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M. Q. SHARPE, Governor

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A GEOLOGY *of* SOUTH DAKOTA

PART III
MINERAL RESOURCES

by
E. P. Rothrock

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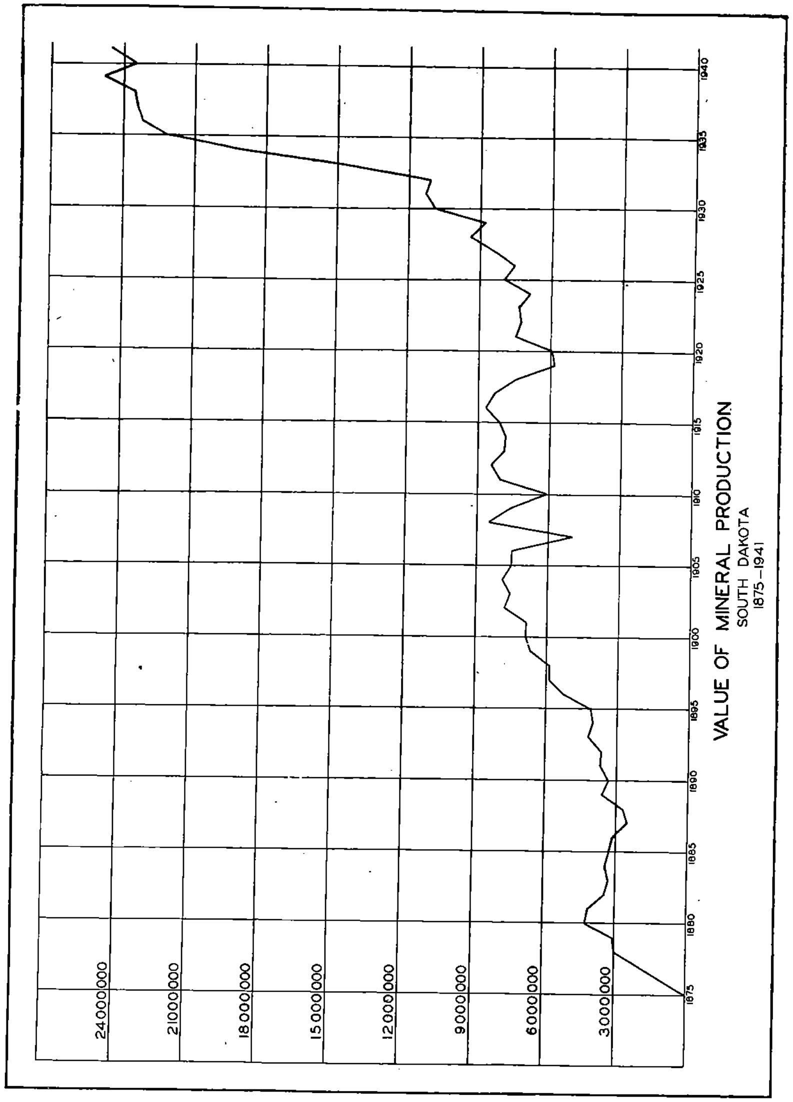

INTRODUCTION

South Dakota has been a mineral producing state since 1874 when gold was discovered in the Black Hills. Since that time, however, mineral production has spread till there is no part of the state that is not affected by the production or use of mineral products. Some products, like the metals, are useful for their monetary value, while others like fuels and water supplies are valuable because they offer materials needed to make living and working in South Dakota easier. The problem of mineral development is not solely a question of how much can be mined and sold, but also how much can be used, and of methods of conserving certain resources so that they will serve as long as they are needed.

The total income from mineral production has increased steadily during the history of the state and has reached the point where an appreciable portion of the population depends on it for a living. Starting as a series of roistering gold camps in the Black Hills, the industry has spread to include the production of rare metals, fuels, building and ornamental stone, crushed stone, sands and gravels, the ceramic materials, clay, and feldspar, and some miscellaneous materials used locally and for export. South Dakota's mineral deposits are, however, still poorly developed, and many are lying unused, waiting either for market demand or for human initiative to put them to use.

Any attempt to make a complete list of the possible mineral resources of South Dakota would end in failure because of the changing demands of industry for mineral products and the delicate balance between profitable and unprofitable mineral operation. A few years ago experimentation with filaments for radio tubes showed that caesium had decided advantages over the ordinary metals, producing certain characteristics. Immediately caesium became an important mineral resource and much money and effort was spent in trying to find a supply. Before the supply came into production, however, it was discovered that certain tungsten alloys would produce the same characteristics, and caesium again became just an interesting metal with no market value. Small changes in mining or metallurgical practices make it possible to use lower grade deposits than were thought practicable, and such deposits immediately became ores. The fortunes of the recent war show how quickly the demand for a mineral deposit can be created and lost.

Political expediency, slight economic and geographic advantages, all play a part in determining whether a state's mineral deposits will be exploited. Thus the commercial value of any metal deposit depends upon a rather delicate balance of factors. The size of a deposit and the percentage of values it can produce are of prime importance. This, however, is much tempered by the economic considerations of location, cost of extraction, and competition.

All of these factors are further modified by the factor of human industry, managing ability, and capitalization. In some cases a very poor deposit may be made into a producing mine, while in other cases a very high grade deposit may net its developers nothing. A good example of this balance was afforded when the price of gold was raised, allowing many low grade deposits, which had been lying idle, to be put into production. Since this condition exists in the mining industry, this compilation will attempt to set down only such materials as have proved valuable in the past economy of the State or seem to offer some chance for development in the near future and under the conditions that probably will prevail during our generation.

Few states offer as large a variety of mineral products as South Dakota. They include representatives of nearly every large group of mineral products. Metals are represented by commercial gold and silver, some shows of iron, lead, copper, zinc, and manganese, and the rare metals, lithium, beryllium, tungsten and tin, and caesium. Fuels are represented by large deposits of lignite coal, small gas shows, and petroleum as shale oil and possible pool oil. Ceramic materials and clays are abundant and some unusual ones are in production. Structural and ornamental stone, and sand and gravel form a substantial part of the State's industry. Water supplies are one of the State's most important resources. They have been brought sharply to our attention since the last drouth, by difficulties encountered in supplying agricultural, industrial and municipal needs.

In order to obtain organization in the description of such

a variety of products, it will be best to group them under the following headings:

I Metals
II Fuels
III Structural Materials
IV Clays and Ceramic Materials
V Miscellaneous Minerals Products
VI Water Supplies

DIVISION I METALS

The metals that have been produced in South Dakota have all come from the central part of the Black Hills. This is due in part to the fact that it is a region where there was a great deal of volcanic activity in the past, and many metal deposits are formed by vulcanism. It is also due in part to the early discovery of precious metals in this region. The importance of other metals in the future economy of the State makes it important, however, to consider in this report certain undeveloped deposits which lie in other parts of the State.

Precious metals, gold and silver, have been the chief income producers in South Dakota metal mining. Second in importance has been a group of rare metals which are found in only a few places in North America outside of the Black Hills. The so-called base metals, iron, aluminum, etc., are present in small amounts but have never been important in our mineral economy. This is a rather unusual situation, but as time goes on and methods of beneficiating lower grade ores are developed, the base metals will doubtless assume greater importance and may even take a very important place in mineral production.

Metal deposits of South Dakota, therefore, will be grouped in this report as follows:

I Precious Metals.
  Gold, Silver
II Rare Metals.
  Beryllium, Caesium, Lithium, Tin, Tungsten, Uranium
III Base Metals.
  Aluminum, Copper, Iron, Lead, Magnesium, Manganese, Zinc

Though the distribution of deposits, as will be shown, covers a wider area, commercial production of metals has come from the core of the Black Hills. This region is locally divided into two parts; a northern one centering at Lead and Deadwood called the Northern Hills, and a southern one covering a somewhat larger area about Harney Peak. The last is usually referred to as the Southern Hills, though it actually lies near the center of the mountains.

The Northern Hills region is characterized by vein deposits, and its chief output is gold and silver. Small amounts

of tungsten, lead and copper have also been encountered. The Southern Hills or Harney Peak region includes similar vein deposits and pegmatite dikes, evidently offshoots of the near-by Harney Peak granite. Its chief metallic output is gold, silver and rare metals, particularly lithium, tungsten and beryllium. Tin, tantalum, and uranium have also been found in these dikes.

This geographic distribution appears destined to persist for the present at least, but certain types of metal production could be developed in other parts of the state. The use of magnesium from dolomites might lead to mining industries around the outer edge of the Black Hills; manufacture of sponge iron might lead to the use of iron deposits in the northern plains, and the development of manganese could open a large metal industry in the lower Missouri Valley. Should the manufacture of aluminum from low grade shales and clays ever become feasible, operations might be opened in almost any part of the state.

With this general picture of the kinds of metals and their locations in mind, it is now in order to give more detailed description of the metal deposits.

PRECIOUS METALS

Gold nuggets have been found in the glacial gravels of the Big Sioux Valley in eastern South Dakota; these at one time created sufficient interest to cause the opening of a gold mine in the gravels at Big Stone City. None of these shows, however, have been of sufficient importance to furnish commercial production.

For a good many years, however, South Dakota has been a leading gold producing state because of the deposits in the core of the Black Hills. The discovery was made in the valley of French Creek, near the site of the present city of Custer, in 1874, by Horatio N. Ross, a miner attached to a military exploring expedition headed by General George A. Custer. During that winter a party of miners moved in and extracted seventy ounces of gold valued at twenty dollars an ounce before they were ejected by soldiers. The stampede of prospectors that would have followed was held back by the United States Government because of a treaty with the Sioux Indians. The pressure finally became too strong, and in February, 1877, the country was thrown open to white occupation and immediately swarmed with gold miners. The placer claims on French Creek were not sufficiently rich to support the number of prospectors that came, and they spread northward. The first lode claims, the Grant and Old Abe, near Deadwood were located by J. P. Pearson, on December 11, 1875. These claims constituted the first openings on what is now the Homestake lode.

This early mining was done by small operators, usually prospectors, working singly or in pairs. In the fall of 1877, however, the original Homestake claim, which had been located by Moses Manuel and Hank Harney a year before, was purchased by George Hurst and consolidated with the adjoining Gold Star claim. Thus the entire Homestake property at the time of the incorporation of the Homestake Mining Company covered about 14 acres. This mine has since grown to become the largest gold producer in the United States. Other lode mines have been worked by smaller companies and added their share to the total gold production. It is, however, relatively small compared to the production from the Homestake mine. According to the best records available, South Dakota produced $182,925,217 worth of gold between

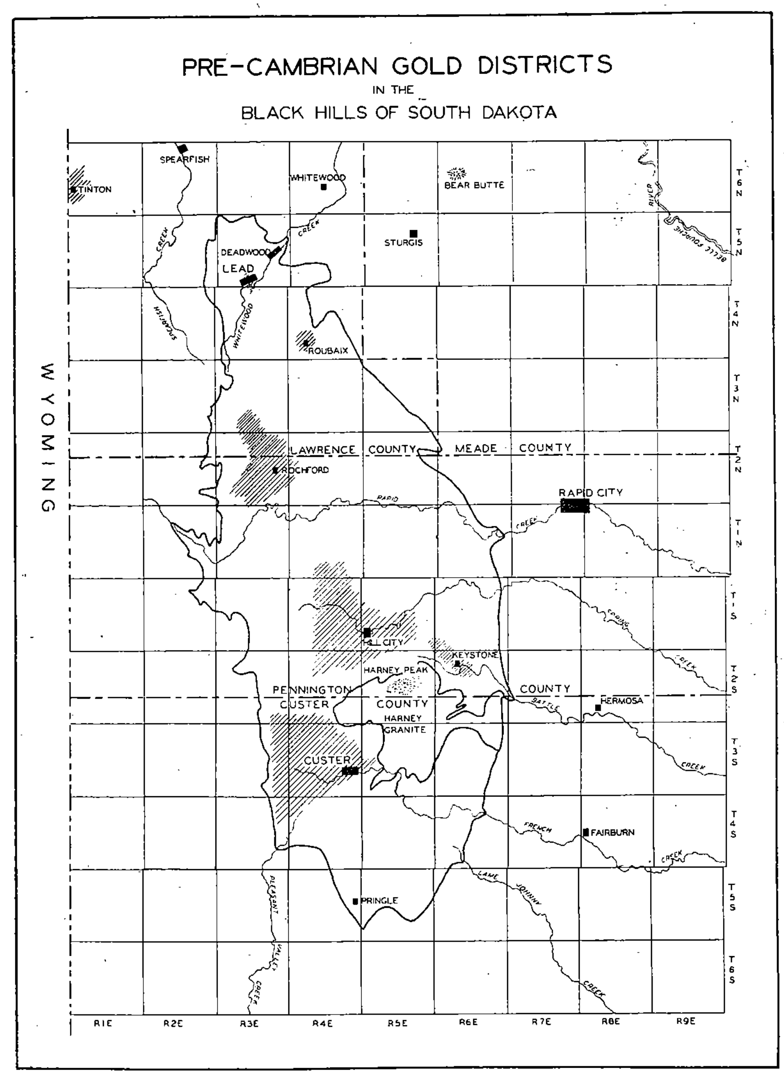

Fig. 1. Locations of Vein and Shear Zone Deposits.

1876 and 1942, when all gold mining was stopped by government order. During that time gold production had steadily increased until in 1941 it had reached 600,637 ounces, valued at $21,022,295.

Three types of precious metal deposits occur in South Dakota.

I. Vein and Shear Zone Deposits: Ore bodies of these deposits are formed by filling openings in the country rock with minerals precipitated from volcanic solutions.

II. Replacement Deposits: Ore bodies of these deposits are formed by replacing the country rock with metals derived from volcanic solutions.

III. Placer Deposits: These are mechanical concentrations of gold in the channels of ancient and modern streams.

In the following descriptions, the Black Hills gold deposits will be grouped according to the foregoing classification of their origins.

I. VEIN AND SHEAR ZONE DEPOSITS

A. In Pre-Cambrian Rocks.

Though none of the deposits of this type have been as valuable as some of the other types, from a commercial point of view, they are by far the most numerous gold deposits in the Black Hills. Such deposits are products of the cooling of large masses of volcanic rock, which in the case of the Black Hills was probably the same rock mass that is exposed in Harney Peak. Vapor solutions from such a cooling mass work their way towards the surface through cracks or joints in the country rock, filling them with mineral matter. Most of the mineral matter is quartz, and in the Black Hills this takes the form of white milky quartz, smoky quartz, and even rose quartz. In some of the solutions, metallic minerals were deposited with the quartz, forming what are usually called fissure veins or fissure filled veins.

Shear zone deposits are somewhat similar to fissure veins except that the joints are not so conspicuous. These occur along fracture zones in the schists of the country rock. Such fracture zones make many openings along which volcanic solutions can escape to the surface. These openings are filled with quartz, sometimes carrying metallic values.

The two types of deposits are alike in that they are

made by filling openings with mineral matter. Veins, however, are characterized by being single masses of quartz; whereas shear zones are brecciated masses of country rock with vein quartz filling all the interstices. The quartz varies all the way from little stringers to veins six feet across and several hundred feet in length.

Gold-Silver Deposits:

Quartz veins are sprinkled throughout most of the pre-Cambrian area of the Black Hills. The gold bearing veins and shear zones, however, can be roughly organized into six districts.

I. In the vicinity of Lead, two mines have been opened on this type of deposit: one, the Pennsylvania mine, two miles northwest of Lead, which produces from a shear zone; and a second, the famous Cloverleaf or Uncle Sam mine at Roubaix, which is a typical vein deposit.

II. The Nigger Hill district is on the state line directly west of Lead. Small gold quartz veins, which have furnished considerable gold to placers of the district, appear in this region, but no veins have been discovered large enough to work profitably.

III. The Rochford district includes the mines in a belt nine miles long, which extends four miles southwest of Rochford to Myersville and five miles north 30 degrees west of Rochford to Nahant. The same formations that occur in the Homestake mine in Lead have been recognized in the Rochford district but the ore occurs in shear zones. This region has also been characterized as the "hornblende belt" and the "iron quartz-tremolite belt."[1]

IV. The Hill City belt includes mines lying in a strip extending from six miles southwest of Hill City to five miles northeast. The Hill City deposits are quartz, fissure veins, and mineralized shear zones.

V. The Keystone district is a short belt about five miles long extending three and a half miles northwest of Keystone to one and a half miles southeast of it. Shear zone and fissure vein deposits characterize this region.

VI. The Custer district includes a group of scattered mines to the west, northwest, and southwest of the city of

[1]O'Harra, B. M., The gold-bearing and quartz-tremolite belt of the Black Hills: Eng. and Min. Jour. vol. 101, pp. 770-773, 1916.

Custer. These are all fissure veins and furnished the placer deposits discovered in French Creek by Horatio Ross, which started gold mining in the Black Hills.

It is interesting to note that in all of the districts recorded, except the Custer area, both shear zones and quartz veins carry gold values. In the Custer district, fissure veins are the only type of deposit. It is not certain that there is any significance in this distribution. These deposits are all in pre-Cambrian rock and appear to have been formed in pre-Cambrian times by solutions rising from the cooling of the Harney Peak batholith which underlies the entire region.

Three famous vein mines are worth describing as examples of this type of deposit. The most northern is the Cloverleaf mine, which is about seven miles from Lead; the southernmost is the Holy Terror mine in the Keystone district, and the westernmost is the Standby mine at Rochford.

The Cloverleaf Mine

"The country rock in the vicinity of Roubaix is Algonkian mica schist, with some associated mica slates, chloritic schists, quartzite, and amphibolites.

The strike and dip of the metamorphics vary a good deal, especially in the vicinity of the vein. The principal ore body is a large saddle-shaped mass of quartz on a pitching anticlinal fold in the mica schist. The crest of the anticline strikes about N. 64 degrees, W., and the pitch, measured from the surface to the fifth level, is 31 degrees to the southeast. The northern limb of the vein, designated in the camp as the "North" or "Vertical" vein, strikes about N. 40 degrees W., has a very steep dip to the northeast from the surface to the fourth level and is practically vertical from there to the seventh level. Toward the crest, of course, the dip approaches the pitch of the fold. The south limb, known as the "South" or "Dipping" vein, strikes S. 75 degrees W. Its southwesterly extension dips to the northwest about 75 degrees. Toward the crest of the fold the dip reverses and lessens until it conforms with the pitch of the fold. The "North Vein" has an average thickness of about 20 feet, the "South Vein" about 12 feet. The thickest part of a vein is at the crest. The operators thought of these as two separate intersecting veins. The discovery was made in the large body of quartz at the crest of the fold or "intersection" of the veins.

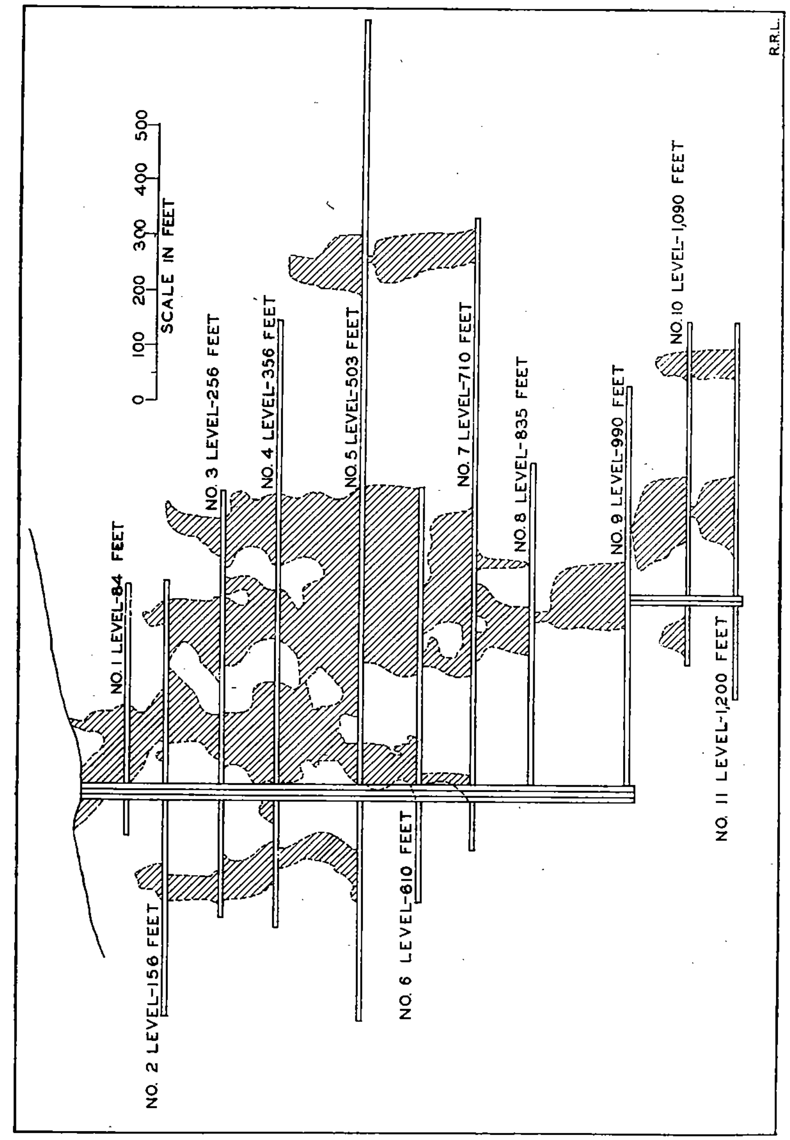

Fig. 2. Cross Section of Holy Terror Mine Paralleling Strike of the Vein. Shaded areas indicate stoped portions. (After Johnson 1935)

The principal gangue minerals are white milky quartz, with some included chlorite and mica from the schist walls. The gold is fairly coarse free gold and some handsome specimens have been taken out. Galena, zinc blende, and pyrite are present in some abundance, and the gold is closely associated with all of these metallic minerals, more particularly with the galena. The zinc blende contains minute inclusions of chalcopyrite."[1]

According to an engineer's report by Waldemar M. Ervin, "the graphitic schist adjacent to the quartz ore bodies is mineralized for a considerable distance from the crest of the fold. This mineralized schist and included small lenses of quartz contain pyrite, pyrrhotite and arsenopyrite."[2] Samples taken by Mr. Ervin in 1936 showed crude ore averaging from about 3 to 6 dollars a ton.

The Holy Terror Mine

The Holy Terror mine is located at Keystone and has been one of the largest producers of the fissure vein mines. Its total recorded production is $1,293,988.50. "The ore deposit * * * is a well defined quartz fissure vein. The strike of the vein is about N. 35° W., and the dip 70° to 80° NE. At the surface the vein was mined for only about 80 feet along the strike; at the second or 150 foot level, ore shoots were opened for 700 feet; at the fifth level 500 feet below the collar, ore shoots were opened for 1,200 feet along the vein The vein widens and pinches along the strike, often being only a narrow seam between lenses. It ranges in width from a few inches to 18 in the upper workings and from 3 to 6 feet on the lower level.

The gangue material is massive white quartz and the ore mineral is coarse flaky gold. Very little arsenopyrite, pyrite, and other sulphide minerals are reported. From the record of production, the grade appears to be higher in the upper and narrower parts of the vein than in the lower and wider parts.

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[1]Connolly, J. P., and O'Harra, C. C., Mineral Wealth of the Black Hills: South Dakota School of Mines, Bull. 16, p. 113, 1929.

[2]Allsman, Paul T., Reconnoissance of gold mining district in the Black Hills, South Dakota: Bull. 427, U. S. Bur. Mines, p. 15.

The mine is open to a depth of about 1200 feet."[1]

The Standby Mine

The description of this mine is included here as an example of the shear zone deposits. The Standby mine lies about one-half mile east of Rochford. Though not a big producer, its workings have recently been accessible and have been studied by several investigators. It, therefore, offers a good example of this type of deposit.

The Standby deposits are in pre-Cambrian metamorphic rocks which can be correlated with the formations about the Homestake mine. They are intensely folded, the strike being N. 40° W., and the dip 63° to 80° NE. Most of the ore bodies lie in the quartz-cummingtonite schist.

"The ore shoots are irregular lenses in an intensely folded section of the quartz-cummingtonite schist. Generally the plane of schistocity is visible; however, where ore bodies are formed the schist is massive. Two ages of quartz are found in the ore bodies. The earlier quartz exists as stringers and lenses interbanded with the schist and following its schistocity. The later quartz is found in stringers and lenses occupying fissures and cutting across the schistocity at various angles. Where quartz of the second type occurs, the rock also contains considerable chlorite and more gold; frequently considerable arsenopyrite and pyrite are also present.

The lengths of the ore shoots that have been mined range from 120 to 160 feet and the width from 50 to 100 feet. The ore shoots have been continuous to a depth of 200 feet. The ore has not been followed beyond this level; however, stoping on the 425-foot level indicated either that the ore shoots opened above pitch to the southeast or that a new ore shoot has been found."[2]

Silver-Lead-Gold Deposits

While most of the veins of the Black Hills are gold-bearing quartz veins, two districts are of interest because they carry a suite of metals which includes lead-silver ores and some zinc. One is known as the Silver City District from

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[1]Allsman, Paul T., Ibid.

[2]Allsman, Paul T., Ibid., p. 113.

Silver City on Rapid Creek. The mining area occurs about two miles north of Silver City. The other is at Spokane, four miles south and two miles east of Keystone on Spokane Creek.

Silver City District

The schist and slates in this district stand vertically and are cut by narrow veins 10 to 24 inches wide, strike N. 45° E. nearly at right angles to the strike of the country rock.

The ore mineral in this deposit is jamesonite, a compound of sulphur antimony and lead ($2Pb.Sb_2S_3$). This mineral carries varying amounts of silver. Associated with the jamesonite is arsenopyrite (FeAsS) in considerable abundance It varies somewhat in the amount with jamesonite. Where the latter is abundant, arsenopyrite is scarce and vice versa. Pyrite (FeS_2) is also abundant and the zinc minerals, shalerite (ZnS) and the copper mineral chalcopyrite ($CuFeS_2$) make up the metal bearing minerals. The rest of the vein is of quartz with fine sericite mica.

Gold and silver values are carried by jamesonite, the higher grade ore averaging about .8 ounces of gold and a little more than two ounces of silver per ton.[1]

The gold is free milling, yielding 70% or more to amalgamation.

Spokane District

At the Spokane mine, the ore body is a quartz vein which contains occasional crystals of microcline feldspar. Near the surface it is about 15 inches wide, increasing to about 10 feet on the 200-foot level and is reported to be wider at greater depths. Alteration of the wall rock has introduced arsenopyrite and pyrite into the mica schist which was the country rock. The ore minerals are sphalerite and silver bearing galena accompanied by considerable pyrite. The silver apparently occurs in an isomorphous mixture or solid solution with the galena, and is sometimes associated with the sphalerite. No definite silver minerals have been reported from any of the observations made on this ore.

[1]Connolly, J. P., and O'Harra, C. C., Mineral Wealth of the Black Hills: S. Dak. School of Mines Bull. 16, pp. 174-175, 1929.

The ratio of silver to lead varies from 32 to 82 ounces of silver per ton for each percent of lead.[1]

B. Veins in Tertiary Porphyry

In the northern mineralized section of the Black Hills gold veins have been encountered, cutting Tertiary porphyry. One area lies northwest of Lead, its northern extremity being near Maitland. Mines have been worked in a porphyry mass that runs from Maitland about three miles, south and east. The second area is about two miles west of Galena or six miles southeast of Lead where mines have been opened along Strawberry Creek.

The following description of the Cutting mine, which was opened in a large irregular mass of quartz monzonite porphyry, on the south side of Blacktail Gulch, near Central City, will illustrate the character of these veins: "The main 'vein' is a brecciated zone in the porphyry along a fault that strikes N. 75 degrees E. and dips steeply to the southeast. * * *

"The mineralization has consisted of intense silicification and some sericitization of the porphyry fault-breccia, deposition of much fluorite and fine grained, dirty green epidote, and the introduction of the ore minerals. The ore minerals consist of abundant fine grained pyrite, some tetrahedrite, and in places much telluride in very fine crystal grains. Michrochemical tests on polished surfaces indicate that this telluride is calaverite, * * *. It would appear * * * that a large part of the values was carried in the pyrite and smaller amounts in the telluride, tetrahedrite, and as native metals, silver and gold. The Ag/Au ratio is high, 4.49 plus, as is the case with most of the Tertiary ores in the Black Hills."[2]

[1]Connolly, **op. cit.** p. 185.
[2]Connolly, J. P. and O'Harra, C. C., Mineral wealth of the Black Hills: S. Dak. School of Mines Bull. 16, pp. 174-175, 1929.

II. REPLACEMENT DEPOSITS

Deposits of the replacement type are similar in origin to vein deposits in that they are formed by precipitation from volcanic solutions working their way towards the surface through openings in the country rock. They differ from vein deposits, however, in that the solutions replace some of the wall rock with volcanic minerals. Minerals of the wall rock may be dissolved and their place taken by quartz or metallic minerals or the chemical composition of wall rock minerals may be changed by the addition of metallic or other volcanic elements from the solutions. Such replacement takes place readily only in carbonate rocks. Limestones, limey shales, and limey sandstone are the best loci for these ore bodies. Thus replacement bodies are formed where a joint crosses a limey stratum. Above and below this limey stratum, both the vein and wall rock may be barren but in the limey stratum, an ore body developes on both sides of the joint, reaching out irregularly as far as the solutions can act.

Replacement deposits are found only in the northern Black Hills within a radius of about seven miles of the city of Lead. Some of them, like the ore bodies of the Homestake lode, occur in pre-Cambrian rocks. A second and most important group is found in the Cambrian Deadwood formation and includes the refractory or blue ores, and the gold-tungsten deposits. The third set of replacements is found in the thick Pahasapa limestone (Mississippian) not far from Spearfish Creek.

A. Pre-Cambrian Replacements

I. *The Homestake Lode.* The only large replacement in pre-Cambrian rocks has formed the largest gold deposit in the Black Hills. This is known as the Homestake lode and underlies the city of Lead. In this vicinity lies a thickness of 9,450 feet of rock which once lay on a sea bottom as horizontal beds of clay, sand, and limestone. Mountain folding, however, has changed their appearance and mineral composition until only an expert could identify their original character. The same mountain folding has crumpled the beds as though they were tissue paper, smashing them into tightly compressed folds, which in places thin and pinch out some formations while others are swollen to make rock masses many

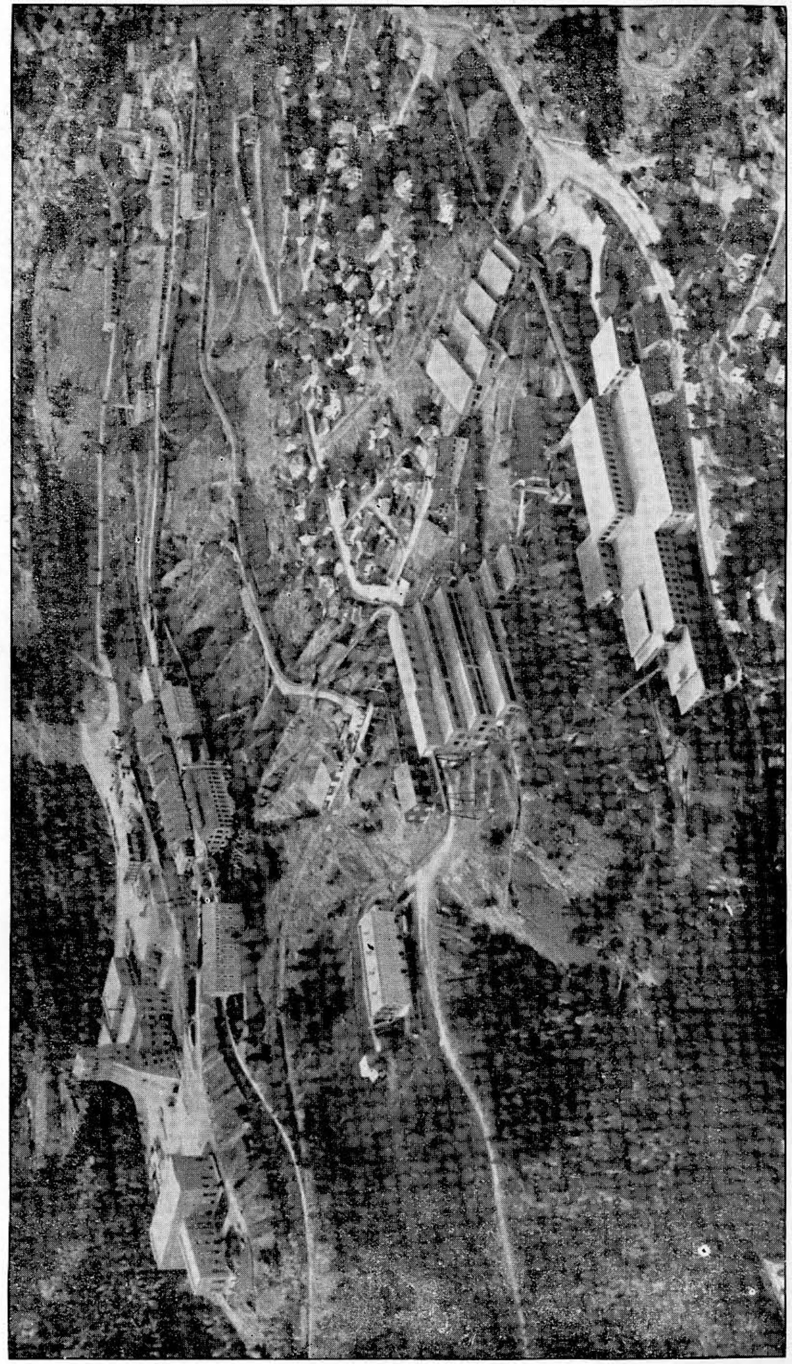

Plate 1. The Homestake Mine   Yates Shaft at upper left of picture.

times their original thickness. The following formations have been identified in the vicinity of the Homestake mine:

Pluma formation—Alternating beds of garnet schist and carbonaceous slates, some of which are pyritiferous— 4000 feet

Garfield formation—Banded, fine grained, cherty ferruginous quartzite; black and red bands; pyritiferous; locally known as the "Iron Dike"; contains some carbonates— 60 feet

Northwestern formation—Green, finely foliated garnet mica schists and quartzites— 2200 feet

Ellison formation—Slate; fine grained grey slate and slaty mica schist; thin black quartzite, medium grained grey micaceous quartzite— 300 feet

Homestake formation—Cummingtonite and chlorite beds, with contorted quartz stringers; constitutes main ledge series, in places dolomitic— 70 feet

De Smet formation—Garnet schist; alternating light and dark bands; micaceous, fibrous, thinly foliated— 300 feet

Poorman formation—Slates and phyllites; calcareous, graphitic, pyritiferous— 2500 feet

Total— 9430 feet

These rocks have been folded into a large anticline and syncline which at Lead is about a mile wide and two miles long whose axes trend north and south and plunge towards the south. On the flanks of these big folds, lie secondary and tertiary folds making the entire structure an intricate mass of tightly compressed folds. The ores are concentrated at the anticlinal or eastern fold.

The rocks were cut with small fissures which allowed solutions from an underlying volcanic mass, evidently the Harney Peak granite, to work their way upward. Where the solutions crossed the Homestake formation, replacement took place so that the ore bodies are confined entirely to this formation. As pointed out in the above section, the Homestake formation is characterized by cummingtonite and chlorite with contorted quartz stringers and in places it is dolomitic. This formation according to Connolly,[1] was made largely of

[1]Connolly, J. P., and O'Harra, C. C., Mineral Wealth of the Black Hills: S. Dak. School of Mines Bull. 16, p. 178, 1929.

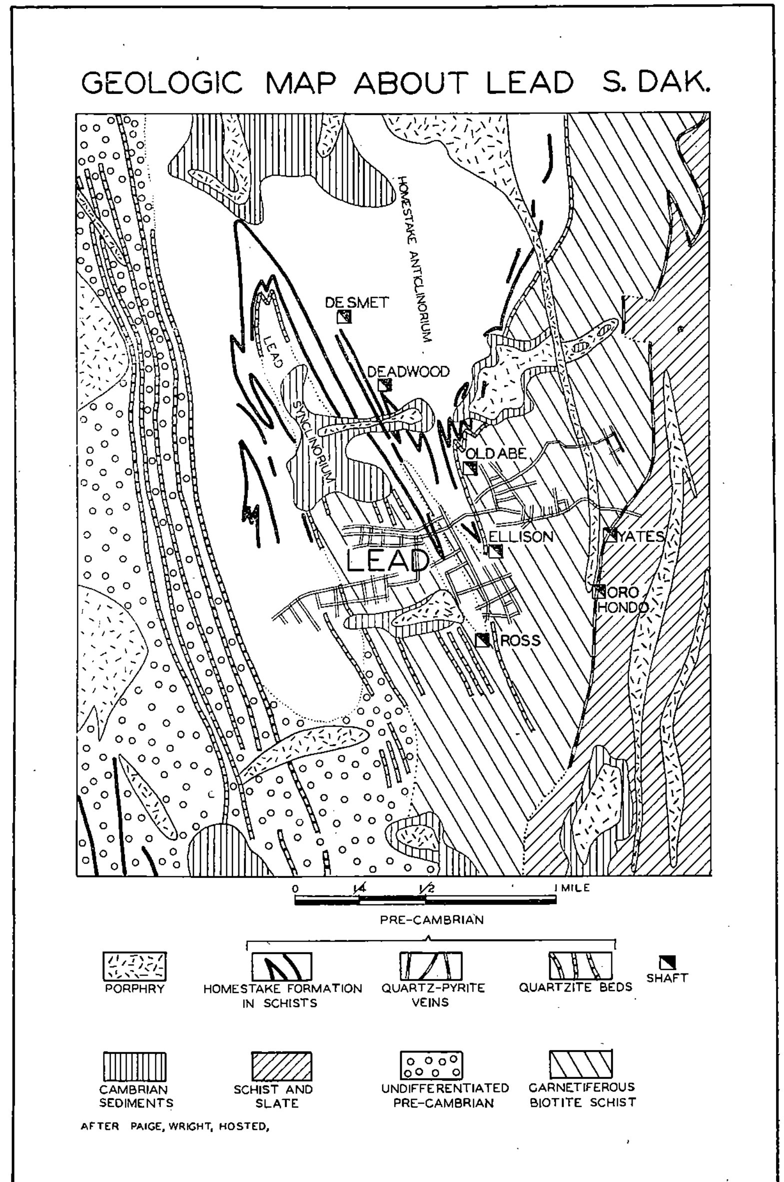

Figure 3

carbonate rock originally, rich in iron and magnesium but poor in lime. Evidently it was an easily replaceable rock for the ore bodies lie in the Homestake formation with very few exceptions while the other formations are barren.

"Gold occurs in small visible particles of the native metal in the Homestake ore. Whether it also occurs in other ways than as free gold has not yet been demonstrated. 'Coarse' gold, or 'specimen' ore from the Homestake usually consists of masses of chlorite and quartz with leaves, rods, or regular masses of free gold attached, the size of the gold particles seldom being more than 7 or 8 millimeters in largest dimension, and usually they are much smaller. Such specimen ore is quite rare. Most of the gold is very fine (in size), intimately associated with the sulphides, and, therefore, to be seen only with a microscope."[1]

Connolly also states that the gold is associated with and often trapped in arsenopyrite (the arsenic ore or white iron of the miners), pyrite (fools gold), and a great deal of dark gray quartz.

Minerals containing lead, zinc, and copper have been identified in small quantities and in such places there is an abundance of calcite and dolomite. The following have been listed as the gangue minerals of the Homestake ore bodies:[2] Cummingtonite, chlorite, biotite, quartz, iron-magnesian carbonates, some calcite, a little garnet, and a very small amount of fluorite. The ore minerals are listed as follows: arsenopyrite, pyrrhotite, pyrite, magnetite, specularite, chalcopyrite, gold carrying low silver, galena, sphalerite and a bismuth telluride.

The gold always carries silver in a ratio of approximately 5 to 1.[3] "Ore bodies range in width from 50 to 150 feet or more owing to refolding which repeats the bed (Homestake formation). The length along the strike ranges from 300 to 700 feet and occasionally is much greater. To the south-

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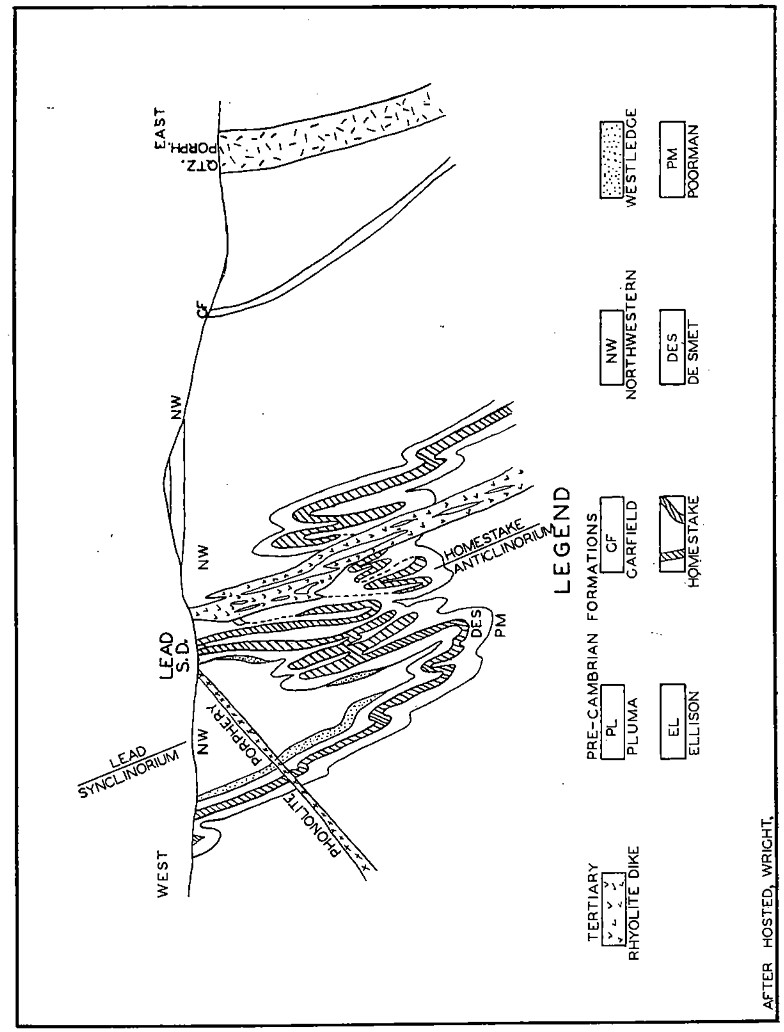
[1]Connolly, J. P. **op. cit.**, p. 96.
[2]Connolly, **op. cit.**, p. 103.
[3]Connolly, **op. cit.**, p. 107.



GEOLOGIC STRUCTURE SECTION
OF THE
HOMESTAKE DISTRICT

Figure 4

east the ore bodies generally terminate against an arch of slate of the Ellison formation, and to the northwest they terminate against garnet schist of the De Smet formation or slates and phyllites of the Poorman formation."[1]

Though ore minerals of lead, copper, and zinc are reported in the Homestake suite, only gold and silver have been produced from this mine.

Rhyolite and phonolite dikes cut the pre-Cambrian rock in the Homestake mine. These volcanic dikes were injected in Tertiary times (probably Eocene) and some mineralization took place along with this injection. Some authors have gone so far as to suggest that the entire Homestake deposit was made by Tertiary volcanism. Connolly has shown, however, that this is not the case and that most of the mineralization was done in pre-Cambrian times, supplemented to a minor extent by a Tertiary volcanism. The following table gives his interpretation of the date of mineralization in this lode:

Mineral	Pre-Cambrian Mineralization	Tertiary Mineralization
Iron-magnesian carbonates	————————	
Quartz	————————	——
Cummingtonite	————	
Garnet	———	
Biotite	—————	
Chlorite	—————	
Calcite	—?—	—————
Fluorite		————
Arsenopyrite	——	
Pyrite	——	————
Pyrrhotite	——	
Gold	—————	————
Magnetite	—?— - - -	
Specularite	—?—	
Chalcopyrite	- -?- ——?—	
Sphalerite	- -?- ————	————
Galena	- - - -?- - -	————
Bismuth Telluride		————

[1]Allsman, op. cit., p. 12.

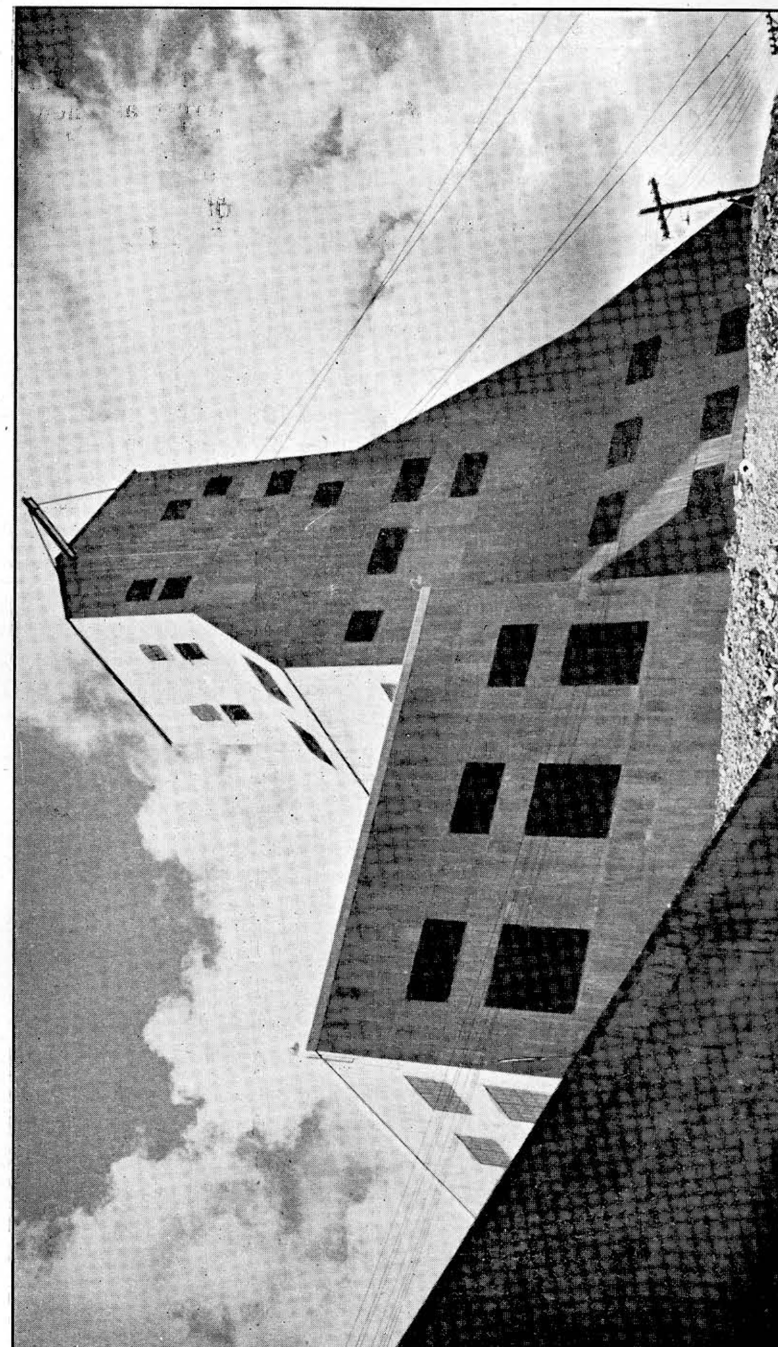


Plate 2. Head Frame of the Yates Shaft, Homestake Mine.

The presence of the minerals pyrrhotite, magnetite, and specularite in the deposit are of particular interest as they indicate that the Homestake deposits were formed under intense volcanic conditions; high temperatures, and pressures. In other words, a large mass of igneous material, probably the Harney Peak granite, lies not far below the Homestake mine.

B. Replacements in the Deadwood Formation

Gold Ores

The deposits which can be grouped under this heading, all lie within a radius of about six miles of Lead and form a circle of deposits nearly surrounding that city. They are usually grouped in five areas: the Bald Mountain area southwest of Lead, the Lead area, in the immediate vicinity of the city, the Yellow Creek area, a mile and a half south, the Two Bit area about five miles east, and the Garden area, five miles north of the city. These deposits were all made during Tertiary time and are the result of volcanic solutions rising through fissures in the Deadwood formation and replacing limey members of that formation.

The Deadwood formation is roughly described as having three divisions or members. At its base, is a massive sandstone which, in some places, is very conglomeratic. This sandstone varies from a few feet to a hundred feet in thickness. Above it lies a zone of shale alternating with limestone and sandy limestone. This shale is about 500 feet thick and is capped with a hundred feet or more of heavy sandstone which is characterized by an abundance of worm burrows which paleontologists have identified as Scolithus. These burrows are characteristic of the upper Deadwood sandstone over a large area in the northern Black Hills.

The replacement ore bodies occur in two dolomitic layers in the middle section of the Deadwood formation some 500 feet apart stratigraphically. The upper one, called by miners the "upper contact" deposit, lies 8 to 30 feet below the Scolithus sandstone. The lower one lies 15 to 25 feet above the bottom of the Deadwood formation. In most places it is separated from the pre-Cambrian schist by a thin quartzite and lies almost directly on top of it, while in other places the quartzite is missing entirely and the shales below the lower

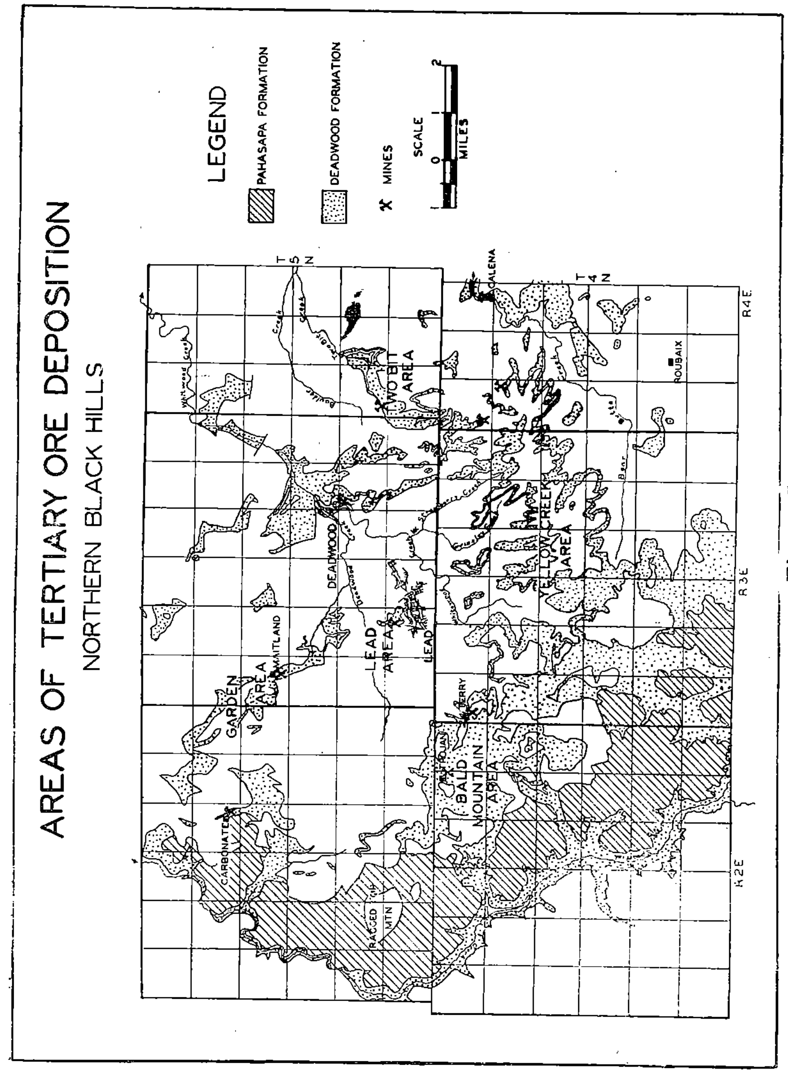


Figure 5

contact zone, lie immediately upon schist. Both contacts have not been worked in any one district largely because each district has only one contact exposed. In the Ruby basin district of the Bald Mountain area, the lower contact has been mined exclusively, while in the Portland district of the same area, the upper contact has furnished the ore. In the Garden, Lead, and Yellow Creek areas, only the lower contact ores have been mined as the upper ones are completely lost by the erosion.

Since the ore bodies were formed by volcanic solution rising through vertical cracks and replacement of sedimentary beds where they were crossed by these joints, the ore bodies form long tunnel-like shoots. Where the joints are sufficiently close together to cause the replacement to overlap, large irregular masses are developed. Local miners use the term "flat formations" for these ores and the cracks along which replacement took place are usually called "verticals." "In vertical dimension they are limited by the thickness of the replaceable beds of rock. On the lower contact the floor of the ore bodies is usually quartzite and the roof is often shale. On the upper contact the floor is likewise a quartzite, and the roof is often shale but frequently a porphyry sill. The ore shoots vary in thickness from three or four feet to eighteen or twenty. Twelve to fifteen feet is perhaps a fair average. In length the variation is great. Some ore bodies are only a few feet long. Others "made" by strong verticals or an overlapping series of verticals are several hundred feet long. The variation in width is as great as in length. In some cases mineralization has extended only a few inches on each side of a fracture. Where the fractures are strong, or where the mineralizing solutions appear to have been very active, ore has made out into the dolomite for a distance of eight or ten feet on each side of the vertical. * * * The greatest ore bodies of all have been formed where there are two sets of closely spaced verticals intersecting each other. * * * The cross-section shape of the ore bodies is often very irregular due to beds of impervious or non-replaceable rock within the main dolomite bed. * * * According to Irving the ore bodies also have a tendency to widen upward, as though the mineralizing solutions were impounded and spread under the impervious shales or porphyries."[1]

[1]Connolly, J. P., op. cit., pp. 157, 159.

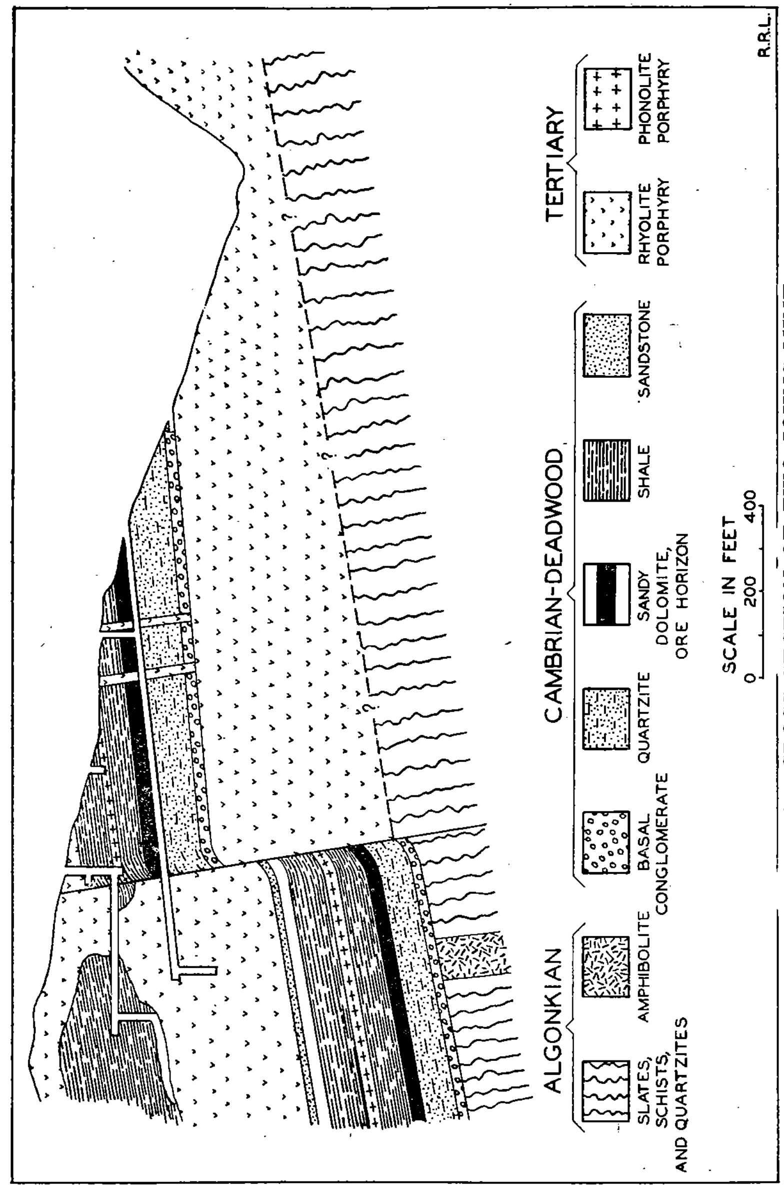


Figure 6 CROSS SECTION OF TWO JOHNS MINE

The primary ore is usually known as blue ore because of its color, and often as "refractory ore" because of the difficulty of beneficiation. The replacement has brought in quartz and pyrite in very small grains, so fine in fact, that it is difficult to see them with the unaided eye. Gold is trapped in the pyrite in even smaller particles, so that it is well shielded from the ordinary processes of gold extraction. The ore, therefore, cannot be amalgamated, and ordinary cyanide treatment gives only poor results since most of the gold is protected by minerals which are not soluble in mercury or cyanide solutions. Little or no gold is recovered by amalgamation and only 20 to 40 percent upon leaching with cyanide.

The processes of weathering change this ore to a brown color and free a larger percentage of the trapped gold allowing higher rates of recovery of precious metals. This effect is probably due to the fact that weathering disintegrates the pyrite which traps much of the gold freeing it sufficiently to make leaching possible. Most of the production of Deadwood ore to date has come from these oxidized portions of the ore bodies.

In describing the blue ores Connolly[1] lists the following minerals:

Quartz	SiO_2
Pyrite	FeS_2
Glauconite	$K_2(Mg,Fe)_2Al_6(Si_4O_{10})_3(OH)_{12}$
Arsenopyrite	FeAsS (Trace)
Sylvanite	$(Au, Ag)Te_2$
Fluorite	CaF_2
Galena	PbS
Sphalerite	ZnS
Stibnite	Sb_2S_3
Gypsum	$CaSO_4 \cdot 2H_2O$
Barite	$BaSO_4$

The presence of fluorite, stibnite and the telluride sylvanite indicate that these deposits were formed at shallow depths and not under the intense conditions of heat and pressure that obtained when the pre-Cambrian ores were formed.

Connolly also points out that the gold-silver ratios in Tertiary ores are always less than one and often run one part of gold to five parts of silver. The presence of more silver

[1]Connolly, J. P., op. cit., pp. 160-163.

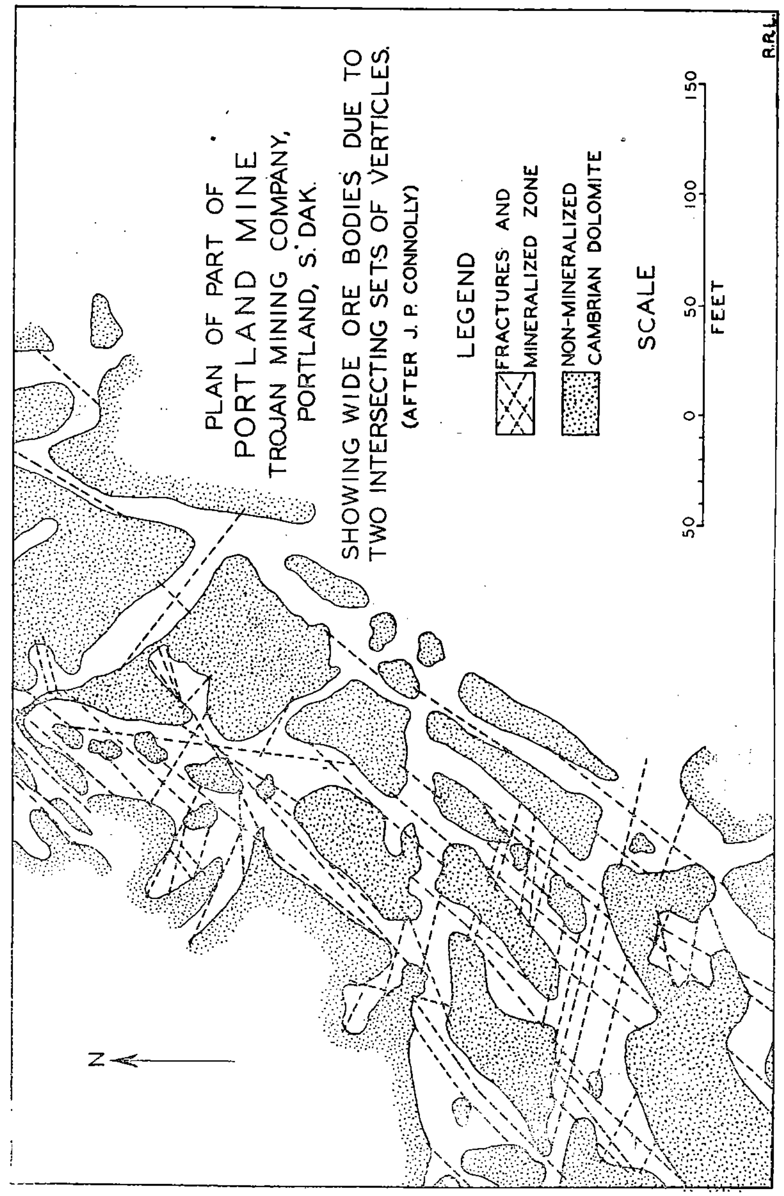


Figure 7

than gold is in sharp contrast with the pre-Cambrian ores like those of the Homestake lode in which the opposite ratio prevails. On the average, smelting ores run 1.42 silver to 1 of gold, though in milling ores it averages higher; namely, 3.77 to 1.[1]

A classic example of this type of deposit is that in which the Golden Reward mine has been operated.

The Golden Reward Mine. This mine, which was one of the largest producers for a good many years, lies in the southern part of Bald Mountain area. It is a property containing more than 440 claims, including about 3400 acres, and was in continuous operation until 1918 when it was shut down because of the refractoriness of the ore. It is estimated that there are about 2,000,000 tons of ore left on the property, and the company decided to leave it in the ground rather than mine it for the low recovery possible with the methods then available. In the seventeen years of its operation, it is estimated to have produced about $21,000,000 worth of gold, with gold at $20 an ounce.

"Although most of the deposits are in the lower contact horizon, they are not mined from a single level. Considerable faulting and igneous intrusions in the form of laccoliths, sills, and dikes have displaced the ore bodies both vertically and horizontally. Often it is necessary to mine from various levels and through inclined drifts and crosscuts.

"It is reported that mining was done from various adits where the ore outcropped at the surface and from six vertical shafts, the deepest of which is 587 feet. The property has nearly 30 miles of lateral workings, most of which are inaccessible."[2]

This short sketch of the Golden Reward mine and the accompanying illustrations are characteristic of the geology of the replacement of bodies in the Deadwood formation.

Gold-Tungsten Ores

In the Lead and Yellow Creek areas and at Deadwood, replacement deposits in the Deadwood formation carry tungsten. In none of these has the tungsten been sufficiently valu-

[1]Connolly, J. P., and O'Harra, C. C., **op. cit.** pp. 106-168.
[2]Allsman, Paul T., **op. cit.**, p. 39.

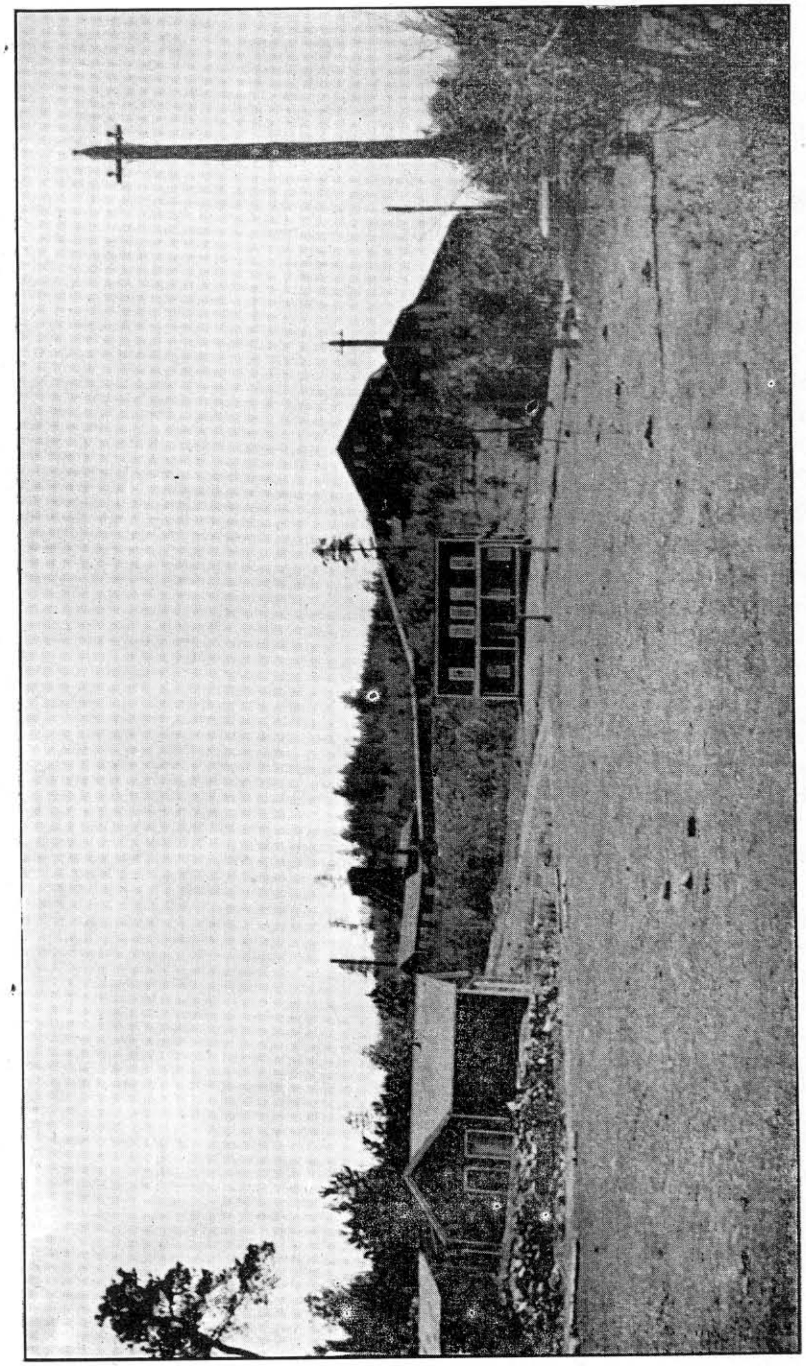


PLATE 3. The Golden Crest Mine, four miles southeast of Deadwood. Operating on a Tertiary Replacement of the Deadwood formation.

able to pay for itself, but with the accompanying gold it has made commercial mining of these deposits profitable during times when the price of tungsten was high.

The tungsten replacement deposits represent a basic phase of the siliceous gold ores. Some of them form a rim around the outer edge of the silicious ore shoots, in some cases making a capping or partial envelope on the silicious ore mass. Margins of this kind are also scattered in irregular masses throughout the silicious ores or may occur as lenses or stringers in partly silicified dolomite. It is also found as thin irregular layers replacing the uppermost portion of the basal quartzite which is calcareous.[1] Since the use of the florescent character of scheelite in tungsten prospecting, it appears that there is more scheelite in the deposit than has been recorded by the earlier investigators.

The Lead area, on top of the hill north of that city, in part overlies the Homestake mine. During the first World War, most of this tungsten was mined out, and, although it is still possible to find low grade ore in this deposit, it has not been profitable to work any of it since.

"The ore varies from a dense heavy black rock with a fine texture to nearly solid wolframite grains, to a grey quartzose rock containing small black, shiny specks of the mineral. The wolframite in these phases does not commonly exhibit crystal boundaries but shows small flat metallic cleavage surfaces. Individual grains are rarely more than one thirty-second of an inch in diameter but recently ores have been found that contain individual curved cleavage surfaces of more than an inch in diameter. * * * A considerable amount of black manganese dioxide in places has impregnated the rock and has often been mistaken for the ore * * *.

According to W. J. Sharwood (personal communication) all analyses of the ore have shown the ore minerals to be wolframite low in manganese with small amounts of scheelite. Thus a typical carload of concentrate containing 60-61% WO_3 would probably carry between 3 and 4% manganese, with about 17% iron and 1% calcium, a minute amount of phosphorus, and not more than a trace of tin or copper. The

[1]Paige, Sidney, The central Black Hills: U. S. Geol. Survey Folio 219, p. 29, 1925.

following proportions of the principal minerals of a specimen of the ore have been calculated formerly from analyses by W. F. Hillebrand. * * *

Wolframite (FeMn) WO_4	75.60
Quartz SiO_2	12.54
Scheelite CaWO	4.77
Barite $BaSO_4$	.06
Ferric Oxide Fe_2O_3	3.85
Water H_2O	.20
Arsenic Oxide	1.25
Residual Clay (kaolin)	1.34

"In the Homestake ore (Lead area) tin, copper and antimony, occur only in traces; while in the Wasp No. 2 (Yellow Creek area) ore antimony frequently occurs, and occasionally appreciable amounts of copper. * * *

"The ore concentrated at the mill for the past years has averaged nearly 3 per cent WO_3 and $4.00 in gold per ton."[1] (Gold at $20.67 per ounce).

At the Wasp No. 2 mine in the Yellow Creek area, a similar suite of minerals exist but the percentage of antimony in the form of the mineral stibnite (Sb_2S_3) is noticeable. Barite ($BaSo_4$) in well formed tabular crystals and in radiating aggregates is also a prominent feature of this deposit.

In the search for tungsten during the first World War, it was discovered that tungsten ore was used unwittingly as foundation stone for some houses in Deadwood. Investigation showed that the mineralization had taken place in calcareous members of the lower Deadwood formation lying above the city. These are in all respects similar to those in the Lead and the Yellow Creek area but prospecting has failed to reveal workable ore bodies of either tungsten or gold.

A few stray deposits have been found in the Deadwood formation on Strawberry Ridge a mile and a half or two miles northeast of the Yellow Creek area. This lies about half way between the Yellow Creek and the Two Bit areas. At the north end of the ridge, there are some veins in Tertiary

[1]Runner, J. J., The occurrence, chemistry, metallurgy and uses of tungsten: South Dakota School of Mines, Bull. 12, pp. 72-74, 1918.

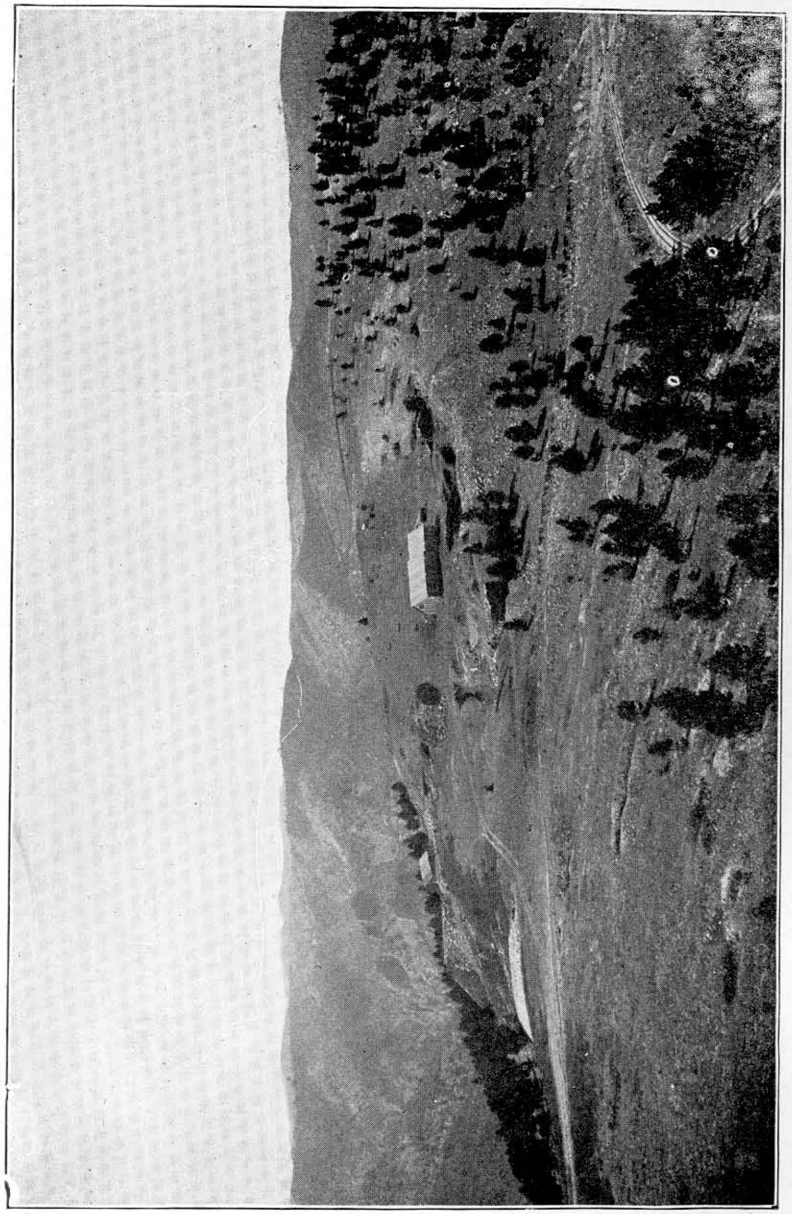


PLATE 4. The Hidden Treasure Mine, on Spring Gulch near Lead. One of the richest of the fossil placers (Cement Ores)

porphyrys. The deposits further south, however, are replacements in the Deadwood formation and should be classed with those of the Yellow Creek and Lead areas.

Age of the Deposits

From what has been said, it is evident that these deposits are not of pre-Cambrian age. Both the replacement gold deposits and tungsten-gold replacements are, therefore, much younger than the Homestake ore bodies or the quartz vein and shear zone deposits which have been described. The presence of tungsten veins in Tertiary intrusives at Strawberry Ridge as well as gold bearing veins in intrusives of the same age, indicate that the time of mineralization occurred during this period. It probably followed closely intrusion of the Tertiary igneous masses, solutions rising through cracks in the schist and overlying sedimentary rocks and depositing metals where conditions for replacement were favorable. In the case of the ores just described, these conditions were found in the lower part of the Deadwood formation.

This Tertiary mineralization has been well described by Connolly,[1] and the reader is referred to his report for more detailed information.

Only two periods of mineralization are recognized in the Black Hills. The first, the pre-Cambrian, is characterized by the presence of minerals of deep-seated origin, formed under intense temperature and pressure conditions. The gold in these deposits is largely free milling, 70% to 75% being recoverable by amalgamation. This is due to the amount of free gold that is un-trapped in other minerals or is in such large grains that it is easily exposed by crushing the ore. The ratio of gold to silver is always greater than one to one and usually approximates five to one.

Minerals associated with the ore include such indicators as pyrrhotite (Fe_{1}-xS), specularite (Fe_2O_3), hematite (Fe_2O_3) and arsenopyrite (FeAsS) and magnetite (Fe_3O_4).

Ores deposited in Tertiary times, on the other hand, are refractory, yielding little or no gold on amalgamation and but 20 to 40 percent of its gold upon cyaniding. This is thought to be due to the fineness of the trapped grains of

[1]Connolly, J. P., Tertiary mineralization of the northern Black Hills: South Dakota School of Mines, Bull. 15, 1927.

gold which can not be exposed so as to contact mercury or cyanide solutions by the ordinary grinding methods. Its gold to silver ratio is always less than one and often as low as one to five. Tertiary deposits are also characterized by a suite of minerals formed under much less intense conditions of temperature and pressure than the pre-Cambrian deposits. Gold telluride, barite ($BaSO_4$), fluorite (CaF_2), and carbonate minerals are good indicators of such an origin.

Using the characters outlined above, it is not a difficult matter for a miner or mineralogist to date the deposit which he may be prospecting.

Silver-Lead Ores

Similar replacement in the Deadwood formation has produced silver-lead ores in the vicinity of Galena. During the years 1881 to 1883, they furnished more than $750,000 worth of silver and lead. Like the gold ores and gold tungsten ores, the silver-lead ores of the Galena district are found as replacements around "verticals" that cut dolomitic and sandy dolomitic layers in the Deadwood formation. Mines have been opened on both the upper and lower contacts.

"The ore in this district lies in shoots or in long irregular lenticular bodies, which follow vertical fractures that traverse both the Deadwood strata and the intruded porphyry. * * * The shoots range from small, scarcely perceptible seams to flat bodies 20 feet wide and from a few inches to 2 feet thick, and exceptionally 4 feet thick. * * * The ore-bearing rocks consist of sandstone cemented by calcite and shaley limestone, presumably dolomitic. Most of the ore bodies lie in the uppermost layers, immediately below a cap of shale."[1]

Most of the ore that has been mined has been the oxidized portion of the ore bodies. Connolly described this material as "puzzling, and baffles exact identification." It is a white to yellow, fine grained mixture. In some mines it is very hard and in others very soft. It always runs high in lead and very often in silver.

The following minerals have been identified, however, in fresh and partly oxidized ores: galena (PbS) carrying silver, pyrite (FeS_2) carrying a little gold, small amounts of chalcopyrite ($CuFeS_2$), and a little sphalerite (ZnS). Connolly reports vanadinite ($Pb_5Cl(VO_4)_3$) and loellingite ($FeAs_2$) from the upper contact ores.

[1]Paige, Sidney, The central Black Hills: U. S. Geol. Survey Folio 219, p. 29, 1925.

The silver content of these ores varies a great deal. Ores from the Richmond or Sitting Bull mine were reported to have yielded as high as 2,000 ounces of silver to the ton. Most of it, however, averaged closer to 6 or 8 ounces a ton.

Spruce Gulch District

In Spruce Gulch which enters Whitewood Creek Valley at the eastern end of the city of Deadwood, a small deposit of silver-lead ore, which has never proved commercially valuable, has been opened. The ores are in the lower contact horizon of the Deadwood formation not far from an intrusion of Tertiary rhyolite.

The ore minerals are characterized by an abundance of pyrite (FeS_2) and sphalerite (ZnS), minor amounts of galena (PbS) and arsenopyrite ($FeAsS$), and a very little chalcopyrite ($CuFeS_2$). Low values of gold and silver ore are obtained, apparently trapped in the galena and pyrite as in other ores of this nature.

C. Replacements in the Pahasapa Limestone

The Pahasapa formation in the northern Black Hills is a limestone 400 to 600 feet thick. It is of Mississippian age and, therefore, lies stratigraphically above the Deadwood formation. In fact, it is separated from it by only 140 feet of Ordovician and early Mississippian limestone. As was pointed out in Part I of this report, this limestone makes the plateau surrounding the crystalline area of the Black Hills.

In the part of the plateau between the crystalline area at Lead and Spearfish Creek, replacement deposits occur, formed by Tertiary volcanic solutions which penetrated the formation at the same time that the Deadwood replacements were being deposited. Whether these solutions came from small Tertiary volcanic masses, which are found not far away from the deposit, or whether they worked their way through major joints, which cut the underlying Cambrian and Ordovician formations, is not certain. Whatever their source, however, they found in the Pahasapa limestone, an easily replaceable rock, and proceeded to exchange the quartz and metallic minerals which they were carrying for portions of the limestone.

Gold Ores

Ragged Top Mountain District

Gold bearing replacements have been found in the Pahasapa limestone in a district about five miles long lying immediately west of Spearfish Creek in the large bend of Spearfish Canyon. Ragged Top Mountain is at the center of the district, and the most productive mines were found near this mountain which was formed by an intrusion of Tertiary volcanic rock. The first mines were opened at a place called Dacy about a half mile north of the mountain. These were followed by mines on Calamity and Johnson Creeks, a half to three-quarters of a mile directly west of the mountain. Prospecting has shown that these deposits extend as far as Annie Creek, two and one-half miles south of the mountain and as far as the mouth of Squaw Creek, about the same distance north of the mountain. The general character of these deposits is perhaps well illustrated by the Ragged Top Mines group as described by Allsman[1] as follows:

"The ore bodies are in a series of nearly equally spaced vertical fractures ranging in strike from N. 36° to 59° E. The fractures range in width from small crevices to 10 feet. Below the zone of surface alteration the ore passed laterally into the limestone walls without any structural disturbance. The veins are said to narrow downward; however, they have not been explored generally to any great depth.

"The ore is a hard, light-buff, highly silicious limestone. The hardness and color are the only visual means of distinguishing the ore from limestone; on close examination the limits of mineralization are sharply marked.

"In addition to gold and some silver, the ore contains tellurium, from which it is concluded that the precious metals were in the form of tellurides before oxidization. Satisfactory recoveries of gold were made by cyanidization at local mills, and recent tests by the Ragged Top mines indicate that

[1]Allsman, op. cit., p. 51.

by moderately fine grinding the gold becomes easily amenable to cyanidization."

Irving, who examined these ores in 1904 when many of the mines were still accessible, reported that the ores consisted almost entirely of silica, one analysis showing 96% of that mineral. He also mentions the tellurium referred to above and the presence of much brilliant purple fluorite. He also makes the statement that "the mineralized zone narrows downward, so that at a maximum depth of about 60 feet the ore bodies thin out."[1]

Carbonate District

What is usually called the Carbonate district is really a continuation of the Ragged Top Mountain mineralization north of Squaw Creek. The gold bearing ore bodies are found in a region a little less than a mile square lying on the divide between Squaw Creek and Rubicon Gulch. Little Crow Peak is a little Tertiary intrusion lying about the middle of this area and a second intrusion occupies the northern part crossing the valley of Rubicon Gulch. About ten mines have been opened in this area on what appears to be two "verticals." The mineralized crevices are from one to 20 feet in width and strike S. 85° W.

So far as is known, the mineralogy of this region is like that of the Ragged Top district.

Silver-Lead Ores

Carbonate District

Silver and lead were produced in the early days from a contact deposit near the mining camp of Carbonate. At this place, the Tertiary volcanic mass, referred to above, cuts the Pahasapa limestone, forming replacement ore bodies near its boundary. According to Paige,[2] "The ore deposits were of two types, the first consisting of large, irregular bodies of lead carbonate merging into galena and occuring mainly near porphyry contacts, and the second of veins formed by the par-

[1]Irving, J. D., Economic resources of the northern Black Hills: U. S. Geol. Survey Prof. Paper 26, p. 127, 1904.

[2]Paige, Sidney, The Central Black Hills: U. S. Geol. Survey Folio 219, p. 29, 1925; p. 163, 1904.

tial filling of crevices with galena, lead carbonate, and cerargyrite in connection with extensive replacement of the limestone by ferruginous jasper. A deposit of the first type, which was the chief source of silver, was worked most extensively by the Iron Hill mine, which followed the east side of a wide porphyry dike. Here also a large mass of vanadinite ($Pb_5Cl(VO_4)_3$) was found, and the minerals cerusite ($PbCO_3$), cerargyrite ($AgCl$), matlockite ($PbO.PbCl_2$), wulfenite ($PbMo\ O_4$), pyromorphite ($Pb_5Cl(PO_4)_3$), plattnerite (PbO_2), and atacamite ($Cu_2Cl(OH)_3$ were associated with the galena (PbS)."

III. PLACER REPOSITS

A. FOSSIL PLACERS OF THE DEADWOOD FORMATION

While placers of both gold and tin have been worked in the Black Hills, those producing gold have proved by far the most profitable. Probably the most unique of these are the fossil placers found in the Deadwood formation and called "cement ores" by the miners because they occur in solid rock. Cement ores have been reported in the Deadwood formation from three different areas in the Black Hills and probably occur at many more. The first area which has been the most important commercially is within a few miles of Lead. A second area is ten miles almost due west of Hill City and a third area is not far from Rockerville, or about five miles northeast of Keystone. From these locations, it is evident that the Homestake lode and probably many of the quartz vein areas in the "southern Hills" stood out as islands or reefs in the Cambrian sea, probably due to the superior resistance of the rocks of which these deposits are composed. Wave action, however, tore these masses apart and eventually ground them into sands and gravels, releasing the gold which they contained. This gold appears to have been moved by strong undertow and shore currents into depressions in the sea bottom and deposited there with the coarser gravels. Gold is found not only in the gravel itself, but lying in the schists which formed the sea floor, apparently trapped in cracks and other irregularities of the surface. The grains are flattened and rounded as in modern placer gold. The deposit is similar to the beach placers found in the vicinity of Nome, Alaska. Gold was deposited in the gravels that lie at the base of the Deadwood formation which was eventually cemented into a conglomerate.

The deposits in the vicinity of Lead have been further enriched by the Tertiary volcanic solutions which made the replacement deposits described above. The early investigators, who had a chance to study the mines while they were open, state that it is possible to readily distinguish between pre-Cambrian gold and that introduced by Tertiary solutions. Apparently the latter gold was but a small addition and these cement ores, therefore, are classed here as placer deposits.

The first mill brought into the Black Hills to work gold was set up a short distance above Gayville in Deadwood Gulch for the purpose of treating cement ore from the Hidden Treasure mine. Before the close of the first year, this mill had produced $20,000 in gold. Since the first rich yield in the 1880's, however, the cement ores have not been mined very vigorously.

B. GRAVEL PLACERS

Big Sioux Placers

As mentioned above, gold has been found in the gravels of the Big Sioux Valley, but so far, not in workable quantity. These gravels are of glacial origin having been brought to the State from southern Canada by ice-sheets of the Pleistocene epoch. These ice-sheets rode over metal deposits in southern Canada, incorporated some of the metals into the debris they were carrying, and transported them to South Dakota.

Upon melting, the ice sent torrents of water into the Big Sioux Basin, carrying along the debris from the ice. Gravel and sand sorted from this debris was deposited in the channels of the old spillways in which both gold and copper nuggets have been found. In the gravels near Big Stone City, sufficient gold was discovered a number of years ago to induce the opening of a drift mine in the terrace on the west side of the channel in which Big Stone Lake lies. Nuggets have also been found in gravel pits at Hawarden, Iowa, across the channel of the Big Sioux River from northeastern Union County. None of these finds, however, have carried sufficiently large pay streaks to make commercial mining possible.

It is possible that similar stray nuggets may be found in many gravel deposits in eastern South Dakota. It is very doubtful, however, whether any of them would have a concentration of gold sufficient to pay for mining.

Black Hills Placers

The following information is taken from an excellent report by Dr. J. P. Connolly.[1]

The Cambrian fossil placers described above are the first placers developed in the Black Hills. These were followed by three periods of placer formation in which the placers are now found in loose gravels instead of the hard rock of the cement ores.

The first period occurred in Tertiary times. The Black Hills had been elevated into mountains shortly before this period and the pre-Cambrian rocks containing the gold lode and veins had been exposed by stream erosion. Gold from the Homestake lode and quartz veins was washed into the valleys and perhaps some of the Cambrian fossil placers were torn apart and redistributed down the Tertiary streams. Thus placers were formed in what were wide valleys coming out of the core of the Black Hills.

The second period occurred during the Pleistocene epoch. Uplift of the mountains rejuvenated the streams and caused them to cut sharper, narrower valleys in and across the old Tertiary valleys. The ancient Tertiary gravels were left as high terraces on the divides between the younger streams.

The third period is the present since modern streams have deepened the valleys below the Pleistocene level and are forming new placer bars at the present levels.

Since Tertiary gravels are now found on divides and high terraces they are known as the high level bench placers. One of the best known of these is at Rockerville, half way between Rapid City and Keystone, where high level terraces on the south side of Spring Creek Valley once made a very thriving gold camp of Rockerville. The name Rockerville is significant of the fact that the gravels lay on high ground where it was impossible to obtain water enough for sluicing. The mining and extraction, therefore, had to be done almost entirely with hand rockers.

These high level terraces are now found lying 100 to 300 feet above the bottoms of the modern stream.

The second (Pleistocene) set of gold bearing gravel benches lies about 15 to 20 feet above the bottoms of the modern valleys. These represent the depth to which the stream had cut during the time between the late Tertiary period and the Pleistocene epoch. While ice stood over eastern South Dakota, western South Dakota was deluged with heavy rain which gorged the valleys draining the Black Hills, widening them and leaving their channels filled with placer gravels.

[1]Connolly, J. P., Geologic history of Black Hills gold placer: South Dakota Geol. Survey Rept. Inv. 16, 1933.

These placers contain gold eroded from the primary deposits in the crystalline area and probably also from the cement ores and re-worked material from the high level Tertiary gravels.

Modern stream valleys have been cut into these old Pleistocene valleys, tearing away their gravels and re-working the gold into placers which now lie as bars in valley flats and stream beds.

Prospectors thus have three sets of gravels in which to search for placer gold; first, the high level benches 100 to 300 feet above the present valleys; second, the low level benches 10 to 15 feet above the bottoms of these valleys; and third, the bars in the bottoms of these valleys. A list of the placer districts of the Black Hills, taken from Connolly's[1] report, is included here.

County	District	Subdivisions
Custer	French Creek (Custer)	
	Lightning Creek	
	Pleasant Valley Creek	
**	****	****
Lawrence	Deadwood	Blacktail Gulch
		Bobtail Gulch
		Deadwood Creek
		Gold Run
		Sawpit Gulch
		Whitewood Creek
	Galena	Bear Butte Creek
		Ruby Gulch
		Strawberry Creek
	Nigger Hill (Tinton)	Bear Gulch
		Beaver Creek
		Iron Creek
		Mallory Gulch
		Nigger Gulch
		Poplar Gulch
		Potato Gulch
		Sand Creek
	Spearfish Creek	
	Two Bit	Spruce Gulch
		Two Bit Creek

[1]Connolly, J. P., op. cit., pp. 12-13.

County	District	Subdivisions
**	****	****
Pennington	Battle Creek	Harney
		Hayward
		Iron Creek
	Castle Creek	Cheese Hill
		Crooked Gulch
		Hoodoo Gulch
		Mystic
	Hill City	Newton Fork
		Palmer Gulch
		Upper Spring Creek
	Junction	
	Little Rapid Creek	
	Rapid Creek	Bear Gulch
		Big Bend
		Nielsens
		Nugget Gulch
		Pactola
		Placerville
		Victoria Creek
	Rockerville	
	Sheridan (Lower Spring Creek)	
	Slate Creek and Skull Gulch	

It will be noted that all of these districts lie in the outer margin of the crystalline area of the Black Hills, and in stream valleys which head in this area. Gold placers have been found in regions farther away from the Black Hills, but workable placers do not seem to have been formed very far from the source of the gold. Prospecting outside the Hogbacks which surround the Black Hills has not proven profitable.

The placers of the Black Hills also yield other minerals which under some market conditions have been and might be of value to the miner. The most important accessory mineral has been cassiterite (tin stone). Some of the placers in the Nigger Hill district about Tinton have yielded enough tin to sell. Tin should also be found in placers emanating from the pegmatite districts of Keystone and Custer. However, none has been found in sufficient quantities to operate for tin alone, and Nigger Hill district is the only one which has furnished saleable quantities. Columbite and tantalite have also been reported from placers of the southern Hills. Placers in the vicinity of Keystone and Custer can furnish these minerals which yield niobium, and tantalum important to the steel industry. Other minerals which have been listed, from the placers are, wolframite ($(Fe,Mn)WO_4$), scheelite ($CaWO_4$, (both tungsten ores), zircon ($ZrSiO_4$), beryl (an ore of beryllium), monazite (thorium ore), garnet, magnetite (iron ore), hematite (iron ore), ilmenite (titanium iron ore) tourmaline and barite.

The Black Hills placers have sometimes been called "Poor man's placers" because the pay streaks have amply repaid simple mining methods but have not been sufficiently rich to pay for the investment of a large amount of capital. Some dredging was tried on Castle Creek and hydraulic methods on Rapid Creek in the early days of placer mining. However, these were not profitable and were soon abandoned. During the recent depression, between 1934 and 1938, there was a considerable revival of machine mining but most of this was done with mechanical bowl separators and small power shovels. At least three of these machines were used in French and Spring Creeks and proved fairly successful. Most of the mining that has been done, however, has been with sluice box, rocker, and hand shoveling. This latter method allowed the miner to follow the pay streaks better than did machine methods and thus gave him a satisfactory return for his labor.

RARE METALS

I. Pegmatite Deposits

South Dakota has the distinction of producing certain rare metals, which are found in but a few places. At present, the demand has been for beryllium for making spring steel and lithium for a great many uses including glass making and welding. In the past, however, the state has produced tin, tungsten, tantalum, niobium, and caesium. All of these minerals appear in a volcanic rock of rather unusual origin, known as pegmatite.

The pegmatites in South Dakota are granites which have cooled at a low temperature (for volcanic rock) and thereby allowed unusually large crystals to form. While still in a liquid state, the pegmatites injected themselves into country rock so that they occur as dikes or tabular shaped bodies bulged so as to resemble an irregular biconvex lens. Most of them have been pushed between the leaves of the foliated schists, "Like the water in a blister causing the schist layers to spread apart. * * * There is definite field evidence that these bodies are not shaped like a pane of glass, thus extending down to some mass of parent igneous rock with only minor changes in thickness. Rather they seem to be more or less isolated masses suspended at bulges in the schist. They are thus not dikes in the ordinary elementary textbook sense of the word. In places they are so thick that apparently disconnected bodies may be part of one single mass which has extremely pronounced pinch and swell structure; these may represent truly disconnected bodies (pinched to zero thickness) or they may be connected below the present surface, or they may have been connected above the present surface."[1] In places they take a rounded form more or less beehive in shape. Such is the case with the famous Etta pegmatite at Keystone, which was originally called the Etta Knob because of its topographic appearance. These are also referred to as conoliths by Gwynne. "There is every gradation from the dike-like masses having tabular or lenslike outline in cross-section through those that are elliptical, rounded, and irregu-

[1]Fisher, D. J., Preliminary report on some pegmatites in the Custer District: South Dakota Geol. Survey Rept. Inv. 44, p. 5, 1942.

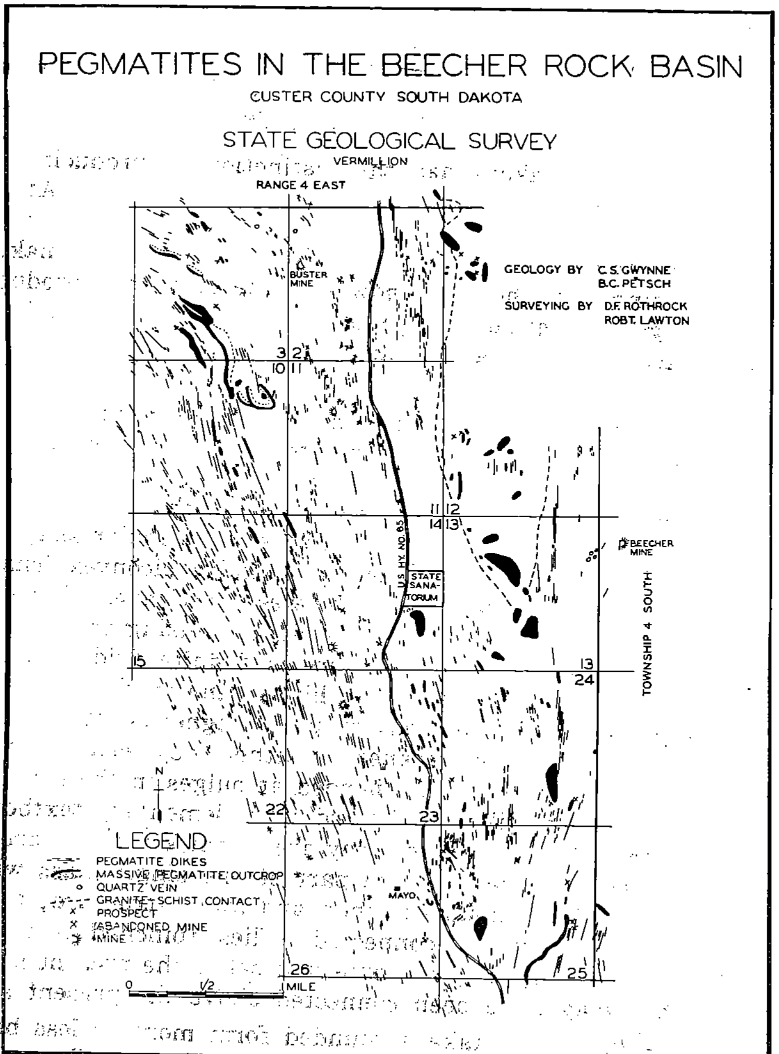


Figure 8

lar. Some are massive but of unknown outline, and some shown as massive pegmatites may consist of thick closely spaced dikes. * * * Some of the areas underlain by these massive pegmatites are hundreds of acres in extent."[1]

All investigators concede that these dikes are injections from the Harney Peak batholith formed during the latter stages of the batholith's intrusion.

It is believed by most observers that pegmatites are formed from residual solutions coming from deep in the magma after a considerable shell has been frozen on the magma. Cracks in this outer shell allow the solutions to work out of the original mass into the surrounding rocks.

In these solutions were collected a suite of rare chemical elements which did not crystallize at the higher temperature at which the main mass of the magma froze. These include the rare metals that have been mentioned above.

Fisher[2] states that there are at least three stages in the formation of these pegmatites. The first takes place while the magma is like a boiling cauldron of slag. The higher pressure finds certain lighter parts of the magma pushed into the pegmatite zone shoving schist layers apart and forming the bulk of the original pegmatite material which consists mostly of potash feldspar, some soda-feldspar, quartz, muscovite, mica, and tourmaline. The second stage of injection comes later, as an increasing amount of the magma crystalized at depth. Residual, relatively fluid portions were forced out and upward, following the paths of the first injection. These solutions were relatively rich in water and dissolved out some of the earlier formed material, replacing it with beryl, muscovite, cleavelandite (tabular soda spar), spodumene, (lithium silicate) and amblygonite (lithium phosphate). The third stage followed sometime after the solutions themselves had cooled down considerably. The tendency was to get replacement veins cutting through the pegmatite roughly up-dip and containing apatite (calcium phosphate), lithiophilite (lithium phosphate) usually altered to purpurite, and

[1]Gwynne, C. S., Pegmatites in the Beecher Rock Basin: South Dakota Geol. Survey Rept. Inv. 48, p. 15, 1944.

[2]Fisher, op. cit., p. 6.

loellingite ($FeAs_2$) in close association with the soda feldspar cleavelandite.[1]

Fisher further states, "No two pegmatites studied were similar in all respects. In some the first stage is greatly dominant or even the only one recognized; in others the intermediate stage has been of very great importance. * * * All pegmatites do not show important developments of all stages, but there is almost infinite variation."[2]

Pegmatites occur in the so-called southern Black Hills, roughly surrounding Harney Peak. Important commercial pegmatites have been operated on all sides of the outcrop of the Harney Peak granite except the east. The oldest pegmatite mine in the state is the famous Etta mine at Keystone which was opened in 1885. Since then several others have been opened in that vicinity. A second group of pegmatites is found in the vicinity of Hill City, some of which were very important during the tin boom in the early 1880's. A third group lies near Oreville on the west side of the granite mass, and a fourth about Custer, which is at present the most important of the pegmatite districts. In the Custer district, pegmatites occur in a strip twelve miles long between Custer and Pringle. In the upper part of this area, which has been termed the Beecher Rock Basin, 1498 dikes were mapped in an area of 12 square miles.[3]

An isolated group of pegmatites occurs at Tinton on the South Dakota-Wyoming line directly west of Lead.

According to Fisher, these pegmatites are a phenomena confined to the immediate vicinity of the batholith. The enormous number of pegmatites between Custer and Pringle, therefore, would indicate that the top of the Harney Peak batholith was but a short distance below the surface in this area.

There are many characters that differentiate pegmatites from ordinary igneous rocks but the one that strikes the

[1]Fisher, D. J., **op. cit.**, p. 6.

[2]**Idem**, pp. 6-7.

[3]Gwynne, C. S., Pegmatites of the Beecher Rock Basin: South Dakota Geol. Survey Rept. Inv. 48, 1944.

PLATE 5. Spodumene Crystals, Etta Mine, Keystone, S. Dak. These "Logs" are a source of lithium.

casual observer most forcibly is the size of the grain. In ordinary granite, grain sizes up to 1/8 of an inch in diameter are considered coarse. In pegmatites, however, these same minerals make crystals up to a foot or two in diameter commonplace; mica, which ordinarily makes scales a quarter inch or less, comes out of pegmatites in sheets which may average anywhere from three or four inches, to eight or ten inches, and in some cases one or two feet across.

Giant crystals are not uncommon; especially in some of the larger pegmatites, the mineral spodumene, a lithium silicate, tends to make long columnar crystals, called "logs," by the miners. Logs have been reported from the Etta mine measuring 47 feet in length and in making a scafford a 10 foot plank was set across the short dimension of a large beryl crystal at the Bob Ingersol mine near Keystone.

The pegmatites of the Black Hills are granite and, therefore, are made largely of quartz, feldspar, and mica,—usually the white mica, muscovite. In most pegmatites, black tourmaline crystals are very conspicuous, making long needles or columns which break into chunks resembling hard coal. Sprinkled through these pegmatites, however, some fifty or more minerals have been reported. Sometimes these minerals are isolated crystals, but in other cases they occur in segregated masses sufficiently large to make ore shoots. The following list of minerals has been compiled by Connolly.[1]

PEGMATITES

1. Apatite
2. Arsenopyrite
3. Autunite
4. Barite
5. Beryl
6. Biotite
7. Bismuth
8. Cassiterite
9. Chalcocite (secondary)
10. Chalcopyrite
11. Columbite
12. Corundum (?)
13. Dolomite
    Feldspar, see albite, anorthoclase, microcline, oligoclase, orthoclase
14. Fluorite
15. Galenite
    Garnet, see almandite, grossularite, spessartite
16. Gold (by assay)
17. Graphite
18. Griphite
19. Ilmenite
20. Leucopyrite
21. Lithiophilite
22. Loilingite
    Mica, see biotite, lepidolite, muscovite
23. Molybdenite
24. Monazite
25. Petalite
26. Pollucite
27. Pyrite
28. Quartz
29. Rubellite
30. Scapolite

[1]Connolly, J. P., and O'Harra, C. C., Mineral wealth of the Black Hills: South Dakota School of Mines, Bull. 16, p. 231, 1927.

PEGMATITES—Continued

31. Siderite
32. Spodumene
33. Stannite
34. Struverite
35. Tantalite
36. Tapiolite
37. Titanite
38. Torbernite
39. Tourmaline
40. Triphylite
41. Triplite
42. Uraninite
43. Wolframite
44. Zircon

Present knowledge of the pegmatites is too limited to predict the mineral make-up of an unprospected pegmatite. Since the mineral suite depends upon the number of stages of mineralization that took place, there is a great variation in the mineral suite which different dikes contain and in the percentage of the same mineral in different dikes. As there must be some organization to the mineral make-up in different localities, however, it is to be hoped that it will be revealed in the near future and thus eliminate a great deal of expensive exploratory mining. Present production may not be an index of what may be expected in the future, since so few of the tremendous number of pegmatites have been opened.

Of the rare metals, however, the Custer district has produced considerable lithium from the minerals spodumene ($LiAlsi_2O_6$), ambligonite ($LiAlRFO_4$) and a little from the lithium mica lepidolite. The Beecher mine has produced all three lithium minerals. Lepidolite, however, is not widespread in this district.

Beryl ($Be_3Al_2Si_6O_{18}$) is found in a great many mines in this district. The recent demand for this mineral and the work of Mr. Lincoln Paige of the U. S. Geological Survey, has disclosed a large volume of beryl which had been overlooked because of its lack of crystal faces and the small size of the grain. This district should be an important source of the metal beryllium.

Other rare minerals have been reported but in very small amounts. The most interesting is the metal caesium which was found in the mineral pollucite ($Cs_4Al_4Si_9O_2,H_2O$) at the Tin Mountain mine. A small production was obtained during a demand in the early days of the radio because it furnished a valuable alloy used in radio tubes. In spite of the name of the Tin Mountain mine, tin does not occur in any quantities which might give commercial production in the Custer pegmatites. Tungsten minerals are found in some, however.

The Keystone district on the other hand, is a lithium producer, and has been such since the early days of the pegmatite mining. The silicate minerals, lepidolite and spodumene were first used exclusively as ores of this metal. Later the phosphate ambligonite was discovered and has furnished most of the production. For some purposes, as in the manufacture of glass, lepidolite is still used.

Most of the metals found in the Custer district occur at Keystone also, but in minor quantities. They are saved, however, until enough have accumulated to sell; but they have not made the important production of the district. The most important of these has been tungsten, usually in the form of wolframite, the iron tungstate.

It is interesting to note that in none of the pegmatite districts have rare metals been found in sufficient quantities to pay for mining the pegmatites for them alone. As will be explained under ceramic and miscellaneous minerals, these pegmatites have produced feldspar and mica as their chief products. So much of these latter minerals have to be removed to obtain a shipment of rare metals that rare metal mining is to a large extent, dependent on the price of feldspar and mica.

Though tin was first discovered in 1883 at the Etta mine near Keystone and during a boom in the 1880's, tin mining was attempted at Hill City, the chief interest and the largest tin deposits seemed to be the pegmatites of the Tinton district on the Wyoming line in Lawrence County. A careful investigation was made of this district and a report issued by Ward C. Smith and Lincoln R. Paige.[1]

Though 240 pegmatites were examined with core drills, only 40 contained tin, the richest ore containing not over two percent cassiterite (SnO_2), the only tin ore mineral. Most of these cassiterite bearing pegmatites lay along the crest of Nigger Hill or east of it. Cassiterite is scattered through the dikes sometimes in grains and clusters of grains as large as two inches in diameter. Much of it is disseminated through the ore shoots in small grains, known to the miners as "pepper tin," however, the average content of the best pegmatite examined was 6.33 pounds of tin per ton. When the examination was made in 1941, the average price of tin

[1]Smith, W. C., Paige, L. R., Tin-bearing pegmatites of the Tinton District in Lawrence Co., South Dakota: U. S. Geol. Survey Bull. 922-T, 1941.

was about fifty cents a pound and the cost of producing tin at Tinton was about one dollar a pound. For this reason, these pegmatites have not yielded to commercial exploitation. It has been estimated that the best pegmatites in the Tinton district contain about 11,002 tons per 100 feet depth and enough ore is in sight to run a 150 ton mill about three years.[1]

Beecher Lode

The Beecher lode, 4½ miles S-SE of Custer, contains many characters common to all pegmatites and the description of it is here included to illustrate the general occurrence of these bodies and their mineral contents.

"This (The Beecher Pegmatite) consists of a lenticular mass about 200 yards long extending north-south; it appears to have a maximum thickness slightly in excess of 100 feet at the outcrop * * *. The exposures are practically limited to the three main pits sunk in it * * *, together with subsidiary "gopher holes" and tunnels, since the surface is otherwise covered with a very thick scrubby secondary growth. At first glance one is reminded of a baby duplicate of the famous Etta mine, because of the rusty appearance and the large powdery spodumene logs, shown especially well in the east walls of the Middle and South Pits. In general the best specimens can be collected from the numerous small dump piles, since large parts of the mine itself are covered with debris and many of the small holes are badly caved. It is very difficult to find specimens that are free from limonite stains or other alterations. The first impression might indicate that this is because of weathering that has occurred largely subsequent to the time of starting mining operations. However, the persistence of the limonite veinlets and staining films with depth clearly indicates that secondary deposition has been very important, and in the main this antedated man's activities here. One of the most important problems in connection with further development, especially as regards possible utilization of the feldspar, is to determine to what depth such alteration has proceeded.

"Little is known of the actual dip of the pegmatite body. Drill holes numbers 1 and 3 * * * were put down in the sum-

[1]Gardner, E. D., Tin Deposits of the Black Hills, South Dakota: U. S. Bureau of Mines Information Circular, 7069, p. 56.

mer of 1941 and were reported to cut the footwall at depths of 51 feet and 23 feet respectively. No. 1 struck a serpentinized amphibolite with the amount of dip of its schistoxity about 20 degrees different from the dip of the hole 65 degrees due west; No. 3 dip 62 degrees due east went into mica schist. The average dip of the base of the pegmatite between these two holes is thus approximately 25 degrees to the west. The collars of these holes were at an elevation of 5551 feet. Drill hole No. 2 in the base of a stope of the North Pit with collar at 5552 feet went through 50 feet of pegmatite and 6 feet of amphibolite carrying small lilac garnets. The dip of the amphibolite schistosity was parallel to the dip of the hole 45 degrees to N. 80 degrees west. * * *

"Exposures in the three approximately horizontal tunnels which have been put into the pegmatite are significant in this connection. The adit (floor at 5571 feet) to the North Pit is cut through footwall mica schist dipping from 25 degrees to 45 degrees in a westerly direction. The tunnel (floor at 5551 feet) to the Middle Pit shows footwall mica schist with schistosity approximately horizontal; however, just inside the pit (well seen near the east side of the north end) this plunges off steeply to the west. In short here the base of the east edge of the pegmatite is nearly horizontal as if it were lying down. * * * The small tunnel (floor at 5521 feet) near the south end of the Beecher pegmatite * * * cuts through pegmatite with many large spodumene logs 10 feet or more long and 18 inches or more through. But at the west end of this adit the floor extends into mica schist with nearly horizontal schistosity. In short, here too, the pegmatic floor is more or less horizontal, with rolls in the underlying schist.

"At the southwest corner of the Middle Pit there is a remnant of a tourmalinized schist block analogous to a small roof pendant. A few yards to the northwest there are fragments of schist probably not far out of place. There is a large mass of infolded schist at the northwest corner of the North Pit. This carries many tiny lilac spodumenes.

"Although some spodumenes or spodumene remnants are found in many pegmatites of the Custer area, at no other place observed except the Louise Lode * * * is spodumene so abundant; * * * the spods are really large logs only at the Beecher. The latter is also unique for the Custer area because of its peculiar milky beryls that lack crystal faces.

Moreover the large reported columbite yield could not have been found at any other known Custer-district mine.

"The North Pit shows in its west wall large surfaces of rusty microcline, with only a few spodumenes. These are more pronounced in the east wall, where they are of medium to large size, but less thick than in the same wall of the other two pits. Nodules of amblygonite may be seen in the stope in the west wall opposite the tunnel. This slopes down at about 45 degrees and extends from the 5570 level of the main pit to the lower tunnel (running north from the middle pit) at about the 5552 level. A few feet north of the entrance to this stope is a Y-shaped tunnel sloping down from the 5570 level towards the west from which fair samples of cleavelandite cutting the microcline perthite were obtained. Another similar sloping entry is shown * * * at the north end of the pit. Just south of the end of this is where the original shaft opening of the Beecher Lode is reported to have been sunk 60 feet deep; this is now completely covered by debris. * * * Three yards north of the North Pit * * * is a small pit about 10 feet deep; its walls are composed of quartz-cleavelandite-muscovite rock, except near its east side, where the quartz rapidly disappears and cassiterite becomes important. Hand samples with 5% of this tin mineral are easily collected here, presumably not far from the footwall.

"The spods of the west wall of the Middle Pit are nearly limited to its lower third; they are much more pronounced in the east wall where they occur in a heavily limonite-stained cleavelandite-muscovite-quartz rock which is locally very rich in muscovite. There is a large mass of limonite-stained bull quartz (translucent whitish, not true milky) in the lower part of the south half of the west wall of this pit. This is cut by the striated molds made by platy euhedral spodumenes, up to 3 feet long and 6 by 2 inches in cross-section, which formerly cut through it at all angles. Such spodumenes commonly show a partial aureole of cleavelandite-muscovite quartz rock, as is so well exhibited at the Hugo and Etta mines near Keystone. The upper part of this wall seems to be mainly quartz-cleavelandite-muscovite rock. * * *

"The spire between the Middle and South Pits that rises to 5587 feet is capped by about 6 feet of coarse microcline resting on massive whitish quartz; the contact between these two dips about 45 degrees to the west. This same quartz is prominent in both walls of the trench immediately to the east; much columbite is reported to have been removed from here.

"The South Pit, like the North one, has its floor covered with debris. The walls seem to be mainly a quartz-rich cleavelandite-muscovite rock with much spodumene in the east wall * * *, considerable less on the west. A couple of "gopher holes" * * * extend 4 to 5 yards sloping down 30 degrees into the east wall; they show some large spods. From a shaft sunk in this pit much spodumene is reported to have been removed."

This description is taken from a report by Dr. Fisher.[1]

II Replacement Deposits

The only rare metal that occurs in replacement deposits is tungsten. These deposits are found only in the northern Black Hills in connection with Tertiary gold replacements in the Deadwood formation. Since they have been described in previous pages (see pages 36 to 42), the descriptions will not be repeated here.

III Tin and Tungsten Placers

The tin ore mineral, cassiterite, and tungsten mineral, wolframite, are very heavy and, therefore, yield readily to concentration in the gravel bars of streams in the vicinity of tin or tungsten-bearing primary deposits. Placers in the northern Hills and in the Custer district have yielded small amounts of these minerals. However, they have not been in sufficient quantities to pay for extraction.

The placer deposits in the vicinity of Tinton have yielded a little tin and at various times small amounts have been sold by placer miners. So far, these placers have yielded neither a large nor a steady production. In times of crises, however, they might supply an amount sufficient to make their operation worthwhile.

[1]Fisher, D. J., **op. cit.**, p. 25.

BASE METALS

I Aluminum

The metallurgist's dream of producing aluminum from clays and shales has captured the popular fancy in South Dakota to a point where it seems advisable to insert a note on the possibilities of obtaining this metal in the State. The idea originated from the fact that the basis of most clays and shales is the mineral kaolin, a hydrous silicate of aluminum ($Al_2O_3.2SiO_2.2H_2O$). The mineral now used as aluminum ore is the oxide, bauxite (Al_2O_3). Since the supply of bauxite is limited, and clay or shale is found nearly everywhere, it is argued that all that is needed is a process of extraction to produce an inexhaustible supply of the metal.

Pure kaolin contains 39.5% alumina (Al_2O_3) which would make a good ore if the mineral bauxite ($Al_2O_3.2H_2O$), did not contain 73.9% alumina. Added to the difference in the amount of metal contained by the two minerals is the fact that alumina and silica form a chemical bond which is not easy to break with commercial processes, though it can be done in the laboratory. The bonds between aluminum and oxygen in bauxite, on the other hand, can be easily and cheaply broken. The problem, therefore, reduces itself to one of economics. As long as bauxite can be obtained easily and cheaply and in sufficient quantities, it will be much more attractive to aluminum producers than will clay and shale. However, if a cheap process of extracting aluminum from clay is developed, the picture will reverse.

Pure kaolin contains a fairly large per cent of alumina, but few shales or clays are made of pure kaolin. Much quartz, mica, organic matter and other materials go into the make-up of the average clay or shale, and most of these are non-aluminum bearing; therefore, most clays and shales cannot yield nearly as large a quantity of the metal as the bauxite ores or even as good kaolin.

Few of South Dakota's shales have been analyzed for their aluminum content, but an investigation was made of the Pierre shale along the Missouri River and of some miscellaneous samples collected about the Black Hills. The average of six miscellaneous samples from the Pierre shales around the Black Hills, the horizon of which is not known, gave

18.8% alumina (AL_2O_3) or about 9.9% of metallic aluminum. The following table gives the aluminum content of the Pierre shales along the Missouri River.

ALUMINUM CONTENT OF THE PIERRE SHALES[1]

Member of Pierre Formation	Location	Per Cent Aluminum
Verendrye	Stanley County	9.74
Oacoma	Stanley County	7.15
Virgin Creek	2 miles east of Teton, Stanley Co.	10.84
Gregory shale	Sec. 32, T. 9 S., R. 5 E., Fall River Co.	12.27
Sharon Springs	Sec. 32, T. 9 S., R. 5 E., Fall River Co.	8.04
Elk Butte	Sec. 3, T. 96 N., R. 68 W., Gregory Co.	12.67
Mobridge	" "	8.21
Upper Virgin Creek	" "	11.52
Lower Virgin Creek	" "	10.96
Verendrye	" "	8.64
Oacoma	" "	10.97
Gregory chalk	" "	4.52

If the extraction of aluminum from shale becomes metallurgically and economically possible, South Dakota can offer several sources of raw material. The Pierre shales exposed in the Missouri Valley and outcropping over about a third of the state west of the Missouri have been mentioned. Certain clays in the Tertiary rocks of the Bad Lands, south of the White River, might yield useable materials. Under-clays beneath the coal beds in the upper Cretaceous formations north of the Moreau River also offer some interesting possibilities.

East of the Missouri River, the entire country is veneered with glacial drift. These clays vary a great deal in material, some being sandy and others sticky gumbo. All of them contain aluminum, though, like the bed rock shales west of the River, there has been no attempt to analyze them with their aluminum possibilities in mind.

Assuming these low grade shales and clays could be used, the location of plants would depend more on fuel, transportation, and other geographic factors than on the grade of ore available. The enormous amounts of clay and shale scattered widely over the state do not give any region an advantage in materials.

[1]Gries, J. P., Economic possibilities of the Pierre shale. South Dakota Geol. Survey Rept. Inv. 43, p. 66, 1942.

II Iron

The recent search for limonite deposits to be used in making iron and steel by the so-called "sponge iron" process, raised the question whether the state could supply any material of that sort. Iron is the fourth most abundant element in the outer shell of the earth but it is concentrated in deposits that can be worked as ore in only a few places. Attention has been focused on two possible sources: first, hematite deposits in the pre-Cambrian rocks of the Black Hills, and second, concentrations of limonite in gravels which occur on the Great Plains.

Hematite Ores

Hematite ores have been reported from five places in the Black Hills. Four of these deposits are interbedded with the pre-Cambrian rocks in much the same manner as the Lake Superior ores. This has given rise to the idea that the rocks of the two regions were approximately of the same age. Such inter-bedded ores occur in the upper Boxelder Valley near Nemo, at Bench Mark, at Hat Mound, ten miles northwest of Rapid City, and at Iron Mountain, three miles south of Keystone. The total thickness of iron-bearing rocks at Iron Mountain is about a thousand feet. The ore bodies show an approximate thickness of fifty feet and can be traced for about a mile. A fifth location is on Battle Creek near Hayward and occurs on the divide between Battle Creek and Foster Gulch. This deposit is a replacement deposit lying at the contact of the pre-Cambrian shales and the Cambrian conglomerates.

The following analyses will give an idea of the character of the ore. The analyses of Hat Mound iron ore, representing a general sample across the face of the ore body.

Analyses of Hat Mound Iron Ore[1]

Fe_2O_3	84.050
SiO_2	11.220
Al_2O_3	3.380
P_2O_5	0.801

[1]Analyses as given by Coolidge, C. W., and Overpeck, L. S., in Mining Science vol. 60, p. 319, 1909.

S	0.080
MnO_2	Trace
CaO	Trace
MgO	Trace

Analyses of Hayward Red Hematite[1]

Fe	50.30%
SiO_2	17.70
Al_2O_3	Trace
P	0.15
S	0.17
MnO_2	Trace
CaO	1.08
MgO	Trace

It has not been profitable to mine this iron.

Limonite Ores

The sponge iron process uses the mineral limonite ($2Fe_2O_3.3H_2O$), instead of hematite which is the common iron ore mineral in United States. Limonite is a secondary product usually caused by the weathering of hematite or magnetite ores and often precipitated in the bottoms of stagnant marshes and ponds in a spongy mass known as bog ore. It often takes a buck-shot structure due to the formation of small limonite concretions in it.

Such a deposit of bog ore occurs in a number of patches in the bottom of the north and south forks of Rapid Creek near Rochford and has furnished a small commercial production. One of the patches is about a thousand feet long and forty to sixty feet wide with an average depth of six feet. In the early 1900's it supplied paint rock for a small mill in Custer. These deposits were formed by the weathering of iron-bearing minerals in the pre-Cambrian rocks of the neighborhood.

Some interesting bog ore deposits are found in the northwestern quarter of the state where iron is leached from the upper Cretaceous sedimentary formations, particularly the Hell Creek formation. Limonite is precipitated as concretions and small masses of bog ore which are concentrated in the stream valleys as gravel deposits. These gravels are found as terraces along the Moreau and its tributaries and in some

[1]Coolidge, C. W., and Overpeck, L. S., **Idem.**

places have been used as road gravel. A few of these deposits were mapped northwest of Timber Lake. They lie on valley bluffs as terraces in which the limonite is three or four feet thick and in deposits containing volumes up to 200,000 cubic yards. Similar deposits have been noted in many places on the Hell Creek formation and in the stream valleys immediately surrounding its outcrops. While not large deposits, under the proper economic conditions, these might be used as raw materials for sponge iron or paint rock. Most of the deposits contain considerable clay making yellow and brown ochers. Much of it is also characterized by the buck-shot structure which makes possible its use as road gravel. However, the concretions are so firmly cemented in the pit that it is necessary to blast the iron loose before it can be handled with shovels or scrapers.

III Magnesium

A search for sources of magnesium has been aroused by the present war, and while most of it produced thus far has been obtained from sea water, some has come from dolomitic limestone. There has been considerable interest in the possibility of obtaining more from this source.

Magnesium is a metal that has about half the weight of aluminum and offers certain distinct advantages by causing reduction of weight when alloyed with various other metals. It has been used in making castings, engine crank cases, bearings, microscope parts, moving picture machine parts, surveying instruments and as a flashlight powder.

Pure dolomite contains 47.9% carbon dioxide, 34% lime and 21.7% magnesian (MgO). Most dolomitic limestones, however, do not reach this percentage because of foreign matter in the rock.

Three formations in South Dakota would offer an unlimited amount of dolomite as a source of magnesium. The biggest one is the Pahasapa formation which makes most of the limestone outcropping on the limestone plateau in the Black Hills. This is of Mississippian age. Above it, the Permian Minnekahta limestone, though only 40 feet thick, outcrops in such a manner that it can easily be quarried at many places. In the northern Black Hills, the Whitewood limestone lying below the Pahasapa also offers a source of this material.

Systematic sampling and analysis of these limestones has not been carried on. It is of interest to note, however, that the following analyses show nearly 20% magnesia from the Minnekahta limestone.

Analysis of Minnekahta Limestone[1]

by Geo. Steiger of the U. S. Geological Survey

Constituent	Per Cent
Lime	31.51
Magnesia	19.85
Alumina, iron, etc.	.36
Water	1.25
Carbonic acid	44.66
Sulphuric acid (SO_3)	.07
Silica	1.12
Manganese, soda, and potash	None
	98.82

At several places in the Hills, fine grained dolomite sand has been formed by the disintegration of the Pahasapa formation. A chemical analysis of the largest of these deposits which lies near Piedmont, gave 49.89% magnesium-carbonate. This is about the percentage found in pure dolomite. An analysis of the Whitewood limestone not far from the city of Deadwood, showed a magnesium carbonate content of 35.89%. These limestones, therefore, might offer a profitable source of magnesium if a demand were created for carbonate ores.

IV Manganese

The largest manganese deposit in the United States lies in the lower part of the Missouri Valley in South Dakota. During the earlier part of the war, it attracted considerable national attention which resulted in the erection of a pilot plant near Chamberlain by the U. S. Bureau of Mines for a series of experiments. This plant was later used by the International Metals Corporation which had planned to mine and beneficiate this ore. The international situation halted the project, however, and this huge deposit has not yet been exploited.

The deposit is of sedimentary origin, the manganese oc-

[1]Darton, N. H., Central Black Hills Folio 219, p. 9, 1925.

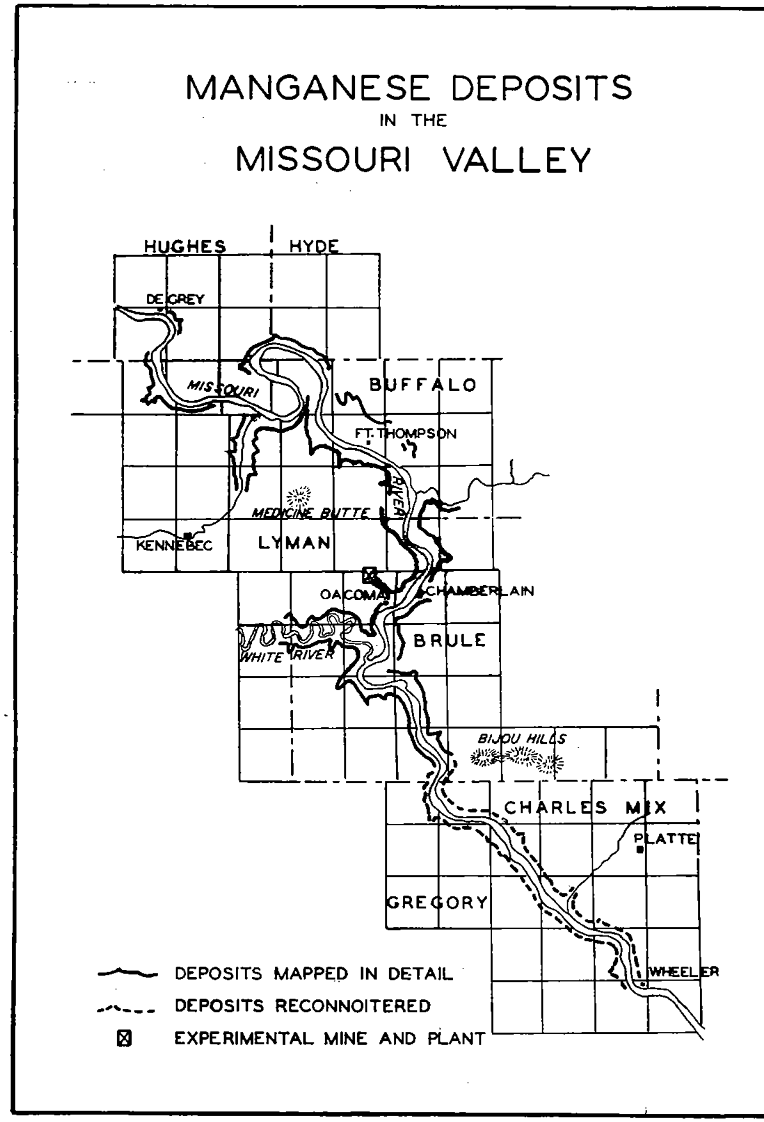


Figure 9.

curring in iron carbonate nodules which are concentrated in a zone in the lower part of the marine Pierre formation. This formation consists of a thick series of grey shales, some zones of which are sufficiently calcareous to be termed marl or even chalk. These shales overlie the Niobrara formation with apparent conformity and form the bed rock over most of the area in the manganese district. The Pierre formation has been divided into six members as indicated on the following table:

Elk Butte Member

Medium gray shale, flaky, few ferruginous concretions, mostly small.
Thickness: 100-243 feet.

Mobridge Member

Chalky shale and chalk which weathers to shades of buff on outcrop.
Thickness: 90-241 feet.

Virgin Creek Member

Upper Virgin Creek: Yellowish gray shale which weathers to gumbo and in upper Missouri Valley is silicious.
Thickness: 65-142 feet.
Lower Virgin Creek: Shale, bluish-gray with many bentonites.
Thickness: 26-145 feet.

Sully Member

Verendrye Zone: Gray shale with abundant flat sideritic concretions.
Thickness: 88-180 feet.
Agency-Oacoma Zone: Gray, dominantly siliceous shale with many bentonites, siliceous in the north, manganese-bearing in the south.
Thickness: 23-124 feet.
Crow Creek Zone: Chalk and sand.
Thickness: 2-15 feet.

Gregory Member

Light gray to buff shale with many concretions and calcareous layers.
Thickness: 35-125 feet.

Sharon Springs Member

Dark bituminous shale with abundant fish scales.
Thickness: 7-35 feet.

Niobrara Formation

Chalk rock.
Thickness: 200 feet.

The manganese lies in the Agency-Ooacoma zone of the

Sully member. This zone, therefore, is the only one of interest to this description. In the upper part of the Missouri Valley where it is exposed from the mouth of the Grand to the city of Pierre, this zone is a siliceous shale with few concretions. This was called the Agency shale zone. South of Pierre, however, it changes its character and becomes a gumbo shale with many concretionary nodules of iron-carbonate which carry manganese. This has been designated as the Oacoma zone. Since the two are variations of the same zone, the names were combined into Agency-Oacoma zone.

The manganese-bearing portion of the Oacoma beds has been traced from DeGrey, 20 miles east of Pierre, to the Rosebud bridge in Gregory County. This may be considered the workable extent of the deposit, since it is the portion of the zone in which the manganese-bearing concretions are sufficiently concentrated to offer commercial possibilities.

The Oacoma zone is characterized by an abundance of bentonite beds separated by shale, which gives it a tendency to weather in step-like forms, the bentonite making the treads and the shale, the risers. In the eastern and southern parts of the area, Fort Thompson to the Rosebud bridge, the shales are gummy and clay-like in structure. Towards the west and north, however, there is a noticeable increase in siliceous material and the shales take on a paper-like appearance which was noted and described in the area around Fort Pierre and northward.[1] The lower limit of the zone is quite sharp, being designated as the top of a chalky marl, the Crow Creek marl, about seven feet thick. Immediately below the marl lies a thin, very persistent sand about a foot thick, known as the Crow Creek sand. These two conspicuous beds make the bottom of the zone extremely easy to identify.

The upper limit is not so easily placed. Manganese-bearing concretions in some sections are scattered sparingly, high up in the shales of the Verendrye zone, which overlies the Oacoma. In all good sections, however, the concentration of nodules thick enough to be of possible commercial interest, ends rather abruptly at the base of, or in the lower few feet of a light colored shale which has been designated as the "banded beds." In most of the area, the top of the

[1]Wing, M. E., A structural survey of the Pierre gas field: South Dakota Geol. Survey Rept. Inv. 29, 1938.

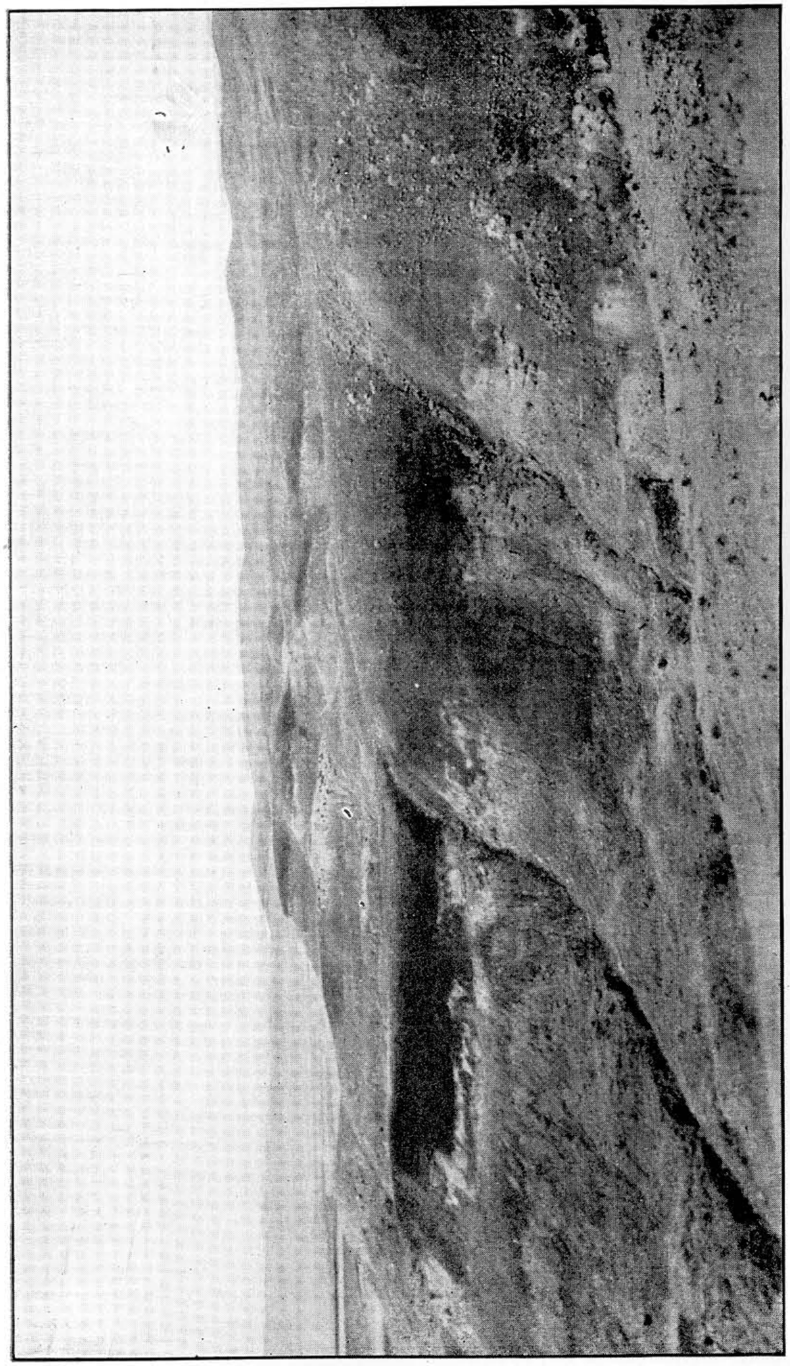


PLATE 6. A Typical Outcrop of Manganese Ore in the Missouri Valley Near Chamberlain
Manganese zone makes the top of all the shoulders seen in the center of the picture.

Oacoma is five to ten feet below a layer of large rusty concretions and about ten or twelve feet above a twelve-inch bentonite bed, thick and persistent enough to be a good marker. The Oacoma zone outcrops on both bluffs of the Missouri and up its tributaries for a distance of several miles and is known to underlie the uplands on both sides of the Missouri Valley at a depth of about 200 feet. Judging from the location of the outcrop, it is fairly safe to assume that it underlies about one-eighth of the area of the State.

Thickness

The thickness of the zone varies considerably but there seems to be no order in the variation. Opposite the mouth of the White River, 65 feet were measured, while at the Rosebud bridge, near the southern limit of the deposit, the zone was 35 feet thick. At De Grey, at the northern end of the deposit, 34 feet were exposed. Over most of the area, however, a rather uniform thickness averaging 44 feet was observed.

Manganese-bearing Nodules

The manganese is carried in concretions of iron-carbonate which occur in layers parallel to the bedding, and separated from each other by one to two feet of shale. Some of these nodules are small, being little larger than marbles, while others are very large, making continuous layers or beds a score or more feet across. They vary in thickness from a half inch to five or six inches. Many of the concretionary layers seem to be associated with bentonite beds lying either directly over or directly under the bentonite. It is not clear whether there is any relation between the two, however. The nucleus of most of these concretions is not apparent. Many, however, are formed about the shells of mollusks and it is of interest to note that the mollusk shells and also the bones of vertebrate fossils found in the zone are usually impregnated with manganese. Though a search was made, no manganese was found in the shales separating these layers, nor do any veins or vein-like structures carrying manganese occur.

The method of occurrence of the metal in the nodules is largely a matter of conjecture. Under the high powered microscope, the grains are too small to be easily identified. Nothing resembling the pink manganese carbonate, rhodochrosite, could be identified. It is probable that the manganese occurs as a compound of manganese carbonate and iron carbonate, sometimes known as mangano-siderite and mangano-calcite. In the weathered portions of the nodules, bluish-black metallic grains of pyrolusite, the manganese dioxide, were identified. These are apparently a secondary product caused by the weathering of the nodules. A qualitative analysis of one of the nodules showed the following elements to be present:

Manganese	Magnesium (small amount)
Iron	Carbonate
Aluminum	Phosphate
Calcium	Silicate

The presence of aluminum and silica is accounted for largely by the clay trapped in the concretions. Iron and the carbonate radical make up the bulk of the concretions. Samples run for iron and manganese show that where the percentage of manganese is high, the percentage of iron is low and vice versa. This suggests the presence of a double salt of magnesium and calcium-carbonate. A chemical analysis of thirteen samples which did not give the minor constituents showed an average phosphate content of 0.407%, silica 12.39%, alumina 2.65%.[1]

An average of more than two hundred analyses taken between Fort Thompson and the White River showed 17% manganese. Between Fort Thompson and DeGrey, a similar number of analyses gave a little higher average, 18.9%. The lowest manganese percentage in any layer was 9% and the highest 31.3%. These are extremes, however, most of the analyses showing a percentage near the average.

The following analyses show the manganese content of the individual layers in four columnar sections:

ON WHITE RIVER

Section 36, T. 104 N., R. 74 W., Lyman County[1]

Layer	% Mn	% Fe	Layer	% Mn	% Fe
A	25.73	5.02	J	27.52	8.27
B	15.82	17.83	K	22.51	9.04
C	27.99	4.00	L	18.57	3.64
D	27.47	5.56	M	21.40	18.02

[1]Hewitt, D. F., Manganese-iron carbonate near Chamberlain, South Dakota: U. S. Geol. Survey, Memo for the press, Feb. 5, 1930.

Layer	% Mn	% Fe	Layer	% Mn	% Fe
E	26.42	3.20	N	21.59	3.37
F	16.09	18.76	O	25.02	3.44
G	24.65	3.03	P	24.20	2.83
H	27.68	3.32	Q	19.01	2.98
I	21.47	4.96			
			Average:	21.30	6.9

N. E. OF OACOMA

Section 6, T. 104 N., R. 71 W., Lyman County[1]

Layer	% Mn	% Fe	Layer	% Mn	% Fe
A	20.58	6.69	I	20.27	4.78
B	18.44	13.50	J	18.69	12.88
C	13.23	19.28	K	21.05	7.30
D	19.54	11.77	L	20.86	3.06
E	23.18	2.99	M	21.92	3.26
F	19.63	3.07	N	21.81	2.55
G	20.15	5.33	O	22.72	2.88
H	22.79	3.35	P	22.43	4.72
			Average	20.40	6.72

DE GREY SECTION

SW¼ of Sec. 6, T. 109 N., R. 75 W., Hughes County[2]

Layer	% Mn	Layer	% Mn
A	15.82	J	21.39
B	16.99	K	19.45
C	23.03	L	20.04
D	24.66	M	19.50
E	20.21	N	21.32
F	25.84	O	21.09
G	23.78	P	20.98
H	19.76	Q	12.74
I	23.46		

Adding the thicknesses of the concretions only, the thickness of manganese nodules in an average section is found to vary between 28.6 and 55 inches, with an average of 39 inches (3¼ feet). Thus the manganese concretions make up approximately 7% of the volume of the Oacoma zone.

Results obtained in test mining at the Pilot mine of the U. S. Bureau of Mines at Chamberlain showed a ratio of nodules to shale of one to twenty-five, or four per cent. This figure is probably low, due to a loss of much small material

[1]Rothrock, E. P., and Gries, J. P., Manganese deposits of the lower Missouri Valley in South Dakota: South Dakota Geol. Survey Rept. Inv. 38, pp. 73-74, 1941.

[2]Rothrock, E. P., Missouri Valley manganese deposits between Lower Brule and De Grey: South Dakota Geol. Survey Rept. Inv. 46, pp. 34-36, 1943.

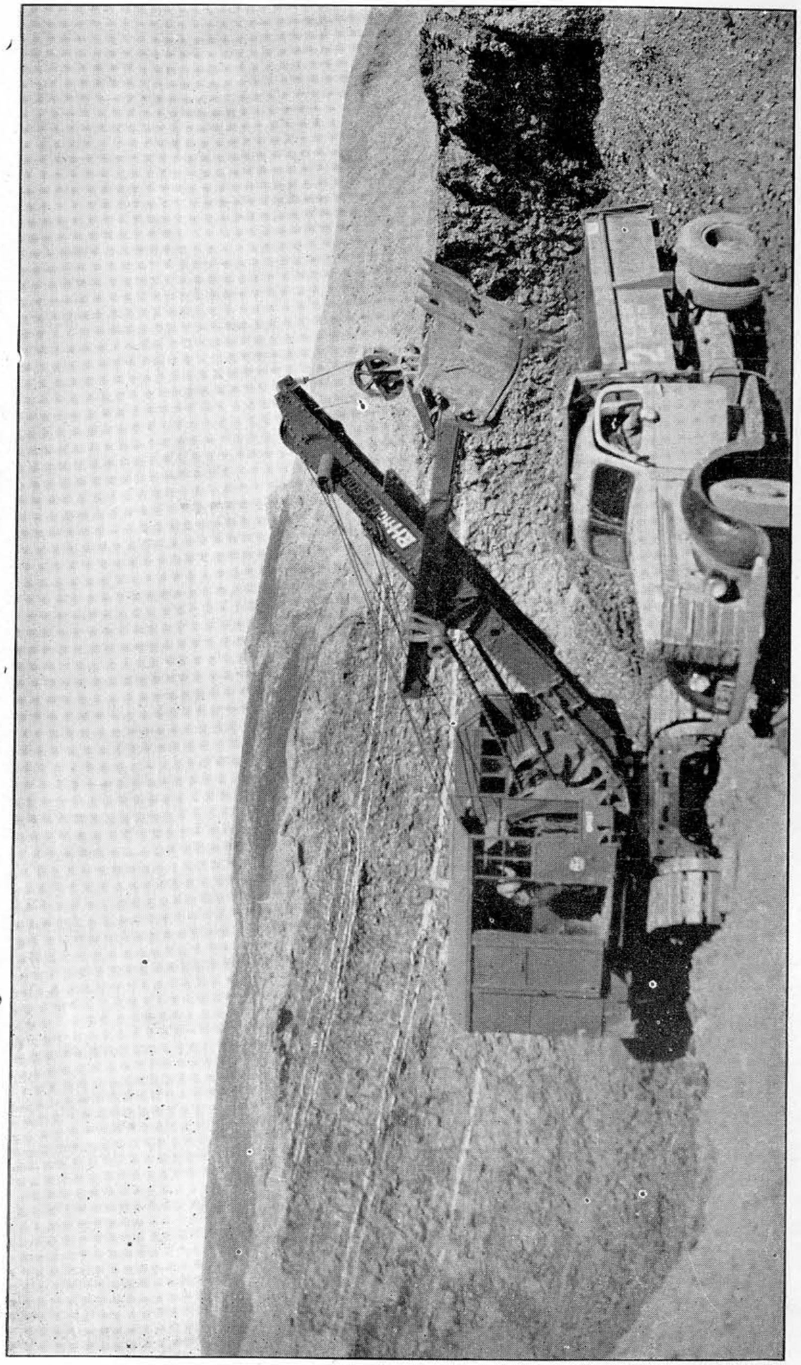


PLATE 7. Excavating Manganese Ore
U. S. Bureau of Mines pilot mine at Oacoma

through the screens. Concentrations vary widely from four per cent in some sections to ten per cent in others.

Figures for the amount of ore available, vary considerably because of the necessity of estimating. There is available on the outcrops, however, about 22,395 acres which can be easily excavated. The best figures indicate that there are about 5,500 tons of nodules per acre. Using these figures, there are about 185,000,000 tons of ore on the outcrop This would yield some 35,000,000 tons of metallic manganese Estimates of the amount under ground run to four or five billion tons of ore.

Mining and Beneficiation

As with most low grade ores, the problem of operating this deposit is one of mining and metallurgy. Large volumes must be handled cheaply to make mining profitable. A number of experiments were carried out in an effort to determine a cheap and easy way to remove the nodules from the clay which sticks to them very tightly. Crushing, washing, and explosion by steam under pressure did not yield satisfactory results. Hand picking reduced the cost considerably but wasted a great deal of material.

The most satisfactory process yet devised appears to be one using a jig which concentrates cheaply and with a minimum of waste.

Being a carbonate ore, it is possible to reduce it fairly easily by processes involving leaching and electroplating.

The obstacles in the way of mining this manganese are not insurmountable and this deposit should some day be contributing its share to the American Steel Industry.

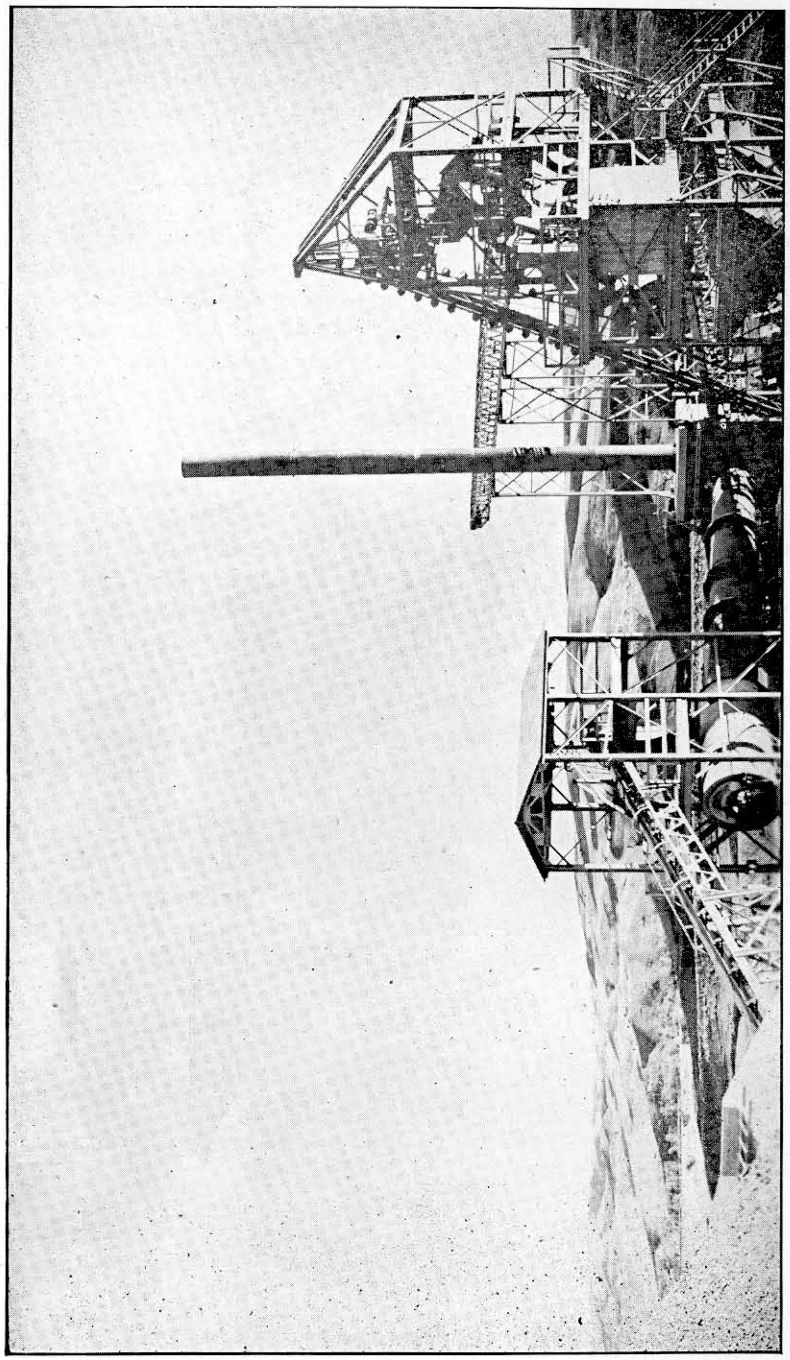


PLATE 8. Pilot Plant of the U. S. Bureau of Mines at Oacoma, S. D. experimentation on manganese ores.

DIVISION II FUELS

Fuels are the most important mineral resource in the development of any region. Under the existing industrial order they are an absolute necessity for power, for manufacturing, and transportation. In a climate like South Dakota's they are a necessity for domestic and public heating. It is doubtful, therefore, whether we could have a population in this state if it were not for mineral fuels. Being bulky commodities, transported fuels are expensive. It will pay South Dakotans well, therefore, to develop the local supply to the utmost.

South Dakota has coal, gas, and oil shale within its borders, and it is still good prospecting ground for pool oil. Very little use is made of these fuels at present. The coal lies dormant, gas is being wasted into the air, the oil shale has never been touched, and only haphazard testing for pool oil has been carried on.

COAL

I. COALS IN THE DAKOTA SERIES

A. East of the Missouri River

Though the commercial coal fields of South Dakota lie in the northwestern quarter of the State, attention has been repeatedly called to the fact that coal is present in the southeastern quarter. Coal flakes are frequently found in the glacial drift south of Highway 16 between Sioux Falls and Mitchell. Two to four inch seams are exposed in the Dakota formation of the Big Sioux Valley and in the Niobrara formation near Springfield. Water well drillers have encountered coal at depths varying from 60 to 100 feet in the vicinity of Stickney in Aurora County, Geddes in Charles Mix County, and near Fulton in Hanson County. These coals have at times caused considerable excitement locally, as they lie in a region far from fuel supplies. According to legend, interest waxed so strong in homestead days that a shooting affair occurred over a thin seam in the Big Sioux Valley.

These coals all lie in the sand series in the base of the Cretaceous system in or near the top of the Dakota sandstone and the sandy base of the Graneros formation. Though some of the coals are shiny and have been mistaken for high rank bituminous and even anthracite, they have all proved to be lignite.

Outcropping seams in the Big Sioux Valley have never exceeded four to six inches in thickness, most of them averaging but one or two inches. Reports of 8 to 10 feet of coal both south and east of Mitchell have been investigated but never verified. Subsequent testing has shown these to be less than a foot in thickness, black shale above or below the seam being mistaken for coal.

In spite of this adverse evidence, however, it is well to remember that these occur in a typical coal making situation, the sands and shales representing the shoreline of an advancing sea. Lagoons and swamps abound in such situations, and there is no reason to believe that coal materials might not have accumulated to a sufficient depth locally to be of commercial importance.

Under these conditions, therefore, it would be unwise to condemn any coal find in southeastern South Dakota without a careful investigation. Coal seams of this type pinch and swell notably, and it is entirely possible that some of these seams could yield a supply for local consumption, even though it might be too small for commercial exploitation.

B. West of the Missouri River

Similar small seams are exposed in the Dakota-Lakota sand series in the southern Black Hills not far from Edgemont, and some mining has been attempted there. An unsuccessful attempt was made to mine one such seam north of Rapid City. Coal in a similar position has been also reported from near Whitewood.[1]

Coal mines were opened in the coals near Edgemont in the early 1900's, but have long since been unused. "On the south bank of the river (Cheyenne) three miles below the town (Edgemont) a drift has been run in on a thin bed of coal in the basal portion of the Dakota sandstone fifty feet below the top ledges of this formation, in which a thickness of three feet of coal of fairly good quality is exposed. Beginning at the second bend of the river, five miles southeast of Edgemont, where the stream is flowing nearly due south, there are a number of coal openings in the bluffs on the east

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[1]Todd, J. E., Mineral resources of South Dakota: South Dakota Geol. Survey, Bull. 3, p. 111, 1902.

bank. * * * In the bend where the river turns east northeast again, there is a mine which has been worked to a small extent, exhibiting four feet of coal lying in a basin which is seen thinning out to the east. * * * It lies * * * about 40 feet above the base of the Lakota formation."[1]

II. COALS IN UPPER CRETACEOUS FORMATIONS

Coals offering commercial possibilities lie in the northwestern quarter of the State in Harding, Perkins, northern Meade, Dewey, and Corson Counties. More than one billion tons of coal in beds more than two feet ten inches thick are available in Harding and Perkins Counties according to an old estimate made by the federal government.[2] This estimate does not include the entire coal reserve in South Dakota since it leaves out an enormous quantity of coal in less than two foot beds, and it does not cover the entire coal area. If all the coal that could be mined were included, the figure would be much higher, perhaps double or treble the old estimate.

A. Fox Hills Coal

The oldest coal-bearing formation in this part of the State is the Fox Hills formation, a sandy series of beds lying immediately on the thick Pierre shale. It represents the first shore deposits of the retreating Cretaceous sea. Though the Fox Hills is fairly extensive in this part of the State, it carries coal only in a small area in northern Meade County immediately south of the Moreau River in the vicinity of Stoneville and Center Point post offices. It underlies an area of 30 to 40 square miles.

A generalized section of the Fox Hills in the Stoneville area follows:

	Thickness in feet
Upper sandstone member	
Sandstone, with thin beds of shale.	
Clays occur in the upper part	139-149
Stoneville member	
Shale, clay, sandstone, coal	10-46+
Lower sandstone member	

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[1]Darton, N. H., U. S. Geol. Survey 21st Ann. Report., Part IV. p. 583.

[2]Winchester, D. E. and others, The lignite field of northwestern South Dakota: U. S. Geol. Survey Bull. 627, p. 46, 1916.

Sandstone with thin beds of shale	135
Shale and sandstone member	
Shale and sandstone in alternating layers	150+
Total	434-480 feet

The Stoneville coal-bearing member thus lies in the upper third of the formation. It is characterized by a thin succession of beds composed of clay, sandstone and coal and is wholly or in part of continental origin. It carries one or more thin beds of coal and several other zones of highly carbonaceous shale known to the miners in the region as "blackjack." This blackjack or bone coal contains beds of coalified plant matter inter-bedded and mixed with considerable clay. There is considerable variation in the thickness of the components of this member. In some sections where coal and carbonaceous beds are thickest, no sandstone is reported, whereas, elsewhere, most of the zone is sandstone and the shales and carbonaceous beds are thin. The occurrence of these beds is well illustrated in a section measured two miles east of Stoneville.

Shaft log of York mine, in the NE¼, NE¼, Sec. 9, T. 9N., R. 12E., Meade County. Reported by Mr. D. E. York.

Stoneville member	
Shale	20 feet
Sand with rock	7 feet
Blackjack	4-6 feet
Soapstone, light gray	4 feet
Blackjack	6 feet
Coal	2 5/6-4 5/12 feet
Blackjack	0-5/6 feet
Lower sandstone member	
Hard sand, in sump	3½-4 feet
Depth of shaft to bottom of sump	49½ feet

The coal is bright black, hard and relatively brittle. Its streak (color of the powder) is brown. It is much darker, however, than most of the South Dakota coal. Analysis shows it to be a lignite of high rank, as indicated by its vertical jointing which breaks it into blocks, similar to the fracture of bituminous coal. Like the Hell Creek coal at Isabel, the Stoneville contains resin bodies in unusual amounts. They

are pale lemon yellow and irregularly shaped. Some specimens of coal show several of these pellets of resin to the cubic inch ranging in size from mere specks to one quarter inch in diameter. Some have been reported over a half inch across.

At some places, small pebble-like masses of light gray shale one-half inch or more in diameter, occur in the coal, and some small sandy pebbles have also been reported. These coals are also cut in some places by sandstone dikes, strongly impregnated with iron pyrite.

The coal seams vary in thickness from a few inches up to four and a half feet thick. Over most of the area, however, the thickness averages two feet or less.

In spite of the lenticular character of the coal, it has been estimated that at least 50,000,000 tons of coal underlie the Stoneville area including thick and thin seams.[1] Of this total, however, only about 1,220,000 tons appeared to be thick enough and sufficiently accessible for mining.

B. Hell Creek Coal

Overlying the Fox Hills formation is the Hell Creek member of the Lance which carries a large part of the coal in South Dakota. These beds outcrop in a rough semicircle through Corson, Dewey, Perkins, and Harding Counties. Throughout the formation, thin seams of coal are common. In three places they have become sufficiently thick to mine commercially. The easternmost is the Isabel-Firesteel area in northwestern Dewey County. The second region is near Gopher, northwest of Isabel in Corson County. The third is in and about the Slim Buttes of Harding and Perkins Counties.

The name "somber beds" used by earlier writers in describing the Hell Creek beds was well chosen, for it describes well the impression they make on the observer. Dark gray buttes rising above dark gray badlands give an impression of color monotony which would be depressing if it were not for the variety of topographic forms which this formation makes.

Gumbo is present in many of the beds of this member. Buttes and badlands display bare slopes of sand and clay

[1]Searight, W. V., The Stoneville coal area: South Dakota Geol. Survey Rept. Inv. 22, p. 17, 1934.

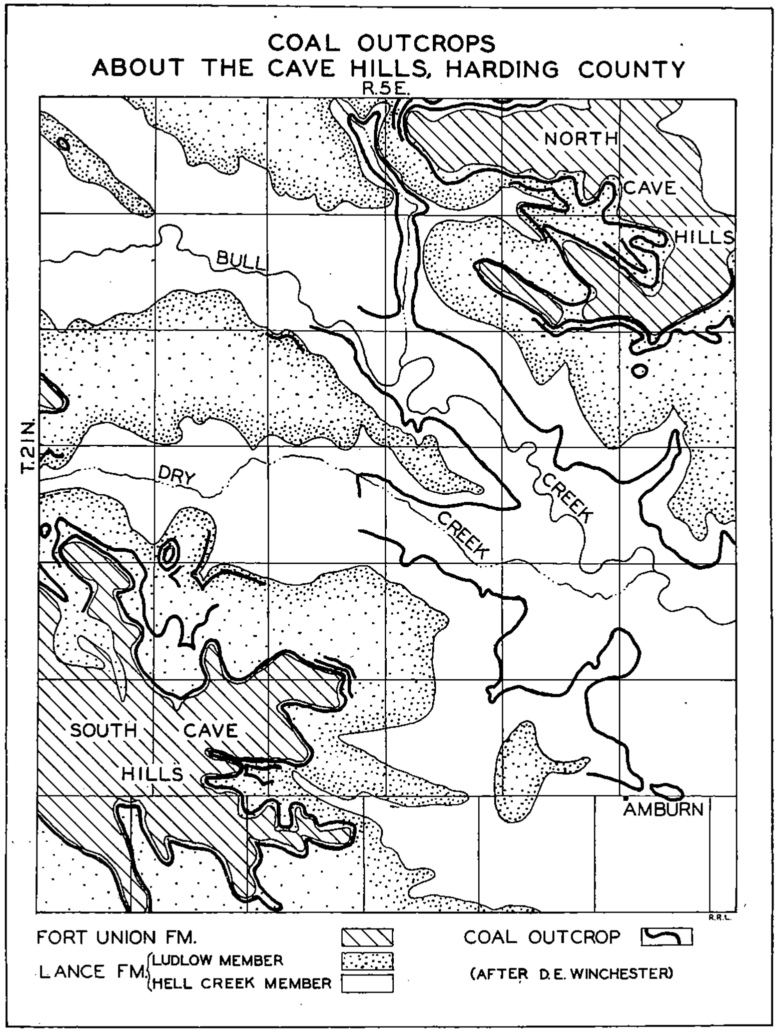

Figure 10

which stand nearly vertical. The material is slippery when wet, but when dry is so tough that it is with difficulty that a pick is driven into it. In a few places, the sand becomes loose enough to blowd uring very dry times, but on most dry outcrops a pick bounces off or loosens only small chips. It is as though the sand grains were stuck together with stiff tar. These gray gumbo sands contrast sharply with the loose yellow sand of the underlying Fox Hills formation and the overlying yellow Ludlow formation and red Fort Union beds.

Bone fragments of Cretaceous reptiles are not uncommon in these beds. Their presence led paleontologists to designate them as the "Ceratops Beds" because of the abundance of bones of the dinosaur Triceratops.

The formation measures 452 feet thick at the southern end of the Slim Buttes.[1]

In the eastern end of the area, the Isabel-Firesteel region, one coal bed occurs whose relation to the other rocks of the Hell Creek formation is illustrated by the following section taken not far from Isabel:

SECTION OF THE HELL CREEK BEDS[2]

Showing the Isabel-Firesteel coal bed and overlying beds, exposed in an abandoned mine in the SE¼, SW¼, Sec. 22, T. 17 N., R. 22 E., Dewey County

		Feet
6.	Soil, buff, sandy	1
5.	Sandstone, buff to gray in lower part, brown in upper part, brown in places in lower part; massive, cross laminated. Cross bedding dips eastward. Contains large flattish gray calcareous concretions. Rests on coal at east side of mine and also at southwest side	8
4.	Shale, brownish gray, hard. Contains sticks and stems and glance coal. Pinches out at southwest and east ends of mine	0-1
3.	Coal, Isabel-Firesteel bed, black, vertically jointed	3
2.	Shale "blackjack", black, carbonaceous	¼
1.	Clay, dark gray, exposed	¼
	Total	12½–13½

A typical section in the western end of the area was taken at the northern end of Slim Buttes.

[1]Winchester, D. E., The lignite field of northwestern South Dakota: U. S. Geol. Survey Bull. 627, p. 19, 1916.

[2]Searight, W. V., The Isabel-Firesteel coal area: South Dakota Geol. Survey Rept. Inv. 10, p. 11, 1931.

SECTION OF THE HELL CREEK BEDS NORTHWEST OF SLIM BUTTES[1]

Sections 8 and 9, T. 19 N., R. 7 E., Harding County

		Feet
Coal		3
Sand and clay, sand yellow; this interval not detailed		62
Sand, yellow-gray with shelly ledges		5
Lignitic shale, marks the base of the Ludlow		.3
Banded beds, alternating yellow sands and gray gumbo clay. Beds average one inch thick		15
Upper Coal zone:		
Clay	2 feet	
Coal	1 foot	
Clay	2 feet	
Lignitic shale and blackjack	1 foot	
Coal	1½ feet	7.5
Sandy clay		5
Coal and Blackjack, designated Middle Coal		3
Gumbo Clay, dark gray; some sandy		9
Gumbo sand		5
Blackjack and coal	1 foot	
Clay, top is black fireclay	1½ feet	
Coal and blackjack, (lower coal)	1½-2 feet	4
Gumbo, dark gray		20
Gumbo sand, yellow; designated Bull Creek sand in mapping		10
Coal		1
Gumbo, dark gray		7
Coal		1
Gumbo, dark gray		10
Gumbo sand, yellow; designated as sand X in mapping		15

The coal of the Hell Creek member is black, has well developed cleavage and is jointed vertically. Its streak is brown, indicating that it is a lignite but it lacks the woody texture and structure common to most lignite. The black color and lack of woody texture are characteristic of bituminous coal. The brown streak, certain chemical properties, the presence of moisture, and the high percentage of volatile matter shown in the accompanying analyses indicate lignite. These properties, both chemical and physical, indicate that the coal is of higher rank than brown lignite, however, and resembles what has been called sub-bituminous coal.

[1]Rothrock, E. P., Structural conditions in Harding County. South Dakota Geol. Survey Rept. Inv. 28, p. 12, 1937.

PLATE 9. Outcrop of a ten-foot coal seam near the north end of the Slim Buttes in Harding County.

PLATE 10. The Firesteel Coal Seam in the Runkle Mine, Firesteel, S. Dak.

A perusal of the accompanying analyses shows that the moisture content is relatively high for sub-bituminous coal but is low compared with brown lignite. The average moisture of the samples as received at the mine is 36.8%. In some cases it runs as high as 42%. Volatile matter, a characteristic of lignite coal which makes it burn easily, averages 26.6%. This is a little higher than in typical sub-bituminous coal. Fixed carbon on the other hand is 29.4% which is a little less. The coal, therefore, should be properly classed as a high rank lignite or low rank sub-bituminous coal.

TABLE 1

ANALYSES OF HELL CREEK COALS[1]

Name and Location[2]	Analyst[3]	Form of Analyses[4]	PROXIMATE: Moisture	Volatile Matter	Fixed Carbon	Ash	ULTIMATE: Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	HEATING VALUES: Calories	B. T. U.
1	M	A	34.96	30.33	28.80	5.91	0.30	----	----	----	----	----	7,144
		C	----	46.63	44.29	9.08	0.46	----	----	----	----	----	10,984
2	M	A	34.90	27.57	32.69	4.84	0.30	----	----	----	----	----	7,101
		C	----	42.35	50.22	7.43	0.46	----	----	----	----	----	10,907
3	M	A	34.98	25.34	31.15	8.53	0.31	----	----	----	----	----	6,854
		C	----	38.97	47.91	13.12	0.48	----	----	----	----	----	10,541
4	G	A	42.5	23.2	25.3	9.00	1.16	7.07	35.22	0.62	46.93	3,310	5,950
		B	17.7	33.2	36.2	12.88	1.66	5.83	50.39	0.88	26.86	4,735	8,520
		C	----	40.4	44.0	15.64	2.02	4.08	61.21	1.08	15.97	5,750	10,350
		D	----	47.8	52.2	----	2.39	4.84	72.56	1.28	18.93	6,815	12,270
Averages of Hell Creek Coals		A	36.83	26.61	29.48	7.07	0.52	----	----	----	----	----	6,762
		C	----	42.09	46.60	11.32	0.85	----	----	----	----	----	10,695
Averages of Lower Hell Creek Coals		A	34.95	27.75	30.88	6.43	0.30	----	----	----	----	----	7,033
		C	----	42.65	47.47	9.80	0.47	----	----	----	----	----	10,811

1./Analyses 1, 2, and 3 are samples of lower Hell Creek coals.
2./Name and location: (1) Robbins mine near Isabel; (2) Kennedy mine near Gopher; (3) Anderson mine near Gopher; (4) Phillips mine, Strool, SW¼, Sec. 7, T. 17 N., R. 11 E.
3./Analyst: M—Charles Bentley, from Connolly, J. P. and O'Harra, C. C., The Mineral Wealth of the Black Hills: South Dakota School of Mines Bull. No. 16, p. 396, 1929.
G—E. E. Somermeier and A. C. Fieldner, U. S. Geol. Survey and U. S. Bureau of Mines.
4./Form of Analyses: (A)—As received; (B)—Air dried; (C)—Moisture free; (D)—Moisture and ash free.

LOCALITIES: As stated above, Hell Creek coal beds occur in some localities in thickness sufficient for mining. These are grouped in the eastern part of the outcrop area in Corson, Dewey, and Ziebach Counties and west of the Slim Buttes in Harding County. In the eastern localities valuable beds occur in the vicinity of Isabel and Firesteel in Ziebach and Dewey Counties and near Gopher and Lightcap in Corson County. Several beds of coal in the Hell Creek west of Slim Buttes in Harding County were mapped by the Winchester survey.[1] Only one of these is known to have been mined recently.

Isabel-Firesteel locality. A coal bed northeast of Isabel has been mined in Sec. 22, T. 17 N., R. 22 E. This bed is black and where seen is without inter-bedded clay. It contains but little sulphur in the form of iron pyrite. Thickness is variable, that measured by the writer being 4 feet 10 inches, and borings made by Ganley Bros. in 1929 at intervals of 300 feet show a maximum thickness of 6 feet 5 inches. A quarter of a mile north of the Midwest Fuel Company strip pit borings show the thickness to be only 3 feet, whereas three-quarters of a mile south of the pit the bed apparently is absent.

The following table of succession shows this coal bed and associated beds in strip pit of Midwest Fuel Co., SW¼ sec. 22, T. 17 N., R. 22 E.

		Feet
4.	Sandstone, fine brownish, friable, soft, lignitic at base	9–30
3.	Shale, bituminous, "blackjack"	0–½
2.	Coal, black, little pyrite in thin sheets, no clay seams	4–5/6
1.	Clay, hard gray ……exposed	
	Total	13 5/6 – 35 1/3

A coal bed lies northwest of Firesteel in Secs. 7, 8, and 18, T. 17 N., R. 22 E. It occurs in approximately the same position in the Hell Creek as the bed north of Isabel. The table of succession which follows shows the coal as it was exposed in the Hammerly mine.

1—Winchester, D. E., and others, Maps of Harding County accompany U. S. Geol. Survey Bull. 627, 1916.

Section of coal and associated beds in Hammerly mine in the NE¼ sec. 18, T. 17 N., R. 23 E.

		Feet
6.	Clay, shale, brown, bedding obscure	3–4
5.	Siltstone and fine sandstone, light gray, weathers buff and yellow	7–8
4.	Clay shale, hard, medium gray, bedding obscure or absent	7–8
3.	Shale, carbonaceous, "blackjack"	¾–5/6
2.	Coal, clean, black, bright	5
1.	Clay, hard, gray	exposed
	Total	22¾–25 5/6

A coal bed, possibly the same as that of the Hammerly mine, is present north, northeast, and southwest of Firesteel in Secs. 15, 16, and 21, T. 17 N., R. 23 E., where the thickness has been reported as ranging between 5 and 7 feet.

Coal beds of the Hell Creek member occur also southwest of Isabel and south of Firesteel. The tables of succession which follow indicate the thickness of the coal beds and the character and thickness of the associated strata southwest of Isabel.

Section of Hell Creek coal exposed in Hammond strip mine in NE¼ sec. 8, T. 16 N., R. 22 E.

		Feet
5.	Sandstone, friable, and slope mantle	4–12
4.	Shale, brown to drab, brittle	9–12
3.	Shale, black, carbonaceous	2
2.	Coal, black	3½
1.	Shale, black, bony coal or "blackjack"	5/6–1
	Total	19 1/3

Section exposed in Reichert mine in the NW¼ sec. 7, T. 16 N., R. 22 E.

5.	Sandstone, friable, gray to buff, cross-bedded, fine, claylike at top	10–12
4.	Coal, black	1/6–¼
3.	Shale, carbonaceous, "blackjack" or bone	¾–1
2.	Shale, black and carbonaceous at top, dark gray at base, tough	2
1.	Coal, black	4
	Total	16 11/12–19¼

Coal of similar character and relations occurs along Irish Creek where the average thickness is reported as five feet.

The succession in which the coal occurs is shown in the table which follows:

Section of coal and associated beds exposed in the Tidball (Rosander) mine in the NE¼ sec. 23, T. 16 N., R. 20 E.

		Feet
7.	Covered, probably shale and friable sandstone	30
6.	Shale and friable sandstone	6
5.	Shale, brown, carbonaceous, and fine; hard white sandstone in lenses, sandstone cuts through shale and rests on coal along 200-300 feet of the outcrop	2–6
4.	Shale, black, carbonaceous, "blackjack," cut out by overlying white sandstone in places	0-1
3.	Coal, black, bright	5
2.	Shale, black carbonaceous, bone of "blackjack"	5/6
1.	Clay, hard gray, structureless	1
	Total	44 5/6-49 5/6

Gopher locality. In the Gopher locality clean, black vertically jointed coal occurs in a bed of sufficient thickness for mining. The succession in this locality is well exposed in mines in the southern part of Sec. 7, T. 18 N., R. 20 E., as shown in the table which follows:

Section of Hell Creek coal and associated strata exposed in the Kennedy and Anderson mines in the SE¼ of SK¼, and SW¼ of SE¼ sec. 7, T. 18 N., R. 20 E.

		Feet
4.	Sandstone, light gray, fine, much clay, bedding obscurely crossbedded and thin bedded, logs of glance coal in lower 1 foot. Erodes to badlands	34
3.	Coal, black, bright, brittle, vertically jointed	5½
2.	Shale, black, carbonaceous	¾
1.	Clay, drab at top, dark brown below, sandy, starchy fracture	7
	Total	47¼

Lightcap locality. A very similar succession including a coal bed has been observed southwest of Lightcap in Secs. 25-36, T. 19 N., R. 21 E., where there are several small local strip mines. The similarity of this succession with that of the Gopher locality suggests that the coal of the two localities may be continuous. The succession near Lightcap is given in the table which follows:

		Feet
4.	Clays, and sandy clays, light, medium and dark gray, in beds from few inches to 15 feet of one shade, beds continuous for ¼ mile or more. Li-	

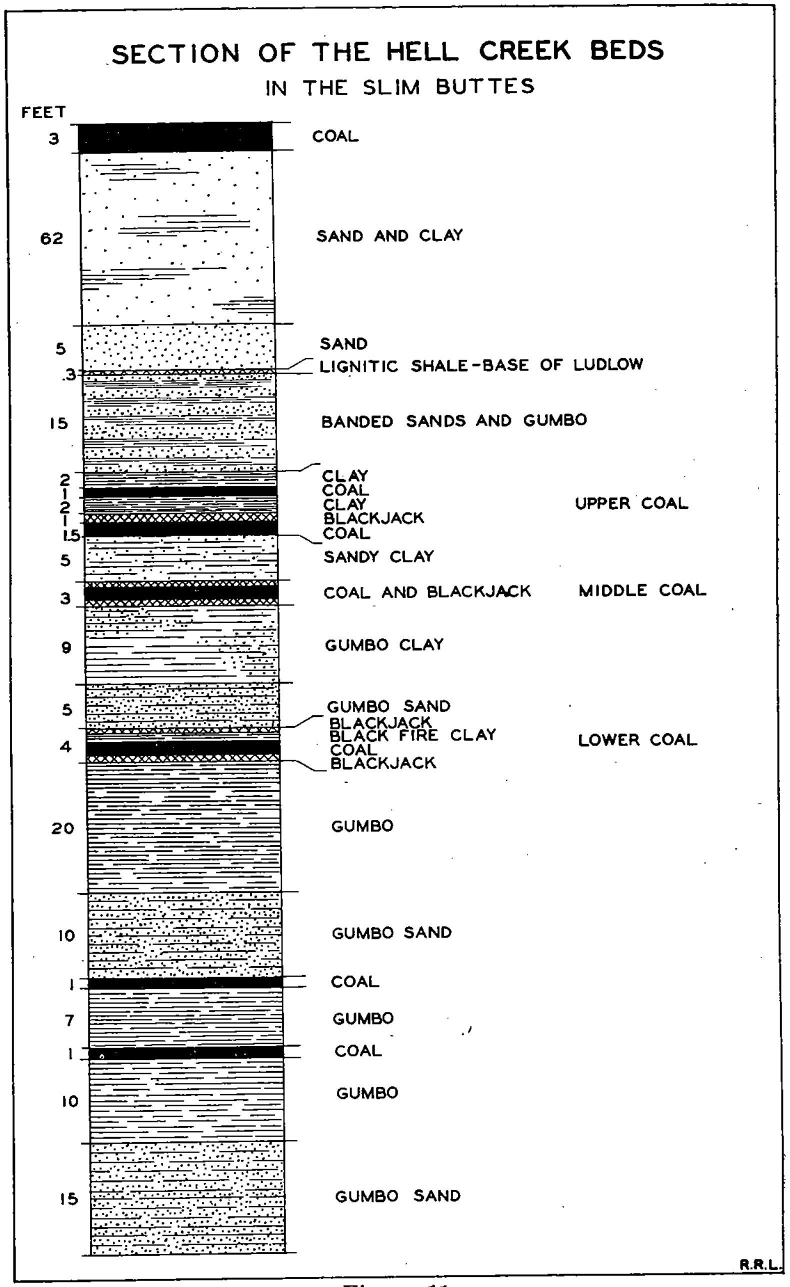

Figure 11
Columnar Section showing position and numbers of Coals in the Hell Creek Beds of Harding County, S. Dak.

	monite concretions (bog iron in masses up to 10 in. thick and 3 ft. in diameter) especially abundant in upper part	200+
3.	Sandstone, fine, light gray	15
2.	Coal, black, laminated, bright, considerable glance coal, jointed vertically	4–4½
1.	Clay, underclay, brown, starchy fracture	5+
	Total	224+

C. Ludlow Coals

On the Hell Creek beds lie two members of the Lance formation. In Perkins County, in the eastern part of the coal field, is a marine member known as the Cannonball member from Cannonball Creek in North Dakota. This member is not coal-bearing. In Harding County at the same horizon, terrestrial and shore line deposits occur which are made of yellow sands and sandy shales with an abundance of lignite seams. This member was named the "Ludlow lignitic member" from Ludlow post office in Harding County.[1] The coals of this member are the most persistent and the thickest in the South Dakota coal field. The greatest thickness measured is fourteen feet. The Ludlow beds outcrop in an arc about twenty miles wide which enters the state from North Dakota in Ranges 3E. and 4E. in Harding County and extends southeast 75 miles to the eastern line of Perkins County in T. 20N., R. 17E.

Physical and Chemical Character

Ludlow coals are typical lignite for the most part. When fresh the coal is mostly brown in color although lenses and beds of brownish black and black are common. Indeed, in some localities, the greater part of the coal is black with only minor amount of interbedded brown coal. Both brown and black varieties produce a brown streak. The brown part of the coal is tough, woody and fibrous, whereas the black variety is more or less brittle and contains much glance coal. In beds mostly made up of black coal cleavage is parallel to the bedding and vertical jointing is common. Fusain, or mineral charcoal, is very common in these beds in some localities.

The chemical composition of the coal beds of this mem-

[1]Winchester, D. E., The lignite field of northwestern South Dakota: U. S. Geol. Survey Bull. 627, 1916.

ber is typical of lignite. The moisture content is high, the average of available analyses (Table 2) being 37.92 per cent: Drying of the fuel in air reduces this percentage to an average of 8.62. Fixed carbon in the coal, as received, averages 26.25 per cent, and volatile matter averages 28.43. In the moisture free coal, fixed carbon is 37.91 per cent and volatile matter is 37.26 per cent. The average percentage of ash in Ludlow coals is 10.55 per cent, as reecived, or 16.17 per cent in moisture free samples. This figure is somewhat higher than the average for the lower Hell Creek beds, and is a little higher than that of the average Hell Creek coal. The analyses indicate, however, that the ash content of certain Ludlow beds in certain localities closely approximates that of the average Hell Creek coal. Some Ludlow beds contain a very high percentage of ash. Sulphur is somewhat more abundant in most Ludlow coals than in the Hell Creek beds although sulphur content of South Dakota coals is low as compared with that of eastern coal. Heating value of Ludlow coals, as indicated by analyses, is somewhat lower than those of the Hell Creek, the average moisture free heating value of the former being 9197 B. T. U. as compared with 10696 B. T. U. in the latter.

Floor, roof, and overburden. The Ludlow coal beds are underlain by beds of hard gray structureless clay. In some cases the material is tough. The roof in many places is shale, shale and sandstone, or sandstone. Over the coal beds of the lower part of the Ludlow these beds are relatively soft and probably would form only fair roof for underground mining. West of the Slim Buttes, shale and sandstone beds have proven satisfactory roof materials.

Overburden varies from a few feet to a few hundred feet in thickness. The beds which must be removed in stripping operations consist of shales and sandstones which ordinarily are removed without difficulty. In many places, however, large sandstone concretions must be removed with the overburden. These are particularly troublesome in small scale operations. No beds occur over the available Ludlow coals which cannot be readily removed by heavy power machinery.

Localities: In the pages which follow, representative localities are described in which Ludlow coal beds occur. For descriptions of other beds and localities and for the extent of these and other beds, the reader is referred to the report and maps of the Winchester survey.[1] Typical exposures occur in the vicinity of Coal Springs, southwest of Bison, and near Strool in Perkins County and near Reva, west of the Slim Buttes, south of Ralph, southeast of Ludlow, and near the Cave Hills in Harding County.

Coal Springs locality. Coal beds lying at and near the base of the Ludlow member have been mined for many years in the vicinity of Coal Springs, where coal has been mined both north and south of Coal Springs, P. O. Wherever exposed in this vicinity, however, coal at this position is split by shale partings into benches too thin to be of more than local value. The table of succession in the Sundermeyer mine is given here for the convenience of the reader.

Section exposed in the Sundermeyer strip mine in the NE¼ sec. 20, T. 17 N., R. 17 E.

		Feet
8.	Sandstone, log concretions in upper 20 feet	36
7.	Shale and sandstone in alternating thin beds	9
6.	Coal, black, much glance	2½
5.	Clay, shale, medium gray	1
4.	Coal black, top 6 inches bony, pyrite masses to six inches in diameter	2 1/3
3.	Clay shale, medium to dark gray	¼-2/3
2.	Coal, black, vertically jointed, fairly hard, much glance	1
1.	Clay, drab brown	1
	Total	53

Bison locality. Coal which occurs at the base of the Ludlow has been mined for many years southwest of Bison. In this locality a bed, possibly the lower bench of the Coal Springs locality, thickens to 5 feet. This coal is black throughout, hard, bright, and vertically jointed. The lower bed contains no clay or shale, but pyrite occurs in masses of a size up to one inch thick by 4 inches in diameter which appear, however, to average a size sufficiently large to be readily dis-

[1]Winchester, D. E., The Lignite field of Northwestern South Dakota, U. S. Geol. Survey Bull. 627, 1916.

carded in mining. The tables which follow show the coal and associated beds, the first at the Carlson mine in the NE¼ sec. 20, T. 17 N., R. 13 E., and the second in the Hafner mine in the SE¼ sec. 17, T. 17 N., R. 13. E.

Section of basal Ludlow exposed in the Carlson mine in the NW¼ sec. 20, T. 17 N., R. 13 E.

		Feet
8.	Grass covered slope	10
7.	Shale, medium gray, contains plant remains, leaves and stems	11
6.	Coal, impure, clay streaked	1
5.	Shale, medium gray, fairly hard, contains plant remains	3
4.	Coal, impure, thinly laminated, with thin clay streaks	1½
3.	Shale, lignitic, brown	¼
2.	Coal, black, joints into cubical blocks	5
1.	Clay, hard, gray, somewhat siliceous, contains fossil rootlets	5
	Total	36¾

Section of the Ludlow exposed in the Hafner mine in the SE¼ sec. 17, T. 17 N., R. 13 E.

		Feet
8.	Soil, sandy	1
7.	Sandstone and sandy shale, contains large log concretions	5
6.	Coal, impure, thinly laminated, thin clay streaks	1/3–1
5.	Shale, light medium to medium dark gray, abundant plant leaves where thinnest	2½–18
4.	Coal, impure, thin clay streaks	¾–1¼
3.	Shale, medium gray, prominently jointed from top to base, considerably fractured into angular pieces	9–15
2.	Coal, black, bright, horizontally bedded, hard, vertically jointed	4½–5
1.	Clay, tough, medium gray, jointed; contains rootlets	2
	Total	18 1/12–68¼

Strool locality. Coal at the base of the Ludlow member of the Lance has been mined east and somewhat south of Strool. Northwest of Strool a coal higher in the member is mined.

The coal to the east of Strool is only a few miles from that southwest of Bison and apparently lies in the same stratigraphic position. As in the Bison locality the coal is

black and bright, but where observed is thinner. In some places it contains considerable pyrite in flattish masses arranged along the bedding planes.

The succession in which the coal occurs in the Van Lee mine is shown in the following table:

Section of basal Ludlow exposed in the Van Lee mine in the SW¼ sec. 31, T. 18 N., R. 12 E.

		Feet
8.	Soil	1
7.	Sandstone, buff, fine, thin bedded	2½
6.	Coal, impure	1/12–5/6
5.	Sandstone, gray, fine, contains large gray concretions, one being from 8 to 11 inches thick, 80 feet long; reported more than 40 feet wide	3–4
4.	Clay ironstone, concretionary	2
3.	Shale, and shaly sandstone, for the most part cross-bedded	3–7
2.	Coal, black, bright, flattish masses of pyrite along bedding planes	3–4
1.	Clay, hard, medium gray	exposed
	Total	11 7/12–21 1/3

Coal mined northwest of Strool is very different from that in the section described above. This bed contains much dark brown and brownish black coal, is tough and woody, and also contains much fusain, or mineral charcoal, where it has been observed. The succession in which it occurs is different from that east of Strool and southwest of Bison. The table of succession which follows shows the coal and the strata with which it is associated.

Section of Ludlow strata exposed in the Gray mine in the SW¼ sec. 26, T. 19 N., R. 10 E.

		Feet
6.	Sandstone, buff, fine, friable, homogeneous, massive	11
5.	Sandstone and shale, inter-bedded; sandstone, buff, shale light to medium gray; in alternating beds from 1 to 9 inches thick. Oblate concretions of hard, bluish gray, limy sandstone to 4 by 8 feet or more at top. Concretions present in upper half	20
4.	Sandstone, buff, friable, massive, but thin-bedded	10
3.	Sandstone and shale, inter-bedded in thin layers; sandstone buff, shale medium gray	3
2.	Coal, black to brownish black, vertically jointed, ½ inch of clay, 1 foot from top	2

1.	Coal, tough, brownish black, somewhat bony, much fusain	1 5/6–3 5/6
	Total	36 5/6

Reva locality. Coal is mined for local use between Reva and Slim Buttes. A bed mined at the Hodge mine contains some brown coal, but most of it is black in color. The bed here is without clay partings and appears to be of good quality. The coal ranges between 12 and 14 feet thick in the Hodge mine. The table which follows shows the coal and overlying beds at this place.

Section of the Ludlow in the Hodge strip mine in the NE¼ sec. 17, T. 18 N., R. 8 E.

		Feet
3.	Rubble, derived from White River beds	1½
2.	Shale, medium gray, silty texture, well preserved leaves of deciduous trees in lower 3 feet	7
1.	Coal, mostly black, some brown	12–14
	Total	16½–18½

Locality West of Slim Buttes. Two beds of coal which occur in the Ludlow member along the west flank of the Slim Buttes mesa are particularly well exposed in Sec. 36, T. 18 N., R. 7 E. The lower of these beds is thick and has been mined by drifts for local use. Where observed, this bed consists of two benches separated by clay shale which varies in thickness from 3 inches to 3 feet within a half mile. The lower bench is jointed vertically into blocks of roughly cubical shape. The upper bench is tough and somewood woody. The thickest exposure of this coal was noted in the Olsrud mine in the NW¼SE¼ sec. 36, T. 18 N., R. 7 E. This exposure and one less than a half mile south are shown with their associated beds in the tables of succession which follow.

Section of the Ludlow coal and associated beds exposed along west flank of Slim Buttes in the Olsrud mine in the NW¼SE¼ sec. 36, T. 18 N., R. 7 E.

			Feet
6.	Shale, sandy, buff, poorly exposed, exposed along road		50
5.	Shale, gray, and buff, thin bedded		8
4.	Coal, black and brown, tough	7–8	
3.	Clay shale, gray	¼	
2.	Coal, black, some brown	6–7	
			14½

1.	Clay, blue gray; hard	1
	Total	73½

Section of Ludlow coal and overlying beds exposed at the opening of the Geisniss mine in the SW¼SE¼ sec. 36, T. 18 N., R. 7 E.

		Feet
4.	Shale, gray and buff, thin-bedded	4
3.	Coal, black, some brown, woody and tough	4–5
2.	Clay, shale, light gray, structureless	3
1.	Coal, black, some brown	7½
	Total	18½–19½

Ralph locality. A thick bed of coal has been mined for many years southwest of Ralph in northeastern Harding County. This coal like that in the bed last described is split into two benches by a clay parting. Here, however, no difperences in character between the upper and lower benches are apparent. Both benches were black in color but somewhat weathered where observed. The bed is well exposed at the opening of the Pintar mine in Sec. 35, T. 21 N., R. 8 E. where the following section was made.

Section of Ludlow coal and overlying beds exposed in and above the opening of the Pintar mine in Sec. 35, T. 21 N., R. 8 E.

		Feet
5.	Shale and sandstone, shale sandy and sandstone argillaceous, inter-bedded	8
4.	Shale, pinkish gray, irregularly jointed	3
3.	Coal, black, vertically jointed	7¼
2.	Clay, light gray	½–5/6
1.	Coal, black, hard	5
	Total	23¾–24 1/12

Ludlow locality. Lignite has been mined in this locality for many years. Two thick beds were mapped in this locality by Winchester survey.[1] The Gionnanati bed occurs in the upper part of the Ludlow and the Widow Clark 50 to 70 feet below it. The coal of the Gionnanati bed as observed is black for the most part. It contains much brown and woody material, however. The coal is tough and breaks away from the

[1]Winchester, D. E. and others, U. S. Geol. Survey Bull. 627, geologic map of Harding County, and pp. 94-95, 1918.

bed when mined in flat, irregularly shaped pieces. This bed and the overlying strata are described in the table of succession which follows:

Section of the Gionnanati coal bed and overlying strata in the mine in the NE¼ sec. 29, T. 21 N., R. 7 E.

		Feet
3.	Sandstone, hard, ripplemarked	4
2.	Sandstone, friable, buff and yellow, micaceous; cross-bedded and massive in lower 13 feet; elongate sandstone concretions to 8 inches thick by 3 feet wide by 12 feet long in basal part	71
1.	Coal, black, with considerable brown, tough	9
	Total	84

The total thickness of the coal bed is not exposed here. Two or more feet of coal are reported below that exposed, separated from a thick lower bench of hard black coal by a clay bed one foot thick.

A coal bed possibly stratigraphically higher than the Gionnanati bed has been mined in recent years near the North Cave Hills in the SW¼ sec. 26, T. 22 N., R. 5 E. The character and thickness of this bed together with associated strata are shown in the following table:

Sections of upper Ludlow coal and associated beds exposed in the Doane strip mine in the SW¼ sec. 26, T. 22 N., R. 5 E.

		Feet
4.	Sandstone and shale, interbedded; sandstone shaly, drab; shale brown; 3 inches of highly lignitic shale one foot from base	8
3.	Coal, impure, weathered	2½
2.	Coal, brown and black, woody parts brown, somewhat tough	5½
		8
1.	Clay, light gray	5
	Total	21

Locality South of Cave Hills. Lignite has been mined in the southern part of the South Cave Hills for 15 years or more. The beds from which coal is obtained occur in the upper 90 feet of the Ludlow member. The most important bed is the Hilton bed, formerly mined in the old Hilton mine, in Sec. 6, T. 20 N., R. 5 E., and this bed is split into five benches by thin clay partings. The lower three benches approximate one foot each in thickness, the uppermost is 16 to

17 inches in thickness, and the fourth bench is 7½ feet thick. This thick bench is composed of coal which is mostly black, but it contains some brown woody material. In mining the coal is taken out in tough sheets.

TABLE 2

ANALYSES OF LUDLOW COALS

Name and Location[1]	Analyst[2]	Form of Analyses[3]	PROXIMATE				ULTIMATE					HEATING VALUES	
			Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	B. T. U.
1	M	A	32.98	28.41	29.10	9.51	1.31	----	----	----	----	----	7,075
		C	----	42.39	43.42	14.19	1.95	----	----	----	----	----	10,555
2	G	A	39.2	24.7	27.8	8.35	2.22	6.60	.53	38.02	43.28	3,505	6,310
		B	17.8	33.3	37.6	11.28	3.00	5.02	.71	51.38	28.61	4,735	8,520
		C	----	40.6	45.7	13.72	3.65	3.70	.87	62.49	15.57	5,760	10,370
		D	----	47.2	52.8	----	4.23	4.29	1.01	72.43	18.04	6,675	12,020
3	M	A	40.01	23.56	30.08	6.35	0.42	----	----	----	----	----	6,150
		C	----	39.27	50.14	10.59	0.70	----	----	----	----	----	10,251
	B	A	31.2	27.1	31.0	10.7	2.4	5.9	.6	40.9	39.5	3,750	6,750
		B	11.9	34.8	39.6	13.7	3.0	4.5	.8	52.4	25.6	4,806	8,650
		C	----	39.5	45.0	15.5	3.4	3.6	.9	59.4	17.2	5,450	9,810
		D	----	46.7	53.3	----	4.1	4.2	1.0	70.4	20.3	6,456	11,620
4	G	A	41.5	24.0	24.3	10.2	.55	----	----	----	----	3,140	5,650
		B	10.4	36.8	37.3	15.5	.84	----	----	----	----	4,810	8,650
		C	----	41.0	41.6	17.4	.94	----	----	----	----	5,365	9,660
		D	----	49.6	50.4	----	1.14	----	----	----	----	6,495	11,690
	G	A	41.1	25.8	24.0	9.1	1.14	----	----	----	----	2,955	5,320
		B	10.3	39.3	36.5	13.9	1.74	----	----	----	----	4,495	8,090
		C	----	43.9	40.7	15.4	1.94	----	----	----	----	5,015	9,020
		D	----	51.9	48.1	----	2.30	----	----	----	----	5,930	10,680
5	G	A	34.7	27.2	29.0	9.1	.95	----	----	----	----	3,475	6,250
		B	11.1	37.1	39.4	12.4	1.29	----	----	----	----	4,735	8,520
		C	----	41.7	44.4	13.9	1.46	----	----	----	----	5,325	9,580
		D	----	48.3	51.7	----	1.70	----	----	----	----	6,185	11,140
6	M	A	40.85	23.80	26.36	8.99	0.90	----	----	----	----	----	5,791
		C	----	40.23	44.57	15.20	1.53	----	----	----	----	----	9,790

TABLE 2—Continued

ANALYSES OF LUDLOW COALS

Name and Location[1]	Analyst[2]	Form of Analyses[3]	PROXIMATE				ULTIMATE					HEATING VALUES	
			Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	B. T. U.
	B	A	44.4	24.0	19.7	11.9	0.7	6.70	0.40	28.50	51.80	2,467	4,440
		B	3.8	41.6	34.0	20.6	1.2	3.5	.7	49.4	24.6	4,267	7,680
		C	----	43.2	35.4	21.4	1.3	3.2	.8	51.3	22.0	4,439	7,990
		D	----	55.0	45.0	----	1.6	4.0	1.0	65.3	28.1	5,644	10,160
7	G	A	39.8	25.3	23.8	11.1	.96	----	----	----	----	3,045	5,480
		B	10.2	37.8	35.5	16.5	1.44	----	----	----	----	4,545	8,110
		C	----	42.0	39.6	18.4	1.59	----	----	----	----	5,060	9,110
		D	----	51.6	48.4	----	1.95	----	----	----	----	6,200	11,160
8	G	A	34.7	26.4	27.6	11.3	1.08	----	----	----	----	----	-----
		B	18.8	32.9	34.4	13.3	1.34	----	----	----	----	----	-----
		C	----	40.5	42.3	17.2	1.65	----	----	----	----	----	-----
		D	----	48.8	51.2	----	1.99	----	----	----	----	----	-----
9	B	A	38.0	24.4	25.5	12.1	1.0	6.3	.5	34.6	45.5	3,067	5,520
		B	12.9	34.3	35.8	17.0	1.4	4.4	.7	48.7	27.8	4,306	7,750
		C	----	39.4	41.1	19.5	1.6	3.4	.8	55.9	18.8	4,944	8,900
		D	----	48.9	51.1	----	2.0	4.2	1.0	69.4	23.4	6,144	11,060
10	B	A	37.1	27.2	24.3	11.4	.9	5.9	.5	33.2	48.1	2,789	5,020
		B	7.3	40.1	35.8	16.8	1.3	3.5	.7	49.0	28.7	4,117	7,410
		C	----	43.2	38.7	18.1	1.4	2.9	.8	52.8	24.0	4,439	7,990
		D	----	52.8	47.2	----	1.7	3.5	1.0	64.5	29.3	5,422	9,760
11	B	A	34.4	25.5	28.8	11.3	1.2	6.1	.5	37.6	43.3	3,367	6,060
		B	2.9	37.7	42.7	16.7	1.7	3.7	.8	55.7	21.4	4,978	8,960
		C	----	38.8	44.0	17.2	1.8	3.4	.8	57.3	19.5	5,128	9,230
		D	----	46.9	53.1	----	2.1	4.1	1.0	69.2	23.6	6,194	11,150
12	B	A	29.8	26.5	31.3	12.2	1.7	5.9	.6	40.8	38.6	3,767	6,780
		B	2.3	36.8	43.6	17.3	2.4	3.8	.8	56.8	18.9	5,239	9,430

ANALYSES OF LUDLOW COALS — TABLE 2—Continued

Name and Location[1]	Analyst[2]	Form of Analyses[3]	PROXIMATE Moisture	Volatile Matter	Fixed Carbon	Ash	ULTIMATE Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	HEATING VALUES Calories	B. T. U.
		C	----	37.7	44.6	17.7	3.4	3.7	.8	58.1	17.3	5,361	9,650
		D	----	45.8	54.2	----	3.0	4.5	1.0	70.6	20.9	6,511	11,720
13	B	A	33.0	25.8	26.1	15.1	2.4	5.9	.5	35.2	40.9	3,228	5,810
		B	3.9	37.0	37.5	21.6	3.5	3.7	.8	50.5	19.9	4,633	8,340
		C	----	38.5	39.0	22.5	3.6	3.4	.8	52.6	17.1	4,822	8,680
		D	----	49.7	50.3	----	4.7	4.3	1.0	67.9	22.1	6,222	11,200
14	B	A	40.5	25.5	22.8	11.2	1.6	6.8	.5	32.6	47.3	2,867	5,160
		B	3.0	41.6	37.2	18.2	2.6	3.7	.8	53.2	21.5	4,678	8,420
		C	----	42.9	38.3	18.8	2.7	3.5	.8	54.9	19.3	4,822	8,680
		D	----	52.9	47.1	----	3.4	4.3	1.0	67.6	23.7	5,939	10,690
15	B	A	40.7	24.4	22.2	12.7	1.7	6.3	.4	30.7	48.2	2,683	4,830
		B	6.2	38.5	35.3	20.0	2.7	3.5	.7	48.6	24.5	4,239	7,630
		C	----	41.1	37.6	21.3	2.9	3.0	.7	51.8	20.3	4,522	8,140
		D	----	52.2	47.8	----	3.7	3.9	.9	65.9	25.6	5,750	10,350
16	B	A	46.5	20.6	25.0	7.9	.7	7.2	.5	33.0	50.7	3,033	5,460
		B	5.1	35.6	44.3	14.0	1.3	4.3	.8	58.5	21.1	5,372	9,670
		C	----	38.5	46.8	14.7	1.4	3.9	.9	61.6	17.5	5,661	10,190
		D	----	45.2	54.8	----	1.6	4.5	1.0	72.2	20.7	6,639	11,950
Averages		A	37.92	28.43	26.25	10.55	1.25	6.33	.50	35.01	45.20	3,143	5,770
		B	8.62	37.26	37.91	16.17	1.92	3.97	.76	52.20	23.87	4,661	8,391
		C	----	38.68	42.26	16.98	2.00	3,43	.82	56.20	18.96	5,074	9,197
		D	----	49.59	50.41	----	2.58	4.16	.99	68.68	23.25	6,160	11,090

1./Name and location of sample: (1) Carolson Bros. (old Sexton mine), NW¼ sec. 20, T. 12 N., R. 13 E.; (2) Chet Grey mine, Strool, NW¼ sec. 35, T. 19 N., R. 10 E.; (3) Hodge mine, Reva, SE¼ sec. 22, T. 19 N., R. 8 E.;

ANALYSES OF LUDLOW COALS — TABLE 2—Continued

(4) Mendenhall Prospect, Sec. 1, T. 17 N., R. 7 E.; (5) Newcomb mine, SW¼ sec. 10, T. 20 N., R. 9 E.; (6) Gionnanati mine, SE¼ sec. 20, T. 21 N., R. 7 E.; (7) Hilton mine, Sec. 6, T. 20 N., R. 5 E.; (8) Knudsen mine, NE¼ sec. 2, T. 17 N., R. 10 E.; (9) Pelham mine, SW ¼ sec. 6, T. 21 N., R. 6 E.; (10) Bar H mine, SW¼ sec. 27, T. 19 N., R. 8 E.; (11) SW¼ sec. 28, T. 19 N., R. 8 E.; (12) NW¼ sec. 21, T. 19 N., R. 8 E.; (13) NW¼ sec. 27, T. 19 N., R. 8 E.; (14) SE¼ sec. 21, T. 19 N., R. 8 E.; (15) SE¼ sec. 27, T. 19 N. R. 8 E.; (16) SE¼ sec. 20, T. 21 N., R. 7 E.

2./Analysts: B.—H. M. Cooper, U. S. Bureau of Mines; G.—E. E. Somermeier and A. C. Fieldner, U. S. Geol. Survey and U. S. Bureau of Mines; M.—Charles Bentley, South Dakota State School of Mines.

3./Form of analysis: (A) As received; (B) Air dried; (C) Moisture free; (D) Moisture and ash free.

D. Fort Union Coal

The Fort Union formation overlies the Ludlow-Cannonball members of the Lance formation, outcropping in a belt about six miles wide extending southeast from the North Dakota line in Range 7E. It occupies about two townships in the extreme northeastern part of Harding County and about four in the northwestern part of Perkins County.

At one time, coal beds of this formation covered a fairly wide area but erosion has reduced the former extent to small outliers capping only the higher stream divides. Most of the Fort Union coal occurs in northern Perkins County in the vicinity of Lodgepole Post Office although small patches occur southeast of Ellingson and near the middle of the northern boundary of Perkins County.

Two or more coal beds occur in the Fort Union. The lower bed which lies above the basal sandstone, however, appears to be the only bed of sufficient thickness for profitable mining.

Physical and chemical character. The coal of the Fort Union like that of the Hell Creek member of the Lance is black when fresh. Bright and dull coal commonly occur in approximately equal amounts as thin laminae. The coal is commonly fairly brittle, the tough character of Ludlow coals being absent.

Analyses (Table 3) suggest that in chemical as well as physical character the Fort Union coal is similar to coals of the lower Hell Creek. Moisture content, as received, averages 34.26 per cent, volatile matter 29.13 per cent, and fixed carbon 29.39. Dry samples average 42.68 per cent, volatile matter, and 43.35 fixed carbon. Heating values average 7001 B. T. U. as received and 10,269 for moisture free samples.

TABLE 3

ANALYSES OF FORT UNION COALS[1]

Name and Location[2]	Analyst[3]	Form of Analyses[4]	PROXIMATE: Moisture	Volatile Matter	Fixed Carbon	Ash	ULTIMATE: Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	HEATING VALUES: Calories	B. T. U.
1	M	A	30.65	29.91	34.68	4.76	0.79	----	----	----	----	----	7,045
		C	----	45.13	50.51	6.86	1.01	----	----	----	----	----	10,158
2	G	A	33.3	28.9	27.3	10.5	.76	----	----	----	----	3,865	6,960
		B	15.4	36.7	34.6	13.3	.97	----	----	----	----	4,905	8,830
3	G	A	32.6	30.6	28.5	8.3	1.53	----	----	----	----	4,085	7,360
		C	----	45.4	42.3	12.3	2.27	----	----	----	----	5,070	10,920
4	G	A	40.5	27.1	27.4	5.0	.76	----	----	----	----	3,690	6,640
		C	----	45.5	46.0	8.5	1.28	----	----	----	----	6,205	11,170
Averages		A	34.26	29.13	29.47	7.14	.96	----	----	----	----	3,880	7,001
		C	----	42.68	43.35	10.24	1.38	----	----	----	----	5,728	10,269

1./Analyses: 1 and 2 are of samples of South Dakota coal; 3 and 4 of North Dakota coal added for completeness.

2./Name and location: (1) Warner mine, SW¼ sec. 20, T. 21 N., R. 12 E.
(2) Nelson mine, NW¼ sec. 29, T. 21 N., R. 12 E.
(3) Nipper and Monroe mine, NW¼ sec. 16, T. 129 N., R. 94 W.
(4) Washburn Lignite Coal Co. mine, Sec. 1, T. 142 N., R. 80 W.

3./Analyst: (M)—Charles Bentley, from Connolly, J. P., and O'Harra, C. C., The Mineral Wealth of the Black Hills, South Dakota School of Mines, Bull. No. 16, p. 396, 1929.
(G)—E E. Somermeier and A. C. Fieldner, U. S. Geol Survey and U. S. Bureau of Mines.

4./Form of Analysis: (A) As received; (B) Air dried; (C) Moisture free; (D) Moisture and ash free.

LOCALITIES:

Lodgepole locality. As previously stated, the region around Lodgepole comprises the greater portion of the Fort Union coal of the State. The coal underlies two important areas, one south and one north of Lodgepole. The tables of succession which follow indicate the position and thickness of the coal and associated beds, the first south of Lodgepole P. O. and the second north.

Section of Fort Union coal and associated strata exposed below, in and above the Warner mine in the SW¼ sec. 20, T. 21 N., R. 12 E.

		Feet
10.	Float, quartzite boulders	—
9.	Covered	10
8.	Sandstone, white and yellow, friable, with ovoid concretions of cross-bedded sandstone to 10 feet in diameter	18
7.	Silt, sandy, brownish yellow	10
6.	Bone, brownish black	2
5.	Coal, black	1
4.	Clay, brown, hard	1
3.	Shale, gray, tough	18
2.	Coal, black, some pyrite	8
1.	Clay, gray, hard	1
	Total	69

Section exposed at opening of Clark mine in the NE¼ sec. 32, T. 22 N., R. 12 E.

		Feet
4.	Sandstone	20
3.	Clay shale gray	4
2.	Coal, black, few spherical masses of pyrite to 1½ inches	8
1.	Clay, hard, gray	1
	Total	33

Ellingson locality. Fort Union coal which is apparently the Lodgepole bed occurs in a narrow flat topped ridge which forms the divide between North Fork and South Fork of Grand River. This small area lies six miles south and three miles east of Ellingson. Here the coal lies close to the surface and resulting roof conditions are poor. The table which follows shows the succession at this locality.

Section of Fort Union at opening of the Johnson mine in the NE¼ sec. 9, T. 21 N., R. 11 E.

		Feet
6.	Shale, light gray	7
5.	Sandstone, hard	½
4.	Shale, light gray, weathered yellow and white	21
3.	Shale, brown	1/3
2.	Coal, black	7
1.	Clay, underclay, gray, hard	1
	Total	36 5

Wolf Butte locality. Several small areas underlain by coal occur in the vicinity of Wolf Butte. Locally at least the coal thickens to an average of 9 feet. Coal of this thickness with the usual character of the Lodgepole bed is well exposed at the Butte mine. The succession at this mine is given in the table which follows:

Section of Fort Union coal and associated beds exposed at the Butts mine in the SE¼ sec. 34, T. 22 N., R. 12 E.

4.	Covered slope	
3.	Shale, gray, weathers white	20
2.	Coal, black, average 9 feet thick	8–10
1.	Clay	1
	Total	29–31

E. Summary

From the foregoing, it will be evident that there is a large supply of coal in northwestern South Dakota in beds of sufficient thickness to be workable. The Fox Hills coal is in the thinnest and the Ludlow coal in the thickest beds. Hell Creek coal comes in four to six-foot beds.

No attempt has been made to estimate the amount of available coal except that made by Winchester in 1916.[1] In this estimate it was assumed that the heating value of air dried samples was 8,830 B. T. U. and that with this B. T. U. a lignite bed must be two feet and ten inches thick in order to be considered sufficiently valuable for classification. The total content of each seam was determined by multiplying its area in square miles by its average thickness in feet. This figure was then multiplied by 152,000, the number of short

[1]Winchester, op. cit., p. 46.

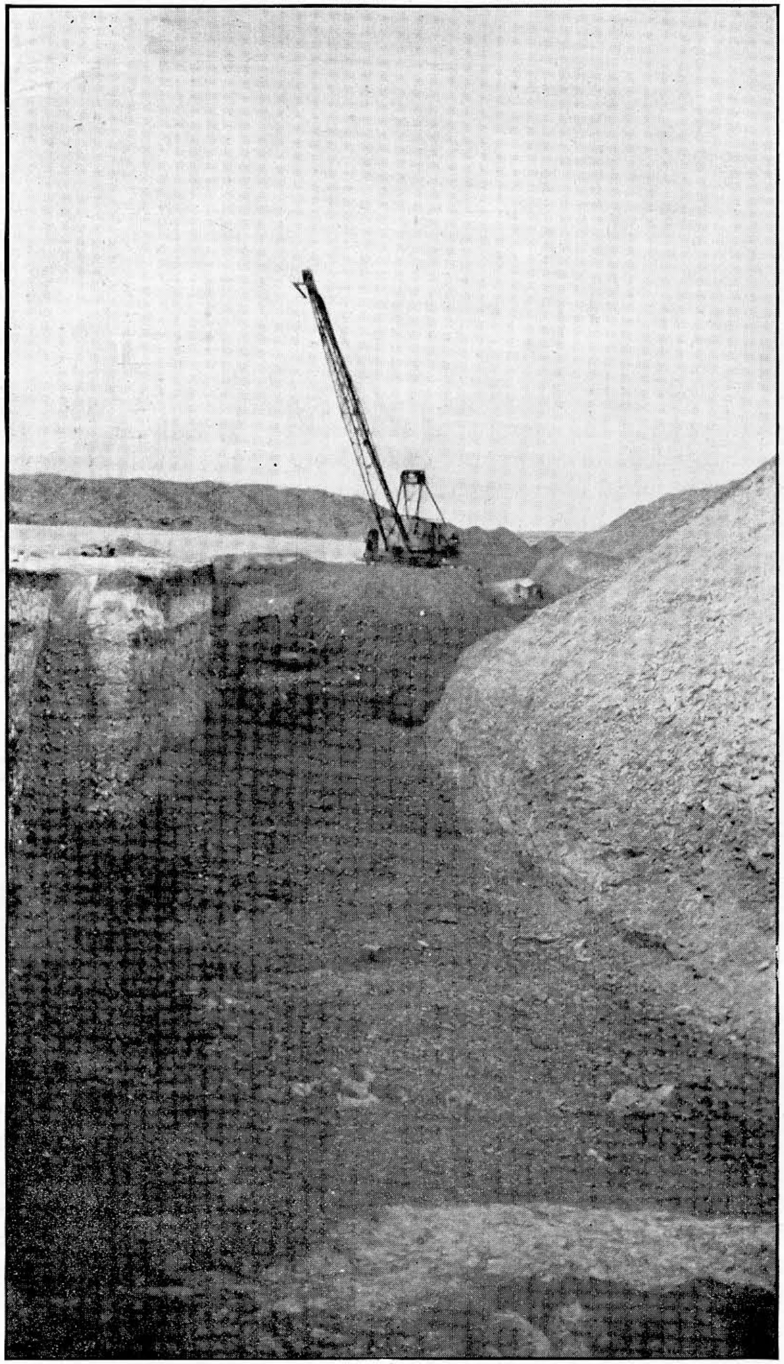

PLATE 11. Stripping Operations, Runkle Coal Mine, Firesteel, S. Dak.

tons of lignite having a specific gravity of 1.3 in a square mile of land underlain by a bed one foot thick. This computation gave a total of 1,096,480,000 tons of mineable lignite in Perkins and Harding Counties. Winchester's estimate did not include the Hell Creek coal in the vicinity of Isabel in Dewey and Corson Counties, nor the Fox Hills coal of the Stoneville area.

The thick coals of the Ludlow member are typical lignite, being brown in color, giving a brown streak, and having a woody structure. On the other hand, Hell Creek coals and Fort Union coals should be classed as high rank lignites or possibly sub-bituminous coals. Their color is black, the woody structure in most of them has disappeared, and the ratio of volatile matter to fixed carbon lies nearer to that of typical sub-bituminous than it does to typical lignite.

All of these coals slack on storage. The slacking indices, however, do not appear to be directly related to the rank or quality of the coal. Thus the lignite coals within the Ludlow member do not show as great a tendency to slack as the coals at the base of the Ludlow and as the Lodgepole-Haynes bed of the Fort Union. Both these latter coals are less lignitic than most of the Ludlow coal. The coals of the Fort Union and lower Hell Creek beds, which are similar in other physical and chemical characteristics, differ considerably from each other in their slacking character.

Though the B. T. U. is not as high as that of most bituminous coals, these lignites can be used as steam coal. Using over-draft furnaces and fine grates, similar coal has been used for firing boilers in a sugar beet factory at Belle Fourche and in the Homestake mine at Lead. Tests made by the State Geological Survey indicate that in heating an ordinary house about twise as much Hell Creek lignite was needed to maintain the same temperature as that furnished by a good grade of bituminous coal. In this test, it was discovered that there was considerable advantage in firing in an over-draft furnace rather than in the under-draft used in domestic heating with bituminous coal.

Briquetting has been tried with some success. It did away with some of the storage troubles arising from slacking. The cost of briquetting lignite, however, has never been sufficiently low to make it commercially feasible.

These coals have never been investigated for their by-product values. Liquid fuels are being made in foreign countries by passing super heated steam over lignite coal. It is probable that South Dakota coals would serve excellently for this purpose. They may, therefore, offer a source of gasoline, should the supply of pool oil run low.

NATURAL GAS

Small quantities of natural gas have been produced in South Dakota since the early days of water well drilling. Though some gas was struck in shallow wells in 1881, it was not brought to public attention until the early 1890's when the Norbeck Co. developed methods of drilling artesian farm wells. These small diameter, deep wells ran into gas pockets in drilling along the Missouri River. No commercial gas field has been developed from this supply. A relativelw small proportion of it has been caught and used, but most of it has been wasted for over forty years.

Most of this natural gas will burn. Some has been struck, however, which will not.

Three geological horions have furnished gas in South Dakota. The shallowest comes from glacial drift in the eastern part of the State; next in depth is that which comes from the base of the Niobrara formation, and the deepest of all is that which comes from the Dakota sandstone.

I. Gas from Glacial Drift

In drilling farm wells east of the Missouri, gas is often struck at depths varying from 50 to 100 feet. Those that have been investigated showed that this gas came from buried swamps. In the recent past, geologically, eastern South Dakota has been covered by a succession of four ice sheets with considerable interval of time between invasions. The younger ice sheets often over-rode swamps on the surface of debris left by older ice. Thus it is not uncommon to run across buried logs and other evidences of vegetation in drilling wells through these drift sheets. In Day County, such buried swamps are found at depths as great as 400 feet. This figure, however, is perhaps the maximum for South Dakota. Marsh gas (CH_4) is generated by the buried vegetation, and can not escape through the clays of the drift cover until punctured by the well.

One of the earliest reports of gas was given by a Mr. S. W. Bauman of Ashton, Spink County, South Dakota, who gave the following account to Mr. James Todd.[1]

"The gas was first discovered by John Bushell in digging

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[1]Todd, J. E., Mineral resources of South Dakota: South Dakota Geol. Survey Bull. 3, p. 114. 1900.

a well near the center of town, at a depth of 66 feet. The gas took fire from a miner's candle he was using. He seized the rope and was drawn up as quickly as possible, but was so badly burned that he was confined to his bed for six or eight months. The gas was found in a light colored clay overlaid by blue clay.

"This was in the fall of 1881. Nothing more was done until October, 1885, when a three-inch well was put down through the 66-foot flow to a stronger flow at 89 feet, which was also in a light colored clay mixed with gravel, overlaid with blue clay. The closed pressure was forty-six pounds. I immediately piped this into my hotel and used the gas in my kitchen and office until the next March, when water broke in and gave me so much trouble that I abandoned it. During the same time Stevens and Co. heated and lighted their large general store from the same well. There appeared to be as much gas when we quit using it as when we commenced."

Similar wells have been struck near Alexandria in Hanson County and near Spencer in McCook County. A 125-foot well at Vermillion gave gas which was largely nitrogen and, therefore, could not be burned. A similar well drilled on Ree Heights, south of Miller, in Hand County, blew gas and pebbles out of the well with considerable force for a day or two and continued to make gas for about a week.

Enough gas to furnish fuel for cooking was produced from a hundred-foot well, four miles west of Scatterwood Lake in Faulk County.

These examples are sufficient to indicate that small pockets of gas are widely spread over eastern South Dakota. In most cases, they were allowed to blow into the air and waste. Some of the earlier discoveries were harnessed and used for fuel.

None of these can be counted on as a commercial supply and none of them will last very long unless carefully handled. However, these small supplies, if promptly taken care of when first struck and used conservatively, can supply gas for domestic uses for a considerable period of time. Such wells should be well cased and the casings sealed to prevent escape of gas around the outside. They should also be capped with a control valve so that only the gas that is to be used can leave the well.

II. Gas in the Niobrara Formation

Small quantities of gas have been encountered at the base of the Niobrara formation in widely separated parts of South Dakota. The most easterly reported is in Aurora and Charles Mix Counties. A well drilled for soft water a few miles south and east of Stickney, in Aurora County, struck gas at 280 feet, after drilling 11 feet into a chalk rock. This gas was struck in 1931 and used in the farm house of the owner, Mr. John Houtkooper. A second show occurred in Charles Mix County, four miles west and two miles south of the city of Wagner, on land owned by the Tabor State Bank. A water well drilled for the farm house struck gas at about 200 feet which gave a sufficient flow to furnish cooking fuel and light for about twenty years. It might have continued indefinitely had it not been flooded out by water from an oil test drilled near by. The following analysis of this gas was made by the Omaha Testing Laboratories:

Analysis of gas from farm well, NW of SW¼, sec. 15, T. 95 N., R. 64 W., Charles Mix County.

CO_2	0.6%
O	2.0%
CO	None
Unsaturates	None
Water	None
CH_4	30.0% methane
N	67.9%

No test on B. T. U. but estimated by laboratory at 300 to 500.

The depth at which gas was reported from some wells in the area about Aberdeen, suggests that the gas came from the Niobrara. However, these wells have not been investigated.

On Bull Creek, south of Chamberlain, three wells have produced gas from this horizon. One in Section 1, T. 102, R. 73; the second well, a half mile south of the one just mentioned; and the third, three miles south of the first well, in Section 23, T. 102, R. 73. These wells are 350 feet deep. Their curbing lies about 40 or 50 feet above the Niobrara and they produced from the base of the formation or immediately below it. The gas has been used in the ranch house but difficulties in keeping the wells and equipment in repair caused the owner to discontinue its use.

A third locality where gas has been produced from the Niobrara is at Provo in Fall River County. On the western flank of the big Chilson Anticline, there is a minor structural fold which brings the Niobrara to the surface. At Provo, a number of shallow water wells have been drilled which produced gas. This gas has never been used so far as our records show. It was usually burned in a flambeau and according to reports made an interesting spectacle for the local inhabitants and for travelers on the Burlington trains passing through Provo.

Like the gas from glacial drift, that from the base of the Niobrara formation does not give much prospect of commercial production. However, it apparently occurs in larger quantities, since flows like the one at Wagner, promised to last indefinitely for the small domestic use to which they are put, while most of the drift wells are rather short lived.

III. Gas from the Dakota Sandstone

The first record of gas from the Dakota sandstone is from a well drilled for the Indian school at Pierre in 1894. This was followed by a well drilled by the proprietor of the Locke Hotel in Pierre. In 1898 a company was organized to sink a well for gas and power. They succeeded in finding a supply estimated at 80,000 cubic feet per day, which supplied fuel for a 60-horse power engine for their pumping station, a 57-horse power engine for a mill, and four smaller engines of four-horse power each with enough gas left over to light the entire city and supply stoves in many houses.[1]

In the decade between 1900 and 1910, a great many artesian wells which produced gas, were drilled in Hughes, Stanley, and Lyman Counties. Drilling also was continued up the river and gas was struck at the Cheyenne Indian Agency in Dewey County and as far north as Selby in Walworth County.

These wells were all drilled for the purpose of obtaining artesian water and the gas was a by-product. At Pierre and Fort Pierre, the gas was trapped and sold to the cities. A few ranch houses also installed traps and used the gas for

[1]Todd, op. cit., p. 116.

heating and lighting. The water from these artesian sands, however, is very corrosive and well casings were soon disintegrated. Owing to the difficulty of keeping wells properly cased, most of them have been allowed to run wild, the gas escaping into the air.

This gas lies in a belt roughly paralleling the upper Missouri Valley. The southernmost wells are about latitude 44° N. which crosses in the middle of Lyman County Wells at McClure in Lyman County, Capa in Jones County, and Midland and Nowlin in Haakon County, seem to mark the southern boundary of the gas producing area. Deep wells south of this boundary have not produced gas from the artesian sands. At its southern end, the belt is about 60 miles wide.

Most of the deep wells in Stanley and eastern Haakon Counties have given shows of gas. This includes the area about Fort Pierre; and it is interesting to note that one township in Stanley County, southeast of Fort Pierre, has been named the "Gas Belt Township." A number of township wells in Stanley County were drilled in the early days for community water supplies and all of them gave small shows of gas. Typical are the wells at the old Lacy post office, Meers township and Willow Creek township. The most westerly well at this latitude was found near West Fork post office on the Dan Bierwagen Ranch.

Farther north, the field narrows considerably, the wells being confined to a belt not more than 25 miles in width. Gas was struck at Cheyenne Agency, but not at Gettysburg 20 miles to the east. It was also struck along the Missouri River in the vicinity of Akaska and Selby in Walworth County. Gas has also been reported from a well at Pollock in Campbell County, only a couple of miles from the North Dakota line.

Source of Dakota Gas

Though the first investigators assumed this gas came from the sandstone, for many years it was thought that it was shale gas which was generating slowly and, therefore, gave the wells a long life.[1]

Later studies, however, seem to indicate that it is an accumulation in the sands of the Dakota. In the first place, it

[1]Moulton, G. F., Natural Resources of South Dakota: Circular 16, p. 21, 1924.

is not produced until the artesian water horizon is encountered. In the second place, the belt extends along the front of a large structural terrace, the Eureka-Mission Terrace, which lies on the east flank of the Lemmon geo-syncline, to be described later under the head of petroleum. (See p. 133). The gas lies on the front of the terrace, in a region where a steep westerly dip of the reservoir rock is changed to a nearly horizontal position. Such terrace structures are natural places for the accumulation of oil and gas. Gas is localized in smaller folds on the main structure. For example, though most of the gas in Pierre and in wells to the east rises with artesian water, dry gas was struck in a well on a pronounced structure which acted as a trap on Dry Run, six miles east of the city. As far as it has been possible to map structures, it appears that even the gas in the artesian water is confined to structurally high areas.

Composition

There are only a few analyses of this gas, but those available show it to run high in marsh gas, (methane, CH_4), the important ingredient in fuel gas. None of the analyses show sulphur, and the nitrogen and inert gases make a very small percentage. The composition of the gas in the southern part of the field may be represented by the following analysis of the gas from the well at the State Capitol at Pierre.

Analysis of gas from State Capitol Well, Pierre, South Dakota. Analysts: A. Karsten and Charles Bentley.

Methane (CH_4)	94.00%
Carbon Dioxide (CO_2)	.06%
Oxygen (O_2)	.13%
Illuminants (C_2H_4, etc.)	.00%
Carbon Monoxide (CO)	.00%
Higher hydrocarbons (C_2H_6, etc.)	.00%
Inert Gas (N_2, etc.)	5.70%
	99.89%

B. T. U. per cu. ft. (theoretically calculated from the above chemical analysis as at 60° F. and 27.77 inches mercury plus 12.5 inches water pressure) .... 907.0 B. T. U.

A sample of gas from the Pierre city wells was analyzed

in 1939, in the laboratories of the Carter Oil Company, giving the following results:

Analysis of gas from Municipal Wells, Pierre, South Dakota. Analyzed by the Carter Oil Company.

	Gas Vol. per cent	G. P. M.
Methane	74.8	---
Ethane	13.2	---
Propane	10.7	2.62
Iso-Butane	.4	.13
N-Butane	.9	.25
Total	100.0	3.00

The following analysis will represent the gas in the northern part of the belt. The sample was taken from a well in Potter County a few miles east of the Cheyenne Agency, and the analysis made in the U. S. Geological Survey laboratory in Casper, Wyoming.

Gas analysis from well in Sec. 5, 118 N., R. 178 W., Potter County. Analysis by U. S. Geological Survey.

Carbon Dioxide	0.25%
Oxygen	0.49
Methane	92.01
Ethane and higher	3.77
Nitrogen	3.48
Specific Gravity (calculated)	0.592
Specific Gravity (observed)	Insuffic't sample
Average "n"	1.04

Calculated Gross B. T. U. per cu. ft. at 60° F. and 15.025 lbs. per square inch pressure—1015.

An interesting analysis was made at the U. S. Bureau of Mines laboratory in Amarillo, Texas, on a sample of gas collected by the Geological Survey from the well at the old Lacy post office.

Analysis of gas from old Lacy post office, Sec. 35, T. 7 N., R. 28 E., Stanley County, S. Dak. Analysis by U. S. Bureau of Mines.

Carbon dioxide	3.1%
Oxygen	0.6
Methane	88.7
Ethane	0.0

Nitrogen and helium by difference	7.6
Total	100.0
Helium content	0.04%

This analysis shows about the same proportion of methane and other gases as do the preceding analyses. It is of special interest, however, in that it shows a small percentage of helium. Since helium is a very important gas commercially, and is obtained in only a few places in the world, it is interesting to note that it can be obtained from the gases along the Missouri Valley. The content indicated is very small but it is between one-third and one-half of the helium content of the gases from which helium is now being extracted commercially. In case of a suitable market, it might be possible to obtain helium from South Dakota gases.

The fact that helium is not shown in any of the other analyses does not mean that it is not present. Its detection requires a special chemical technique and it could not be detected in routine gas analysis. No attempt has been made to analyse more than this one sample for helium.

The wells at Pierre and Fort Pierre have furnished enough gas for limited use in those cities since 1890. None of the gas shows, so far, have given a large enough volume to be called commercial. Dry gas struck in a well east of Pierre, however, raises hope that similar structures elsewhere will have accumulated a sufficient quantity of dry gas to allow the development of a useable field. It should be borne in mind, however, that some of these wells have more than enough gas for heat, light, and cooking in a large ranch house. In a country where fuel is as scarce as in the gas region, therefore, it is a waste not to make the best use of it. The use of carefully sealed wells, cased with noncorroding pipe which is changed sufficiently often to keep the well in good condition, can supply a ranch or even a small community. There is always the possibility that some large structure may exist in which a pool of commercial proportions may be developed. This gas is too important as a fuel for this region, and as a possible source of helium, to allow it to be wasted into the air, as is the case in most of the wells from which it is issuing.

PETROLEUM

The dream of making South Dakota a petroleum producing state is an old one. The first report of this Survey[1] de-

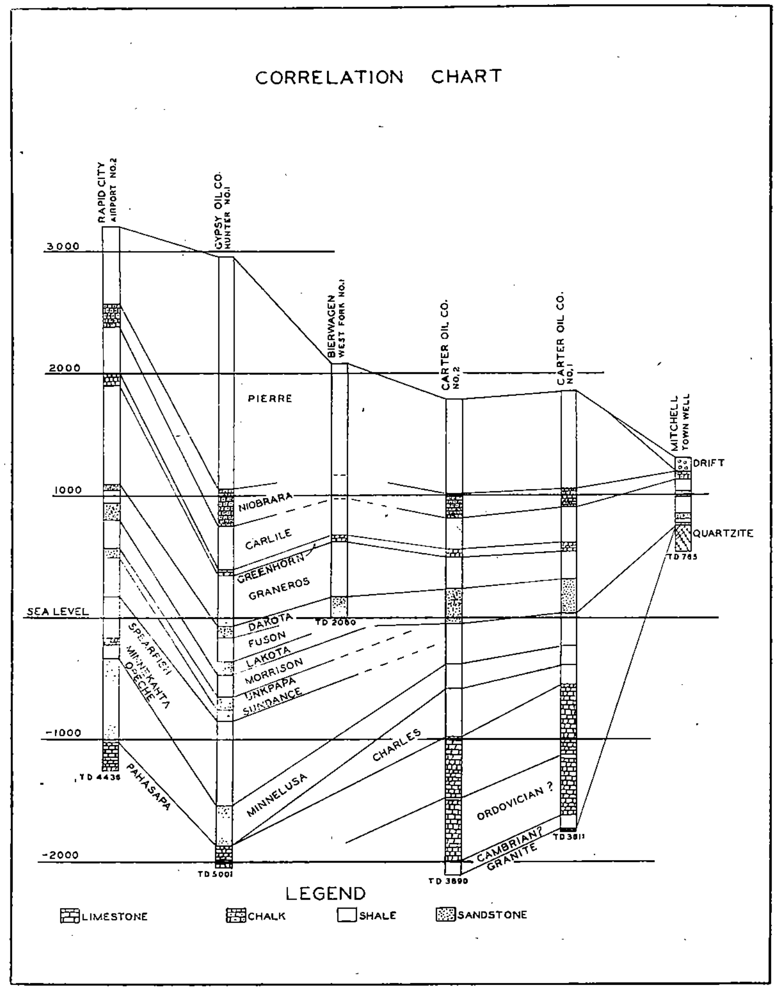

Figure 12. Sedimentary formations underlying South Dakota between Rapid City and Mitchell.

[1]Todd, J. E., A preliminary report of the geology of South Dakota: South Dakota Geol. Survey Bull 1, 1894.

votes considerable space to its possibilities. The numerous reports that have been published since, indicate the sustained interest of South Dakota's citizens and absentee land owners in petroleum possibilities. Though wildcat oil tests have been drilled at widely separated points, no production has yet been encountered. However, the finding of oil in neighboring states in formations which also underlie South Dakota, the encountering of small shows of oil in wells as widely separated as Rapid City and the Standing Butte well, 25 miles northwest of Pierre, and the presence of gas in the Missouri Valley just described, and in Fall River County, have kept interest in the state alive and warrant considerable further investigation.

Prospecting has been retarded in South Dakota by a combination of factors. Probably the most important factor was the lack of geological information on structure and stratigraphy. The eastern half of the State is mantled by a veneer of glacial drift and much of the western half exposes only the Pierre shale. Early geologists, therefore, could not unearth much of the information on which oil prospecting depends. Changing techniques and new instruments have allowed geological prospecting to proceed rapidly in the last few years and much valuable information has been unearthed. There is still much work of this nature that needs to be done, however.

The large area of the State and the small size of the largest oil pool make a haphazard search much like the proverbial search for the needle in the haystack. The cost of drilling to the necessary depths to make complete tests has also been prohibitive to prospecting by drilling alone. Wells, 4,000 to 8,000 feet depths are very expensive and can be attempted only when all other signs are favorable. Thus producing companies have been slow to attempt work in South Dakota, preferring to prospect areas near known pools and in regions where drilling was less expensive.

The discovery of new oil pools, however, has not kept pace with the rate at which old pools are being depleted. It is, therefore, largely a matter of time before such areas as South Dakota must be thoroughly prospected in order to keep the necessary supplies of petroleum available. The stratigraphic and structural conditions affecting oil, therefore, will be considered in order.

I. Stratigraphy

Petroleum, like natural gas, originates only in sedimentary rocks. It collects in porous strata through which it moves until it is caught by some sort of trap. The kinds of rock underlying any region are, therefore, of first concern to an oil prospector. As is pointed out in Part II in this treatise, most of the State is underlain by sedimentary rocks. These include the ordinary limestone, sandstone, and shales, and many of them are equivalents of the oil-bearing strata in neighboring parts of the United States. A generalized column of these rocks follows:

System	Formation	Description	Thickness
Quaternary	———	Glacial drift covering the eastern half of the State. Of no interest as an oil prospect	0-400 Ft.
Tertiary	Brule	Clays and sands exposed largely south of White River as the Bad Land beds. Not interesting as an oil prospect	0-475 Ft.
	Chadron	Chadron makes base of White River beds, heavy gumbo clay, and arkosic sand	0-180 Ft.
Cretaceous	Fort Union	Sandstone; occupies small area in Harding and Perkins Counties. Not interesting as an oil prospect	425 Ft.
	Lance	Lance formation occupying the northwestern corner of State only; coal beds, clay, gumbo, and sand, not a possible oil horizon	600-800 Ft.
	Fox Hills	Sandstone with some shale; a good water sand but not of interest as an oil prospect	25 Ft.
	Pierre	Occupies most of South Dakota. Shales with some chalk and a few sandy beds; oil shales making the bottom member in the Missouri Valley	1000-1500 Ft.
	Niobrara	Underlies most of South Dakota. Chalk rock in some places shaly; produces gas in small quantities in Fall River County and along the Missouri River, gave a show of oil at Ponca, Neb., opposite Elk Point	200 Ft.
	Carlile	Mostly shale, contains Wall Creek sand, a good oil horizon, in western South Dakota	215-750 Ft.

System	Formation	Description	Thickness
	Greenhorn	Shaly limestone with some chalk beds above and below. Some shale is also included in this formation. A good horizon marker but not a good oil reservoir	25-65 Ft.
	Graneros	Dark shale, carries Newcastle sand in the west which is a good oil and gas horizon	65-1150 Ft.
	Dakota-Lakota Series	Largely sand; in the west separated into the Dakota Fuson and Lakota formations. In the east, a series of three to five sands separated by shale. These carry oil in the Wyoming fields	150-700 Ft.
Jurassic	Morrison	Maroon, brown, and black and various colored shales with some thin sand beds	0-150 Ft.
	Unkpapa	Patchy bright red, white, yellow, lavendar colored thin sandstone	0-225 Ft.
	Sundance	Sandstone at top and base, with center section of limestone, thin sandstone and green shale. A possible oil horizon; carries at least one seep at the northern end of the Black Hills	0-300 Ft.
Triassic	Spearfish	Red beds; sand, sandy shales, and silt stone with much gypsum	0-700 Ft.
Permian	Minnekahta Limestone	Found only in western South Dakota. Thin bedded almost to lamination; gives bituminous odor from fresh break	0-40 Ft.
	Opeche	Red beds, dark maroon sands and shales with a little gypsum	0-130 Ft.
Pennsylvanian	Minnelusa	In Black Hills outcrop, thick sandstone at the top and alternations of sand, lime and shale, in typical Pennsylvanian style in lower part of formation. Top sandstone thins rapidly eastward. A good oil horizon which has given shows about the Black Hills	0-500 Ft.
Mississippian	Big Snowy Group	A series of partly terrestrial formations which underlies the northern and central portions of South Dakota covering nearly half of the State, but does not outcrop. The Heath sand, shales, and gypsum, Otter limestone, Kibbey gypsum, sand, and shale; Charles limestone with beds of anhydrite are represented. Thickness	0-600 Ft.
	Pahasapa	Massive limestone outcropping in the Black Hills and underlying the western half of South Dakota. Oil bearing in widely separated wells	0-600 Ft.
	Englewood	Purple limestone, very fossiliferous	0-50 Ft.
Ordovician	Whitewood	Yellow limestone and buff limestone occupying northern part of Black Hills and probably underlying northern half of western South Dakota	0-80 Ft.
Cambrian	Deadwood	In western South Dakota heavy sandstone on top and bottom with intermediate member of alternating sands, shales, and thin limestones. Probably thins eastward and southward; represented by thin sandstone at Aberdeen; gave oil show in a deep well in Harding County, otherwise not commonly oil-bearing	0-450 Ft.
Pre-Cambrian	Group	Designated "granite" by drillers and lies below all possible oil-bearing strata. Pink quartzite in the east; schist, and gneiss and dark granite in northeast quarter of the State, white granite encountered in the James Valley; schists, quartzite, marble in western half.	

It will be noted that some of these formations do not underlie the entire State. This is especially true of the younger formations, namely, those above the Pierre and of all the Paleozoic formations. The former have been removed by erosion as they once covered all or nearly all of the State. The older ones, however, probably never did cover more than they do at present. In general, it should be noted that the Paleozoic rocks thin towards the east and many of them overlap one another and are overlapped in turn by formations of the Cretaceous system. There are few parts of the State that do not have some formations which might carry oil.

The only areas that can be condemned as oil prospects are (1) the core of the Black Hills, (2) the region between Sioux Falls and Mitchell underlain by the Sioux formation, largely pink quartzite and (3) a small area just west of Big Stone Lake. In these regions, the pre-Cambrian rocks are at the surface. Pre-Cambrian rocks for several reasons, which need not be discussed here, do not carry oil. It is, therefore, hopeless to drill in the areas where they outcrop since younger rocks cannot lie beneath them. Neither is it profitable to drill into them where they underlie the younger formations. These pre-Cambrian beds form the basement or foundation on which all possible oil-bearing strata rest.

From the foregoing, it is evident that the sedimentary sections vary greatly in different parts of the State, and where complete testing is to be done, the entire section should be penetrated. The available information indicates that the thickest section of sedimentary rocks lies in the northwestern corner of the State. Eight thousand feet were penetrated in two wells in Harding County. In the upper Missouri Valley, in Potter County, 3,600 feet were drilled. At Aberdeen, the thickness of sediments was 1,142 feet, and at Milbank in Grant County, the sediments thin to zero.

There is no series of wells farther south in the State which have been drilled through to the pre-Cambrian; however, it is estimated that approximately 5,000 feet should be encountered near Ardmore in Fall River County, 3-4,000 feet in the vicinity of Chamberlain, and zero feet at Mitchell. In Charles Mix County, four miles west and two south of Wagner, pre-Cambrian was struck at 1,400 feet, at Yankton at 898 feet, at Vermillion at 420 feet, and at Jefferson at 1,030 feet.

In general the sections are thicker toward the northwest and thin toward the east.

II. Stratigraphic Traps

The thinning of sedimentary strata makes traps in which oil and gas pools can accumulate. If a reservoir rock like a sandstone formation, lying between two impermeable shale formations, thins out, oil will migrate to the point of thinning, but can go no farther. The same is true of overlapping formations. If an impermeable shale overlaps a permeable sandstone, it effectively seals in the end of the sand formation, causing a trap in which oil and gas may accumulate. Such traps occur in South Dakota.

It is known that the Ordovician system thins out southward in its outcrops in the Black Hills and also in sections found in well logs between Aberdeen and Rapid City. This offers a chance for stratigraphic traps in a northeast-southwest direction across the middle of western South Dakota. The exact location of these traps, however, is dependent upon sub-surface information which is not now available and which can be obtained only from the records of many wells.

As has been pointed out, the other Paleozoic formations, which outcrop in the Black Hills, thin eastward, disappearing somewhere between the Missouri valley and the Big Sioux valley. From the information now available, it seems that most of them pinch out between the Missouri and the James valleys. They are all overlapped by Cretaceous formations, thereby offering another good set of stratigraphic traps running roughly north and south.

The Big Snowy Group of the Mississippian system described above, does not outcrop in the State. It is known only from well records. These, however, indicate that it enters the State from Montana and North Dakota underlying the northwestern quarter and thins southward. Its edge lies in a festoon-like curve from the State boundary in Butte County southward to Wall in Pennington County and thence eastward as far, at least, as the Cheyenne Indian Agency in Dewey County.

This edge offers another series of stratigraphic traps caused by pinching of the formations in the Big Snowy Group itself and by the overlapping of this group by the Pennsylvanian Minnelusa formation.

Stratigraphic traps are the most difficult of all to locate since their whereabouts has to be determined largely through drilling and careful recording of well cuttings. Certain types of geophysical prospecting have assisted in their location. Geophysics, however, has been most successful in determining the exact location of the trap after its approximate position has been ascertained from drilling records.

III. Structures

Structure (the attitude of sedimentary beds) has played a very important part in the accumulation of oil pools and for

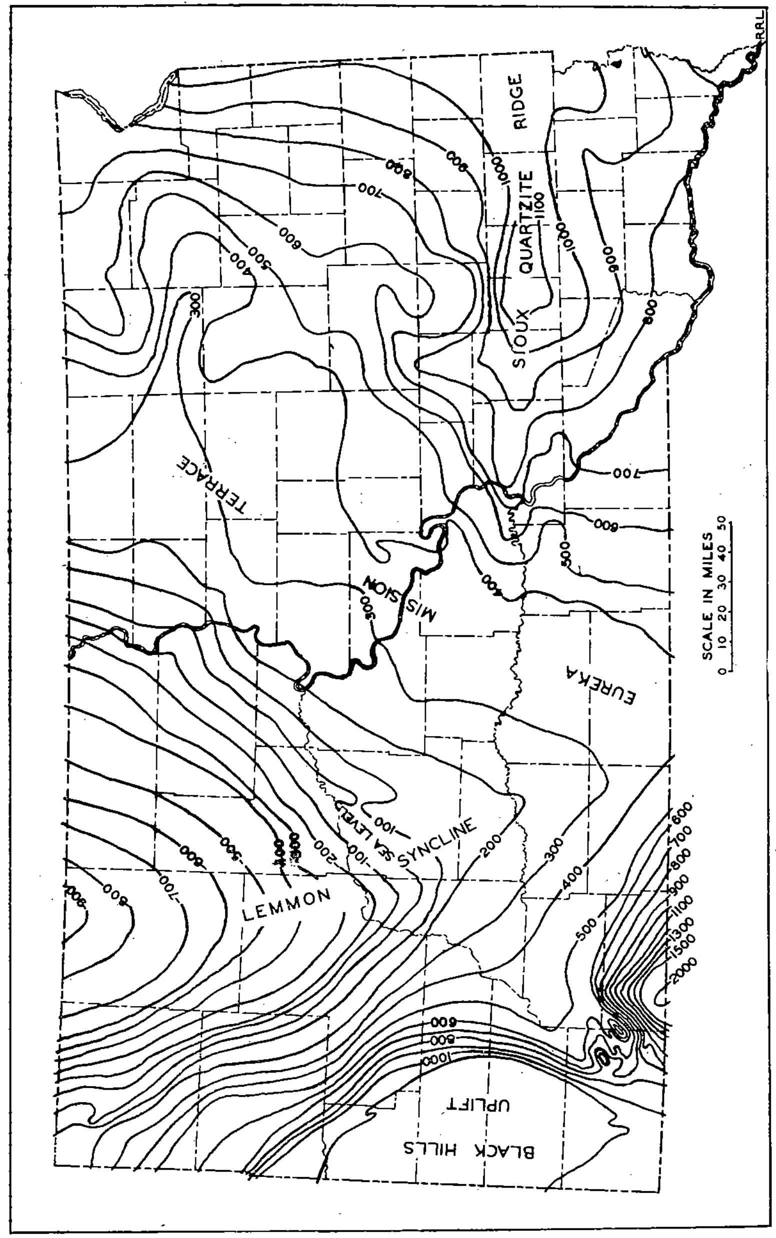

Figure 13

Structure Map of South Dakota. Contoured on the top of the Dakota Sandstone. Contour interval 100 feet.

a great many years was the only basis for scientific prospecting. When an oil reservoir rock, such as a bed of sandstone, is tilted, oil migrates up the slope until it is stopped by some sort of bend or flexure in the bed which prevents it from rising higher. Some of these flexures are in the form of great arches or troughs covering many hundreds or thousands of square miles, the geanticlines and geosynclines. Both are of interest because oil tends to migrate out of geosynclines and lodge in small anticlines about its edge. This has given rise to the "basin theory" of oil accumulation which has guided prospecting a great deal in the past. Such geosynclines as the Powder River Basin in Wyoming, may be rimmed with a great many oil pools in some cases, while in others only a few scattered pools are to be found.

The dominant structure in South Dakota is the southern end of one of these great basins which reaches northward through North Dakota and into Saskatchewan, Canada. This great basin is known as the Moose Jaw Synclinorium and is a trough caused by the pressures which thrust up the Black Hills and the Cedar Creek anticline in Montana. The southern end of this fold lies between the Black Hills and the Missouri River with its axis plunging northward into the portion of the geosyncline known as the Williston Basin in North Dakota. This axis trends a little west of north, passing through the cities of Phillip in Haakon County and Lemmon in Perkins County. It has been called, therefore, the Lemmon geosyncline. Thus the sedimentary beds in all parts of western South Dakota slope upward from this axis to the west, east, and south. This structure is bounded on the west by the Black Hills and the end of the Cedar Creek anticline in Montana which separates it from the Powder River Basin in Wyoming.

East of the axis the sediments rise until they reach approximately the longitude of the Missouri River Valley. Here they flatten to a nearly horizontal position which continues eastward until they thin out against pre-Cambrian rocks along the eastern border of the State. This part of the structure is a terrace and since its front edge has been traced between Eureka in McPherson County and Mission in Todd County, it has been named the Eureka-Mission Terrace. It is along the front of this terrace that so many artesian wells have encountered gas.

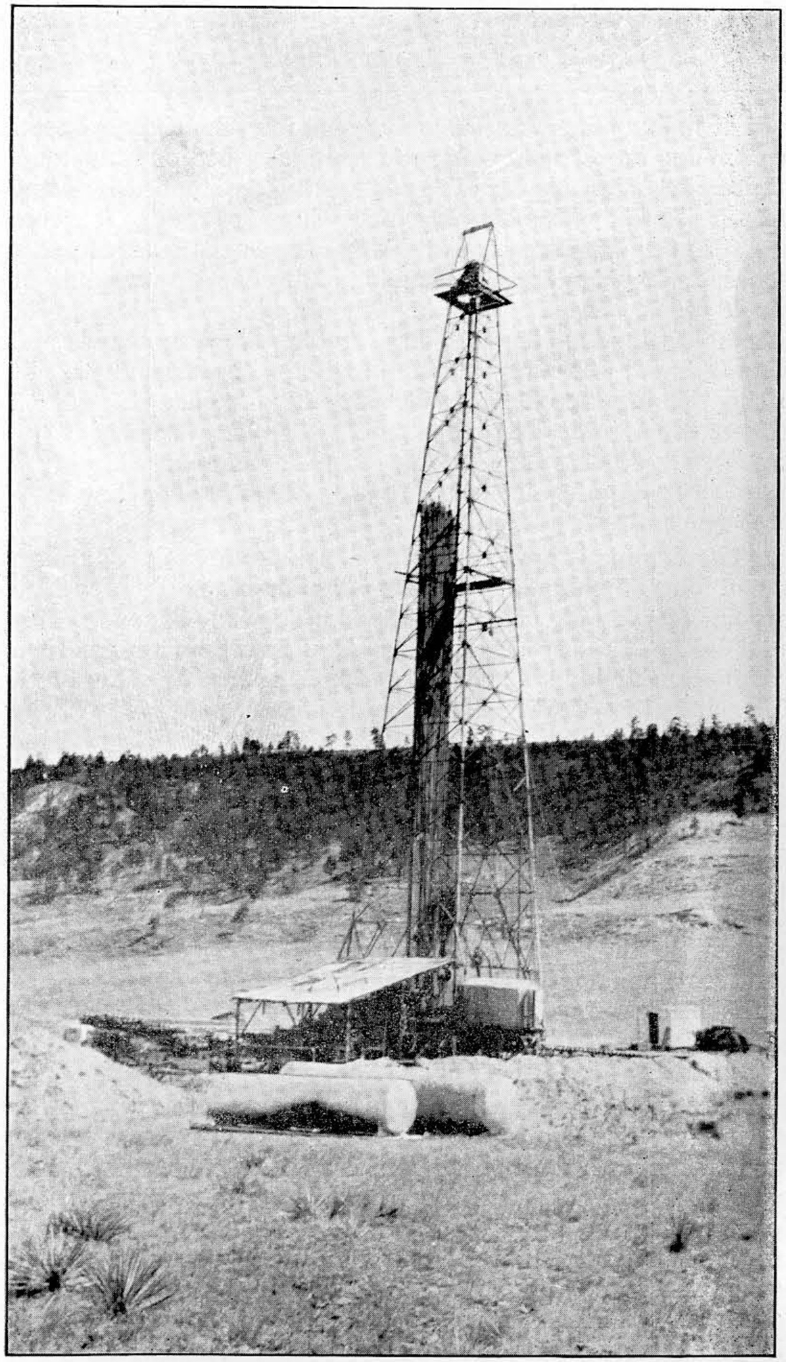

PLATE 12. A Deep Oil Test
Harding School Land Well No. 1, four miles west of Camp Crook, Harding County, S. Dak.

Along the edge of this big structure lie smaller folds, generally elongated with their long axes parallel to the axis of the geosyncline. Most of these are low folds or plains type of anticlines and, therefore, have been much sought as drilling sites.

Only a few of these have been mapped and much future prospecting will depend upon the location of these smaller structures on the flanks of the geosyncline. The few that have been mapped, however, give some indication of the size and character of others which may exist.

In Harding County, three anticlines were mapped on the structural divide between the Lemmon Basin and the Powder River Basin in Montana. These are about two miles in length and a half to three-quarters of a mile in width and lie in the northwest corner of Harding County. They have been designated as the Fox Hills dome, Gallop Creek dome, and Camp Crook anticline. Drilling on the latter has produced several shows of gas.[1]

On the eastern flank of the geosyncline, one very large structure was mapped west of Chamberlain, the Medicine Butte Structure.[2] This is a large fold lying in eastern Lyman County between the Big Bend of the Missouri River and the mouth of the White River. Its axis has been traced for 42 miles in a northwesterly direction and it covers a width of 20 miles.

Small unnamed structures have been mapped farther up the Missouri River, all conforming to the same structural pattern.

A structure which has aroused considerable interest lies in eastern Haakon County between the Bad River and the Cheyenne River. West Fork post office is at its north end and it has been called, therefore, the West Fork structure A gas well rewarded prospectors in a shallow test made many years ago on the Dan Bierwagen ranch in Section 11, T. 6 N., R. 21 E., Haakon County.

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[1]Moulton, G. F., Bass, N. W., Oil and gas prospects in the Cedar Creek anticline and vicinity in Montana, North Dakota, and South Dakota: U. S. Geol. Survey, Memo for the press, January 11, 1922.

[2]Petsch, B. C., The Medicine Butte Anticline: South Dakota Geol. Survey Rept. Inv. 45, 1942.

In Fall River County, three structures form a turkey track off the southern end of the Black Hills. These are all plunging anticlines. The easternmost, known as the Cascade anticline, has its axis trending directly south. It is about eight miles long and five miles wide. Its neighbor on the west is the long Chilson anticline which has been followed from the Black Hills to the Nebraska state line and is finally lost beneath the Tertiary sediments in Nebraska. This one has been mapped for 18 miles north and south and varies from ten miles in width in the northern end to two miles in width near Ardmore at the south. A gas field has recently been encountered on the axis near Ardmore.

The third Fall River structure has no name but lies west of the Chilson anticline, its axis pointing southwest.

IV. Summary

Oil prospecting in South Dakota has not yet reached the stage where it can be stated with certainty that oil will be produced. It has progressed to the point, however, where the State cannot be condemned as an oil prospect. Oil-bearing formations in other states, extend into South Dakota and are of the same character as in regions where they carry oil. Stratigraphic traps are abundant but difficult to find. Structural conditions are entirely favorable since a large basin dominates the structure of most of the State and is surrounded by minor structures in which oil and gas can accumulate.

Oil shows have been encountered in a number of places around the Black Hills; Belle Fourche and Rapid City both having had good shows, and a small production of approximately five or ten barrels a day having been pumped from wells in the Barker structure in southwestern Custer County. Other oil shows have been encountered as far east as northeastern Stanley County and as far north as Harding County.

The presence of a gas field in Fall River County on a well developed structure and of gas in the Dakota sands along the Missouri is also a favorable indication.

Thus the geological conditions are all favorable to oil accumulation. The answer to the question of where the accumulation may take place is one which will require a great deal of geologic work and a tremendous amount of test drilling.

The Lemmon geosyncline offers one of the large prospecting areas in the United States and it is certain that as supplies of petroleum grow less and the difficulties of obtaining it grow greater, this area will be thoroughly prospected. South Dakota should yield a rich return in petroleum products, but it does not appear from the present indications that it will be a poor man's oil paradise. The high cost of prospecting, deep drilling, and the number of wells necessary to prove a structure make oil hunting in South Dakota expensive.

OIL SHALE

Oil shale has not been used as a source of petroleum in this country though it is an important source in Europe. The time will come when we will have to turn to it here. Most states have made a careful survey of their oil shale resources. In South Dakota, however, we can only give some generalizations. Oil shale has been noted in the Graneros and Pierre formations. The first formation carries it in the Big Sioux Valley, but there has never been an opportunity to discover the amount or the extent of this shale. So far as is known, the same formation in its western outcrop contains no oil shale.

The Sharon Springs member of the Pierre is a very persistent oil shale horizon. As was noted under the description of this member, it is characterized by an abundance of fish scales and other fish remains which may account for some of the oil present in it. It has been sold for coal in Charles Mix County and an open fire was kept burning for several weeks by simply shoveling more shale onto a burning heap. It was not very satisfactory as coal, however, because of the high ash content, as much clay being left as was put into the furnace. The Burning Bluff, one mile north of the Rosebud bridge in Gregory County is in this member, and much of the smoke that issues from it in wet weather is due to the fact that the sulphides which ignite are hot enough to distill and set fire to the oil in the shale.

The Sharon Springs member of the Pierre outcrops in the Missouri Valley from Yankton to Chamberlain and about the southern Black Hills and could doubtless be excavated under shallow cover at many places in the State.

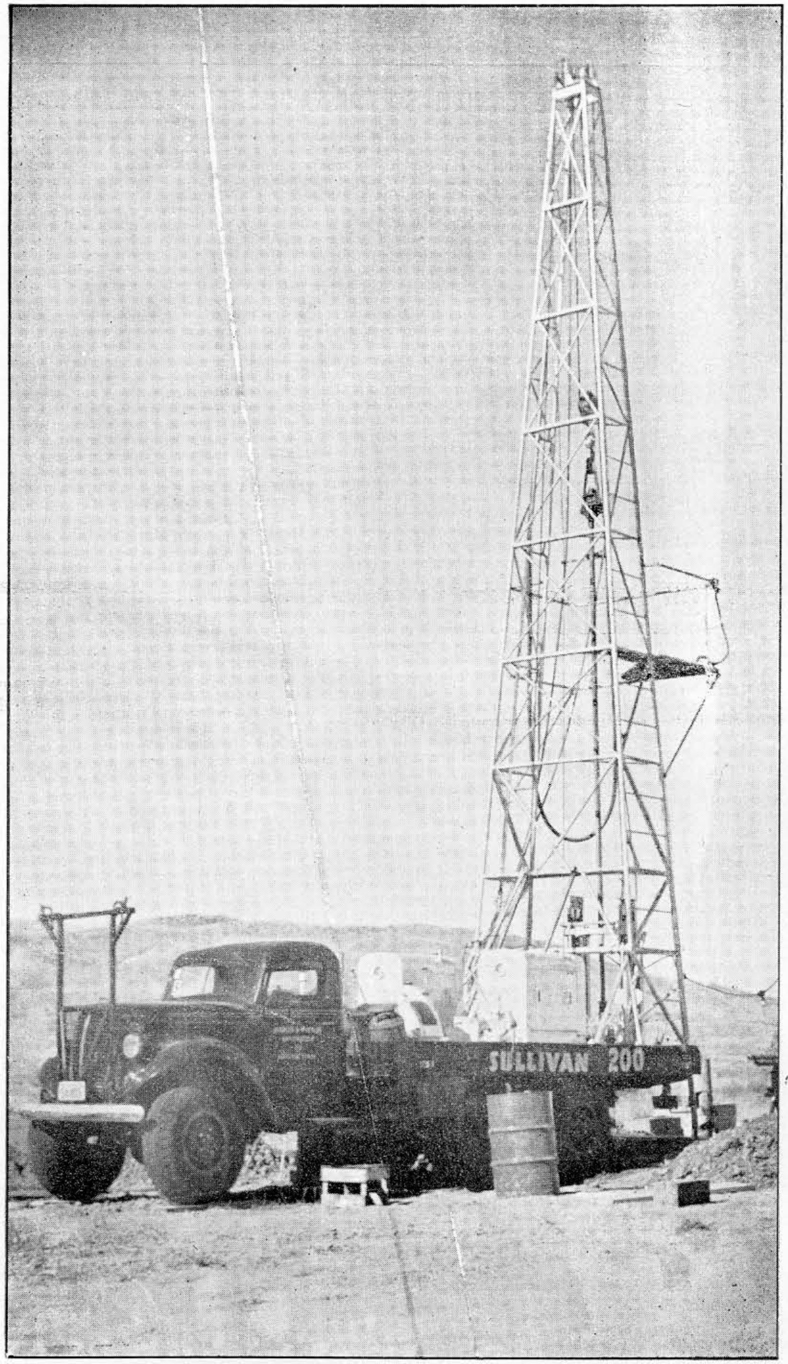

PLATE 13. Oil Test on Dry Run
Five miles east of Pierre in Hughes County, S. Dak.

DIVISION III. STRUCTURAL MATERIALS

Under the heading of structural materials will be grouped those mineral products which are used by the building industry for the construction of buildings, highways, bridges, and the like. They fall into three catagories, (1) stone, (2) sand and gravel, and (3) cement materials. They are the fundamental building materials in the development of any region and are especially important to South Dakota because the State is not near the production centers of such materials. As they are all very heavy, the cost of transporting them is very high.

Some use of local material is being made to good advantage. However, a great deal of material is still shipped in that could be furnished locally. The following descriptions, therefore, will be an attempt to summarize the building materials in the State and give the information now at hand on their possible usefulness.

STONE

Rock suitable for building purposes is found in quantities only in the extreme eastern and extreme western parts of the State. In these locations, bodies of hard rock are large enough to allow commercial exploitation. Such hard rock is available in only two and three per cent of the State's area, however.

For small structures, it is sometimes possible to obtain sufficient local material east of the Missouri River from glacial boulders which are strewn over much of the territory. West of the River, small amounts of well cemented rock can be found on butte tops and at the edges of some breaks where case hardening of sand has made rock that can be quarried. Such sources can not furnish commercial production, but the hard rock areas in the extreme eastern and western parts of the State can furnish very large quantities and are so located as to be within easy reach of most parts of the State where large scale building is in immediate prospect.

Most stone goes to market as building block, ornamental stone, rip rap, and crushed rock. Though the use of stone as building block is not as common as a few years ago, due to inroads made by concrete construction, there still is a demand for such material, especially where it has an ornamental value. Such rock is usually granite, sandstone, quartzite, or limestone. To be useful for such purposes, a rock must have a fairly high crushing strength so as to stand the weight of the structure which rests upon it. It must be uniformly grained and weather to an even color. Blotchy color, iron stains, and other blemishes reduce its value as a building stone.

The two prime requisites for an ornamental stone, which can be used for monuments, interior finishing, or other decorating, are first, that it take a high polish, second, that it has a pleasing color or combination of colors. A porous rock like sandstone, which might be an excellent building block, cannot be used as an ornamental stone because it will not polish. The openings between the grains prevent it. For exterior use, ornamental stone must be chemically inert to withstand weathering. There are numerous examples of marble monuments which have lost all semblance of polish and inscription through weathering. For interior decoration, however, such stones are excellent, providing there is no wear or abrasion on them. Thus granite, quartzite, and their relatives are useful either inside or out and can be used as floors or thresholds which take continuous wear. Marbles are best used for interior decoration as wainscoting or pillars but do not last well on floors or stair treads.

For use as rip rap or crushed rock, it is most important that the rock be tough and stand abraison well. It is an asset for a rock used as a concrete aggregate to break in small angular pieces, since they tend to lock, making stronger concrete.

Granite

True granite is a volcanic rock, and occurs in large masses from which unlimited supplies can be obtained. It is tough and has the highest crushing strength of any rock,—so high that no structures have been large enough to break it. It also polishes well and is inert to the chemical processes of weathering. Granite, therefore, is much used as building and ornamental stone where permananency and a pleasing color are desired. Colors range all the way from nearly pure white to very dark gray, thereby offering a great variety to the monument maker.

In South Dakota, two granites occur from which such

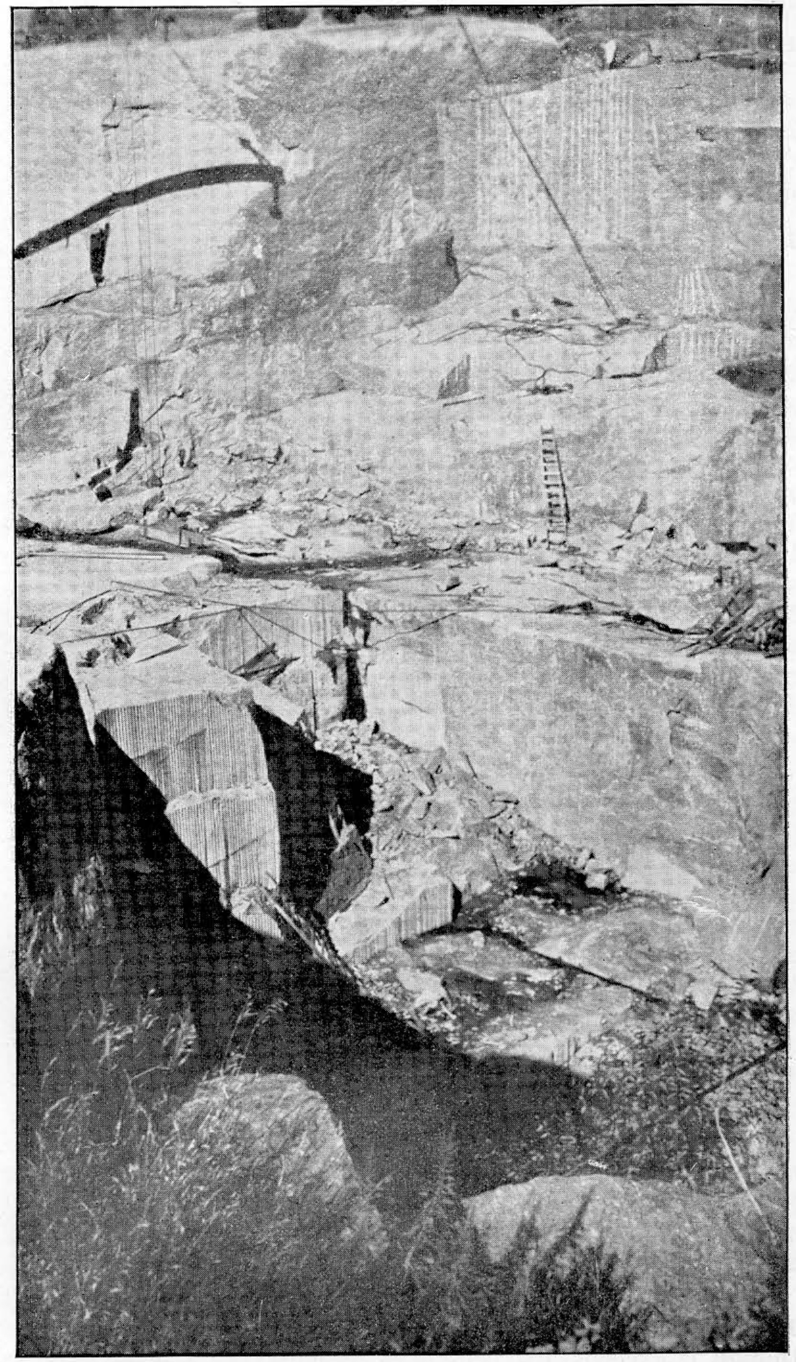

PLATE 14. Mahogany Granite Quarry
Four miles east of Milbank, S. Dak.

stone can be quarried. One, the Milbank granite, outcrops in the extreme northeastern corner of the State in Grant County, and the other, the granite of the Harney Peak batholith in the core of the Black Hills in Custer County.

I. Milbank Granite

This granite outcrops in the northeastern corner of Grant County about the foot of Big Stone Lake. The westernmost outcrop lies five miles east and one and one-half miles south of Milbank, Section 13, T. 120 N., R. 48 W. From this point, granite can be followed eastward for three miles. A half dozen quarries have been opened in this area. A second outcrop lies at the bottom of the valley of Whetstone Creek a mile southwest of Big Stone City, SW. corner Section 17, T. 121 N., R. 46 W., and is reported 27 feet below the bed of the creek at the railroad bridge, one-quarter mile west of the outcrop. It also outcrops in Minnesota in the bottom of the Minnesota River Valley, a mile east of the State line and a mile south of Big Stone City. From the location of the outcrops and information from various water wells drilled to the granite, it is evident that this rock underlies at least 30 square miles in the northeastern part of Grant County.

The rock is a granite, composed of approximately 60 per cent dark red feldspar belonging to the orthoclase group, 25 per cent clear quartz, and 15 per cent biotite mica. The mineral composition gives it a rich dark color which is well described by its trade name, "mahogany granite." The color varies somewhat in different parts of the outcrop, some being a deeper red than others. This has allowed the quarrying of two types which are on the market as "mahogany granite" and "royal mahogany granite." The rock is medium to coarse grained, grains averaging one-half to one inch in diameter. Pegmatite stringers occur here and there in which crystals three to four inches across have been measured.

Its dark mahogany color and ability to take a good polish make it especially valuable as an ornamental stone. The joints in the rock are far enough apart to allow the removal of large blocks. It has been used, therefore, as a basis of South Dakota's largest stone industry.

Crushing strength measured on this granite exceed 15,000 pounds per square inch. This figure is low for granite though it exceeds any pressures that may be applied to it in

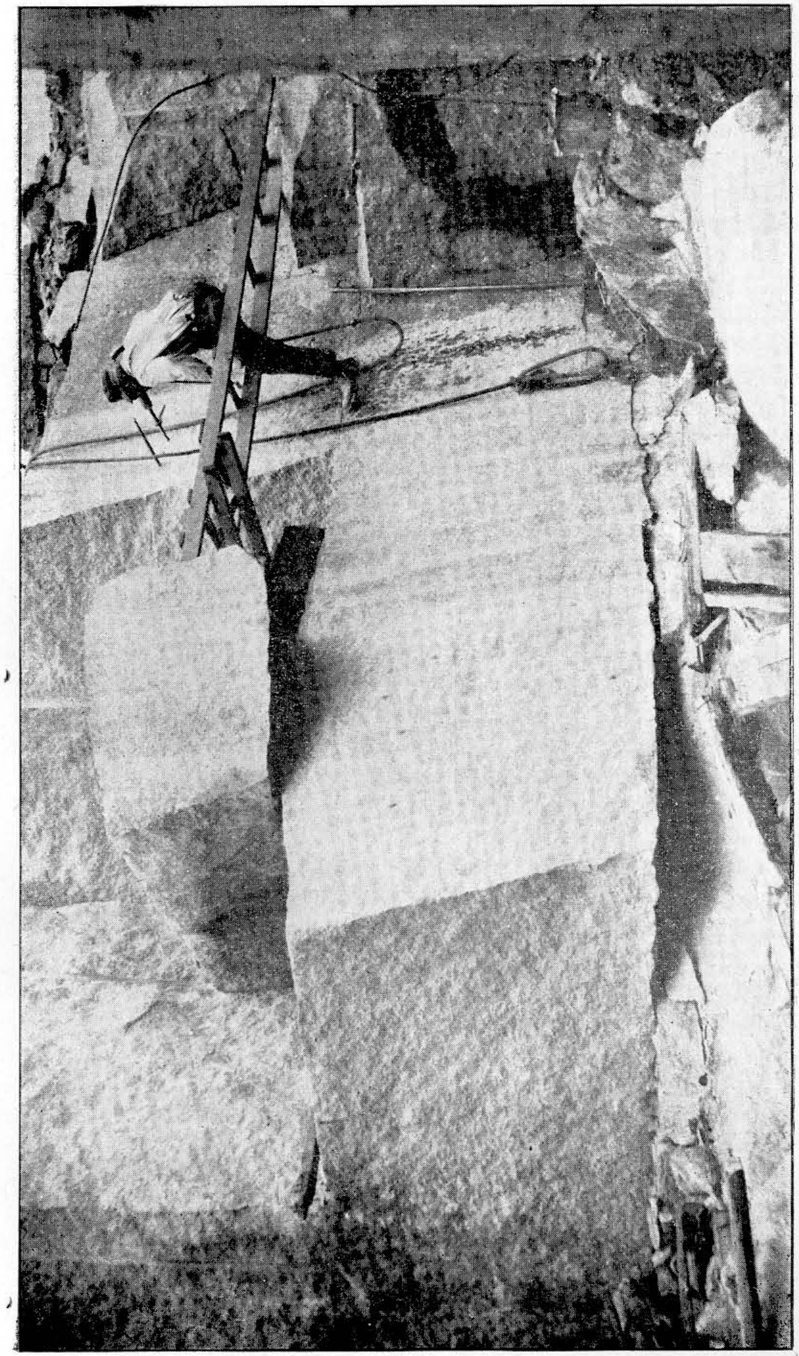

PLATE 15. Quarrying Mahogany Granite
Hunter Granite Co. Quarry, Milbank, S. Dak.

structures. These tests were made on two inch cubes. The coarse grain caused the block to fail along cleavage planes in the feldspar sooner than would be the case if larger blocks could have been used. This granite is quarried chiefly for ornamental stone but will serve equally well for building block, rip rap, or concrete aggregate. It has been used extensively for some very distinctive public memorials, notably the statue of Patriotism by Paul Barttlett at Duluth, Minnesota, and the large columns in the national Catholic Shrine at Washington, D. C.

The first quarrying of this stone was done by Mr. Gus Swanson, stone mason, who used the rock for top stone for building foundations. Real quarrying operations began about 1908 when Robert Hunter erected the first large derrick and opened a commercial quarry. It furnished the first dimension stone quarried in South Dakota which was used in the State Capitol Building at Pierre in 1912. The original Hunter Company is still in existence and operating two quarries and a modern finishing plant at Milbank. Five other companies are also in operation in the State. Milbank granite has been shipped to nearly every state in the Union and also to Canada.

As mentioned above, at least 30 square miles of Grant County are underlain by this granite. Quarries have been opened to a depth of more than 100 feet, showing no changes in the character of the rock. The distribution of outcrops and the character of the rocks show that this granite occurs in a batholith, one of the largest of volcanic rock masses. It is of interest from a commercial point of view because it indicates that an unlimited supply of this rock is available. The only limit to the depth of quarries will be the difficulties encountered in excavation.

II. Black Hills Granite

Granite can be quarried at a great many places in the crystalline area of the Black Hills. Approximately 60 square miles of outcrop in the vicinity of Harney Peak are occupied by granite. Dikes of granite can be followed from Harney Peak southward to Pringle and northward to Hill City, and a small outcrop of granite is reported near Tinton on the State line directly west of Lead.

In contrast to the Milbank granite, the Black Hills granite

is light colored. The feldspars which control the color are largely a flesh color or light tan. The rock is composed of quartz, potash feldspar, and muscovite mica. It can be quarried in blocks and will take a polish. The chief drawback seems to have been the size of the crystals which are uniformly large. Pegmatitic masses and dikes are common. The texture would not be suitable for many of the uses to which granite is put, particularly for ornamental stones where intricate carving is to be done. Coarse crystals tend to chip out and smooth surfaces are difficult to make. For building or polished block, or for rip rap or crushed rock, this granite should prove an excellent material.

Other granite-like rock has been quarried in the Black Hills. One of the most abundant of these is felsite and felsite porphyry which occurs in considerable abundance in dikes and laccoliths in the northern Black Hills. One of the best known outcrops of this material is in the core of Bear Butte near Sturgis. A similar rock is quarried at Lead for use about the city. It is exposed on Whitewood Creek, in Green Mountain, Custer Peak and in many other laccoliths in the vicinity. Felsite is a rock having the composition of granite but not the coarse texture. Grains are microscopic, giving the surface a uniform dull appearance, sometimes called "stony." It will not take a polish and is of no use as an ornamental stone. It is very tough, however, and stands abrasion well. It is, therefore, a useful material as rip rap, crushed rock, and concrete aggregate or for foundation and building stone when blocks of sufficient size can be quarried.

Some years ago, considerable interest was evolved in a green granite which occurred in Rapid Canyon in a dike 200 feet wide, 100 feet high and of undetermined length. This rock was made of a plagioclase feldspar, and quartz with an excess of hornblende which gave it its dark green color. This stone is hard and weighs approximately 200 pounds to the cubic foot. It takes a high polish and has a pleasing dark color.

III. Field Stone

In the glaciated region east of the Missouri River, boulders are very common, varying all the way from a few inches in diameter to three or four feet. About 50 per cent of these boulders are granite, brought from the granite regions in

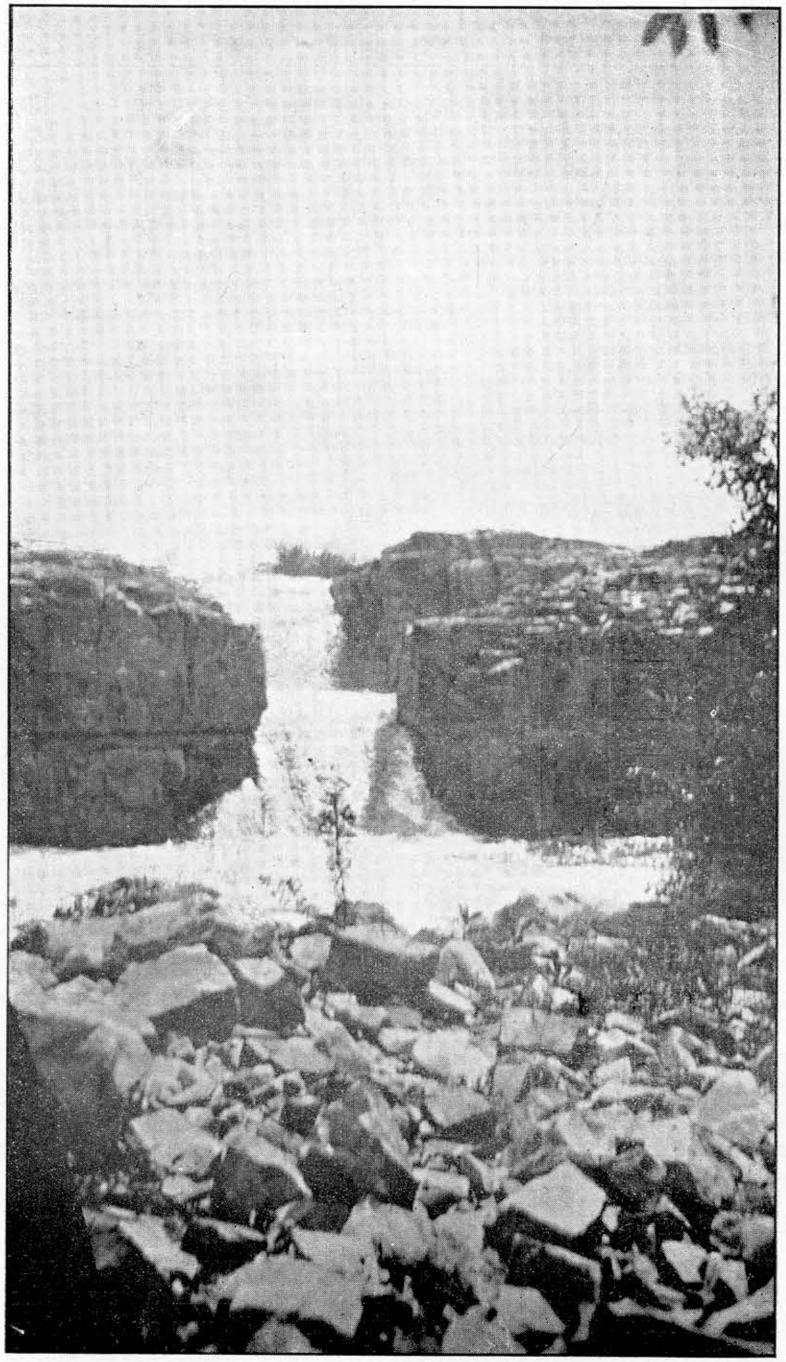

PLATE 16. Sioux Quartzite
Exposed at the falls of the Big Sioux River

Canada and strewn over eastern South Dakota by glacial ice. While these boulders are not the type of deposit on which a large stone industry can be built, they do offer some very pleasing and useful materials for local construction. They have the advantage of variety over the ordinary quarry stone. As many as fifteen or twenty kinds of granite have been counted in one gravel pit, differing from each other in color and texture. These offer a pleasing variety which can be used effectively in the making of walls or buildings. They have been used for this purpose in the city of Pierre where retaining walls and several buildings have been made of them. The boulders can be faced or squared exposing the coloration within. As most of these are medium to fine grained, very dense granite, they will polish beautifully. Such boulders have been used as monuments by polishing an area sufficient for the inscription.

Field stone has also been crushed and used for concrete aggregate and screened for road metal.

Quartzites

A quartzite is a sand which has been cemented so firmly with silica (SiO_2) that the pore space between the grains is nearly or entirely filled with the cement. This makes one of the most durable stones in existence. The quartz of which both sand and cement are made is extremely hard and can stand a great deal of abrasion. It is also extremely resistant to the chemical action of the weather so that little change is observed in the stone although it has been exposed for a great many years. Used as building block, its color remains uniform as long as there is any use for the building.

I. Sioux Quartzite

Ledges of pink quartzite belonging to the Sioux formation outcrop in the valley of the Big Sioux River at Dell Rapids, Sioux Falls, East Sioux Falls, in the valley of the Vermillion at Parker, of Wolf Creek at Salem, Pierre Creek at Alexandria, and in the James Valley south of Mitchell. A considerable industry has developed at Sioux Falls, Dell Rapids and Spencer. Quarries have been opened and operated during prosperous times at East Sioux Falls and at Mitchell. This quartzite is a uniformly dense rock, though here and there, cementation has not been perfected. Some porous sand

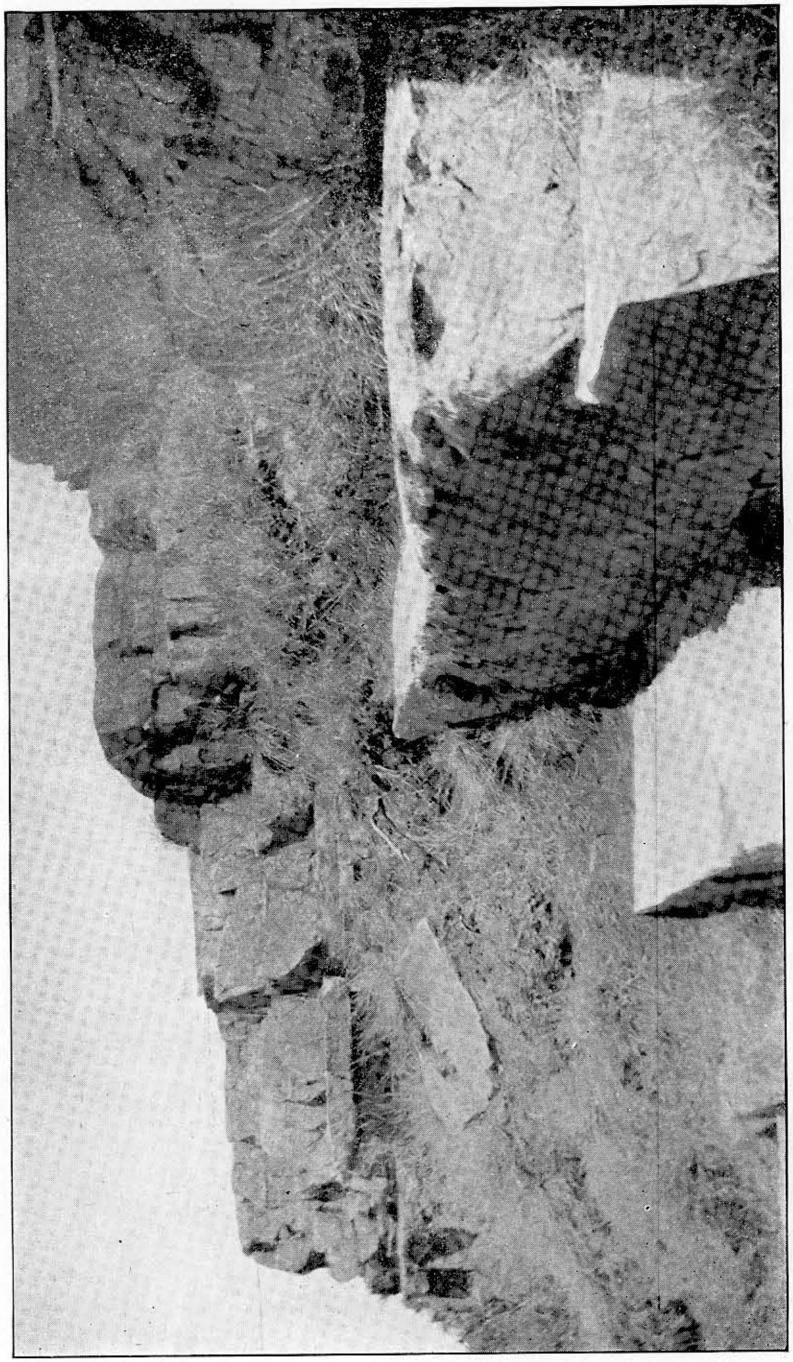

PLATE 17. Sioux Quartzite
Exposed at Dell Rapids, S. Dak.

streaks occur in which it is possible to obtain water wells. Such places are rare, however.

Like all quartzite, the rock is not as tough as the granite and will shatter if heavy charges of powder or dynamite are used in quarrying. In most of the rock, the pores are so well filled with quartz, that it will take a polish. Tests on the absorption of water by the rock indicate the amount of pore space. In the case of the commercial stone tested in this manner, it was less than two per cent. Cross-bedding and ripple marks have given the rock a grain in some places though in most of the outcrops, it can be split across these structures. The following physical tests are representative of the material:

Quartzite from Wisconsin Granite Quarry, Sioux Falls, S. Dak.

Tested by U. S. Bureau of Public Roads
A. T. Goldberg, Engineer of Tests

Specific gravity	2.73
Weight per cubic foot in pounds	170.
Water absorbed per cubic foot (0.30 lbs.)	0.18%
Per cent of wear	2.3
French coefficient of wear	17.4
Hardness	18.7
Toughness	17.
Cementing value	36.380
Crushing strength (lbs. per sq. in.)	

Sioux Quartzite from L. G. Everist Quarry, Dell Rapids, S. Dak.

Tested by U. S. Bureau of Public Roads
A. T. Goldberg, Engineer of Tests

Specific gravity	2.66
Weight per cubic foot, (in lbs.)	166.
Water absorbed per cubic foot (.07 lbs.)	0.04
Per cent of wear	2.5
French coefficient of wear	16.0
Hardness	18.7
Toughness	20.
Cementing value	——
Crushing strength (lbs. per sq. in.)	51,700

Chemically the stone is almost pure silica (SiO_2), analyses giving 97 per cent and more. The pink color is due to a small percentage of iron which the rock contains. The only other element in appreciable amount is alumina which comes from a minute percent of clays included with the sand in its original deposition. This composition is particularly important in uses of the stone as a refractory material. Its

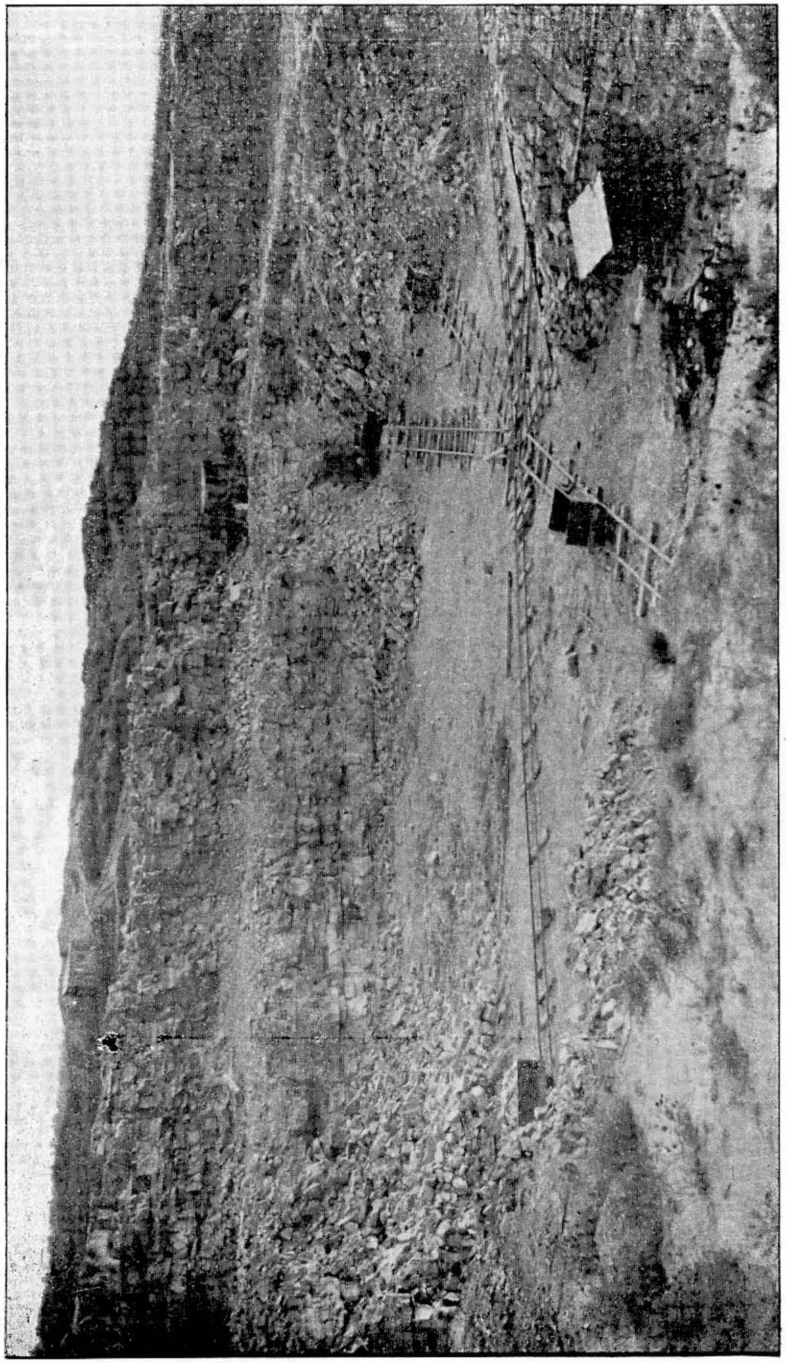

PLATE 18. Quartzite Quarry, Sioux Falls, S. Dak.

purity recommends it for certain industrial processes where nearly pure silica is required.

An analysis of the material from Sioux Falls follows:

Analysis of Sioux Quartzite from Wisconsin Granite Co. Quarries, Sioux Falls, S. Dak.

U. S. Bureau of Public Roads

Moisture	—
Ignition loss	.03
Silica	97.58
Alumina	.31
Ferric oxide	1.20
Lime	.14
Magnesia	.10
Sulphur trioxide	.13
Soda	.10
Potash	.03
Total	99.62

Analysis of Sioux Quartzite from Dell Rapids, S. Dak.

U. S. Bureau of Public Roads

Silica (SiO_2)	99.14%
Ferric oxide (Fe_2O_3)	0.50%
Aluminum oxide (Al_2O_3)	0.28%
Calcium oxide (CaO)	trace
Manganese oxide (MnO)	trace

Analysis of Quartzite from Spencer, S. Dak.

State Chemical Laboratory, Vermillion, S. Dak.

Tested by Guy G. Frary

Silica (SiO_2)	97.82%
Iron and Aluminum Oxide	2.12%
Total	99.94%

The physical and chemical characters suit this quartzite to several types of uses. It has been polished and used as an ornamental stone, and in the early 1900's was put on the market by the Drake Polishing Co. in Sioux Falls. Most of the pieces were small monuments or pillars made in sections. However, pieces large enough to be used as doors on mausoleums were polished. Its value as a polished stone lay in the fact that its color was red with streaks of various shades running through it.

It can be dressed readily in spite of its hardness and has been extensively used as a building stone. Most of the public buildings in Sioux Falls and neighboring cities have used this material. It has even been shipped as far away as Chicago where it was used as paving block.

Because of the hardness of the stone, other materials have been able to compete successfully with it as building block. The main use for the stone quarried at present is rip rap and crushed stone. Much of this rock goes into concrete aggregate and some is used as road metal without a binder.

Its chemical composition makes it a useful material for the manufacture of ganister, silica brick, and similar refractory materials. These materials are used for furnace linings and are especially useful in smelting metallic ores. South Dakota quartzite has never been used for this purpose though the same formation which outcrops in southern Wisconsin is used in this manner.

II. Quartzites of the Black Hills

The pre-Cambrian rocks at the core of the Black Hills contain some very large masses of quartzite. These have never been mapped or described in detail, but the outcrops cover many square miles. "It is among the most durable rocks of the Black Hills. Outcrops are prominent, talus slopes are nearly always made up of large angular blocks, and quarries could be opened in dozens of places convenient to rail facilities. The hardness of the rock has doubtless been a factor in preventing its use except for foundations in bridge and mill structures immediately adjacent to favorable outcrops. * * *

"A very dark quartzite, outcropping in Rapid Canyon, having in it a sprinkling of small bluish pearl-like quartz pebbles, was for a while some years ago polished and sold under the commercial name of 'pearl granite.' "[1]

One area covering over 50 square miles has been mapped between Harney Peak and Rapid Creek. Hill City lies on its western edge and Sheridan on its eastern. Another area covering approximately 15 square miles lies farther north in Lawrence County between Bogus Jim Creek and the town of Bench Mark. There are many thin beds of quartzite scattered through the schist in other parts of the crystalline area. Some of these can be found near the city of Lead.

[1]Connolly, J. P., and O'Harra, C. C., The mineral wealth of the Black Hills: South Dakota Geol. Survey Bull. 16, p. 289.

These quartzites vary in size of grain all the way from conglomerates to those in which the individual grain can hardly be seen. They merge, therefore, into slates and quartz schist. "The beds have been compressed and distorted by crushing, flowage, and recrystallization, and the pebbles and boulders have been squeezed into lenticular forms whose longest diameter lies parallel to the dip of the beds. The feldspathic and clayey material within the matrix has been converted in great part into sericite and chlorite.

Coarse arkosic grits are abundant in the area between Bench Mark and Bogus Jim Creek, where they grade into the conglomerate described above. They were composed originally of quartz and feldspar in various proportions, but most of the feldspar has been altered to sericite and quartz. * * * That the grains have been mashed can be plainly seen with the microscope. The quartz grains, like the conglomerate pebbles, are roughly lenticular. * * * These arkosic rocks have a distinctly greenish hue, which is due to abundant chlorite, but weathered surfaces are red, yellow, or light brown, contrasting sharply with the dark slates and graywackes of the more western areas."[1]

III. Tertiary Quartzite

On many of the buttes on the great plains west of the Missouri River, quartzite chunks are found breaking off the cap rock and rolling down the buttes' sides. Some of this is extremely dense and gives the characteristic greasy luster of good quartzite. Such quartzite is common in the Bijou Hills in Brule County and in the cap rock of the Iona Hills, across the Missouri River, in Gregory County. It is also abundant on many of the buttes in the vicinity of Winner in Tripp County. The Antelope Buttes, in Butte County, contain such an abundance of it that it was suggested as a source of road metal. While the quality of this stone often recommends it for commercial use, the quantity is always too small. This quartzite has been formed by the evaporation of silica-bearing ground water, which percolates through the cap rock of the butte and is evaporated upon reaching the face of the cliff. It usually forms only a thin case hardening over underlying sandstone, which in some cases is so poorly cemented that it

[1]Paige, Sidney, The Central Black Hills: U. S. Geol. Survey Folio 219, p. 3, 1925.

can be excavated with a shovel. For small structures in the vicinity of this material, however, there might be a sufficient quantity of quartzite to prove very useful. No attempt should be made to quarry it for large construction jobs or on a commercial scale. The temptation to use it for such purposes is strong since most of these deposits lie in regions a long way removed from other hard rocks that occur in South Dakota.

Sandstone

I. The Dakota-Lakota Sandstone

The only deposits of sandstone that can be used as a building material occur around the edge of the Black Hills. The Cretaceous sandstones which lie in other parts of the State are too soft, that is, too poorly cemented, to be of commercial use. Where they outcrop about the Black Hills, however, ground water has had a chance to harden them until a very useable stone has been developed. The Dakota-Lakota sand series offers the only sandstone now being quarried. Quarries can be opened in these formations almost anywhere in the Great Hogback, though the only quarries that have been in operation thus far are those at Hot Springs. The oldest and best known of these is the Evans quarry which has furnished stone for most of the buildings in Hot Springs and in many of the surrounding cities in South Dakota, Wyoming, and Nebraska. Todd[1] states that the Dakota formation was also quarried near Spearfish and at Rapid City. He also gives the following on crushing strength: "Samples at the Columbian Exposition tested at the U. S. Ordinance Department at the Watertown Arsenal, Mass., showed a strength of 6,305 pounds to the square inch, and the test stood 7,491 before yielding. (Specimen from Evans quarry) * * * Tests of this stone (from the Burt quarry, three miles north of the Evans quarry) made at the Watertown Arsenal, Mass., Oct. 25, 1900, show that the strength of the stone is 8,047 pounds per square inch, and the chemical composition is 97.75 per cent silica and 2.20 per cent alumina. * * *

"Samples tested in 1893 as before mentioned (specimen from Lookout Mountain at Spearfish) showed a strength of 4,516 pounds per square inch."

[1]Todd, J. E., Mineral Resources of South Dakota: South Dakota Geol. Survey Bull. 3, p. 97, 1900.

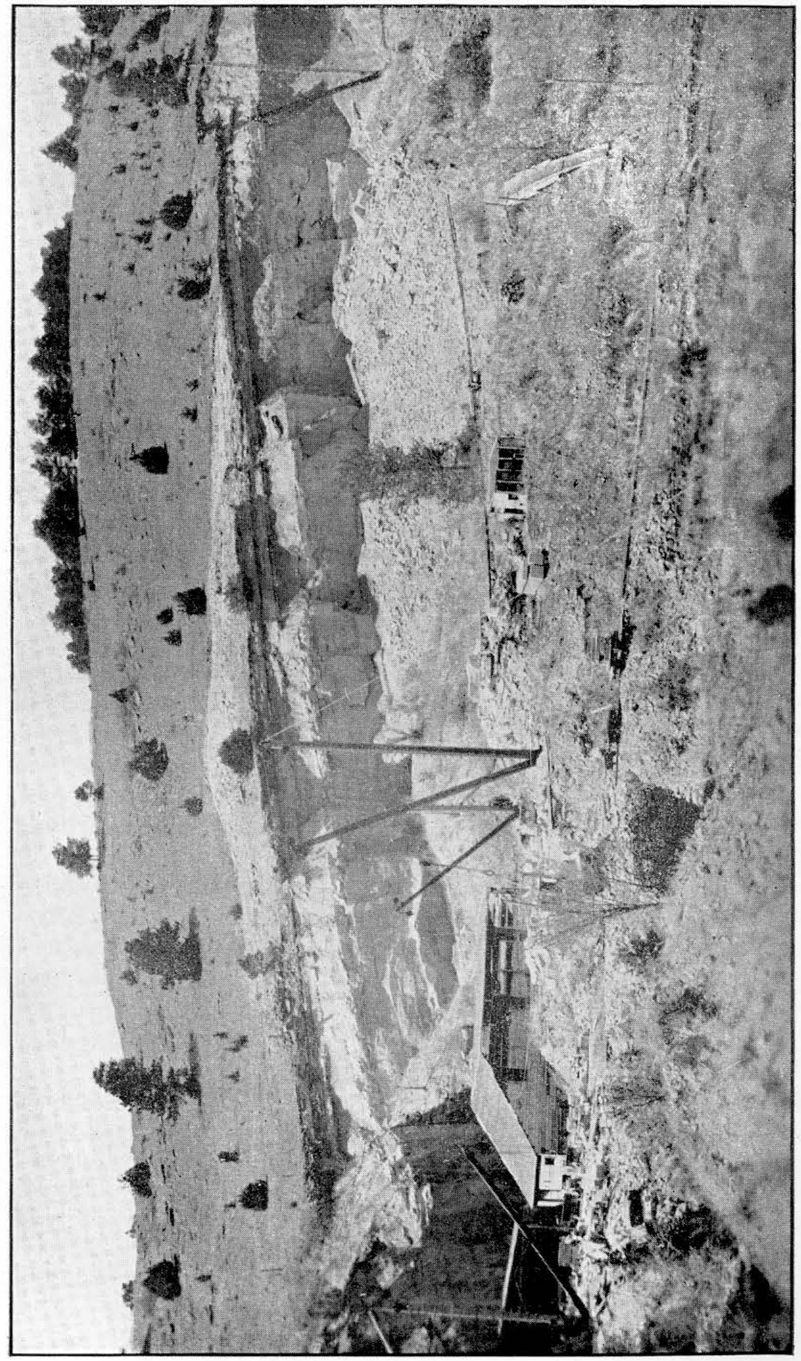

PLATE 19. The Evans Sandstone Quarry, Hot Springs, S. Dak.

When fresh from the quarries, this stone has a light gray or delicate pink color which is very pleasing. It weathers to a uniform brown which can be seen distributed over the face of the buildings in Hot Springs and other places where the stone has been in use since the 1890's. It is not so well cemented as the famous Berea stone from Ohio but can be used for making grindstones.

II. Paleozoic Sandstones

The outcrops of Paleozoic formations about the Black Hills expose some sandstones which can be used for building. Apparently none of them are as satisfactory as the Dakota which has just been described. This may be because a sufficiently careful search for suitable portions of the formations has not been made.

Sandstones at the top and bottom of the Deadwood formation offer excellent prospecting grounds. Most of this sand is highly iron-stained and much of it is conglomeratic, especially the basal sandstone. The upper sandstone, however, contains a considerable thickness of uniformly grained stone from which a good building block could be quarried. The better localities appear to be in the northern Black Hills near the city of Deadwood itself and possibly at Nemo. In the southern Black Hills, the Deadwood formation is thin and most of the stone appears to be a less desirable building material.

The Minnelusa formation also carries a thick sand series in its upper portion and some workable sand beds in the lower half. These would also furnish material which could be quarried on a commercial scale, though much of it is calcareous and does not weather well.

None of these sandstones are sufficiently indurated to be used for anything but building blocks. Some of the stone can be used for rip rap but the cementation is not sufficently complete to make a good rock for concrete aggregate or other crushed material. The proximity of pre-Cambrian quartzite, feldsite, and granite make it unnecessary to use these sandstones for such purposes.

Limestones and Marbles

Limestones and marbles are calcareous rocks and, therefore, have a wider variety of uses than do the silicous rocks described above. The crushing strength of most of them is sufficiently high to allow their use as building block. In fact, some of them will stand a higher crushing force than the sandstone. Being soft rocks, (hardness approximately three on the Moh Scale) they can be easily dressed. They can, therefore, be easily cut into building blocks or turned or carved into pillars or other ornamental forms. Many of the denser varieties will take a polish and can be placed on the market under the trade name of marble. Dense limestone and marble can also be crushed and broken into blocks for rip rap and concrete aggregate. Some of these have been used for road metal but tend to break down under traffic and become very dusty.

Being made of calcium carbonate, all of these rocks can be burned for lime which enters the building industry as cement and plaster.

I. Pre-Cambrian Marble

Marble has been reported in pre-Cambrian rocks both in the outcrops in the core of the Black Hills and in a well drilled near Wagner in Charles Mix County. One outcrop three miles south of Harney Peak has received considerable attention. It is a dolomitic marble lying in three to four-foot beds in a formation 40 feet in thickness. The entire formation stands nearly vertical, dipping south 80° west, and angles vary from 60-70°. The formation has been traced for a distance of about five miles and in the early days was opened in several places.

The rock is a dolomitic, fine grained marble which varies in color from pure white through gray, and is mottled with light and dark green specks and particles of serpentine. It is very compact and takes a high polish. The difficulties which beset the exploiters of this deposit seem to have been largely connected with the quarrying and transportation to Custer, which is the shipping point, five miles distant. This rock offers some interesting possibilities in ornamental stone production.

II. Paleozoic Limestone

All the dense limestone which can be used for hard rock construction, outcrops in the Limestone Plateau of the Black Hills. Two formations have furnished nearly all of this material. The most important one is the Pahasapa formation and the next in importance is the Minnekahta. Considerable limestone from the Whitewood formation has also been excavated in the vicinity of Deadwood. This limestone could be put to a number of uses. Most of it, however, is crushed and reaches the market as crushed rock, concrete aggregate, or lime.

Certain layers in the Pahasapa formation have been described as suitable for lithographic limestone. "In the upper part of the Pahasapa limestone ten miles west of Custer two or three strata of compact fine grained limestone have been found which have proved satisfactory for lithographic work. * * * The stratum is about four feet thick and lies nearly horizontal. * * * Mr. W. R. Bond, of Custer, has sent in samples from the vicinity of Loring, twelve miles south of Custer, which have proved satisfactory for lithographic work of smaller size."[1]

Since most lithographic printing is no longer done with stone, this character is not of as much interest as it used to be. There is still a market for lithographic stone, however, and it is well to keep this quality in mind when considering possible uses of this limestone.

"The Minnekahta limestone, a compact, fine grained rock of varied coloring, takes a good polish and, with its mottled, pinkish, reddish and purple shades, there seems a possibility, where the rock is not too thinly bedded, that it could produce an ornamental stone of some importance.[2]

Burned for lime, both Pahasapa and Minnekahta limestones have found their way into the local industry, particularly for use as flux in metallurgical processes and in the clarification of sugar. Most of the lime burned, however, goes into the manufacture of cement and plaster. An idea of the chemical character of the Pahasapa can be obtained from the three analyses, the samples for which came from outcrops in the southern part of the Black Hills.[3]

Number 1: From the Black Hills Lime Company quarry one and one-half miles west-southwest of Pringle. Mr. Charles Bentley, Analyst.

[1]Todd, J. E., Mineral Resources of South Dakota: South Dakota Geol. Survey Bull. 3, p. 93, 1900.

[2]Connolly and O'Harra, op. cit. p. 295.
[3]Connolly and O'Harra, op. cit. pp. 286-288.

Number 2: The Erpelding quarry just west of Loring Siding. Mr. Charles Bentley, Analyst.

Number 3: Sample of Pahasapa limestone from near Pringle. Mr. W. J. Sharwood, Analyst.

	1	2	3
SiO_2	0.56	0.90	0.91
Fe_2O_3	0.20	0.14	---
			0.29
Al_2O_3	0.06	0.12	---
CaO	53.98	55.24	55.06
MgO	1.64	0.36	1.18
SO_3	Trace	Trace	---
Ignit. Loss	43.77	43.25	43.62
Total	100.21	100.01	100.84

The chemical composition of the Minnekahta limestone is indicated in the following analyses.[1]

Lime (CaO)	31.51	54.65	53.40	52.85
Magnesia (MgO)	19.85	.41	1.57	.72
Alumina, iron (Al_2O_3,Fe_2O_3)	.36	.63	1.10	.51
Water (H_2O)	1.25	.81	.20	.10
Carbon dioxide (Co_2)	44.66	42.30	42.92	42.78
Sulphur trioxide (SO_3)	.07	.21	.12	.12
Silica (SiO_2)	1.12	1.21	1.08	1.42
Manganese oxide (MnO)	.00	.00	.46	.11
Soda (Na_2O)	--	trace	.36	.30
Potash (K_2O)	--	trace	.16	.10
Total	98.82	100.13	100.37	100.24

III. Greenhorn Limestone

The Greenhorn formation, which lies in the lower part of the Cretaceous system, contains a thickness of about 40 feet of shaly limestone which is made up in large part of the shells of a Cretaceous pelecypod (clam). The lime beds average a quarter to a half inch in thickness and are separated by thin seams of shale. In western South Dakota this limestone outcrops outside the Dakota Hogbacks of the Black Hills. It is well exposed north of Belle Fourche and in Fall River County. It also outcrops in the Big Sioux Valley in Union County where its characters are exactly like those in the western outcrops.

[1]Paige, Sidney, The central Black Hills: U. S. Geol. Survey Folio 219, p. 9, 1925.

This rock is not sufficiently massive or dense to be used for building material but it offers a source of burned lime or cement material which has been overlooked. The western outcrops are not of much interest since they are located so close to other sources of lime, but those in the Big Sioux Valley occur in a region where limestone is scarce. It is for this reason that they are included in this description. It is worth investigation as a source of raw material for the manufacture of rock wool, since both the lime and silica are available with the same quarrying. The mixture of lime and clay in the Greenhorn might supply the necessary combination.

Unfortunately, there is little data on the chemical character of this formation.

IV. Chalk

The Cretaceous system which underlies most of South Dakota was so named because it carries the rather unusual limestone known as chalk. This differs from the limestones that have been described, in that it is soft, rubbing off easily on the fingers. On the outcrop it usually appears as a white, yellow or dirty gray rock. The fresh rock is gray when dry, but when wet may look almost black or blue-black. Upon weathering, the cliffs first turn an orange-red and then yellow, and finally bleach to white. Under the microscope, well cuttings of fresh chalk are usually described as speckled shale, black or gray material being dotted with small white grains of calcium carbonate.

The purest and largest mass of chalk is known as the Niobrara formation. This formation outcrops in the Missouri Valley from Fort Thompson to Yankton. It also occurs on the Redfield Hills a mile east and a mile south of that city. It encircles the Black Hills where it occurs in the bottom of valleys and is very seldom seen. Lesser beds of chalk occur in the Greenhorn formation and in the Pierre formation. The lower members of the latter carry a great many beds from four inches to twelve inches in thickness. The thickest chalk in the Pierre formation, however, is the Mobridge member which lies in its upper part and has a maximum thickness of 241 feet. This member is so impure, however, that it is not worthy of consideration as a limestone.

The Niobrara formation, on the other hand, is a very pure limestone and can be used for many purposes. It has

been used to good advantage for building blocks. A number of houses are still in good condition that were built more than fifty years ago. Such houses are found in Yankton, Scotland, and Mitchell. Recently, a number of houses were constructed in the vicinity of Springfield. The rock has the advantage of being easily sawed or shaped and is sufficiently well bound to hold together for handling. Weathering does not effect light colored chalk severely, though there is some change in color. It can be painted and makes a wall which insulates well. One disadvantage is that it can be easily marked or scratched with a fairly soft tool. Thus it is possible to deface a building to which the public has access.

Chalk rock can be burned like any other limestone and can furnish lime for plaster, cement and the other uses to which it is put. South Dakota chalk, however, has not been exploited for this purpose, probably due to the fact that it has been cheaper to ship lime into the State than to ship in fuel to burn it. This chalk was used at one time in the making of cement, however.

The following analyses, made in the State Chemical Laboratory under the direction of Guy G. Frary, will show the character of the chalk in the different parts of the southeastern quarter of the State.[1]

Average analysis of eight samples on Turkey Ridge, Yankton County, NE¼ sec. 12, T. 94 N., R. 52 W.

Calcium Carbonate ($CaCO_3$)	90.98%
Aluminum (Al_2O_3)	.89%
Iron (FeO)	1.40%
Volatile Matter	2.00%
Insoluble Matter	5.21%
Total	100.48%

Average analysis of five samples from the Missouri Bluffs, immediately west of Yankton.

Calcium Carbonate ($CaCO_3$)	84.33%
Aluminum (Al_2O_3)	.81%
Iron (FeO)	1.55%
Volatile Matter	5.10%
Insoluble Matter	6.66%
Total	98.45%

[1]Rothrock, E. P. A preliminary report on the chalk of eastern South Dakota: South Dakota Geol. Survey Rept. Inv. 2, pp. 10, 17, 21, 27, 33, 38, 42, 1931.

Plate 20. Niobrara chalk outcrop, Turkey Ridge, Volin, S. Dak.

Analysis of sample near Springfield, NW¼ sec. 27, T. 93 N., R. 60 W. Cliff on west of railroad tracks.

Calcium Carbonate ($CaCO_3$)	83.04%
Aluminum (Al_2O_3)	2.31%
Iron (FeO)	5.50%
Volatile Matter	3.15%
Insoluble Matter	3.58%
Total	97.58%

Sample taken from Old Quarry, SW corner of NE¼ sec. 34, Perry Twp., T. 104 N., R. 60 W.

SiO2	4.92%
Fe_2O_3	1.40%
Al_2O_3	2.10%
CaO	50.42%
MgO	.78%
SO_3	.19%
S in FeS_2	.00%
Ign. Loss	40.36%
Total	100.17%

Chalk sample in the vicinity of Mitchell, north bluff of Enemy Creek, NE¼ sec. 24, T. 102 N., R. 62 W., Davison County.

Calcium Carbonate ($CaCO_3$)	92.36%
Aluminum (Al_2O_3)	1.60%
Iron (FeO)	1.98%
Volatile Matter	1.72%
Insoluble Matter	4.72%
Total	102.38%

Chalk outcrops in the Valley of Dawson Creek at Scotland

Calcium Carbonate ($CaCO_3$)	80.65%
Aluminum (Al_2O_3)	.57%
Iron (FeO)	.76%
Volatile Matter	2.54%
Insoluble Matter	12.55%
Total	97.07%

Chalk sample taken one and one-half miles up river from Chamberlain, Brule County.

Calcium Carbonate ($CaCO_3$)	74.13%
Aluminum (Al_2O_3)	1.44%
Iron (FeO)	1.37%
Volatile Matter	5.06%
Insoluble Matter	15.46%
Total	97.46%

Like the foreign chalk, that of South Dakota is physically amorphous. This term is much used by whiting manufacturers, but its meaning is rather vague. It is used in connection with chalk to distinguish certain physical properties of the material which are much desired for many uses to which whiting is put. Whiting, made by powdering limestone and marble and precipitating calcite chemically, does not possess these characters and is termed crystalline. The amorphous properties, therefore, are probably due to its noncrystalline character and to the colloidal materials which make up the bulk of the chalk.

The flint or chert nodules, such as are abundant in the English chalk, are conspicuous by their absence from the chalk of South Dakota. Some concretions of iron are to be found in a few outcrops, but such material is very scarce. Gypsum crystals (selenite) are reported by Lounsbery from the chalk about Mitchell, and the same were noted above the chalk at Chamberlain and Yankton, and below the chalk on the Missouri Bluffs south of Gayville. This gypsum, however, is confined to the shales above and below the chalk and, therefore, should not be a detrimental factor in working the material. Selenite found in the bentonite layers in the chalk is apparently developed by weathering and will be found, therefore, only on the surface.

Physical tests made some years ago on samples taken near Yankton showed that whiting from the South Dakota chalk had the same physical characters as that made from the best imported chalk. The only drawback to its use is the fact that the trade is not used to colored material. In the following table, the properties of South Dakota chalk are compared to those of imported chalk then in use by the trade.

Vulcanization Test

South Dakota Material (Collected near Yankton)

Tests by Beacon Falls Rubber Shoe Company

Whiting	South Dakota	Stock
Break	865 lbs.	920 lbs.
P. E.	8.33%	8.33%
Elong	463%	633%
Cure	Steam	Steam
Per cent whiting used	52½%	52½
Ageing test	Satisfactory	

"This sample was of a very dark color, which would prevent its use in some compounds and contains much grit which could be removed by proper grinding. No substances injurious to rubber were found."

SAND AND GRAVEL

Sand and gravel constitute a low priced but very important structural material. It makes up somewhat for the lack of widely distributed stone in South Dakota, by being available in almost all parts of the State in large quantities. There are few areas in the State where sufficient quantities of gravel are not available for local construction. East of the Missouri Valley, glacial sands and gravels are abundant. West of the Missouri, alluvial deposits are found as terraces in all of the big valleys. Bed rock sands and some gravels are available in the northwestern corner of the State in Harding and Perkins Counties and south of the White River in the Rosebud and Pine Ridge Reservations.

It is impossible to go into detail on the location and kinds of gravel to be found in all the deposits of the State. This is due in small part to the tremendous number of small deposits available, and in large part to the fact that it has never been possible to map and appraise these deposits except in relatively small areas. The following may be helpful, however, in showing the general location of the deposits and their general character. The larger deposits that have been mapped to date are indicated on the economic map accompanying this report. It is far from complete, however.

I. Glacial Deposits

The eastern half of South Dakota has been covered several times by portions of a continental ice-sheet, tongues of which moved down the James Valley and spread laterally from this axis till their western edge reached a line somewhere near the present Missouri River. Such ice carried large loads of debris. As the ice melted, the torrents of water thus formed, washed this debris into the spillways, sorting the fine mud and silt from the coarse sand and gravel to carry them far away from the ice front. The sands and gravels were left behind in the channels, sometimes accumulting in deposits of tremendous size.

Three main spillways existed in South Dakota, one in the basin of the Big Sioux, the second in the James Basin, and the third, in the Missouri Basin. Large deposits are, therefore, encountered in all three of these basins. In the upper Big Sioux, large outwash deposits occur in Day and Roberts

Counties. These outwashes are extensively worked in the vicinity of Watertown where three channels come together, one coming from the north down the Big Sioux, another from Wallace and Florence to the west, and a third, from South Shore to the east. Other large outwashes occur near Brookings on the east side of the Sioux River. One of the best known is the long channel at Madison, starting at Lake Herman and emptying into the Big Sioux through Skunk Creek near Sioux Falls. Large terraces occur at Sioux Falls and farther south at Hudson and at Hawarden, Iowa, in the Big Sioux Valley.

Large deposits are not so common in the James Valley as in the Big Sioux, though they are far from lacking. Sandy areas occur in Aberdeen and south of Redfield, and in a long narrow belt north of Woonsocket, followed by Sand Creek. Gravels are found in the vicinity of Mitchell in some abundance and also south to Olivet and Yankton.

Very large deposits are found in the Missouri Basin. Outwashes covering several townships lie in the vicinity of Bowdle, Hoven, and Lebanon in Edmunds and Potter Counties, and a string of gravel deposits lie in the upper part of Okobojo Creek Valley in Sully County. Nearly every big bend in the Missouri Valley has a gravel terrace lying about a hundred feet above the present river. Most of these were a result of glacial outwash from the east. On the high lands south of Miller and west of Wessington Springs, there occur several bodies of outwash formed by drainage into the Missouri Valley through Elm Creek and Crow Creek. Other large deposits are known to occur in Charles Mix County in the channel in which Lake Andes lies and in the Missouri Valley below it.

All of these deposits are typically glacial. Some are very well sorted, but most deposits have sands and gravels poorly sorted, and these require screening to produce a specified size of either sand or gravel. The constituents vary all the way from the finest of sand grains to boulders. The majority of the deposits, however, show predominance of coarse or medium sand and fine to medium gravel. The pebbles are largely of hard materials, granite, quartz, and tough metamorphic rocks. Much shale and chalk is supplied locally from the Cretaceous bed rock in the vicinity.

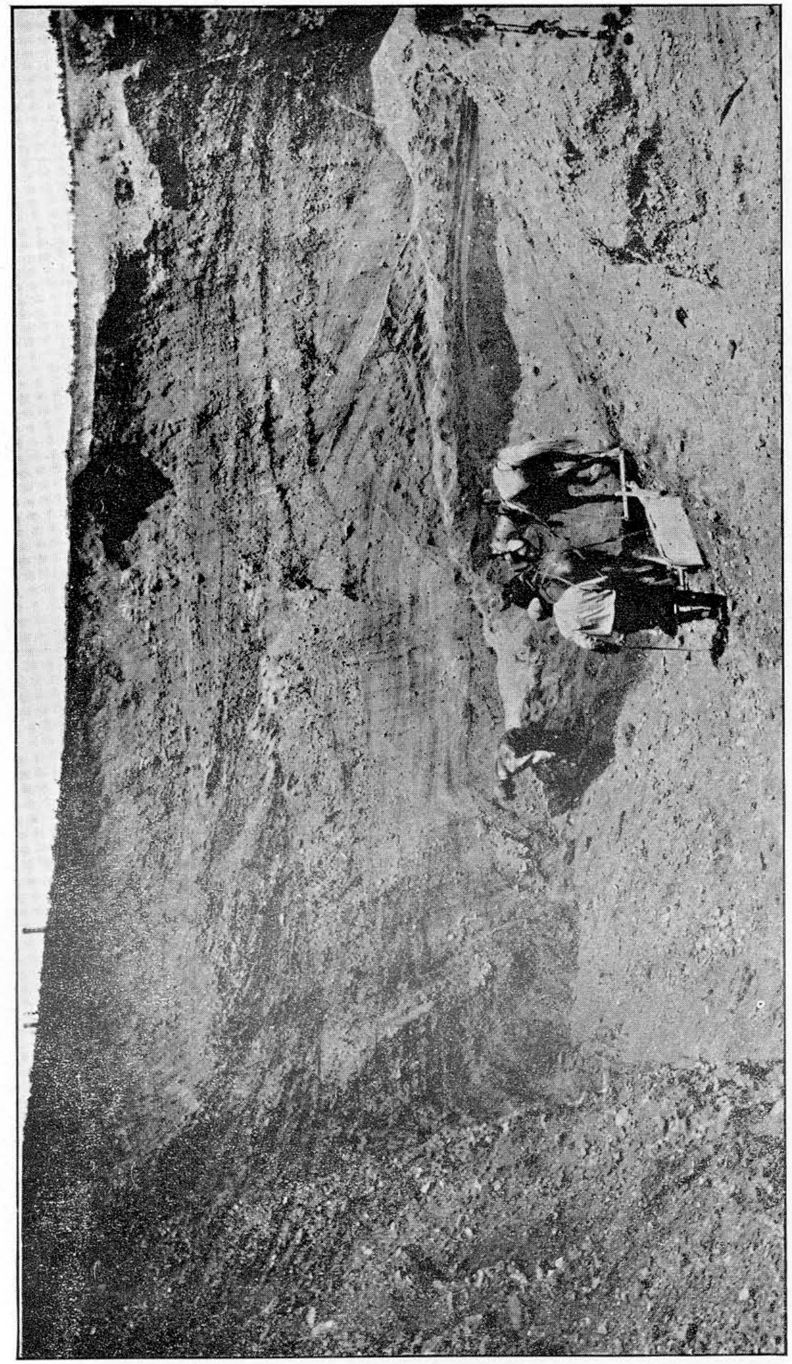

PLATE 21. A Typical Deposit of Glacial Gravel
On Turkey Creek, Yankton, S. Dak. Partial sorting and irregular bedding characterize such deposits.

Sprinkled over the surface between the main spillways are pockets of gravel due to local conditions in the ice. Some of these have allowed the opening of "wagon pits" for meterials to be used in farm construction or even for local road graveling. A few of these deposits are kames and eskers, i. e., deposits of sand and gravel made by streams flowing through cracks in the ice and deposited on the surface as sharp ridges or beehive-shaped hills when the ice melted. Some kames and eskers contain large amounts of gravel. One of the largest is a series of kames in Grant County which are called Mount Tom or Mount Tom Range. This range is a quarter mile wide at the base, three miles long and 50-100 feet high. Most eskers and kames in eastern South Dakota, however, are relatively small, 10,000 to 20,000 yards being a common volume. Though these are large enough to be very useful, they do not compare in volume with the deposits of the Missouri River which contain 20,000,000 to 30,000,000 cubic yards in a single deposit or those of the Big Sioux with similar volumes.

The following analysis from the Hayes Sand and Gravel Pit in the Big Sioux Valley, two miles below Sioux Falls, is fairly representative of glacial material. This gravel is found in a long terrace extending nearly three miles along the east bluff of the Big Sioux Valley, which contains some 6,000,000 cubic yards of gravel. An average sample from the 85-foot face exposed at the Hayes pit gave the following results:

Gravel Analysis, Hayes Pit

Section 11, T. 101 N., R. 49 W., Minnehaha County

Weight per cubic foot	93.2
Specific gravity	2.639
Percent voids	43.5
Percent passing ½-inch mesh	100
Percent sand	98
Material passing ¼-inch mesh:	
Percent passing 20 mesh	64
Percent passing 50 mesh	3
Percent passing 100 mesh	1
Percent silt by volume	3
1-3 7-day tensile	258
Character of material retained on ¼-inch:	
Percent soft	10
Percent medium	24
Percent hard	66

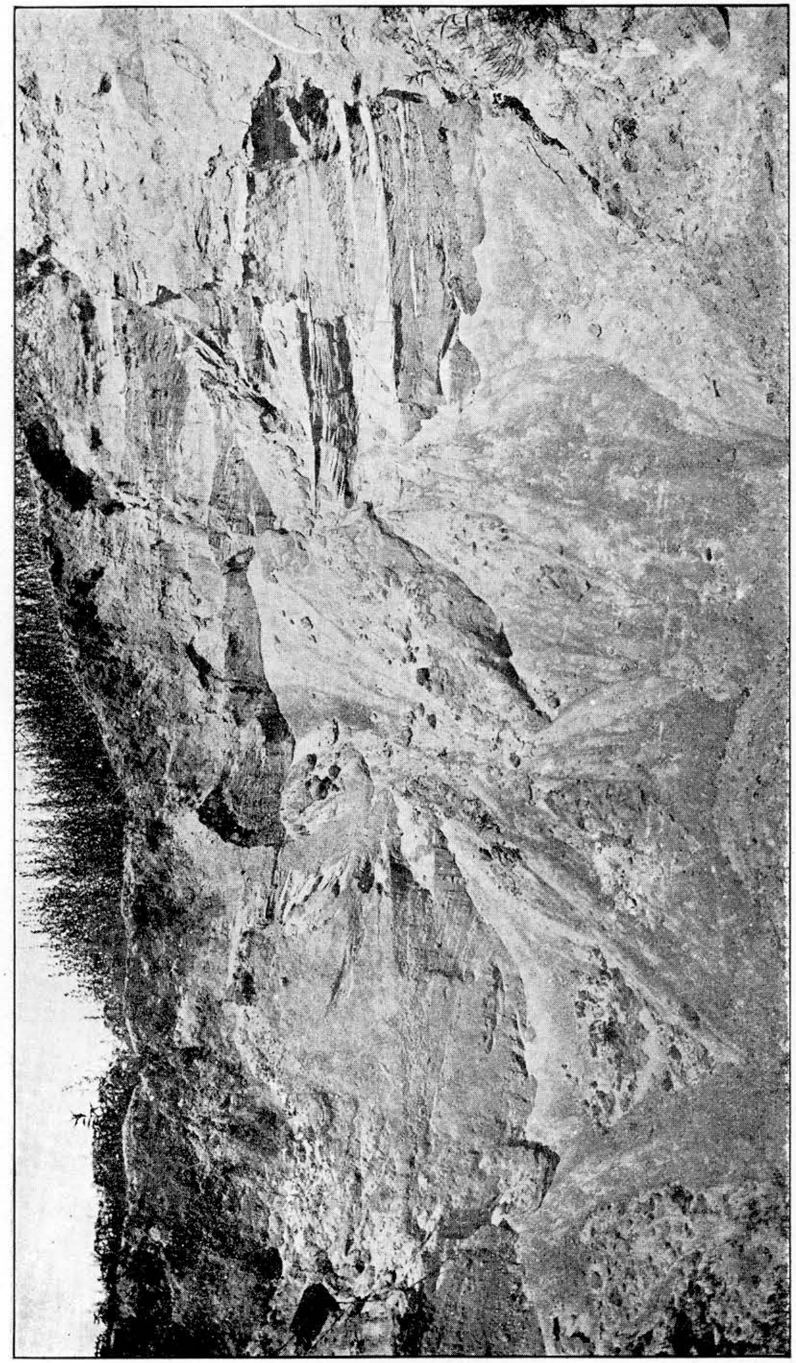

PLATE 22. A Typical Deposit of Glacial Sands near Irene, Clay County, S. Dak.

The material in the Hayes pit is fairly fine since all of the sample passed through the one-half inch mesh. In contrast to this is another sample taken from a large terrace containing about 32,000,000 cubic yards which lies on the east bank of Skunk Creek, three miles north of Hartford in Minnehaha County:

Gravel Analysis Near Skunk Creek
Sec. 34, T. 103 N., R. 51 W., Minnehaha County

Weight per cubic foot	101.6
Specific gravity	2.544
Percent voids	36
Percent passing ½-inch mesh	85
Percent sand	77
Material passing ¼-inch (sand):	
Percent passing 20 mesh	55
Percent passing 50 mesh	16
Percent passing 100 mesh	5
Percent silt by volume	4.5
1-3 7-day tensile	192
Character of material retained on ¼-inch:	
Percent soft	7
Percent medium	70
Percent hard	23

Nearly as many different analyses of glacial gravels could be obtained as there are samples. Some deposits are made of boulders and cobbles predominantly or in large proportion. However, sand is much more abundant than coarser material in most glacial gravels in this State. Some gravels are very "dirty," containing large amounts of silt and clay, and grade into boulder clay. Most of them, however, are fairly clean.

No figure can be given for the amount of glacial gravels available, since appraisals have not been made except in rather limited areas. Deposits like the one at the Hayes pit contain 6,000,000 cubic yards. Deposits of this size are not uncommon in the Big Sioux Valley. Some of the outwash at the head of the basin may contain many times that amount. The large outwashes in the vicinity of Bowdle and Hoven cover one to two townships each. Depths of 10 to 14 feet of gravel in these outwashes give volumes of hundreds of millions of yards.

II. Alluvial Deposits

Alluvial gravels are those which have been formed by stream action as bars, or in the flood plains. Such gravels are

found in the valleys of all the large western rivers flowing into the Missouri. Smaller deposits are sometimes found in the tributaries. Most of these deposits are no longer in the bottoms of the valleys but occur as terraces along its bluffs because of rejuvination of the streams since their deposition. During the Pleistocene epoch, (Ice Age) these valleys filled with gravel and sand. Subsequent uplift of the Great Plains caused the streams to cut below the old valley bottoms and left the Pleistocene gravels perched about 100 feet above the present streams. The removal of enormous amounts of gravels which took place in this process has made secondary bars in the bottoms of the present streams.

The materials of which these gravels are made are all local, being concentrates of the coarser and more resistant materials which the rocks in the immediate vicinity contain. In most instances, the coarser material has not moved very far from its source. Some has been transported a considerable distance down the valleys. Small garnets are found nearly to the Missouri in the Cheyenne and Bad River gravels. These have been transported from the Black Hills. Pebbles of the White River chalcedony are found in the Missouri River gravels which may have been moved half way across western South Dakota in the White River.

Black Hills Gravels

Most of the gravel deposits in the headwaters of the Cheyenne and Belle Fourche Rivers contain a great deal of material from the core of the Black Hills as well as from the rocks surrounding the core. Since gradients are steep coming off from the mountains, the gravel deposits which lie in these two valleys are large and coarse.

Materials of these gravels vary considerably, depending largely on the hard material in the rocks of the immediate vicinity.

Limonite Type Gravels

Gravels in the Grand and Moreau Rivers and headwaters of the Cheyenne tributary are characterized by the presence of limonite pebbles. Much of this iron is formed on weathering of the Hell Creek beds and is concentrated in the stream bars. Some gravels are made almost entirely of the limonite which assumes the characteristic buck-shot structure of residual iron ore. Other gravels contain minor amounts. A pebble count taken on the headwaters of the Moreau near the Butte-Harding County boundary gave the following:

Pebble Count on Limonite Gravel

SW¼ sec. 22, T. 14 N., R. 3 W., Butte County

Boulders:	
Fort Union Quartzite, fine grained, porceline-like and gray quartzitic	71%
Tertiary conglomerate	29
Pebbles (up to 1 and 1½ inch in diameter):	
Limonite	54%
Vein quartz	14
Chert	13
Chalcedony	1
Petrified wood	1.5
Limestone	7
Sandstone	8
Calcite from local concretions	1.5

Some of these deposits contain large quantities of sand, especially in the vicinity of sandy formations such as the Fort Union and Fox Hills. While no generalization can be made on the deposits of this large area, a screen analysis of one deposit in southwest Perkins County may serve to show approximate sizing.

Analysis of Gravel Terrace Near Inland Post Office

NW of NW sec. 16, T. 13 N., R. 10 E., Perkins County
Analysis by C. J. Loomer, Test Engineer, South Dakota Highway Commission

Passing	Retained	Percentage
Oversize		None
1¼ inch	1 inch	3%
1 inch	¾ inch	2.5
¾ inch	½ inch	6.1
½ inch	¼ inch	28.5
¼ inch		59.9
Total		100.00%

Material passing ¼-inch (sand, silt and clay)	Retained	Percentage
¼ mesh		
@ mesh	10 mesh	48.2%
10 mesh	20 mesh	15.2
20 mesh	50 mesh	11.6

50 mesh	200 mesh	19.0
200 mesh		6.0
Total		100.00%

White River Type Gravels

In the southwestern quarter of the State, the gravels are characterized by materials which have been concentrated from the Tertiary beds of the White River. Much of this is a soft white limestone which develops from caliche on the weathering of many of the sandier beds. Gravels in the Pine Ridge and Rosebud Reservations are largely of this type and are confined to the tributaries of the White River almost entirely.

The large deposits are composed of hard materials, however. The characteristic mineral of these gravels is chalcedony. A great deal of it occurs in veins, geodes, and concretions in certain portions of the Bad Lands, and pebbles from these, find their way into the streams draining that country. Some of it is white and some a dark gray to nearly black. Most of it, however, is a milky gray which often has a bluish cast. A second characteristic of this gravel is feldspar. This feldspar is derived largely from arkosic sands of the Chadron formation. It is a flesh colored orthoclase similar to that found in the pegmatites in the Black Hills and occurs in pieces from an eighth of an inch to a half inch across. Cleaved faces are common, often giving a startling reflection from the surface of a graveled road.

Such gravels are found in the White River Valley, throughout its entire length. They are also found in Cottonwood Creek and Buffalo Creek at the head waters of the Bad River. The gravels of the White River between the Murdo and Kadoka bridges, have been described as follows: "The gravels are perhaps most interesting because of the predominance of chalcedony. This mineral makes as high as fifty per cent of the pebbles and cobbles in some bars. Associated with it are pebbles of light gray limestone which have come from the concretions in neighboring bluffs of the Pierre shale, flint and cherts from the Black Hills, and a few, miscellaneous, igneous, and metamorphic rocks. Chunks of feldspar, one-half to one inch across are abundant. These came directly from the Chadron gravels, and give the gravels and coarse

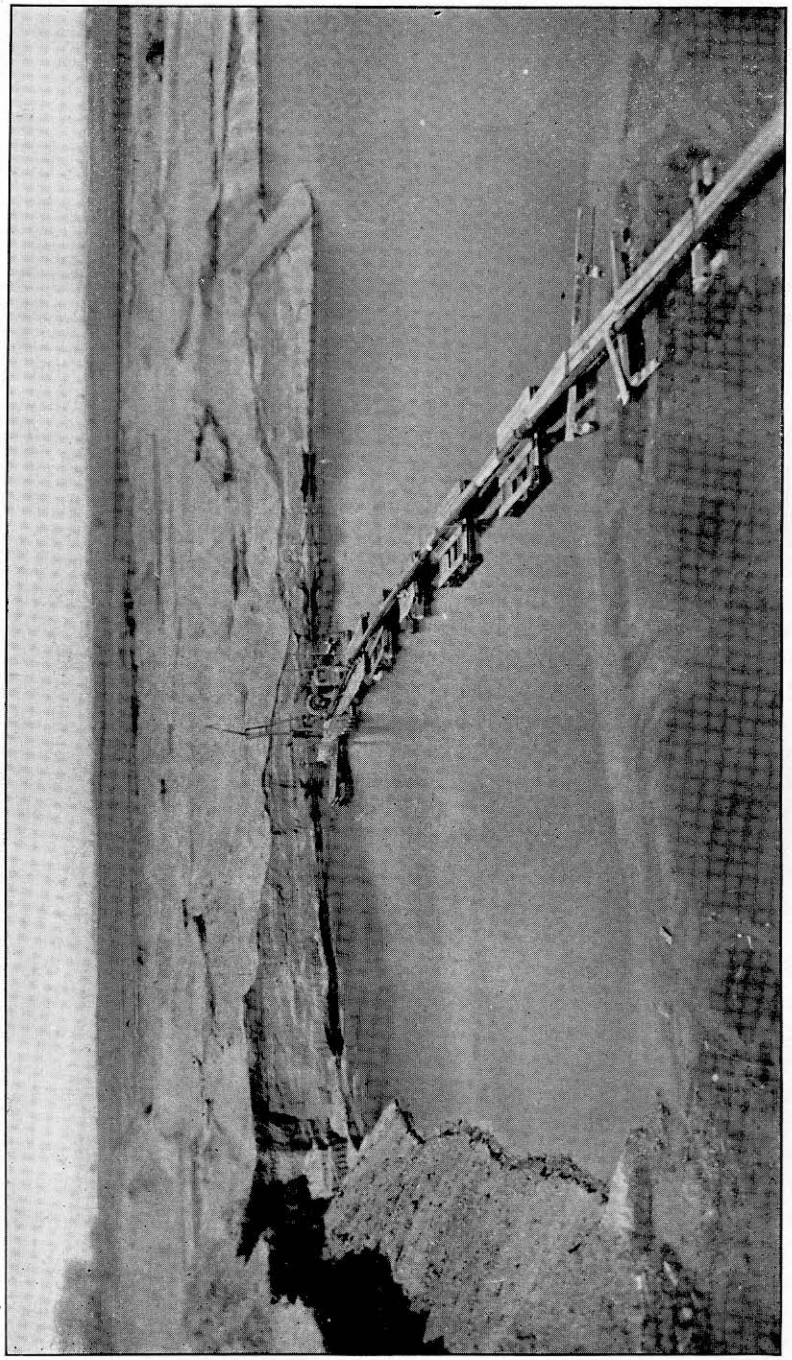

PLATE 23. Excavating With a Sand Pump.
Eagle Sand and Gravel Company Pit, Sioux Falls, S. Dak.

sands of some bars an appearance much like that of the Chadron gravels found in place. Many of the feldspars are perthitic like those of the Black Hills pegmatites, from which they were obviously eroded to form a constituent of the Tertiary gravels, which were subsequently reworked to form the present valley fill."[1]

The similarities of the gravels in different parts of the valley are evident from the two following pebble analyses[1]:

Sample from Test Well on Schwartz Ranch, three and one-half miles south of Stamford Bridge
Depth 10-14 Feet

A.	Sand	
	Vein and chalcedonic quartz	95%
	Milky quartz	1%
	Feldspar (probably orthoclase)	1%
	Garnets	1%
	Limonite	1%
B.	Coarser material from the same sample, pieces one-fourth to one-half inch in diameter	
	Flints and cherts	32%
	Chalcedony	29%
	Vein quartz	9%
	Quartzite	9%
	Concretionary limestone	16%
	Caliche limestone	3%
	Iron (limonite)	2%

Two samples from a test well on the Carley Ranch at the highway bridge south of Kadoka about 30 miles up the White River from the section just described, gave the following account[1]:

Pebble Count on Gravel from Test Well on Carley Ranch at Highway Bridge South of Kadoka

	Depth 20-23 Feet	Depth 26-27 Feet
Flint and chert	30%	9%
Chalcedony	22%	33%
Vein quartz	44%	23%
Light grey concretionary limestone	33%	10%
Dark grey concretionary limestone	4%	2%
Porous lime caliche	11%	2%
Sandstone, quartzitic	1%	----
Feldspar	1%	----
Metamorphic rock	1%	----

[1]Rothrock, E. P., A hydrologic study of the White River Valley: South Dakota Geol. Survey Rept. Inv. 41, p. 15, 1942.

Pyrite ----	2%
Iron (limonite) ----	21%

Though these are reworked gravels, they give a good picture of the kinds of materials that are common in the terrace gravels.

Sorting is not uniform in these gravels but a fair idea can be obtained from a screen test made on samples collected on Buffalo Creek and analyzed in the State Highway Commission Laboratory.

Screen Test on Tertiary Gravels Sampled on Buffalo Creek, S ½ Sec. 33, T. 1 S., R. 18 W., Jackson Co.

Analyst: J. C. Loomer

Passing	Retained	Percent	Percent
Right oversize			
2 inch	1½ inch		8.7%
Gravel			32.4
1½ inch	1 inch	3.9%	
1 inch	¾ inch	7.5	
½ inch	¼ inch	15.	
¼ inch		67.	
	Total	100.00%	
Sand			39.1%
¼ inch	10 mesh	30.4%	
10 mesh	20 mesh	51.0	
40 mesh	50 mesh	12.0	
100 mesh	200 mesh	6.	
200 mesh		.6	
	Total	100.00%	
Clay			19.8%

Bed Rock Deposits

As has been stated, the sandstones of the Cretaceous system are poorly cemented and except for case hardening those exposed in the plains region in South Dakota are loose enough to be excavated with a pick and shovel. These are a particularly good source of sand, north of the Grand River, as are also the Tertiary beds south of the White River. The Arikaree formation south of the White River is very sandy and during very dry times blows into dunes. Some use has been made of this sand near Burke where concrete brick and tile are manufactured from it. The sands in the Fox Hills and Ludlow formations could be used in the same way. So far as is known, however, there are no gravel deposits in these formations.

In the Chadron formation, a beautiful white sand and gravel is often encountered and has been used in surfacing roads in the Pine Ridge Indian Reservation. The same white gravel is known on Fox Ridge, in Meade County and small deposits of similar material occur near Springfield in Bon Homme County and north of Volin on Turkey Ridge in Yankton County. This white Chadron sand and gravel is highly arkosic and made largely of vein quartz, chalcedony and other hard materials with conspicuous feldspar. Its light color makes it a rather unusual material. The white vein quartz and pink feldspar with an occasional dark flint make a rather spectacular gravel which should be used for more small showy construction than it is. Most of the outcrops of this Chadron gravel are found in the breaks of the White River and in a few spots east of the Missouri which were mentioned. No appraisal has been made of the volume of this material, but it is significant that large enough deposits have been found to gravel most of the federal highway running through the Pine Ridge and the Rosebud Indian Reservations.

CEMENT MATERIALS

With the increase in the use of concrete in construction, it has become increasingly important to know where materials of which it can be made are available. This is especially important in a state like South Dakota which is far from lumbering centers and in which large areas are not adjacent to sources of building stone. Building stones are not available over most of the State and the soft character of most of the rocks make it essential that large structures be built of concrete.

Portland cement is made of three essential materials: lime, 60-70%, silica 20-21%, and alumina and iron 5-12%. Less than three per cent of gypsum is usually included to retard setting. This cement is used to bind an aggregate of pebbles or crushed rock and is then called concrete. A concrete structure, therefore, must draw on all of these materials. As they are heavy and bulky, their cost of transportation is high. The shorter the transportation to any building site, therefore, the cheaper will be the cost of its construction.

I. Sources of Lime

Lime is obtained by burning limestone, the sources of which have been discussed under the heading Stone. As has been pointed out in this discussion, limestones are available in the Black Hills, in the Missouri Valley, in the lower James and the lower Big Sioux Valley. The northern half of the State is entirely destitute of such materials except for a chalk outcrop at Redfield.

In the Black Hills, the hard limestones of the Paleozoic formations offer a limitless supply. At present, these are the Whitewood, Englewood, Pahasapa, and Minnekahta formations which outcrop in the limestone plateau about the crystalline core of the mountains. The Minnekahta limestone is being used at present as a source of lime for the State Cement Plant at Rapid City.

The Greenhorn and Niobrara formations also outcrop about the Black Hills but are not as easily accessible as the limestones mentioned and, therefore, will not be of as much interest as a source of lime in this region. They are important sources of lime farther east, however. In the lower Missouri Valley, the Niobrara chalk is available from Fort Thompson to Yankton. It has the advantage of being in close proximity to shale so that little hauling is necessary to obtain the two most important and bulkiest ingredients in the manufacture of cement. Cement was manufactured using the Niobrara chalk at a plant operated by the Western Portland Cement Company, four miles west of Yankton. The plant was erected in 1889 and 1890. In September 1890, production was started which continued to 1910 when the plant was sold to the Medusa Portland Cement Company of Cleveland. The plant had a capacity of 250 barrels a day.

As was indicated in the description of chalk under the heading of Stone, the Niobrara formation, in the vicinity of Yankton, contains 87 to 90% of lime. Its other ingredients are all useful in the manufacture of Portland Cement. The Missouri River, therefore, offers an excellent location for the erection of a cement plant, especially if fuels can be cheaply imported by rail or by water.

The Greenhorn formation outcrops in the lower end of the Big Sioux Valley. It is especially conspicuous at the village of Richland, five miles north of Elk Point in Union County. It underlies the divide between the lower Big Sioux and Brule Creek. Much of it is covered with a deposit of glacial drift which can be easily stripped. As pointed out in the description of the Greenhorn formation, shale partings occur between the slabby lime beds which would furnish part of the necessary silica. A thin chalk bed occurs below the limestone. All of this material, however, is useable in the manufacture of cement. It is unfortunate that a more detailed investigation has not been made of this formation with the view to its possible uses. However, the location of this outcrop, makes the Greenhorn worth investigating in any search for cement materials.

II.—Sources of Alumina and Silica

Alumina (Al_2O_3) and Silica (SiO_2) are constituents of nearly all clays and shales. Clay makes about a quarter of the average Portland cement mixture and is one of the easiest constituents to supply. All the shale formations of the State contain alumina in greater or less proportions. Those most available near the limestones are the Cretaceous shales of the Granerous, Carlisle, and Pierre formations. Some analyses of the Pierre formation follow:

Pierre Shale

Sample obtained from a quarry located along the Northwestern Railroad and U. S. Highway 14-16, five miles east of Rapid City, Pennington County.

SiO_2	56.22%
Al_2O_3	19.63
Fe_2O_3	6.84
CaO	2.57
MgO_2	1.90
SO_3	1.78
Ign. loss	9.60
N D	1.46
Total	100.00%

Sample obtained from Missouri Bluffs near Wheeler, S. Dak. Tested by R. A. Kuever, Consulting Chemist, Iowa City, Iowa.

Silica (SiO_2)	43.25%
Alumina (Al_2O_3)	33.42
Calcium (CaO)	5.60
Carbon Dioxide (CO_2)	4.40
Iron	trace
Alkali (K_2O,Na_2O)	trace
Oil	2.32
Water	11.02
Total	99.01%

Since Pierre shale occurs everywhere close to possible lime supplies, except in the lower edge of the Big Sioux Valley, it will probably be found the most convenient to use. In the lower Big Sioux Valley, however, the Carlisle and the Graneros are exposed. The former is close to the Greenhorn outcrop and probably the most accessible. Glacial clays are available but probably not sufficiently constant in composition to be used.

III. Sources of Gypsum

A little gypsum ($CaSO_4$) is added to most Portland cement to retard its setting. This must always be less than three per cent. Since it takes 680 pounds of raw materials to make a barrel of cement, less than 20 pounds of gypsum is sufficient for a barrel of finished cement.

Gypsum is fairly abundant in most Cretaceous formations. It is found in the bentonite of the Niobrara formation and occurs as crystals on the outcrops of all the shale formations mentioned above. While this would have to be considered in cement manufacturing, so far as is known, it is in no place sufficient to supply all of the gypsum that is needed.

Forty-six analyses of chalk rock were presented to the South Dakota Cement Commission[1] in a report by Carlson and Lonesbury.

These analyses show varying amounts of gypsum from a small fraction of a per cent to about seven per cent. The latter figure was obtained in only two samples which were very much above the average. Most of the samples were very low, the average of the entire group being .78%.

Analyses of the Chalk from the Firesteel Creek

SiO_2	MgO Fe_2O_3	Al_2O_3	CaO	Mgo	SO_3	S in Pyrite	Ignition Loss
4.56	2.38	1.26	50.85	0.33	0.04	0.00	40.57
3.06	1.12	1.52	51.38	0.32	0.03	0.00	41.64
24.08	4.72	9.18	28.69	0.56	0.91	1.31	31.74
24.12	2.83	5.73	32.49	1.89	1.21	3.35	28.44
23.16	3.46	9.76	30.02	0.52	0.85	0.55	31.56

The commercial gypsum in South Dakota is all found in the Triassic redbeds which come to the surface at the Red Valley surrounding the core of the Black Hills. Here there are a great many lenses of rock gypsum varying all the way from veinlets to beds 20 feet thick. The largest one seems to be a 20-foot bed which can be traced from Spearfish to Rapid City. A great many 4 and 5-foot beds occur throughout the outcrop. Calcining plants have been in operation on this gypsum at Hot Springs, Rapid City, and Black Hawk. The only one which is now in operation is at Tilford, where the gypsum is being mined by underground methods and calcined by the U. S. Gypsum Company.

Besides its use in cement, gypsum is used for plaster, wall board, various kinds of insulating blocks, and other building materials. Some of it is dense enough to have been used as the ornamental stone, alabaster.

III. Aggregate Materials

Materials for concrete aggregate have been discussed under the head of Stone. Most concrete mixtures call for a coarse aggregate with pieces approximately one inch in diameter. This is mixed with finer aggregate, which is either

[1]Private report by Carlson and Lonesbury, E. D., Report to the South Dakota Cement Commission, p. 14, August 18, 1920.

medium gravel or sand, which fills the interstices between the grains of the coarse aggregate. This makes sufficient strength and uses a minimum amount of cement. The cost is thus reduced by using materials cheaper than cement. Such aggregate material, for best results, should be clean and fairly well sorted as to size. It should also be made of hard material which will not break or weather out on the surface, leaving chips or holes. For highway construction, it must also take most of the wear the pavement receives. The aggregate used in most construction is either crushed rock or sand and gravel.

As has been stated, rock sufficiently dense for crushing can be found in the eastern part of the State where the Sioux quartzite outcrops between Sioux Falls and Mitchell. It is also possible to use the granite at Milbank for this purpose. Either of these stones makes an excellent concrete material when properly screened, and because of its location can be used to supply projects in the eastern half of South Dakota and adjacent states, direct from the quarries by either railroad or truck. In western South Dakota, rock suitable for aggregate is all in the Black Hills. The quartzite and granite in the core of the mountains and the limestones about the core furnish an abundance of material for crushing. As has been stated, limestone is not as hard as the quartzites and granites and, therefore, will not take the same amount of wear. However, it is used a great deal in walls and pavement and is cheaper to crush.

Though crushed rock has the advantage of locking grains, which takes some of the stress from cement in structures where heavy stresses have to be sustained, sand and gravels are most commonly used as aggregate materials because of their ease of preparation. They are very widespread in South Dakota, as has been indicated, being found in large deposits in the Big Sioux, James, and Missouri Valleys and in all the big river valleys of western South Dakota.

The glacial gravels of the east contain a high percentage of hard materials; granite, quartzite, vein quartz, flint, and chert, and gneiss. In most deposits, however, there is a sprinkling of soft materials such as chalk and shale. The gravels in the valleys west of the Missouri also contain a predominance of hard materials. In this case, however, the materials are largely varieties of quartz. Vein quartz, chalcedony, chert and flint predominate. Those in the northern streams carry rather high concentrates of iron oxide which is rather soft and weathers upon exposure. Gravels around the Black Hills contain a mixture of chert and flint, quartzite, vein quartz, limestone, and sandstone. These gravels are all easily excavated with power shovels or drag lines and, with a little screening and washing, will make good concrete aggregate of any size required.

DIVISION IV

CLAYS AND CERAMIC MATERIALS

Though clays are one of the most widespread mineral products in South Dakota, very little is known about them. The sticky gumbo clays found west of the Missouri, forced themselves on the attention of early travelers by their ability to "roll up" on the wheels of vehicles until progress was impossible. Certain glacial clays were used for brick before the competition of rail hauled lumber forced them off the market. The startling exposures of clays in the Bad Lands areas of the State have caused many citizens to opine that they should be good for something. Such casual observations are of interest but will hardly develop a ceramic industry. There is, therefore, a great need for a careful examination of the clays available in the State.

Useable clays are known to occur in the Paleozoic formations but are confined to the Black Hills. Cretaceous shales are very widespread over the State and certain formations have furnished commercial clay. These include the Fuson, Graneros, Carlisle, and Pierre. Other Cretaceous formations are of types that could furnish useful clays. Tertiary clays so widely exposed south of the White River may offer some useful material. Most of them, however, have such high shrinkage coefficients that no sweeping statements can be made of their useability. Glacial clays found universally east of the Missouri Valley have been used for brick making and while not ideal clays for this purpose might be a very important material for some ceramics.

The following descriptions of clays, which have been brought to public attention through geological exploration and commercial exploitation, will serve to reveal some of the possibilities of South Dakota clays.

Bentonite

Bentonite is an unusual clay, formed by the alteration of volcanic ash under sea water. It is very smooth, very white in color, and usually contains no grit. Most of it has the property of swelling to several times its normal size under water. Under the microscope, it shows the splintery structure of volcanic glass. It is very colloidal and weathers to a

smooth sticky gumbo. It is responsible for the gumbo character of much of the Pierre shale.

This clay has found its way into commerce largely on its ability to swell and because of its fineness of grain. The largest percentage of the production at present is being used by well drillers in the making of drilling mud. It is also used in medical dressing for burns, and in salves, and in cosmetics where it forms the "Denver Mud" of commerce which is the basis of most cosmetic clays. It has even been used in the manufacturing of a paper, sold under the trade name of Alsifilm used for the making of permanent records. Alsifilm is resistant to fire and cannot be destroyed by mildew or insects which destroy ordinary paper.

Bentonite is very common in the rocks of the Cretaceous system, being found from the extreme eastern to the extreme western boundary of the State. Most of the beds are too thin for commercial exploitation, a quarter of an inch to a few inches in thickness being common. There is, however, a large tonnage of bentonite in these thin beds, and in many localities, especially in the Missouri Valley, there are zones composed of several closely spaced beds which would add up to a considerable thickness. If some method could be devised to separate bentonite from the enclosing shales many deposits which are now unnoticed might be commercialized.

I. Pierre Bentonite

Only one zone in this formation has produced bentonite. It outcrops in the lower Missouri valley and in Fall River County. It has been quarried in the latter location for use as a water softener. This zone lies at the base of the Pierre formation in the Sharon Springs bituminous member. In the lower Missouri valley, "Numerous bentonite beds are a conspicuous feature of the outcrop. They are usually thin, though one-foot beds are not unusual and one measuring over two feet was observed. In a fourteen foot section near the mouth of Crow Creek, Buffalo County, a total of 44 inches of bentonite was recorded."[1] These have been noted as far north as Fort Thompson Indian Agency, and as far south as Yankton.

1Rothrock, E. P., Manganese deposits of the lower Missouri Valley in South Dakota: South Dakota Geol. Survey Rept. Inv. 38, p. 10, 1941.

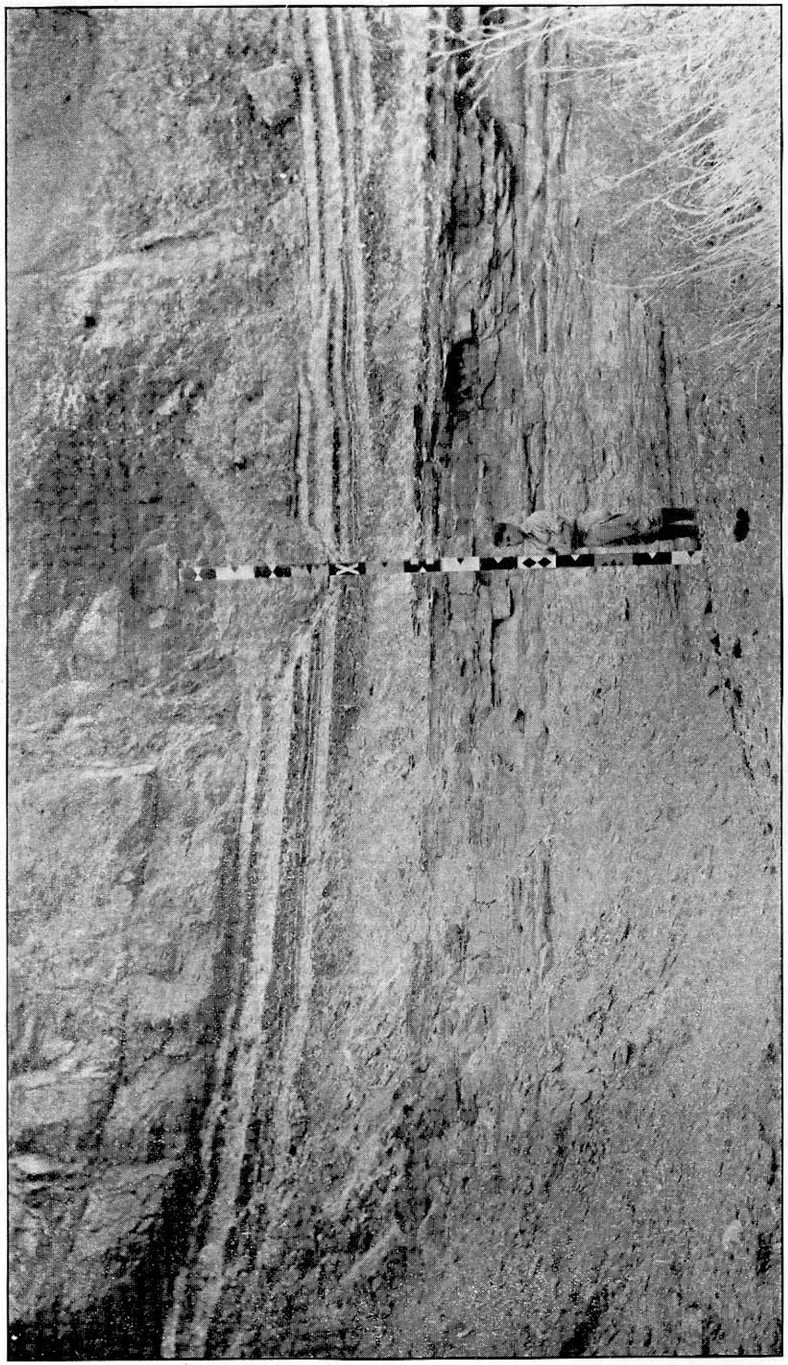

PLATE 24. Bentonite in the Base of the Pierre Formation in the Missouri Valley near Chamberlain.

The following section is characteristic of the zone in the Missouri Valley:

Detail of Niobrara-Pierre Contact

NW¼ sec. 9, T. 102 N., R. 71 W.

	Feet	Inches
Pierre Formation—		
Sharon Springs Member		
Shale, dark gray, weathers with formation of yellow veins; fish fragments. 5 thin streaks may be bentonites; exposed	17	0
Bentonite	—	½
Shale, as above	—	3
Bentonite	—	6
Shale, as above	—	4
Bentonite	—	10
Shale, same, with 3¼" bentonites	1	2
Bentonite	—	5
Shale, as above	1	7
Bentonite	1	6
Shale	—	4
Bentonite	—	5
Shale	—	1
Selenite layer	—	½
Niobrara Formation—		
Chalk	6 plus	

In the outcrops in Fall River County, a zone of bentonite which appears to correlate with the one just described, lies 100 feet above the bottom of the Pierre formation. It can be traced northward past Provo a distance of 15 miles on the west side of the Chilson anticline. It can also be traced about six miles north on the eastern side of the anticline. At Ardmore, it is excavated and processed as a water softener. The zone in this region consists of a bed of bentonite about 38 inches thick above which lie a varying number of thinner beds from four to six or eight inches thick, separated by one or two-foot partings of dark shale. A section taken at the pit of the Refinite Company immediately west of Ardmore, showed the following alternations of shale and bentonite:

Section of Lower Pierre Formation

In NW¼ sec. 8, T. 12 S., R. 4 E., Fall River County

Feet	Inches	Soil
28	--	Shale, with a layer of gray limestone concretions 5 feet above the base and another layer 20 feet from the bottom.
--	7	Bentonite
1	7	Shale

Feet	Inches	Soil
—	11	Bentonite
2	11	Shale
—	8	Bentonite
—	8	Shale
1	2	Bentonite
—	7	Shale
—	6	Bentonite
—	6	Shale
—	6	Bentonite
1	—	Shale
—	1	Bentonite
—	4	Shale
—	4	Bentonite
—	3	Shale
—	5	Bentonite
2	—	Shale
3	2	Bentonite, "Ardmorite"
1	—	Shale, containing numerous gray limestone concretions
—	8	Bentonite
9	—	Shale
1	—	Shale, with few scattered limestone concretions
15	—	Shale
—	¼	Bentonite
6	6	Shale
—	1	Bentonite
—	5	Shale
—	6	Bentonite
—	1	Shale
—	1	Bentonite
—	11	Shale
—	1	Bentonite
—	3	Shale
—	1	Bentonite
—	11	Shale
—	2	Bentonite
2	8	Shale
—	5	Bentonite
—	10	Shale
—	1	Bentonite
1	—	Shale
—	1	Bentonite
1	1	Shale
—	3	Bentonite
—	8	Shale
30	—	Chalk, Niobrara, bottom not exposed
120	3	Total Section

This bentonite zone has been traced around on the eastern side of the Black Hills to a point about 36 miles northwest of Belle Fourche. No attempt has been made to exploit it, however, except at Ardmore.

II. Graneros Bentonite

The only other formation which carries bentonite of commercial thickness, so far as is now known, is the Graneros formation. In the exposures in eastern South Dakota, along the Big Sicux Valley, this formation does not carry bentonite of sufficient thickness to be of interest commercially, but in the Black Hills region, two zones are of importance. "Bentonite occurs in the Graneros at several horizons. There are three to five thin beds in the upper part and about 130 feet below the top of the formation a three or four-foot bed is usually present. In the oligonite zone, (near middle of the formation) at least one bentonite is present at all outcrops where the lower part of the zone is exposed. In a few exposures as many as four bentonites ranging in thickness up to three feet can be seen."[1]

These two bentonite zones were traced from the State line south of the Cheyenne River through Fall River, Custer, and Pennington Counties. North of Rapid City, the upper zone was lost and the lower zone disappeared for a distance of 20 or 30 miles. This lower zone, however, reappears north of the Black Hills and is quarried at Belle Fourche and farther west in Wyoming. The lower zone can be identified as it lies just above or immediately on top of the Mowry member of the Graneros formation. This is a silicous shale, light gray in color and carrying an abundance of fish scales and spines.

Composition

The mineral composition of bentonite as determined from samples taken in western South Dakota is largely montmorillonite, the formula for which has been given as $Al_2O_34S.O_2nH_2O$.[2]

[1]Spivey, R. C., Bentonite in southwestern South Dakota: South Dakota Geol. Survey Rept. Inv. 36, p. 17, 1940.

[2]Ross, G. F., and Shannon, E. G., Minerals of the bentonite and related clays and their physical properties: Am. Ceramic Soc. Jour. vol. 9, pp. 77-79, 1926.

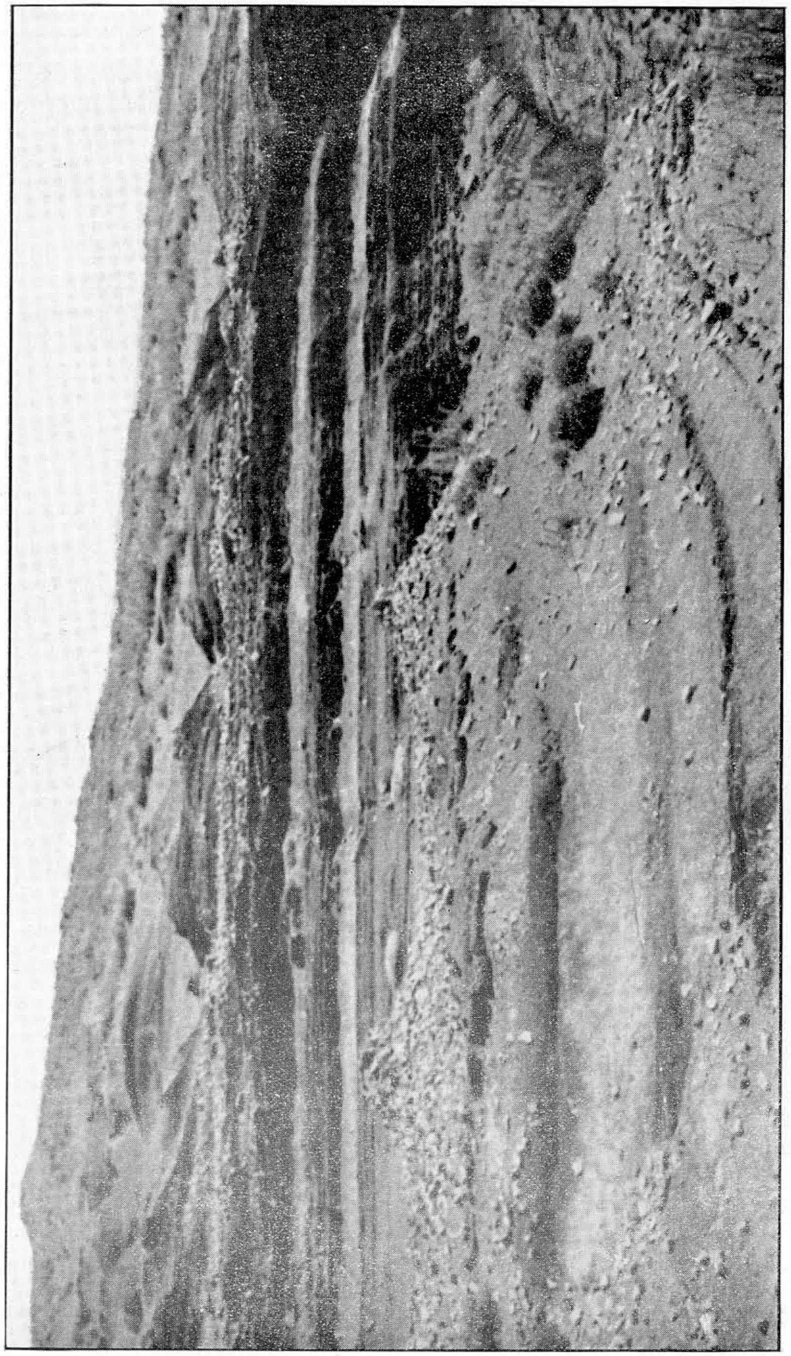

PLATE 25. Bentonite at the Base of the Pierre Formation Near Ardmore in Fall River County

The following chemical analyses will illustrate the chemical composition of South Dakota bentonite:[1]

Bentonite Analyses

	1	2	3	4
SiO_2	54.01	56.42	55 52	53.77
Al_2O_3	19.20	23.62	21.95	22.70
Fe_2O_3	3.57	1.64	1.91	4.05
FeO	----	0.18	----	----
Mn_3O_4	----	0.04	----	----
CaO	1.91	0.62	0.55	1.23
MgO	4.41	4.24	3.43	3.25
K_20	----	0.01	----	----
Na_2O	1.38	0.07	3.32	2.46
SO_3	----	Trace	----	----
Moisture at 110° C.	----	6.13	----	----
Loss on Ignition	16.91	7.18	13.28	12.17

1. Bluish gray bentonite from Ardmore bed of Pierre formation about 14 miles south of Hot Springs, Fall River County, S. Dak., SE¼ sec. 32, T. 9 S., R. 6 E. (Analysis made at South Dakota State Chemical Laboratory, Guy G. Frary, State Chemist, 1939.)
2. Light colored sample from property of the Refinite Company, Ardmore, S. Dak. (Analysis by Charles Bentley in Connolly and O'Harra, South Dakota School of Mines, Bulletin No. 16, page 331, 1929.)
3. Bentonite from upper part Graneros formation, about 14 miles south of Hot Springs, S. Dak., SE¼ sec. 18, T. 9 S., R. 5 E (Analysis at South Dakota State Chemical Laboratory.)
4. Bentonite from oligonite zone of Graneros formation, one mile west of Edgemont, South Dakota. (Analysis at South Dakota State Chemical Laboratory.)

A chemical analysis of the high grade Belle Fourche bentonite shows the following constituents:

Analysis of Bentonite, American Colloid Company Pits
NW of Belle Fourche, Sec. 15, 23, 25, T. 9 N., R. 1 E., Butte County
Analyst: W. A. Selvig, U. S. Bureau of Mines.[2]

SiO_2	60.64 per cent
Al_2O_3	23.26 per cent
Fe_2O_3	3.92 per cent
TiO_2	.12 per cent
CaO	.59 per cent
MgO	2.19 per cent
K_2O	.37 per cent

[1]Spivey, R. S., Bentonite in southwestern South Dakota: South Dakota Geol. Survey Rept. Inv. 36, p. 51, 1940.

[2]Analysis by W. A. Selvig, Bentonite—Private publication of the Belle Fourche Bentonite Products Co., Inc.

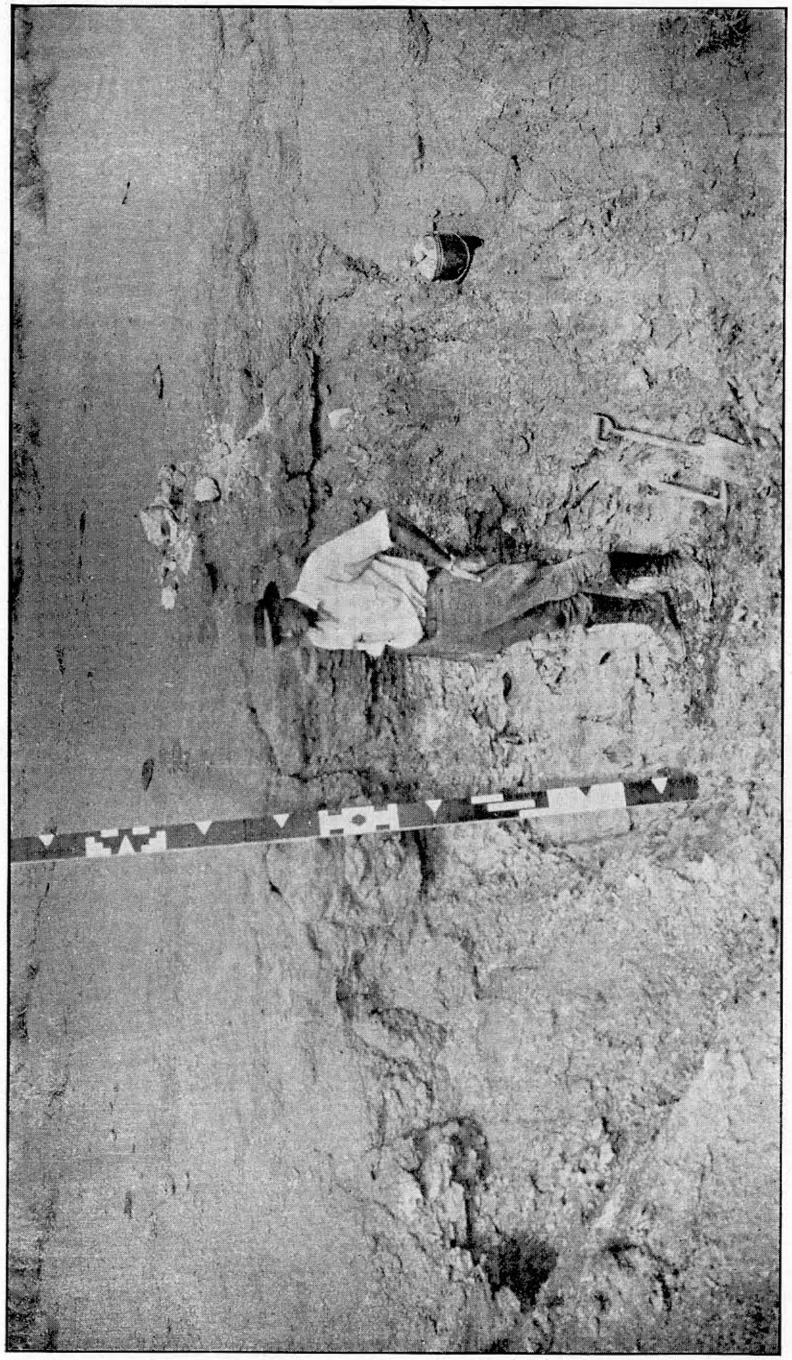

PLATE 26. Bentonite in the Graneros Formation
Near Edgemont in Fall River County, S. Dak.

Na_2O	----------------------------------	4.33 per cent
H_2O	----------------------------------	2.83 per cent

Properties of Bentonite

Bentonite is often divided into two types; one, that which swells with the addition of water, and two, a non-swelling type. Aside from this property, the physical characters of the two seem to be much alike. The following information on the character and uses of bentonite is taken from a report by Dr. Monta E. Wing:[1]

One of the outstanding characteristics of type one bentonite and one upon which many of its properties depend is its extremely minute grain size or texture. Bentonite is composed of flake-like crystals which are exceedingly small in diameter. Crystals of montmorillonite, the principal mineral found in type one bentonite, are between 1 and 0.1 micron in size. It is estimated that while English ball clay has an average of 3,400 grains per linear cm., bentonite has 20,000.[2] In other words, bentonite particles have a diameter of only one-sixth that of English clay.

Because of the shape of its particles and its extremely minute grain size, type one bentonite has a very large surface area per unit volume of material. Again comparing English ball clay with bentonite,[2] the former has an average area of 7,400 sq. cm. per gram, while bentonite has an area of 50,000 sq. cm. per gram.

Type one bentonite will take up six to seven times its weight of water and in doing so will expand as much as fifteen times its dry volume. In this condition it forms gels which have the consistency of heavy grease. Water not only enters the lattice structure of the crystal, but a film of water covers the surface of each. Since the surface area per volume is extremely large, the amount of water absorbed by bentonite is very large and it swells enormously.

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[1]Wing, M. E., Bentonites of the Belle Fourch district: South Dakota Geol. Survey Rept. Inv. 35, pp. 12-19.

[2]Norton and Hodgdon, Some Notes on the Nature of Clay: Am. Ceramic Soc. Jour., vol. 15, p. 3, 1932.

This power of swelling is reversible and is not diminished unless drying is done at over 400° F. It is not totally lost until bentonite is heated to 1200° F. Bentonite will not swell in alcohol, gasoline or similar liquids.

Another property of type one bentonite is that it will remain in suspension in distilled water even as dilute as one part in 10,000. This property is caused by the extremely minute character of the particles as well as by the electric charge carried by each particle.

Bentonite particles are negatively charged and when placed in turbid liquids particles attract positively charged impurities causing flocculation. Thus the liquid is freed of impurities held in suspension.

Type one bentonite has base exchange properties also. In solutions the sodium and potassium of the bentonite are exchanged for calcium and magnesium, thus making a material which can be used as a water softener.

Other properties of this type of bentonite are its high degree of plasticity, its great bonding strength, and its specific gravity of 2.65. It fuses completely at 2400° F.

Uses of Bentonite

Bentonite has been called the "clay with a thousand uses". Some of the more important uses are described below. Since these are definitely related to the unusual properties of bentonite, attention is called to the particular property or properties which make the use possible. A study of these will undoubtedly suggest many additional places where bentonite will fit into industry.

As a Drilling Mud

One of the principal uses of bentonite is found in oil well drilling where the rotary system is used. This system employs a cutting tool fastened to a drill pipe which extends from the surface to the bottom of the hole. The pipe is rotated by means of machinery at the surface. Cuttings must be removed from the hole, and this can be accomplished only by floating them out by forcing a liquid into the hole through the drill pipe and allowing it to escape around the outside.

Various muds have been developed for this purpose, but type one bentonite of high quality such as that from the Belle Fourche district is superior to others, because only a relatively small quantity must be mixed with water in order to produce a gel capable of suspending and carrying cuttings from the hole, and because this type of bentonite will remain suspended in water indefinitely instead of settling as will ordinary muds.

A good drilling mud should also be free from abrasive grits and should have some lubricating qualities. Here again Belle Fourche type bentonite is superior to the ordinary muds used for this purpose.

Bentonite is also effective in sealing sands through which the drill has passed against loss of water.

It is suggested further that where drillers fill the space between the casing and wall of the well with mud, in order to prevent corrosion of the casing or to shut off water above the oil-bearing sand, bentonite might be used to advantage. Bentonite will maintain its gel-like consistency indefinitely. Thus, it seems that the use of bentonite in this way might prevent the casing from "freezing" in the hole and might permit its removal later with much greater ease.

It is suggested further that during times of over-production or when a well is shut down for any reason, it be plugged with a bentonite mud-fluid or gel. Bentonite will form an impervious plug and should protect the well until it is desired to operate it again.

As a Bonding Agent in Foundry Sands

Bentonite is being used extensively in foundries as a bonding agent in sand.

Foundry sands vary a great deal in quality, depending on the type of metal being poured and on the particular class of work. In general, however, foundry sands should possess important properties. They should possess plasticity so as to increase their workability. They should be as fine as possible so as to give a smooth surface to the casting. They should possess mechanical strength so that the mold or core can be handled and will be able to withstand the pressure and washing effect of molten metal. They should not fuse when the molten metal comes in contact with the sand of the core or mold. Lastly, sands should be permeable so as to permit the escape of gases generated when the hot metal is poured into the mold.

Obviously these properties depend primarily on the sand, but they are also dependent in part on the character of the bond in the sand. Bentonite of the Belle Fourche type is highly plastic and adds to the ease with which sands may be molded. It has greater bond strength than other clays, and so, less may be used in obtaining the desired strength in sand. This, in turn, increases the permeability of sand, since clay tends to fill the openings between sand grain. Thus, a finer sand may be used and still maintain the same permeability. The use of a finer sand gives a smoother finish to the casting. Bentonite contains no organic matter, and in addition less water is required when bentonite is used, so that less steam or other gases are generated when the hot metal comes into contact with the sand. Finally, bentonite does not act as a flux, nor lower appreciably the fusion point of sand. A small percentage of the bentonite may, because of the high temperature involved, lose some of its properties, but the necessary replacement is small.

Thus in foundries where scientific management or control is maintained, bentonite of the Belle Fourche type is used as the bonding agent. The principal use is as a binder for silica sand, but bentonite is used also for reclaiming sand and for making molds and cores and core washes.

As a Water Seal

Bentonite has another important use in stopping water flow and it is very effective in waterproofing concrete and stucco, but its more important use is in sealing reservoirs against leakage and especially in preventing seepage underneath dams. For the latter purpose bentonite is mixed with water to the desired consistency and is injected into the sand or gravel under pressure. Irrigation ditches and reservoirs can be made leak-proof if bentonite is mixed with the upper several inches of sand and clay while the sand and clay are still dry.

Type one bentonite is an excellent grouting material because it is exceedingly fine grained when mixed with water. It has greater slipperiness than any other material used. Because of these two properties it can be forced into very small

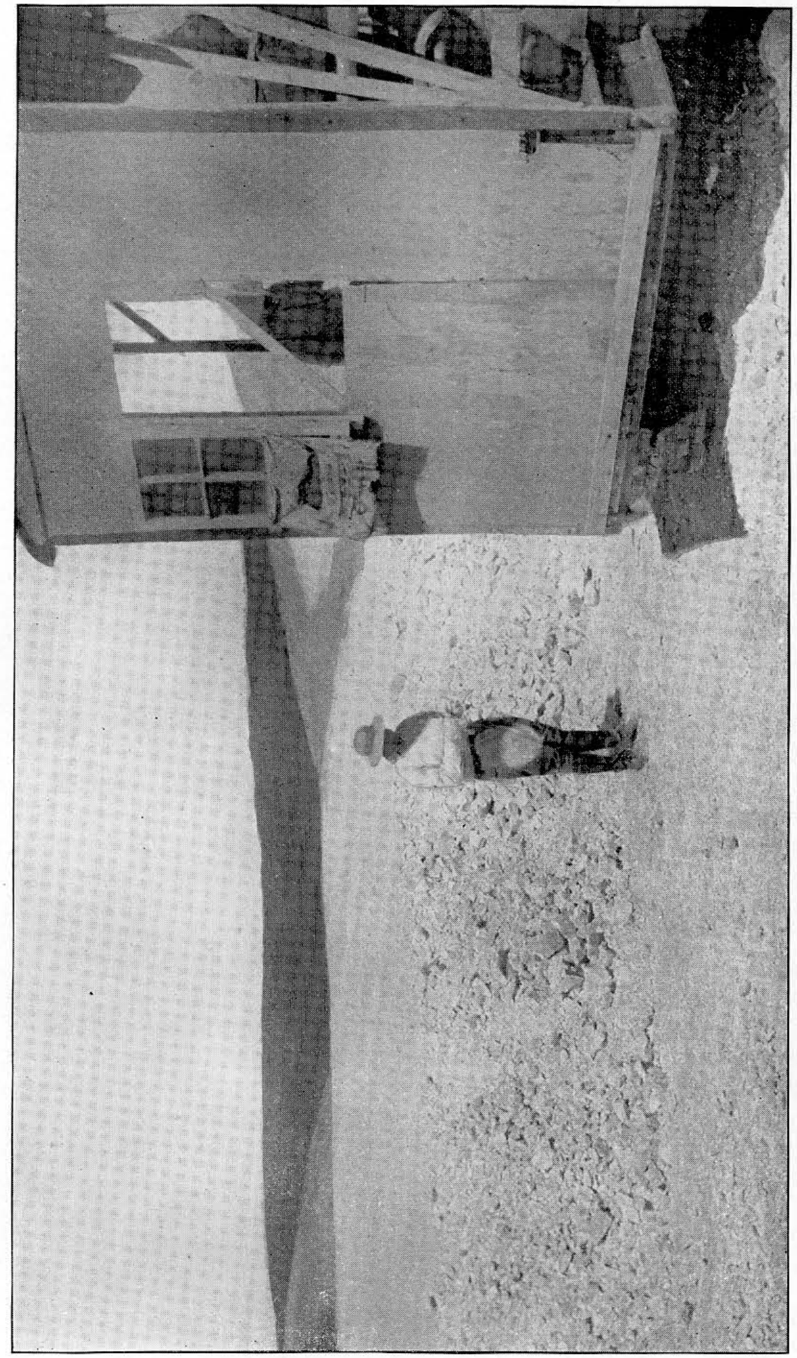

PLATE 27. Bentonite in the Graneros Formation
American Colloid Company's pit near Belle Fourche, S. Dak.
The cover has been stripped from the bentonite bed preparatory to excavating it.

openings in the rocks. When so used it has been very effective in stopping the leakage of water.

As a Coagulent in the Purification of Water or as a Clarifying Agent

Bentonite is used in sanitary engineering as a coagulent in the purification of water. Olin and Gauler[1] say in discussing this use, "The alkali bentonites in water dispersion form in general highly colloidal systems of negatively charged particles which react with mono-, di-, and trivalent cations to form absorptive flocs in accordance with well established physical laws." It is also pointed out by these authors that, "Lime softening of a water containing carbonate hardness presents a particularly favorable situation for use of bentonite for clarification." In other words, bentonite may perform a double function when used in treating a water supply. It will clarify the water by forming readily filterable flocs of impurities held in suspension and it will serve to reduce the hardness of water by exchanging its sodium and potassium for the calcium and magnesium in solution in the water.

Olin, Campbell and Gauler[2] in a later paper showed that bentonite can be used economically and effectively in treating sewage.

Still further uses based on this property of bentonite to attract positively charged particles of matter in suspension is in clarifying wines, honey, fruit juices, vinegar and other liquids.

In the Ceramic Industry

The use of bentonite in the ceramic industry is growing rapidly.

Bentonite of the Belle Fourche type is composed largely of colloidal particles and is remarkably plastic. Even when a small quantity is added to non-plastic and lean ceramic materials, the mobility and the ease with which the latter may be worked is greatly enhanced. At the same time, the

[1] Olin, H. L., and Gauler, J. V., The Use of Bentonite Clays in Water Treatment: Am. Water Works Assoc. Jour., vol. 30, pp. 498-506, March, 1938.

[2] Olin, H. L., Campbell, Chas. L., and Gauler, J. V., Experience with Bentonite in the Purification of Sewage: Waterworks and Sewerage, July 1937.

strength of the ceramic body is greatly increased and its porosity reduced. There are no adverse effects such as an increase in drying and fire shrinkage or discoloration caused by firing as long as bentonite is used in small quantities. Only a small quantity need be added to clay to greatly increase its plasticity and workability.

In Concrete

Likewise bentonite when added to a concrete mix will increase workability of the latter. The concrete will be made waterproof. The strength of Portland cement used will be increased and its time of set reduced. Bentonite also serves to hold sand and gravel particles in suspension and will result in a better distribution of these ingredients in the concrete.

In Laundries

One of the oldest uses of bentonite is in washing blankets, overalls, shop rags, etc. This use was probably suggested because of the resemblance of bentonite mud to soft soap. Indians are reported to have washed their blankets in bentonite, and later the Hudson's Bay Company adopted the same practice. Now many commercial laundries use bentonite wholly or partly in place of soap.

The detergent value of bentonite is due to its dispersing, emulsifying, and suspending energies. It unites with oils or greases readily to form an emulsion which is easily removed. Its negatively charged particules attract positively charged particles of dirt, which are floated away.

Bentonite is also used as an ingredient of soaps, cleansers, and polishes, and as such, it is not merely a filler but possesses unique properties which function actively.

In Making Alsifilm

The most interesting new use for bentonite is in making Alsifilm, a transparent, flexible and fairly tough paper or film. This film has the further beneficial properties of being fireproof, waterproof, and chemically inert. It is unaffected by mold and unattractive to insects. It has been suggested that this new product be used for wrapping electric wires and telephone cables, for permanent documents, or to line food or beverage containers, and to wrap butter, tobacco, cigarettes, and other perishable or oily products. Alsifilm was discovered by Dr. Earne A. Hauser, Massachusetts Institute of Technology in 1938.

Other Uses

Other uses of bentonite are:

1. As a suspending, spreading, and adhesive agent in making horticultural sprays, insecticides, fungicides.
2. In making emulsions and aqueous suspensions of bitumens, asphalts, latex, rubber, rosins, and other water-immersible substances.
3. As a thickening and suspending agent for valve-grinding and other pastes and in polishes and cleansers.
4. In adhesives and sizings in combination with starches and other substances.
5. As lubricant in combination with geled oil.
6. In pharmaceuticals and cosmetics and as a sorbent, penetrant and gelatinizing medium.[1]

[1]Reported in Minerals Yearbook, 1938.

POTTERY CLAYS

Clays suitable for the manufacture of pottery doubtless exist in South Dakota. No investigation of them has been made and very little attempt has been made to use them. The clays over most of the State either burn red or do not have the physical character of pottery clays. It is of interest to note, however, that certain clays from the upper part of the Cretaceous system have been used rather extensively in the manufacture of pottery in North Dakota. The same clays are to be found as underclays of the coal beds in the Hell Creek beds of northwestern South Dakota and could doubtless be used for the same purpose. Certain of the clays in the Fuson formation have been used for making some types of pottery in the Black Hills. None of these, however, have reached the commercial stage. The entire subject of pottery clay, therefore, is one which still needs investigation.

The chemical character of some of the under clays from the Cretaceous formations follows:

Analyses of Clays from the Lignite Field[1]

Analyst: Charles Bentley, State School of Mines, Raid City, S Dak.

	Hodge Mine	Robbins Mine	Warner Mine
SiO_2	62.04	62.20	63.62
Fe_2O_3	2.76	4.10	2.20
Al_2O_3	15.94	19.28	20.94
Mn_3O_4	0.24	0.16	0.24
CaO	2.56	1.26	0.66
MgO	2.96	2.34	1.76
K_2O	2.64	----	----
Na_2O	1.36	----	----
SO_3	0.12	0.02	0.08
Moisture	1.51	2.20	1.22
Loss on Ignition	7.76	5.99	6.85
Total	99.89	97.55	97.57

Because of their light color, the clays of the White River Bad Lands are often suggested as a source of pottery or china clays. There may be beds in these sediments that could be used for this purpose but the general information now at hand is not as favorable for this use as would seem on casual observation. Most of these clays are very smooth and plastic

[1]Connolly, J. P., and O'Harra, C. C., The mineral wealth of the Black Hills: South Dakota School of Mines, Bull. 16, p. 312. 1929.

when wet but shrink on drying, leaving a rubble of gumbo over the surface which attains depths of a foot or more in dry weather. This makes trouble in air drying products made from clay. The fire shrinkage which occurs when the clays are burned is not so great at lower heats but does become high at temperatures over 1,000 degrees centigrade.

One analysis from each of the two formations found in the White River beds will illustrate the general characteristics of these clays.

Analysis of Clay from Thin-Bedded Shaly Sandstone in Lower Oreodon, White River Bad Lands

Tested by Heinrich Ries

Texture	Fine grained, much fine silt
Plasticity	Good
Water of plasticity	40.00%
HCL treatment	No effervescence
Behavior in drying	No warping or cracking
Linear air shrinkage	12.00%
Modulus of rupture	850 lbs. per sq. in.

Fire Tests:

Temp.	Fire Shrinkage	Absorption	Color
950 C.	0.0%	11.4%	Red
1050 C.	3.0%	11.2%	Red
1090 C.	4.0%	3.5%	Red
1150 C.	5.0%	2.8%	Red
1190 C.	Viscous		

Analysis of Clay from the Upper Titanotherium Beds, White River Bad Lands

Tested by: Heinrich Ries

Texture	Fine grained
Plasticity	Good
Water of plasticity	50.00%
HCL treatment	Some effervescence
Behavior in drying	Warps and cracks badly
Linear air shrinkage	14.00%
Modulus of rupture	Not tested, bars cracked in drying

Fire Tests:

Temp.	Fire Shrinkage	Absorption	Color
950 C.	3.00%	4.1%	Pink
1050 C.	3.00%	3.5%	Red
1090 C.	4.00%	1.2%	Red
1150 C.	Viscous		

BRICK AND TILE CLAYS

In the 1890's, brick plants sprang up in a great many places in South Dakota. Nearly every town on the Missouri River had a small one and similar plants were erected at Rapid City and the larger towns in the Black Hills. In all cases, local material was used and the plants abandoned when the immediate demand was satisfied. The coming of cheaper lumber, however, forced these plants entirely out of existence and no permanent brick industry remained.

South Dakota is well supplied with brick and tile clays. The glaciated eastern half of this country offers useable material almost any place that a plant can be erected. Much of this clay contains chalk, however, which tends to make the brick soft. Because of the cheapness and abundance of this material, however, it should be possible to overcome the handicaps of the boulder clay with modern methods of handling. Large areas in the Big Sioux Valley from Watertown south, have a cover of loess which is a useable material for this purpose and does not contain the boulders and pebbles such as must be separated from the ordinary glacial till or boulder clay.

The Pierre shales outcropping over a large area in western South Dakota can be used for this purpose as can most of the other shale formations. A brick plant at Mina, Edmunds County, used Pierre shale. One now operating in Sioux City, Iowa, uses Graneros shale and loess. A brick plant at Belle Fourche, now in operation, manufactures brick and tile from the shales of the Fuson formation.

Clays can probably be found in the Tertiary area though the air and fire shrinkage test will have to be applied experimentally before recommending any clay from this region.

REFRACTORY MATERIALS

I. Fire Clays

Refractory clays are those used to make furnace linings and articles that have to withstand high heats. Such clays are characterized by a high content of silica (SiO_2). Two sources of such materials present themselves in South Dakota; one, zones of silicous clays in the Pierre and Graneros formations and, two, the fire clays in the Fuson formation.

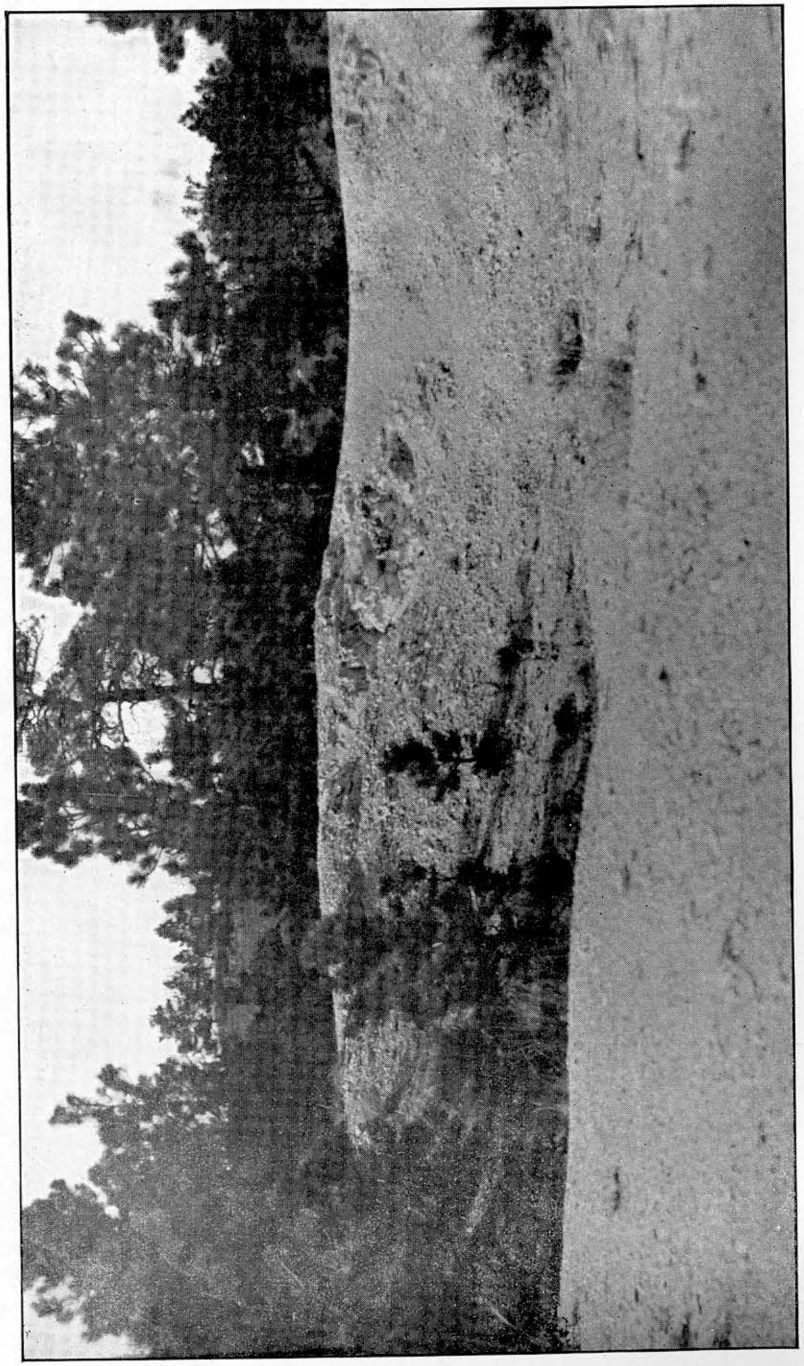

PLATE 28. Fire Clays in the Fuson Formation
Near Rapid City, Pennington County, S. Dak.

A silicous shale known as the Mowry member of the Graneros has been widely publicized in geological literature. This enters the State from the west, outcropping both north and south of the Black Hills. The shale breaks into small flakes which rattle when shaken together and which do not make mud when wet. They are characterized by an abundance of fish remains, spines, scales, etc. So far as is known, this has never been used as a fire clay, nor has its possibilities been examined. If refractory materials are wanted, however, this clay contains the necessary silica.

Two similar silicous shales occur in the middle part of the Pierre formation in the Missouri Valley. The first is known as the Agency member because it outcrops near the Cheyenne Agency. It was first recognized in this region because of its failure to become wet and slippery after a rain. In fact, it was used as a road metal on that account. The silicous Agency member disappears under ground at the mouth of the Moreau and changes to a gumbo shale south of Pierre.

A higher member of the Pierre formation known as the Virgin Creek member, is a gumbo shale, over most of the State. In the vicinity of Mobridge, however, it turns silicous, forming a wedge of silicous shale, thinning southward. Its southern limit lies about six or eight miles north of the mouth of the Moreau River. Its northern limit has never been determined. Above Mobridge it makes the cliffs exposed by the River's under-cutting.

Like the Mowry shales, the silicous members of the Pierre, have never been investigated and are mentioned there because they appear to offer a source of refractories for use in any metallurgical development that may come with power on the Missouri.

Fire clays from the Black Hills were much advertised in the early days. A large outcrop in the Fuson formation on the Hogback south of Rapid City shows a seam 45 feet thick. It is a very light colored silicous clay breaking with a peculiar concoidal fracture and apparently covering a large territory. Between Rapid City and Sturgis, this clay was used for a while by a local brick plant for making furnace lining for Black Hills smelters. The following analyses were made by Dr. R. L. Slagle at the South Dakota School of Mines:

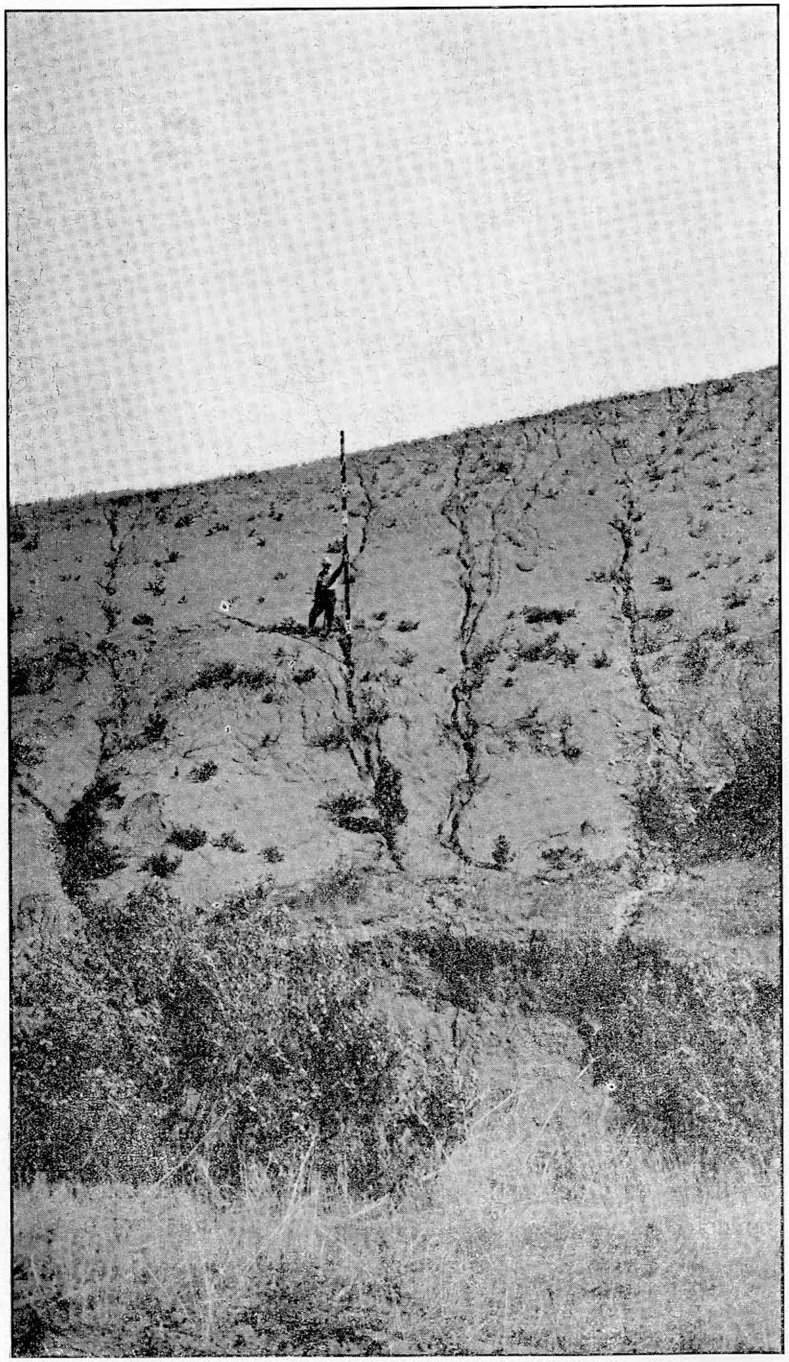

PLATE 29. Outcrop of Siliceous Shale in the Pierre Formation In the Missouri Valley near the mouth of Swan Creek, Walworth County, S. Dak.

Analysis of Fire Clays from Fuson Formation, near Rapid City[1]

SiO_2	76.78	81.98
Al_2O_3	14.43	13.08
Fe_2O_3	.18	.21
C_2O	2.18	1.46
MgO	.95	.31
Alkalis	Trace	Trace
Loss on ignition	4.62	4.07
	99.14	100.86

Doubtless other formations could yield fire clays if search were made for them. Much fire clay is obtained from the clays beneath coal beds in the eastern coal regions of United States. Investigation of the underclays in the coal regions of South Dakota should reveal clays useful for this purpose. Available analyses of the underclays showed a high per cent of silica, though not as high as in the fire clay of the Fuson given above. The three analyses on page 201 of this report show a clay in Harding County with 62.04% silica and 15.96% alumina; a clay from near Isabel in Dewey County with 62.20% silica and 19.28% alumina; and a clay from Lodgepole in Perkins County with 63% silica and 20.94% alumina. It would appear from these analyses that the underclays were fairly similar over most of the coal region and carry enough of the refractory elements to be worth consideration in a search for fire clays.

II. Quartzite

Under the description of stone, the possibility of using quartzite for making refractories has been mentioned. The purity of the silica in the Sioux formation offers an especially good source of this material for mixture with other ingredients used in the manufacture of such refractories as silica or magnesite brick. As was pointed out, this stone contains about 97% silica. The quartzites of the Black Hills have never been examined with this point in view but it is probable that many of them will show similar percentages of silica. The small amount of iron in the Sioux quartzite precludes its use for transparent glass but by mixing with other materials as flux, a good refractory glass should be obtained.

[1]Todd, J. E., Mineral Resources of South Dakota: South Dakota Geol. Survey, Bull. 3, p. 104, 1900.

III. Sillimanite and Andalusite

These two minerals are sometimes called the "spark plug minerals" because of their use in making refractory clays for the manufacture of spark plugs. They are aluminum silicates (Al_2SiO_5) and when fused give a material that melts at a temperature of 3,300 degrees Fahrenheit, is very strong, is a poor conductor of electricity, and has a low coefficient of expansion. These minerals are found in limited quantities along the contacts of pegmatite dikes in the vicinity of Custer. They were formed as an alteration product where the volcanic pegmatites cut through aluminum bearing rocks. No production of these minerals has been developed in South Dakota, probably because prospecting for them has not been carried on with sufficient diligence.

Conclusion

As stated above, little is known of the possibilities of South Dakota's refractories. The foregoing has been presented, however, to show that refractory materials are present in the State in considerable abundance. The development of these materials will depend in part on the demand for them and in part on human aggressiveness.

FULLER'S EARTH

Just before the turn of the century clays were discovered in western South Dakota which had the properties of fuller's earth. These clays lay at the base of the Chadron formation in the Titanotherium beds. "These beds seemed to have been formed in the valleys of the Cretaceous clay before the mass of the Tertiary was laid upon them."[1]

"Some of the clays, especially those near the bottom of the Titanotherium beds have the property of declorizing or clarifying oils."[2]

"In the Chadron formation adjoining the Black Hills there are thousands of square miles of deposits having the chemical and physical properties of fuller's earth. * * * Mining operations were begun at a point three miles southwest of

[1]Todd, J. E., Mineral resources of South Dakota: South Dakota Geol. Survey, Bull. 3, p. 108, 1900.

[2]O'Harra, C. C., White River Badlands: State School of Mines, Bull. 13, p. 61, 1920.

Argyle, and on the east side of the Hills three miles south of Fairburn, but the first shipment failed to yield satisfactory results. * * * It is claimed by owners of the Argyle property that their trial shipment was not selected with sufficient care exclude extensive admixture with the more sandy associated beds, and the failure at Fairburn appears to be due to a similar hasty shipment without careful selection of the best material. As tests of the small samples were satisfactory, the miners supposed that the earth was all serviceable and did not discriminate in making a bulk shipment. * * * The tests made of small samples of these earths from Argyle and from beds a mile northeast of Fairburn have given excellent results with cottonseed oil and, as they possess all the characteristics of genuine commercial fuller's earth, they deserve to be carefully developed."[1] Connolly described the Fairburn earth as "yellowish gritty clay having a somewhat nodular structure. It makes up a bed having a thickness of eight feet. * * * There is a fuller's earth bed 18 feet thick two miles west of Argyle It covers a fairly large area and according to Ries has the same character as the earth near Fairburn. Other deposits are known to occur near Hermosa and farther east and southeast toward and beyond the Cheyenne River.

"The fuller's earth from both the Argyle and the Fairburn deposits when properly prepared was found to possess excellent bleaching qualities."[2]

Chemical analysis does not seem to have much to do with the clarifying property of fuller's earth. Some analyses made years ago may be of interest, however.

Analyses of Fuller's Earth[3]

	Sample from Fairburn	Sample from Argyle
Silica (SiO_2)	68.23	57.00
Alumina (Al_2O_3)	14.93	17.37
Ferrous Oxide (FeO)	3.15	2.63
Lime (CaO)	2.93	3.00
Magnesia (MgO)	0.87	3.03
Loss on Ignition	6.20	15.35
	96.31	98.38

[1]Darton, N. H., U. S. Geol. Survey 21st Ann. Rept. part vi, p. 591 1900.

[2]Connolly, J. P., and O'Harra, C. E., op. cit., p. 317.

[3]Analyses made by Prof. Flinterman at South Dakota School of Mines.

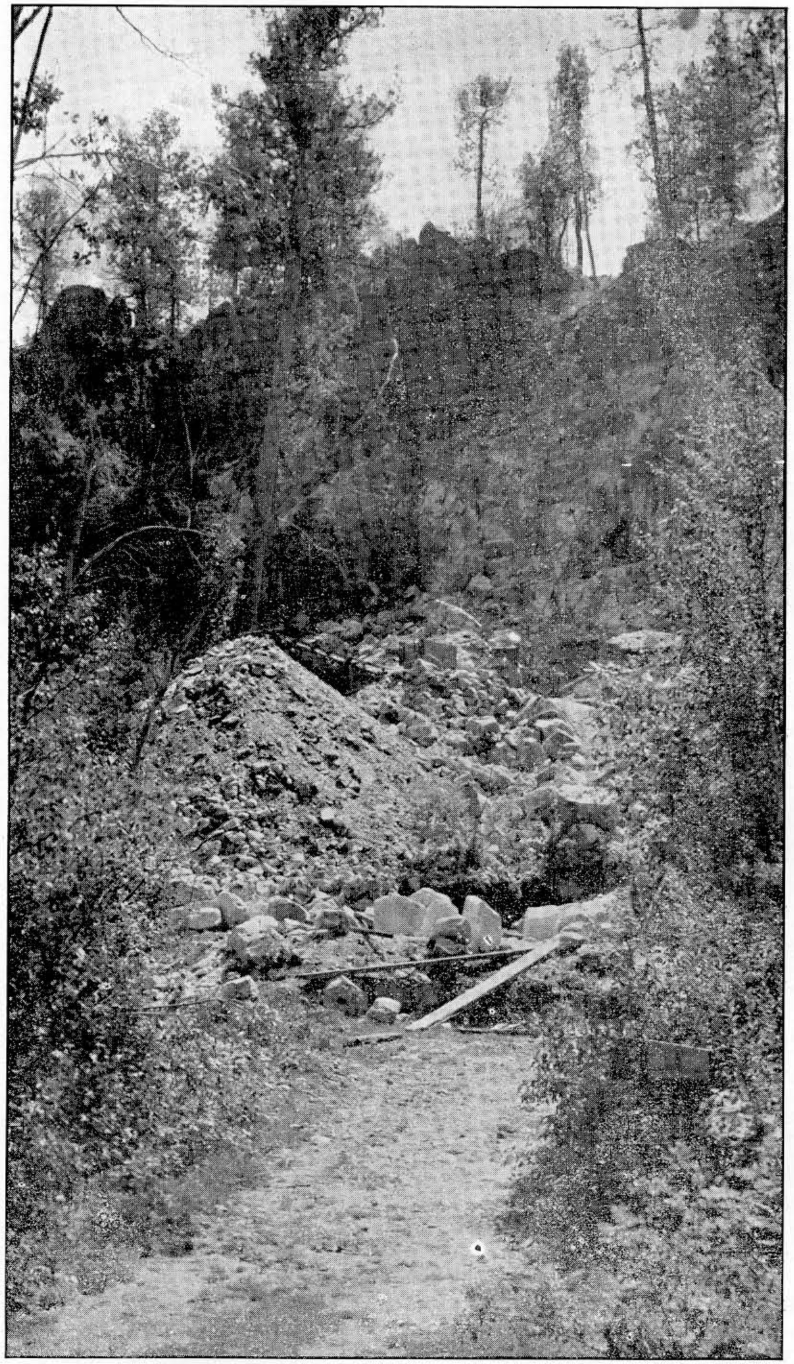

PLATE 30. A Feldspar Mine Near Custer
Elkhorn Mine, Custer County, S. Dak.

As there is a large market for this clay in the refining of petroleum products, it would be profitable to have more information on the fuller's earth of South Dakota.

FELDSPAR

Feldspar is an extremely useful product since it furnishes a great many necessary things from the enamel on the kitchen sink to grandmother's false teeth. It is also used as an abrasive, especially in polishing powders which are not supposed to scratch glass or the finer metals. This mineral is fairly abundant in the rocks of South Dakota but is usually in such small pieces that commercial extraction is impracticable. The pegmatite dikes in Custer County and Pennington County offer, in their huge crystals, an easily obtainable supply of this mineral. The principal variety is microcline, a potassium bearing feldspar usually of a pale buff or cream color. A considerable abundance of the white, soda-bearing feldspar, albite, is also present. Orthoclase, the pink or flesh colored potash feldspar, is present in considerable quantity. Of these feldspars, the microcline and orthoclase are most important commercially. They are used in making enamel, in glazing china and pottery, and as abrasive material in scouring soaps. Crushing plants are now in operation at both Keystone and Custer and the number of pegmatites in this region offers a supply of this material which should keep the industry in South Dakota indefinitely.

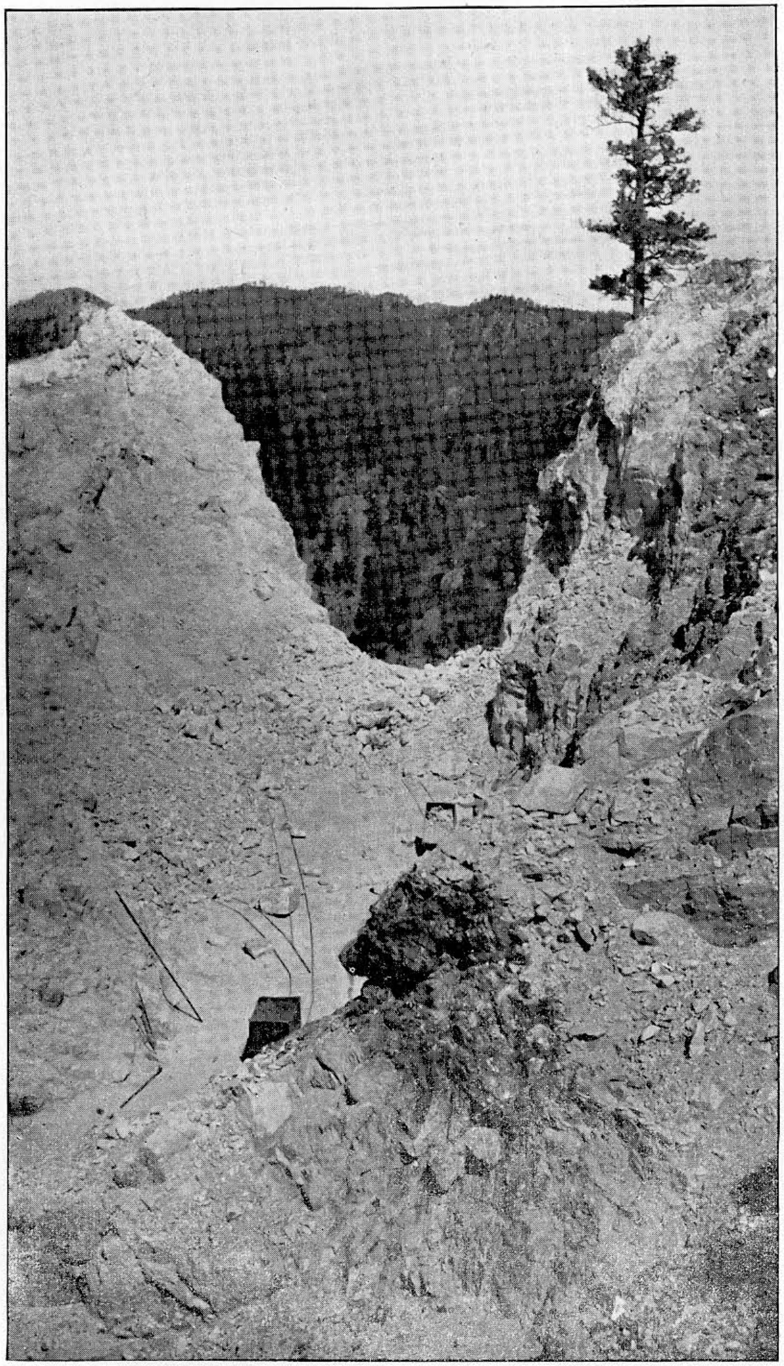

PLATE 31. Feldspar Mine at Keystone
Hugo Mine, Pennington County, S. Dak.

DIVISION V.—MISCELLANEOUS MINERALS

GEM STONES

There is a fairly steady business in ornamental stones in South Dakota, carried on largely through small shops for the tourist trade. No gems of great value have been discovered, but South Dakota has a great many minor semi-precious stones which can be cut and polished into ornaments. A list of them would include such minerals as moss and banded agates, garnets, gem varieties of spodumene, and feldspars, gem tourmaline, and rose quartz.

There are also ornamental stones and souvenirs made by cementing collections of curious and bright colored bits of rocks and minerals on ornamental bases. The pre-Cambrian rocks contain some highly colored, well cemented conglomerates, slates, and schists banded with white quartz, green chlorite, and other colors which make them attractive.

Such gems are by no means confined to the Black Hills. The glacial gravels contain considerable quantities of the more common jasper, brown and yellow flint, and gray and mottled flint. Agates are found in the Big Sioux Basin and in some places along the Missouri. In the gravel terraces along the valleys west of the Missouri, one finds the milky and smoky quartz, brown and tan flint, and a great variety of calcedony, much of which contains moss agate. Nearly a peck of this material was collected from the top of Fox Ridge in Meade County. Bits of opalized wood in these same gravels offer interesting gem hunting as do also the small garnets which have been washed into the gravels from the Black Hills. The garnets, however, are, in most cases, too small to cut.

Other semi-precious stones are found in the Black Hills. Garnets as large as the end of one's thumb have been picked up and enormous amounts of smaller ones. Green tourmaline occurs in at least one of the pegmatite mines near Keystone, and the pale moonlight variety of spodumene known as kunzite is occasionally encountered among the spodumene logs of the pegmatites.

The most important of the semi-precious stones, commercially, is rose quartz which is mined from a vein south of Custer known as the Scott rose quartz mine. The white and smoky varieties of quartz are very common and need nothing but the skill of the lapidary to make them into pleasing sets for rings or brooches.

The mineral beryl occurs in a number of pegmatites and much of it is yellow. Diligent search might reveal golden beryl of gem quality though none has been placed on the market.

Gem production from South Dakota will be a haphazard affair as it will have to depend on the sharp eyesight and persistence of individual gem collectors.

Large quantities of the semi-precious minerals are on hand but large amounts must be searched to find specimens of gem quality. Several small businesses are carried on to supply the tourist trade. These include several lapidaries, at least one souvenir manufacturer specializing in Black Hills minerals, and makers of alabaster, book ends, and other ornaments.

Whether they ever develop into large industries or not, these gems will always offer interesting and profitable search for the amateur collector and small dealer.

MICA

A lively mica business was carried on in the vicinity of Custer during the early 1900's. After 1912 production declined greatly and was not revived till the present war shut off foreign supplies and made mica a very important strategic material.

The mica of commercial size all occurs in the pegmatites about Harney Peak in the Black Hills from which the feldspars and rare minerals are produced. Some of these dikes carry large crystals of mica but the shape of the crystals and their interference with other minerals have made it impossible to extract a great quantity of "plate" mica, most of the mica being shipped as punch and scrap. Pieces up to six inches across, however, are easily obtained.

The mica grows in platy, crystalline masses called "books" by the miners. It belongs to the variety known as muscovite, sometimes called muscovy glass, or the potash mica. It is of good quality and much of it has been called rum or wine mica because of its pale rose or brown tint. Most of the books are faulty. Some are "ruled," that is, they have an extra cleavage nearly perpendicular to the basal cleavage which causes the flakes to break into narrow ribbons. Others are wedge-shaped with quartz or feldspar crystals in the thick part of the wedge which interferes with splitting uniformly sized pieces out of the books.

"The individual mica books found near Custer are, as a rule. larger than those found near Keystone."[1] For this reason the making of sheet mica has been confined largely to that southern part of the Black Hills, the Keystone and Nigger Hills regions furnishing largely scrap mica. The use of built-up mica made of "splittings," irregular sheets 1/1000th of an inch thick and not less than one square inch in area has opened up a large field for the use of scrap mica. With the impetus mica production has received, it should be possible to keep this industry in South Dakota, which once furnished one-third of the mica produced in the United States.

VOLCANIC ASH

This is one of the products that has made itself very important as an abrasive. Volcanic ash contains a large proportion of glass, usually devitrified, which makes an excellent scouring material. It is not as hard as quartz or corundum and yet is a little harder than most surfaces which have to be polished. It is fine grained and needs only a small amount of processing to put it on the market.

Volcanic ash was spread over the State from early Cretaceous times to the close of the Ice Age. Some of this ash, as has been explained above, was turned to bentonite which has no value as a polishing material. Other ashes, however, are still gritty and can be used in powders, soaps, and other scouring material.

In the White River Badlands, at the top of the Brule formation, is a layer of ash which has been designated the "White Ash Layer."[2]

It is fairly pure ash over a large area. In some places, however, it is mixed with other sediments. It is thickest in the Big Badlands where it reaches 15 feet or more. The ash

[1]Darton, N. H., and Paige, Sidney, Central Black Hills Folio: U. S. Geol. Survey Folio 219, p. 30, 1925.

[2]Wanless, **op. city.**, p. 190-269.

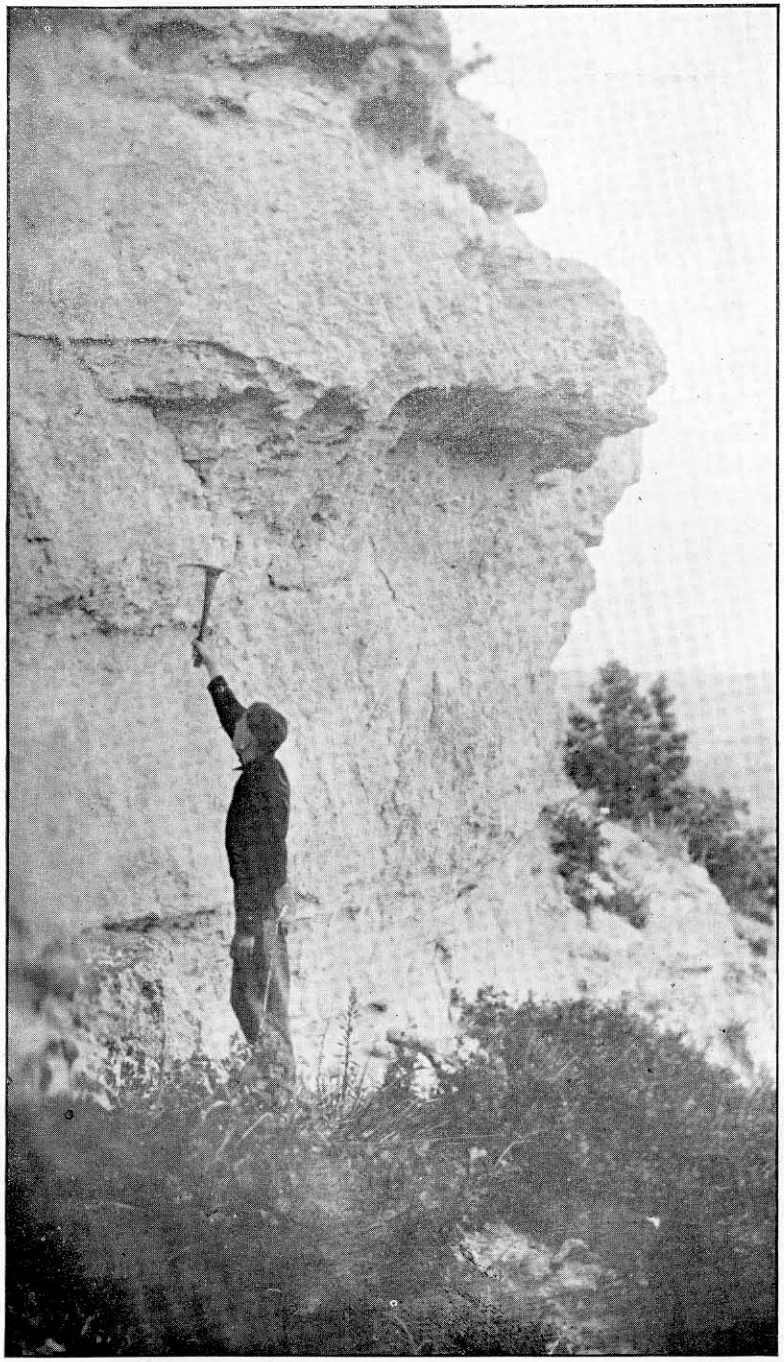

PLATE 32. Volcanic Ash Deposit on Turtle Buttes Near Wewela, Tripp County, S. Dak.

runs high in silica and alumina and low in bases as is shown by the following analysis:[1]

White Ash Bed in the Badlands

Analyst, A. H. Phillips, Princeton University

Silica (SiO_2)	68.21
Alumina (Al_2O_3)	10.97
Iron Sesquioxide (Fe_2O_3)	2.89
Iron Protoxide (FeO)	0.13
Manganese Oxide (MnO)	0.12
Magnesia (MgO)	1.13
Lime (CaO)	1.08
Soda (Na_2O)	3.13
Potash (K_2O)	4.41
Titanium Oxide (TiO_2)	0.32
Water	8.06
	100.45

An ash which might be known as the Turtle Butte ash, because of a small deposit which is found on Turtle Butte in southern Tripp County, is also in undifferentiated Tertiary rock, probably of Arikaree age. This ash differs from the white ash layer in that it is non-resistant to erosion. It occurs in drifts south of the White River throughout the eastern part of the Pine Ridge and all the Rosebud area and a thin bed of it has been found in the Missouri brakes in road cuts in Nebraska opposite the city of Springfield.

This ash is silvery gray in color and has a pearly luster. The microscope shows that it is made almost entirely of fresh glass. This is probably the reason for the luster since devitrification of the glass tends to give ash a dull luster. It is extremely fine grained and extremely well sorted as though it had traveled on the wind a long way. Whether it is a product of the Yellowstone Park vulcanism to which the white ash bed was assigned by Connolly or whether it came from later explosions in the Cascade ranges is uncertain. The drifts seem to vary in size but those that were measured contained about 100,000 cubic yards of material each.

A two-inch ash layer occurs in the glacial drift near Hartford, in Minnehaha County. No other Pleistocene ash deposits have appeared in South Dakota though they do occur farther south. It may be that on further prospecting, especially among the older drifts, such ash may be uncovered.

[1]Connolly, J. P., and O'Harra, C. C., Mineral Wealth of Black Hills, South Dakota School of Mines, Bull. 16, p. 336, 1929.

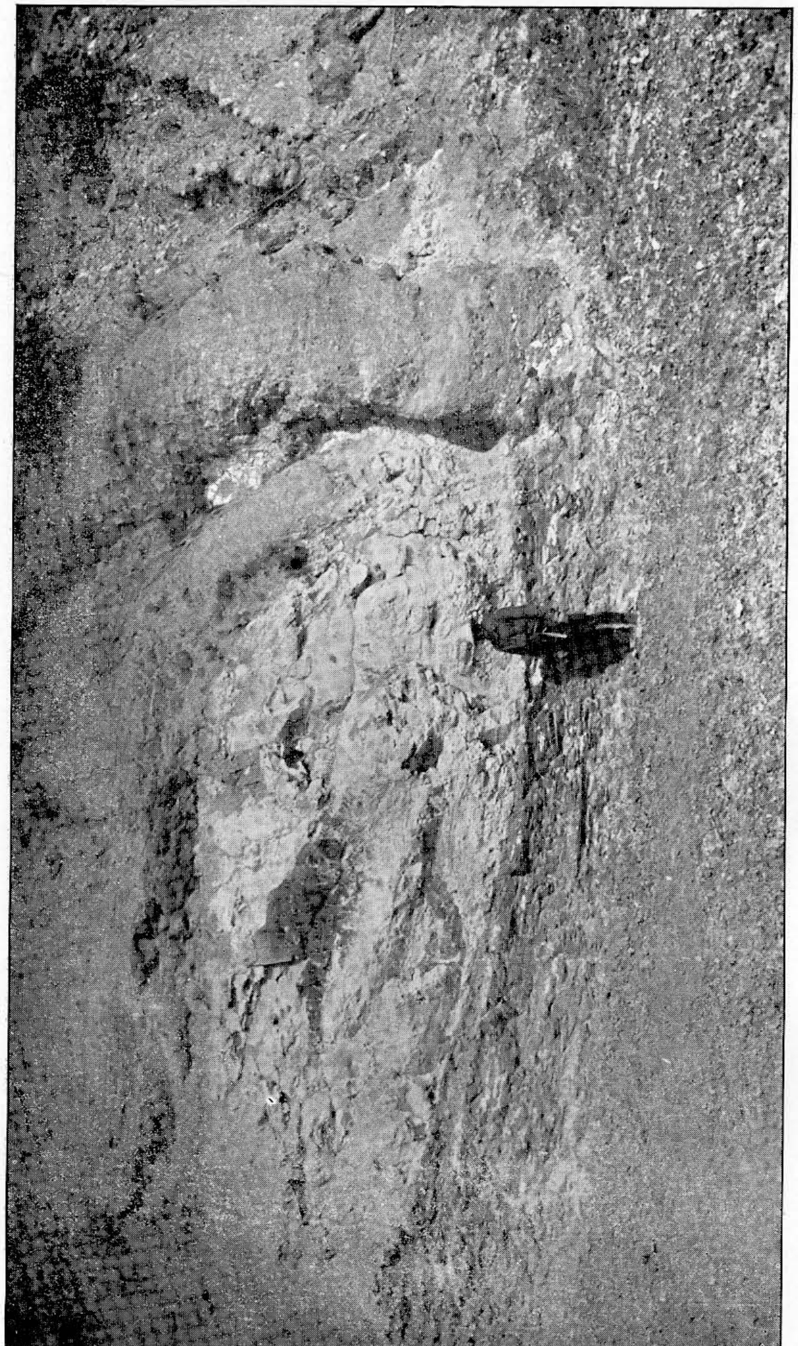

PLATE 33. Volcanic Ash Deposit in the Agency Member of the Pierre Formation.
In the Missouri Valley near the mouth of Steamboat Creek, Potter County, S. Dak.

DIVISION VI. WATER SUPPLIES

The most important mineral resource in the state of South Dakota is water. Located on the edge of the Great Plains, this State is one of the regions where a few showers in summer spell the difference between agricultural success and failure. Surface water, therefore, is not abundant and ground water must be relied on for much of the supply.

A careful and intelligent use of water supplies is necessary for maintaining the larger cities and towns. Irrigation can be practiced in some regions to good advantage, but the water problem is always before the irrigator. Even the small amounts necessary on the ordinary farm require careful attention, and in many places serious difficulties have resulted during drouth periods through inefficient use of available supplies. The problem of conservation of wild life including fish and game and the recreational facilities of the state are also tied up with the water supply, both surface and underground. There are some possibilities of using water as a source of power which are not fully developed.

In general the water supplies are adequate for all the demands that may be made on them in the next few generations, but no one supply, surface water, shallow water, or deep wells, is sufficient to warrant its waste; and in many instances it will take the careful use of all supplies to insure an adequate amount during times of drouth.

SURFACE WATERS

1 Rivers

Like all surface water supplies in South Dakota, the rivers are extremely sensitive to the rainfall of the region. Streams with a uniform year-around flow do not exist in the State, and the few that can be called permanent streams fluctuate greatly during the season and from year to year. This is due largely to the fact that the water table is low and streams are not fed from ground water sources when surface waters are lacking. These factors tend to make most of the streams flood channels.

The Missouri River has the largest flow, but fluctuates in level many feet. In late fall and early winter it is very low, often being so shallow that it is possible to wade across it in places. During spring and early summer, however, it rises to

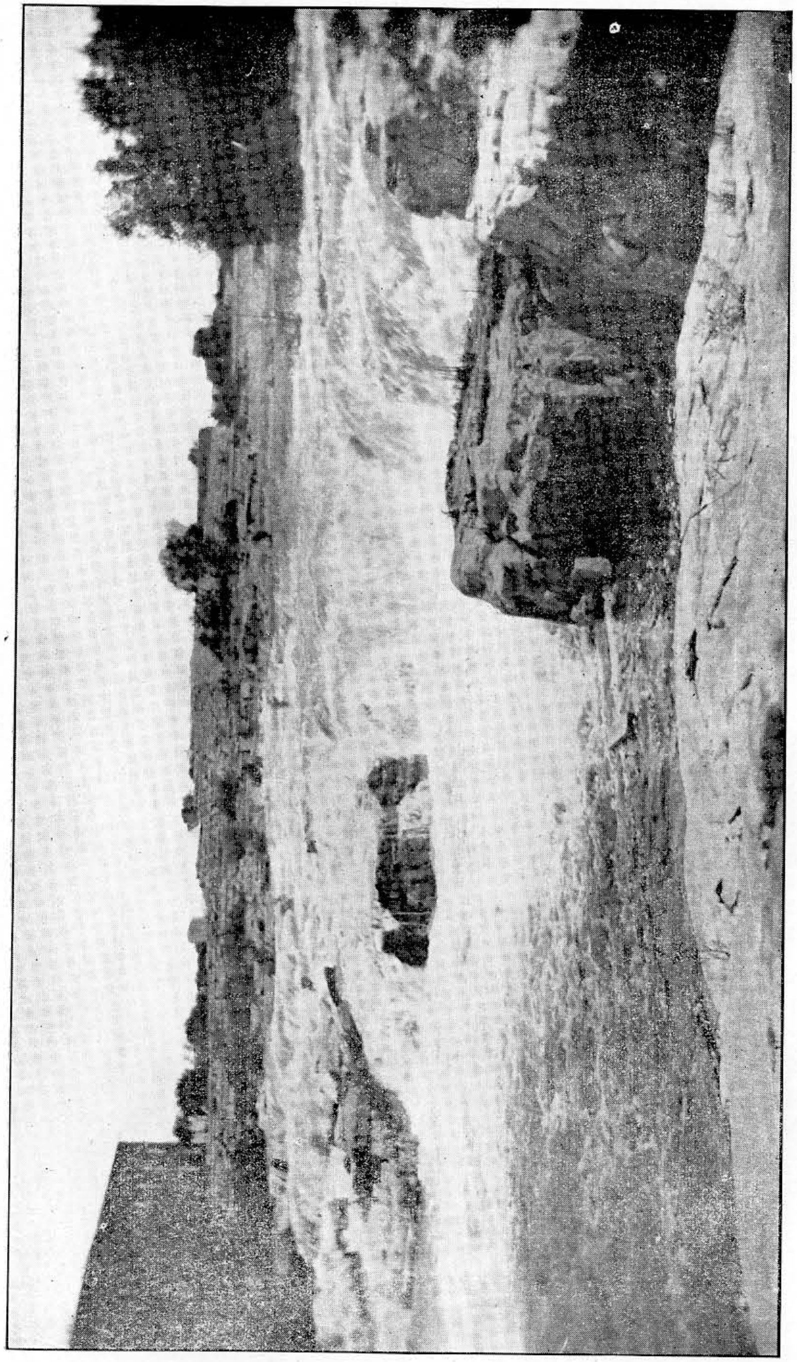

PLATE 34. The Falls of the Big Sioux River, Sioux Falls, S. Dak. A source of water power.

floods which fill its channels. A small ice jam may send its waters out of the banks to cover the entire valley lowland. The highest normal levels are reached each year during the "June rise" when the water from the melting snows of the Rocky Mountains reaches this State. Gaging records for the water year 1936 (October 1935 to September 1936 inclusive) will serve to illustrate this variation. The figures are taken from records of the U. S. Geological Survey for the gaging stations at Mobridge, Pierre, and Yankton.[1]

Station	Mobridge	Pierre	Yankton
Annual run-off in acre-feet	11,380,000	11,650,000	13,110,000
January run-off in acre-feet	356,400	350,500	444,300
June run-off in acre-feet	2,387,000	2,358,000	2,377,000
Maximum discharge	April 16	April 17	April 18
in second-feet	122,000	104,000	102,000
Minimum discharge	Nov. 6-9	Nov. 14-17	Nov. 25-26
in second-feet about	4,300	3,700	3,700
Maximum gage height	March 18	March 19	March 21
in feet	12.65 (ice jam	10.90 (ice jam)	7.85 (ice jam)
Minimum gage height	Sept. 15	Sept. 18-28	Nov. 24
in feet	2.15	2.10	0.20

The eastern tributaries of the Missouri, the James and the Big Sioux, carry water most of the time. During the driest times, however, both of them have ceased to flow in parts of their courses. The volume of water flowing in these streams in normal times, however, is small compared to the Missouri. A gaging station in the lower James River near Scotland showed a run-off of 54,970 acre-feet for the water year of October 1935-September 1936. A record kept on the Big Sioux at Akron, Iowa, gave the run off of 513,800 acre-feet for that stream during the same year.

The western tributaries, White, Bad, Cheyenne, Grand, and Moreau, are all very much alike in that they carry enormous quantities of flood water in times of heavy rains or heavy snows, and are so dry that they can be forded during most of the summer. Most of them dwindle to small pools during the hottest part of the year. This is the most danger-

[1]U. S. Geol. Survey, Surface Water Supply of the U. S. 1936, part 6, Missouri River Basin: U. S. Geol. Survey Water Supply Paper 806, p. 29-31, 1938.

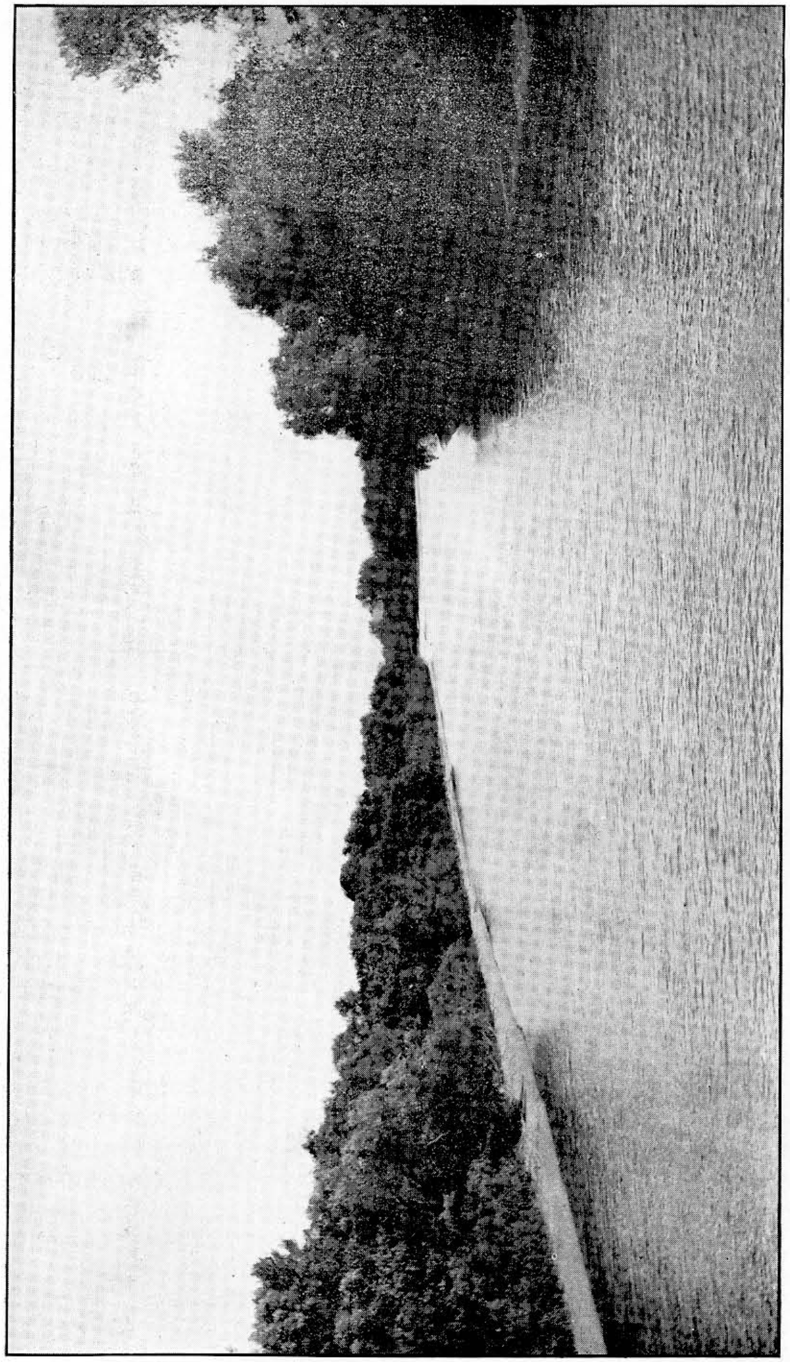

PLATE 35. The James River in Yankton County. A sluggish stream, seldom dry but subject to floods.

ous season to be camped in or about the channels of these streams, for a sudden thunderstorm up the river will send an enormous volume of water that brings the river to a flood stage for a few hours, only to subside again to a dry stream bed as rapidly as it came. The Bad River receives its name because of such floods which periodically tear out roads and bridges and create general havoc in the valley.

The following run-off records, taken near the mouths of the Grand, Moreau and Bad Rivers for the water year 1936 (Oct. 1935-Sept. 1936) show this seasonal character:[1]

1935	Grand River gaging station near Wakpala Acre-feet	Moreau River gaging station at Promise Acre-feet	Bad River gaging station at Ft. Pierre Acre-feet
October	0	0	0
November	0	0	0
December	0	0	0
1936			
January	0	0	0
February	0	0	0
March	35,630	21,760	14,820
April	11,180	14,140	7,990
May	1,960	451	758
June	352	933	110
July	0	0	0
August	0	0	0
September	0	0	0
Total	49,120	37,280	23,680

During this year the Cheyenne and White Rivers showed a run-off each month of the year though it fluctuated greatly. The maximum occurred in the summer months as it did for those just described. During the water year of 1936 the Cheyenne run-off at the station south of Eagle Butte amounted to 250,000 acre-feet varying from a minimum of 1,850 in February to a maximum of 94,670 in March. A station near Oacoma showed that the White River discharged 168,700 acre-feet during the same year, its low mark was 46 acre-feet in August while its highest was 103,100 acre-feet which it discharged in March.

The streams in the Black Hills are for the most part live streams because of the fairly uniform precipitation due to thunder showers. During the driest part of the drouth, how-

[1]U.S.G.S. **op. cit.**, pp. 149, 150 and 157.

ever, all but the largest of them went dry. Rapid Creek and Spearfish Creek are the best known of the permanent streams, these two being the only streams that can cross the limestone outcrops and flow into the head waters of the Cheyenne when rainfall is not abundant. A gaging station at the Big Bend on Rapid Creek showed an annual discharge of 16,900 acre-feet. The uniformity of flow is well brought out by a comparison of the monthly flow of this stream with that of the Grand, Moreau, and Bad Rivers given above.

Rapid Creek Run-off at Big Bend, S. Dak.[1]

1935	Acre-Feet
October	1,700
November	1,820
December	1,600
1936	
January	1,290
February	1,380
March	1,840
April	2,690
May	1,960
June	1,300
July	253
August	587
September	476
Total	16,900

These streams are almost entirely undeveloped at present, due to the cost of making such development. The common uses of stream water are for power, irrigation, and navigation. Six streams are being used for water power at present. The Homestake Mining Company has two hydroelectric plants on Spearfish creek, one at Spearfish, and one at Maurice. Smaller plants are to be found on Rapid Creek, Red Water creek, and Fall River in the Black Hills. The Little White river near the city of White River in Mellette county furnishes power for a hydroelectric plant which supplies current locally. This stream has a minimum fluctuation since it is fed by the sands of the Tertiary formations. Still another hydroelectric plant is located on the Big Sioux at Sioux Falls. The water power supplies part of the energy used in making the electricity for the city. The flow is regulated by a dam at the head of the Falls which impounds water in the Big Sioux Valley.

[1]U.S.G.S. op. cit., p. 153.

The larger streams have never been dammed though there have been attempts to do so. The Cheyenne River, especially near its head in Fall River County, offers some excellent places for such a project. A number of projects have been promoted along the Missouri River where a total fall of 550 feet across the State seems to offer possibilities of generating power.

A survey of power possibilities of the Missouri River was made in 1920 for a power commission created by the previous legislature.[1]

Eight possible sites were investigated and the details of cost and construction were estimated for one, the Mobridge site, as an example. At this site it was estimated that at the minimum flow there could be developed 16,000 continuous horsepower with an eight turbine installation on a dam giving a thirty-foot head. This power might be increased to 32,000 horsepower in times of high water (100 000 second-feet discharge).

Missouri River power projects, however, are still waiting either cheap transportation of the power generated or a bigger market in the immediate vicinity of the river. Though the generation of enormous amounts of power is not an immediate necessity, it would seem that in a country where fuel is as scarce and expensive as it is in South Dakota, the streams should be developed to their full capacity. Small dams and small power plants can serve an average community effectively.

Small scale irrigation is practiced at a number of places in the State. The only large project, however, centers about Newell in Butte County. The large dam on Owl Creek at Orman impounds 300,000 acre feet of water and irrigates from 75,000 to 100,000 acres. Water can be impounded in a great many of the streams on the Great Plains as the fall is sufficient, especially near the breaks of the large rivers, to give a considerable depth of water with a relatively small dam. The farmers and ranchers in these regions have been using small dams for stock water and household water ever since the country was first settled. The Missouri is the only stream

[1]Mead, D. W., and Seastone, C. V., Feasibility of the Development of Hydroelectric Power from the Missouri River in the State of South Dakota: Report to South Dakota's Hydroelectric Commission, 1920.

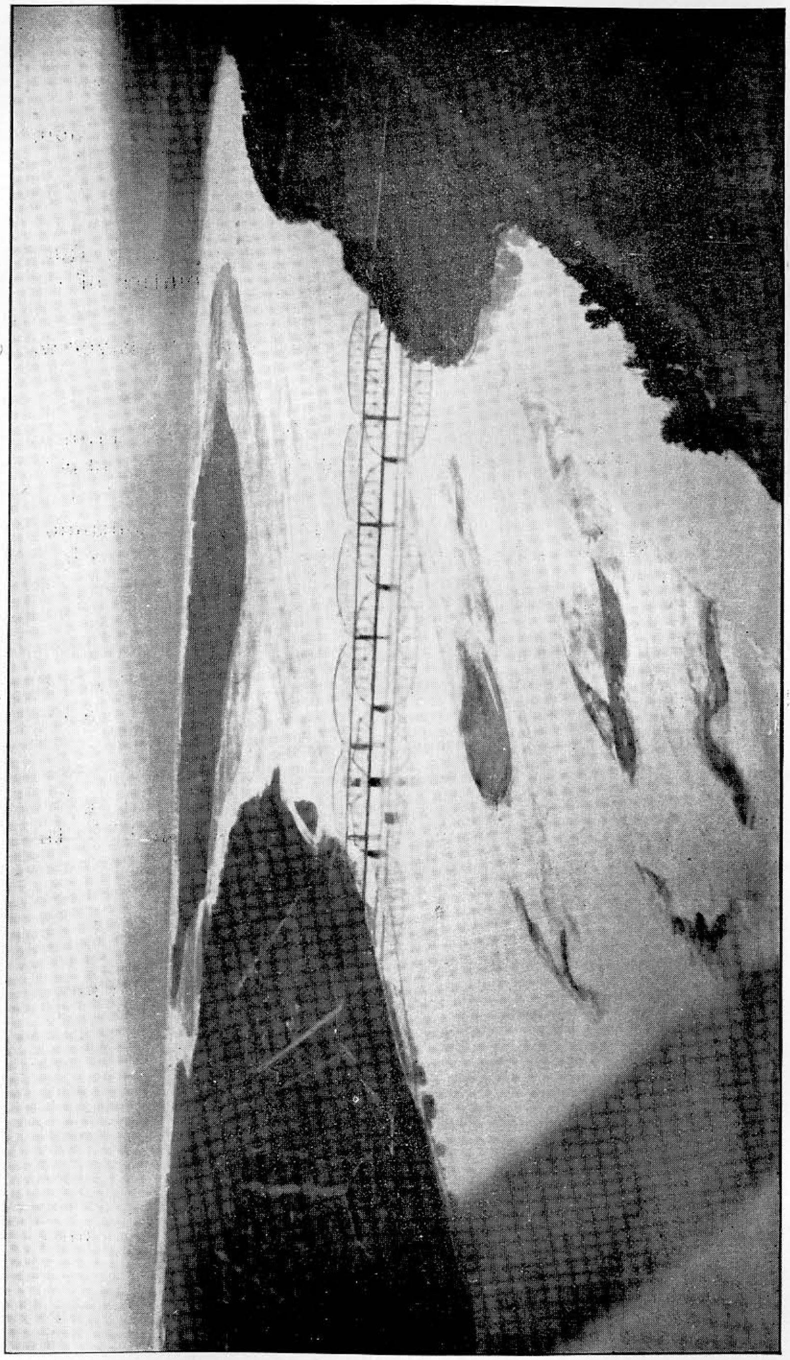

PLATE 36. The Missouri River at Pierre Offers water power, irrigation, and navigation

that furnishes sufficient flow for pumping directly from the river. The other streams would require dams.

Irrigation, however, has been practiced on a relatively small scale in the State, and while it is applicable only to small areas there are enough of these to make it an important consideration in agricultural development. These regions will be in the valleys of such streams as the Missouri, Cheyenne, Belle Fourche, and possibly the Grand and Moreau.

The only navigable stream in the State is the Missouri River, which in the early history of this territory was the main highway between the east and the northwest. It served a large territory before the railroads came. Cities like Pierre, Fort Pierre, Chamberlain, and Oacoma owe their origin largely to the fact that they were loading places for river traffic. Work on the Mississippi and lower Missouri has shown that it is possible to harness these streams into a channel which can be kept navigable and a considerable trade is being developed on them. The cost of such development, however, is very large and, therefore, river navigation has been slow in coming to South Dakota.

Its chief advantage is that heavy and bulky commodities can be hauled cheaply. It could be used to good advantage in importing such commodities as coal and exporting bulky mineral products. For ordinary commerce, however, the river is far too slow, as food products shrink or decay on long hauls, and lighter materials can be transported so much more quickly by other means. It is hopeless, therefore, to expect river traffic to take the place it held in pioneer times when everything had to come into the State by water. Navigation of the Missouri will require confining the river to a definite channel and the maintenance of a channel deep enough to float river barges. This, of course, is expensive, but it is hoped by the promoters of navigation projects that the dams necessary for maintaining the depth of the water can also be used for hydroelectric power and irrigation.

II. Dams and Lakes

Lake basins are abundant, especially in the glaciated part of the State east of the Missouri River. Lakes, however, are rather scarce. West of the James Valley there are but three natural lakes worthy of note. Most of the natural lakes are clustered at the head of the

Big Sioux Basin nestling deep in the glacial hills and in the large gravel outwash plains and valley trains. The reason for this is that lakes, like permanent streams, are dependent on the level of the ground water, the permanent surface of the lake never rising above the level of the water table. Diversion dams have turned flood waters into lakes and raised them temporarily only to have them sink again to the ground water level due to seepage underground. The fluctuation of the lakes has been shown to be about 15 feet in eastern South Dakota.[1]

About 1892, the first great recorded drouth lowered the water in the lakes until most of them were dry. A few of the deepest ones like Pickerel and Enemy Swim still contained water. By 1918, the lakes had come back to the highest level recorded. They stayed at this level for nearly a decade. The diminishing rainfalls, however, brought them to another low stage in 1934, with the lake levels 15 to 18 feet below the high water mark of 1918. Since that time, increases in rainfall have again raised the levels. The struggle of the lakes to maintain themselves is of interest because measurements since the drouth of 1934 have shown that, in lakes fed by large gravel channels, water levels raised much more rapidly than in those which were not. As an example, Kampeska and Blue Dog Lakes were nearly back to their high water mark in 1939. Pickerel Lake in Day County, fed by a large underground outwash, was also back nearly to its highest level. Lakes Waubay, Minnewasta, and Roy, with no such source of supply, barely held their own, or even lost water.

Other factors in determining lake levels are evaporation, underground seepage, and artificial drainage of the lakes. The amount of annual evaporation is approximately 40 inches which takes an enormous toll on lakes that do not recharge rapidly. If this is added to a large outflow over the surface or through gravel channels underground, the lake has little chance of maintaining its level. Enemy Swim Lake is a case in point. A surface ditch was dug to drain a swamp at one end of the lake which lowered the lake several feet. Further drainage by seepage through a gravel channel leading into

[1]Rothrock, E. P., and Ullery, Dorothy, Ground Water Fluctuations in Eastern South Dakota: South Dakota Geol. Survey Rept. Inv. 32, 1939.

Blue Dog Lake has prevented its return to higher water levels as rapidly as its neighbor to the south. Kampeska,[1] on the other hand, has a large intake. Its waters cannot seep away because of an underground clay dam not far from its outlet. Consequently its level raised very rapidly. The same is true of Pickerel Lake in Day County.[2]

Some attempts have been made to maintain lake levels and to bring water back to the original levels after they had been lowered. The damming up of outlet channels did very little good because the ground water levels were soon below them and seepage and evaporation did not stop. Diversion dams to turn stream water into the lakes had a temporary effect. During spring floods water levels raised slightly, only to fall again to ground water level when the surface inflow of water was not continued. The same difficulty has been discovered in some dams and artificial lakes.

It is well to take all possible precautions to maintain these lakes at maximum levels, since they afford not only recreational areas, but in many cases they are used as water supplies. Each lake, however, must be studied as an individual project and its inflow and water losses determined before it is possible to weigh what is best to do. It is necessary to keep lakes fresh by a change of water. New water must be added either from the surface or by seepage, and excess water must be drained as much as possible. Any means of diverting more water into a lake basin and preventing its leakage will help to maintain its level. Damming of outlets and diversion of water, therefore, should be practiced as far as practicable. Our best efforts, however, are too puny to completely defeat the forces of nature that make and unmake lakes, and in the end the lake levels will be controlled by the amount of rain received and the level of the ground water. Our duties consist of preventing wasteful drainage of lake waters and encouraging the recharge of lake and ground water reservoirs.

[1]Rothrock, E. P., Water Supplies and Geology at Lake Kampeska: South Dakota Geol. Survey, Rept. Inv. 17, 1933.

[2]Rothrock, E. P., The Geology and Water Resources of Day County, South Dakota: South Dakota Geol. Survey Rept. Inv. 25, 1935.

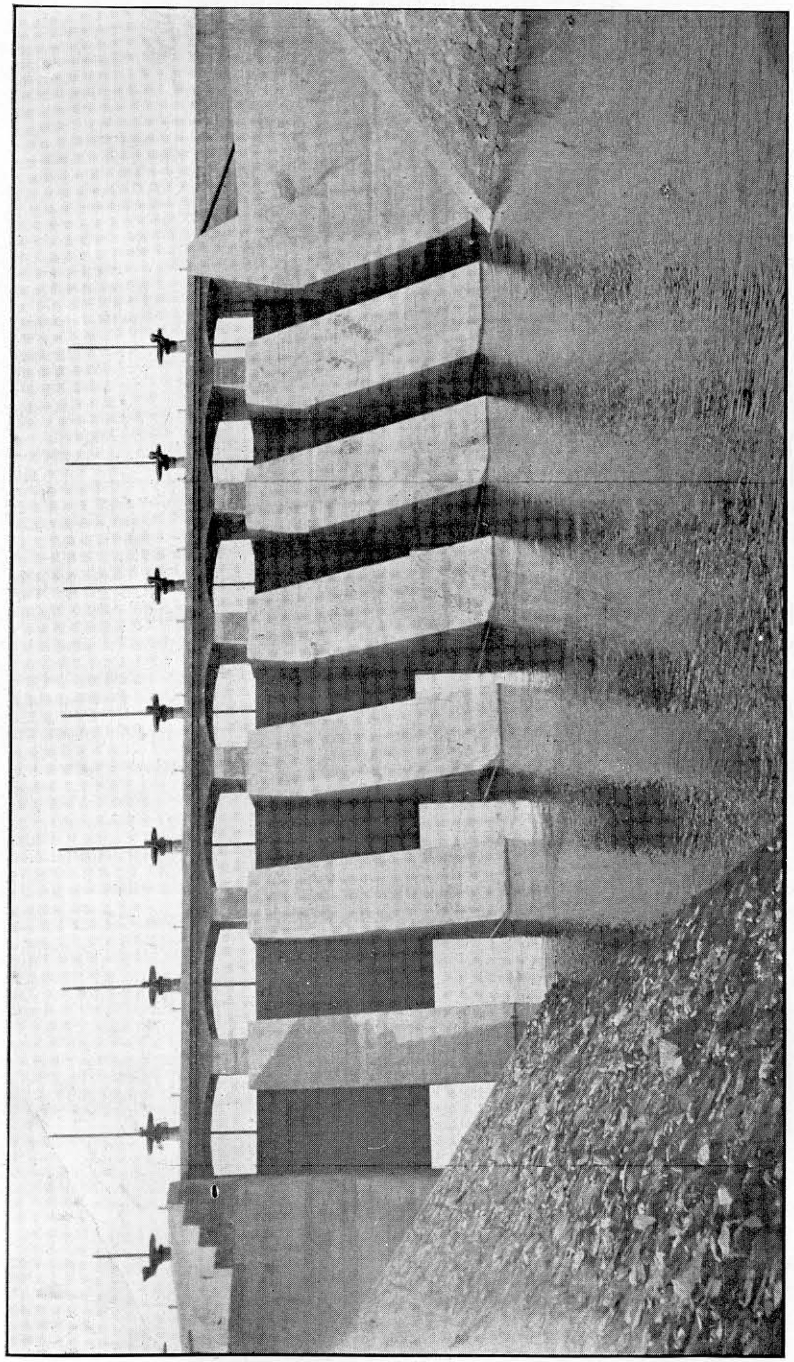

PLATE 37. Regulator at Intake. Belle Fourche Irrigation Project

SUB-SURFACE WATER

Shallow Well Supplies

Underflows. Gravel fills occur in most stream valleys and also in ancient glacial spillways. These vary in depth from a few feet in the small streams to 240 feet in the lower Missouri valley. In the ordinary course of stream flow, the fine materials are floated to the top and the coarser materials dropped on the bottom. Thus we find the fills of most valleys containing considerable amounts of sand, bars of gravel, and some sheets of clay and loam. Most of the material, however, is sandy, and in this sand we find a large volume of water moving in the general direction of the stream's flow. This is known as the underflow, and in most of the valleys in South Dakota, it carries more water than does the stream channel. For this reason, underflows are extremely important as sources of water supply. The Grand, Moreau, Cheyenne, and White River valleys now carry such underflows as do also the Missouri, James, and most of the Big Sioux Valley.

Most of these water supplies can be reached by drive points and bored wells, and make an especially useful source of water to the rancher and farmer. Some attempts have been made to use this water for irrigation with excellent results. The installation of pumps for the irrigation of gardens and small fields has proved especially successful in the White River valley near Kadoka.

These water supplies have the tremendous advantage of being recharged by every large flow of water that comes down the channel and, therefore, come back much more rapidly than do similar supplies taken from bed rock reservoirs. Irrigation on a large scale from these sources, however, should be attempted only after a careful study of the volume of water these reservoirs contain, and the average rate at which they can be recharged.

Drift Wells. Water is available in the glacial drift at many places. In some cases it is found by digging into sandy pockets in the drift which act as collecting basins for water. In other cases it is fed into the well through the till (boulder clay) itself. Most till is dense, however, and feeds water so slowly that it is impossible to get large supplies from these sources. For farm wells, however, they have proved useful in a good many localities, since they can be dug by hand or

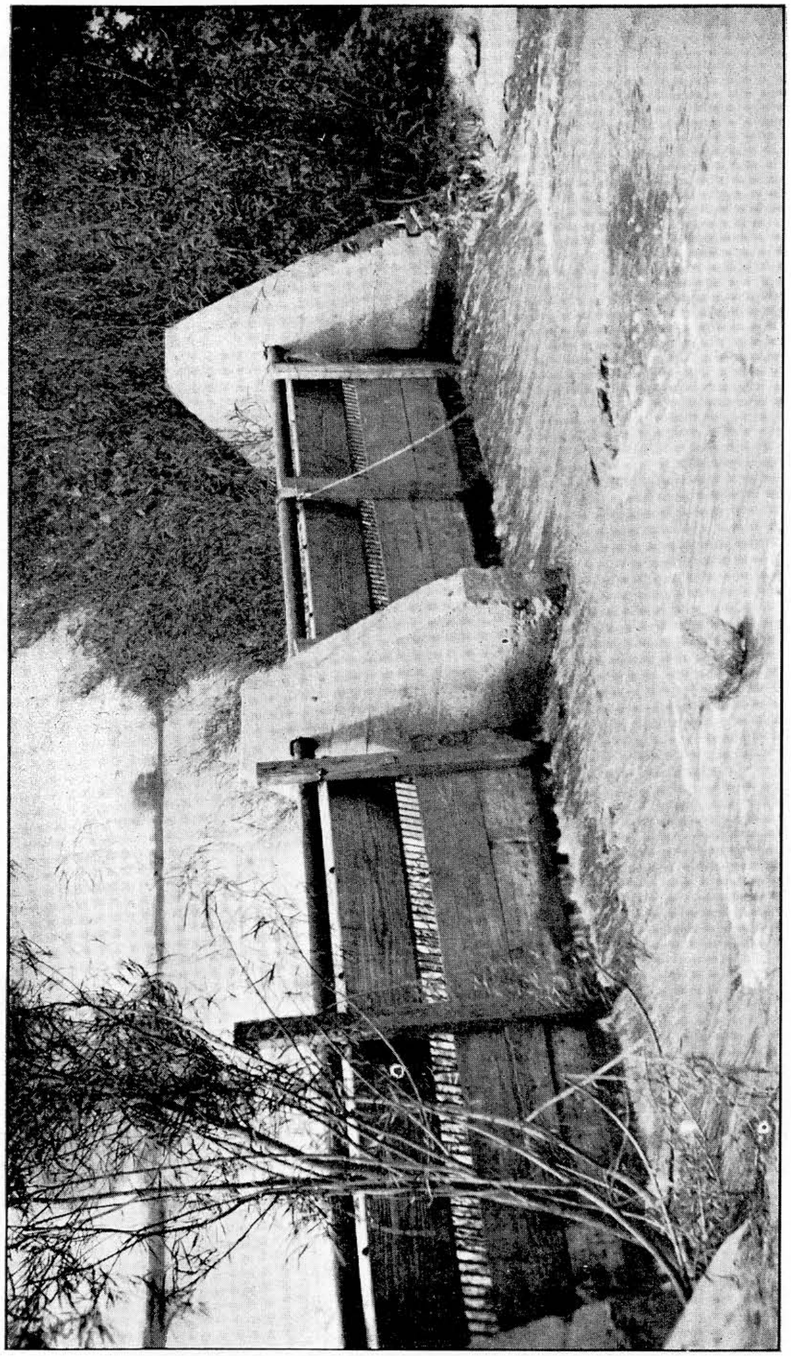

PLATE 38. Dam at Outlet of Swan Lake, in Turner County, S. Dak.

bored. Such wells are never as satisfactory as wells ending in a good sand stratum and should never be relied upon as a source of supply where large amounts are needed.

Buried Outwash and Channels. In eastern South Dakota there are a good many instances of gravel deposits buried beneath boulder clay. These make excellent water reservoirs. In fact, some of them are large enough to be used as city supplies. One such supply was used for the city of Huron during the worst of the drouth. The large outwash underlying the Prairie Hills in Grant County, indicated by a row of springs about half way down the great escarpment on the east side of the Coteau, has been described. Similar buried gravels have been mapped near Mitchell and along the lower end of the James Valley, and doubtless occur at a number of places on the Missouri Coteau. This source of water has been overlooked and, therefore, very little information on it is obtainable. It is capable of supplying enormous quantities, however, if properly developed, and should be one of the most important sources of water in eastern South Dakota. The only use of this water at present is in the city of Huron and for the city supply at Milbank in Grant County.

Bedrock Reservoirs. Shallow wells are obtainable from sandstone bedrock over a large area of the State. Most of this area, however, is west of the Missouri River. East of the Missouri River the Dakota sandstone may be reached at a depth of a few hundred feet in parts of Union County and a corresponding sand outcrops in Davison County. Tubular sands, as they are sometimes called, are within a few hundred feet of the surface and are extensively used in the lower James Valley. Most of these come from the Codell sandstone at the base of the Niobrara formation. This sand is used largely in the counties in the James Basin south of Huron. It is sometimes known as the "pump sand" to distinguish it from the "artesian sands" which give flowing wells. Its water is soft where it has not been contaminated with artesian water. This sand pinches out east of Yankton and apparently is very poorly represented on Bull Creek south of Chamberlain. It is apparently represented by thin, sandy streaks, "tubulars" at Huron indicating its northern limit.

A shallow well driller near Miller reports water from the Pierre shales on the Missouri Coteau northwest of Miller in

Potter and Sully Counties. The Agency member of the Pierre shale underlies this region and it is probable that where it nears the surface water can be obtained from the joints in the shale. No information is available on the quantity of water or the rate at which these wells can produce.

The sandstones of the upper part of the Cretaceous system produce excellent water in northwestern South Dakota. The sands of the Fox Hills and the Hell Creek formations are especially good aquifers producing large quantities of excellent water. The Ludlow formation also contains abundant water which tastes slightly alkaline. The Fort Union formation contains similar water. In areas where these formations outcrop, water sands can be reached near the surface. It is usually possible to obtain water by drilling immediately below the surface or into the first sand the formation yields. Seldom will they fail to yield water within a few score feet of the surface.

These same formations may be reached where they underlie younger rocks by determining the number of formations that must be penetrated at the desired location and adding the maximum thickness indicated for these formations in the section on stratigraphy.

Some attempts have been made to irrigate with pumps from wells penetrating these formations. Undoubtedly this will be possible if irrigation is not attempted on too large a scale. It must be remembered, however, that these sands are recharged by local rainfall and, before extensive operations are contemplated, carefully collected data on the available water supply and recharge rate should be ascertained.

The situation in the Tertiary area south of the White River is similar to that just described in the northwestern quarter. Parts of the Chadron formation and all the Arikaree formations are very sandy and yield excellent wells. Some sands in the White River beds seem to be good aquifers also, so that it is usually a matter of drilling into the first sand below the water table to obtain a good supply of water.

In the Black Hills much of the water supply comes from springs and the only profitable places for shallow wells are in the shallow fills at the bottom of the gulches. These are rarely more than a few feet deep.

Thus it will be seen that shallow water supplies are well

distributed over the State. In most places these are not the best sources for large quantities of water though in the bedrock sands and the larger gravel outwashes, sufficient supplies can be developed for cities and small scale irrigation. Most of them furnish a much better quality of water than do the artesian sands. Because of their widespread use as farm and ranch supplies, they should be considered the State's most important source of water.

Artesian Supplies

The term artesian well has been used rather loosely for wells of several kinds. The original wells at Artois, France, were drilled into a water horizon from which water rose to the surface under its own head. Artesian wells, therefore, were supposed to be those with sufficient head to make them flow. In other regions the term was used for any deep well. In the careful use of the term, artesian wells must be those in which water rises from a confined aquifer in which a hydraulic pressure has been developed. Water may rise high enough to flow out at the surface or may rise but a few feet above the aquifer.

In South Dakota, the latter interpretation has to be used because it has become a custom to refer to all wells producing from certain deep sands as artesian though many of them never raised water to the surface. Others which originally flowed have now ceased to flow due to a lowering of the pressure, and in still other cases, very shallow wells in sand pockets in the glacial drift flowed in true artesian fashion.

There may be several agents which will make wells flow, but the chief requisites seem to be twofold. First, the aquifer must be sealed beneath impervious beds. This condition is best realized where a porous sandstone underlies a "tight" shale or clay bed. Second, the system must be on a slope so that the water level in the upper end of the aquifer is higher than the surface at the site of the well. Such a system developes pressure much as does a city water system in which the stand pipe corresponds to the sand reservoir and the faucet in the kitchen sink to the well.

These conditions are well developed in South Dakota. The Lemmon geosyncline with its steep eastward slope from the Black Hills and its more gentle westward slope from the quartzite ridge and pre-Cambrian outcrops has tipped all aquifers. The total slope, as has been shown, averages about 10 feet to the mile, making the highest artesian aquifer in the James Valley, the Dakota-Lakota sands, lie more than 2500 feet below the elevation of their outcrops in the Black Hills. This situation is aided by the fact that the James Valley and the Missouri Valley are lowlands compared to the regions in which the aquifers outcrop. Thus a sufficient head was developed between the outcrops and the location of the wells to raise the water in some instances two hundred feet above the surface. Every sand formation lying in the geosyncline produces a hydrostatic head so that there are many artesian sands in the basin.

The stratigraphy of the artesian sands is best known about the Black Hills where the aquifers can be readily traced back to the outcrops. Five formations in this region develop artesian heads. The Dakota-Lakota group can always be counted upon for one or more good flows at good pressures and in most parts of the State produces flowing wells. The Sundance-Morrison group of sands also has given artesian heads which raised water 500 feet in the Hunter well in Pennington County and to a reported flow in the Standing Butte well in Stanley County. In the immediate vicinity of the Black Hills, the Minnelusa is an excellent water sand but 50 miles east at the Hunter well gave only one bailer of water an hour. At the Standing Butte well, near Pierre, it was again reported as furnishing a flow. The porous Pahasapa limestone which takes nearly all the water from the streams flowing out of the Black Hills shows two artesian heads in the Hunter well, one at a depth of 4855 and another at a depth of 4953. The pressure in the latter horizon raised the water 4000 feet. Though a thick section of Pahasapa was drilled in the Standing Butte well, no water was reported from it. The Deadwood sandstone furnishes an artesian head in the immediate vicinity of the Black Hills. It is used as the city supply at Edgemont where the pressure carries it into a reservoir 100 feet above the level of the city.

East of the Missouri River where artesian water is used in the largest quantities, the only aquifers known are those of the Dakota-Lakota group. At least three sands furnish artesian water in this part of the basin. Few wells have been drilled below these sands, and the possibilities of underlying Mesozoic and Paleozoic rocks are not known.

Character of Water. The water from the different artesian sands differs greatly from place to place and systematic collections of samples and analyses have not been carried on. over most of the State, however, the first artesian sand, usually called the Dakota, carries water highly charged with solids. In most of the James Valley this water is used largely for stock though in some places it is being used for city water supplies. It seems to be more fresh near both eastern and western outcrops than away from them. Salt (NaCl) is detected in much of this water which contains it in large enough quantities to be tasted. The most objectionable mineral matter, however, is iron sulphate which gives the water a bitter taste. The saltiest water in the State according to Guy G. Frary, State Chemist,[1] was analyzed from the flow wells along the Missouri River in Potter County. The wells at Pierre contain a large percentage of salt. A high salt content seems to be roughly associated with the regions in which this sand produces gas. Water from the deeper flows in many parts of the State seems to be fresher. It is very difficult, however, to get samples which are known to come from this flow only. The habit of drawing from both artesian sands and the fact that the water from the upper sand is very corrosive makes it almost impossible to obtain a good sample. A sample from a deep well drilled at Kadoka, which penetrated the lower flows but also includes the upper, is here included for comparison with the salty waters of the upper flows.

Analysis of Water at Midland, South Dakota

	P.P.M.	G.P.G.
Total Solids	2686.0	156.5
Silica	23.0	1.34
Sulphate	2.0	0.12
Chloride	850.0	49.60
Calcium	6.5	0.38
Magnesium	1.5	0.1
Alkalinity as $CaCO_3$		
Phenolphthalein	None	
Methyl Orange	1170.0	68.2
Hardness as $CaCO_3$	24.0	1.4
Iron	1.0	0.06

[1]Guy G. Frary, State Chemist, Personal Communication.

Manganese	None	
Fluoride	2.5	
Hypothetical Combinations		
	P.P.M.	G.P.G.
Silica	23.0	1.34
Sodium chloride	1395	81.35
Sodium sulphate	3	0.18
Sodium carbonate	1255	73.20
Calcium carbonate	16	0.93
Magnesium carbonate	5	0.29
Iron	1	0.06
	2698	

Analysis of Water Taken from Oil Test South of Kadoka[1]

Lot 1, sec. 32, T. 2 S., R. 22 E., Jackson County

	P.P.M.	G.P.G.
Dissolved Solids	1873	108.6
Loss on Ignition	26.0	1.5
Silica (SiO_2)	31.0	1.8
Iron (Fe)	1.7	.1
Calcium (Ca)	11.6	.7
Magnesium (Mg)	Trace	----
Sulphates (SO_4)	647.5	37.5
Chlorides (Cl)	74.5	4.3
Alkalinity in terms of $CaCO_3$		
Phenolphthalein	12.0	.7
Methyl Orange	704.0	40.8
Hypothetical Combinations		
	P.P.M.	G.P.G.
Sodium chloride (NaCl)	123.0	7.1
Sodium sulphate (Na_2SO_4)	957.0	55.5
Sodium carbonate (Na_2CO_3)	915.0	53.0
Calcium carbonate ($CaCO_3$)	29.0	1.7
Ferrous carbonate ($FeCO_3$)	4.0	0.2
Silica (SiO_2)	31.0	1.9

In the northern James Basin it is generally recognized that there is an upper salty and alkaline flow of soft water and a lower flow of non-saline, non-alkaline water which is hard.

Analyses of the waters of other sands far enough away from the outcrops to give a good idea of their character are not available. One from the city of Edgemont, however, shows the characteristics of the water from the Deadwood sandstone.

[1]Analysis by State Chemical Laboratory, Guy G. Frary, State Chemist.

Analysis of Water at Edgemont, South Dakota[1]

Fall River County

	P.P.M.
Total Solids	1097.0
Loss on Ignition	47.0
Silica (SiO_2)	40.5
Iron (Fe)	1.3
Calcium (Ca)	130.0
Magnesium (Mg)	29.5
Chlorides (Cl)	250.0
Sulphates (SO_4)	317.0
Alkalinity	
Phenolphthalein	None
Methyl Orange	181.0
Total Hardness	448.5
Hypothetical Combinations	
Sodium chloride (NaCl)	412.5
Sodium sulphate (Na_2SO_4)	85.2
Calcium sulphate ($CaSO_4$)	350.4
Calcium carbonate ($CaCo_3$)	66.0
Magnesium carbonate ($MgCO_3$)	103.3
Ferrous carbonate ($FeCO_3$)	2.6
Silica (SiO_2)	40.5
Loss on Ignition	47.0
	1107.5

Origin of the Water. The origin of artesian water has not yet been satisfactorily determined. News stories and popular scientific articles have led the layman to assume that water was poured into the outcrops, moved through the aquifers into the basin, and thence out of the artesian wells. This, of course, would be a diagramatic explanation of an artesian basin, but it must be remembered that there is an enormous amount of friction, and that water moves through sandstone at an exceedingly low velocity. There is little doubt in the minds of most hydrologists that pressure is due to the difference in elevation of the various parts of the aquifer. It has been estimated, however, that it would take about 400 years for water to move from the outcrops in the Black Hills to the James Valley portion of the basin. It would seem probable, therefore, that much of the water that is being drawn from the artesian sands is water which was buried with the sediments. Fresh water from the outcrops scarcely has had time

[1]Analysis made by the State Chemical Laboratory, Vermillion, South Dakota.

to recharge any part of the artesian basin since the first artesian wells were drilled.

Temperature. Over most of the artesian basin no unusual temperatures are noted. One interesting phenomena, however, is the "hot spot" which occurs in the middle of the State. Artesian waters at Capa in Jones County were noted years ago as being much warmer than normal and some attempt was made to capitalize on them as a health resort. The artesian waters at Pierre are also above body temperature. Hot artesian waters have since been found to extend from Philip to somewhere east of Pierre and from Whitehorse in Dewey County to Kadoka in Jackson County, an area of approximately 100 by 72 miles. Most of the wells in this region have water at about 100 degrees Fahrenheit in contrast to temperatures of 50 to 60 degrees Fahrenheit for normal artesian water. The hottest water on which there is an accurate measurement was found in an oil test on the Granger Ranch, south of Kadoka, on the White River, where a temperature of 130 degrees Fahrenheit was recorded. Wells in Haakon and Ziebach Counties registered from 96 to 120 degrees Fahrenheit, in western Stanley County 100 degrees, in eastern Stanley County from 88 to 90 degrees, and in the northeastern part of the same county 98 degrees. The well at Whitehorse in Dewey County has a temperature of 80 degrees while to the south at Chamberlain, temperatures run about 74 degrees. In Tripp County 85 degrees Fahrenheit is recorded, and one well reports as high as 114 degrees. It appears, therefore, that the center of the "hot spot" lies south of Kadoka, its axis trending more or less north and south.

No explanation can be given for these unusual temperatures. So far as is known, there is no volcanic activity in this region unless it be so deeply buried that there is no evidence of it. Many minor faults are observed at the surface, and it is possible that shifting of sediments at depths has had something to do with heating the rocks. It may be significant that the West Fork anticline in Haakon County lies near the hottest wells.

Conservation of Artesian Water. More than 1600 artesian wells have been drilled in the James Basin alone, and most of these have been left to run wide open since their drilling. Some of them have been running this way for nearly 40

years. As a result there has been an enormous drain on the artesian reservoir which has lowered the pressure over the entire area and in some places has caused wells to cease flowing. West of the Missouri River, Robinson reports that pressure in a well at Vale in Butte County dropped 20½ feet between the time it was drilled—sometime between 1909 and 1917—and 1935. This well is but 15 miles from the outcrop of the Dakota sandstone. The same author reports a drop in head in the vicinity of Chamberlain of 230 feet since the first well was drilled in 1891[1] and at Pierre a drop of 300 feet since 1895.[2] In Day County the first artesian pressure was recorded in 1904 which raised water to an elevation of 1658 feet above sea level. By 1934 the level had dropped to an elevation of 1400 feet, a total of some 258 feet, at a rate averaging 8.6 feet per year.[3] Rates as high as 15 feet per year have been recorded by Robinson[4] for the Chamberlain area, but the best data available for the James Valley as a whole gives an average figure in the neighborhood of seven feet.

One thing noticeable in all studies of the fall in the artesian head is that it varies greatly from place to place. Where large amounts of water are taken out or wells allowed to run wild, the drop is much greater than in regions where this has not happened. Thus it is evident that while the whole system is more or less affected by waste, the recharge is so slow that a drain in one area is not felt immediately in other parts of the basin.

From a perusal of the problem it is very evident that artesian water will not flow in South Dakota very many years if the present practices are continued. This will be a decided loss to the State in that much free pumping will be lost and the cost of installation and operation of pumps and pumping equipment will be an unnecessary item of expense added to the farmer's budget which intelligent control could avoid. It is doubtful whether we will drain the entire artesian basin, because as the wells cease to flow, less water will be used and

[1]Robinson, T. W., Artesian conditions in west-central South Dakota: South Dakota Geol. Survey Rept. Inv. 26, pp. 46-48, 1938.

[2]Robinson, op cit., p. 47.

[3]Rothrock, E. P., Geology and water resources of Day County: South Dakota Geol. Survey Rept. Inv. 25, p. 37, 1935.

[4]Robinson, op. cit., p. 46.

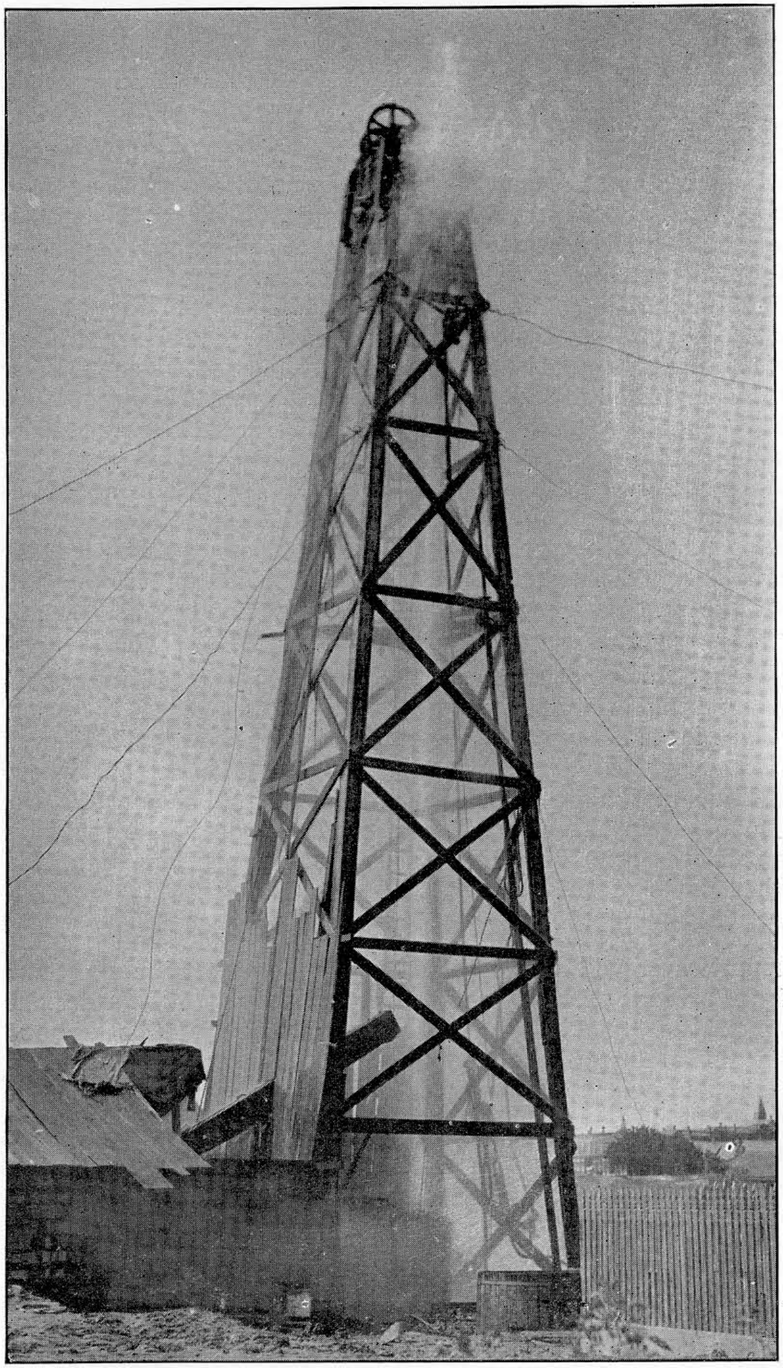

PLATE 39. Artesian Pressure in 1886

This well furnished the power for the city light plant at Redfield when first drilled. Its initial pressure was gaged at 177 pounds per square inch. Wells about Redfield still flow but under very low pressures.

the rate of recharge may be able to keep pace with the amount that is pumped.

Another consideration which presents itself, however, is the contamination of other waters by waters from the artesian sand. As has been shown, the artesian water from the first flow is high in salt and contains some waterials which are not particularly desirable, and others, like fluorine, which in high concentrations have a decidedly disadvantageous effect. Such corrosive water in poorly kept wells soon eats through the casing and is forced into shallow water sands. This is particularly true in the glacial area of the James Basin and could be true of the Tertiary and Cretaceous regions where shallow wells can be obtained from bedrock. Mixing these waters with the waters of the shallower sands, contaminates the shallow sands by changing the chemical composition. Such has been taking place in the Codell sand in the lower James Basin. This sand used to furnish a very soft water, but it has been contaminated with artesian waters until in many places the two waters are very similar.

The only complete solution to this problem of contamination and waste is to plug all unused or wild artesian wells from the bottom and to maintain well cemented and uncorroded casing in all wells that are used. These wells should be provided with cut-off valves so that no more water is used than is needed. If such a program were carried out, it is probable that the artesian head would remain at least where it is and might possibly, over a long period of years, be raised somewhat by a recharge of the artesian basin. Such a program has not been feasible largely because of the expense involved, but it is absolutely mandatory if the artesian head is to be preserved.

From what has been said in the preceding paragraph, it must be evident that though the most effective work should be on a state-wide basis, possibly including even our neighbor states, it is possible to do a good deal locally by applying the same principles. The large loss of head around Chamberlain is used as an example because a number of wells in the region have been allowed to run wild. Irrigation wells have been drilled and allowed to run the year around though their water is used but a comparatively short time each year. Such wells naturally reduce the head locally a great deal and where such conditions exist it is possible to partially remedy the situation by controlling wells within the locality. County wide efforts would be a decided help and might spread to state-wide cooperation. It is to be hoped that the methods will be put into practice before the deeper artesian sands are tapped for South Dakota has a vast, though not inexhaustible, source of water which will meet all needs if properly used. The use of surface supplies, when they are available, will conserve shallow and deep well supplies. The use of the shallow supplies, where they are available, will preserve the artesian supplies for areas that cannot obtain shallow water. Thus the spectre of water famine, whose shadow was so close during the recent drouth, need never trouble this State if its water supplies are intelligently developed and used.

CONCLUSION

In the preceding pages, an attempt has been made to give a picture of the geology of South Dakota; its topography has been described in Part I, the underlying rocks and their structures have been enumerated in Part II, and the economic products set forth in this volume. No volumes of similar size could exhaust any one of these subjects, but it is hoped that what has been said has given the layman an insight into the raw materials on which the State must depend for its prosperity, and the professional man a foundation from which he can start in the solution of the geologic problems which are now present and which will arise in the future.

Nature has endowed this State with a surface over which travel is easy. Any part of it can be reached by roads and railroads with a minimum of effort, and access to the large markets and centers of trade offers no problems. The Black Hills has been blamed for shunting all transcontinental railroads around the State and for many years the Missouri River was a serious handicap to east-west travel. Good highways and bridges have caused these obstacles to disappear and any part of the State is easily reached by anyone with the will to travel there. Playgrounds and places of interest for the tourists abound, and the broad stretches of the central lowland section and the Great Plains offer the best possible topographic conditions for farming and grazing.

The underlying rocks carry not only a most interesting record of the history of the State and the forces that were instrumental in making it what it is today, but contain a wealth of raw materials with which to supply local needs and build up industries. Fuels, structural and ceramic materials, and metals offer a variety of products surpassed by few plains states. Some have been partly developed and all offer new fields of endeavor for those who would pioneer in these mineral industries.

If the geographer's maxim is true, that a community's fate is sealed by three factors—namely, climate, access, and resources—South Dakota's fate should be a good one. It is possible, however, that the prediction should be changed to read that the community's fate is sealed by the use it makes of these factors. Whichever is correct, the geology and resources are here for those to use who know how to use them and for those to enjoy who know how to enjoy them.

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