WATER RESOURCES AND GEOLOGY

MOUNT RUSHMORE NATIONAL MEMORIAL SOUTH DAKOTA

GEOLOGICAL SURVEY
WATER-SUPPLY PAPER 1865

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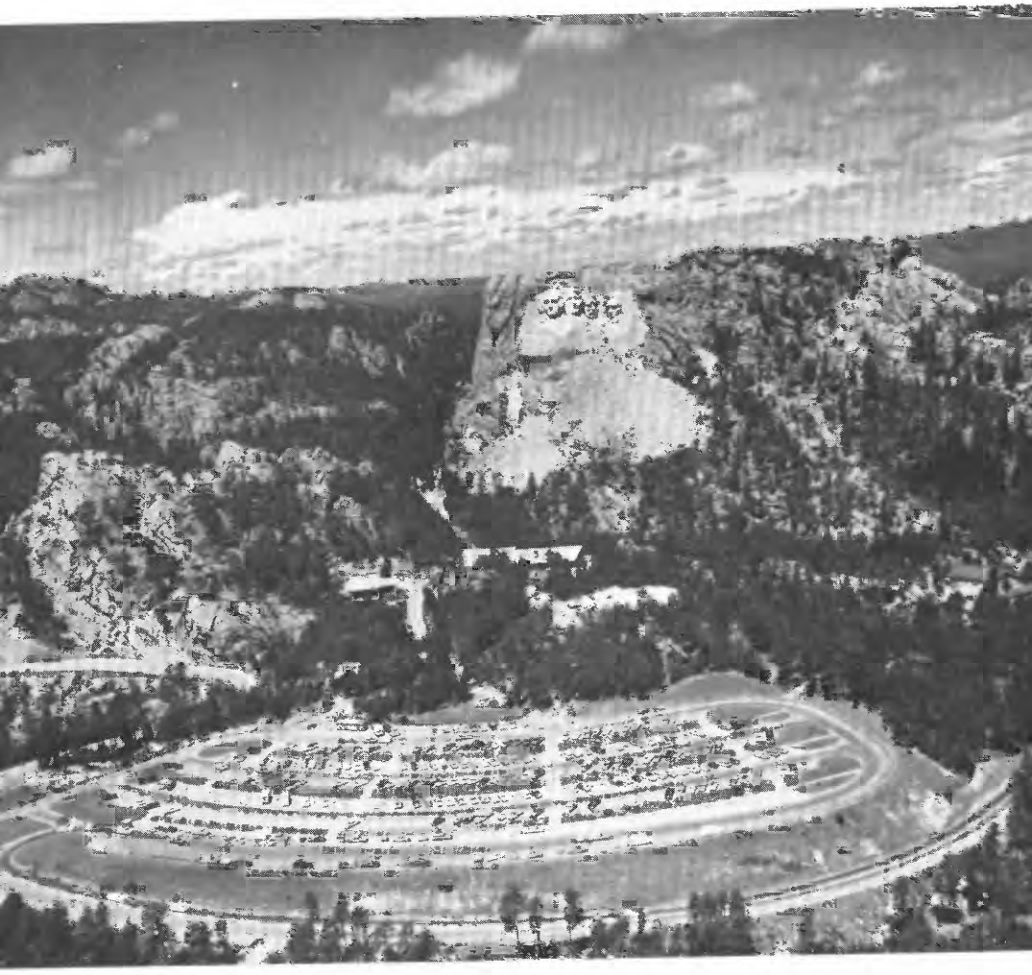

View of sculpture at Mount Rushmore National Memorial. Visitor reception area in foreground. (Photograph courtesy of National Park Service.)

Water Resources and Geology of Mount Rushmore National Memorial, South Dakota

By J. E. POWELL, J. J. NORTON, *and* D. G. ADOLPHSON

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1865

Prepared in cooperation with the National Park Service, Department of the Interior

Water-yielding characteristics of metamorphic rocks intruded by granite

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CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope	2
Location, area, and existing facilities	3
History	3
Present water supply and future demand	5
Previous investigations	6
Well-numbering system	6
Fieldwork and acknowledgments	7
Geography	9
Topography and drainage	9
Climate	9
Geology	9
Origin of the rocks and topography	10
Geologic setting	12
Description of the rocks	13
Metamorphic rocks	13
Mica schist	14
Mica schist and quartzite	14
Grunerite schist and quartzite	15
Quartz-mica schist and mica schist	16
Hornblende schist	16
Granite and pegmatite	17
Structural geology	18
Schistosity, bedding, and folds	18
Structures of granitic bodies	19
Joints and shear zones	24
Economic geology	24
Water resources	25
Ground water	26
Distribution of aquifers	27
Starling basin	28
Lafferty Gulch basin	29
East Boundary basin	30
Other localities	31
Test drilling and well construction	31
Prior investigations	31
This investigation	35
Results of pumping tests	36
Recharge and discharge	40
Streams	41
Water quality	43
Suggestions for future development	48
References	49

ILLUSTRATIONS

FRONTISPIECE. Photograph of sculpture at Mount Rushmore National Memorial.

		Page
PLATE 1.	Geohydrologic maps of the Mount Rushmore National Memorial	In pocket
FIGURE 1.	Map showing location of Mount Rushmore National Memorial and other localities mentioned in this report	4
2.	Graph showing total number visitors per year 1942–70 and estimated totals to 1980	7
3.	Sketch illustrating well-numbering system	8
4.	Diagrams showing average monthly precipitation and percentage distribution of precipitation by months, Mount Rushmore National Memorial, 1962–70	10
5.	Point diagrams, equal area net, lower hemisphere, poles to schistosity and bedding	20
6.	Point diagrams, equal area net, lower hemisphere, poles to planar structures of granite and pegmatite	22
7.	Graph showing drawdown and recovery curves for wells 3 and 4	39
8.	Histogram showing monthly discharge at Battle Creek gaging station near Keystone, S. Dak.	44
9.	Histogram showing monthly distribution of runoff at Battle Creek gaging station near Keystone, S. Dak.	45

TABLES

		Page
TABLE 1.	Record of wells	27
2.	Logs of wells and test holes	32
3.	Chemical analyses of water from selected wells, springs, and streams	42

WATER RESOURCES AND GEOLOGY OF MOUNT RUSHMORE NATIONAL MEMORIAL, SOUTH DAKOTA

By J. E. Powell, J. J. Norton, and D. G. Adolphson

ABSTRACT

Ground water suitable for public supply can be obtained from fractured metamorphic and igneous rocks at Mount Rushmore National Memorial, S. Dak.

The memorial comprises three main drainage basins: Starling basin, Lafferty Gulch basin, and East Boundary basin. Ground water is most prevalent in Lafferty Gulch basin but Starling basin contributes the most surface water.

The total water supply was obtained from springs until 1967 when increasing numbers of visitors required development of additional sources. As a result of this investigation, wells 3 and 4 were drilled in Lafferty Gulch basin and East Boundary basin. Well 3 is 200 feet deep in mica schist and granite. It produced 7.3 million gallons of water in 1968 and 7.7 million gallons of water in 1969, the total supply for the memorial. Well 4 is 500 feet deep, also in mica schist and granite. It is not used at the present time (1970) but will be used in the future when more water is needed. Water from both wells is potable, but the quality of water from well 3 is superior to that from well 4.

Mica schist is the most abundant rock in the memorial. The more prominent hills and mountains, however, are in large, northerly striking granite sills, some of which are several hundred feet thick. Pegmatite sills and dikes are also numerous. The western boundary of the memorial is at the east edge of the Harney Peak Granite batholith. The dip of schistosity and bedding in schist adjacent to the batholith is about 30° E. but increases across the memorial to about 65° E. in the northeast corner.

At some locations in the memorial, granite or pegmatite sills act as ground-water dams preventing the movement of ground water down gradient. A pegmatite or granite sill is probably the cause of the accumulation of water in the vicinity of well 3. The well flows when it is not being pumped.

The occurrence of ground water is dependent upon the presence of joints and fractures in the schist and granite bedrock. The rocks themselves are relatively impermeable and would yield little or no water in their unaltered state.

Mica schist that has been intruded by granite and (or) pegmatite is more fractured and yields more ground water in the memorial than mica schist alone. This condition may be due to jointing and to the greater fracturability of the intruded rocks in the vicinity of granitic intrusions.

Ground water is also available from alluvium in major valleys such as Starling basin and the valleys of Grizzly Bear Creek and Battle Creek.

Evapotranspiration is the greatest use-item in the water budget. An approximation of evapotranspiration based upon an average annual precipitation of 19 inches is 1,600 acre-feet, or 80 percent of the annual precipitation.

Several locations in the memorial have potential as future sources of ground-water supplies. The most promising areas are near spring 6 in the southeast corner and alluvium in the valleys of Battle and Grizzly Bear Creeks.

Developed and potential water resources in the memorial probably are sufficient to meet demands beyond the year 2000.

INTRODUCTION

For many years after the dedication in 1927 of Mount Rushmore National Memorial (hereafter called "the memorial"), a water supply adequate for use at the memorial was obtained from springs. As visitors to the memorial became more numerous, a water-supply shortage developed and became progressively more serious during the 5 years preceding 1967. The shortage became critical as the number of annual visitors to the memorial approached two million in 1966.

PURPOSE AND SCOPE OF THE INVESTIGATION

At the request of the National Park Service, the U.S. Geological Survey made a study of the memorial to locate additional sources of water. The quantity, availability, and chemical quality of all potential supplies, both surface and underground, were investigated.

This report presents an assessment of available water supplies; a description of the geology and hydrology; a geologic map; data on streamflow, water quality, wells, springs, and test holes; and suggestions for a solution to the water-supply problem.

The availability of water in the memorial is largely controlled by the complex geology of the area. It therefore was desirable to study the physical characteristics of the rocks. A detailed study by J. J. Norton of the petrology and structural geology in the vicinity of the memorial was underway and, although not originally planned as a part of this investigation, could provide the needed geologic framework. Accordingly, arrangements were made for modification of that project to provide petrologic and geologic information and a geologic map to include in this report. Although funds available were insufficient to provide extensive test drilling, the detailed map of the surface geology provided valuable information regarding subsurface conditions, a necessary prerequisite to understanding the occurrence of ground water in the area.

LOCATION, AREA, AND EXISTING FACILITIES

The memorial is in southwestern Pennington County in the east central part of the Black Hills section of the Great Plains physiographic province as defined by Fenneman (1931, p. 8). It has an area of about 1,280 acres in secs. 12 and 13, T. 2 S., R. 5 E., and secs. 7, 8, and 18, T. 2 S., R. 6 E. (See fig. 1.) Access to the visitor area near the sculpture of the four presidents is by State Highway 87, which meanders through the memorial from its eastern border to its northwestern corner. The visitor area includes a large parking facility, a headquarters building containing administrative offices and tourist information center, a concessionaire's building, and a dormitory building for summer employees of the concessionaire. Other manmade features include shop maintenance structures, water-storage facilities, and the park residence area for permanent employees of the National Park Service.

HISTORY

The Indians called the Black Hills "Pahasapa" and believed the area to be the home of the "Great Spirit." They did not live in the Black Hills, but made frequent visits to gather lodgepoles, make "medicine," and hunt for game. The first white men to visit the hills may have been members of the Francis and Louis-Joseph Verendrye expedition in 1743; however, the exact route of their expedition is unknown. Fur trappers and military expeditions traversed the area in later years, but no white men settled there because the land was part of the Great Sioux Reservation, created by treaties.

Stories of gold in the Black Hills were commonplace in the 1850's, but it was not until 1874, when General G. A. Custer led a party into the hills, that the news of gold was announced officially. Miners flocked to the area by the thousands. In 1876, after negotiations were completed with various Sioux chiefs, an agreement was signed by which the Indians gave up their rights to the Black Hills.

The first railroad reached the area in 1885 and, soon after, chambers of commerce were formed in various communities to promote campaigns to attract tourists. The nation's first National Monument, Devil's Tower, Wyo., was established in the northwestern part of the Black Hills in 1906.

In 1924, Doane Robinson, then State Historian of South Dakota, proposed carving massive figures (later to be called Mount Rushmore National Memorial) on some of the granite pinnacles located

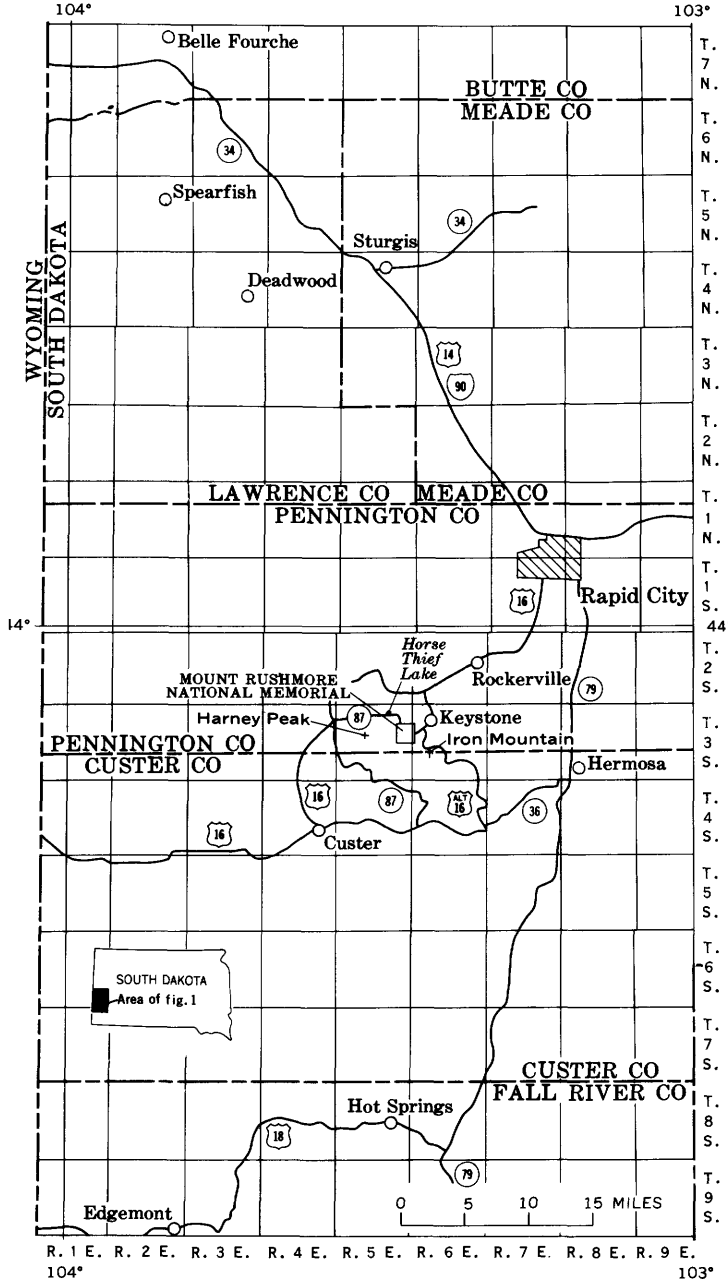


FIGURE 1.—Location of Mount Rushmore National Memorial and other localities mentioned in this report.

south of Harney Peak and known as the Needles. Robinson suggested that the figures honor western heroes and predicted such carvings would be a boon to the tourist trade. A letter to Gutzon Borglum, who was then carving Stone Mountain in Georgia, brought the sculptor to the Black Hills in August 1925 for a preliminary inspection of the area. He tentatively accepted the idea but urged that the figures be national in character. As a result, four presidents, Washington, Jefferson, Lincoln, and Theodore Roosevelt, were chosen as subjects for the sculpture because they had contributed significantly to the growth of the American ideal.

With the aid of United States Senator Peter Norbeck and Congressman William Williamson, both of South Dakota, legislation to permit the carving in the Black Hills National Forest was secured from Congress in 1925. Mount Rushmore, named in 1885 for Charles E. Rushmore, a New York lawyer, was selected for the carving because its southeast face had the proper lighting and the granite mass was large enough for the planned sculpture.

Work on the sculpture began August 10, 1927, the day President Calvin Coolidge dedicated the memorial. The main problem in construction was the removal of unwanted rock. Over 400,000 tons was ultimately removed and it was necessary to change the large model of the group nine times owing to rock conditions. The figures are to the scale of men 465 feet tall.

The Washington head was dedicated July 4, 1930, by Doane Robinson, South Dakota State Historian, and the Jefferson head was dedicated on August 30, 1936, by President Franklin D. Roosevelt. The Lincoln head was dedicated September 17, 1937, by Senator Edward R. Burke of Nebraska, and the Roosevelt figure on July 2, 1939, by Governor Harlan J. Bushfield of South Dakota and William S. Hart, silent-screen star. The work was terminated in October 1941; it cost slightly less than one million dollars and involved about 6½ years of actual work over a period of more than 14 years.

PRESENT WATER SUPPLY AND FUTURE DEMAND

Before 1967 a group of closely spaced, developed springs known collectively as "Rushmore Spring" (2–6–7cdd1), and designated as spring 3 in this report, provided the water supply for the memorial. In July 1967, well 3 (2–6–7cdd2) was drilled as a part of this investigation, and in October 1967 the well replaced the springs as the principal water source for the memorial.

Water from well 3 is pumped to a nearby 500,000-gallon underground reservoir from which it flows by gravity to the residential area about 1,800 feet to the northeast (pl. 1). Overflow is stored

in an adjacent 32,500-gallon underground reservoir, from which it flows back to the 500,000-gallon reservoir on demand. Water is pumped from the 500,000-gallon reservoir to a 75,000-gallon tank about 2,700 feet to the southwest. It then flows by gravity to the visitor-use complex on Doane Mountain. Water in excess of that needed by these systems is pumped into a 2,000,000-gallon reservoir near well 3 for standby storage and is used during the summer when demand is greatest. This reservoir is emptied and cleaned in the winter and filled in the spring of the following year.

In August 1967, well 4 was drilled to a depth of 500 feet in East Boundary basin, for use in the future when more water is needed.

In 1968, 1969, and 1970 the total water consumption at the memorial was 7.3, 7.7, and 6.8 million gallons, respectively, and the projected demand in 1980 is 11.3 million gallons. The increasing demand for water parallels the increase in visitors from 141,000 in 1942 to 1,760,000 in 1969, and a projected 3,000,000 by 1980 (fig. 2).

PREVIOUS INVESTIGATIONS

No previous detailed investigation of the geohydrology has been made in the memorial area, but the area has been included in regional studies of other geological features. Darton (1918) discussed the stratigraphy and general availability of water from artesian wells at Hermosa about 12 miles southeast of the memorial. Darton and Paige (1925) described the economic geology and surface-water flows in the central Black Hills. Paige and others (1953) described the pegmatites of the sotuhern Black Hills. Gries (1960), in an administrative report to the National Park Service, described the occurrence of ground water at selected sites in the memorial.

WELL-NUMBERING SYSTEM

Each well, spring, or test hole tabulated in this report has been assigned a number based on its location, according to the Federal land-survey system used in western South Dakota. The number consists of the township, range, and section numbers separated by hyphens; three lowercase letters after the section number indicate respectively the quarter section (160 acres), quarter-quarter section (40 acres), and quarter-quarter-quarter section (10 acres), in which the well, spring, or test hole is located. The number of lowercase letters indicates the accuracy of each location; if it can be located within a 10-acre tract, three lowercase letters are shown in the number. For example, 2–6–7cdd2 (well 3) is in the SE¼ SE¼SW¼ sec. 7, T. 2 S., R. 6 E. (pl. 1). If two or more locations

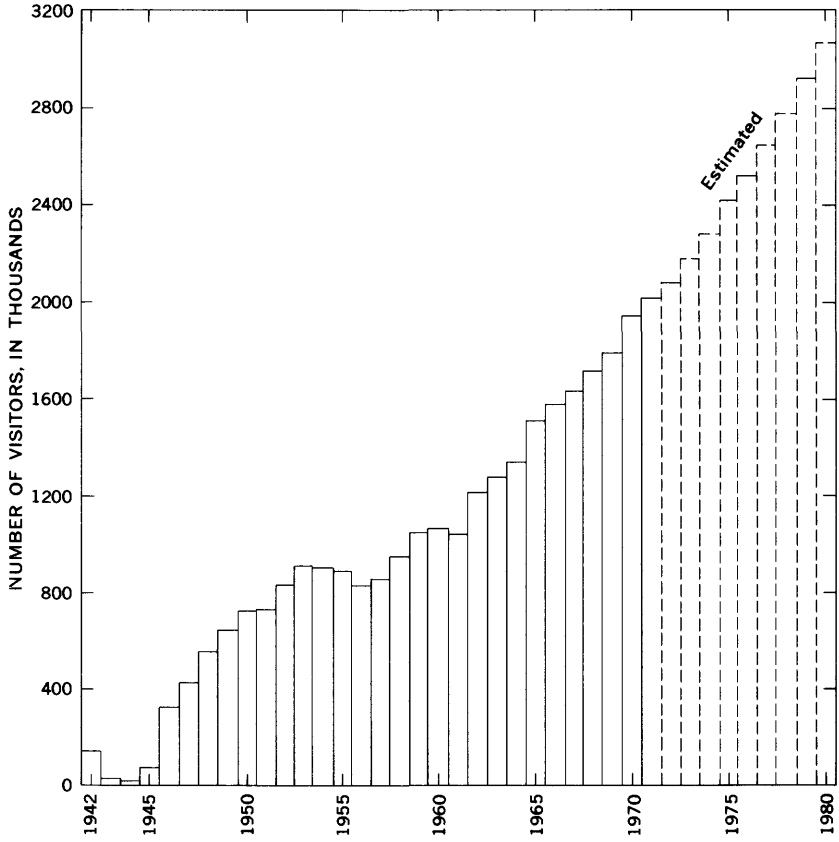


FIGURE 2.—Total number visitors per year 1942–70 and estimated totals to 1980.

are within the same tract, consecutive numbers, beginning with 1, are added as suffixes to designate the order in which the points are described (fig. 3).

Because all sections (legal land description) within the memorial have different numbers, rock outcrops and other geologic features are located by section number and quarter section only.

FIELDWORK AND ACKNOWLEDGMENTS

Fieldwork was done during the spring and summer of 1967. It consisted of mapping the surface geology and hydrologic features of the entire memorial, collecting eight water samples to determine the quality of surface and ground waters, measuring water levels in wells, monthly gaging of stream flows, and a field reconnaissance of the memorial and surrounding area to locate potential ground-water supplies. In addition, sites were selected for the

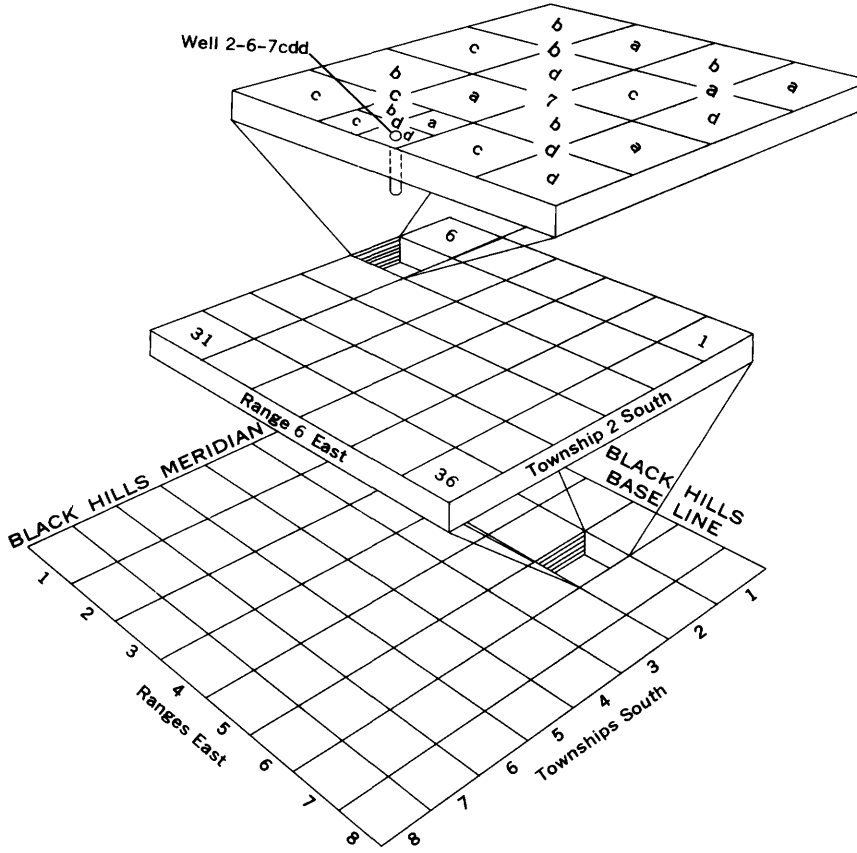


FIGURE 3.—Sketch illustrating well-numbering system.

locations of deep test holes to explore the ground-water potential of the rocks. Two test holes were drilled and completed as supply wells 3 (2–6–7cdd2) and 4 (2–6–8cad1). Tests of 72 hours' duration were made of each well to determine the water-yielding capacity of the aquifer.

Acknowledgment is made of the cooperation of the Water Resources Section, Office of Land Acquisition and Water Resources, National Park Service.

During the investigation, considerable assistance was provided by memorial superintendent W. O. MacCaw, chief ranger W. B. Elms, maintenance supervisor Gene Koevenig and maintenance foreman William Zwetzij. Subsurface information was provided by Warren and Gene Hamm, who drilled the test holes and completed wells 3 and 4. Dr. J. P. Gries, South Dakota School of Mines and Technology, Rapid City, provided valuable help by making a

petrographic study of the cuttings from both test holes and by reviewing this report.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Black Hills is an irregular domed uplift into which streams flowing out of the central mountain area have cut deep canyons and gorges. Harney Peak, the highest peak in the Black Hills, with an altitude of 7,240 feet, is about 4 miles southwest of the memorial. Altitudes at the memorial range from 4,420 feet, near Highway 16A in the valley of Battle Creek 0.3 mile northeast of the northeast corner at the east boundary, to 5,725 feet at the summit of Mount Rushmore. Old Baldy Mountain, 1 mile north of Mount Rushmore, has the second highest altitude with a summit of 5,605 feet. Other prominent topographic features are sharp-backed linear ridges alined with corresponding steep-walled gulches or valleys.

Starling basin, tributary to Grizzly Bear Creek, provides drainage for the southwestern part of the memorial and is the largest valley. The intermittent creek in East Boundary basin drains the eastern part, and Lafferty Gulch, tributary to Battle Creek, drains the central part. The northwestern part drains directly to Battle Creek.

CLIMATE

The climate of the area is subhumid and is characterized by long cold winters and short cool summers. For the period 1962 through 1970, the mean annual temperature at the memorial was 46.3° F. The highest temperature recorded was 99° F in June 1970, and the lowest was −38° F in January 1963.

Most precipitation falls as rain during the late spring and summer (fig. 4). The average annual precipitation for 1963 through 1970 was 23.36 inches. However, this average is based upon a short 8-year record, 5 years of which had unusually heavy rainfall. The maximum precipitation for this period was 32.15 inches in 1965, and the minimum was 19.07 inches in 1966. The average precipitation in the memorial vicinity, based upon the isohytal map for the Black Hills area (U.S. Dept. of Agriculture, U.S. Dept. of Interior, 1967), is about 19 inches.

GEOLOGY

Mount Rushmore is composed of granite, as are most mountains in the western part of the memorial. Elsewhere in the memorial are many small bodies of granite and a rock called pegmatite that

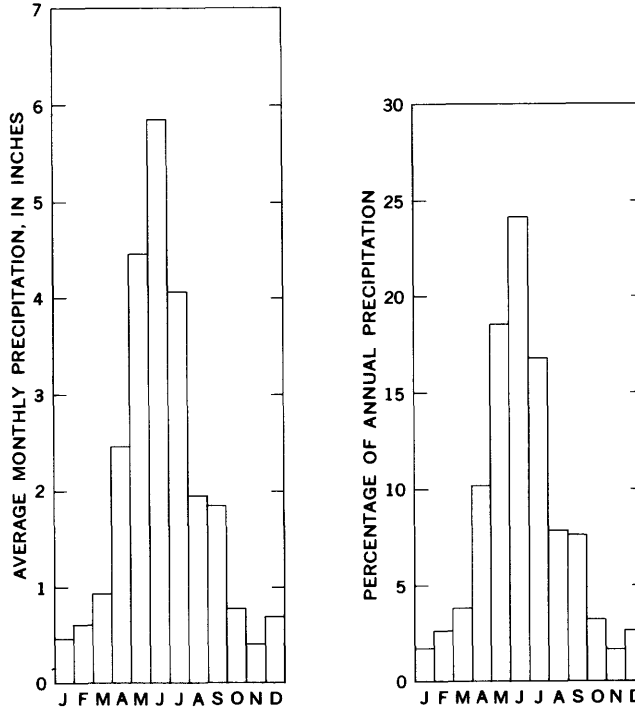


FIGURE 4.—Average monthly precipition and percentage distribution of precipitation by months at Mount Rushmore National Memorial, 1962–70.

is very similar to granite but has somewhat larger grains. Virtually all other rocks within the memorial are schist formed by the alteration of sedimentary rocks (pl. 1) under high temperature and pressure.

The main processes by which the rocks and topography were formed can be described in simple terms. Highlights are presented in the following section, entitled "Origin of the rocks and topography." To avoid lengthy or complex discussions, many statements are not accompanied by a description of the evidence on which they are based. For readers who are interested in the more technical aspects of the geologic investigation, the rocks and their structural features are described in greater detail in the section following "Origin of the Rocks and Topography."

ORIGIN OF THE ROCKS AND TOPOGRAPHY

The origin of the rocks and the origin of the mountainous topography are two distinctly different topics. The rocks of the memorial area are ancient, whereas the topography was formed in very recent geologic time.

The age of the granite at the memorial and nearby Harney Peak is about 1,600 million years, and the other rocks are even older. The granite originated as a molten mass, rising from deep in the earth's crust. As the molten material cooled, it crystallized to form the granitic rock that makes up many bodies of various sizes and shapes throughout the region.

Before the granite was formed, the region contained a great thickness of shale and sandstone that had been deposited earlier as mud and sand in seas that occupied the region. When the granite crystallized, a thickness of several miles of these sediments lay above it; high temperature and pressure at this great depth caused the sedimentary rocks to be changed or "metamorphosed." What had been shale became mica schist, and the rock acquired a structure called schistosity, which causes it to break easily into thin slices. Sandstone became quartzite, which is a dense, hard, and glassy rock. At the same time, some minerals were destroyed and new minerals of larger grain size formed in their place. Micas (muscovite and biotite) are the most abundant new minerals, but others include garnet, staurolite, sillimanite, cordierite, and feldspar.

The metamorphic rocks were folded and otherwise deformed before and during the intrusion of granite. The results are less apparent in the memorial than in many nearby places. On the geologic map (pl. 1), one can see a few folds along the contact of the unit of mica schist and quartzite that trends north across the center of the area. The map is accompanied by a geologic section—in effect, a vertical slice across the area—which shows that the rock units are tilted downward to the east. Farther east, near Keystone, they turn up to a nearly vertical position, and to the west and southwest near Harney Peak they become nearly horizontal.

The history of the region is unknown from 1,600 million to 500 million years ago; none of the rocks were formed in this period, and in the absence of rocks there is no record of what happened. Several miles of rock must have been eroded from above the granite during this time. The erosion may have been largely completed by 1,200 million years ago, for marine sediments of that age exist only about 110 miles to the east.

The history from 500 million years ago until the present time is known from many studies of the rocks and fossils found along the flanks of the Black Hills. These rocks have been totally eroded from the memorial and Harney Peak region. One can see them along the highway from Rockerville to Rapid City, and a broader view of them can be gained by looking east from the top of Iron Mountain. They show that great quantities of sand and mud were

deposited on the floor of seas in the region. As the pile of sediment became thicker and more compact, the sand became sandstone and the mud became shale or limestone. Occasionally, the region was above sea level, but ordinarily it was not high enough for erosion to be vigorous until the birth of the Black Hills.

About 70 million years ago the earth's crust in this region began to move upward and, as it rose to higher and higher altitudes, the rocks decayed to form soil, and streams carried away the soil. During the long time in which these processes continued, valleys were formed and hills or mountains were left standing between the valleys. Ultimately erosion uncovered the granitic rocks. Because granite is difficult to break down, it formed hills and mountains, while valleys were cut in less resistant rocks nearby.

The process was interrupted about 30 million years ago when a great thickness of mud and sand was deposited in rivers and lakes over many thousands of square miles on all sides of the Black Hills. These sediments are the rocks exposed in the South Dakota Badlands. The same deposits covered the lower parts of the Black Hills, where remnants of them still exist; but higher places such as the memorial were unaffected.

Erosion began again about 10 million years ago, and in the ensuing period the topography was carved in the form we see it today.

GEOLOGIC SETTING

The memorial is on the northeast side of the area underlain by the Harney Peak Granite. Beyond the west boundary of the memorial, and southwest of State Highway 87 near Horse Thief Lake (fig. 1), an area of many square miles is occupied almost entirely by granite. This granite has several large offshoots; one of them is the belt of interconnected bodies of granite that extends from the south end of Starling basin to Mount Rushmore and on to Old Baldy Mountain (pl. 1).

Pegmatite sills and dikes are abundant for about 1 mile east of Mount Rushmore, but the northeast corner of the memorial has only a few pegmatite dikes. One-half mile farther to the northeast is the outer limit of the pegmatite-bearing region of the southern Black Hills.

The metamorphic rocks of the southern Black Hills form a dome around the Harney Peak Granite. The memorial is on the easterly dipping flank of this dome in such a position that the dip of schistosity and bedding increases from about 30° near the west border of the memorial to about 65° near the east border. Farther east, the influence of the dome disappears, and dips are generally more

than 75°, either east or west. A geologic map of the area to the north and east (Norton, 1960) shows many isoclinal folds, faults, and amphibolite intrusives; the structural complexity is in marked contrast to the simplicity of the arrangement of metamorphic rocks in the memorial (pl. 1).

DESCRIPTION OF THE ROCKS

METAMORPHIC ROCKS

Nearly all the metamorphosed sedimentary rocks are mica schists, which are described as three lithologic units. The lowermost unit, and probably the oldest, is a mica-rich schist that extends across most of the western half of the memorial; before metamorphism, this unit was shale. The middle unit is mica schist with a few beds of quartzite; it was shale and sandstone before metamorphism. The top unit, occupying the eastern part of the memorial, is of quartz-mica schist and mica schist, more siliceous and less aluminous than the older schists. The composition of this unit suggests an origin from a mixture of shale and impure sandstone or graywacke.

Sillimanite and staurolite metamorphic zones extend around the north side of the Harney Peak Granite and across the memorial. Sillimanite is a common accessory mineral everywhere in the memorial except near the northeast corner. Though not abundant enough to be easily noticed in outcrops, it was observed in many thin sections. Staurolite occurs only near the northeast corner of the memorial, but it is abundant outside the memorial to the east and north.

Amphibole rocks are sparse and of varied nature. A thin and discontinuous bed of amphibole schist lies between the two upper mica schist units in the SE¼ sec. 7 and the NE¼ sec. 18. Because it has quartzite lenses and because grunerite is its main amphibole, this is unquestionably a metamorphosed iron-formation. An additional metamorphosed iron-formation lies to the east, just outside the memorial boundary in the E½ of sec. 18. Other amphibole units consist chiefly of common hornblende, quartz, and plagioclase; they resemble sills of diabasic composition described by Redden (1963, p. 215–216), but have more quartz and less plagioclase, and may be tuffs rather than sills. Calc-silicate nodules, formed by metamorphism of concretions (Runner and Hamilton, 1934), are found mainly in the northeast part of the memorial and are sparse elsewhere. Some of the quartzite in the unit of mica schist and quartzite has actinolite, which implies that the ancestral sandstone had some carbonate cement.

The metamorphic rocks described in this report are designated by lithologic names rather than formal stratigraphic names. Possibly they are equivalent to the Loues Formation and the lower part of the Bugtown Formation, described by Redden (1968, p. 354–358) 12 miles to the west, but insufficient information is available from intervening areas to establish the correlation.

MICA SCHIST

The mica schist unit generally has well-developed schistosity and in many places has a "salt and pepper" appearance. Ordinarily the rock contains 15–25 percent biotite, 10–30 percent muscovite, and 30–55 percent quartz. Other common minerals are plagioclase, microcline, cordierite, and garnet, each of which may form as much as 30 percent of thin beds. Less prominent minerals include sillimanite, tourmaline, apatite, chlorite, and opaque minerals. Quartz and biotite are abundant everywhere, but all other minerals can be negligible or absent in some specimens. Grain sizes rarely exceed 1 mm (millimeter). The average for biotite is about 0.6 mm long and 0.1 mm thick; muscovite grains are about the same length but only half as thick. Quartz, feldspar, and cordierite grains are more nearly equidimensional and generally 0.2–0.6 mm long, but some are 2 mm or longer.

A rusty-weathering outcrop in the NE¼SE¼ sec 13, in a roadcut made for the new highway 0.3 mile south of the memorial, contains a distinctive thin-bedded biotite schist in which quartz, cordierite, garnet, and microcline are abundant. These beds cannot be traced along strike, because the abundance of granite causes schist outcrops to be sparse.

The mica schist unit is likely to be stratigraphically equivalent to the Oreville Formation of Ratté and Wayland (1969, p. B2-B5) 5 miles to the northwest in the Hill City quadrangle. It may also be equivalent to Redden's Loues Formation in the Berne quadrangle and to units of quartz-biotite-garnet schist and mica schist elsewhere in the Berne quadrangle that perhaps are a part of the Loues Formation (Redden, 1968, p. 354–356, 362–367). These localities have mica schists that resemble the mica schist at Mount Rushmore, and they have biotite schists with a pronounced similarity to the thin-bedded biotite schist exposed south of the sculpture.

MICA SCHIST AND QUARTZITE

Outcrops are uncommon in the belt of mica schist and quartzite that crosses the map area from Lafferty Gulch south through the middle of sec. 18. In many places the main evidence that the unit

exists is the presence of float blocks of quartzite. The schist is well exposed only along State Highway 87 in the SE¼ sec. 7 and NE¼ sec. 18.

The quartzite is mostly a massive, nearly glassy rock that ordinarily has 70–90 percent quartz. The quartz is in sutured grains, generally 0.2–0.5 mm across. The most noteworthy accessory minerals are actinolite and clinozoisite. Actinolite commonly makes up as much as 15 percent of the rock, and in a few places it is as abundant as quartz. Other accessory minerals include plagioclase, microcline, biotite, muscovite, tourmaline, garnet, and epidote.

The mica schist, though it forms few outcrops, is undoubtedly far more abundant than the quartzite. It generally contains 20–30 percent biotite, 10–20 percent muscovite, and 40–60 percent quartz, and thus is somewhat more biotitic and quartzose than the schist to the west, which it otherwise resembles. Accessory minerals include feldspar, garnet, tourmaline, sillimanite, cordierite, apatite, and opaque minerals. A distinctive feature of this schist in outcrops north of the memorial, though uncommon within the memorial, is the prominence of euhedral red garnets, about 2 mm in diameter, which in places form more than 10 percent of the rock.

A conglomeratic rock, perhaps actually a pseudoconglomerate, is widespread in the mica schist at many localities in the surrounding region, and probably also exists within the memorial. It consists of quartzite fragments enclosed by schist.

GRUNERITE SCHIST AND QUARTZITE

A thin layer of metamorphosed iron-formation, consisting of grunerite schist and quartzite, extends from the north boundary of the memorial in the SE¼ of sec. 7 to the south edge of the NE¼ sec. 18. A small amount of the same iron-formation occurs near the center of the SE¼ sec. 18. North of the memorial, the iron-formation disappears for a short distance, but then crops out again near the floor of Lafferty Gulch and continues north for about half a mile. The maximum thickness may be as great as 20 feet, but ordinarily is between 3 and 10 feet.

An even smaller unit of iron-formation lies to the east near the center of the E½ of sec. 18. Float blocks indicate that this locality has one or two other units of iron-formation that are too small to map.

The iron-formation generally consists of grunerite schist with quartzite layers and lenses a fraction of an inch thick. In a few places, however, quartzite is the predominant rock. The grunerite

schist contains 70–80 percent grunerite (N_Z=1.70–1.71) and 15–25 percent common hornblende (N_Z=1.68–1.70). Occasionally the grunerite is in rosettes, about 2 mm in diameter, but mainly it is a dense schistose matte. Most of the grunerite and hornblende is in grains 0.3–1.0 mm long, but some grains reach a length of 2 mm. Grunerite also forms fine-grained interstitial material in which grains are 0.1 mm long. Porphyroblasts of diopside (N_Z= 1.17) are 1 mm to at least 1 cm (centimeter) across. Garnet, 0.5–2 mm long, is elongate parallel to the schistosity. Other constituents include apatite and iron oxides. Grains of quartz in the quartzite are generally about 0.5 mm in diameter; the largest grain observed is 2 by 3 mm.

QUARTZ-MICA SCHIST AND MICA SCHIST

The schist in the eastern part of the memorial is less schistose than the rocks to the west. Quartz-mica schist, some in beds a foot or more thick, is interlayered with more micaceous schist. The schists ordinarily have about equal quantities of biotite and muscovite, each generally amounting to 10–20 percent of the rock, and the rest is predominantly quartz. The more schistose layers have as much as 50 percent mica, and massive beds have as much as 85 percent quartz. Other minerals include plagioclase, sillimanite, garnet, tourmaline, apatite, cordierite, and opaque minerals; staurolite occurs near the northeast corner of the memorial. The schist is generally finer grained than the schists to the west; grains of quartz and mica in most specimens have an average length of 0.1–0.3 mm.

A few beds at the base of this unit, along the upper side of the iron-formation, are of a micaceous and garnetiferous schist that resembles the schist beneath the iron-formation. Also, a bed of quartzite is exposed in the NE¼SE¼ sec. 18. For simplicity, these rocks are not shown separately on the geologic map.

HORNBLENDE SCHIST

Three small beds or sills of hornblende schist are exposed in the SE¼ sec. 7 and E½ sec. 18. These consist mainly of common hornblende (N_Z=1.67) in crystals that are mostly 1–3 mm long. The hornblende is moderately well alined in some thin sections, but more commonly it is almost randomly oriented. Quartz and plagioclase (An_{30-40}) are interstitial to the hornblende. Diopside porphyroblasts are as much as 6 mm across. Fine-grained micaceous material appearing in several places is probably vermiculite but may be phlogopite. Other minerals include biotite, epidote, clinozoisite, garnet, apatite, and opaque minerals. A small patch

of iron-formation is associated with hornblende schist in at least one place.

This hornblende schist differs from the amphibolite common in nearby areas in that hornblende is unusually abundant and quartz is more plentiful than plagioclase. Much of the amphibolite of the southern Black Hills is clearly an intrusive igneous rock (for example, Redden, 1963, p. 215–216, and 1968, p. 361) but the somewhat peculiar composition of the hornblende schist in the memorial suggests that it is a metamorphosed tuff.

GRANITE AND PEGMATITE

The lithologic distinction between granite and pegmatite of this region is at best a subtle one; for practical purposes, the two are the same. Nevertheless, in the geologic literature of the Black Hills, the term Harney Peak Granite has long been used as the name of the rock in the larger intrusives, and the smaller bodies in outlying areas have generally been called pegmatites.

The granite consists mostly of albite (An_{3-8}) and quartz with lesser amounts of perthite and muscovite. Average grain size of quartz and albite is about 3 mm, and muscovite grains are generally a little smaller. Much of the perthite, however, exists as crystals several inches or several feet long, which gives a distinct pegmatitic cast to the rock. In many places, the perthite is concentrated in layers; the result is an alternating sequence of albite-perthite-quartz layers and albite-quartz layers. Coarse-grained perthite and quartz are also prominent in many pegmatitic pods and fracture fillings in the granite.

The pegmatite sills and dikes characteristic of the eastern part of the memorial have a range of texture from coarse to sugary, but the coarse pegmatite texture is their most prominent trait. They have large crystals of perthite in a matrix of quartz, albite (An_{0-5}), and muscovite. Perthite may be sparse or absent near the contact, and the outer part of the pegmatite is a small wall zone or border zone of quartz, albite, muscovite, and tourmaline. The center of a pegmatite may have lenses of massive quartz.

Bulk compositions of pegmatite and granite are similar. Modal compositions of exposures of granite and pegmatite determined by Orville (1960, p. 1485) in samples from five nearby localities range from 26.4 to 33.3 percent quartz, 39.5 to 49.4 percent albite, 12.2 to 20.1 percent microcline, and 2.9 to 11.2 percent muscovite. Some of the granite and pegmatite in the memorial have as much as 15 percent muscovite and 2 percent biotite, but otherwise the compositions are similar to those determined by Orville.

No systematic change in bulk composition has been noticed from the granite in the western part of the memorial to pegmatites in the eastern part. Even if there is such a change, it would be hard to detect because both granite and pegmatite have wide local variations that greatly overshadow any regional variation in bulk composition.

Commonly observed accessory minerals are tourmaline, biotite, and garnet. Closer examination will reveal occasional apatite, beryl, and lithiophilite-triphylite. A bright-green beryl crystal, 13 inches long, is in a 2- to 4-foot-thick perthite-quartz fracture filling exposed on the sculpture between the figures of Lincoln and Roosevelt. The same fracture filling has a crystal of red-brown garnet 3 inches in diameter.

By comparing the geologic section (pl. 1) with the geologic map, one finds that granite and pegmatite seem to be less abundant in the subsurface than on the surface. One reason for this discrepancy is that the section shows only intrusions actually observed at the surface or found in the drill holes; doubtless there are others concealed beneath the surface. On the other hand, the map tends to exaggerate the abundance of granitic rock because many sills are exposed on dip slopes, and appear to be much larger than they really are.

The age of the granitic rock is very close to 1,600 million years. Results of uranium-lead age determinations on uraninite from the Bob Ingersoll No. 1 pegmatite, which is 2.2 miles N. 10° E. of the memorial, are 1,600 million years (Wetherill and others, 1956) and 1,620±20 million years (Eckelmann and Kulp, 1957, p. 1130). Rubidium-strontium work by R. E. Zartman (written commun., March 21, 1967) has yielded similar ages for two samples of granite, one collected from within the memorial and the other from a locality 2 miles to the southwest.

STRUCTURAL GEOLOGY

The memorial is on the northeast flank of the Harney Peak dome. Strikes of schistosity and bedding, and of pegmatite sills, are northerly through much of the memorial, but they change to northwest on approaching the north side of the dome. The dip ranges from about 30° near the west boundary of the memorial to about 65° at the northeast corner. Details of the principal structures are shown on equal area nets in figures 5 and 6.

SCHISTOSITY, BEDDING, AND FOLDS

In most of the memorial, the strike is between N. 20° E. and N. 20° W., and the dip is 35°–55° E. In the area from Mount

Rushmore to the northwest corner of the memorial, most dips are between 20° and 45° east and northeast, and most strikes are between due north and N. 80° W. The northeast corner of the memorial has northeasterly strikes and steep southeast dips; these attitudes are in rocks entering the axial region of a fold that is beyond the boundary of the memorial and outside the region on which the Harney Peak dome has an important influence on the structure.

A few folds have been mapped in sec. 18 along the contacts of the unit of mica schist and quartzite. Exposures are so sparse near the axes of these folds that structural data are incomplete. On the geologic map the folds are shown as having rounded hinges, to accord with available evidence from float and outcrops, but analogy with folds outside the memorial suggests they may be more nearly isoclinal.

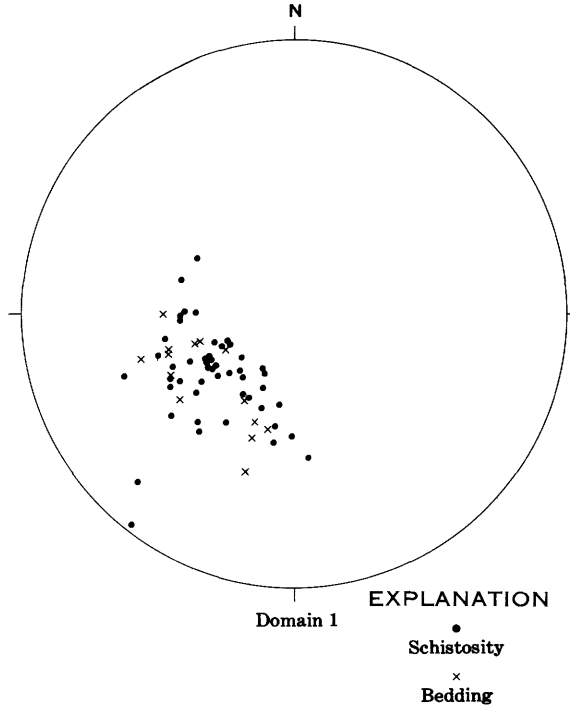
Schistosity and bedding are approximately parallel. Where small folds can be recognized, as they have been in only a few places, the schistosity is rarely at a noticeable angle with bedding or with fragments of transposed bedding.

STRUCTURES OF GRANITIC BODIES

The granite exposed along the western boundary of the memorial, in sec. 13, is at the east edge of the Harney Peak batholith. All other large bodies of granite in the memorial are sills, parallel or subparallel to the country rock structure. At Mount Rushmore, for example, schist is visible below the sculpture, and the granite contact is parallel to the schistosity. In few places are the granite sills more than 300 feet thick, but the sill south of Doane Mountain may be as much as 1,000 feet thick. All of the large sills are connected to each other, and to the batholith, by smaller sills and dikes. They also have offshoots that finger out into the country rock; the best example is south of Old Baldy Mountain, where several long sills come out of the granite.

Pegmatites as little as 1 foot thick and 40 feet long are shown on the geologic map. Many sills and a few dikes are 10–100 feet thick and 200–2,000 feet long. One of the long, steeply dipping dikes in the northeast part of the memorial extends for more than a mile, and most of it is less that 10 feet thick.

Sills are more abundant than dikes everywhere except in the northeast part of the memorial, where most of the pegmatites are northeast striking vertical dikes. A single pegmatite can occur as a dike in some places and a sill in others. Two of the three long dikes in the northeast part of the memorial, near their southwest end, turn parallel to the schist structure and become sills,



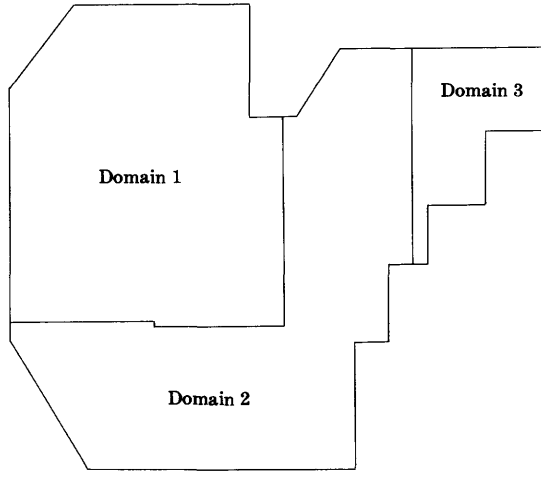
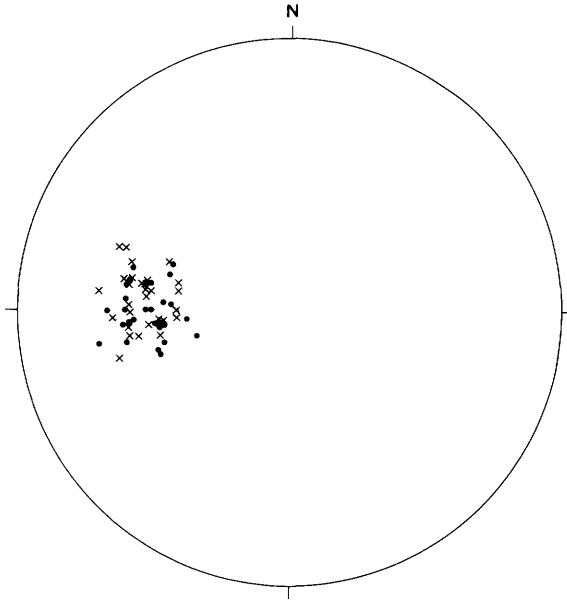
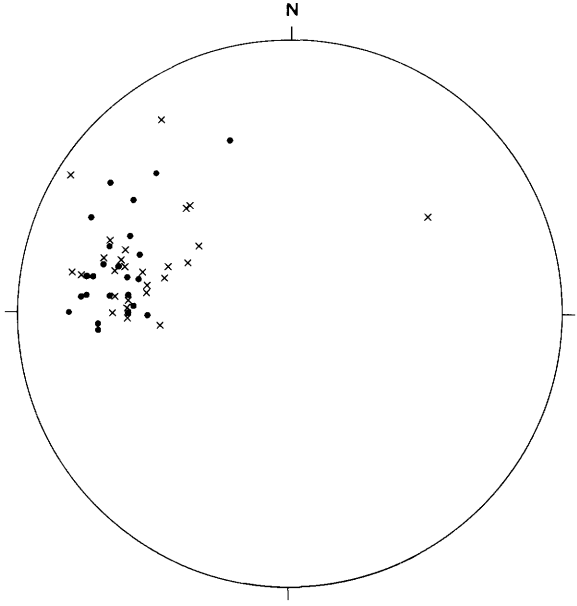


FIGURE 5.—Point diagrams, equal area net, lower hemisphere poles to schistosity and bedding.

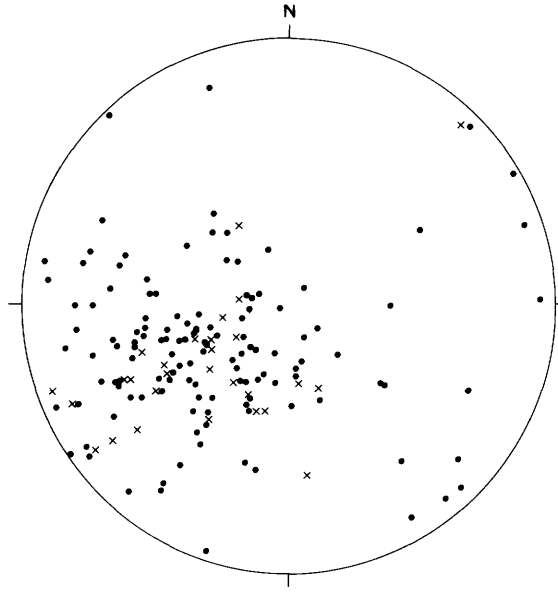


Domain 2

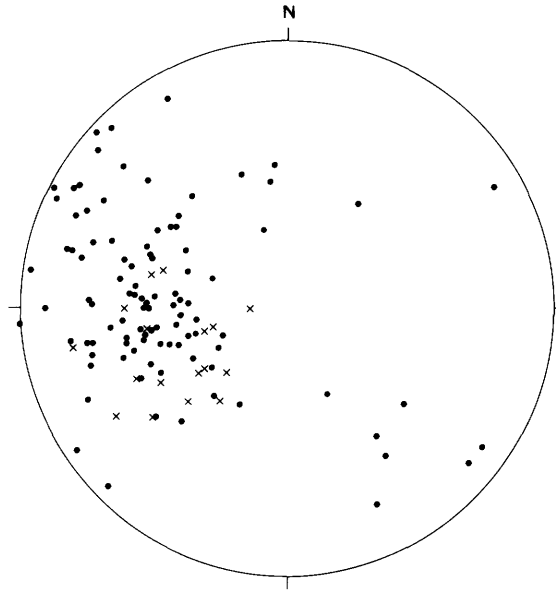


Domain 3

FIGURE 5.—Continued.

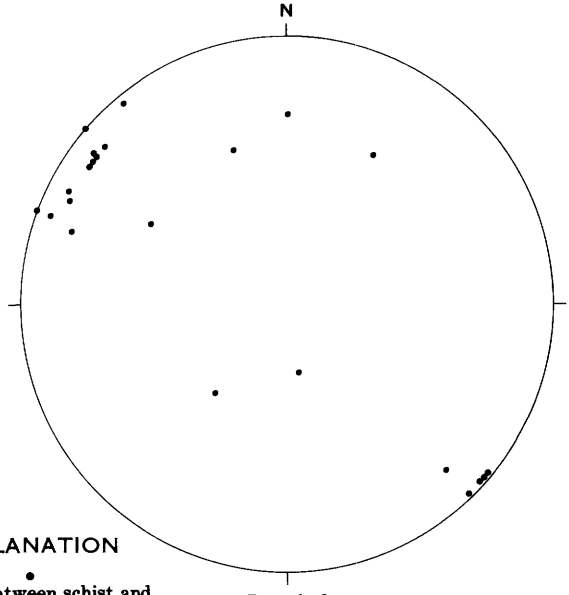


Domain 1



Domain 2

FIGURE 6.—Point diagrams, equal area net, lower hemisphere, poles to planar structures of granite and pegmatite. The lower right diagram shows attitudes of pegmatitic fracture fillings



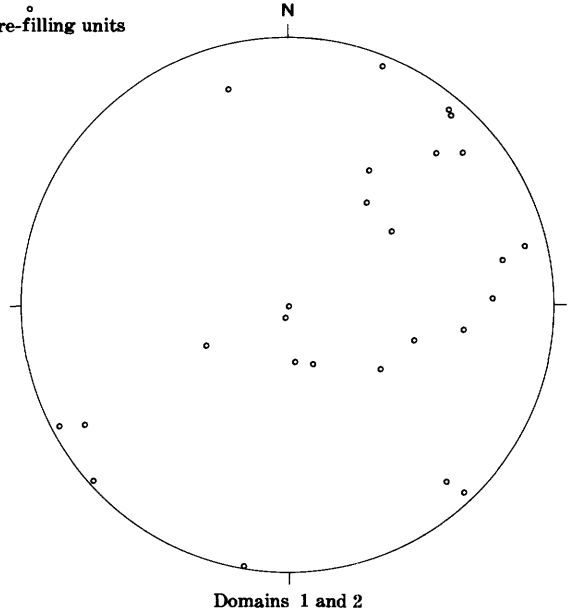
Domain 3

EXPLANATION

● Contact between schist and granite or pegmatite

× Schist inclusion in granite

○ Fracture-filling units



Domains 1 and 2

in granite. Other diagrams show attitudes of schist contacts and schist inclusions. Domains are the same as in fig. 5.

and the third has an S-shaped structure at its southwest end that is in part concordant with the schist. Each of these three dikes also has offshoots that are parallel to schistosity, as in the SE¼NE¼ sec. 18.

Within the granite bodies are many inclusions and narrow bodies of schist that protrude into the granite from the wallrock. Interleaving bodies of schist at Doane Mountain are large enough to show on the map. Most inclusions are tabular in shape, and their schistosity ordinarily has about the same strike and dip as the schistosity of the country rock. Some of the inclusions may be schist screens separating structurally independent bodies of granite, and others may be remnants of schist that were surrounded by magma and moved slightly or not at all from their original position.

Layering in the granite is generally parallel to the nearest contact, but fracture fillings have a wide range of attitudes (fig. 6). A sizable share of the fracture fillings have a strike between N. 15° E. and N. 60° W. and a dip between 40° and 85° W., approximately parallel in strike but perpendicular in dip to many of the granite sills.

JOINTS AND SHEAR ZONES

Joints are so abundant in outcrops of every kind of rock that a study of them was not practical. How many of them are merely near-surface effects and how many extend deep into unweathered rock can only be guessed. The top of Mount Rushmore and some of the other granite hills and mountains have deep clefts in the rock, which probably signify the presence of strong joints or groups of joints. The strike is commonly N. 45°–65° E., and the dip is steep.

The only evidence for a large shear zone or fracture zone is the lineament trending N. 8° W. through Starling basin and to the north. This lineament is prominent on aerial photographs, but no clear-cut reason for its existence was found in the field. Contacts that cross it are not displaced or are displaced very slightly, and neither breccia nor slickensides have been observed.

ECONOMIC GEOLOGY

Small prospect pits scattered across the eastern half of the memorial indicate that the area has been searched for mineral deposits. The present study has produced no evidence that deposits of economic significance have been overlooked.

Two pits in schist in the NE¼SE¼ sec. 7 and another pit in the NW¼NW¼ sec. 17 appear to have been sources of material

for road construction. Two pits in the SE¼SW¼ sec. 7 were for flagstone used in early construction at the memorial.

The numerous prospect pits in pegmatite seem to have been made mostly for sheet mica and potash feldspar. A small deposit called the Mica Hill, in the SE¼SW¼SE¼ sec. 7, produced sheet mica in the period 1943–45 (Page and others, 1953, p. 25). The four thin pegmatite sills near the center of the SE¼NE¼ sec. 18, which is outside the memorial, have patches rich in muscovite. They cannot be mined under normal price conditions, but they would have merited exploration at the high price levels of World War II.

Most of the potash feldspar of the pegmatites is too intermixed with other minerals to be recovered by hand-cobbing. A few small lenticular bodies, however, resemble deposits elsewhere in the Black Hills that have supplied a modest quantity of feldspar.

All other prospect pits were probably for gold, and all are unpromising. The widest part of the metamorphosed iron-formation, in the SW¼SE¼ sec. 7, contains pits that almost surely were gold tests, because early-day gold prospectors in the region gave close attention to iron-formation. Several pits also were dug in hornblende schist, probably because small aggregates of sulfide minerals were observed. The few pits in mica schist may have had small fracture zones, lenses of vein quartz, or other peculiarities that are not obvious now. The group of pits near well 4, for example, may be where the iron-stained and pyritic schist logged in the drill hole was exposed at the surface.

Neither mining nor prospecting is permitted within the memorial.

WATER RESOURCES

Starling basin, Lafferty Gulch basin, and East Boundary basin together constitute about 75 percent of the memorial area. They are probably hydraulically connected in the subsurface but are separate basins topographically in that each is separated from adjoining areas by a drainage divide. Two separate areas in the northwest and southeast parts of the memorial are parts of larger drainage basins that extend beyond the memorial boundaries.

The names Starling basin and Lafferty Gulch basin have been previously used in published topographic maps, but the name East Boundary basin is used for the first time in this report.

Pine forests grow on the peaks and on the sides of valleys, and deciduous trees and shrubs, together with pine, grow near the streams. The ponderosa pine is the conspicuous tree in the pine

forest and is the dominant plant in the memorial. At the higher altitudes, the pines are straight and evenly spaced; the forest floor is free of brush and large shrubs and is covered with extensive mats of bearberry (kinnikinnick).

Subdominant conifers include juniper and spruce, and prominent deciduous trees are birch, aspen, and scrub oak.

Deciduous streamside shrubs include several species of willows, red osier dogwood, Canadian buffalo berry, chokecherry, serviceberry, hazelbush, and pineberry. The area near spring 3 (2–6–7cdd1) has considerable growth of red willow, a significant phreatophyte or "water user."

It is beyond the scope of this report to determine precisely the amount of water in the memorial area that is lost by transpiration by plants and trees; however, the amount is significant and probably is the greatest single factor contributing to water discharge. Water entering the transpiration process becomes nonrecoverable. Such water is picked up by the root system of plants and trees, passes through the trunk, and is expelled or transpired into the atmosphere through the leaves.

Evapotranspiration, as it relates to the total water budget of an area, may be productive or nonproductive. Productive transpiration involves water transpired by trees or plants that yield products of economic or esthetic worth, whether they be food, fiber, or recreational opportunities. Nonproductive transpiration involves plants or trees such as underbrush, dwarf trees, and weeds which do not yield these products.

Long-term records of precipitation, streamflow, water use, and evaporation are necessary to determine quantitative values for transpiration. The National Weather Service (U.S. Weather Bureau) station at the memorial has existed for only 9 years (1962–70). Maintenance of this station to provide continuous climatological data would be of considerable help in determining transpiration and the total water budget for the area in future years.

A rough approximation of transpiration and evaporation, based upon an average annual precipitation of 19 inches, is 1,600 acre feet or 80 percent of the estimated annual precipitation (2,000 acre ft) that falls upon the memorial area.

GROUND WATER

The igneous and metamorphic rocks in the memorial have been extensively fractured by heat, pressure, and frost or ice action. Over much of the area these fractures are interconnected to provide secondary permeability and permit the infiltration and lateral movement of rain and snowmelt. The amount of ground

water available at a given location depends, therefore, upon the volume of broken or fragmented and fractured rocks present in the subsurface at that location.

Mica schist that has been intruded by granite and (or) pegmatite probably is a better aquifer than mica schist alone. Both Starling basin and Lafferty Gulch basin are underlain by mica schist extensively intruded by granite and pegmatite; they have considerably more ground water than East Boundary basin, which is predominantly schist intruded by few pegmatites.

The greater abundance of ground water, evidenced by the prevalence of springs in Starling and Lafferty Gulch basins, is probably due to more extensive fractures in the bedrock. The productivity of the aquifer penetrated by well 3 (2–6–7cdd2) is evidence of the extensive fractures in the schist bedrock in the vicinity of intrusives.

Ground water also occurs in alluvium and colluvium in the main stream valleys of Lafferty Gulch and Starling basins and in many of their tributary valleys. The material consists mostly of schist fragments, with lesser amounts of granite and pegmatite.

No test holes were drilled in alluvium in the valleys of Battle Creek or Grizzly Bear Creek, but field studies indicate that both valleys are underlain by as much as 100 feet of saturated material. The valleys are promising sources of future ground-water supplies.

DISTRIBUTION OF AQUIFERS

In the following discussion wells and springs are designated by number only. Records of wells are listed in table 1 and their locations are shown on plate 1.

TABLE 1.—*Records of wells in Mount Rushmore National Memorial*

[T, turbine; E, electric; S, submersible; N, not used; PS, public supply; I, industrial, X, records available]

Number and location	Depth of well (ft)	Diameter (in)	Water level: Range in depth below land surface (ft)	Water level: Period or date of measurement	Altitude (ft)	Type of lift	Use of water	Log on file	Chemical analyses	Aquifer
Well 2: 2–5–13 ddd	58	8	2.10–3.60	12–66 to 5–68	4,880	None	N	X	--	Alluvium
3: 2–6– 7 cdd2	200	6	Flowing	7–67 to 5–68	4,850	S, E	PS	X	X	Metamorphic rock
4: 2–6– 8 cad1	500	6	4.80–7.50	9–67 to 5–68	4,430	None	N	X	X	Do.
1: 2–6– 8 cad2	62.5	8	4.50–9.50	12–66 to 5–68	4,440	None	N	X	X	Alluvium
K_1: 2–6– 4 ccc	350	6	150	5–15–67	4,380	T, E	I	--	X	Metamorphic rock

Note:
In well 3, average flow was 10 gpm from August to September 1967.
Well K_1 is located in town of Keystone.

The following tabulation lists six of the larger springs inspected during this field investigation.

Number and location		*Average flow (gpm) 1967*	*Altitude (ft)*
Spring 1:	2–5–13aac	5	5,120
2:	2–5–13dda	1	4,920
3:	2–6–7cdd1	20	4,850
4:	2–6–8ccb	1	4,560
5:	2–6–18abb	7	4,810
6:	2–6–18dbb	4	4,940

Locations of the springs are shown on plate 1.

STARLING BASIN

Starling basin, which trends approximately north-south, includes about 335 acres in sec. 13. It has a floor mostly of schist mantled by alluvium, and is surrounded by high hills of granite and schist. The east side of the valley is formed by the granite bodies of Doane Mountain and Mount Rushmore, and the west side is approximately a dip slope of schist.

A lineament trending N. 8° W., which may be a zone of steeply dipping fractures, follows the axis of the valley and continues to the north. At the northwest side of Mount Rushmore, a notch in the granite is large enough to be recognized in topographic contours (topographic contour interval, 40 feet). The notch is probably the result of a northeast-trending set of fractures which, if projected, would cross the lineament mentioned above at the site of spring 1. An additional influence on the site of this spring may be a small pegmatite dike that dips to the north and is exposed on a hill to the west. Possibly this pegmatite acts as a dam, causing water flowing in the fractured schist to rise to the surface at the spring.

Ground water probably migrates down the dip slope of the schist toward the center of the valley on the west side and merges with ground water moving into the valley through fractures in the granite on the east side. The ground water then moves downgradient through the alluvium and underlying fractured schist bedrock toward Grizzly Bear Creek.

Well 2, in the lower end of Starling basin, penetrates 58 feet of alluvium consisting mostly of sand. During 1967 the water level in the well ranged from 2.14 to 3.60 feet below land surface and averaged 3.10 feet below land surface.

The areal extent of the relatively thick alluvium deposit in the vicinity of well 2 is not known, but ground-water flow is impeded a short distance north of the well by a granite body that extends across the valley. South of well 2 the alluvium is continuous to the confluence of Starling basin and the valley of Grizzly Bear Creek.

The alluvium in Starling basin is potentially a productive aquifer. However, it is separated from existing-water distribution facilities by 0.5 mile of rugged topography and is 400 feet lower in altitude. The water-yielding potential of the underlying mica schist bedrock may also be substantial, but it has not been investigated because of inaccessibility of the area.

In Starling basin, two undeveloped springs (not modified or improved by man) contribute water to an unnamed tributary of Grizzly Bear Creek: spring 1 flowed an average of 5 gpm (gallons per minute) during 1967; spring 2 flowed only during periods of snowmelt and heavy rainfall and by July 1967, all flow had ceased. An undeveloped spring, outside but near the boundary of the memorial, contributes water to a tributary that enters Starling basin from the west. The tributary had an average flow of 7 gpm in 1967 at its confluence with the main Starling basin drainage. Ground-water discharge from springs and seeps furnished virtually the entire flow from Starling basin during the driest parts of the summer and fall of 1967, a comparatively dry year, and during the summer and fall of 1968.

LAFFERTY GULCH BASIN

Lafferty Gulch basin includes about 380 acres in the S½ sec. 7, the SE¼ sec. 12, the NE¼ sec. 13, and the N½ sec. 18. The axis of the basin approximately follows the strike of the rocks, but prominent tributary valleys cross the strike. Sills of granite and pegmatite are abundant on the west side of the gulch, and mica schist and quartzite occupy most of the east side. The floor of the valley is of mica schist that is much less resistant to erosion than granite and pegmatite. The valley trends to the east in its upper reaches in the N½ sec. 18 and extends around a fold of mica schist and quartzite. The head of the valley is in the NW¼ sec. 18 between two ridges formed by granitic sills.

The small valley in which well 3 is located trends east, probably because of the absence of erosion-resistant pegmatites in that direction. The easterly trends of this and other small valleys tributary to the main drainage in Lafferty Gulch may also be due to zones of weakness caused by a series of joints.

The aquifer that supplies well 3 is mainly mica schist. The rocks apparently are extensively fractured and permeable, as water production from other individual wells in the schist in the central Black Hills is considerably less than production of well 3. The aquifer, the principal aquifer in the memorial, underlies about 120 acres, most of which is southwest of and topographically higher than well 3.

The water-bearing characteristics of the rocks in Lafferty Gulch east of well 3 are not definitely known. However, the absence of springs and seeps indicates that water is less plentiful than at the higher altitudes in the basin to the west.

In Lafferty Gulch basin two developed springs, spring 5, locally known as Red Spring, and spring 3, locally known as Rushmore Spring, issue from the fractured schist aquifer and contribute water to Lafferty Gulch. The only improvement at Red Spring is a section of 1¼-inch pipe thrust into the seep area. Average flow during 1967 was about 7 gpm. However, the spring is downgradient from sewage filters in the memorial and may be susceptible to contamination.

Spring 3, which is about 400 feet west of well 3, flows into an elaborate catchment system. It furnished the total water supply for the memorial from 1927 to October 1967. The average flow was 20 gpm for the period 1960–67. The lowest flow recorded was 11 gpm in April 1962, and the greatest was 80 gpm in June 1962.

The flows of well 3 and spring 3 result from the hydraulic head produced by a pegmatite or granite sill. This intrusive body acts as a ground-water dam that forms a reservoir at higher altitudes in the subsurface to the southwest. If it were not for the damming effect of the sill, water would drain rapidly from the aquifer, which slopes about 12° NE. The flow at spring 3 probably is from a joint or fracture system that intercepts the aquifer.

Lafferty Gulch basin has a narrow outlet through which the escaping ground water must migrate and surface water must flow. The gradient of the valley floor is much steeper than in Starling basin, and the topography and geology are more complicated. Ground water probably is as plentiful but is more erratic in its distribution than in Starling basin.

EAST BOUNDARY BASIN

East Boundary basin contains about 318 acres in part of the SW¼ sec. 8, the SE¼ sec. 7, and the NE¼ sec. 18. The geology differs from that of the other two basins in that the rocks include fewer pegmatites and a different kind of schist. The schist is less micaceous and less schistose and probably contains fewer fractures and less ground water than schist in the other two basins.

The valleys in this part of the memorial rarely have flowing streams except during times of heavy precipitation. Most of the water leaving the basin, therefore, is ground water migrating through the alluvium and fractures in the underlying bedrock near wells 1 and 4.

OTHER LOCALITIES

The largest area not included in the three main drainage basins comprises about 237 acres in sec. 18 in the southeast part of the memorial. Pegmatite is especially abundant in the south half of sec. 18, which contains an upland area and a steep slope down to Grizzly Bear Creek. Water probably drains readily from this upland down to the creek level, thus maintaining high water levels in the alluvium even when the creek does not flow.

East of the center of sec. 18, a small but pronounced east-trending valley and several tributary valleys cut through the few places where pegmatite is absent or scarce. Water from spring 6, in the upper reaches of this valley, flows for a short distance and is collected and used at the Grizzly Bear Campground to the east. The geology here is similar to that at spring 3, where a pegmatite or granite sill blocks the flow of ground water. The area in the vicinity of spring 6 is a promising site for a supplemental groundwater supply for the memorial; it is accessible by road and by pipeline from the main storage and distribution system.

The remaining part of the memorial not included in the three main drainage basins consists of about 110 acres in the SE¼ of sec. 12. The bedrock here is mica schist which has been intruded by granite and pegmatite. A few small springs are associated with contacts of intrusions. Groundwater is probably available from fractured mica schist, but it would be very costly to pipe it to the water-storage area at the memorial.

TEST DRILLING AND WELL CONSTRUCTION

PRIOR INVESTIGATIONS

Previous test drilling in the memorial was for an investigation in 1960. The first test hole was drilled in July 1960 near the northeast boundary in East Boundary basin and later was completed as well 1 (2–6–8cad2). The drill penetrated 61 feet of alluvium. The logs of this and other wells and test holes cited in this report are given in table 2.

The second test hole drilled during the 1960 investigation, here designated well 2 (2–5–13ddd), was in Starling basin in the southwest part of the memorial. The test hole was drilled and cased to a depth of 58 feet. The well has not been used because other sources of water are nearer to the distribution system.

A third test hole (2–6–8ccb) drilled in 1960 was at the site of a small spring near the point State Highway 87 crosses the west line of sec. 8. The test hole was not developed as a supply well because the material penetrated had low permeability and contained very little water.

TABLE 2.—*Logs of wells and test holes drilled*

[Wells 1 (2–6–8cad2) and 2 (2–5–13ddd) and test hole (2–6–8ccb) were drilled during previous investigations. Wells 3 (2–6–7cdd2) and 4 (2–6–8cad1) were drilled during this investigation]

Mount Rushmore National Memorial well 1 (2–6–8cad2) at East Entrance area 2,550 ft from west line, 1,850 ft from south line, NE¼SW¼ sec. 8, T. 2 S., R. 6 E., Pennington County, S. Dak. Drilled July 1960. Cuttings examined and described by J. P. Gries.

Material	*Thickness (ft)*	*Depth (ft)*
Silt, sandy, buff to gray; consists of quartz and muscovite mica with minor amounts of weathered feldspar	10	10
Do	5	15
Sand, silty, gray micaceous; consists of angular to subangular quartz with much muscovite and biotite mica; few fragments of muscovite-quartz schist	5	20
Sand, silty, gray; same as unit above, more fragments of fresh quartz-muscovite schist	5	25
Silt, sandy; consists of quartz, muscovite and biotite mica; no coarse fragments	5	30
Do	5	35
Sand, coarse to fine, poorly sorted, subangular; fragments of weathered and fresh schist	2	37
Silt, sandy; consists of quartz, muscovite and biotite mica; no coarse fragments	3	40
Sand, coarse to fine; coarse quartz and schist fragments, which may possibly be caved	5	45
Sand, same but yellow; weathered-looking	5	50
Sand, same but more coarse quartz	5	55
Sand, same but more coarse quartz fragments	6	61

Mount Rushmore National Memorial well 2 (2–5–13ddd) at south boundary 500 ft from east line, sec. 18, and just north of south line, sec. 13, Pennington County, S. Dak. Drilled July 1960. Cuttings examined and described by J. P. Gries.

Material	*Thickness (ft)*	*Depth (ft)*
Sand, coarse; consists of quartz, muscovite, and white feldspar; typical "granite wash"	10	10
Granules and coarse sand, composition as unit above	5	15
Same as unit above, with much interstitial clay and silt, buff	3	18
Sand, gray, micaceous; consists of the same three minerals	2	20
Sand, fine, and gray silt; composition as above	10	30
Sand, light, clean; still quartz, white feldspar, and muscovite mica	5	35
Sand and grit, clean, white; mostly quartz and feldspar with minor amounts of mica	4	39
Sand, same but dirty, with interstitial silt and clay, gray-brown	3	42
Sand, clean; quartz and feldspar with minor amount of muscovite mica	3	45
Do	10	55
Sample labeled "washed into bottom of casing" consists of clean quartz-feldspar-mica sand with an assortment of heavy black minerals	3	58

TABLE 2.—*Logs of wells and test holes drilled*—Continued

Mount Rushmore National Memorial test hole (2–6–8ccb) at spring area 100 ft west of junction of U.S. Highway 16A and State Highway 87, Pennington County, S. Dak. Drilled 1960. Cuttings examined and described by J. P. Gries.

Material	*Thickness (ft)*	*Depth (ft)*
Silt, yellowish-gray; consists of quartz, weathered feldspar, and both muscovite and biotite mica	5	5
Silt and fine sand, light-gray, fresh; consists of quartz, mica, and feldspar	5	10
Silt, same as unit above, but not so fresh in appearance	5	15
Do	5	20
Silt and fine sand, gray, no coarse fragments	5	25
Do	10	35
Silt, same as unit above but few sand grains	5	40
Do	10	50
Silt, same as unit above, weathered yellow (sand and silt, but coarser at 55 ft)	5	55
Silt, dirty, yellow	5	60
Silt and fine sand, gray but weathered	5	65
Silt and fine sand, same	5	70
No sample	5	75
Silt, fresh, light-gray; mostly quartz and biotite	5	80
No sample	10	90
Silt, fresh, light-gray, mostly quartz and biotite	4	94

Mount Rushmore National Memorial well 3 (2–6–7cdd2) below springs in water storage area, Pennington County, S. Dak. Drilled July 1967 by Hamm Construction Co. Cuttings examined and described on July 14, 1967, by J. P. Gries.

Material	*Thickness (ft)*	*Depth (ft)*
Granite wash, consists of white feldspar, quartz, and mica	5	5
Granite, same as unit above, and gray mica schist	5	10
Schist, mica, finely drilled up	5	15
Do	15	30
Schist, apparently a weathered zone	5	35
Schist	15	50
Schist, fresher than above	5	55
Schist, more weathered	10	65
Schist, fresher	5	70
Schist, same as unit above with some granite; may be caved from top	10	80
Schist	5	85
Schist, fresh	10	95
Schist, weathered streak	5	100
Schist, fresh	5	105
Schist, weathered	5	110
Schist, fresh	5	115
Schist and some granite, may be cavings	5	120
Schist and some caved granite	5	125
Schist, very fine grained	5	130
Schist, some weathered	10	140

TABLE 2.—*Logs of wells and test holes drilled*—Continued

Mount Rushmore National Memorial well 3 (2–6–7cdd2)—Continued

Material	*Thickness (ft)*	*Depth (ft)*
Schist, fresh	15	155
Schist, weathered	10	165
Schist and granite	5	170
Schist	5	175
Schist, slightly weathered	10	185
Granite, fresh; consists of white feldspar, quartz, and mica	5	190
Granite, very fine grained. Apparently very hard, as stained by bit fragments	5	195
Granite	5	200

Mount Rushmore National Memorial well 4 (2–6–8cad1) in East Entrance area, Pennington County, S. Dak. Drilled August and September 1967 by Hamm Construction Co. Cutings to 400 ft examined and described by J. P. Gries.

Material	*Thickness (ft)*	*Depth (ft)*
No samples	20	20
Schist, mica, fine-grained, weathered	5	25
No sample	10	35
Schist as above, and some coarse quartz, mica, and feldspar. Driller logged granite pegmatite at 35 ft	5	40
Probably white granite, much schist cavings	5	45
Granite, white; trace of caved schist	5	50
Granite or quartz-mica dike. Sample appears very low in feldspar	5	55
Granite, consists of white feldspar, muscovite, quartz, and much pyrite	5	60
Schist and granite. Probably a schist horse or stringer within the granite	5	65
Granite, plus about half schist as above	5	70
Granite, white	5	75
Muscovite mica with a trace of quartz. Probably a mass of low-grade mica	5	80
Granite, fine-grained, white	5	85
"Bull-mica" zone consisting of fine to coarse mica and quartz	5	90
Granite, fine-grained mica, feldspar and quartz. Driller logged change at 104 ft	15	105
White pegmatite, consists of mica and quartz with a trace of feldspar	5	110
Pegmatite, same, plus some weathered pyritic schist	5	115
Schist, less weathered	5	120
Schist, mica, pyritic; some caved pegmatite	5	125
Mica schist, same. Most of iron stain is from bit chips	10	135
Mica schist, fresh and unstained, pyritic	25	160
Mica schist, very pyritic, some oxidized	5	165
Schist as above, and new white granite. Driller logged change at 168 ft	5	170

TABLE 2.—*Logs of wells and test holes drilled*—Continued

Mount Rushmore National Memorial well 4 (2-6-8cad1)—Continued

Material	*Thickness (ft)*	*Depth (ft)*
Granite, somewhat coarser	5	175
Granite, white, somewhat bit-stained	10	185
Granite, same, but probably weathered or altered	5	190
Granite, weathered to fresh	5	195
Granite, same, and some red contact zone rock	10	205
Biotite-garnet-tourmaline schist	5	210
Schist, as above, with some granite as below	5	215
Granite, white but slightly weathered	5	220
Granite, slightly stained; some border zone rock	10	230
Granite, white, and biotite-garnet schist. Driller logged change back to schist at 234 ft	15	245
Biotite-garnet schist	20	265
Schist with biotite and muscovite	5	270
Contact zone, with garnet schist and fine-grained schist	5	275
Mixture, same as unit above	5	280
Biotite schist	5	285
Biotite-garnet schist	5	290
Schist and border zone pegmatite	5	295
Muscovite-tourmaline schist	5	300
Muscovite-biotite-garnet schist	15	315
Garnet schist	5	320
Biotite-garnet schist	5	325
Schist, same, slightly stained by bit chips	5	330
Biotite schist, slightly bit-stained	15	345
Biotite-garnet schist	5	350
Muscovite-biotite schist	10	360
Schist, same, bit-stained	10	370
Tourmaline-biotite-muscovite-garnet schist, in addition to bit-stain. Driller logged oxidized zone 370–375 ft	5	375
Same as above, and into fine-grained granite	5	380
Granite, white, fine- to coarse-grained	5	385
Granite, same, and some very garnetiferous schist	5	390
Border zone between chilled granite and schist	10	400
Driller's log by Hamm Drilling Co., Rapid City, S. Dak.		
Schist, fine-grained, gray fracture	10	410
Schist, fine to coarse, gray fracture	5	415
Schist, fine, medium-hard, white	20	435
Schist, fine, gray	25	460
Do	10	470
Schist, medium, hard, gray	5	475
Schist, fine, hard, gray; garnets; possible fractures at 480 ft	25	500

THIS INVESTIGATION

Information gathered during this investigation indicates the presence of potential ground-water sources in several areas of the memorial. Two of these sites, near existing water-supply and pipeline facilities, were selected for testing.

The first test hole was drilled near the water-storage tanks and was later completed as well 3 (2–6–7cdd2). The site is a few feet downgradient and 400 feet east from spring 3. The hole was drilled with a cable-tool rig to a depth of 200 feet and was completed July 14, 1967. The rocks consisted of 185 feet of mica schist with numerous fracture zones showing weathering and 15 feet of granite. A few thin stringers of pegmatite also are in the initial 185 feet. Water began to flow from the test hole at a rate of 10 gpm when the interval from 95 to 120 feet was penetrated by the drill. The interval from 185 to 200 feet consists of very hard fine-grained granite which almost certainly is part of a sill. The well was cased to 200 feet with 6-inch diameter steel casing, and perforated from 30 to 200 feet with 12-inch long by ¼-inch wide slots. The casing is cemented in the interval from land surface to 30 feet below land surface.

Well 3 was connected to the water-distribution system on December 31, 1968, and since that time has been the principal source of supply for the memorial.

The drilling of the second test hole, later completed as well 4 (2–6–8cad1), was begun with cable-tool equipment on July 24, 1967, and completed on September 8, 1967. The well is near highway 16-A at the east boundary of the memorial. The test hole was drilled to a depth of 500 feet and penetrated mostly mica-schist. Pegmatite was penetrated from 40 to 115 feet, 168 to 234 feet, and 380 to 400 feet. Water-saturated fractures occurred in the intervals 105 to 125 feet, 370 to 379 feet, 395 to 410 feet, 415 to 435 feet, and 480 to 495 feet. When the test hole was completed, the static water level was 7.4 feet below land surface. The test hole was cased to 500 feet with 6-inch steel casing. The casing was cemented to a depth of 30 feet and was perforated with 12-inch long by ¼-inch wide slots from 100 to 120 feet, 140 to 170 feet, 200 to 220 feet, 240 to 260 feet, 280 to 300 feet, 320 to 340 feet, and 370 to 500 feet.

RESULTS OF PUMPING TESTS

Controlled pumping tests of wells 3 and 4 were made during the late summer and fall of 1967. Inasmuch as the aquifers penetrated by the wells are composed of dissimilar materials and are of unknown and probably small areal extent, no aquifer coefficients could be determined. However, considerable data were accumulated that provide a basis for estimating the response of the aquifers to prolonged pumping.

On August 14, 1967, well 3, which was flowing 11 gpm at land surface, was shut-in for 12 hours; at the end of this time shut-in

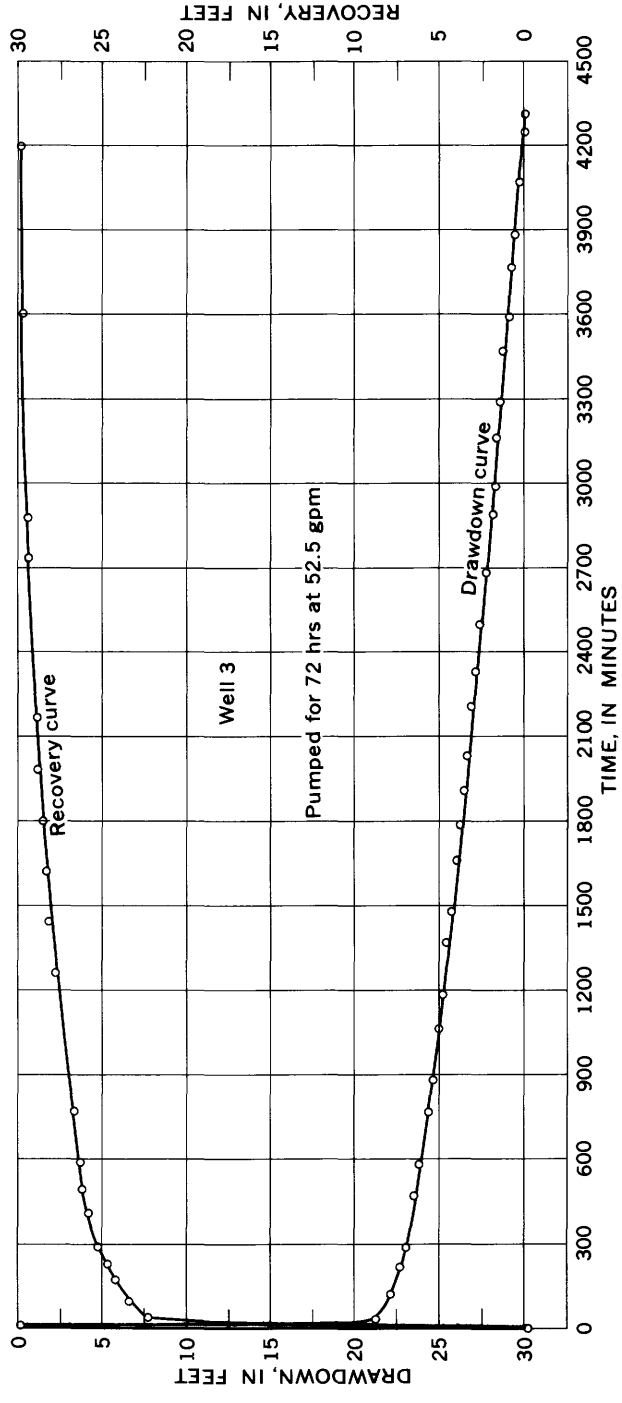
pressure at land surface was 1.6 psi (pounds per square inch). From August 15 to 18, 1967, well 3 was pumped for 72 hours at a rate of 52.5 gpm. The water level dropped 30.15 feet during the test and recovered to the original static level 72 hours after the pump was stopped. During 1968, the well flowed at an average rate of 10 gpm and had 1.5 psi shut-in pressure at land surface. The average flow in 1969 was 12 gpm; the well then had 1.6 psi shut-in pressure at land surface.

From September 18 to 22, 1967, well 4 was pumped for 72 hours at an average rate of 46 gpm. The water level in the well dropped 125.20 feet. After the pump was stopped, the water level recovered rapidly for 24 hours, but the rate of recovery gradually decreased so that the water was still 4.50 feet below the original static level after 72 hours and 1.60 feet below after 172 hours. The slow rate of recovery of water level in the last 4.50 feet probably indicates that the aquifer was partially dewatered during the pumping period. The following tabulation lists total drawdowns and specific capacities for the two wells.

Well	*Well depth (ft)*	*Pumping rate (gpm)*	*Depth to water (ft)*	*Total drawdown (ft)*	*Specific capacity (gpm per ft)*
3	200	52.5	Flowing	30.15	1.74
4	500	46	7.40	125.20	0.38

Drawdown and recovery curves based upon wetted-tape measurements of water levels in wells 3 and 4 during the pumping tests are shown in figure 7. These curves are used to determine the relative yields of the two wells. For example, after 40 hours of pumping, well 3 was yielding 52.5 gpm with 27.5 feet of drawdown. The water level in well 4 during the same interval of pumping at the lesser rate of 46 gpm had dropped 108 feet, almost four times the drawdown in well 3. The aquifer penetrated by well 3 probably was partially dewatered during the test. This is evidenced by the slow rate of recovery of water level in the well and by displacement of points from the drawdown curve in figure 7.

The results of the tests show that well 3, which is 200 feet deep, will produce more water with less drawdown than well 4, which is 500 feet deep. The difference in production from the two wells is due entirely to differencs in geology at the two locations. The aquifer penetrated by well 3 is more fractured and has greater permeability than that penetrated by well 4. In the vicinity of well 3 an intrusive body inhibits the movement of ground water downgradient from the well. There is no evidence of similar conditions in the vicinity of well 4. Well 3 can sustain pumping


RECOVERY, IN FEET
30
25
20
15
10
5
0
Recovery curve
Well 3
Pumped for 72 hrs at 52.5 gpm
Drawdown curve
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
3900
4200
4500
TIME, IN MINUTES
0
5
10
15
20
25
30
DRAWDOWN, IN FEET

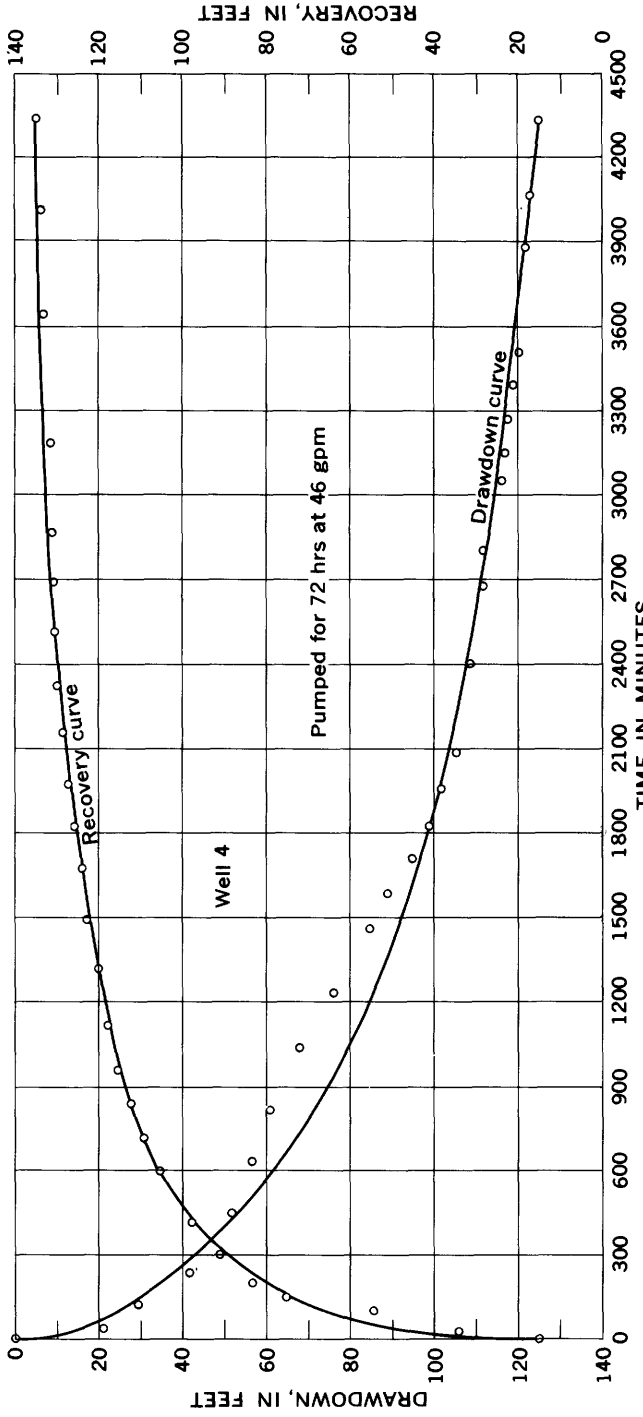


FIGURE 7.—Drawdown and recovery curves for wells 3 and 4

rates of up to 50 gpm, and well 4 rates of 25–30 gpm for periods of 10–12 hours per day during times of normal or slightly less than normal precipitation. During periods of deficient precipitation, pumping rates would have to be reduced to maintain continuous production of water from either well.

RECHARGE AND DISCHARGE

Recharge to aquifers in the memorial is entirely from precipitation. The high altitudes of numerous ridges, and the steep slopes of deeply incised valleys prevent ground water from moving in from adjacent areas. Heavy stands of pine forests and covering underbrush on the forest floor retard runoff and thus encourage infiltration of water into the fractured bedrock aquifers. In years when snow cover is heavy and temperatures rise rapidly in the spring, much of the accumulated snow melts and runs off, but when temperatures rise gradually a greater proportion of the snowmelt infiltrates into the bedrock. The distribution and intensity of rainfall influence recharge in a similar manner.

An average annual precipitation of 19 inches would provide sufficient ground-water recharge to maintain spring flow, streamflow, and production of water from wells in the memorial. However, if annual precipitation is less than about 15 inches, spring discharge will be greatly reduced, streamflow will probably cease, and well production will diminish. Each inch of annual precipitation in excess of 15 inches provides about 20 acre-feet or 6,500,000 gallons of water. Only a small part of this, however, would be available to recharge an individual aquifer.

The three main drainage basins probably are hydraulically connected in the subsurface by fractures and joints in the bedrock. However, interbasin exchange of ground water is probably small. The direction of ground-water movement in the basins is normal to the main drainages where entering and parallel to the main drainages where leaving the basins.

Transpiration by trees is the greatest single parameter in ground-water discharge. The heavy forest cover in the memorial transpires an estimated 1,600 acre-feet of ground water per year or four times the average annual runoff. The pine tree transpires considerably more water than a hardwood of comparable size (Swank and Miner, 1968, p. 948). Increased efficiency in reporting and controlling fires and insect and fungus diseases has resulted in heavier forest cover in the memorial and throughout the Black Hills. This has caused increased discharge of ground water by transpiration and a consequent reduction in spring discharge and streamflow.

Flow from springs in the memorial is also a significant factor in the discharge of ground water. Springs vary in size from small seeps on cliff faces to strong flows issuing from valley floors. The complicated structure of the rocks causes a haphazard distribution of springs and an apparently illogical location for many of them. At some locations springs flow from fractures in solid rock, and in other locations the water is brought to the surface as a result of underground dams of intrusive dikes or sills or fault structures. Generally the water migrates for a considerable distance through fractured rocks in the subsurface before it reaches the rock structure necessary to bring it to the surface. All springs, however, are intimately associated with fractures, fissures, and schistosity or bedding planes in igneous or metamorphic rocks exposed throughout the area. The aquifers that supply the springs are recharged by rain and snowmelt at higher altitudes.

Sufficient data are not available to calculate the percentage of the average annual runoff that is the result of ground-water discharge. However, a conservative estimate is 20 percent or about 80 acre-feet or 26 million gallons. It would not be practical to intercept and use all of this discharging ground water. However, additional wells in carefully selected locations could intercept a sufficient amount of water to provide the memorial's needs for many years into the future.

STREAMS

The estimated average annual runoff from the memorial is 400 acre-feet, or 130 million gallons per year. Thus, more than twice the 7.7 million gallons of water used in 1969 would be available if 12 percent of the runoff could be intercepted and used. The runoff estimate is based upon data from the gaging station on Battle Creek near Keystone just east of the memorial.

Battle Creek drains the memorial and the area to the north and west. It is joined east of the memorial by its major tributary, Grizzly Bear Creek, which flows along the south boundary and across the southeast corner. Many relatively small spring-supplied tributaries flow from the memorial to Battle and Grizzly Bear Creeks. The flows of Battle and Grizzly Bear Creeks gradually diminish during the fall and winter months, and many days of no flow are recorded during some years. A large percentage of the annual runoff normally occurs during the snowmelt and heavy rainfall periods.

The 15 inches of precipitation per year, necessary to maintain streamflow in the memorial, is an amount slightly in excess of the estimated demands of evapotranspiration. The estimate is

based upon average annual runoff of 400 acre-feet and average annual precipitation of approximately 19 inches. The estimate of evapotranspiration is the difference between average annual runoff and average annual precipitation. Additional factors which influence streamflow are areal distribution of precipitation, humidity, temperature, and wind velocity.

The only permanent stream-gaging station near the memorial is on Battle Creek near Keystone in SW¼SW¼ sec. 18, T. 2 S., R. 7 E., about 4½ miles southeast of the memorial. The average discharge at this station for the period July 1945 to July 1947 and October 1961 to September 1969 was 11.1 cubic feet per second (cfs) or 8,040 acre-feet per year. Figures 8 and 9 show monthly discharge and monthly distribution of runoff, respectively, for the period of record.

The discharge measurements on page 43 were made on Grizzly Bear Creek for the period April 3 to December 21, 1967. The annual precipitation in 1967 was about average for this part of the Black Hills. The location of the measuring section was 50 feet downstream from the highway bridge at Grizzly Bear Campground near the southeast boundary of the memorial.

TABLE 3.—*Chemical analyses of water from*

[Chemical constitutents are given

Name and location	Source	Elapsed time after start of pumping (minutes)	Date of collection	Temperature (°C)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)
Starling Basin Creek 2–5–13ddd.	Creek		5–15–67	6	42	20	0.06	0.05
Well K1, Northwest Beryllium Co., town of Keystone 2–6–4ccc[1].	Metamorphic rock	Continual	5–15–67	12	53	18	.48	1.1
Spring 3, Lafferty Gulch basin 2–6–7cdd1.	Spring Flowing from metamorphic rock		5–15–67	8	47	23	.05	.04
Well 3, Lafferty Gulch basin 2–6–7cdd2.	Metamorphic rock	120	7–17–67	12	54	27	.08	.00
Well 4, East Boundary basin 2–6–8cad1.	do	60	9–19–67	9	49	20	4.1	.27
		4,260	9–22–67	9	49	22	1.0	.09
Well 1, East Boundary basin 2–6–8cad2.	Alluvium	5	4–12–67	8	46	4.0	6.2	.43
		240	4–12–67	8	46	17	.26	.06
Grizzly Bear Creek at campground 2–6–17bcb.	Creek		5–15–67	6	42	16	.05	.02

[1] Well K1 is outside the Memorial in the town of Keystone about 5,000 ft northeast from the east entrance.

Date (1967)	Mean velocity (fps)	Discharge (cfs)
April 3	0.49	0.64
May 15	1.08	3.30
June 21	2.35	16.3
September 6	.68	.25
October 17	.51	.34
November 7	.92	.22
November 30	2.43	.41
December 21	.85	.23

WATER QUALITY

Analyses of surface and ground water show that the chemical quality of water in the memorial generally is very good. However, water from wells 1 and 4 in East Boundary basin near the east entrance contains excessive amounts of iron and manganese. Table 3 lists chemical analyses of water from wells, springs, and streams in the memorial and from one private well, No. K_1, in Keystone a short distance east of the memorial. The analysis of water from the latter well is included for comparison. All analyses were made at the U.S. Geological Survey laboratory in Lincoln, Nebr.

selected wells, springs, and streams

in milligrams per liter]

Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (Residue on evaporation at 180° C)	Hardness as $CaCO_3$: Calicum and magnesium	Hardness as $CaCO_3$: Noncarbonate	Alkalinity as $CaCO_3$	Specific conductance (micromhos at 25° C)	pH	Color
8.2	2.5	4.5	1.7	27	21	0.5	0.2	0.2	0.00	88	31	9	22	106	6.8	5
108	52	14	5.8	173	345	13	.7	.0	.05	699	484	342	142	922	7.8	3
11	1.9	6.3	2.1	54	7.0	1.4	.1	3.2	.00	100	35	0	44	116	7.0	2
11	2.2	10	2.3	49	7.0	2.5	.1	5.5	.02	97	36	0	40	117	6.8	2
38	14	12	5.5	179	23	5.3	.6	.1	.04	210	152	5	147	336	7.6	1
43	15	13	5.0	193	31	3.4	.6	.0	.02	233	168	10	158	372	7.4	1
39	11	9.4	57	184	9.2	59	.2	.0	.07	289	143	0	151	524	7.9	2
33	11	7.6	4.5	152	12	12	.2	.0	.01	195	128	3	125	303	7.4	4
6.0	1.7	3.5	1.7	25	12	.5	.2	.1	.02	60	22	2	20	73	7.0	7

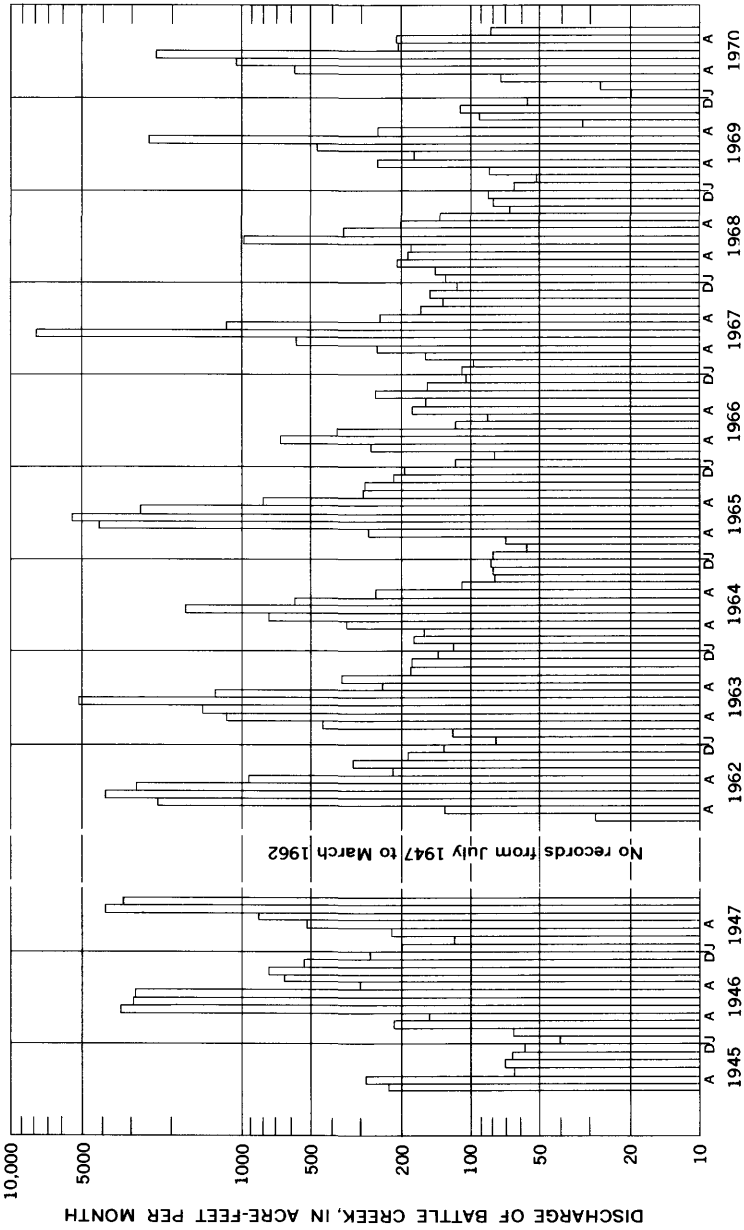


FIGURE 8.—Monthly discharge at Battle Creek gaging station near Keystone, S. Dak.

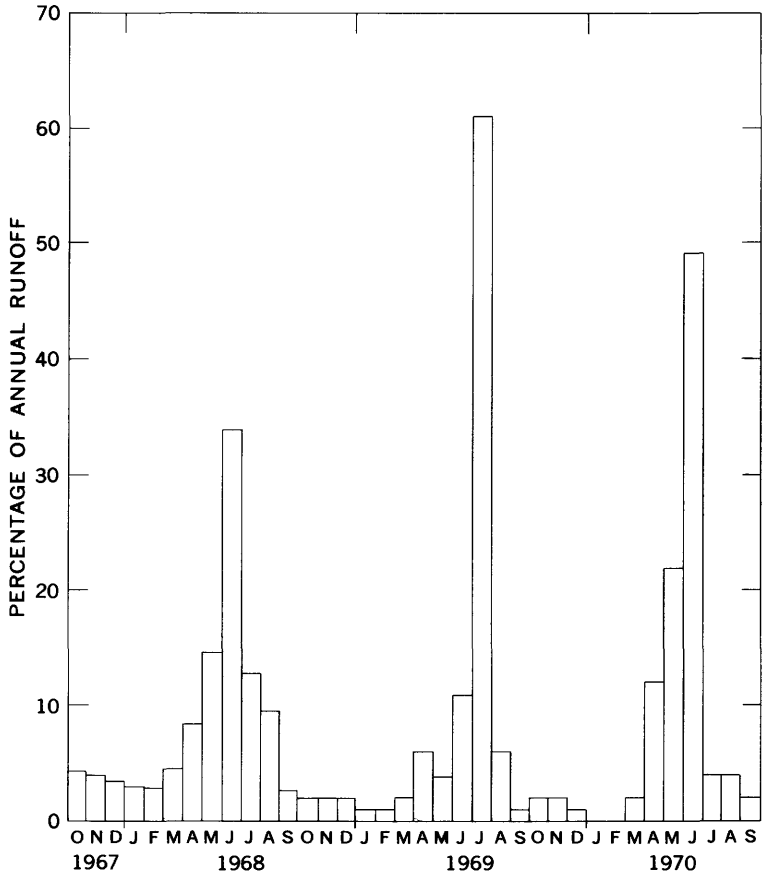


FIGURE 9.—Monthly distribution of runoff at Battle Creek gaging station near Keystone, S. Dak.

The analyses show only the dissolved mineral content of the water, not its sanitary condition. The dissolved mineral constituents are reported in milligrams per liter.

Water dissolves part of the soluble mineral constituents of rock or other soil particles as it moves through an aquifer or over the land surface. The amount of minerals dissolved depends principally on the concentration and type of soluble materials and the length of time that the water is in contact with them. Therefore, in a given aquifer, water that has been stored underground for a long time or that has traveled a long distance usually is more highly mineralized than water that has infiltrated recently or that has moved only a short distance. If the rocks are composed of constituents that impart undesirable characteristics to the

water, such as calcium, magnesium, or iron, the water may be of poor quality. However, if the rocks are composed largely of silica compounds or other compounds relatively resistant to solution, the water will be of superior quality for human use.

The U.S. Public Health Service (1962) has established standards for drinking water used on common carriers in interstate traffic. Listed below are the recommended maximum concentrations of some of the chemical constituents commonly present in drinking water:

Chemical constituents	*Recommended maximums (mg/l)*
Iron (Fe) plus manganese (Mn)	0.3
Magnesium (Mg)	125
Manganese (Mn)	.05
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F) *	1.5*
Dissolved solids	500

*Based on annual average maximum daily air temperature of 58.4°F.

Silica (SiO_2) may occur in water as finely divided or colloidal suspended matter. In concentrations commonly found in natural or treated water, silica seems to cause no adverse physiological effects to man, livestock, or fish. Silica concentrations in ground-water samples were near or slightly above the recommended limit of 20 mg/l for use as feedwater in boilers at pressures of 250 psi, or less. The silica content of surface-water samples collected for this project ranged from 16 to 23 mg/l.

Iron (Fe) is present in small quantities in most natural water. Surface water, unless it is acidic, rarely contains more than a few tenths of a miligram per liter. Ground water, however, may contain several milligram per liter of iron. Iron in solution may impart an unpleasant taste to water and, upon precipitating from solution, may form sediments that stain laundry, utensils, and fixtures. Iron in small quantities can be removed from water by aeration and settling or filtration, but water having large concentrations of iron may require other treatment. The iron content ranged from 0.05 to 6.2 mg/l in ground-water samples, and in wells 1, 4, and K_1, it exceeded the U.S. Public Health Service recommended upper limit of 0.3 mg/l for drinking water. The iron content of surface-water samples ranged from 0.05 to 0.06 mg/l. The fact that the surface water contains less iron than the ground water is probably due to aeration and subsequent oxidation of iron after ground water entered the stream channels from seeps and springs.

Fluoride occurs in sedimentary, igneous, and metamorphic rocks in minerals such as fluorite and apatite. In most natural surface

water, fluoride is present in only small concentrations, whereas in ground water it is present in somewhat larger concentrations, occasionally as high as several milligrams per liter. Fluoride in excess of the U.S. Public Health Service recommended limit was not present in any of the water samples for which fluoride determinations were made.

Nearly all water has constituents that cause hardness. Hardness is caused mostly by ions of calcium and magnesium. For the purpose of this report water containing less than 60 mg/l hardness as $CaCO_3$ is considered soft, 61–120 mg/l is considered moderately hard, 121–180 mg/l is considered hard, and that containing more than 180 mg/l is considered very hard. Carbonate (CO_3) hardness refers to the hardness expressed in terms of calcium carbonate ($CaCO_3$) equivalent to the concentrations of carbonate and bicarbonate. Carbonate hardness of water samples collected in the memorial ranged from 22 to 168 mg/l, but water from well K_1, which was drilled in metamorphic rocks about 1 mile northeast of the east entrance to the Memorial, had a carbonate hardness of 484 mg/l.

Any hardness in addition to carbonate hardness is reported as noncarbonate or permanent hardness. Noncarbonate hardness of water in samples collected in the memorial ranged from 0 to 10 mg/l, but water from well K_1 had 342 mg/l noncarbonate hardness.

Water from well 3 and from surface-water sources is soft. Water from wells 1 and 4 is high in iron and is hard, but is otherwise satisfactory for most uses.

In general, water from wells in the memorial is low in dissolved solids but high in silica and iron. Water samples collected from Starling and Lafferty Gulch basins are low in hardness and those from East Boundary basin are high in hardness. Water from well 3 is of excellent quality for drinking and is satisfactory for most uses. Surface water in the memorial is of excellent quality.

Water from well K_1 in Keystone is more mineralized than water from wells at the memorial and is of the calcium-sulfate type. The greater mineralization of this water probably is due to sulfide ore bodies, grunerite schist, and drainage from nearby mines.

Well 1, after it was drilled in 1960, produced only about 30 gpm of water that was too high in colloidal material and suspended sediment to be used. As a part of this investigation, the colloidal material was analyzed by X-ray diffraction in samples taken after 5 minutes and 60 minutes of pumping from the well. The minerals constituting the colloidal material were hydrous mica, montmorillonite, kaolinite, quartz, and feldspar. Sediment concentrations in the samples decreased from 1,180 to 58 mg/l during the 55-minute

interval between samples and the turbidity (mg/l as SiO_2) from 330 to 40. The decrease in suspended sediments probably resulted from the lower entrance velocity of water at the well screen as the water level in the well declined and the pumping rate decreased. Water from well 1 probably would be of satisfactory quality for general use if the pumping rate is not greater than 20 gpm.

SUGGESTIONS FOR FUTURE DEVELOPMENT OF WATER SUPPLIES

Several locations in the memorial have a potential for the development of supplementary ground-water supplies. One of the more promising areas for future well or spring development is near spring 6. A pegmatite intrusive at this location acts as a ground-water dam in much the same manner as the pegmatite sill at spring 3. This area has the additional advantage of being easily accessible for drilling and is near an existing water main.

Alluvium in the valley of Grizzly Bear Creek at the extreme southeast corner of the memorial in sec. 18 is another potential source of ground water. This site is also accessible to a drilling rig. No test wells have been drilled nearby, but the valley of Grizzly Bear Creek probably is underlain with saturated alluvium.

The area where Lafferty Gulch intersects the valley of Battle Creek is an apparently favorable site for a well in alluvial deposits. Although no test holes have been drilled here, the valley is quite wide and conditions are favorable for a considerable thickness of saturated alluvium. A pipeline probably could be constructed along the road which follows the axis of Lafferty Gulch to its confluence with the valley of Battle Creek.

The mica schist bedrock may be productive of water in the SW¼ sec. 7 in Lafferty Gulch and the NE¼ sec. 13 in Starling basin. When locations are selected for test hole sites in these areas, careful attention should be given to the distribution of pegmatite intrusives. The mica schist bedrock may be more fractured and hence more permeable near intruded granite or pegmatite.

Well 1 has not been used because of the high turbidity of the water. This condition could be considerably improved by pumping the well at a lower rate (about 15–20 gpm). The lower pumping rate would reduce the entrance velocity of water at the well screen and also the turbidity. During times of normal precipitation, well 1 probably could maintain production of about 12,000 gallons of water per day.

Surface-water reservoirs might prove feasible as future sources of water supply. However, long-term measurements of flow in

Starling basin and Grizzly Bear and Battle Creeks would be necessary to determine the amount of water available over a long period of time. The rugged terrain and the relative remoteness of potential reservoir sites from administrative headquarters would make the storage and distribution of surface water costly.

Existing wells will furnish an adequate supply of water for the next few years, unless there is a prolonged drought. Arithmetic projections of yearly visitation totals indicate that potential sources in the memorial will furnish sufficient water to the year 2000 and beyond.

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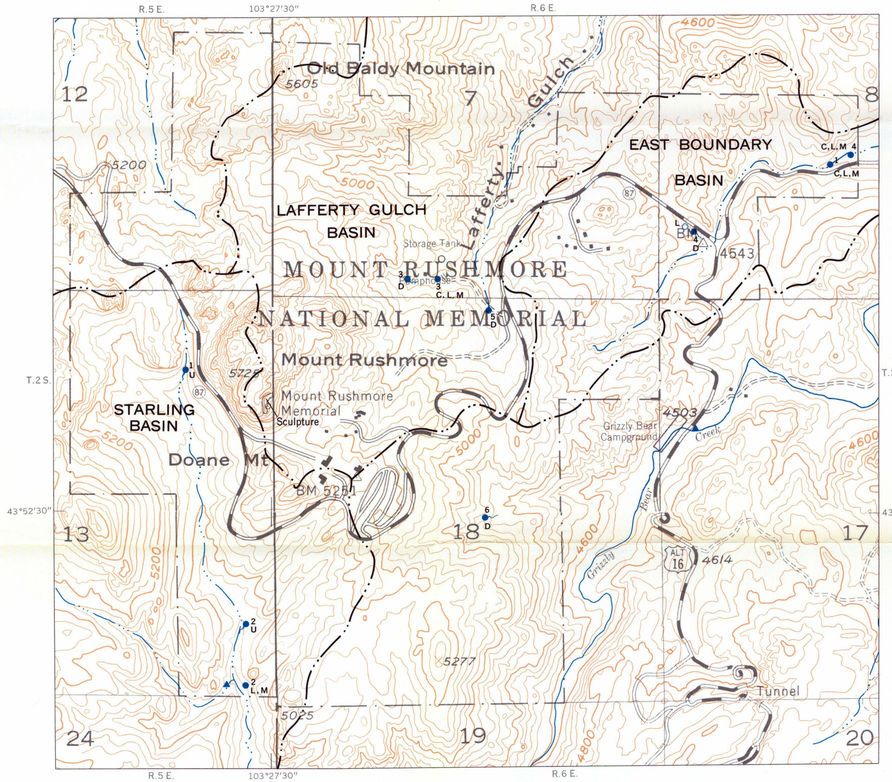


Base from U.S. Geological Survey, Mount Rushmore and Iron Mountain, 1:24,000, 1954
Photorevision as of 1971

A. LOCATIONS OF GEOHYDROLOGIC DATA-COLLECTION SITES

EXPLANATION

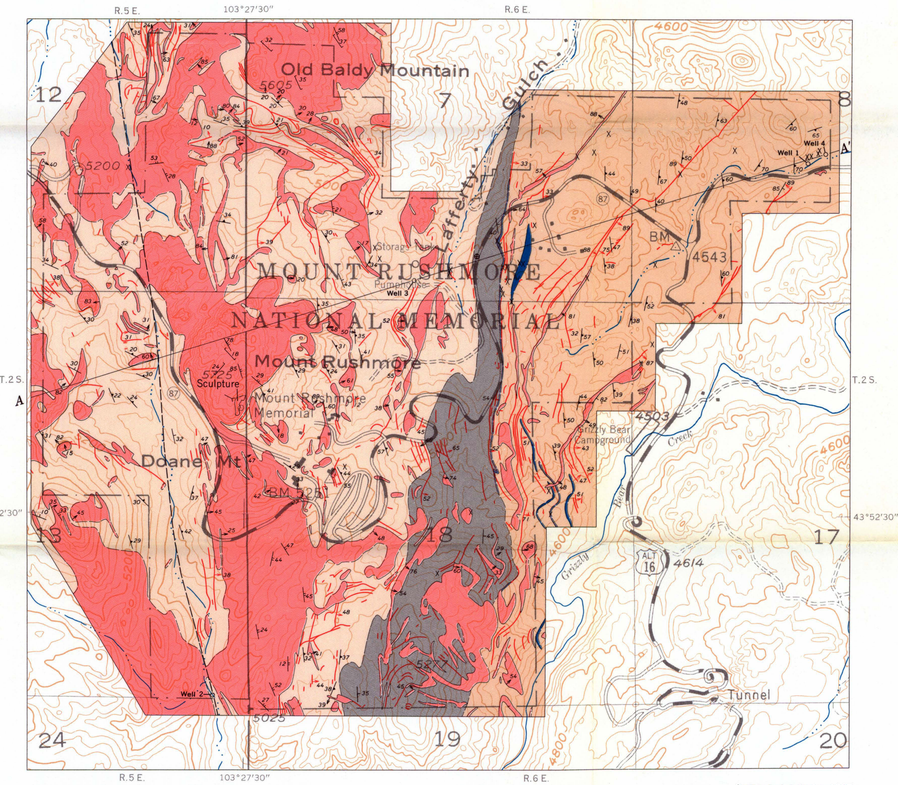
Water well
3, *Well number*
C, *Chemical analysis available*
L, *Well log available*
M, *Water-level measurements available*

Test hole
L, *test-hole log available*

Spring
2, *Spring number*
U, *Undeveloped spring*
D, *Developed spring*

Streamflow-measurement site (gaging station)
Supplemental base-flow measurements available

Drainage-basin boundary



Geology by J. J. Norton, 1967

EXPLANATION

Granite and pegmatite

Hornblende schist

Quartz-mica and mica schists

Grunerite schist and quartzite
Metamorphosed iron-formation

Mica schist and quartzite

Mica schist

32
Contact, showing dip
Dashed where approximately located

Lineament

32
Strike and dip of bedding

52
Strike and dip of schistosity

78
Strike and dip of inclusions in granite

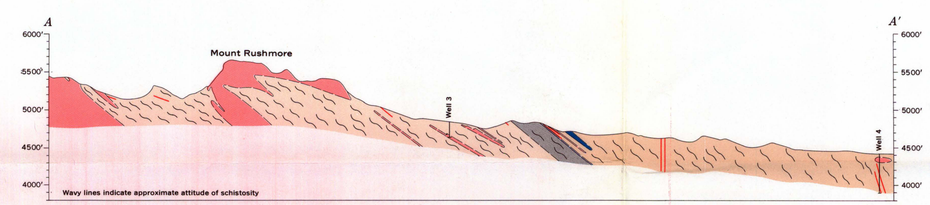
32
Strike and dip of layering in granite

65
Dip of pegmatite

Adit

Pit

Group of pits



B. GEOLOGIC MAP AND SECTION

NOTE
Culture revised after geologic mapping had been completed. As consequence, positions of some geologic features are not exactly correct with respect to roads and buildings, especially in central and west-central parts of map.

SCALE 1:12 000

½ 0 1 MILE

.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

GEOHYDROLOGIC MAPS OF THE MOUNT RUSHMORE NATIONAL MEMORIAL, SOUTH DAKOTA

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