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BENTONITE DEPOSITS OF THE YELLOWTAIL DISTRICT MONTANA AND WYOMING

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MONTANA AND WYOMING

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INTRODUCTION

The Cretaceous sedimentary rocks of the western interior of the United States contain extensive deposits of bentonite, a valuable rock material consisting essentially of clay that has resulted from alteration of volcanic ash. Unusually thick beds of bentonite crop out in a belt of plains that skirts the northeast flank of the Bighorn Mountains in Montana and Wyoming. In some localities these beds are more than 15 feet thick. A segment of this belt lying mostly in the Crow Indian Reservation, in Big Horn County, Montana, but extending for a short distance into the adjacent part of Wyoming, may appropriately be referred to as the Yellowtail district because it includes land along the Bighorn River that is involved in the U. S. Bureau of Reclamation's Yellowtail project for electric power development, irrigation and flood control.

Large deposits of bentonite are present in the Yellowtail district at many sites where mining may be feasible; some of these deposits contain clay that may be suitable for industrial use. Because they are of interest to the clay industry, to the Bureau of Reclamation, and to the Indians of the Crow Reservation, the bentonite deposits within two somewhat arbitrarily delimited tracks northeast of the Bighorn Mountains (Fig. 1) have been the subject of a study by the Geological Survey as part of the program of the Department of the Interior for development of the Missouri River Basin. These two tracts lie mainly in Big Horn County, Montana, but include about 8 square miles in Sheridan County, Wyoming. The general geology of part of the district is shown on a recently-published map by Richards and Rogers (1951).

Generous cooperation the authors have received from R. E. Grim, of the Illinois Geological Survey, and H. G. Fisk of the University of Wyoming Natural Resources Research Institute, has added substantially to the value of the laboratory test data presented in this report.

In studying the bentonite beds of the Yellowtail district, where in recent years a small tonnage has been mined by stripping, attention has been given primarily to their stratigraphic positions, thicknesses, geologic structural relations, accessibility, and content of material that might be suitable for industrial use. In general, bentonite beds of this region range in thickness from a few inches to more than 15 feet.

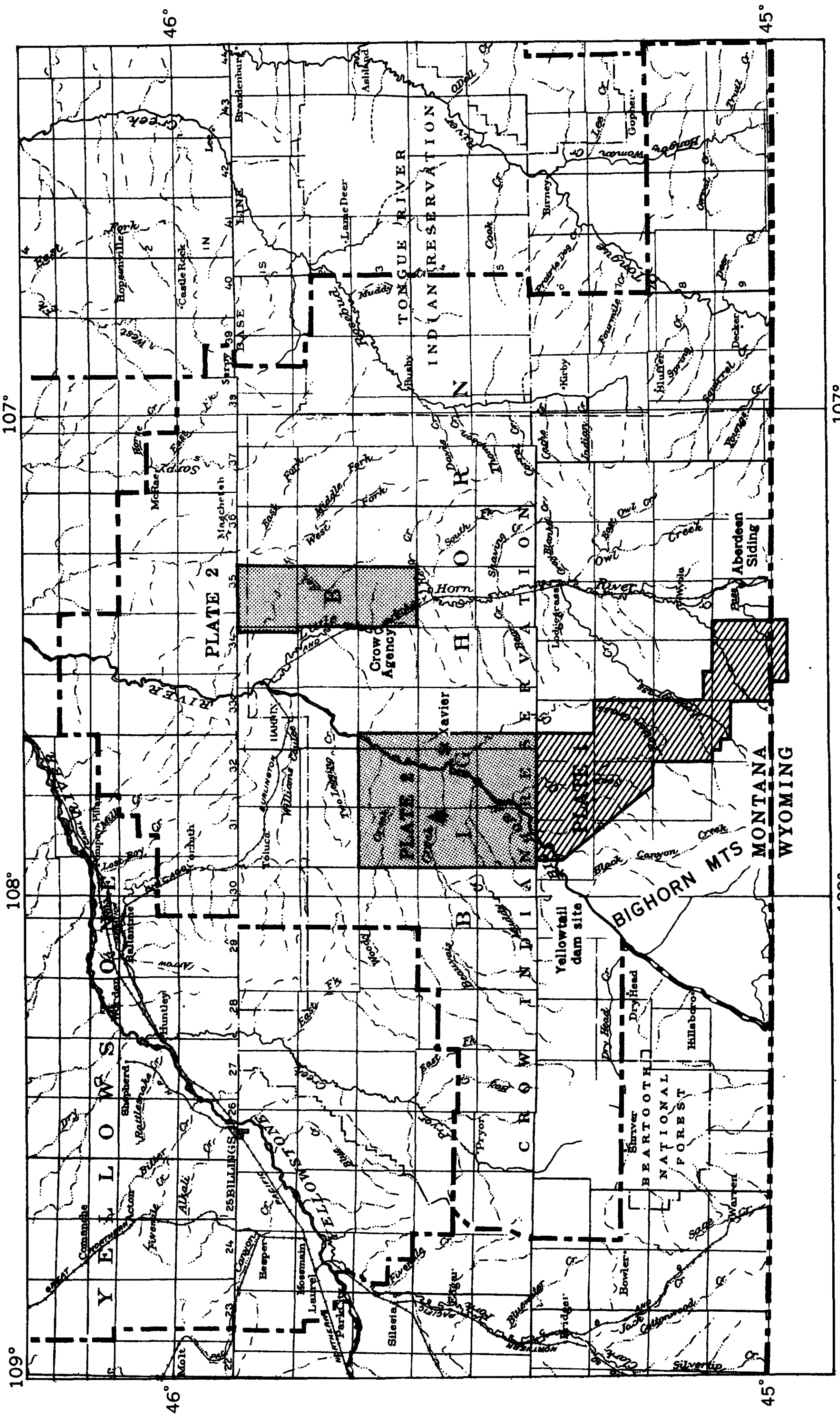

Figure 1. Map of parts of Montana and Wyoming showing the location of areas of Plates 1 and 2.

Locally one bed attains a thickness of 45 feet owing to flowage, and other unusual thicknesses may be due to flowage or swelling. As a rule, beds averaging less than 3 feet in thickness cannot be mined profitably and thinner beds are therefore not included in the estimates presented in this report.

The beds of minable thickness are interspersed among strata (pl. 1, fig. 2) that belong to Cretaceous formations ranging from the Thermopolis shale upward to the Bearpaw shale. A bed in strata that are equivalent to the Frontier formation and the Belle Fourche member of the Cody shale, another in the Greenhorn calcareous member of the Cody shale, and two beds in the Bearpaw shale are extremely thick locally and are favorably situated for mining along some parts of their outcrops.

The beds of minable thickness that are exposed within the area studied are estimated, roughly and tentatively, to contain a total of more than 90,000,000 short tons of bentonite lying in belts more than 50 feet wide under less than 30 feet of overburden. How much of this material conforms to present specifications for commercial bentonite can be determined only in a general way from data based on the small number of samples so far tested for useful properties. Preliminary tests nevertheless suggest that all of the beds contain some bentonite that would be suitable for use as foundry clay and the available tonnage of such material is believed to be large. Some of the bentonite of this district also could be used as an ingredient of drilling mud, although it is probably not in general so well suited to that role as are the best grades of drilling clay mined in the Black Hills district.

TYPES OF BENTONITE AND MINERAL CONTENT

The bentonites of the Yellowtail district belong in general to the gel-forming types, though they differ considerably, from bed to bed and at different places, in their behavior toward water. Results of differential thermal analyses, performed with a portable apparatus by Elizabeth Fischer of the Geological Survey (informal communication, (1947) on several samples collected during the present investigation, indicate that the bentonite deposits of the Yellowtail district consist predominantly of the clay mineral montmorillonite. Small amounts of other minerals - most commonly mica, feldspar, quartz, glass shards, calcite, gypsum and soluble alkaline salts - are disseminated through the clay.

Most of the bentonite has a waxy consistency, and granular or other non-waxy textures are commonly restricted to layers near the top and base of the light-colored material. Tiny but plainly visible residual particles of non-clay minerals, many of which are dark, are present in all the beds and are referred to collectively as "grit" by producers and buyers of bentonite. The content of grit varies greatly from layer to layer, some layers showing conspicuous amounts, others little or none.

The floor of most of the bentonite beds is marked by a sharp contact with the subjacent shale, which is locally silicified just below the bentonite to form a thin, hard, cherty layer. In general, the roof is less definite and the bentonite of the upper part of the bed ordinarily grades through an indistinct zone of dark bentonitic shale into the overlying bedrock, which is most commonly dark gray shale. Ordinarily the bentonite bed itself is made up of a number of clay layers which differ from one another in one or more characteristics such as color, texture or colloidal properties.

CHARACTERISTICS OF OUTCROPS

The freshly exposed bentonite ranges in texture from essentially homogeneous, firm, waxy clay to loosely-compacted granular material, some of which resembles corn meal. When freshly exposed in mine excavations and prospect openings, much of the bentonite quickly crumbles to grains, flakes and lumps of various sizes and shapes. The ground in the vicinity of the bentonite exposures is commonly littered with residual fragments of selenite and calcite or aragonite and, in a few places, with conspicuous large limestone concretions that appear to have formed within certain bentonite beds. During rainy periods, bentonite of moderate to high swelling capacity soaks up many times its own volume of water, swells and becomes a slippery thixotropic gel. On drying, the swollen clay contracts nearly to its original volume, and in so doing cracks up to form a peculiar popcorn-like rubble. In general, the bentonite beds resist weathering and erosion to a slightly greater degree than the enclosing Cretaceous shales and therefore tend to stand out as conspicuous hillside ledges and buttresses.

THICKENING OF BEDS BY SUBSURFACE FLOWAGE

The bentonite beds have locally become thickened by subsurface flowage of the bentonite, which is softer and more plastic than the enclosing bedrock. Differential loading may have caused the flowage. Many of the measurements of bentonite beds recorded in the present report were obtained along outcrops at which the thickness may have been altered by flowage. However, these measurements are regarded as representative of the thicknesses that would be found in the vicinity in mining within a 30-foot overburden limit.

EFFECTS OF WEATHERING UPON COLOR AND COLLOIDAL PROPERTIES

The prevailing hues shown by most outcrops of the light-colored material of the bentonite beds are olive-green, cream and drab, representing discoloration of the bentonite upon exposure. Where the beds pass under more than a few yards of cover, such colors are ordinarily supplanted by shades of bluish-gray or nearly white which predominate in subsurface sections of the light-colored material. The discoloration, which is thus associated with exposed parts of the beds, is an effect of weathering.

In the Black Hills district weathering of the bentonite is associated with an apparent enrichment of its valuable colloidal properties. A rule employed by the miners holds that, with few exceptions, bentonite under more than 30 or 40 feet of overburden and generally bluish gray has little or no commercial value, whereas bentonite at shallower depth, which is largely discolored, includes much highly colloidal clay that may be mined at a profit. The data at hand do not reveal the extent to which this rule may be applicable in the Yellowtail district.

Experiments performed by Margaret D. Foster of the Geological Survey (written communication, 1948) on samples from the Black Hills district that were collected for the present study confirm the generally held view that the discoloration of the bentonite beds that takes place as they are weathered at their outcrops is due chiefly to oxidation, from the ferrous to the ferric condition, of small amounts of iron in the clay. Undiscolored bentonite, when allowed to weather in the laboratory over a period of eleven months, became distinctly discolored as the iron rapidly oxidized. Weathering during the 11-month period also resulted in an appreciable increase in the swelling capacity of the bentonite.

UTILIZATION

Some bentonites have peculiar physical properties that make them of value to the petroleum, foundry, pharmaceutical and other industries. The upper part of the Missouri River basin, including the part lying in Canada, contains much bentonite of the kind customarily called "Wyoming" or "Black Hills" type, characterized by an extraordinary ability to absorb water, and thereupon to "swell" enormously, and by its ability to stay in suspension permanently when thinly dispersed in water. The bentonite deposits of the Missouri River Basin contain much material that is well suited for use as a bond in foundry moulding sand, and they also contain most of our known resources of bentonite having properties, discussed elsewhere, that are essential for its use in preparing rotary well-drilling mud.

Most of the bentonite that is produced in the vicinity of the Black Hills and other localities in Wyoming is sold for these two purposes and the rest is marketed for a variety of other industrial uses. At the time of writing, however, very little of the bentonite of this region has been found to be suitable for use by the oil refineries which obtain their supplies for catalyzing, filtering and decolorizing petroleum products mainly from the southern and southwestern States.

The percentages of available alumina in clays derived directly from volcanic materials and consisting essentially of montmorillonite are, as pointed out by Allen (1946, p. 124), generally low as compared with the alumina content of certain clays of different origin. This is no doubt true of the bentonite deposits of the Yellowtail district, inasmuch as they are composed largely of montmorillonite. It seems unlikely, therefore, that these deposits will ever be worked for their alumina content.

LABORATORY TESTS AND RESULTS

Modern research procedures employed in determining the identity, character and mode of origin of clays include differential thermal analysis, X-ray diffraction and electron microscope studies, optical examination, base-exchange experiments and chemical analysis. These diverse means have yielded a large amount of information concerning the composition, geochemistry and petrology of bentonite and related clay materials, much of which has been summarized by Ross and Hendricks (1945). Resulting new concepts of the composition and crystalline structure of clays have suggested reasonable explanations for some of the distinctive properties of bentonites that determine their commercial value.

Nevertheless, most actual testing of bentonite for its various uses is empirical. Results of such tests indicate that although the bentonite deposits of the Yellowtail district include much potentially valuable material, some of it is deficient in the physical properties that give commercial value to bentonites. This result was to be expected as bentonite of different beds, and even of different places within the same bed, commonly differs greatly with respect to such properties.

Significance of the bonding tests

The results of bonding tests of samples of bentonite from the Yellowtail district are summarized in the table (Table 1). For comparison, results of tests on a sample of a commercial bonding bentonite mined near Belle Fourche, South Dakota, and on twelve other samples collected from the Black Hills district are given. The twelve samples from the Black Hills include some material that is probably of little value as foundry clay and, as the commercial clay tested conforms to no established standard, samples that do not appear to compare favorably with it may nevertheless have valuable bonding properties. Also, only four percent of clay by weight was used for all the bonding tests made in this investigation and, both the green and dry strength of samples appearing weak would be much greater if six or eight percent of clay were used. Although there are no established bonding strength requirements for clays of this type, samples from the Yellowtail district that have green compression strength of at least 8 pounds per square inch with more than 1. 2 percent of tempering water and dry compression strength of at least 50 pounds per square inch with 2 percent or less tempering water present, appear to compare favorably with most bentonite that is produced for foundry bonding purposes.

Preliminary tests of the bentonites of the Yellowtail district confirm the conclusion (Grim and Cuthbert 1945, p. 11) that bentonites attain their maximum green strength at definite percentages of moisture content. The moisture requirements for maximum green strength vary somewhat but all samples tested attained their greatest green strength with between 1. 2 and 1. 6 percent of tempering water present.

Several samples with low dry strength proved to have exceptionally high green strength, and most of those having exceptionally high dry strength possessed only average green strength. This apparently inverse relation between green and dry strength is not well understood but, as both types of bentonite occur in the Yellowtail district, the possibility of blending may increase the economic potentialities of both.

Results of the tests suggest that most of the bentonite sampled in this district meets requirements for synthetic foundry molding and bonding material with respect both to green and dry strength and essentially all of the material that is not thus doubly endowed gives satisfactory tests either for green or for dry strength. Probably large amounts of clay that would satisfy most of the ordinary requirements for foundry use can be obtained at many localities along the outcrops of bentonite beds that are shown on the accompanying maps. However, evaluation of bentonite deposits as sources of foundry sand bonding clay is largely a problem of economics. Most of the bentonite that is produced in the Missouri River basin for sale to foundries is transported hundreds of miles to industrial centers where it must compete with other types of clay that can be delivered to the foundries at much lower cost. Almost always bentonite is used as the bonding material where exceptionally high strengths are required in foundry molds, but in ordinary practice the desired results are often obtained by using larger amounts of inferior clays. To compensate for the high transportation costs and still compete successfully with cheaper clays, a bentonite must be a very efficient bonding clay. Consequently the producers of foundry bentonite select for shipment only clay having exceptionally high bonding strength. No doubt nearly all of the bentonite available for mining in the Yellowtail district would satisfy ordinary foundry requirements, but probably not more than two thirds of it has the exceptionally high quality demanded by present markets for bonding clay produced in the Missouri River basin.

Significance of the drilling-mud tests

Many types of clay, mixed with other materials, are used in rotary well-drilling fluids, preparation of which has become a specialized field. Because of its highly colloidal nature, some of the bentonite of the Missouri River basin that has high swelling capacity is much in demand for use as one of the ingredients.

The results of tests for swelling, viscosity, yield, gel strength (thixotropy), wall-building capacity and grit content that are set forth in the table (Table 1) indicate that much of the bentonite of the Yellowtail district can be used in preparation of drilling mud, and some is better than much of the bentonite obtained for that purpose in the vicinity of the Black Hills. Much material that is below commercial grade can nevertheless be made to serve by using slightly larger amounts than are required when the better grades are employed.

Swelling capacity. --All bentonites that are regarded as highgrade drilling-mud material possess in marked degree the characteristic propensity of the "Wyoming-type" material to absorb water and thereupon to "swell". However some bentonites having ample swelling capacity lack some of the other essential properties of good drilling-mud material. Swelling tests were therefore made on all of the samples under investigation and those with moderate or high swelling capacity were selected for further testing of their suitability for use as drill-mud material. The procedure outlined in the American Colloid Company's Data Sheet no. 251 was followed in making the swelling tests. In this procedure, a two gram sample of the ground and dried bentonite is added slowly to distilled water contained in a graduate. The volume of the resulting gel, in milliliters, is herein referred to as the "swelling capacity".

A swelling capacity of at least 20 ml was somewhat arbitrarily chosen in selecting clays to be tested further for use in drilling mud, although a few other samples were tested for viscosity, yield, gel strength and wall-building capacity. Most samples that swell to less than 20 ml represent drilling-mud material inferior to that now in demand, and were not considered worth further testing. Perhaps some inferior materials could nevertheless be used for the purpose under special conditions such as might exist if wells were being drilled close to the bentonite deposits, where the disadvantage of having to use larger amounts would be more than offset by reduction of transportation costs.

Viscosity. --The viscosity of a fluid, which is usually expressed in centipoises, has been defined as a measure of its internal resistance to flow. This important property of drilling fluids has been measured in the present investigation by means of a Stormer viscometer. As the viscosity of suspensions in water of any individual clay is subject to variation in response to difference in the proportions of clay to water used in their preparation, test data on the viscosity of suspensions of different clays are readily comparable only when these proportions are the same for each suspension. Viscosity measurements of a six-percent-by-weight suspension have therefore been made and are given in the table for each of the samples from the Yellowtail district that have been tested for use in drilling mud. For each of these samples, also, the viscosity of two or more suspensions containing random percentages of clay was measured and results for two of these additional suspensions are also given. The additional measurements were made primarily to obtain data for computing yield by the method to be described below, but the results of the three measurements given for each sample are also indicative of the amount of change in the viscosity of each suspension that results from known variations in its content of clay.

Yield. --The term yield, as employed by producers of bentonite in describing their product, denotes the number of barrels of a slurry of specified viscosity that can be prepared from a short ton of clay; a viscosity of 15 centipoises is generally accepted as a standard for comparative yield determinations and was used as a basis for the determinations set forth in the table. In general, clays showing satisfactory yield also possess most of the other properties that are considered desirable in clay material to be sold for use in drilling mud.

Gel strength (thixotropy). -- "Wyoming-type" bentonite when mixed with water, forms a fluid that becomes a jellylike mass if left undisturbed for a short period but again becomes fluid when agitated. Such an isothermal reversible transformation from a fluid to a gel is referred to as thixotropy or gelling. As indicated by Stern (1941, p. 371), the ability of "Wyoming-type" bentonites to form a strong gel is not considered as important as it once was, though it is still a much-desired property. The function of thixotropy in drilling fluids is primarily to prevent weighting material and cuttings from settling in the hole when the drill pipe and mud-circulating system are not in motion. Nearly all of the clays from the Yellowtail district that are shown by the tests to have the viscosity and wall-building properties of good drilling-mud material also show satisfactory gel strength.

Wall building. --Some of the "Wyoming-type" bentonites of high-swelling capacity are the most effective of all known drilling-mud materials for forming a thin impervious layer, or "wall", on the sides of holes bored with rotary well-drilling equipment. This wall tends to reduce water-loss from the mud, thus permitting greater control over viscosity, and to prevent cave-ins which sometimes occur when soft rock materials absorb moisture from drilling fluids. The wall-building propensities of samples from the Yellowtail district that swelled to more than 20 mls. were tested with the aid of a low-pressure filter press in accordance with the procedure outlined by the American Petroleum Institute.

Content of non-clay material. --In estimating the percentages of material other than clay minerals present in the bentonites listed in the table, each of the ground samples was examined microscopically, employing the immersion liquid method. Because of the great variety of minerals in the non-clay material, the estimates are based on volume and not weight.

Whiteness

Many of the samples were white or nearly white when pulverized, a primary requirement for bentonite that is to be used in pharmaceutical preparations, for paper filling and for many other purposes. Both high- and low-swelling materials are in demand for the varied uses of white bentonite and the amount of swelling of these white samples covers a broad range. Samples that were white when ground are indicated on the table.

OUTLOOK FOR MINING

A small bentonite processing plant, the only one in Montana, has been in operation since 1946 at Aberdeen siding, 6 miles south along the railroad from Wyola. Bentonite is obtained from a small strip mine in Wyoming on the north side of Gay Creek, close to the Montana state line. Crude oil is used as fuel at this plant. Electric power for the operation of additional bentonite processing plants in the future may be available at the Yellowtail dam, which is to be constructed by the U. S. Bureau of Reclamation across the canyon of the Bighorn River 35 miles southwest of Hardin, Montana.

Nearly all of the bentonite that has been mined in the principal producing districts of Wyoming and South Dakota has been taken from the Clay Spur bentonite bed, in the topmost strata of the Mowry shale. This bed is believed to have been recognized in the Yellowtail district, but it is not here present in situations where mining would be profitable, and consequently the possibility of producing bentonite in this district must depend upon the potentialities of other beds.

Though bedrock containing thick bentonite deposits crops out extensively in this district, the deposits are ordinarily somewhat obscured by surficial debris and trenching or hand-boring is required for accurate measurement of their thicknesses and for sampling the clay.

The bedrock above and below almost all of the bentonite beds is shale. That just above the beds can generally be removed by stripping with bulldozers or other heavy equipment. The hard, chert-like, silicified shale of the floor below some beds should facilitate loading the bentonite with draglines or power shovels without admixture of the underlying material.

In the present investigation the search has been directed primarily toward the discovery of beds comparing favorably in thickness and quality with the Clay Spur bentonite bed mined in the Black Hills district of Wyoming and South Dakota; the thickness of the Clay Spur bentonite bed there ranges from 1½ to 5 feet. In the Yellowtail district attention has been directed largely to beds averaging 3 feet or more in thickness, but thinner beds have been measured and sampled at some places. A few of the beds are persistent and can be traced for considerable distances, but their thicknesses may vary considerably from place to place. Some of the beds are lens-shaped and crop out locally with great thickness only to pinch out completely within a few miles. In some outcrops the typical light-colored bentonite passes laterally into dark bentonitic shale which grades in turn into shale like that of the enclosing bedrock.

Outcrops of bentonite beds comparing favorably in thickness with the deposits that are mined in the Black Hills district are mapped on Plates 1 and 2. in relation to the geologic structure. For each of these beds the approximate areal extent of bentonite deposits present under light overburden also is indicated. For any bed the bentonite between the line of outcrop and a roughly-sketched subsurface line along which the overburden upon the deposits is estimated to be 30 feet is considered to be well within the reach of strip-mining. The significance of this line in relation to estimates of tonnages of clay available for mining is commented upon elsewhere in this report. The shallow deposits thus outlined underlie belts of land that tend to be elongated approximately in the directions of strike of the beds and these belts vary in width because of change in the dip of the bentonite beds and irregularities of the land surface. Accordingly, the belts underlain by shallow deposits tend to be widest, and to offer the most promising strip-mining sites, where the beds are horizontal, or nearly so, and where the slope of the land is gentle.

In several wide tracts along the axial portions of folds the dip of the rock strata is prevailingly gentle. In some of these tracts thick bentonite beds crop out in areas of many acres in which the land slopes gently as, for example, in some parts of the syncline extending across T. 7 S., R. 32 E. Here they are largely under light cover of the superjacent bedrock and, as this consists generally of soft shale that could easily be removed, large amounts of bentonite could be mined in such areas by stripping methods. However, in some belts on the flanks of folds, the bentonite beds are steeply inclined as, for example, near the base of the Big Horn Mountains in T. 5 S., R. 30 E. In such belts a bed could be mined only in a narrow strip along its outcrop and would yield relatively little bentonite.

RESERVES

The estimated reserves of bentonite in the Yellowtail district in deposits of minable thickness beneath less than 30 feet of overburden in belts more than 50 feet wide, assuming bulk density of crude bentonite to be 100 pounds per cubic foot, is about 90,000,000 tons.

Although the bentonite included in the estimate of reserves conforms only in part to current specifications for commercial bentonite, probably increasing amounts of it will meet revised specifications that can be expected as technology improves. More detailed determinations of the reserves of bentonite conforming to current specifications can be made when test data based on more detailed sampling than is represented by the widely scattered points given in the table become available. The estimates also can be improved when more precise data are available on other such important factors as the bulk density of bentonite and the thickness of bentonite and overburden back of outcrops of the beds. Reserves of bentonite, unweathered and mostly of submarginal grade, beneath a cover of 30 to 60 feet of overburden may amount to two or three times the reserves given above.

One of the most critical assumptions involved in the estimates has to do with the bulk density of the clay material. In arriving at these estimates, the bulk density of crude, unmined bentonite, with its large content of moisture, was taken, somewhat arbitrarily, to be 100 pounds per cubic foot, which is the figure employed by at least one of the companies producing bentonite in the Black Hills district. A volume of 20 cubic feet of clay is thus assumed to be equivalent to one short ton, whereas that volume of dry bentonite is computed to weigh approximately 1.34 short tons on the basis of a specific gravity of 2.155 postulated as falling midway between the limits, 2.13 to 2.18, given by George (1943, p. 364) for bentonites in general. Actually the bulk density varies from place to place and from bed to bed, mainly because of inequalities in the amount of moisture contained in the clay, which frequently makes up as much as 45 percent of the weight. Also, the tonnages given do not take into account a large aggregate quantity of accessible clay present in this district at sites at which the belt of material under less than 30 feet of overburden is less than 50 feet wide.

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