and 346 were collected from the upper 4 feet of the bentonite-porcellanite interval at site 13 and combined for laboratory testing. Yield and water loss values are, respectively, 68 barrels per ton and 20 milliliters. Following chemical enhancement, this bentonite may be suitable for nearly all major uses of high-swelling bentonite. Near-surface weathering may enhance the physical properties of bentonite by increasing the ratio of exchangeable sodium to calcium cations (11, 31, 109). The relatively high yield, low water loss, and high water-sorption values for the bentonite-porcellanite interval at site 13, which was collected from beneath 3 feet of overburden, may be the result of such weathering. This also may account for the relatively better test results obtained from samples 319 and 321. These samples were collected at site 6 where the bentonite-porcellanite interval is covered with 6 feet of overburden. Sample 320, which also was collected at site 6, has lower yield and higher water loss values, perhaps because it is contaminated with nonsmectite materials. Whether near-surface weathering similarly would enhance other parts of the bentonite-porcellanite interval is unknown.

Despite the relatively low yield, high water loss, and low water-sorption values obtained from most of the samples collected from the bentonite porcellanite interval along Bighorn Ridge, the bentonite might be suitable for some industrial applications. Dry compressive strength values at several of the sites range from about 50 to 70 pounds per square inch. Although such values do not equal those reported in the literature and those obtained by analysis of a commercially produced, swelling-bentonite product (table 2), they do compare favorably with bentonites collected from producers' pits (table 1). The bentonite bed or beds occurring in the bentonite-porcellanite interval should be suitable for use as a reservoir or pond sealant and as a binder for animal feed and gray-iron foundry sand, but their water loss values generally are too high for civil engineering applications without chemical treatment.

Samples 322 and 323 were collected from a stratigraphically higher bentonite bed at site 7 (pl. 3). The bed is 3.5 feet thick and has yield and water loss values, respectively, of 76 barrels per ton and 11.6 milliliters. Where sampled, the bed is composed of high-swelling bentonite and, with chemical enhancement, should be suitable for nearly all major uses of swelling bentonite.

Although this bentonite bed appears to have greater potential for industrial application than the bentonite occurring in the bentonite-porcellanite interval it overlies at site 7, its areal extent is undetermined. In addition, strata become more steeply inclined northward along the eastern side of Winkleman Dome. Should the bed occur elsewhere along Winkleman Dome, it may not be minable without removing considerable overburden. Additional fieldwork, which should include sampling and drilling, is necessary to determine the areal extent and economic potential of this bed.

Samples 311 through 318 were collected from sites 4 and 5 (pl. 3). Yield and water loss values of these samples, respectively, range from 46 to 55 barrels per ton and from 15.8 to 107.4 milliliters. In general, they are low- and intermediate-swelling bentonites that, without chemical enhancement, appear to be suitable only for binding animal feed and gray-iron foundry sand.

None of the samples collected from the bentonite beds occurring along Bighorn Ridge and Winkleman Dome were treated with soda ash or a commercial polymer. Several samples, collected at sites 3 and 6 have water loss values less than 24 milliliters and yields of at least 55 barrels per ton. The BLM has determined that a bentonite with such properties can be chemically enhanced and used for manufacturing drilling mud. These samples and some collected at sites 7 and 13 should be chemically treated and retested, owing to the potential of the areas for strip mining.

## North of Arapahoe Reservoir

Four bentonite beds were sampled in the area north of Arapahoe Reservoir (pl. 3). Strata of the Frontier, Mowry, and Thermopolis Formations crop out here, forming a ridge that dominates the topography. One bed was sampled (site 12P) along the northwest-trending part of the ridge. To the east, three other beds were sampled along the same ridge after it bends northeastwardly. Most prominent of these stratigraphically lies in the upper part of the Mowry Formation near the crest of the ridge. This bed was sampled in three places (sites 9P, 8, and 9). Another bed, occurring in the Frontier Formation, was sampled nearby at site 1. The final bed sampled on this part of the ridge, at site 10P, stratigraphically lies in the lower part of the Mowry Formation or the upper part of the Thermopolis Formation. (These beds are described elsewhere in this report in the section discussing minable beds.)

Sample 214, collected at site 12P (pl. 3), has yield and water loss values, respectively, of 70 barrels per ton and 18.6 milliliters. It has a water-sorption capacity of 705 percent, the highest detected during the study. It is an intermediate-swelling bentonite and should be suitable for several industrial applications. Untreated, possible applications include sealing ponds and reservoirs, pelletizing taconite ore, and binding animal feed and gray-iron foundry sand. Table E-4 reports the results of treating sample 214 with soda ash and a commercial polymer, FR-76. Following treatment, the bentonite meets API specifications and, therefore, would be suitable for use in manufacturing drilling mud. Such treatment also may enable the bentonite to be suitable for some civil engineering applications. Whether chemical treatment would increase the dry compressive strength of the sample is unknown, but its potential for binding foundry sands is not promising.

Although the bentonite appears to be suitable for several industrial applications, whether it can be mined is unknown. The bed is inclined at a high angle where it crops out at site 12P, and its areal extent is undetermined. Should the bed exist beneath shallow alluvium elsewhere along the ridge, it perhaps could be strip mined parallel to the ridge for several miles. Unless the inclination of the bed decreases rapidly away from the ridge, however, only a narrow stripping width would be possible without removing considerable overburden. Additional fieldwork, including drilling and sampling, is necessary to thoroughly evaluate the potential of the bed.

Samples 328 through 330 were collected from the bentonite bed occurring in the Mowry Formation at site 8 (pl. 3). Sample 330 was contaminated with fragments of an underlying shale unit and was not sent to the laboratory for analyses. Samples 328 and 329 were analyzed by Tanner and by the BuMines. According to Tanner (table E-3), sample 328 has a yield of 78 barrels per ton and a water loss of 11.0 milliliters. His analyses of sample 329 indicate a yield of 84 barrels per ton and a water loss of 10.4 milliliters. The samples were combined before being analyzed by the BuMines. Results obtained from testing the combined samples indicate that the bentonite has a yield of 51 barrels per ton and a water loss of 35.5 milliliters. As discussed in table E-3, Tanner's testing procedure involved using more bentonite in each analysis than was used by the BuMines. This commonly produced higher yield and lower water loss values than were reported by the BuMines. The variation between results obtained from the two laboratories, however, is much greater for the samples collected at site 8. In addition, the BuMines analyses of the sample collected nearby at site 9P (sample 211) indicates a yield of 85 barrels per ton and a water loss of 16.4 milliliters. (Site 9P is located near the crest of the ridge and about 20 feet southwest of site 8.) The cause of the relatively low yield and high water loss values reported by the BuMines for samples collected at site 8 is unknown, and these values are not considered in subsequent discussions of the bed. Other test results, similarly reported by the BuMines for these samples, also appear anomalous and are not considered in subsequent discussions of the bed.

Samples 331 and 332 were collected from the same bed at site 9 (pl. 3) and combined for laboratory analyses. The bentonite sampled at this site has a yield of 70 barrels per ton and a water loss of 12.6 milliliters.

Yield and water loss values for the bentonite samples collected from the bed, therefore, range from 70 to 85 barrels per ton and from 12.6 to 16.4 milliliters. (These are the values determined by the BuMines and are used to remain consistent with other laboratory results discussed in this report.) Owing to their low water loss values, the samples are considered to be high-swelling bentonites, and their physical properties compare favorably with samples collected from producers' pits (table 1). Untreated, the bentonite should be suitable for blending with higher-quality bentonite in manufacturing drilling mud, binding animal feed and gray-iron foundry sand, and sealing ponds and reservoirs. It also may be suitable for some civil engineering applications. Dry compressive strengths of the samples, which range from 58.8 to 63.5 pounds per square inch, do not surpass the strength of a commercially produced bentonite product (table 2) or the specifications given in the literature for bentonite used in binding steel foundry sand, but they approximate the strengths of bentonite samples collected from producers' pits (table 1).

Table E-4 shows the results of treating samples 211, 328, and 329 with soda ash and FR-76, a commercial polymer. Following such treatment, yield and water loss values range, respectively, from 94 to 109 barrels per ton and from 11.0 to 12.0 milliliters. All surpass API specification for drilling mud. Whether chemical treatment altered other physical properties was not determined.

Information necessary for determining the tonnage of bentonite minable from the bed is unknown. An approximation of the amount of bentonite occurring in the bed, however, may be calculated if several assumptions are made. These include a stripping width of 600 feet (approximate distance from the outcrop at which the projection of the bed is covered by 50 feet of alluvium), a stripping length of 1.1 miles (approximate length of known outcrop), and an average bed thickness of 4.5 feet. Using these assumptions, approximately 1 million tons of bentonite is present within the bed. Should the inclination of the bed decrease outward from the ridge, wider stripping widths would be possible. This can be determined only by additional fieldwork, which should include drilling and sampling.

Sample 300 was collected at site 1 (pl. 3) from a bentonite bed in the Frontier Formation. Yield and water loss values, respectively, are 73 barrels per ton and 18.5 milliliters. Its water-sorption capacity is 586 percent, and its dry compressive strength is 68 pounds per square inch. Untreated, the bentonite at this site is suitable for sealing ponds and reservoirs and binding animal feed and gray-iron foundry sand. Although its water-sorption capacity is less than the required 600 percent, it might be suitable for binding taconite pellets. It also may be suitable for use as a binder for steel foundry sand. After treating with soda ash and a commercial polymer, FR-76, its yield increased to 100 barrels per ton and its water loss decreased to 13.0 milliliters. With such values, the bentonite surpasses API specifications and is suitable for use in manufacturing drilling mud. Civil engineering applications also seem probable following enhancement. Whether the water absorption capacity and dry green strength are increased by such treatment is unknown.

The areal extent of this bed is undetermined. It probably extends to the northeast beneath alluvium, paralleling the ridge and overlying the previously described bentonite bed in the Mowry Formation. Southwestwardly, the bed increases in inclination as the ridge bends to the northwest. Additional sampling and drilling are necessary to adequately evaluate the potential of this bed and to determine if it can be mined in conjunction with the bentonite bed in the Mowry Formation.

Sample 212 was collected at site 10P (pl. 3) from a bentonite bed exposed along a drainage. The bed stratigraphically lies in the lower part of the Mowry Formation or the upper part of the Thermopolis Formation. Yield and water loss values of the sample are, respectively, 70 barrels per ton and 14.5 milliliters. Its water-sorption capacity is 608 percent. Untreated, the bentonite is suitable for use as a pond or reservoir sealant and as a binder for animal feed, taconite ore, and gray-iron foundry sand. Its low water loss also may permit its utilization for some civil engineering applications. The areal extent of this bed is unknown, and additional fieldwork is necessary to determine its potential for mining.

### Northern Slope of Blue Ridge

Additional samples were collected along the northern slope of Blue Ridge at sites 10, 11, and 12 (pl. 3). Yield and water loss values for the samples range, respectively, from 55 to 71 barrels per ton and from 14.7 to 25.0 milliliters. Water-sorption capacities range from 415 to 697 percent. These samples are intermediate- and high-swelling bentonites. Untreated, they are suitable for sealing ponds or reservoirs and for binding animal feed and gray-iron foundry sand. Samples 333 and 344, which were collected at site 12, and the samples collected at site 10 (samples 333 through 337) have water-sorption values exceding 600 percent making them suitable for use in pelletizing taconite ore. Table E-4 lists the yield and water loss values after treating most of the samples collected at sites 10 and 11 with soda ash and a commercial polymer. Such treatment increases the yield to a range of 97 to 104 barrels per ton and decreases the water loss to between 13.2 and 14.2 milliliters. All of the treated samples surpass API specifications and are suitable for use in manufacturing drilling mud. The enhanced bentonite also might have civil engineering applications. Whether chemical treatment would enhance other properties of the samples was not determined.

Information necessary to determine the amount of minable bentonite within the bed is unknown. An estimate of the tonnage of bentonite occurring in the bed, however, can be obtained by assuming a stripping width of 3,200 feet (approximate distance from face of outcrop northward to a paralleling sandstone ridge), a stripping length of 6 miles (approximate distance from western edge of outcrop to where the bed exits tribally owned land), and an average thickness of 4.5 feet. Calculations based on these assumptions indicate that about 40 million tons of bentonite occurs within the bed.

Additional fieldwork, including drilling and sampling, is necessary to determine the potential of the bed for mining. Areal extent, continuity, thickness, and hardness of an overlying sandstone bed also should be determined.

### Recommendations

Additional fieldwork and laboratory analyses are required to evaluate possible industrial applications and to determine minability of bentonite beds in each of the three areas having mining potential. The fieldwork should provide sufficient information for investigators to determine the extent, orientation, and quality of the two bentonite beds sampled at sites 7 and 13 in the Bighorn Ridge-Winkleman Dome area; the four bentonite beds sampled at sites 9P, 10P, 12P, 1, 8, and 9 north of Arapahoe Reservoir; and the bentonite bed (or beds) sampled at sites 13P, 10, 11, and 12 along the northern slope of Blue Ridge. In order to determine the grade within each of these beds, laboratory work should include analyzing additional samples for their physical properties. In addition, several samples already collected from bentonite beds in the Bighorn Ridge-Winkleman Dome area and selected samples collected during any future fieldwork should be chemically treated and retested to determine whether such treatment would permit their utilization for industrial applications.

## GOLD RESOURCES

### Introduction

Prospectors have been attentive to the presence of gold in the vicinity of the Wind River Indian Reservation since 1842, when placer gold was found in the Sweetwater District. Several attempts were made to mine an area about 40 miles south of the reservation near where the "Overland Trail" crosses the Sweetwater River (64, 96).

Gold-bearing deposits, both placer gravels and quartz lodes, were mined or prospected on all sides of the reservation. These attempts usually met with little or no success. The best known and most productive activity was in the Atlantic City-South Pass District. In this district, which lies about 25 miles south of the reservation, considerable prospecting was done and many mines were operated. Quoted production figures from placer and lode mines in the district vary widely, ranging from 1 to 6 million dollars (64). Mine operation was intermittent; one group of operators succeeded another, and none apparently achieved any sustained degree of success. The same story, on a smaller scale, is true of deposits to the north, west, and east of the reservation.

# Mining on the Reservation

## Lode

Within the reservation boundaries, lode gold deposits were prospected with cuts and pits in many places in the Wind River Range and the Owl Creek Mountains. Intensive prospecting was conducted on quartz veins in at least three places. In the Wind River Range along St. Lawrence Creek in T 1 N, Rs 3 and 4 W, irregular quartz lenses and stringers up to 4 feet in thickness were prospected. The quartz is in granitic pegmatite dikes in Precambrian granites and schists. Near the entrance to the Wind River Canyon in the Owl Creek Mountains, in Tps 5 and 6 N, R 6 E, narrow quartz veins in Precambrian rocks were prospected for gold. Along the crest of the Owl Creek Mountains in the headwaters of Willow and Cottonwood Creeks, T 6 N, R 3 E, quartz veins associated with diorite dikes occur in granite and schist. The veins are gold bearing, and contain minor amounts of sulfide minerals. Secondary copper minerals, such as malachite, are present as "copper stain." Several shafts were sunk and numerous adits driven to explore the veins.

Although none of these vein deposits proved rich enough to be mined, some investigators believe that these and similar veins, which also occur in the mountains bounding the Wind River Basin, are source areas for the placer gold found in the basin (13, 92).

## Placer

Placer gold was discovered along many of the major streams within the Wind River Reservation by the 1860's, and some large- and small-scale efforts were made to mine them. In 1910, a mining boom mentality prevailed in the Wind River region, and placer mining claims were staked along the courses of all major streams on the reservation (92). Substantial placer operations were attempted on the Wind River and some of its tributaries.

One of the more spectacular efforts occurred on the Wind River about 6 miles northeast of Riverton at the boundary between Tps 1 and 2N, R 5 E. When six drill holes showed promising results, the Shoshone Gold Dredging Co. installed a gold dredge. After 6 weeks of operating with poor results, additional test holes were drilled farther downstream. These gave negative results. Poor gold recovery was claimed, despite favorable dredging conditions, and the effort was abandoned. Schrader (92) suggests that the failure was due to low and erratic values, rather than to poor gold recovery.

A similar project was attempted by the Riverton Mining and Dredging Co. 7 miles west of Riverton, in T 1 N, R 3 E. This company intermittently operated a dredge for several years. It also was unable to recover gold in paying quantities and attributed the fact to the inefficiency of their gold-saving devices.

Another company carried out extensive exploratory work on the Wind River about 15 miles northwest of Riverton, in T 2 N, R 2 E. Eventually, the project was abandoned without attempting production.

## Source of Gold

Previous investigators attribute the source of the gold occurring on the reservation to the erosion of gold-bearing veins and rocks in the Wind River Range and Owl Creek Mountains. Schrader believes the distribution pattern of of the gold indicates these sources.

More recent studies by Antweiler and Love (6) and Antweiler and others (7) show significant gold values in all formations younger than Early Cretaceous in age throughout much of northwestern Wyoming. The northwestern part of the Wind River Basin is on the perimeter of this area, and the Wind River Formation is one of the more auriferous of the formations studied. Source of the gold found by Antweiler is from Precambrian rocks in a now-buried uplift located northwest of the present Teton Range. The Wind River Basin probably has received alluvial gold from the ancient uplift described by Antweiler, as well as from Precambrian rocks occurring in the Wind River Range and the Owl Creek Mountains.

## Present Investigation

At the request of the Joint Business Council of the Shoshone and Arapahoe Tribes, only Tribally owned land was investigated. In addition, those areas previously evaluated for placer gold by the USGS were not restudied. Accordingly the objective of this study was to investigate terrace and pediment deposits on tribally owned land not located along the principal streams. The principal stream deposits are mostly privately owned (fig. 1) and were investigated by Schrader (92). The study, therefore, was an exercise in finding upland terrace or stream gravels that are richer than those along the major streams and occur in quantities great enough to sustain large-scale mining efforts. The most likely candidates are large deposits of upland terrace gravels, which are thick enough to be minable, and tributary streams having a history or legend of past gold production or heading in known lode outcrop areas.

## Sampling

A reconnaissance, based on available geological and property maps, was made of tribally owned areas containing large gravel deposits. Areas were eliminated where deposits were too thin to be mined, and the glacial moraines were eliminated because the large boulders that they contain would make mining impractical. Thirteen sites were selected for sampling and a total of 89 samples was taken. Locations of the sample sites are shown in plate 4, and sample values are shown in appendix F.

The gravel beds sampled ranged from 2 to 13 feet in thickness and are composed of clay-sized sediments and unsorted to poorly sorted gravel- and sand-sized sediments (fig. 8). The gravels are rounded and composed of granite, schist, gneiss, quartzite, sandstone, limestone, chert, chalcedony, and various types of volcanic rocks. The gravels usually are smaller than 0.5 foot in diameter. In places, large boulders are present, but these rarely exceed 1 foot in diameter.

FIGURE 8.—Samples being collected from one of the thicker gravel beds on the Wind River Indian Reservation.

Heavy sands occurring in the gravel deposits contain several minerals. These include magnetite, ilmenite, garnet, zircon, and epidote. Chromite, columbite-tantalite, scheelite, apatite, and monazite possibly are present in small amounts. The amount of heavy sands recovered from each sample ranged from less than 1 gram to 158 grams per cubic foot. A range of 15 to 40 grams per cubic foot was common. Small lenses of nearly pure heavy sands were observed in gravel pit faces, but they were not common. No special effort was made to save the heavy sands, so the actual heavy sand content of the samples may be as much as twice that shown in the sample results (appendix F).

### Field Procedures

A backhoe and skilled operators were obtained from the Arapahoe Tribe. Where possible, samples were cut from exposed faces in gravel pits or roadcuts. Elsewhere, the backhoe was used to trench either to bedrock or to its maximum attainable depth (fig. 9). Samples then were collected along a channel cut upward in the vertical face of the trench at a rate of either 1 cubic foot per linear foot or 1 cubic foot per 2 linear feet. In two cases, where inflowing water interfered with the normal routine, a 1-cubic-foot sample was taken from the backhoe dipper at each appropriate level. The location in the hole for these samples is not as precise as those taken in place.

Each sample then was processed in a Humphrey's mechanical concentrator. The device consists of a trommel having internal water sprays, a vibrating riffle box, and a "tattle tale" sluice box fitted with indoor-outdoor carpeting and Hungarian-type riffles (fig. 10). After processing each sample, the contents of the riffle box was panned to a heavy sand concentrate. After processing all the samples from a test pit, the sluice concentrates also were panned. In addition, tailings of the sluice were panned occasionally as a check on the effectiveness of a particlular operation.

### Laboratory procedures

The amount of heavy sand concentrates obtained from each sample was further reduced by panning to about 1 gram. A binocular microscope was used for counting individual colors and removing them for weighing. As a final check for gold invisible under the microscope or lost in panning, the panning rejects were fire assayed. The weights of the resulting gold beads are included in the total gold values of the sample. In assigning values to the samples, the actual weight of gold was used in some instances. In others, average values were assigned to various size colors, and values were determined by color counts.

## Discussion of Results

### Description of Gold

The gold found is finely divided. It is bright, clean, has a good yellow color, and occurs as thin, flat, tabular flakes, which are less than 0.1 millimeter in thickness. The largest piece measures 0.7 by 0.8 millimeters and weighs 0.53 milligram. Other particles weigh as little as 0.0003 milligram and are barely visible under 30-power magnification. Most colors range from 0.1 to 0.2 millimeters in length and 0.05 to 0.1 millimeters in width and weigh between 0.002 and 0.02 milligrams. Although earlier operators reported a small amount of coarse gold, only one large color was found. The gold floats easily, and care had to be exercised to reduce loss during panning.

## Gold Values Found

Gold values found in terrace and pediment gravel deposits and in tributary stream deposits are substantially lower than those that Schrader (92) obtained along the principal streams. Sites 1, 6, and 7 show no gold or only traces. Sites 2, 3, 4, 5, 9, 12, and 13 show gold, but at a value of 2 cents per cubic yard or less. Sites 8, 10, and 11 show values higher than 7 cents per cubic yard (see appendix F for details).

Schrader's best results, obtained in the area then being worked by the Shoshone Gold Dredge Co., were 27 and 32 cents per cubic yard, at a price of \$20.67 per troy ounce of 999 fine gold (92). (Gold that is 999 fine is accepted as "pure" gold.) This would translate, respectively, to \$5.22 and \$6.19, using an assumed price of \$400 per troy ounce of 999 fine gold. He considered placers having such values to be marginal and minable only if persistent pay streaks were found. His average for the rest of the gravels ranged from 6 cents to 20 cents per cubic yard. (These values are equivalent, respectively, to \$1.16 and \$3.87, using an assumed price of \$400 per troy ounce of 999 fine gold.) He concluded that these values were too low to be minable. Despite the current high gold price, considered to be \$400 per troy ounce of 999 fine gold, this conclusion still appears valid, owing to increases in capital, energy, and labor costs.

None of the deposits tested during this investigation contain values even approaching the best found by Schrader (92) along the main drainages. The higher values found at sites 8, 10, and 11 barely exceed Schrader's lower grade values. It could be that gravels in the present stream channels represent a concentrate produced by reworking of the lower-grade terrace and pediment gravels.

## Observations

The gold values reported in this investigation and by Schrader (92) might be thought of as "recoverable gold," or gold consisting of discrete particles mechanically mixed in the sand fraction of the gravels and occurring in sizes amenable to concentration by gravity methods. The work done by Antweiler and others (6-7) is more in the nature of a geochemical study. Their gold was extracted from the sample by chemical techniques and included gold fractions not obtainable by the methods used by Schrader and during this investigation. The same sample, if treated by the two methods, would give different values. This is demonstrated by Antweiler and Love in Circular 541, "Gold-bearing Sedimentary Rocks in Northwestern Wyoming--a Preliminary Report" (6). Commercial miners are not likely to recover values comparable to the results obtained by analytical, chemical extraction techniques and caution must be exercised in using such techniques when evaluating placers for commercial projects.

FIGURE 9.—Backhoe trenching into a gravel deposit, Wind River Indian Reservation, Wyoming.

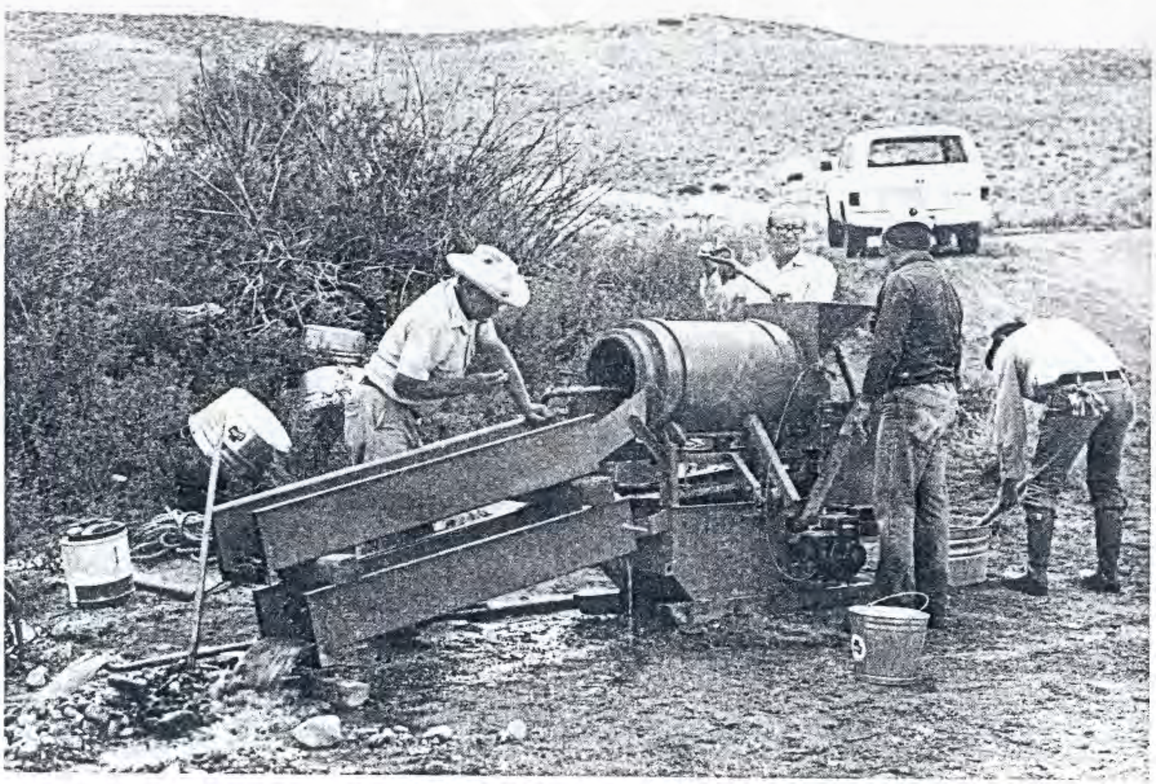


FIGURE 10.—Mechanical concentrator being used to obtain heavy sand concentrates from gravel samples.

Previous failures to successfully exploit placer deposits on the Wind River Indian Reservation have been attributed to the inability of the gold-saving devices used to save the finely divided gold. While it is true that no gold-saving device, or assemblage of devices, has ever given complete recovery, they still can be very effective. Recently, devices such as jigs, hydrocyclones, and Reichert Cones have proven very effective (29). In brief, techniques probably could be established to recover the finely divided gold occurring on the Wind River Indian Reservation, provided it could be found in sufficient grade and quantity to justify the effort.

## Recommendations

This study finds, as Schrader did in 1913 (92), that the real failure to recover economic amounts of gold from Wind River Indian Reservation gravels is because sufficient amounts of gold are not present, rather than the inability of the equipment to recover it. Inadequate and insufficient exploration and metallurgical testing resulted in expensive and elaborate installations, which had little chance for success. Small, rich, pay streaks possibly are present within the large volume of low-grade gravels occurring on the reservation. Finding them, however, would be expensive and time consuming. Should they exist, they certainly would not pay the cost of elaborate mining and recovery installations. Future developments in handling and processing large bodies of low-grade, gold-bearing material may justify reevaluation of the deposits; however, no further work is recommended at this time.

SELECTED REFERENCES

1. American Petroleum Institute. API Recommended Practice. Standard Field Procedure for Testing Drilling Fluids. API, RP 13B, 9th ed., 1982, 47 pp.

2. _______. API Specification for Oil-well Drilling-fluid Materials. API, Spec. 13A, 8th ed., 1981, 14 pp.

3. Ampian, S. G. Clays. Mineral Facts and Problems, Bureau of Mines Bull. 667, 1975, pp. 253-268.

4. Ampian, S. G., and D. W. Polk. Clays. BuMines Mineral Yearbook, 1980, v. 1-2, 1981, pp. 201-236.

5. Andrews, D. A. Geologic and Structure Contour Maps of the Maverick Springs Area, Fremont County, Wyo. U.S. Geol. Survey Oil and Gas Inv. Map OM-13, 1944.

6. Antweiler, J. C. and J. D. Love. Gold-bearing Sedimentary Rocks in Northwest Wyoming - A Preliminary Report. U.S. Geol. Survey Cir. 541, 1967, 12 pp.

7. Antweiler, J. C., J. D. Love, and W. L. Campbell. Gold Content of the Pass Peak Formation and Other Rocks in the Rocky Mountain Overthrust Belt. Guidebook, Rocky Mountain Thrust Belt Geology and Resources, 29th Ann. Field Conf., Northwestern Wyo. Geological Assoc., 1977, pp. 731-749.

8. Bartram, John G., and J. E. Hupp. Subsurface Structure of Some Unsymmetrical Anticlines in the Rocky Mountains. AAPG Bull., v. 13, Oct. 1929, pp. 1275-89.

9. Bates, R. L. Geology of the Industrial Rocks and Minerals. Dover Publications, Inc., New York, 2nd ed., 1960, pp. 130-135.

10. Berry, D. W., and R. T. Littleton. Geology and Ground-water Resources of the Owl Creek Area, Hot Springs County, Wyo. U.S. Geol. Survey Water Supply Paper 1519, 1961, 58 pp.

11. Bleifuss, R. L. Activation of Non-swelling Bentonite. Clay Minerals, v. 10, 1973, pp. 41-50.

12. _______. Evaluation of Western Bentonites. American Institute of Mining Engineers, 32nd Annual Mining Symp. Minn., 1971, pp. 73-84.

13. Bolmer, R. L., and P. Biggs. Mineral Resources and Their Potential on Indian Lands - Wind River Reservation, Fremont and Hot Springs Counties, Wyo. BuMines Preliminary Report 159, 1965, 103 pp.

14. Brindley, G. W. Fullers Earth From Near Dry Branch, Georgia, a Montmorillonite - Cristobalite Clay. Clay Min. Bull., v. 3, 1957, pp. 167-169.

15. Bureau of Indian Affairs. Wind River Land Status Map. Based on Land Title Status as of Dec. 1979.

16. ________. Detailed Land Planning and Classification Report on the Indian Reservation Lands in the Wind River Basin, Wyo. M.R.B. Inv. Rept. 102, 1950, 63 pp.

17. Burk, C. A. Stratigraphic Summary of the Pre-Niobrara Formation of Wyoming. Guidebook, Wyoming Stratigraphy Part I. Subsurface Stratigraphy of the Pre-Niobrara Formations in Wyoming, Wyo. Geol. Assoc., 1956, pp. 91-97.

18. Case, J. D., and W. R. Keefer. Regional Gravity Survey, Wind River Basin, Wyo. U.S. Geol. Survey Professional Paper 550-C, 1966, p. C120.

19. Chisholm, F. Bentonite in Industry. Mines Magazine, July 1960.

20. Clem, A. G., and R. W. Doehler. Industrial Applications of Bentonite. Proc. Tenth National Conference on Clays and Clay Minerals Nat. Acad. Sci.-Nat. Res. Council, 1950, pp. 30-42.

21. Cobban, W. A., and J. B. Reeside. Frontier Formation, Wyoming, and Adjacent Areas. AAPG Bull., v. 36, 1952, pp. 1913-1961.

22. Collier, A. J. Anticlines Near Maverick Springs. Wyo. Geol. Survey Bul. 711, 1920, pp. 149-66.

23. Dana, E. S. A Textbook of Mineralogy. John Wiley and Sons, New York, 1945, p. 683.

24. Davis, C. W., and H. C. Vacher. Bentonite: Its Properties, Mining, Preparation and Utilization. BuMines Tech. Paper 609, 1940, 83 pp.

25. Dengo, G. Geology of Bentonite Deposits Near Casper, Natrona County, Wyo. Geol. Survey of Wyo., Bull. 37, 1946, 28 pp.

26. Eicher, D. L. Stratigraphy and Micropaleontology of the Thermopolis Shale. Yale Univ., Peabody Mus. Nat. History, Bull. 15, 1960, 126 pp.

27. Everett, F. D. High-Swelling Bentonite in Wyoming, South Dakota, and Montana. BuMines MRB Prelim. Rept. 60, 1961, 43 pp.

28. ________. Mineral Resources of the Wind River Basin Wyo. BuMines MRB Prelim. Rept. 35, Sept. 1949, 21 pp.

29. Ferree, T. J. and L. F. Mashburn. Fine Gold Recovery with a Reichert Cone-A Case History. Pres. at Alaskan Placer Mining Conference. April, 1981, Fairbanks, Alaska, obtained from Thomas J. Ferree, N. L. Industries, Inc., Lakewood Colo., 4 pp.

30. Fisher, C. A. The Bentonite Deposits of Wyoming. U.S. Geol. Survey Bull. 260, 1905, pp. 559-563.

31. Foster, M. D. Geochemical Studies of Clay Minerals: Pt. 2-Relation Between Ionic Substitution and Swelling in Montmorillonites. Am. Miner., v. 38, 1953, pp. 994-1006.

32. Glass, G. B., W. G. Wendell, F. K. Root, and R. M. Breckenridge. Energy Resources Map of Wyoming. Geol. Survey of Wyo., 1975, scale 1:500,000.

33. Goodell, H. G. The Stratigraphy and Petrology of the Frontier Formation of Wyoming. Guidebook, Symposium on Early Cretaceous Rocks of Wyoming, 17th Ann. Field Conf., Wyo. Geol. Assoc., 1962, pp. 173-210.

34. Grim, R. E. Clay Mineralogy. McGraw-Hill Book Co., Inc., New York, 2nd ed., 1968, 596 pp.

35. ______. Applied Clay Mineralogy. McGraw-Hill Book Co., Inc., 1962, 422 pp.

36. Grim, R. E., and N. Guven. Bentonites (Geology, Minerology, Properties and Uses). Elsevier Scientific Publishing Co., New York, 1978, 249 pp.

37. Gruner, J. W. Cristobalite in Bentonite. American Mineralogists, v. 25, 1940, pp. 587-590.

38. Haun, J. D., and J. A. Barlow, Jr. Lower Cretaceous Stratigraphy of Wyoming. Guidebook, Symposium on Early Cretaceous Rocks of Wyo. and Adjacent Areas, 17th Ann. Field Conf., Wyo. Geol. Assoc., 1962, pp. 15-22.

39. Hausel, W. D., G. B. Glass, D. R. Lageson, A. J. VerPloeg, and R. H. DeBruin. Wyoming Mines and Minerals Map. Geol. Survey of Wyo. 1979, scale 1:500,000.

40. Heathman, J. H. Bentonite in Wyoming. Geol. Survey of Wyo. Bull. No. 28, 1939, 19 pp.

41. Hewett, D. F. The Origin of Bentonite. Washington Acad. Sci. Journal, 1917, pp. 77-96.

42. Hinton, Gene. Riverton Dome. Guidebook, Southwest Wind River Basin, 12th Ann. Field Conf., Wyo. Geol. Assoc., 1957, pp. 132-36.

43. Hofstadt, C. F., and R. Fahn. Bentonite - A Valuable and Versatile Mineral and Raw Material. Proceedings of the 2nd Industrial Minerals International Congress. 1976, pp. 95-103.

44. Holladay, C. O. Geology of Northwestern Blue Holes Quadrangle, Fremont County, Wyo. Miami Univ., Thesis, 1959.

45. Holmes, R. F., Jr. The Geology of East Fork - Wind River Junction Area, Blue Holes Quadrangle, Fremont County, Wyo. Miami Univ., Thesis, 1959.

46. Hunter, L. D. Frontier Formation Along the Eastern Margin of the Big Horn Basin, Wyo. Guidebook, Big Horn Basin, 7th Ann. Field Conf., Wyo. Geol. Assoc., 1952, pp. 63-66.

47. Industrial Minerals, Bentonite, Sepiolite, Attapulgite, Etc. - Swelling Markets for Active Clays. Mar. 1978, pp. 49-62.

48. Keefer, W. R. Frontier, Cody, and Mesaverde Formations in the Wind River and Southern Bighorn Basins, Wyo. U.S. Geol. Survey Professional Paper 495-E, 1972, pp. E1-E23.

49. ______. Geologic History of Wind River Basin, Central Wyoming. AAPG Bull., v. 49, Nov. 1965, pp. 1878-1892.

50. ______. Stratigraphy and Geologic History of the Uppermost Cretaceous, Paleozoic, and Lower Eocene Rocks in the Wind River Basin, Wyo. U.S. Geol. Survey Bull. 495-A, 1965, pp. A1-A77.

51. ______. Progressive Growth of Anticlines During Late Cretaceous and Paleocene Time in Central Wyoming. U.S. Geol. Survey Professional Paper 400-B, No. 105, 1960, p. B 233.

52. Keefer, W. R., and M. L. Troyer. Geology of the Shotgun Butte Area, Fremont County, Wyo. U.S. Geol. Survey Bull. 1157, 1964, 123 pp.

53. Kisling, D. C. Geology of the Antelope Ridge Area, Fremont and Hot Springs Counties, Wyo. Wyo. Univ., Thesis, 1962.

54. Knechtel, M. M., and S. H. Patterson. Bentonite Deposits of the Northern Black Hills District, Wyo., Mont. and So. Dak. U.S. Geol. Survey Bull. 1082-M, 1962, pp. 893-1030.

55. ______. Bentonite Deposits of the Yellowtail District, Mont. and Wyo. U.S. Geol. Survey Circular 150, 1957, 7 pp.

56. ______. Bentonite Deposits in Marine Cretaceous Formations of the Hardin District, Mont. and Wyo. U.S. Geol. Survey Bull 1023, 1956, 116 pp.

57. Knight, W. C. Bentonite. Engineering and Mining Journal, v. 66, No. 17, 1898, p. 491.

58. Krampert, E. W. The Lander-Hudson Oil Field, Fremont County, Wyoming. Guidebook, Wind River Basin, Wyo., 3rd Ann. Field Conf., Wyo. Geol. Assoc., 1948, pp. 148-52.

59. Lane, R. W. Winkleman Dome Oil Field. Guidebook, Southwest Wind River Basin, 12th Ann. Field Conf., Wyo. Geol. Assoc., 1957, pp. 119-23.

60. Lee, W. T. Correlation of Geologic Formations Between East-central Colorado, Central Wyoming and Southern Montana. U.S. Geol. Survey Professional Paper 149, 1927, 80 pp.

61. Liles, K. J., and H. Heystek. The Bureau of Mines Test Programs for Clay and Ceramic Raw Materials. BuMines IC 8729, 1977, 28 pp.

62. Love, J. D. Mesozoic Stratigraphy of the Wind River Basin, Wyo. Guidebook, Wind River Basin, 3rd Ann. Field Conf., Wyoming Geol. Assoc., 1948, pp. 96-111.

63. ______. Geology Along the Southern Margin of the Absaroka Range, Wyo. Geol. Society of Am. Spec. Paper 20, 1939, 134 pp.

64. Love, J. D., J. C. Antweiler, and E. L. Mosier. A New Look at the Origin and Volume of the Dickie Springs - Oregon Gulch Placer Gold at the South End of the Wind River Mountains. Guidebook, 30th Ann. Field Conf., Wyo. Geol. Assoc., 1978, pp. 379-391.

65. Love, J. D., H. A. Tourtelot, C. O. Johnston, H. H. R. Sharkey, and A. D. Zapp. Stratigraphic Sections of Mesozoic Rocks in Central Wyoming. Wyo. Geol. Survey Bull. 38, 1947, 59 pp.

66. Love, J. D., J. L. Weitz, and R. K. Hose. Geologic Map of Wyoming. U.S. Geol. Survey, 1955, scale 1:500,000.

67. Lowry, M. E., H. W. Lowham, and G. C. Lines. Water Resources of the Bighorn Basin, Northwestern Wyo. U.S. Geol. Survey Hydrologic Atlas, HA-512, 1976.

68. McCabe, W. S., and C. L. Walker. Winkleman Dome, Wyoming. Guidebook, Wind River Basin, Wyoming, 3rd Ann. Field Conf., Wyo. Geol. Assoc., 1948, pp. 166-73.

69. McCaskey, H. D., Gold and Silver. Mineral Resources of the United States, Calendar Year 1913, Part I, Metals, U.S. Geol. Survey, 1914, p. 845.

70. McGreevy, C. J., W. F. Hodson, and S. J. Rucker IV. Groundwater Resources of the Wind River Indian Reservation, Wyo. U.S. Geol. Survey Water Supply Paper 1576-I, 1969, pp. I1-I145.

71. Merewether, E. A., and W. A. Cobban. Unconformities Within the Frontier Formation, Northwestern Carbon County, Wyoming. U.S. Geol. Survey Professional Paper 800-D, 1972, p. D57.

72. Merewether, E. A., W. A. Cobban, and R. T. Ryder. Lower Upper Cretaceous Stata, Bighorn Basin, Wyo. and Mont. Guidebook, Geology and Mineral Resources of the Bighorn Basin, 27th Ann. Field Conf., Wyo. Geol. Assoc., 1975, pp. 73-84.

73. Mills, N. K. Subsurface Stratigraphy of the Pre-Niobrara Formations in the Bighorn Basin, Wyo., Part I. Wyo. Geol. Assoc., 1956, pp. 9-22.

74. Murphy, J. F., N. C. Privrasky, and G. A. Moerlein. Geology of the Sheldon-Little Dome Area, Fremont County, Wyo. U.S. Geol. Survey Oil and Gas Map OM-181, 1956, scale 1:24,000.

75. Murphy, J. F., and G. M. Richmond. Geologic Map of the Bull Lake West Quadrangle, Fremont County, Wyoming. U.S. Geol. Survey Map GQ-432, 1965, scale 1:24,000.

76. Olson, W. G. Circle Ridge and Maverick Springs Oil Fields, Fremont County, Wyoming. Guidebook, Wind River Basin, Wyo., 3rd Ann. Field Conf., Wyo. Geol. Assoc., 1948, pp. 178-85.

77. Osterwald, F. W., D. B. Osterwald, J. S. Long, Jr., W. H. Wilson. Mineral Resources of Wyoming. Geol. Survey of Wyo. Bull. No. 50, 1966, pp. 84-87.

78. Paape, D. W. Tectonics and Its Influence on Late Cretaceous and Tertiary Sedimentation, Wind River Basin, Wyo. Guidebook, Wind River Basin, Wyo. 16th Ann. Field Conf., Wyo. Geol. Assoc., 1961, pp. 187-194.

79. Papke, K. G. Montmorillonite Deposits in Nevada. Clays and Clay Minerals. v. 17, No. 4, 1969, pp. 211-222.

80. Patterson, S. H., and H. H. Murray. Clays. Industrial Minerals and Rocks, 4th ed., Port City Press, Baltimore, Maryland, 1975, pp. 523-546.

81. Reeside, J. B., Jr., and W. A. Cobban. Studies of the Mowry Shale (Cretaceous) and Contemporary Formations in the United States and Canada. U.S. Geol. Survey Professional Paper 355, 1960, 126 pp.

82. Regis, A. J. Correlation Between Physical Properties and Exchangeable Chemistry of Bentonites from the Western United States. U.S. Bureau of Land Management, Technical Note 313, January 1978, 56 pp.; available from Denver Service Center, Federal Center Building 50, Denver, Colo., 80225.

83. Reynolds, D. H. Bentonite - Occurrences, Properties, Utilization. New Mexico Miner, Mar. 1952, pp. 9, 24-25.

84. Reynolds, M. W. Physical Evidence for Late Cretaceous Unconformity, South-Central Wyoming. U.S. Geol. Survey Professional Paper 575-D, 1967, pp. D24.

85. Richmond, G. M. Three Pre-Bull Lake Fills in the Wind River Mountains, Wyo. - a Reinterpretation. U.S. Geol. Survey Professional Paper 501-D, 1964, pp. D104-D109.

86. ______. Three Pre-Bull Lake Fills in the Wind River Mountains, Wyo. U.S. Geol. Survey Professional Paper 450-D, No. 159, 1962, pp. D132-D135.

87. Richmond, G. M., and J. F. Murphy. Geologic Map of the Bull Lake East Quadrangle, Fremont County, Wyoming. U.S. Geol. Survey Map GQ 431, 1965, scale 1:24,000.

88. Rosenkrans, R. R. Stratigraphy of the Ordovician Bentonite Beds in Southwestern Virginia. Va. Geol. Survey Bull. 46, 1936, pp. 85-111.

89. Ross, C. S., and S. B. Hendricks. Minerals of the Montmorillonite Group. U.S. Geol. Survey Professional Paper 205-B, 1955, pp. 23-79.

90. Ross, C. S., and E. V. Shannon. Minerals of Bentonite and Related Clays and their Physical Properties. Am. Ceram. Soc. J., v. 9, No. 2, 1926, pp. 77-96.

91. Ross, J. S. Bentonite in Canada. Department of Mines and Technical Surveys, Ottawa, Canada, Mines Branch Monograph 873, 1964, 61 pp.

92. Schrader, F. C. Gold placers on Wind and Bighorn Rivers, Wyo. Contributions to Economic Geology 1913, Part I, U.S. Geol. Survey Bull. 580, 1913, pp. 127-145.

93. Seeland, D. A., and E. F. Brauch. Status of Mineral Resource Information for the Wind River Indian Reservation, Wyo. U.S. Geol. Survey and BuMines Administration Rept. BIA-8, 1975, 66 pp.

94. Sharkey, H. H. R. Geologic and Structure Contour Map of Sage Creek Dome, Fremont County, Wyo. U.S. Geol. Survey Oil and Gas Inv. Prelim. Map OM-53, 1946.

95. Slaughter, M., and J. W. Earley. Minerology and Geological Significance of the Mowry Bentonites, Wyoming. Geol. Soc. of Amer. Special Paper No. 83, 1965, 116 pp.

96. Spencer, A. C. The Atlantic Gold District and the North Laramie Mountains. U.S. Geol. Survey Bull. 626, 1916, 85 pp.

97. Thomas, H. D. Some problems of the Earlier Cretaceous Rocks of Wyoming. Guidebook, Symposium on Early Cretaceous Rocks of Wyoming, 17th Ann. Field Conf., Wyo. Geol. Assoc., 1962, pp. 28-32.

98. Thompson, R. M., J. D. Love, and H. A. Tourtelot. Stratigraphic Sections of Pre-Cody Upper Cretaceous Rocks in Central Wyoming. U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 36 (Sheets 1 & 2), 1949.

99. Thompson, R. M., M. L. Troyer, V. L. White, and G. N. Pipiringos. Geology of the Lander Area, Central Wyo. U.S. Geol. Survey Oil and Gas Inv. Map OM-112, 1950.

100. Thompson, R. M., and V. L. White. Geology of the Riverton Area, Central Wyo. U.S. Geol. Survey Oil and Gas Inv. Map OM-127, 1954.

101. Tourtelot, H. A., and R. M. Thompson. U.S. Geol. Survey Oil and Gas Investigations Prelim. Map 91, 1948.

102. Towse, D. Frontier Formation, Southwest Powder River Basin, Wyo. AAPG Bull., v. 36, 1952, pp. 1962-2010.

103. Troyer, M. L. Geology of the Lander (Hudson) and Plunkett Anticlines and Vicinity, Fremont County, Wyo. Wyo. State Thesis, 1951.

104. Wayland, T. E. Geologic Occurrences and Evaluation of Bentonite Deposits. Pres. at AIME Ann. Meeting, Denver, Colo., Feb. 15-19, 1970, 52 pp.

105. Weitz, J. L., and J. D. Love. Geologic Map of Southern Big Horn Basin. Guidebook Big Horn Basin, 7th Ann. Field Conf., Wyo. Geol. Assoc., 1952.

106. Whitcomb, H. A., and M. E. Lowry. Ground-water Resources and Geology of the Wind River Basin Area, Central Wyo. U.S. Geol. Survey Hydrologic Inv. Atlas HA-270, 1968, scale 1:250,000.

107. Wilcox, R. E. Some Effects of Recent Volcanic Ash Falls With Special Reference to Alaska. U.S. Geol. Survey Bull. 1028N, 1959, 67 pp.

108. Williams, F. J., B. C. Elsley, and D. J. Weintritt. The Variations of Wyoming Bentonite Beds as a Function of the Overburden. Clay and Clay Clay Miner. Society, 2nd Nat. Conf. Proc., 1952, pp. 141-151.

109. Williams, F. J., M. Neznagko, and D. J. Weintritt. The Effect of Exchangeable Bases on the Colloidal Properties of Bentonite. J. of Phys. Chem., v. 57, 1953, pp. 6-10.

110. Williams, M. D., and H. H. R. Sharkey. Geology of the Bargee Area, Fremont Area, Fremont County, Wyo. U.S. Geol. Survey Oil and Gas Inv. Map OM-56, 1946.

111. Wolfbauer, C. A. Bentonite Resources in the Eastern Bighorn Basin, Wyo. Guidebook, Geology and Mineral Resources of the Bighorn Basin, 27th Ann. Field Conf., Wyoming Geol. Assoc., 1975, pp. 249-254.

APPENDIX A

General Geology of the Wind River Indian Reservation (13)

## Stratigraphy (13)

An aggregate of 15,000 to 22,000 feet of sedimentary rocks, ranging from Cambrian to Tertiary time, was deposited in the Wind River and Bighorn basins (fig. 4). Pre-Cretaceous sediments are largely of marine origin, whereas later strata are of fresh or brackish water origin. Quaternary surficial deposits, largely floodplain, terrace, pediment alluvium, some glacial moraine, and minor sand dunes, are widespread.

The Paleozoic Era is represented by several thousand feet of marine sediments. All systems but the Silurian are present (table A-1). The stratigraphic section is thickest in the western part of the Wind River Basin and the southern Bighorn Basin. Rocks, ranging considerably in lithology, include include limestones, dolomites, sandstones, and shales (table A-2). Strata of the Paleozoic Era are well represented along the flanks of the Wind River Range and the Owl Creek Mountains, and in the Wind River Canyon.

The Paleozoic-Mesozoic contact is shown by a lithologic change. There are no measurable angular unconformities within the Mesozoic strata of the area. Lithologies include predominantly shales, sandstones, siltstones, claystones, and minor limestone, gypsum, and bentonite beds (table A-3). Mesozoic rocks dip into the Wind River Basin and are well exposed both along the flanks of the surrounding mountains and in eroded, northwest-trending folds, which are present in the western and northern Wind River Basin and southern Bighorn Basin. Contacts between some of the Mesozoic strata are gradational and somewhat unclear; various authors place contacts at different horizons, and make different correlations between units in various areas of the reservation and Wind River Basin. This is particularly true within the Cretaceous System.

Steeply dipping Mesozoic strata are unconformably overlain by nearly horizontal beds of Cenozoic age in many areas within the Wind River Basin. Tertiary rocks include conglomerates, arkosic sandstones, siltstones, and claystones. Quaternary surficial deposits within both basins are represented by stream alluvium, terrace and pediment gravels, slopewash material, glacial moraine and outwash deposits, dune sand, landslide debris, and other unconsolidated deposits (table A-4).

## Structure (13)

Although early geologic events are obscure, sedimentary rocks aggregating some 10,000 feet in thickness were deposited in the area of the present Wind River Basin during Paleozic and Mesozoic times. No significant deformation of these strata occurred until the beginning of the Laramide mountain building episode and the creation of the present Rocky Mountains at the close of the Cretaceous Period.

Formation of the major structural features of the basin continued sporadically throughout early Tertiary time. During the various formative stages, material eroded from the rising mountain highlands and was trapped in the subsiding basin. The later Tertiary sediments within the basin were deposited into continential, fluvial, or lacustrine environments. Extensive erosion marked the intervals between these depositional cycles. Debris from the Absaroka volcanic field contributed significantly to the material deposited in the basin throughout the Tertiary Period.

Prominent features include exposures of Precambrian crystalline rocks in the cores of mountain uplifts along basin margins, upturned Paleozoic and Mesozoic sedimentary rocks along the flanks of the mountains, folds and faults in the older sediments along the mountain fronts, and nearly horizontal Tertiary strata in the interior of the basin.

The western margin of the basin is formed by a major asymmetrical arch that was created in older sedimentary rocks by the uplift of the Wind River Range. Erosion has since removed all but the lower limbs of this structure, exposing the central granitic core of the range. The pattern of the major arch is repeated in a secondary fold and fault system along the eastern front of the range. Here, the folds also are asymmetrical to the west and, in some cases, are bounded by thrust faults dipping to the east. A high-angle reverse fault, which dips easterly beneath the crystalline core, borders the western flank of the Wind River range.

The more complex Owl Creek Mountians along the northern margin of the basin represent a compound, anticlinal structure. Several topographically high areas of Precambrian rocks occur along its axis. These are separated by areas of a synclinal nature in which strata of Mesozoic age extend almost completely across the axis of the uplift. The Precambrian rocks represent the cores of large flexures. These flexures have a common feature of asymmetry to the southwest and associated thrust faulting along their steeper limbs. A principal feature of the southern side of the uplift is a tendency to override and overthrust the basin margin. The existence of a major thrust fault, now concealed by overlying strata of Tertiary age, is suggested.

The Absaroka Mountains, which extend into the northwestern corner of the reservation, consist of a thick series of extrusive rocks of Tertiary age, now deeply intrenched by streams.

TABLE A-1.— Nomenclature of rocks on the Wind River Indian Reservation[1]

| ERA | SYSTEM | SERIES | FORMATION AND MEMBER |
|---|---|---|---|
| CENOZOIC | QUATERNARY | Holocene and Pleistocene | Alluvium terrace, pediment, landslide, wind blown and glacial deposits |
| | TERTIARY | Oligocene | Wiggins Formation |
| | | Eocene | Unnamed tuff |
| | | | Tepee Trail Formation |
| | | | Aycross Formation |
| | | | Wind River Formation |
| | | | Indian Meadows Formation |
| | | Paleocene | Fort Union Formation |
| MESOZOIC | CRETACEOUS | Upper Cretaceous | Lance Formation |
| | | | Meeteetse Formation |
| | | | Mesaverde Formation |
| | | | Cody Shale |
| | | | Frontier Formation |
| | | Lower Cretaceous | Mowry Shale |
| | | | Thermopolis Shale[2]: "Upper Thermopolis" |
| | | | Thermopolis Shale[2]: Muddy Sandstone |
| | | | Thermopolis Shale[2]: "Rusty Beds" |
| | | | Cloverly Formation |
| | --?--?--?--?--?--? | --?--?--?--?--?--? | ?--?--?--?--?--?--?--?--?--?--?-- |
| | JURASSIC | Upper Jurassic | Morrison Formation |
| | | | Sundance Formation |
| | | Middle Jurassic | Gypsum Spring Formation |
| | | Lower Jurassic | Nugget Sandstone |
| | --?--?--?--?--?--? | --?--?--?--?--?--? | |
| | TRIASSIC | Upper Triassic | Chugwater Group: Popo Agie |
| | | | Chugwater Group: Crow Mountain |
| | | | Chugwater Group: Alcova Limestone |
| | | | Chugwater Group: Red Peak Formation |
| | | Lower Triassic | Dinwoody Formation |
| PALEOZOIC | PERMIAN | | Phosphoria Formation |
| | PENNSYLVANIAN | Middle Pennsylvanian | Tensleep Sandstone |
| | | Lower Pennsylvanian | Amsden Formation |
| | MISSISSIPPIAN | Lower Mississippian | Madison Limestone |
| | DEVONIAN | | Darby Formation |
| | ORDOVICIAN | | Bighorn Dolomite |
| | CAMBRIAN | Upper Cambrian | Gallatin Limestone |
| | | Middle Cambrian | Gros Ventre Formation |
| | | | Flathead Sandstone |
| PRECAMBRIAN | | | Granite, granite gneiss, migmatites. |

1 Adapted from Seeland and Brauch (93).

2 See discussion of Thermopolis and Mowry Formations

TABLE A-2. - Generalized Paleozoic Stratigraphy

| System | Formation | Thickness, ft | Lithologic character |
|---|---|---|---|
| Permian | Phosphoria | 190-130 | Cherty dolomite, dolomitic limestone, and thin dolomitic shales and siltstones that are often phosphatic |
| Pennsylvanian | Tensleep Sandstone | 270-390 | Hard, massive, quartz sandstone, and some thin dolomites and limestones |
| | Amsden | 240-270 | Alternating sequence of shales, sandstones, limestones, and dolomites; massive sandstone at base |
| Mississippian | Madison Limestone | 465-825 | Massive to thin-bedded gray limestone, dolomitic in part |
| Devonian | Darby | 0-200 | Dolomite, thin shales and sandstones |
| Ordovician | Bighorn Dolomite | 140-235 | Massive, pure dolomite |
| Cambrian | Gallatin Limestone | 200-530 | Dense limestone, some thin shales |
| | Gros Ventre | 300-760 | Glauconitic shales, some limestone and sandstone |
| | Flathead Sandstone | 175-280 | Thin-bedded sandstone, quartzitic in part |
| Precambrian | - | - | Granite, gneiss, and schist; numerous pegmatites, quartz veins, and basic dikes |

TABLE A-3. - Generalized Mesozoic Stratigraphy

| System or Series | Formation | Thickness, ft | Lithologic character |
|---|---|---|---|
| Jurassic | Morrison | 100-250 | Sequence of variegated siltstones, claystones, shales, and sandstones with minor limestone |
| | Sundance | 170-385 | Glauconitic limestone, sandstone, and shale in upper part; non-glauconitic oolitic limestone, shale, and sandstone in lower part |
| | Gypsum Springs | 140-265 | Red shales and thin beds of gypsum, dolomite, and limestone overlying 50-125 ft of massive white gypsum/anhydrite; some red siltstone at base |
| | Nugget Sandstone | 0-425 | Massive to thick-bedded sandstone; locally thin, red shale and siltstone at base |
| Triassic | Chugwater Group | 955-1,313 | Thin limestone bed separates interbedded claystones, limestones, red shales, and sandstones of upper part from gypsiferous red shales, siltstones, sandstones of lower part |
| | Dinwoody | 50-120 | Thin-bedded dolomite siltstones, shales, and sandstones; locally some limestone and gypsum |

TABLE A-3. - Generalized Mesozoic Stratigraphy--Continued

| System or Series | Formation | Thickness, ft | Lithologic character |
|---|---|---|---|
| Upper Cretaceous | Lance | 500-1,000 | Massive sandstones, some shales and sparse coalbeds |
| | Meeteetse | 1,000-2,000 | Carbonaceous shales and thin sandstones, numerous coalbeds |
| | Mesaverde | 250-1,000 | Massive to thick-bedded sandstones; carbonaceous shales and some coalbeds |
| | Cody Shale | 2,500-4,430 | Fine-grained sandstone; soft shales in upper part, soft sandy shale in lower part |
| | Frontier | 550-1,000 | Interbedded sandstones and dark shales; major bentonite, tuff, carbonaceous shale, lignite, and coalbeds |
| Lower Cretaceous | Mowry Shale | 425-600 | Dark, soft to highly siliceous shales, numerous bentonite beds, some thin sandstones |
| | Muddy Sandstone | 30-110 | Massive to thin-bedded sandstone, some dark shale |
| | Thermopolis Shale | 145-230 | Dark, soft, fissile shale; some thin bentonite and sandstone beds |
| | Cloverly | 210-485 | Sandstone having dark shale at top, variegated claystone in middle, sandstone with chert conglomerate at bottom |

TABLE A-4. - Generalized Cenozoic Stratigraphy

| System | Formation | Thickness, ft | Lithologic character |
|---|---|---|---|
| Quarternary | Alluvium | | Unconsolidated deposits of clay, silt, sand, gravel, cobbles, and boulders in flood plains, fans, terraces, and pediments |
| | Landslide deposits | | Unsorted and unbedded rock debris from mass weathering |
| | Wind-blown sand | | Active and dormant sanddunes |
| | Glacial deposits | | Unconsolidated masses of boulders, cobbles, and gravel in terminal and lateral moraines of local valley glaciers |
| | Glacial outwash | | Debris eroded from glacial moraines and redeposited on pediments and in valleys |
| Tertiary | Wiggins | 1,000 + | Volcanic conglomerates, interbedded tuffaceous claystone |
| | Tepee Trail | 575 + | Interbedded sandstone, andesite and basalt conglomerate, and tuffaceous claystone |
| | Aycross | 20 + | Variegated tuffaceous claystone and sandstone grading laterally into sandstone and shale |
| | Wind River | 0-430 | Interbedded variegated claystone and siltstone, shale, sandstone, and congolmerate; locally minor tuff, clay, carbonaceous shale, and freshwater limestone |
| | Indian Meadows | 200-725 | Interbedded variegated claystone and siltstone, shale, sandstone, and conglomerate; some limestone |
| | Fort Union | 0-1,920 | Variable sequence of interbedded soft shale, siltstone, claystone, carbonaceous shale and thin coal beds |

# APPENDIX B

## Bentonite Characteristics

## Chemical and Physical Properties

Clay minerals belonging to the smectite group (formerly referred to as the montmorillonite group) include montmorillonite (the most common), beidelite (next in abundance, but uncommon), nontronite, hectorite, and saponite; the last three minerals are rare and important only in a few occurrences (89). Grim (34-35), Ross (91), and Grim and Guven (36) describe the chemical and structural composition of smectite minerals and much of the following several paragraphs comes from their works.

Chemically, these clay minerals are hydrous aluminum silicates having the general formula $(OH)_4 (Si_8) (Al_4) (O_{20}) n(H_2O)$ (where OH represents an hydroxyl ion; Si, a silicon atom, Al, an aluminum atom, O, an oxygen atom, and $n(H_2O)$, an unspecified quantity of water molecules). Substitutions of aluminum for silicon, and magnesium, iron, lithium, and zinc for aluminum produce the individual clay minerals of the group. Such substitutions always cause the molecules of the resulting clay mineral to have an overall negative charge. Positive ions or cations, most often calcium ($Ca^{+2}$) and sodium ($Na^{+1}$), become attached to the clay molecules in order to compensate for the negative charge. The magnesium cation ($Mg^{+2}$) also may be present in relatively small amounts, usually when calcium is the dominant cation (34). The cations are not joined strongly to the clay molecules and may be replaced by each other or by other cations having similar diameters; accordingly, they are referred to as exchangeable cations. There is, however, a preferential order in which the exchangeable cations replace each other. In general, divalent cations, such as $Ca^{+2}$ and $Mg^{+2}$, will replace $Na^{+1}$ and other monovalent cations more readily than the reverse exchange (34). As will be explained below, the population of exchangeable cations determines to a large degree the physical properties exhibited by a smectite mineral when it is mixed with water and, therefore, many of its possible industrial applications.

Another factor influencing the physical properties of smectite minerals is their molecular structure. Atoms comprising the molecules of these minerals are arranged into sheets that commonly have lengths and widths between 10 and 100 times their thicknesses. These sheets are stacked atop each other, similar to pages in a book, to form individual clay particles. Owing to this structure, smectite minerals possess extremely large surface areas, another property useful in some industrial applications. According to Grim (34), completely dispersed montmorillonite sheets would have a surface area approximately equal to 800 square meters per gram of clay. The large surface area allows some bentonites to be employed as catalysts and adsorbents in chemical processes and as carriers for many materials, such as medicines and insecticides.

Exchangeable cations cling to the edges and surfaces of the molecular sheets. Grim (34) reports that nearly 80 percent of the exchangeable cations are located along the upper and lower surfaces of the sheets. The number of locations where exchangeable cations can cling to a clay mineral is known as its cation-exchange capacity. Most bentonites in the Western United States have a cation-exchange capacity ranging from 40 to 90 milliequivalents per 100 grams (82). This is higher than any other clay mineral and enables some bentonites to be utilized in manufacturing processes where chemicals must be selectively adsorbed or where catalysts are involved.

Smectite minerals that have been air-dried or dried in an oven at low temperatures will readily adsorb water molecules whenever they are available. Most of the adsorbed water is oriented as layers along the upper and lower surfaces of the molecular sheets comprising the smectite structure. The exchangeable cation population adhering to the molecular sheets largely determines the number of water layers that may be oriented in this manner. A smectite carrying either sodium or calcium as the exchangeable cation can orient only a few layers of water molecules. If a mixture of the two cations are present, however, a much larger number of water layers can be oriented.

Orientation of water layers along the molecular sheets of smectite minerals causes the sheets to move apart. The resulting volume increase explains the characteristic swelling nature displayed by smectites when they are mixed with water. A smectite carrying calcium as the predominant exchangeable cation is capable of adsorbing only a few additional water layers. Accordingly, such minerals swell only slightly more than other clay minerals and develop little or no plasticity when mixed with water (20, 83). This variety usually breaks apart in water and forms a number of irregularly sized granules, which collect on the bottom of the container. If a smectite mineral carrying sodium as the predominant exchangeable cation is mixed with water, a much larger number of water layers are adsorbed. This variety will form a highly plastic mass and swell as many as thirty times its original volume when mixed with water (83). In general, the higher the ratio of sodium to calcium exchangeable cations, the greater the swelling (82). If sufficient water is adsorbed, the molecular sheets separate or become dispersed, forming an extremely large number of rather uniform flakes that are surrounded with layers of adsorbed water. Agitating the smectite-water mixture increases the rate and extent of dispersion. What results is a viscous, highly colloidal suspension that, upon standing for a few minutes, assumes a more solid form known as a gel. Apparently, the individual molecular flakes are able to orient sufficient water molecules to produce the more rigid form (35). If the gel is agitated, some of the oriented water molecules will be disrupted, allowing the molecular flakes to disperse again. This property of repeatedly forming liquid and gel forms is known as thixotropy. The high plasticity, ability to form viscous suspensions, and thixotropic nature displayed by some bentonites accounts for their usefulness in numerous industrial applications.

## Varieties

Bentonites are classified with respect to their physical properties when mixed with varying amounts of water. An informal classification, which gave rise to the use of several geographic terms to describe the types of bentonite, is based on the degree of swelling.

Bentonite carrying calcium as the predominant exchangeable cation will swell only slightly more than other clay minerals when mixed with water. Accordingly, this variety is referred to as "nonswelling bentonite" and "calcium bentonite." Bentonites carrying sodium as the predominant exchangeable cation swell many times their original volume when mixed with water. This variety, therefore, is known as "swelling bentonite" and "sodium bentonite."

Until the 1930's, nearly all high-swelling bentonite was produced in Wyoming; consequently, such material became known as "Wyoming bentonite" and "Western bentonite" in order to distinguish it from a nonswelling bentonite which was being mined in Mississippi. The nonswelling variety became known as "Mississippi bentonite" and "Southern bentonite." These informal names should not be construed to imply the actual physical properties that would be displayed by the bentonite-water mixture of a particular geographical occurrence. Most occurrences of bentonite in Wyoming and the western United States are not the high-swelling variety--they do not carry the proper ratio of exchangeable cations and/or they are too contaminated with nonsmectite minerals.

In 1978, Regis proposed a formal classification for swelling bentonites (82). His classification is based on laboratory analyses of more than 600 samples. The laboratory test that he used determined the ratio of exchangeable sodium to calcium and magnesium cations ($Na^{+2}/Ca^{+2}$, $Mg^{+2}$), percent exchangeable sodium cations, viscosity or yield, filtration rate or water loss, and water-holding capacity or liquid limit. Viscosity, which is expressed in centipoises, is the resistance of a fluid or suspension to changes in shape or motion. It results from chemical and physical attractions between molecules of smectite minerals and water in a bentonite-water suspension, which is prepared in a specified manner. Yield, which is expressed as barrels per ton, is a common method of expressing the viscosity of a bentonite-water suspension. It is the number of 42-gallon barrels of drilling mud that can be produced by mixing 2,000 pounds of bentonite with sufficient water to produce a bentonite-water suspension having a viscosity of 15 centipoises. Filtration rate or water loss is a measure of the amount of water passing from a 15-centipoise drilling mud through a 9-centimeter, Whatman #50 filter paper in 30 minutes under a pressure of 100 pounds per square inch. Water-holding capacity or liquid limit is the percent water within a bentonite that corresponds to an arbitrarily selected boundary between the liquid and plastic states of consistency for the bentonite. The parameters for each variety of swelling bentonite as proposed by Regis are:

| | |
|---|---|
| Calcium-rich bentonite ("low-swelling variety") | $Na^{+2}/Ca^{+2},Mg^{+2}$ ratio $<0.1$<br>Exchangeable sodium cation $<5$ percent<br>Yield $<45$ barrels per ton<br>Water loss $>50$ milliliters<br>Liquid limit $<150$ percent |
| Intermediate (Calcium-Sodium) bentonite<br>("intermediate-swelling variety") | $Na^{+2}/Ca^{+2},Mg^{+2}$ ratio = 0.1 to 0.9<br>Exchangeable sodium cation = 5 to 48 percent<br>Yield=45 to 75 barrels per ton<br>Water loss = 18 to 50 milliliters<br>Liquid limit = 150 to 600 percent |
| Sodium-rich bentonite ("high-swelling variety") | $Na^{+2}/Ca^{+2},Mg^{+2}$ ratio $>0.9$<br>Exchangeable sodium cations $>48$ percent<br>Yield $>75$ barrels per ton<br>Water loss $<17.0$ milliliters<br>Liquid limit $>600$ percent |

## Origin

Most authors believe that bentonite forms by the alteration of wind-deposited, coarse volcanic ash and tuff. Evidence for its origin is available from bentonite studies throughout the world. In Wyoming, the composition and relative purity of the clay in the bentonite, the gradation of unaltered ash or tuff into bentonite within the same beds, and the similarity in texture, structure, and distribution of the bentonites and volcanic beds, support these conclusions (80, 95). In addition, differing mineral and rock-fragment assemblages between the bentonite and other surrounding sedimentary rocks, the relatively angular, unweathered condition of individual mineral grains (other than clay) in the bentonite, and the dissimilarity of overlying and underlying sediments on the reservation indicate that the bentonites probably formed from predominantly poorly-consolidated, airborne deposits. Other sedimentary rocks on the reservation primarily were waterlain. That there has been some reworking of very fine ash by water is shown by laminations near the tops of some bentonite beds. Physical differences, such as graded bedding and pronounced changes in grain size of minerals other than bentonite, can also be explained by air sorting.

A simplified reconstruction or summary of the deposition of the volcanic ash is as follows: Large quantities of volcanic material erupted to heights as much as 150,000 feet above a volcano and formed an upward-moving, 50-mile-diameter or greater, mushroom-shaped cloud. During and after the ascent of the cloud to its maximum height, ash began to fall. Ash distribution was controlled by high altitude winds and the diameter of the cloud perpendicular to the wind. Larger particles settled out first downwind in an elongate pattern. The actual pattern varied depending on differences in explosive intensity, and wind velocity and direction.

Bentonite distribution patterns are comparable in many respects to present-day volcanic ash deposits. These patterns generally show two or more distinctive tongue-shaped lobes of deposition very similar to lobes of Wyoming bentonite (95, 107). Because there is no evidence of volcanism in the subject formations, it is believed that the Wyoming bentonite lobes are disconnected from the source areas, a feature that is seen in some present-day volcanic deposits (95). Studies show that lobes of ash separated from their source area are possible when a high-intensity explosion occurs and high-velocity winds are present. Further information on the origin and distribution of volcanic material is given by Slaughter and Earley (95).

Field evidence suggests that much of the volcanic material was deposited directly into shallow alkaline lakes or seas. The contact of the ash with corrosive volcanic gases could have prepared this material for rapid decomposition upon entering water (9). Bentonite containing a large amount of impurities may have been deposited on land and mixed with other materials when washed into adjacent water bodies.

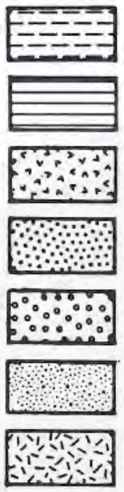
Opinions differ concerning the process and time needed for alteration of the ash. Patterson and Murray (80) believe that changes occur to the ash beds virtually throughout their geologic history, caused first by the original marine or alkaline conditions, and later by ground water. Papke (79) believes that one type of bentonite forms early after deposition in alkaline lakes or seas, while another type forms more slowly as the result of ground water alteration. Some bentonite deposits are known to be formed by hydrothermal activity or by hot-spring activity; these methods are not believed appropriate to explain the Wyoming bentonites, however, because of differing physical and chemical properties (80).

Several theories are hypothesized to account for the formation of different types of bentonite by surface weathering. Bleifuss (11) theorizes that varying types of bentonite form by somewhat the same procedure as soils. This is characterized by surface calcification of the deposit. The amount of calcification affects the swelling capacity of the bentonite; surface or shallow exposures generally have greater swelling capacity, whereas the more deeply buried "blue" bentonites have not undergone this type of alteration and have much lower swelling capacity. Williams and others (109) believe that the addition or removal of iron oxide from the surface of the bentonite structure produces the varying types and qualities of bentonite. During normal weathering, iron oxide is removed from the surface of the bentonite structure, and the vacated sites can be filled by either sodium or calcium cations. Sulfate ions are formed, probably by bacterial action, and they, together with progressive dehydration toward the outcrop, remove calcium from the bentonite structure and allow additional sodium replacement.

APPENDIX C

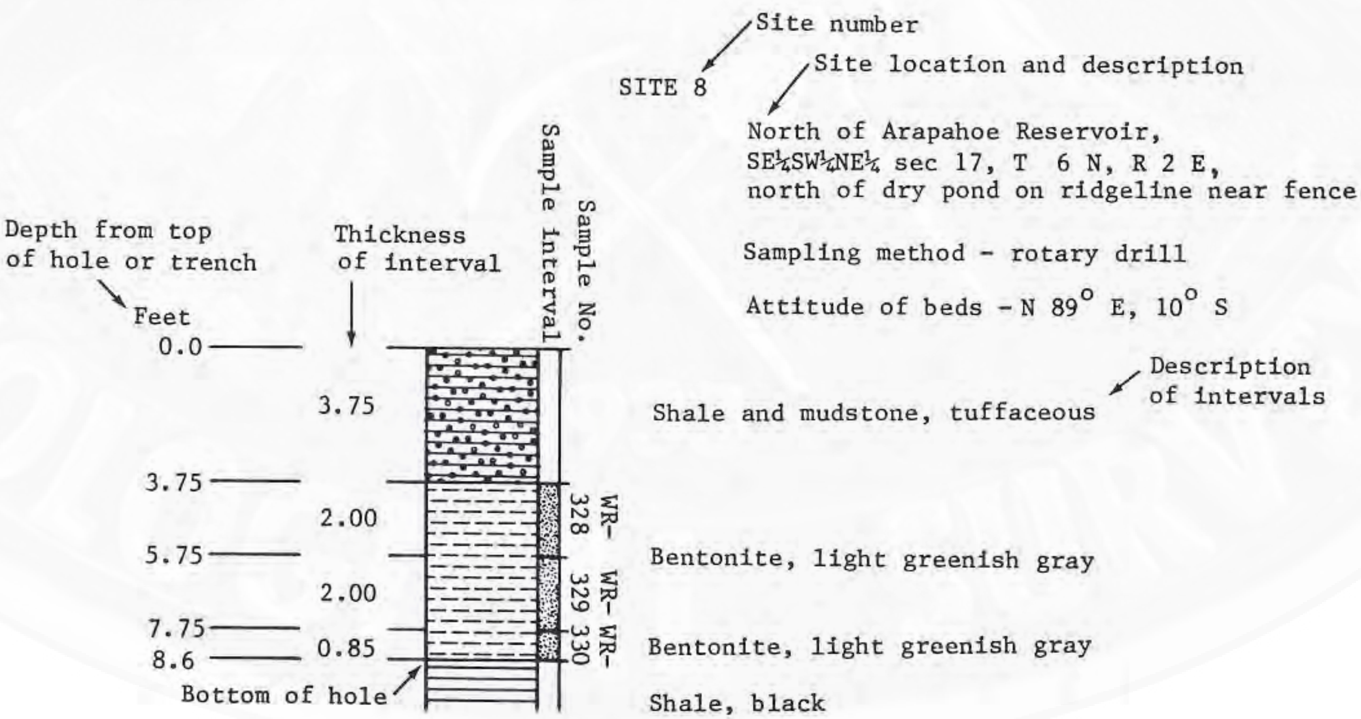
Description of Bentonite Sample Sites 1 through 13

## EXPLANATION

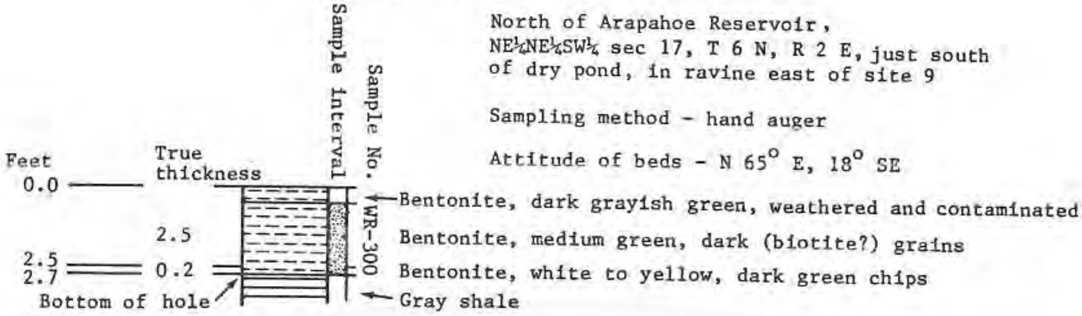


| Symbol | Description* |
| --- | --- |
| | Bentonite |
| | Shale |
| | Porcellanite |
| | Sandstone |
| | Mudstone |
| | Soil, slopework |
| | Fill material |

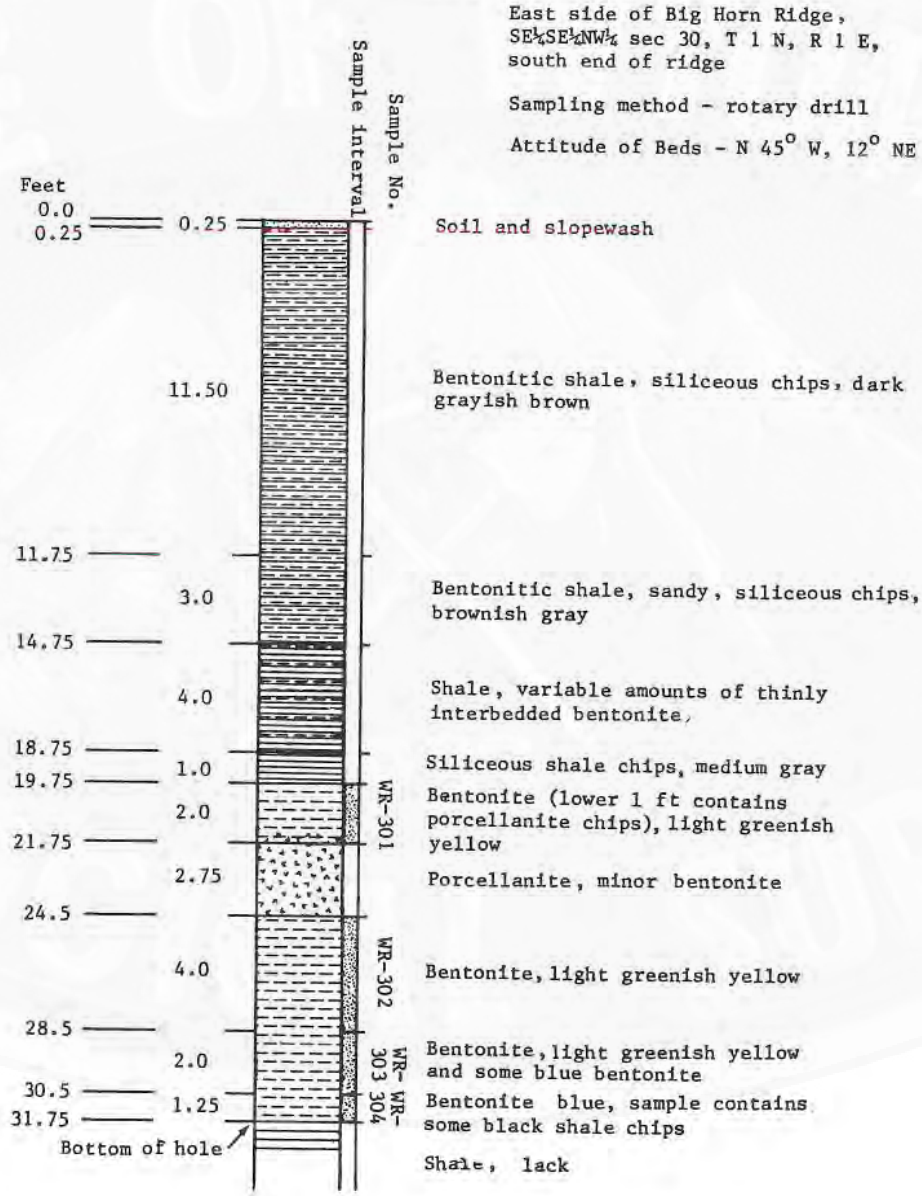
*Combinations of symbols are used



SITE 1[1]




SITE 2[1]



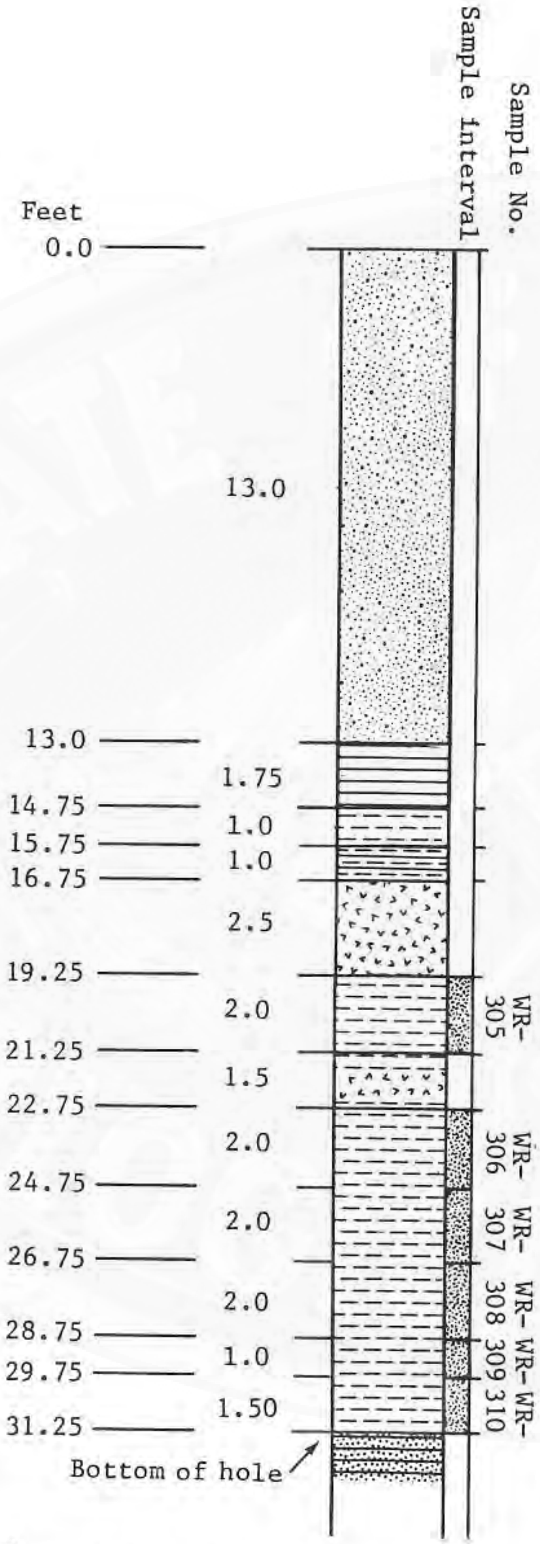

[1]See explanation at front of appendix B

SITE 3[1]

East side of Bighorn Ridge,
NW corner SE¼SE¼SE¼ sec 3, T 1 N,
R 1 W, just west of closed-in well
∽900 ft., N 62° W , from SE corner,
sec 3

Sampling method - rotary drill

Attitude of beds - N 37° W, 20° NW




| Depth (Feet) | Thickness | Sample No. | Description |
|---|---|---|---|
| 0.0 – 13.0 | 13.0 | | Soil and slopewash |
| 13.0 – 14.75 | 1.75 | | Shale, medium gray |
| 14.75 – 15.75 | 1.0 | | Bentonitic clay, light buff |
| 15.75 – 16.75 | 1.0 | | Shale, black, interbedded bentonite |
| 16.75 – 19.25 | 2.5 | | Porcellanite, white to light blueish gray |
| 19.25 – 21.25 | 2.0 | WR-305 | Bentonite, light tan |
| 21.25 – 22.75 | 1.5 | | Bentonite, ∽30% light red porcellanite |
| 22.75 – 24.75 | 2.0 | WR-306 | Bentonite, light tan |
| 24.75 – 26.75 | 2.0 | WR-307 | |
| 26.75 – 28.75 | 2.0 | WR-308 | Bentonite, 1st 1 ft dark brown<br>2nd 1 ft light brown |
| 28.75 – 29.75 | 1.0 | WR-309 | Bentonite, light greenish buff |
| 29.75 – 31.25 | 1.50 | WR-310 | Bentonite, light blue |
| Bottom of hole (31.25) | | | Shale, sandy, black |

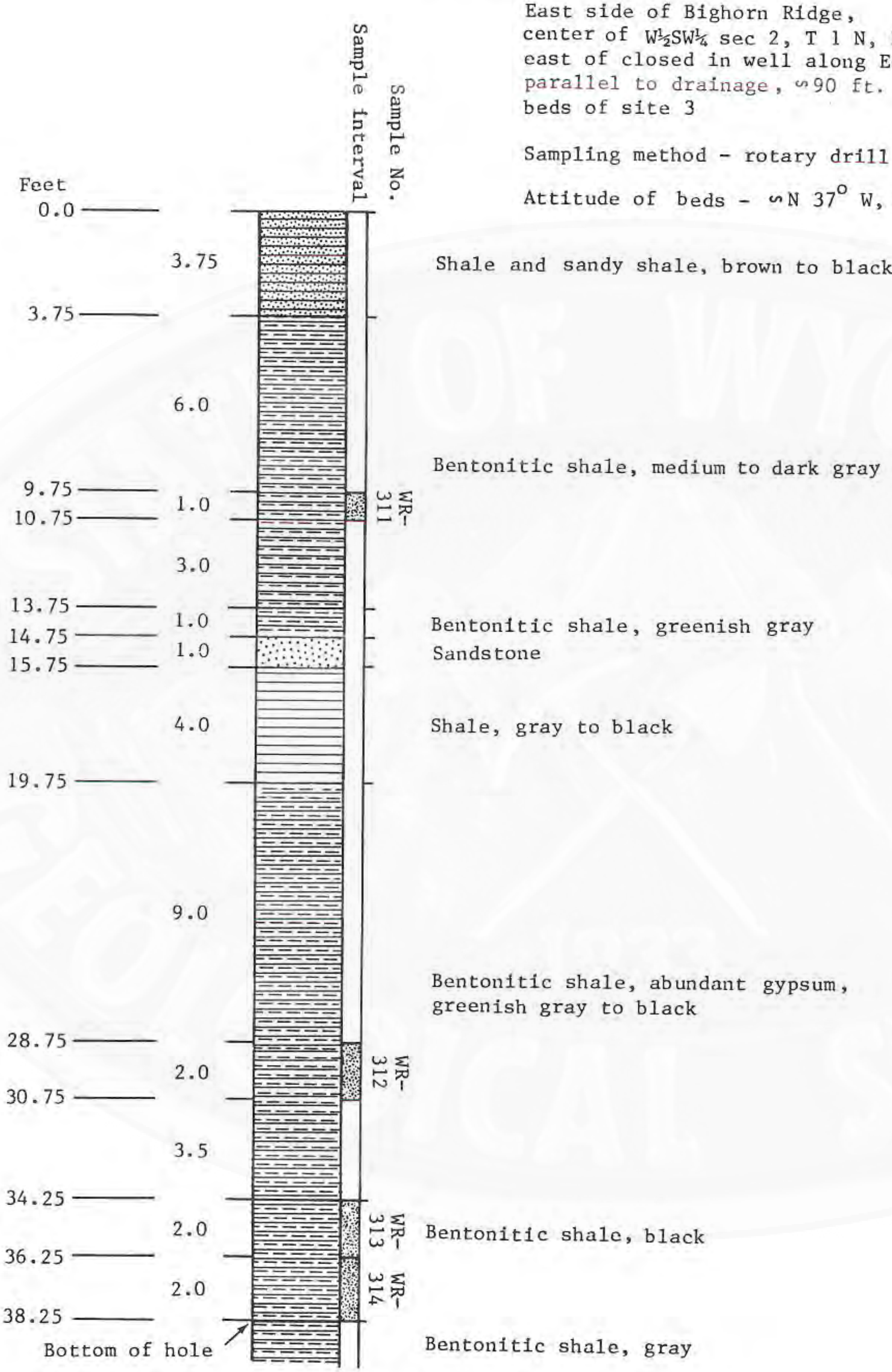
[1]See explanation at front of appendix B

SITE 4[1]

East side of Bighorn Ridge,
center of W½SW¼ sec 2, T 1 N, R 1 W,
east of closed in well along E-W dirt road
parallel to drainage, ∽90 ft. above bentonite
beds of site 3

Sampling method - rotary drill

Attitude of beds - ∽N 37° W, 20° NE



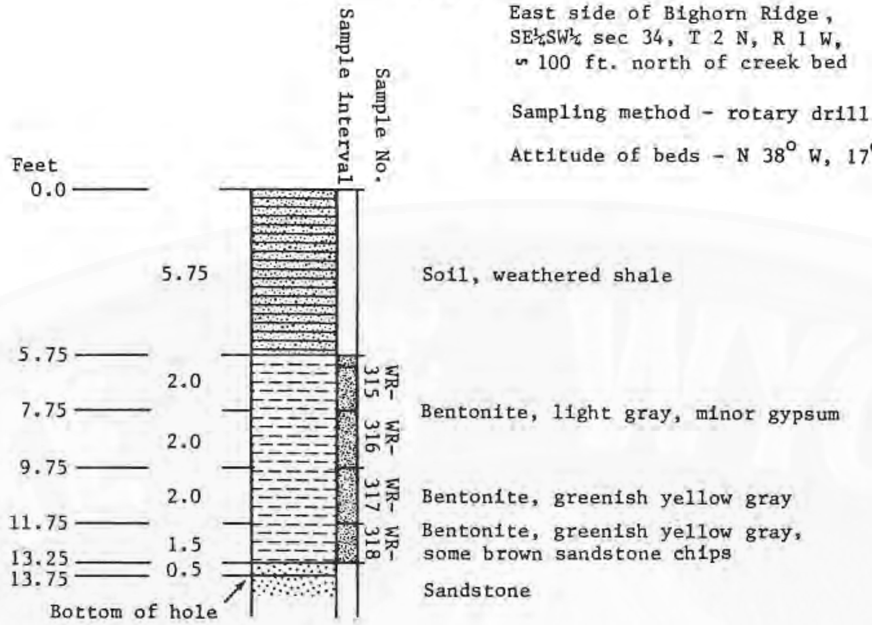

[1]See explanation at front of appendix B

## SITE 5[1]

East side of Bighorn Ridge,
SE¼SW¼ sec 34, T 2 N, R 1 W,
~100 ft. north of creek bed

Sampling method - rotary drill

Attitude of beds - N 38° W, 17° NE



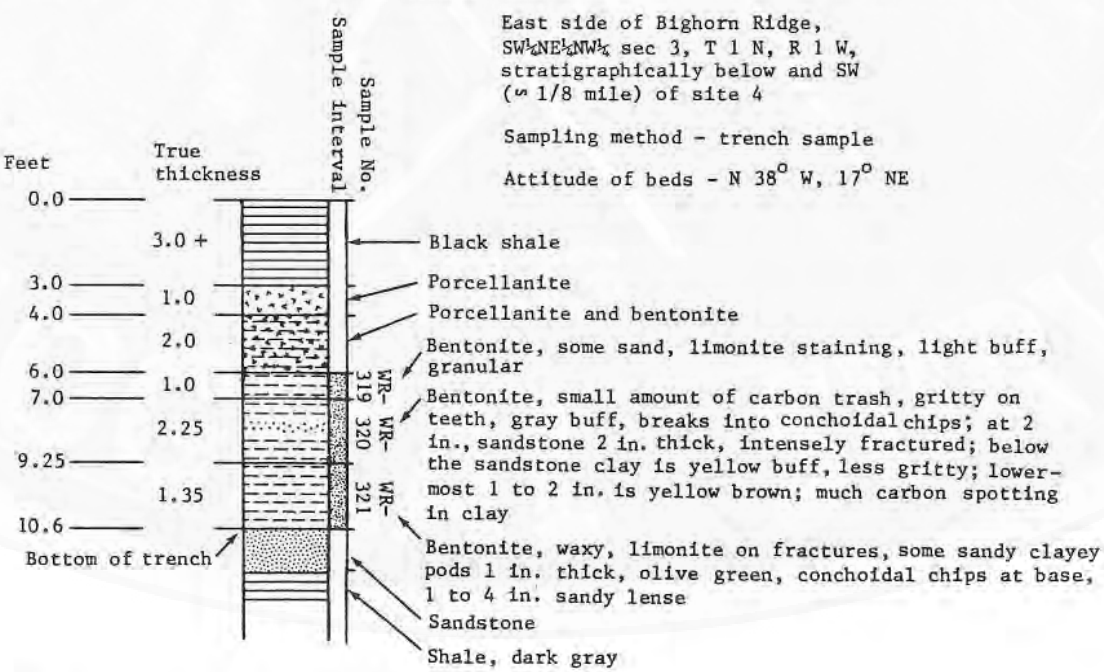

[1]See explanation at front of appendix B

## SITE 6[1]

East side of Bighorn Ridge,
SW¼NE¼NW¼ sec 3, T 1 N, R 1 W,
stratigraphically below and SW
(~1/8 mile) of site 4

Sampling method - trench sample

Attitude of beds - N 38° W, 17° NE



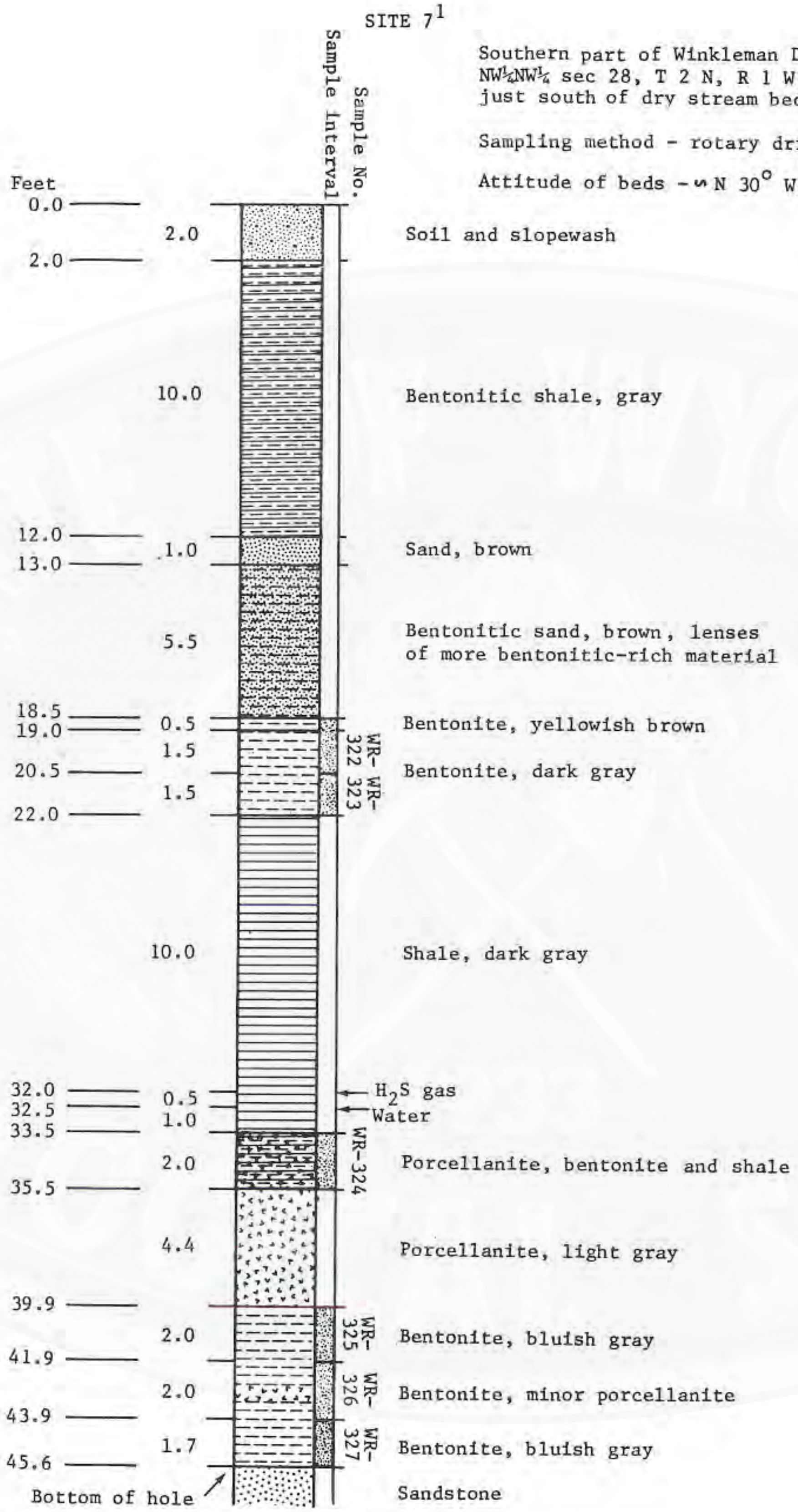

[1]See explanation at front of appendix B

SITE 7[1]

Southern part of Winkleman Dome,
NW¼NW¼ sec 28, T 2 N, R 1 W,
just south of dry stream bed

Sampling method - rotary drill

Attitude of beds - ∽ N 30° W, 10° NE



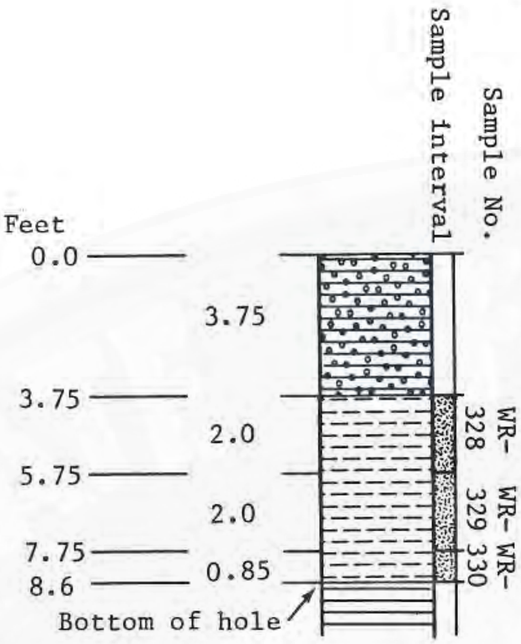

[1]See explanation at front of appendix B

SITE 8[1]

North of Arapahoe Reservoir,
SE¼SW¼NE¼ sec 17, T 6 N, R 2 E,
north of dry pond on ridgeline near fence

Sampling method - rotary drill

Attitude of beds - N 89° E, 10° S




Shale and mudstone, tuffaceous, light to medium gray, larger grains of dark mineral (biotite?)

Bentonite, light greenish gray

Bentonite, light greenish gray (contaminated with shale chips)

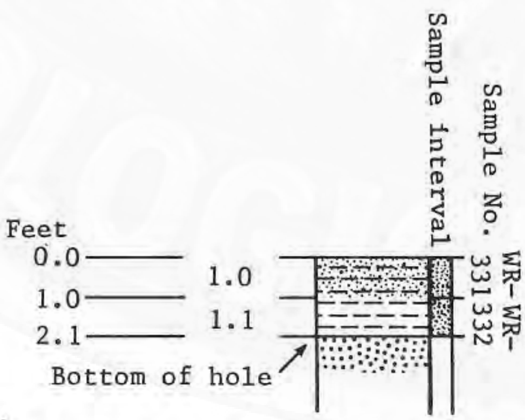
Shale, black

SITE 9[1]

North of Arapahoe Reservoir,
NE¼NE¼SW¼ sec 17, T 6 N, R 2 E,
just southwest of dry pond, west of small ravine

Sampling method - hand auger

Attitude of beds - N 83° E, 9° SE




Bentonite, somewhat contaminated with soil, grayish brown

Bentonite and chips of sandstone

Sandstone

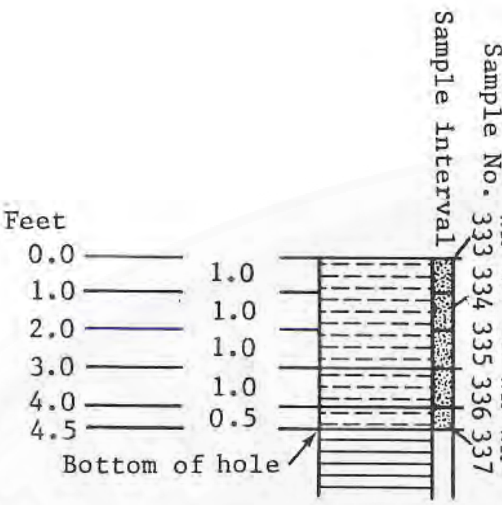
[1]See explanation at front of appendix B

## SITE 10[1]

North slope of Blue Ridge,
SW¼SW¼NW¼ sec 9, T 8 N, R 3 E,
below sheepherder's monument on bench

Sampling method - hand auger

Attitude of beds - N 88° W, 8° N




Bentonite, greenish gray, orange iron staining

Bentonite, light greenish gray

Bentonite, greenish gray, gritty, biotite flakes

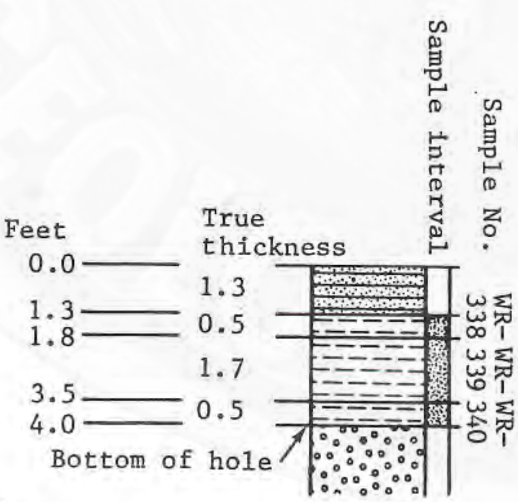
Shale

## SITE 11[1]

North slope of Blue Ridge,
center line, S½NE¼SW¼ sec 11, T 8 N,
R 3 E, on bench along dirt road,
(eastern sample)

Sampling method - trench sample

Attitude of bed - N 88° W, 10° N




Slopewash and white siliceous shale

Bentonite, greenish brown, weathered reddish orange limonite along fractures

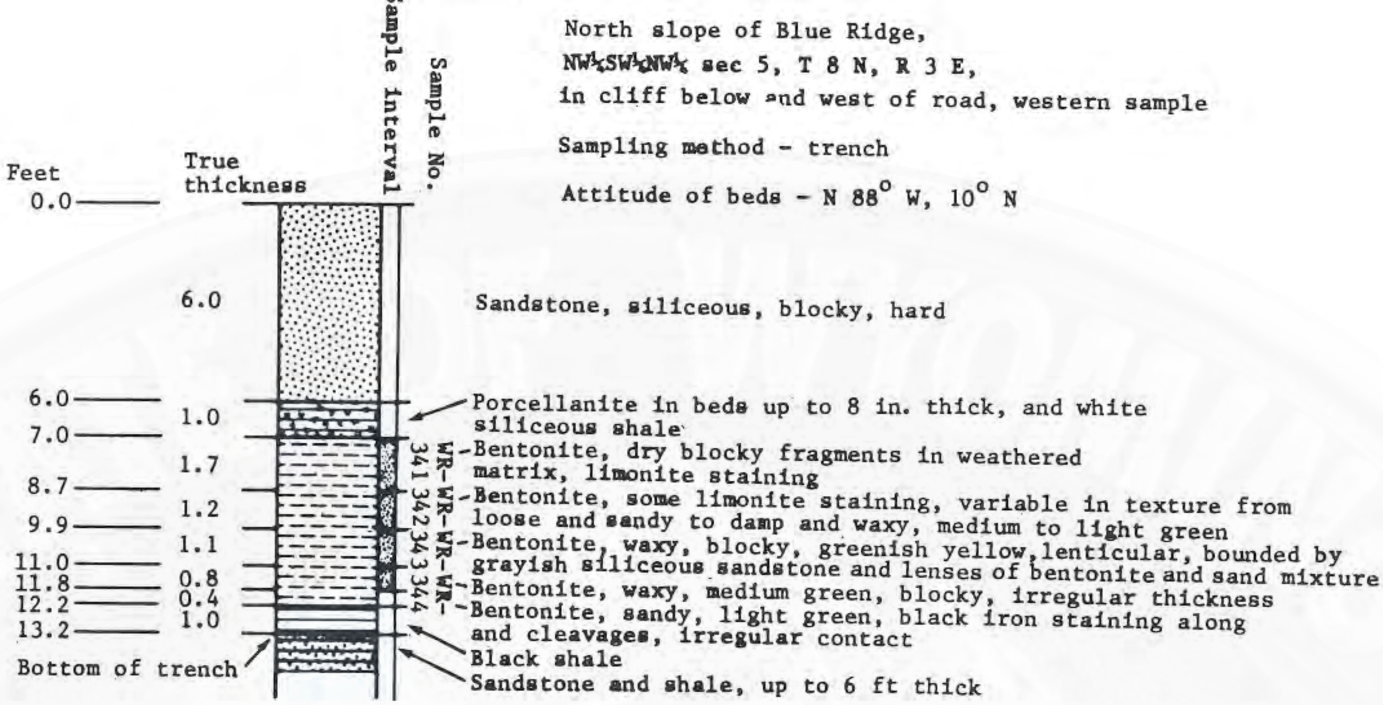
Bentonite, green, some biotite flakes

Bentonite, greenish yellow to yellow buff, lower 1 inch is brown

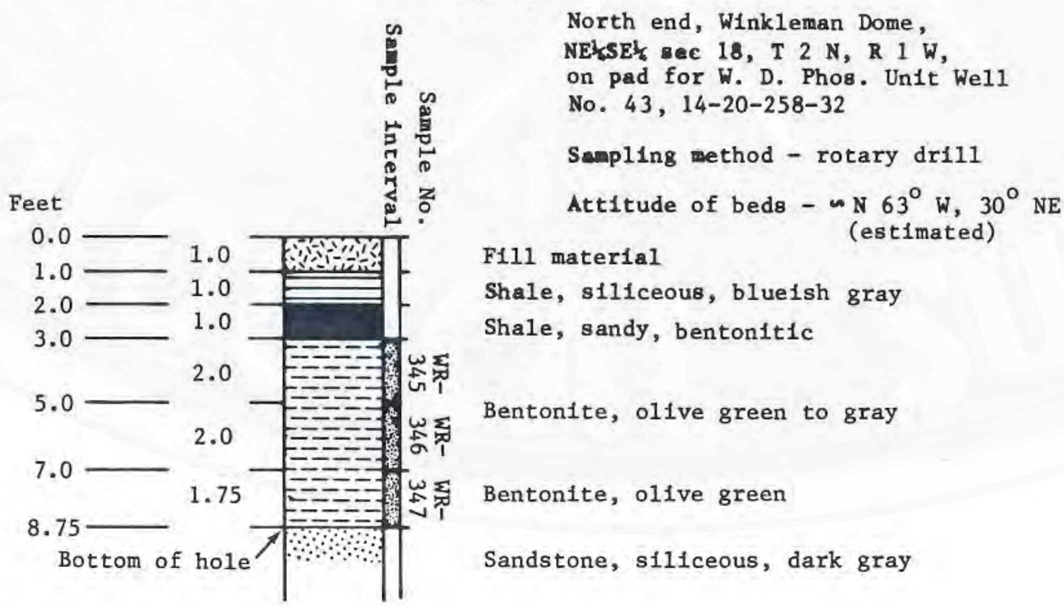
Mudstone, dark gray

[1]See explanation at front of appendix B

SITE 12[1]




SITE 13[1]




[1]See explanation at front of appendix B

# APPENDIX D

## Geology of the Bentonite-Bearing Formations

## Thermopolis Formation

As defined in this paper, the Thermopolis Formation of lower Cretaceous age consists predominantly of black to dark gray, soft, fissile shale. The lower contact, mainly exposed on the reservation in the center of eroded folds, is usually placed at the base of a sequence of black to dark gray shale, sandy shale, and a fine-grained sandstone called the "Rusty Beds." The lower contact is irregular because its stratigraphic position depends on the development of the underlying Cloverly Sandstone. The upper units of the "Rusty Beds" are marked by a zone of concretions in many places.

The Thermopolis Formation originally included the interval from the underlying Cloverly Sandstone to the gradational contact with the Mowry Formation. At the Thermopolis-Mowry contact, the soft black Thermopolis shale changes to a harder, siliceous shale. This definition of the Thermopolis Formation would include (besides the basal "Rusty Beds") a 30- to 150-foot-thick fine-to coarse-grained sandstone interval containing black, carbonaceous shale shale known as the Muddy Sandstone, and an overlying 50- to 200-foot-shale unit that is similar to the unnamed unit between the basal "Rusty Beds" and the Muddy Sandstone. This overlying interval above the Muddy Sandstone is called the "Upper Thermopolis." Above the "Upper Thermopolis" is the Mowry Formation (17, 73).

The upper contact of the Thermopolis has been placed at several horizons. Because the "Upper Thermopolis" is a poor mapping unit and because its contact with the Mowry Formation is difficult to determine in outcrop, many authors consider the "Upper Thermopolis" to be part of the Mowry Formation (62). They believe a better horizon for the upper contact of the Thermopolis Formation lies at the base of the Muddy Sandstone. This would place the Muddy Sandstone and the "Upper Thermopolis" intervals within the Mowry formation.

## Mowry Formation

The Mowry Formation of lower Cretaceous age consists predominantly of hard, siliceous, black to gray shale and siltstone units that typically weather silvery gray. Fish scales are abundant in some horizons, and numerous thin bentonite beds are present.

Thickness and lithology change throughout the Mowry Formation. It thickens from 200 feet near Casper, Wyo., to 400 feet in the western Wind River Basin. In moving from the eastern to the western Wind River Basin, the rock in the uppermost Mowry changes from typical "Mowry-type" shales to "Frontier-type" shales and sandstones. Coincident with this, the shales become slightly softer, less siliceous, and more silty and sandy.

Because of this lithologic change, there is little agreement in the literature for the location of the Mowry contacts. (The location of the Thermopolis-Mowry contact is discussed in the section on the Thermopolis Formation.) The Mowry-Frontier contact is placed at different horizons by authors working in various areas of Wyoming. Love and others (65) place the contact in the western Wind River Basin at the base of a soft, porous sandstone, which lies below a thick, white, bentonite-porcellanite interval. Porcellanite is a light-gray, hard, blocky siliceous rock similar to chert. This bentonite-porcellanite interval may be the same as the unit chosen in this report for the upper contact of the Mowry Formation in the Bighorn Ridge-Winkleman Dome area. Towse (102) reports, "*** some workers have drawn the contact at the base of a thick bentonite lying near a contact between soft black shale and typical siliceous shale in the eastern Wind River Basin." In the southern Bighorn Basin, north of the Owl Creek Mountains, Hunter (46) places the contact at the base of a bentonite bed or the base of the overlying sandstone. The base of the lowermost prominent sandstone, which lies above a thick bentonite bed, is the horizon chosen in this report for the Mowry-Frontier contact in this area. This appears to be the same horizon as chosen by Hunter but is probably not the same bentonite bed chosen for the contact in the Wind River Basin. Slaughter and Earley (95), Mills (73), and Burk (17) give a more detailed discussion of the Mowry-Frontier contact.

For this report, the Mowry Formation is defined as the interval from the upper contact of the "Upper Thermopolis," where soft black shales change into harder siliceous shales, to the bottom of a widespread, 5- to 17-foot-thick interval of bentonite-porcellanite in the Bighorn Ridge-Winkleman Dome area (pl. 3), and to the base of the lowermost prominent "Frontier-type" sandstone in the area north of the Owl Creek Mountains. In the area north of Arapahoe Reservoir, the contact was chosen at the base of the lowermost, prominent, "Frontier-type" sandstone.

Bentonite is present in the Mowry Formation but not well exposed in most locations. North of Arapahoe Reservoir, an eroded section of the Mowry Formation reveals numerous 0.5-foot to 4-foot-thick beds and lenses of poorly exposed bentonite interbedded with thick sequences of siliceous, silvery-gray shale. Information available from previous work by authors in other areas of Wyoming and from field work during this study indicates that this sequence is typical of the bentonite-bearing Mowry Formation.

### Frontier Formation

The Frontier Formation of Upper Cretaceous age, lying between the siliceous Mowry Formation and the black Cody Shale, is predominantly a thick sequence of interbedded bentonitic shales and sandstones. The lithology differs, particularly in the lower part of the formation (95). It consists of lenticular, fine- to coarse-grained, locally silty, gray sandstones that often show red or brown surface weathering; fissile, black to dark gray, siliceous to soft, bentonitic shales; conglomerates; siltstones; and beds of buff, pale-green, or yellow bentonite.

In the western Wind River Basin, some "Frontier-type" sandstones are found in the Mowry Formation below the chosen Mowry-Frontier contact (95). In addition, soft fissile shales comprising the upper part of the Frontier Formation in the southeastern Wind River Basin grade into sandstones and shales toward the western part of the Basin. The formation thickens slightly eastward, from 750 feet in the western Wind River Basin to 950 feet in the eastern part, and becomes older to the east. Overall, lithology changes from sandstones interbedded with shales in the western Wind River Basin to mainly shales in the eastern Basin, owing to lensing out of the sandstones. In the eastern Wind River Basin only one well-developed sandstone is present in the upper part of the Frontier Formation, and in this area, the Mowry-Frontier contact is difficult to determine. The Frontier-Cody contact consists of a zone of interfingering "Frontier-type" sandstones and siltstones, and "Cody-type" shales. Thus, the contact between these units is variably interpreted in different areas by different authors (17, 73).

Numerous beds and lenses of bentonite are present in the Frontier Formation. Except for the lowermost interval of bentonite-porcellanite at the Mowry-Frontier contact in the Bighorn Ridge-Winkleman Dome area, most beds appear not to persist over a large area. Many appear to thicken and thin and lens out or interfinger with shale and/or porcellanite.

# APPENDIX E

## Mineralogical and Physical Properties of Bentonite Samples

TABLE E-1. - Mineralogical composition and physical properties of preliminary bentonite samples, Wind River Indian Reservation, Wyoming

(rpm = rotations per minute; bbl/ton = barrels per ton; ml = milliliters; psi = pounds per square inch; mont = montmorillonite; cli = clinoptilolite; gyp = gypsum; cri = cristobalite; cal = calcite; fel = feldspar; anal = analcime; ND = not determined; NR = not reported)

| Site and sample number | Mineralogical composition[1] | | | Viscometer reading[2] | | Yield[2], bbl/ton | Water loss[2], ml | Water-sorption capacity[2], ml | Compressive strengths | |
|---|---|---|---|---|---|---|---|---|---|---|
| | major | minor | trace | 600 rpm[3] | 300 rpm[3] | | | | green[2], psi | dry[2], psi |
| Site 1P: | | | | | | | | | | |
| 201.. | mont | qtz | cli,gyp | 3 | NR | 30 | ND | 123 | 3.53 | 30.8 |
| Site 2P: | | | | | | | | | | |
| 202.. | -do- | -do- | cli,cal | 2 | NR | <30 | ND | 134 | 4.90 | 51.0 |
| Site 3P: | | | | | | | | | | |
| 203.. | -do- | qtz,cri | cli | 3 | NR | 30 | ND | 268 | 2.45 | 35.8 |
| Site 4P: | | | | | | | | | | |
| 204.. | -do- | cal | qtz,gyp, mica | 3 | NR | 30 | ND | 112 | 4.23 | 66.3 |
| Site 5P: | | | | | | | | | | |
| 205.. | -do- | qtz | qtz,cri, gyp | 4 | NR | 40 | ND | 189 | 5.73 | 49.0 |
| 206.. | -do- | -do- | cli | 4 | NR | 40 | ND | 487 | 4.53 | 58.0 |
| 207.. | -do- | -do- | cli,gyp | 3 | NR | 30 | ND | 106 | 4.35 | 75.8 |
| Site 6P: | | | | | | | | | | |
| 208.. | -do- | -do- | cli,gyp, cal | 3 | NR | 30 | ND | 356 | 2.15 | 29.8 |
| Site 7P: | | | | | | | | | | |
| 209.. | -do- | -do- | cli | 5 | NR | 46 | ND | 104 | 5.33 | 23.5 |

See footnotes at end of table.

TABLE E-1. - Mineralogical composition and physical properties of preliminary bentonite samples, Wind River Indian Reservation, Wyoming--Continued

(rpm = rotations per minute; bbl/ton = barrels per ton; ml = milliliters; psi = pounds per square inch; mont = montmorillonite; cli = clinoptilolite; gyp = gypsum; cri = cristobalite; cal = calcite; fel = feldspar; anal = analcime; ND = not determined; NR = not reported)

| Site and sample number | Mineralogical composition[1] | | | Viscometer reading[2] | | Yield[2], bbl/ton | Water loss[2], ml | Water-sorption capacity[2], ml | Compressive strengths | |
|---|---|---|---|---|---|---|---|---|---|---|
| | major | minor | trace | 600 rpm[3] | 300 rpm[3] | | | | green[2], psi | dry[2], psi |
| Site 8P: | | | | | | | | | | |
| 210.. | -do- | -do- | gyp,mica | 14 | 9 | 71 | 12.1 | 593 | 5.10 | 65.8 |
| Site 9P: | | | | | | | | | | |
| 211.. | -do- | -do- | cli,mica | 23 | 12 | 85 | 16.4 | 513 | 3.80 | 63.5 |
| Site 10P: | | | | | | | | | | |
| 212.. | -do- | -do- | gyp,fel | 13 | 7 | 70 | 14.5 | 608 | 5.70 | 62.8 |
| Site 11P: | | | | | | | | | | |
| 213.. | -do- | -do- | anal | 8 | 4 | 58 | 22.0 | 396 | 1.90 | 33.5 |
| Site 12P: | | | | | | | | | | |
| 214.. | mont | cri,fel | qtz,cli | 13 | 7 | 70 | 18.6 | 705 | 4.4 | 37.5 |
| Site 13P: | | | | | | | | | | |
| 215.. | -do- | qtz | gyp,fel | 5 | 3 | 46 | 35.2 | 303 | 3.9 | 35.9 |

[1]Analyses performed by BuMines Reno Research Center.
[2]Analyses performed by BuMines Tuscaloosa Research Center.
[3]Test conducted with 20.25 grams of dry bentonite; equivalent to 22.50 grams of bentonite containing ten percent moisture content.

TABLE E-2. - Physical properties of bentonite samples 300 through 347,

Wind River Indian Reservation, Wyoming[1]

(rpm = rotations per minute; bbl/ton = barrels per ton; ml = milliliters; psi = pounds per square inch; ND = not determined; } = indicates that samples were combined for analyses)

| Site and sample number | Viscometer reading 600 rpm[2] | Viscometer reading 300 rpm[2] | Yield, bbl/ton | Water loss, ml | Water-sorption capacity, ml | Compressive strengths green, psi | Compressive strengths dry, psi |
|---|---|---|---|---|---|---|---|
| Site 1: | | | | | | | |
| 300... | 15 | 10 | 73 | 18.5 | 586 | 5.1 | 68.0 |
| Site 2: | | | | | | | |
| 301... | 7 | 4 | 55 | 31.4 | 222 | 6.5 | 53.5 |
| 302... } 303... | 6 | 3 | 51 | 34.0 | 346 | 2.2 | 37.5 |
| 304... | ND | ND | ND | ND | ND | ND | ND |
| Site 3: | | | | | | | |
| 305... | 6 | 3 | 51 | 19.8 | 358 | 3.0 | 70.8 |
| 306... } 307... | 7 | 4 | 55 | 18.2 | 359 | 3.1 | 73.3 |
| 308... } 309... 310... | 7 | 4 | 55 | 19.7 | 342 | 2.6 | 73.5 |
| Site 4: | | | | | | | |
| 311... | 6 | 3 | 51 | 30.4 | 342 | 3.1 | 52.3 |
| 312... | 7 | 4 | 55 | 15.8 | 448 | 5.1 | 55.5 |
| 313... } 314... | 5 | 3 | 46 | 80.2 | 118 | 1.8 | 47.0 |
| Site 5: | | | | | | | |
| 315... } 316... | 5 | 3 | 46 | 74.8 | 137 | 2.5 | 69.0 |
| 317... | 5 | 3 | 46 | 107.4 | 177 | 5.4 | 59.8 |
| 318... | ND | ND | ND | ND | ND | ND | ND |
| Site 6: | | | | | | | |
| 319... | 10 | 5 | 63 | 14.3 | 582 | 5.5 | 72.5 |
| 320... | 6 | 4 | 51 | 92.5 | 188 | 4.8 | 50.0 |
| 321... | 8 | 4 | 58 | 19.7 | 464 | 3.8 | 69.8 |
| Site 7: | | | | | | | |
| 322... } 323... | 17 | 9 | 76 | 11.6 | 677 | 4.7 | 62.0 |
| 324... | ND | ND | ND | ND | ND | ND | ND |
| 325... } 326... 327... | 5 | 3 | 46 | 20.0 | 335 | 3.0 | 64.8 |
| Site 8: | | | | | | | |
| 328... } 329... | 6 | 3 | 51 | 35.5 | 427 | 3.6 | 26.8 |
| 330... | ND | ND | ND | ND | ND | ND | ND |

See footnotes at end of table.

TABLE E-2. - Physical properties of bentonite samples 300 through 347, Wind River Indian Reservation, Wyoming[1]--Continued

(rpm = rotations per minute; bbl/ton = barrels per ton; ml = milliliters; psi = pounds per square inch; ND = not determined; } = indicates that samples were combined for analyses)

| Site and sample number | Viscometer reading: 600 rpm[2] | Viscometer reading: 300 rpm[2] | Yield, bbl/ton | Water loss, ml | Water-sorption capacity, ml | Compressive strengths: green, psi | Compressive strengths: dry, psi |
|---|---|---|---|---|---|---|---|
| Site 9: | | | | | | | |
| 331... } 332... | 13 | 8 | 70 | 12.6 | 659 | 5.2 | 58.8 |
| Site 10: | | | | | | | |
| 333... } 334... } 335... | 14 | 8 | 71 | 14.7 | 697 | 4.0 | 58.8 |
| 336... } 337... | 10 | 6 | 63 | 16.8 | 600 | 4.4 | 61.5 |
| Site 11: | | | | | | | |
| 338... } 339... } 340... | 7 | 4 | 55 | 20.0 | 415 | 3.8 | 47.3 |
| Site 12: | | | | | | | |
| 341... } 342... | 7 | 4 | 55 | 25.0 | 466 | 2.3 | 24.5 |
| 343... } 344... | 11 | 6 | 65 | 18.6 | 655 | 3.6 | 22.8 |
| Site 13: | | | | | | | |
| 345... } 346... | 12 | 7 | 68 | 20.0 | 762 | 5.9 | 33.0 |
| 347... | 4 | 3 | 40 | 65.8 | 204 | 2.8 | 28.3 |

[1]Analyses performed by BuMines Tuscaloosa Research Center.
[2]Tests conducted with 20.25 grams of dry bentonite; equivalent to 22.50 grams of bentonite containing 10 percent moisture content.

TABLE E-3. - Viscosity, yield, and water loss values of selected bentonite samples, Wind River Indian Reservation, Wyoming[1]

(rpm = rotations per minute; bbl/ton = barrels per ton; ml = milliliter; } = indicates that samples were combined for analyses)

| Sample number | Viscometer reading 600rpm[2] | Viscometer reading 300rpm[2] | Yield, bbl/ton | Water loss, ml |
|---|---|---|---|---|
| 203...... | 6 | 4 | 51 | 30.6 |
| 208...... | 6 | 3 | 50 | 25.2 |
| 210...... | 7 | 4 | 55 | 27.8 |
| 211...... | 14 | 8 | 71 | 14.8 |
| 212...... | 4 | 2 | 40 | 100.0 |
| 213...... | 9 | 5 | 61 | 21.6 |
| 214...... | 4 | 3 | 40 | 64.4 |
| 215...... | 11 | 6 | 65 | 14.4 |
| 300...... | 24 | 14 | 86 | 15.2 |
| 301...... | 6 | 3 | 51 | 26.4 |
| 302...... } 303...... } | 7 | 4 | 55 | 17.6 |
| 305...... | 6 | 3 | 51 | 17.8 |
| 306...... | 6 | 3 | 51 | 17.6 |
| 307...... | 6 | 3 | 51 | 19.0 |
| 308...... | 6 | 4 | 51 | 17.4 |
| 309...... | 6 | 4 | 51 | 19.0 |
| 310...... | 4 | 2 | 40 | 36.2 |
| 315...... | 12 | 8 | 68 | 22.0 |
| 316...... | 7 | 5 | 55 | 14.0 |
| 317...... | 9 | 6 | 61 | 12.4 |
| 328...... | 18 | 11 | 78 | 11.0 |
| 329...... | 22 | 13 | 84 | 10.4 |
| 333...... } 334...... } 335...... } | 10 | 6 | 63 | 15.4 |
| 336...... | 12 | 7 | 68 | 17.4 |
| 338...... } 339...... } 340...... } | 7 | 4 | 55 | 21.2 |
| 345...... | 5 | 3 | 46 | 52.0 |
| 346...... | 4 | 2 | 40 | 36.0 |

[1]Analyses performed by Kenneth Tanner, Ten Sleep, Wyo.
[2]Test conducted using 22.5 grams of dry bentonite.

See note on page 78.

Note.--Variations between results reported in this table and those shown in tables E-1 and E-2 were produced by different procedures in conducting the test, by different sample preparation procedures, and by inhomogeneity of the bentonite samples. Tanner used 22.5 grams of dry bentonite when testing the samples; however the BuMines, as recommended by the American Petroleum Institute (oral communication between Kenneth Liles, Research Chemist, BuMines Tuscaloosa Research Center and Dr. Ronald D. Watts, Research Laboratory, API, Houston, Texas), used 20.25 grams of dry bentonite, which is equivalent to 22.5 grams of bentonite containing 10 percent moisture. According to Grim (35), viscosity is about 1.9 times greater for a bentonite-water suspension made with 22.5 grams than with one made using 20.25 grams. A number of Tanner's results (viscometer readings) averaged about twice those of the BuMines. Different sample preparation techniques unfortunately were employed when preparing portions of samples 8P, 9P, 10P, and 12P for shipment to each of the laboratories. This perhaps is the reason the BuMines values for these samples are higher than Tanner's. Other variations may be the result of unknown differences in procedures followed by the two laboratories. In addition, the mineralogical and physical properties of bentonite vary throughout each occurrence. Such variations often are sufficient to produce different laboratory results, even from samples collected at the same site.

TABLE E-4. - Viscosity, yield, and water loss values of chemically treated bentonite samples, Wind River Indian Reservation, Wyoming[1]

(rpm = rotations per minute; bbl/ton = barrels per ton; ml = milliliter; pct = percent; lbs/ton = pounds per ton; FR-76 = commercially prepared polymer; } = indicates that samples were combined for analyses)

| Sample number | Treatment | Viscometer reading 600 rpm[2] | 300 rpm[2] | Yield, bbl/ton | Water loss, ml |
|---|---|---|---|---|---|
| 211... | 1.5 pct soda ash........................ | 25 | 15 | 87 | 12.0 |
| Do... | 1.5 pct soda ash and 0.5 lbs/ton FR-76.. | 51 | 36 | 107 | 12.0 |
| 214... | 1.5 pct soda ash........................ | 16 | 10 | 75 | 15.2 |
| Do... | 1.5 pct soda ash and 0.5 lbs/ton FR-76.. | 36 | 26 | 97 | 15.0 |
| 215... | 0.5 pct soda ash........................ | 20 | 14 | 81 | 11.0 |
| Do... | 0.5 pct soda ash and 0.5 lbs/ton........ | 28 | 19 | 90 | 11.2 |
| 300... | 0.5 pct soda ash........................ | 25 | 16 | 87 | 12.8 |
| Do... | 0.5 pct soda ash and 0.5 lbs/ton FR-76.. | 40 | 28 | 100 | 13.0 |
| 328... | 0.5 lbs/ton FR-76....................... | 32 | 22 | 94 | 11.0 |
| 329... | ........do.............................. | 56 | 43 | 109 | 11.2 |
| 333...<br>334...<br>335... | } 0.5 pct soda ash........................ | 13 | 7 | 70 | 13.0 |
| 333...<br>334...<br>335... | } 0.5 pct soda ash and 0.5 lbs/ton FR-76.. | 46 | 36 | 104 | 13.3 |
| 336... | 1.0 pct soda ash........................ | 14 | 7 | 71 | 15.0 |
| Do... | 1.0 pct soda ash and 0.5 lbs/ton FR-76.. | 36 | 27 | 97 | 14.2 |
| 338...<br>339...<br>340... | } 1.5 pct soda ash........................ | 19 | 10 | 80 | 13.4 |
| 338...<br>339...<br>340... | } 1.5 pct soda ash and 0.5 lbs/ton FR-76.. | 38 | 27 | 99 | 13.2 |

1 Analyses performed by Kenneth Tanner, Ten Sleep, Wyo.
2 Test conducted using 22.5 grams of dry bentonite.

APPENDIX F

Laboratory Analyses of Gold Samples

Site 1

NW1/4 sec 28, T 5 N, R 5 W
roadcut on east side of Dinwoody Lake

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; ND = not detectable; cu yd = cubic yard; oz = ounce)

| Heavy sand concentrate, g | Gold, mg | Gold value, cents per cu yd |
|---|---|---|
| 11.64............ | ND | 0 |

NOTE.--A 1 cu ft sample was taken from a 3-foot-thick gravel bed in a glacial moraine. Gold price assumed to be $400 per troy oz of fine gold.

Site 2

sec 36, T 3 N, R 2 W
roadcut along old U.S. Highway 287

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; ND = not detectable; cu yd = cubic yard; NAp = not applicable; oz = ounce)

| Sample | Heavy sand concentrate, g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|---|
| Depth, ft: | | | |
| 0-1......... | 25.33 | 0.08 | 2.78 |
| 1-2......... | 28.77 | 0.02 | 0.69 |
| 2-3......... | 30.77 | 0.06 | 2.08 |
| 3-4......... | 38.71 | 0.12 | 4.17 |
| 4-5......... | 19.93 | 0.12 | 4.17 |
| 5-6......... | 29.14 | 0.04 | 1.39 |
| 6-7......... | 26.05 | 0.08 | 2.78 |
| 7-8......... | 57.09 | ND | 0.00 |
| 8-9......... | 53.35 | ND | 0.00 |
| 9-10......... | 26.58 | 0.06 | 2.08 |
| 10-11......... | 40.55 | 0.02 | 0.69 |
| Sluice box...... | 30.18 | 0.04 | 1.39 |
| Fire assay...... | NAp | 0.0031 | 0.0036 |

Total gold recovered, milligrams.........0.64
Average gold value, cents per cu yd.......................2.03

NOTE.--Samples were taken from 11 ft of pediment gravels capping a bench or terrace 2 miles south of and 475 ft higher than the present-day Wind River; samples were 1 cu ft each. Gold price assumed to be $400 per troy oz of 999 fine gold.

Site 3

S1/2 sec 3, T 1 S, R 1 E
face in gravel pit

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; cu yd = cubic yard; ND = not detectable; trace = less than 0.001 mg visible gold present; NAp = not applicable; oz = ounce)

| Sample | Heavy sand concentrate, g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|---|
| Depth, ft: | | | |
| 2-3........... | 61.84 | 0.084 | 2.92 |
| 3-4........... | 92.51 | 0.004 | 0.14 |
| 4-5........... | 85.91 | ND | 0.00 |
| 5-6........... | 34.86 | 0.04 | 1.39 |
| 6-7........... | 50.68 | ND | 0.00 |
| 7-8........... | 58.61 | ND | 0.00 |
| 8-9........... | 59.94 | 0.04 | 1.39 |
| 9-10.......... | 69.51 | ND | 0.00 |
| 10-11.......... | 46.81 | ND | 0.00 |
| Sluice box........ | 190.71 | 0.004 | 0.14 |
| Fire assay........ | NAp | trace | 0.00 |

Total gold recovered, milligrams.......0.172
Average gold value, cents per cu yd........................0.66

NOTE.--Samples were taken from 9 ft of pediment gravels capping a bench or terrace 2.5 miles south of and 140 ft higher than the Little Wind River. Two ft of overlying white clay and soil were not sampled. Samples were 1 cu ft each. Gold price assumed to be $400 per troy oz of 999 fine gold. "Gold" reported by gravel pit workers is mica.

Site 4

NW1/4 sec 36, T 4 N, R 4 W
Willow Creek, "West," 1.5 miles upstream,
southwest from U.S. Highway 287

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; cu yd = cubic yard; ND = not detectable; trace = less than 0.001 mg visible gold present; NAp = not applicable; oz = ounce)

| Sample | Heavy sand concentrate, g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|---|
| Depth, ft: | | | |
| 0-1......... | 20.70 | 0.004 | 0.14 |
| 1-2......... | 17.19 | 0.008 | 0.28 |
| 2-3......... | 61.22 | 0.044 | 1.52 |
| 3-4......... | 32.40 | 0.04 | 1.39 |
| 4-5......... | 24.55 | 0.04 | 1.39 |
| 5-6......... | 41.07 | ND | 0.00 |
| 6-7......... | 54.49 | 0.10 | 3.47 |
| 7-8......... | 48.94 | 0.02 | 0.69 |
| 8-9......... | 42.63 | 0.305 | 10.59 |
| 9-10......... | 36.22 | 0.06 | 2.08 |
| 10-11......... | 36.92 | 0.004 | 0.14 |
| 11-12......... | 39.91 | 0.04 | 1.39 |
| 12-13......... | 46.04 | ND | 0.00 |
| Sluice box...... | 63.25 | 0.016 | 0.04 |
| Fire assay...... | NAp | trace | 0.00 |

Total gold recovered, milligrams.......0.681
Average gold value, cents per cu yd........................1.82

NOTE.--Samples were collected from a streambed deposit having a thickness of more than 12 ft. Upper five samples were cut samples, others were taken from backhoe dipper. Bed rock was not reached. Legends claim this stream produced some gold. Samples were 1 cu ft each. Gold price assumed to be $400 per troy oz of 999 fine gold.

Site 5

NE1/4 sec 3, T 3 N, R 4 W
Willow Creek "West," 3.25 miles upstream,
southwest from U.S. Highway 287

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; cu yd = cubic yard; ND = not detectable; trace = less than 0.001 mg visible gold; NAp = not applicable; oz = ounce)

| Sample | Heavy sand, concentrate g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|---|
| Depth, ft: | | | |
| 0-4......... | 0.72 | ND | 0.00 |
| 4-6......... | 2.24 | 0.03 | 1.04 |
| Sluice box...... | 32.97 | ND | 0.00 |
| Fire assay...... | NAp | trace | 0.00 |

Total gold recovered, milligrams.......0.03
Average gold value, cents per cu yd.......................0.17

NOTE.--Samples were collected from a streambed gravel deposit that is more than 6 ft thick. First sample was 1 cu ft of the top 4 ft of gravel. Second sample was 5 cu ft of the lower 2 ft of hole. Inflowing water and caving walls resulted in this bizarre precedure. Gold value assumed at $400 per troy oz of 999 fine gold.

Site 7

SE1/4NW1/4 sec 35, T 7 N, R 3 E
Willow Creek, "North," 0.5 mile west of road north from Mexican Pass; not the same creek as sites 4 and 5

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; cu yd = cubic yard; ND = not detectable; trace = less than 0.001 mg visible gold present; NAp = not applicable; oz = ounce)

| Sample | Heavy sand concentrate, g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|---|
| Depth, ft: | | | |
| 0-1.......... | 3.82 | ND | 0.00 |
| 1-2.......... | 7.58 | ND | 0.00 |
| 2-3.......... | 8.33 | ND | 0.00 |
| 3-4.......... | 21.05 | ND | 0.00 |
| 4-5.......... | 9.76 | ND | 0.00 |
| 5-6.......... | 6.02 | ND | 0.00 |
| 6-7.......... | 3.04 | ND | 0.00 |
| 7-8.......... | 3.93 | ND | 0.00 |
| 8-9.......... | 7.14 | ND | 0.00 |
| 9-10......... | 3.46 | ND | 0.00 |
| 10-11......... | 6.88 | ND | 0.00 |
| Sluice box....... | 21.61 | ND | 0.00 |
| Fire assay....... | NAp | trace | 0.00 |

Total gold recovered, milligrams.........ND
Average gold value, cents per cu yd........................0.00

NOTE.--Samples were collected from an 11-ft-thick gravel bed in a stream draining the area of gold- and copper-bearing veins on the crest of the Owl Creek Mountains. Each sample was 1 cu ft. Pit bottomed on bed rock. Gold price assumed to be $400 per troy ounce of 999 fine gold.

Site 6

SE1/4NE1/4 sec 2, T 3 N, R 5 W
Meadow Creek, 6.5 miles southwest of Crowheart
store on U.S. Highway 287

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; cu yd = cubic yard; ND = not detectable; trace = less than 0.001 mg visible gold; NAp = not applicable; oz = ounce)

| Sample | Heavy sand concentrate, g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|---|
| Depth, ft: | | | |
| 0-1........ | 0.31 | ND | 0.00 |
| 1-2........ | 0.74 | ND | 0.00 |
| 2-3........ | 1.00 | ND | 0.00 |
| 3-4........ | 0.77 | ND | 0.00 |
| 4-5........ | 0.71 | ND | 0.00 |
| 5-6........ | 0.34 | ND | 0.00 |
| 6-7........ | 1.06 | ND | 0.00 |
| 7-8........ | 0.80 | ND | 0.00 |
| 8-9........ | 2.23 | ND | 0.00 |
| Sluice box..... | 1.75 | ND | 0.00 |
| Fire assay.. .. | NAp | trace | 0.00 |

Total gold recovered, milligrams.......ND
Average gold value, cents per cu yd......................0.00

NOTE.--Over 9 ft of streambed gravels occur at this site. Each sample was 1 cu ft. Gold price assumed to be $400 per troy ounce of 999 fine gold.

Site 8

SE1/4NW1/4 sec 36, T 5 N, R 2 E
roadcut 0.75 mile northeast of siphon where
Wyoming Canal crosses Muddy Creek

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; cu yd = cubic yard; ND = not detectable; trace = less than 0.001 mg visible gold present; NAp = not applicable; oz = ounce)

| Sample | Heavy sand concentrate, g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|---|
| Depth, ft: | | | |
| 0-3......... | 5.11 | 0.14 | 4.86 |
| Sluice box...... | 6.71 | 0.08 | 2.78 |
| Fire assay...... | NAp | 0.004 | 0.14 |

Total gold recovered, milligrams.......0.22
Average gold value, cents per cu yd.......................7.64

NOTE.--Sample collected from a gravel bed that is up to 3 ft thick and caps a bench or terrace throughout several sections. The terrace is about 20 miles west of Boysen Reservoir and about 770 ft higher in elevation. Sample was 1 cu ft cut across entire 3 ft thickness of the bed. Gold price assumed to be $400 per troy oz of 999 fine gold.

Site 9

SW1/4SW1/4 sec 28, T 1 N, R 1 W
gravel pit 1.5 miles north of Fort Washakie

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; cu yd = cubic yard; ND = not detectable; trace = less than 0.001 mg visible gold present; NAp = not applicable; oz = ounce)

| Sample | Heavy sand concentrate, g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|---|
| Depth, ft: | | | |
| 0-2......... | 62.82 | 0.02 | 0.69 |
| 2-4......... | 64.42 | ND | ND |
| 4-6......... | 148.88 | 0.04 | 1.39 |
| 6-8......... | 141.39 | ND | ND |
| 8-10........ | 97.02 | ND | ND |
| 10-12........ | 158.44 | ND | ND |
| 12-14........ | 81.94 | ND | ND |
| Sluice box...... | 463.60 | ND | ND |
| Fire assay...... | NAp | 0.0063 | 0.03 |

Total gold recovered, milligrams........0.066
Average gold value, cents per cu yd........................0.33

NOTE.--Samples were taken from a 14-ft-thick pediment gravel deposit capping a bench or terrace 1 mile north of and 260 ft higher than the Little Wind River. One cu ft was taken for every 2 ft of thickness. Gold price assumed to be $400 per troy ounce of 999 fine gold.

## Site 10

sec 22, T 5 N, R 3 W
about 0.25 mile northwest of drill site

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram;
cu yd = cubic yard; oz = ounce)

| Heavy sand concentrate, g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|
| 10.08 | 0.28 | 9.72 |

Note.--The sample was 1 cu ft of material that had weathered from a 3-ft-thick lens of comglomerate in the Wind River Formation. Gold price assumed to be $400 per troy oz of 999 fine gold.

## Site 11

SE1/4 sec 8, T 4 N, R 3 W
3.5 miles northeast of Crowheart store on Highway 287

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram;
cu yd = cubic yard; NAp = not available; oz = ounce)

| Sample | Heavy sand concentrate, g | Gold, mg | Gold values, Cents per cu yd |
|---|---|---|---|
| Depth, ft: | | | |
| 0-2......... | 48.98 | 0.576 | 20.00 |
| 2-4......... | 78.69 | 0.4512 | 15.67 |
| 4-6......... | 39.02 | 0.3648 | 12.67 |
| Sluice box...... | 26.38 | 0.0192 | 0.67 |
| Fire assay...... | NAp | 0.0098 | 0.00 |

Total gold recovered, milligrams......1.42
Average gold value, cents per cu yd. ....................16.44

NOTE.--Samples were taken from a bench or terrace deposit 1.25 miles northeast of and 280 feet above the Wind River. The deposit covers several sections. One cu ft of sample was cut for each 2 ft of gravel thickness. Gold price assumed to be $400 per troy oz of 999 fine gold.

Site 12

NE1/4SE1/4 sec 6, T 5 N, R 3 E
Cottonwood Creek, 3.25 miles southwest of Jenkins Mountain

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; cu yd = cubic yard; ND = not detectable; trace = less than 0.001 mg visible gold present; NAp = not applicable; oz = ounce)

| Sample | Heavy sand concentrate, g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|---|
| Gravel lens; depth, ft: | | | |
| 0-2......... | 5.76 | 0.081 | 2.78[1] |
| Stream deposit; depth, ft: | | | |
| 0-1......... | 4.21 | 0.044 | 1.53 |
| 1-2......... | 4.59 | 0.004 | 0.14 |
| 2-3......... | 7.60 | 0.008 | 0.28 |
| 3-4......... | 8.60 | 0.016 | 0.56 |
| 4-5......... | 10.45 | 0.02 | 0.69 |
| 5-6......... | 5.98 | ND | 0.00 |
| 6-7......... | 3.95 | ND | 0.00 |
| 7-8......... | 5.59 | ND | 0.00 |
| Sluice box...... | 11.26 | 0.012 | 0.60 |
| Fire assay...... | NAp | trace | 0.00 |

Total gold recovered, milligrams......0.104
Average gold value, cents per cu yd.......................0.45

[1]Values for this sample are not included in the total gold recovered and average gold values for site 12, owing to the small size of the lens.

NOTES.--One deposit is a 2-ft-thick gravel lens in the bottom of the clayey sand embankment that forms the eastern side of the creek. The other is an 8-ft-thick, sand and stream-gravel deposit forming a bar near the edge of the present channel on the western side of the creek. Samples from the gravel lens were 1 cu ft per 2 ft of depth. Samples from sand and stream-gravel deposit were 1 cu ft per 1 ft of depth. Bedrock was reached. Gold price assumed to be $400 per troy ounce of 999 fine gold.

Site 13

NE1/4NE1/4 sec 6, T 4 N, R 3 E
2 miles east of siphon where the Wyoming Canal crosses Muddy Creek

(ft = foot; g = gram; cu ft = cubic foot; mg = milligram; cu yd = cubic yard; NAp = not applicable; oz = ounce)

| Sample | heavy sand concentrate, g | Gold, mg | Gold values, cents per cu yd |
|---|---|---|---|
| Depth, ft: | | | |
| 0-1......... | 4.40 | 0.024 | 0.83 |
| 1-2......... | 8.95 | 0.104 | 3.61 |
| 2-3......... | 5.67 | 0.112 | 3.89 |
| 3-4......... | 7.43 | 0.024 | 0.83 |
| 4-5......... | 7.63 | 0.024 | 0.83 |
| 5-6......... | 6.77 | 0.032 | 1.11 |
| 6-7........ | 9.71 | 0.12 | 4.17 |
| 7-8......... | 5.10 | 0.008 | 0.28 |
| 8-9......... | 8.46 | 0.004 | 0.14 |
| 9-10........ | 4.56 | 0.02 | 0.69 |
| Sluice box...... | 13.03 | 0.112 | 3.89 |
| Fire assay...... | NAp | 0.0102 | 0.04 |

Total gold recovered, milligrams........0.594
Average gold value, cents per cu yd...................... 2.06

NOTE.--Samples were taken from a pediment gravel deposit that is more than 10 ft thick and caps a bench or terrace throughout several sections. Samples were 1 cu ft per ft of depth. Gold price assumed to be $400 per troy oz of 999 fine gold.

Evaluation of Bentonite and Gold Resources on the Wind River Indian Reservation, Wyoming

R 58

WYOMING STATE GEOLOGICAL SURVEY 1933

*Geology -- Interpreting the past to provide for the future*