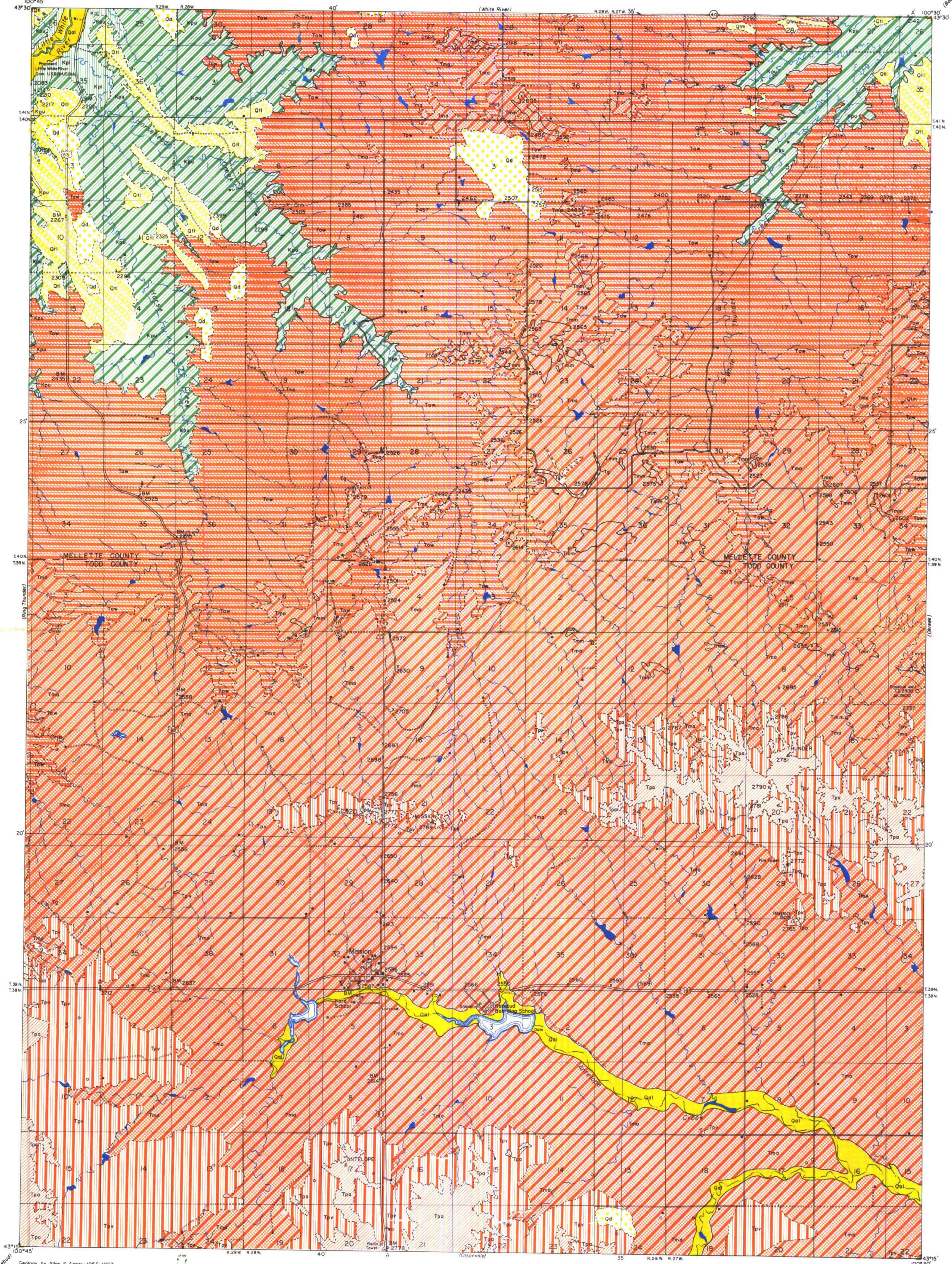
SOUTH DAKOTA GEOLOGICAL SURVEY
DUNCAN J. McGREGOR, STATE GEOLOGIST

STATE OF SOUTH DAKOTA
ARCHIE GUBBRUD, GOVERNOR

GEOLOGY of the MISSION QUADRANGLE SOUTH DAKOTA



Geology by Allen F. Agnew, 1956, 1963
Assisted by Sam G. Collins

Vertical and horizontal control surveyed from triangulation and level lines of Federal surveys.
Drafted by Bruno C. Petsch, 1963

TRUE NORTH / MAGNETIC NORTH 11°49'
APPROXIMATE MEAN DECLINATION, 1960

Scale 1:62 500
1 ½ 0 1 2 3 4 Miles

Vermillion South Dakota
1963

EXPLANATION

QUATERNARY

RECENT

Qal — Alluvium
(Floodplain deposits of silt, sand, and gravel in valleys of present streams; 0–10 feet thick.)

PLEISTOCENE

Qtl — Lower Terrace Deposits
(Fluvial deposits of silt, sand, and gravel about 150 feet above present streams; 10 feet of gravel at base; 20 feet of sand and silt above; total, 30 feet thick.)

Qtm — Middle Terrace Deposits
(Fluvial deposits of gravel and sand derived from Tg and local material, 150 feet above Qtl in northeastern part of quadrangle; less than 5 feet thick.)

Qd — Dune Sand
(Eolian deposits of sand, mainly clear to frosted quartz with some dark minerals; developed on upland.)

TERTIARY

PLIOCENE

Tg — Pliocene ? Gravels
(High- to medium-level gravel and sand with much garnet, derived from Black Hills; vertebrate fossils, possibly reworked, are Early Pliocene in age; in old stream channels and terrace remnants; as much as 20 feet thick.)

UNCONFORMITY

Ogallala Group

Tpa — Ash Hollow Formation
(Light-gray to light-tan calcareous-cemented feldspathic quartz sandstone; abundant caliche masses and local box-work structure; forms rounded caps of hills; Celtis seeds and fossil vertebrates; local dense white thin limestone at base 10–22 feet thick.)

Tpv — Valentine Formation
(Greenish-gray to tan feldspathic quartz sand, ashy near top; gravel at base; 30–65 feet thick.)

UNCONFORMITY

MIOCENE

Tmm / Tma — Arikaree Group
(Undifferentiated)
(Pinkish-brown compact silt and poorly cemented siltstone and silty claystone; local zones of nodular or longitudinal cemented areas; locally at base a thin-bedded and cross-bedded fine- to medium-grained siliceous brownish-gray quartz sandstone, with pea-size clay balls that weather as pits; unit weathers to rounded slopes; 190–245 feet thick. Includes Mellette Facies (Tmm), a series of thin white dense limestones as much as three feet thick, at 45, 75, 130, 160, and 180 feet above base, forming ledges or flat hilltops.)

UNCONFORMITY

OLIGOCENE

Tow — White River Group
(Undifferentiated)
(Brule Formation at top: upper unit - pinkish to olive bentonitic clay, and white to gray wormy siltstone; weathers to rounded humps separated by the siltstone ledges; 70–80 feet thick. Lower unit - banded pinkish to grayish laminated clayey siltstone, and thin layers of hard calcareous light-gray to whitish siltstone; weathers to stair-step profile; about 110 feet thick. Chadron Formation at base; greenish-yellow bentonitic clay and claystone poorly cemented with silica; claystone ledge contains pea-size clay pellets that weather to a pitted surface; basal gravel and sand of well-rounded polished quartz, chert, and igneous pebbles, as much as 10 feet thick; thickness of Chadron, 20–40 feet. Thickness of White River Group, 200-230 feet.)

UNCONFORMITY

CRETACEOUS

UPPER CRETACEOUS

Kpu — Upper Pierre Unit
(Gray to dark-gray calcareous shale below, and light-gray to brownish silty shale above; lower part weathers blocky and light gray, upper part weathers to light-gray or yellowish-brown thin flakes; top is marked by weathered zone 10–15 feet thick, ranging from normal colors to reddish-purple to purple bentonitic shale; erosional relief at top of 30 feet or more; thickness, 185–215 feet.)

Kpl — Lower Pierre Unit
(Medium-gray bentonitic clay-shale that weathers light gray, blocky when fresh but weathers into thin flakes or a structureless mass of clay; upper part contains several zones of lenticular gray limestone concretions; fossil Baculites, and other cephalopods, gastropods, and pelecypods; about 50 feet exposed.)

Geologic Contact
(dashed where approximately located)

× Gravel Pit

× BM 2778
Bench Mark
(monument showing exact altitude above sea level)

x 2572
Spot Altitude

▲ ANTELOPE
Triangulation Station
(monument marking exact geographic location)

○ Rosebud Well

○ Shallow well

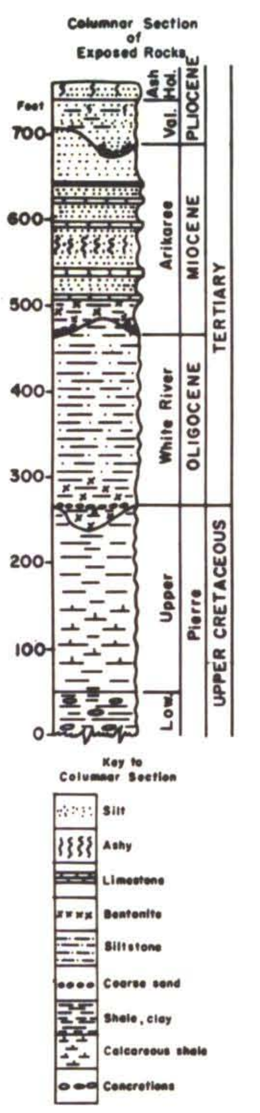
House, School, and Church

MISSION QUADRANGLE

GEOLOGY OF THE MISSION QUADRANGLE

by

Allen F. Agnew



INTRODUCTION

The Mission quadrangle includes approximately 218 square miles in the south-central part of Mellette County and the north-central part of Todd County. The town of Mission (pop. 611) is situated in the southwestern part of the quadrangle.

The mapped area is partly in the Tertiary Tablelands subdivision of the Missouri Plateau and partly in the High Plains, which are part of the Great Plains physiographic province. The topography of the northern two thirds of the quadrangle is characterized by a general northward slope from the east-west Mission divide that lies about two miles north of the town of Mission. This northerly slope is cut by three north-flowing streams, Horse Creek and Horsehead Creek on the west, and White Thunder on the east. White Thunder Creek is a tributary of the White River about 15 miles to the north, which flows eastward into the Missouri River. Horse Creek and Horsehead Creek first enter the Little White River, which flows northward across the extreme northwest corner of the area. Altitudes in the northern two-thirds of the quadrangle range from approximately 2040 feet along the Little White River, to 2790 atop the divide near the eastern border of the area. Although the maximum relief is thus 550 feet, local relief is usually no more than 250 feet. A north-trending divide between Horsehead and White Thunder Creeks is marked by flat-topped buttes and mesas, at altitudes of 2500-2600 feet.

The southern third of the quadrangle includes the dissected northern edge of the High Plains, which is underlain by the Pliocene Ogallala sediments. Antelope Creek bisects this part of the quadrangle, flowing east-southeast to join the Keyapaha River. Its valley is broad and the stream is sluggish, in contrast to those in the northern part of the quadrangle.

The Todd County part of the mapped area is in the Rosebud Sioux Indian Reservation. The east-west U. S. Highway 18 is met two and one-half miles west of Mission by U. S. Highway 83, which passes southward out of the quadrangle toward Valentine, Nebraska, about 35 miles away. Northward from Mission this highway connects with White River, about 25 miles away. The east-west State Route 40 extends for four miles along the northern border of the mapped area near its eastern edge. Secondary roads, which are few, are generally passable when dry, but are impassable when wet. Much of the quadrangle is accessible only by four-wheel drive vehicles or by horse.

The climate is characterized by a wide range in temperatures, by 17-19 inches of rainfall yearly, and by strong winds.

Most of the geology was mapped by the writer during the summer of 1956 with the assistance of Sam G. Collins. Additional mapping and field-checking was done during the Fall of 1957 and the Spring of 1963. The writer profited from field conferences, at various times during the mapping, with Drs. Harold J. Cook, A. L. Lugn, J. R. Macdonald, C. B. Schultz, and Morris Skinner.

Excellent geological observations were made in the Rosebud Reservation by A. B. Reagan (1905), who described geologic sections near the present Mellette-Todd County line, along the eastern edge of the quadrangle. He not only described the rocks well, but collected fossils and identified them so that he was able to arrive at correct correlations of the stratigraphic units. He correctly applied the name Ogallala to rocks in this area; this name was apparently forgotten by later geologists, and was not revived until the work of Lugn (1939).

EXPOSED SEDIMENTARY ROCKS

Tertiary fluviatile and lacustrine deposits of Oligocene, Miocene, and Pliocene ages are present throughout the Mission quadrangle, except in the northwestern and northeastern parts where the Pierre Shale, a marine deposit of Late Cretaceous age, is at the surface. The Oligocene White River strata are silty claystones, siltstones, fine-grained sandstones, gravels and bentonitic clays; the Miocene Arikaree deposits are silty clays, fine-grained sands, and local sandstones and thin limestones; the Pliocene Ogallala strata are unconsolidated ashy sands and sandstones, gravels and conglomerates, and thin limestones.

Pierre Shale, Meek and Hayden, 1862

The Pierre Shale, named from exposures near Ft. Pierre (70 miles north-northeast of the quadrangle), is exposed along the Little White River and some of its tributaries in the northwestern part of the quadrangle, and along White Thunder Creek in the northeastern part. In the Mission quadrangle the writer was unable to divide accurately the Pierre into the members which are recognizable along the Missouri River (Searight, 1937). Thus, the Pierre is here described as the two conformable units recognized in the adjacent White River quadrangle to the north (Agnew, 1957).

Lower Pierre Unit

The Lower Pierre unit (Kpl) is medium-gray calcareous bentonitic clay-shale that weathers light gray. The shale is blocky where fresh, but weathers first into thin flakes and then into a structureless clay. The upper part of this unit is marked by several zones of lenticular gray argillaceous limestone concretions that range up to two feet in diameter. The concretions commonly contain as nuclei the cephalopod *Baculites*, and isolated specimens of this fossil occur locally within the shale. About 50 feet of this Lower Pierre unit is exposed in the Mission quadrangle.

Upper Pierre Unit

The Upper Pierre unit (Kpu) is gray to dark-gray calcareous shale below, and light-gray to brownish silty shale above. The lower part of this unit is calcareous bentonitic blocky shale that weathers light gray. Minute crystals of selenite are common along the bedding planes, as are white calcareous specks that may be crushed shells of Foraminifera. The upper part of this unit is calcareous to noncalcareous blocky to thin-bedded shale that weathers light gray to yellowish brown, with some rust-colored iron-sulfate staining. Thin layers of greenish bentonite occur in the upper part of this unit, as do several one- to two-inch layers of dark-gray argillaceous limestone concretions. Small selenite crystals and fragile iron-sulfate minerals are present along the bedding planes and in veins throughout this unit. A placer of thin limonitic plates locally covers slopes developed on this part of the upper Pierre.

The top of the Pierre is marked by a 10-15 foot weathered zone of light-gray to yellowish-brown to reddish-purple to purple bentonitic shale, and by an erosional surface having a relief of 30 feet or more. This weathered zone, called the Interior Formation by Ward (1922), probably developed as a lateritic soil (Wanless, 1923) during early Tertiary Eocene time as concluded by Dunham (1961) from a study 100 miles west of the Mission quadrangle. Because of this eroded zone at the top, the Upper Pierre unit varies in thickness from 185 to 215 feet in the area.

White River Group, Meek & Hayden, 1858

The White River Group, exposed in the northern half of the quadrangle, has been divided into two formations, the Chadron below, and the Brule. Because of the thinness of the Chadron and its consequent restricted outcrop area, the two formations have been combined on the map as the White River Group, undifferentiated (Tow). However, because of the recognizable differences between these two formations in the outcrop, they are described separately in the following paragraphs.

Chadron Formation, Darton, 1899

The Chadron Formation, named for exposures near Chadron, Nebraska, 100 miles west-southwest of the Mission quadrangle, is greenish-yellow bentonitic clay and claystone, white silt and sand, and gravel. The basal part of the Chadron contains as much as 10 feet of sand and gravel. The sand is very fine- to coarse-grained subangular to well-rounded white quartz, and is locally slightly cemented with silica. The gravel is composed of well-rounded and well-polished quartz, chert, and igneous pebbles ranging up to three inches in diameter.

The basal sand and gravel is usually overlain by one to five feet of grayish-white silt and clay. This silt-clay grades upward into a grayish-green to yellowish-green bentonitic silicified claystone ledge that contains small pea-size pellets. In the adjoining Ring Thunder quadrangle to the west where the resistant ledge is absent, Sevon (1960a) found that the clay weathers into rounded humps; a layer of one- to two-inch lenticular gray limestone concretions is locally present at the top of this clay. The top of the Chadron Formation is marked by the top of the claystone ledge or the limestone concretion layer, and by a slight color change in the silts and clays from light-greenish gray (below) to light-pinkish gray (above). The Chadron is 20-40 feet thick in the Mission quadrangle, owing to the unconformity at its base.

Brule Formation, Darton, 1899

The Brule Formation, named for the Brule Indians who inhabited the Pine Ridge of southern South Dakota where these sediments are well exposed, can be subdivided into the two lithologic units recognized in the White River quadrangle to the north (Agnew, 1957). The lower unit is mainly banded pinkish to grayish laminated clayey siltstone with half-a-foot to one-foot layers of hard calcareous light-gray to whitish siltstone. Some gray poorly cemented fine-grained quartzose sandstone and pinkish bentonitic claystone are present. Local veinlets of white to clear chalcedony fill local fractures. The clayey siltstone weathers into near-vertical slopes, and the harder siltstones and sandstones into ledges that project slightly, resulting in a stair-step profile. This lower unit of the Brule is about 110 feet thick.

The upper unit of the Brule is pinkish to olive bentonitic clay, and white to gray siltstone which weathers to a wormy appearance. The bentonitic clays weather to three smooth rounded humps similar to the Chadron, separated by short steps developed on the wormy siltstones. The wormy siltstones are calcareous to noncalcareous, and locally grade imperceptibly into the somewhat coarser brownish siliceous siltstones of the overlying Arikaree Group. The upper unit of the Brule is about 70-80 feet thick, giving a total for the Brule Formation of 180-190 feet, and a total for the White River Group of 200-230 feet.

Arikaree Group, Darton, 1899

The Arikaree Group (Tma), named for the Arikaree Indians who inhabited western Nebraska where these sediments are well exposed, overlies the White River Group in the southern half of the quadrangle. The strata here described as the Arikaree Group are apparently the same as those called the "Rosebud beds" by Matthew and Gidley (1904), 25 miles to the southwest. Lugn (1939, p. 1270-71) stated that the Rosebud beds are equivalent in age to the Gering (at the base), Monroe Creek, and Harrison Formations of the Arikaree Group, and to at least the lower part of the overlying Marsland Formation of Western Nebraska. Harksen (1960) believed that the Rosebud lithology could be traced 80 miles westward in South Dakota to sediments present above the Harrison Formation in the Sharps Corner area, where it is apparently the age-equivalent of the Marsland Formation (J. R. Macdonald, personal communication, 1959).

The Arikaree Group in the Mission quadrangle is mainly pink very fine-grained poorly cemented sandstone and somewhat porous pink silicified claystone. The base is marked locally by fine- to medium-grained siliceous brownish-gray quartz sandstone that contains pea-size pellets of pink clay which weather out, producing a pitted surface; this sandstone ranges from 0-1 foot or more in thickness. Where the basal sandstone is absent, and locally where it is present, the base of the Arikaree is marked by a brownish wormy siliceous slabby siltstone, which locally grades downward into the lighter-colored White River siltstones. A calcareous cross-bedded channel sandstone marks the base locally.

The Arikaree weathers to smooth rounded slopes, thus contrasting with the stair-step profile of the underlying White River sediments. The total thickness of the Arikaree Group in the Mission quadrangle, including the Mellette Facies described below, is 190-245 feet; this variation is caused mainly by the unconformable contact with the overlying Ogallala Group.

The Mellette Facies (Tmm) of the Arikaree Group, originally named as a separate formation (Agnew, 1957) from exposures a mile north of the Mission quadrangle, has been found by subsequent mapping in adjoining quadrangles (Sevon, 1959, 1960a) to be a facies of variable thickness within the lower and middle parts of the Arikaree Group. It consists of thin ledges as much as 3 feet thick, of flesh-colored dense limestone containing veins and isolated crystals of calcite; the limestone weathers white, and forms shelves on slopes, or caps small mesas and buttes. The limestone contains irregular masses and abundant gastropod shells composed of silica, which weather slightly in relief on the limestone surface.

The limestone ledges occur at about 45, 75, 130, 160, and 180 feet above the base of the Arikaree. They are separated by sediments of normal Arikaree lithology--pinkish very fine-grained sand and clay. Although the limestone ledges are striking topographic features where they form the cap-rock of buttes and mesas (secs. 26, 27, and 35, T. 41 N., R. 28 W.; and secs. 2, 11, 14, 22, 23, and 25, T. 40 N., R. 28 W.), some of them form only narrow shelves in the gentle slopes developed on the Arikaree, and when traced laterally tend to blend with the slope (secs. 4, 5, and 9, T. 39 N., R. 27 W.). The Mellette Facies is thus depicted on the map of the Mission quadrangle as solid outcrop lines (Tmm) within the pattern of the Arikaree Group (Tma).

Ogallala Group, Darton, 1899

The Ogallala Group, exposed in the uplands in the southern part of the quadrangle, includes the Valentine (below) and Ash Hollow Formations. The Ogallala is a series of fluviatile sands, gravels, sandstones, and limestones that were deposited on a Miocene erosion surface having a relief in the Mission quadrangle of at least 60 feet.

Valentine Formation, Barbour & Cook, 1917

The Valentine Formation (Tpv), named for exposures near Valentine, Nebraska, 35 miles south of the town of Mission, is tan to olive-gray fine- to medium-grained feldspathic sand, and similar light-gray sandstone. The base of the Valentine is marked locally (southwestern part of the quadrangle) by an unsorted garnetiferous feldspathic sand and gravel, which is irregularly cemented with calcite. Fossil bones from this gravel in exposures only a few miles to the west, in the Ring Thunder quadrangle (Sevon, 1960a) have been identified (J. R. Macdonald, personal communication, 1959) as correlative with the Mission gravel (Tg), to be described later.

The remainder of the Valentine Formation is sand that contains thin layers of greenish bentonitic clay in the lower part, and elongate irregularly cemented calcareous sand masses that range from 2 inches to 3 feet in length; these masses occur near the base of the formation in the Mission quadrangle, and also near the top in the adjoining Ring Thunder quadrangle (Sevon, 1960a). The Valentine Formation varies from 30 to 65 feet in thickness, governed by the unconformity at its base. The Valentine is thin along the Mission Divide, three miles north of the town of Mission, and thicker to the east and south.

Ash Hollow, Engelmann, 1876

The Ash Hollow Formation (Tpa), named for exposures in Ash Hollow Canyon near Lewellen, Nebraska, about 150 miles south of the Mission quadrangle, is light-tan to light-gray fine- to medium-grained calcareous feldspathic sandstone. The rock contains abundant root-like stringers of caliche (calcium carbonate), which weather into relief and give a very rough surface, forming an intricate mass called "box work".

The Ash Hollow caps the highest elevations in the quadrangle, resulting in low yet prominent bluffs. Locally, a brownish to flesh-colored sublithographic to silty dense limestone occurs at the base of the Ash Hollow, as in Secs. 20 and 21, T. 39 N., R. 28 W., 2½ miles north of Mission. Like the Mellette Facies of the Arikaree, this limestone weathers a brilliant white, and has abundant fossil gastropod shells. These shells, however, are generally larger than those in the Mellette. In addition, the limestones contain masses of greenish opaline silica that weathers chalky white, and locally display liesegang rings, which are arcuate or circular rings that indicate rhythmic precipitation as a gel. Normally, a very ashy silt that is locally a diatomaceous calcareous siltstone characterizes this basal contact of the Ash Hollow with the underlying Valentine; the diatomaceous zone is well exposed in the Spring Creek quadrangle, 30 miles to the southwest (Sevon, 1960b).

The Ash Hollow ranges from 10 to 22 feet in thickness. Small round *Celtis* seeds of the hackberry tree are not uncommon, and other seeds have been found by diligent search.

SURFICIAL DEPOSITS

Unconsolidated deposits associated with the present drainage are separated into four main groups: (1) alluvium, (2) terrace deposits along present streams, (3) dune sand, and (4) high-level terrace deposits along former stream courses.

Alluvium (Qal) consists of silt, sand, and gravel which resulted from reworking by streams of older bedrock and surficial deposits. It is confined to present stream valleys, and is mainly local in origin. The alluvium probably does not exceed 10 feet in thickness. It has been mapped only along the two major streams, the Little White River and Antelope Creek, although a thin veneer of alluvium is present in places along Horse Creek and Horsehead Creek, and White Thunder Creek.

Terrace deposits (Qtl) along present stream courses of the Little White River, Horse Creek, Horsehead Creek, and along White Thunder Creek, consist of clay, silt, sand, and gravel. They occur about 150 feet above the Little White River, and at lesser elevations above the three creeks mentioned. The terrace deposits along the Little White River and its two tributaries contain as much as 10 feet of gravel at the base, with as much as 20 feet of sand and silt above. The gravel is composed of well-rounded pebbles of siltstone, sandstone, limestone, and igneous rocks, together with abundant quartz. The pebbles are generally less than 1 inch in diameter, but may be as large as 3 or 4 inches. The terraces along White Thunder Creek are similar in composition, but not as thick.

Reworked material (Qtm) from ancient stream deposits (Tg) is present in the northeastern part of the quadrangle, at altitudes of 2245-2280 feet, and in the northwestern part at 2300 feet. This material consists of only a thin veneer of mainly local sandstone and siltstone, with a small proportion of material derived from the older, high-level stream gravels (Tg), to be described later.

Dune sand (Qd) is loose very fine to medium grains of subround to round frosted quartz sand. The dune areas are developed on the White River Group in the northwestern part of the quadrangle, on the basal sediments of the Arikaree Group in the north-central part of the quadrangle, and on the basal part of the Valentine Formation in the southeastern part. The dune areas are characterized by knobs and depressions, by sand blowouts, and by the presence of yucca plants.

The high-level gravel deposits (Tg), deposited along the courses of ancient streams, can be traced in a general northeast direction across the Mission quadrangle. They are mapped at altitudes of approximately 2730 feet in secs. 27 and 34, T. 39 N., R. 29 W., 5 miles west of Mission. At this locality they occur at the position of the base of the Valentine. They are mapped separately at this locality because they are clean coarse gravels with the finer components of the basal Valentine having been removed apparently by the action of the Early Pliocene stream which deposited them.

Five to seven miles to the northeast, several isolated patches of these gravels cap hills in sec. 12, T. 39 N., R. 29 W., secs. 6 and 7, T. 39 N., R. 28 W., and secs. 29, 31, and 32, T. 40 N., R. 28 W., at altitudes of approximately 2580 feet.

The largest, thickest, and most striking remnant of these gravels in this part of South Dakota is present at the same altitude and three miles east of the last-mentioned deposit, in Secs. 25, 26, and 35, T. 40 N., R. 28 W. This is the Fox sand pit of Macdonald (1960), from which he described the mammalian "Mission fauna" of Clarendonian age. This deposit of gravel fills a channel carved to a depth of 20 feet or more in the Arikaree sediments. The gravel pebbles and cobbles range up to 4 inches or more in diameter, and consist of well-rounded quartz, pink feldspar, and less-rounded fragments of granitic and pegmatitic rocks. Dark minerals and fragments of dark schist are not uncommon. Garnet is abundant in streaks. The source of this gravel deposit seems to have been the Black Hills, in contrast to the source of the apparently contemporaneous Valentine sediments, which seem to have been derived from the rising Rocky Mountain front farther southwest.

Six miles northeast of the Mission (Fox) gravel pit, in Secs. 32-33, T. 41 N., R. 27 W. and Sec. 6, T. 40 N., R. 27 W., a similar gravel (Qtm) is present at an altitude of approximately 2350 feet. Like the gravels three miles west of the Mission (Fox) pit, these gravels cap hills and are characterized by the same coarseness in particle size and by the same lithologic makeup.

It appears that these gravels of Early Pliocene age were formed under the same conditions and probably at about the same time as those occurring at altitudes of about 2625 and mapped as Qgu in the White River quadrangle to the north (Agnew, 1957), and about the same time as part of those occurring at altitudes of about 2750 and mapped as small terrace deposits (Qt) in the southern part of the Ring Thunder quadrangle to the west (Sevon, 1960a).

SUBSURFACE ROCKS

Rocks that do not occur at the surface in the Mission quadrangle, yet are present in the subsurface, are known from the Rosebud artesian well, drilled 65-70 years ago in the SE¼SW¼ sec. 10, T. 39 N., R. 27 W., at the eastern edge of the quadrangle. This well, bottomed at a depth of 2500 feet, penetrated only as far as the "second sand" in this area, which is probably the Fall River Sandstone of western South Dakota, or the middle sand of the Dakota sandstone sequence of eastern South Dakota. More recently, the Bachman water well, 7 miles northeast of the northeastern corner of the quadrangle, and two oil tests drilled by the General Crude Oil Company in Tripp County 20-25 miles east of the eastern border of the quadrangle, went to the Precambrian basement rock at depths of 2886 and 3024 feet, and gave the sequence of rocks below the Dakota sandstones. An oil test drilled by H. O. English about 50 miles southwest of the Mission quadrangle showed a similar sequence of rocks, but about ten percent thicker.

From the information provided by these five deep holes, in the Mission quadrangle a driller might expect to find, in descending sequence below the Tertiary sediments, the following rock units: Cretaceous Pierre Shale, 1050-1100 feet; Niobrara Marl, 200-300 feet; Carlile Shale, 230-300 feet; Greenhorn Limestone, 50-60 feet; Graneros Shale, 130-190 feet; "First Dakota" Sandstone, 100-130 feet; Skull Creek Shale, 80-115 feet; "Second Dakota" (Fall River?) Sandstone, 60 feet; "Third Dakota" (Lakota) Sandstone, 80-130 feet. Below the four last-mentioned units, which constitute the Dakota Group, lie the Jurassic Morrison-Sundance shale and sandstone, 25-150? feet; Triassic "Redbeds", 260-310 feet; Permo-Pennsylvanian Minnelusa Formation, 150-250 feet; Ordovician Red River Limestone, 120-200 feet; Winnipeg Shale, 20-60 feet; and Winnipeg sandstone or "granite wash", 7-12 feet. The Precambrian basement rock was reached in the two oil tests just east of the Mission quadrangle, and was a pink granite. The Ordovician Red River and Winnipeg may pinch out to the southwest, and thus be absent from part of the quadrangle.

STRUCTURE

The Mission quadrangle lies in the saddle between the Williston Basin in northern South Dakota, and the shallower Kennedy or Nebraska Basin in northern Nebraska. Similarly, it lies in a sag between the Sioux Ridge to the northeast, and the Chadron or Cambridge Arch to the southwest, in Nebraska. Accurate subsurface data are sparse, as can be seen from the foregoing description of Subsurface Rocks. Nevertheless, they permit some generalizations to be drawn.

The surface of the Precambrian shows a general westerly slope or dip at a highly inferential 25 feet per mile (Agnew and Gries, 1960, fig. 2). This slope or dip is repeated in the Paleozoic structure map drawn atop the Red River Limestone (Agnew and Gries, 1960, fig. 4), a few hundred feet above.

The Cretaceous structure shown on the First Dakota Sandstone, however, reveals a west-northwest dip of at least 40 feet per mile, and a map drawn on the Greenhorn Limestone records a dip in a north-northwest direction of only 10 feet per mile.

The surface sedimentary strata of the Mission quadrangle are essentially flat lying (see cross section A-A'). Measurements taken on Tertiary marker beds such as the Mellette Limestone show differences in altitude of 30-40 feet, but these may be due to one or a combination of factors, such as imprecise altitudes, effect of unconformities, and lateral changes in facies of the Mellette limestone sequence within the Arikaree Group.

ECONOMIC GEOLOGY

Ground water is available in all parts of the Mission quadrangle. Sand and gravel are present in terrace deposits at scattered localities in the area, and at the base of the White River and Valentine sediments. Thin limestone layers cap buttes in the central and northern parts of the quadrangle. Bentonitic sediments are present in the northern part of the area. Other potentially economic geologic resources include oil, clay, and volcanic ash.

Ground Water

Ground water adequate in amount for domestic use is available at relatively shallow depths throughout the quadrangle except in the northeastern and northwestern corners, where the bedrock is the Pierre Shale. The water in the Tertiary sediments is excellent in quality (Table 1).

Table 1.--Chemical Analyses of waters from the Mission quadrangle

Name and Location	Source	SO_4	Cl	Ca	Mg	Na	Alk	$CaCO_3$	Fe-Mn	Total Solids
Okreek 1[a] 8-38N-26W	Valentine	7	1	49	5	5	154	143	0	244
Ferned 16-38N-28W	Arikaree	11	0	47	7	13	174	146	0.5	272
Bachelor 26-39N-29W	Arikaree	24	8	30	2	60	172	82	0.1	322
Fox 3-39N-28W	Arikaree-White River	24	3	19	2	80	210	55	0	248
Okreek 4[a] 33-39N-26W	Arikaree-White River	7	1	57	5	9	185	163	0	272
Merrill[b] 19-41N-27W	White River	15	17	71	10	18	29 174	218	0	383
Okreek 5[a] 18-40N-26W	Pierre	2,197	49	524	89	376	231	1,675	9.2	3,748
Wood[c] 25-41N-27W	"First Dakota"	255	590	25	17			850	4	1,850
Krogman[d] 8-40N-29W	"First Dakota"	351	259	11	0.2	630	37 130	28	2.1	1,846
Standard*	--	500	250	---	50	---	---	---	0.3 0.05	1,000

*Revised Drinking Water Standards, U. S. Public Health Service, 1962 (publ. in Jour. AWWA., v. 53, no. 8, August, 1961 and in Federal Register, Mar. 6, 1962, p. 2152-55), modified by South Dakota State Department of Health (written communication, Feb. 5, 1962).

[a] Three to five miles east of quadrangle
[b] One mile north of quadrangle
[c] One mile east of quadrangle
[d] One mile west of quadrangle

Water from the Pierre Shale is likely to contain more than 3000 ppm total solids (Table 1), and is detrimentally high in sulfate, sodium, hardness, and iron. Water from the terrace deposits in the northeastern and northwestern parts of the quadrangle, and from the alluvium along the streams there and in the southern part of the mapped area, is generally similar in quality to that in the adjoining sediments. Because these sediments are very thin and the water table is near the ground surface, this water is highly susceptible to contamination.

Water in larger amounts, probably sufficient for irrigation, can be obtained along the southern border of the quadrangle from the "red rock" of the drillers (probably at the top of the Arikaree Group), where those fine-grained sediments are overlain by the coarser sands and gravels of the Valentine Formation; wells have been reported to develop 200-400 gpm from this zone to the south and southwest of the Mission quadrangle.

In areas where insufficient quantity of water is obtained from the Tertiary sediments, wells drilled to the artesian bedrock have produced 30-50 gpm of fair quality water (1850 ppm, see Table 1) from the "First Dakota" sandstone at depths of about 2000 feet (or 400 feet above sea level) in the northern part of the quadrangle. The "Second Dakota" and "Third Dakota" sandstones, 100-200 feet lower, might also yield similar quantities of water of similar quality. This water should rise in the well to about 1800 feet above sea level.

Artesian water can also be obtained from the Red River limestone, about 1000 feet deeper than the "First Dakota", where it is present under the quadrangle. This water should flow about 30 gpm at the surface where it is 2200 feet or less above sea level; this means that the pumping level in the southern part of the quadrangle would probably not exceed 400 feet in the area near Mission. This water, however, will probably be poor in quality (high in sulfate), and will certainly be hot (130°F or more).

Sand and Gravel

Sand and gravel suitable for road material is present in the Tertiary gravel (Tg). The material is mainly quartz and feldspar, and ranges up to three or four inches in diameter although it averages one inch. This deposit has only been quarried at the Mission (Fox) pit. The other deposits have been test pitted but not quarried, as they are less accessible and thinner than at the Mission (Fox) pit.

The lower terrace (Qtl) is mainly sand, but this material has not been quarried in the Mission quadrangle. The middle terrace (Qtm) material is thin and is a poor mixture of the Tertiary gravel and locally derived calcareous-cemented siltstone, and has not been prospected.

Limestone

Limestones of the Mellette Facies are present as caps of hills in a strip that extends from the center of the northern boundary of the quadrangle southward to the County line, and then east-and-west along the north slope of the Mission Divide. These thin ledges of dense limestone have been quarried in Sec. 10, T. 39 N., R. 29 W., and the material has been crushed and used for road aggregate.

Bentonite

Bentonitic sediments are characteristic of the lower part of the White River Group and the lower part of the Arikaree Group; they are present in the northern half of the quadrangle. Bentonite is used as a sealing or bonding material.

Oil and Gas

Gas shows have been reported from the Pierre-Niobrara contact and from the "Dakota" sandstone (probably "First Dakota" only) in central and southeastern South Dakota. Potential stratigraphic and probably structural traps for oil exist in the Redbeds-Minnelusa sequence (as is suggested by an oil show in Nebraska, 75 miles to the southwest), and in the Red River Limestone.

Other Potential Mineral Resources

Silts from the upper part of the White River Group, when mixed with sand in proper proportions, was formerly used by the Indians as plaster (Reagan, 1905, p. 234). A similar use of the Valentine Formation caused it to be known widely in the Great Plains as the "mortar beds."

The *bentonitic clays* of the lower part of the White River Group have been investigated in the Black Hills for use as Fuller's Earth, because of their bleaching qualities. Weathered and altered clays associated with the unconformity at the Pierre-White River contact have been investigated recently in the Pine Ridge area (75 miles to the west), because of their pottery possibilities (Schultz, 1961).

Volcanic ash is present in the upper part of the Valentine near the Ash Hollow contact, in the southern part of the quadrangle. This ash ranges from one to four feet in thickness, and from nearly pure ash to a mixture of ash and sand. The deposits are poorly exposed, thus masking their areal extent and character. Volcanic ash is used as an abrasive.

Although *uranium* has been found in the White River Group in the Big Badlands and near Chadron, Nebraska, 120 miles to the west and southwest, reconnaissance surveys in the Mission quadrangle and nearby areas showed no anomalous radioactive readings.

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