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HYDROGEOCHEMICAL AND STREAM SEDIMENT DETAILED GEOCHEMICAL SURVEY FOR EDGEMONT, SOUTH DAKOTA; WYOMING

T. R. Butz, N. E. Dean, C. S. Bard,
R. N. Helgerson, J. G. Grimes, and P. M. Pritz
Uranium Resource Evaluation Project

May 31, 1980

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UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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NRC-084-A

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Date of Issue: May 31, 1980

Report Number: K/UR-38

Subject Category: UC-51, Nuclear Raw Materials

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Uranium Resource Evaluation Project

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Prepared for the U. S. Department of Energy
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Grand Junction Office, Colorado
under U. S. Government Contract W-7405 eng 26

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ABSTRACT

Results of the Edgemont detailed geochemical survey are reported. Field and laboratory data are presented for 109 groundwater and 419 stream sediment samples. Statistical and areal distributions of uranium and possible uranium-related variables are given. A generalized geologic map of the survey area is provided, and pertinent geologic factors which may be of significance in evaluating the potential for uranium mineralization are briefly discussed.

Groundwaters containing ≧7.35 ppb uranium are present in scattered clusters throughout the area sampled. Most of these groundwaters are from wells drilled where the Inyan Kara Group is exposed at the surface. The exceptions are a group of samples in the northwestern part of the area sampled and south of the Dewey Terrace. These groundwaters are also produced from the Inyan Kara Group where it is overlain by the Graneros Group and alluvium. The high uranium groundwaters along and to the south of the terrace are characterized by high molybdenum, uranium/specific conductance, and uranium/sulfate values. Many of the groundwaters sampled along the outcrop of the Inyan Kara Group are near uranium mines. Groundwaters have high amounts of uranium and molybdenum. Samples taken downdip are sulfide waters with low values of uranium and high values of arsenic, molybdenum, selenium, and vanadium.

Stream sediments containing ≧5.50 ppm soluble uranium are concentrated in basins draining the Graneros and Inyan Kara Groups. These values are associated with high values for arsenic, selenium, and vanadium in samples from both groups. Anomalous values for these elements in the Graneros Group may be caused by bentonite beds contained in the rock units. As shown on the geochemical distribution plot, high uranium values that are located in the Inyan Kara Group are almost exclusively draining open-pit uranium mines.

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HYDROGEOCHEMICAL AND STREAM SEDIMENT DETAILED GEOCHEMICAL SURVEY FOR EDGEMONT, SOUTH DAKOTA; WYOMING

INTRODUCTION

The National Uranium Resource Evaluation (NURE) Program was established by the U. S. Atomic Energy Commission (AEC), now the U. S. Department of Energy (DOE), in the spring of 1973 to assess uranium resources and to identify favorable areas for detailed uranium exploration throughout the United States. The principal objectives of the NURE Program are: (1) to provide a comprehensive in-depth assessment of the nation's uranium resources for national energy planning, and (2) to identify areas favorable for uranium resources. A NURE Program report covering uranium resource assessment in 116 National Topographic Map Series (NTMS) 1° x 2° quadrangles, which contain 100% of the currently estimated uranium resources, is targeted for 1980. The complete resource assessment of the 272 highest-priority quadrangles is scheduled for completion in 1985, and the first comprehensive assessment report of the entire United States is scheduled for completion in 1988. This program, which is being administered by DOE, is expected to increase the activity of commercial exploration for uranium in the United States.

The NURE Program consists of five parts:

1. Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) Program,
2. Aerial Radiometric and Magnetic Survey,
3. Surface Geologic Investigations,
4. Drilling for Geologic Information, and
5. Geophysical Technology Development.

The objective of the HSSR Program is to provide information to be used in accomplishing the overall NURE Program objectives. This is accomplished by a reconnaissance of surface water, groundwater, stream sediment, and lake sediment. The survey is being conducted by three Government-owned laboratories. Union Carbide Corporation, Nuclear Division (UCC-ND), under contract with DOE, is conducting its survey in 154 NTMS 1° x 2° quadrangles which cover approximately 2,500,000 km^2 (1,000,000 mi^2) of the Central United States. This area includes most of the states of Texas, Oklahoma, Kansas, Nebraska, South Dakota, North Dakota, Minnesota, Wisconsin, Michigan, Indiana, Illinois, and Iowa, as well as parts of Arkansas, Missouri, New Mexico, and Ohio.

As a part of the HSSR Program, detailed geochemical surveys were initiated in the fall of 1978 to supply comprehensive detailed geochemical data from specific areas. These surveys are designed to characterize the hydrogeochemistry, stream sediment geochemistry, and/or radiometric patterns of known or potential uranium occurrences. These data can be used to interpret data from the 1° x 2° NTMS quadrangle basic data surveys. Described herein are the results of the work done by UCC-ND in the Edgemont project area, South Dakota; Wyoming (see Figure 1).

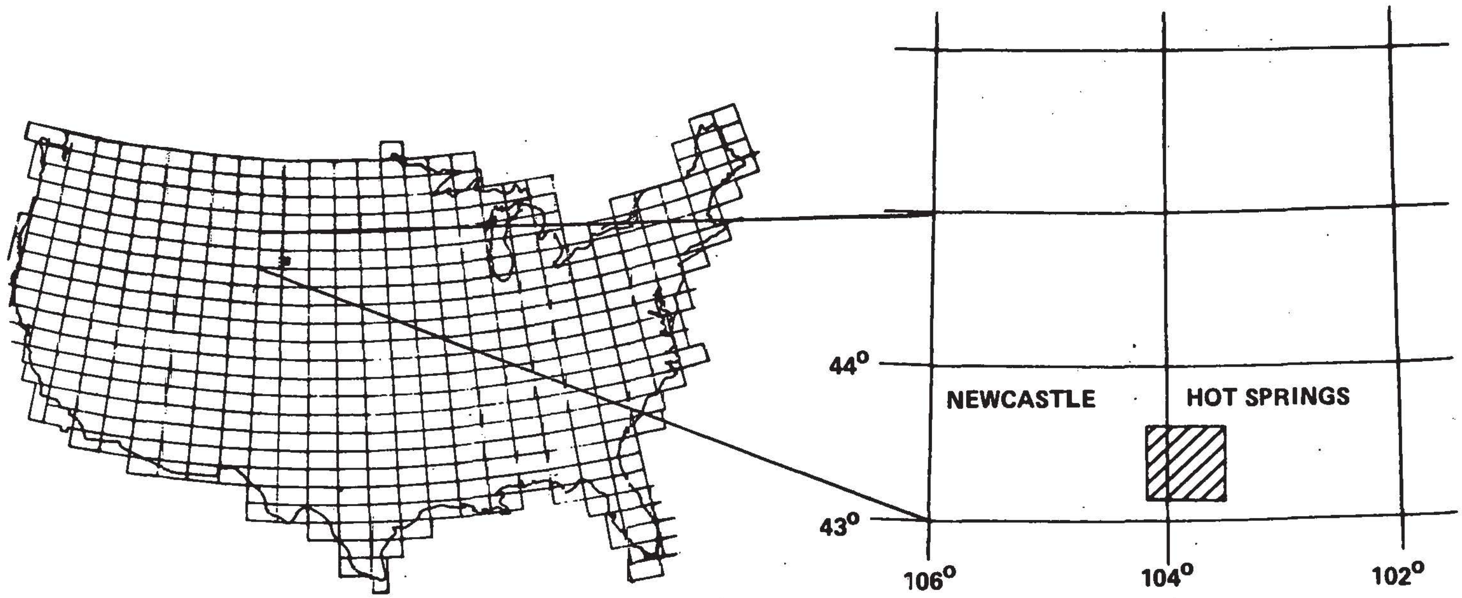

Figure 1

INDEX MAP SHOWING THE BOUNDARIES FOR THE EDGEMONT DETAILED GEOCHEMICAL SURVEY, SOUTH DAKOTA; WYOMING

LOCATION AND PHYSIOGRAPHY

The Edgemont detailed geochemical project area includes approximately 2,220 km^2 (854 mi^2) in southwestern South Dakota and east central Wyoming. The project area lies between lat. 43°07'30" and 43°37'30" and long. 103°30' and 104°07'30" and includes parts of Fall River and Custer Counties, South Dakota and parts of Niobrara and Weston Counties, Wyoming (Figure 2).

The project area lies within two physiographic provinces, the Great Plains and the Black Hills. These two regions are divided by the Cheyenne River, which is the major surface drainage system for the project area. The Cheyenne River generally follows the contact between the Graneros Group shales and the sandstones of the Inyan Kara Group. The Inyan Kara Group to the north of the Cheyenne River forms hogbacks through which streams have incised deep northwest-southeast trending canyons. South of the Cheyenne River are the rolling grasslands of the Great Plains Province. A generalized geologic map of the Edgemont detailed geochemical survey project area, along with a stratigraphic column listing geologic codes used in this report, is presented in Figure 3 and Plate 7.

CLIMATE

The Edgemont project area lies within a semiarid region. The annual precipitation averages about 41 cm (16 in.) and occurs in April through September with a maximum during June (National Oceanic and Atmospheric Administration, 1974). Mean annual temperature is approximately 10°C (49°F); however, temperatures of 39°C (100°F) or higher are experienced during summer months.

RELATED STUDIES

The project area has known uranium mineralization and was extensively mined during the 1950's. During this time, the U.S. AEC funded studies of the uranium district surrounding the town of Edgemont. Most of these studies were done by the U.S. Geological Survey (USGS). Publications include the following: (1) papers by Jones, Frost, and Rader (1957) and Bell and Bales (1954); and (2) USGS Bulletins and geologic maps by Bell and Post, (1971); Braddock (1957, 1963); Brobst (1961); Gott and Schnabel (1963); Ryan (1964); Schnabel (1964); Wilmarth and Smith (1957); and Wolcott, Bowles, Brobst, and Post (1962). Reports by the Raw Materials Division of the U.S. AEC include Casey and Wescott (1957), Illsley (1957), and Illsley and Scott (1956). Gott, Wolcott, and Bowles (1974) describe the accepted source areas for the sediments of the Inyan Kara Group and the method of deposition of uranium in that unit.

Aerial gamma ray and magnetic surveys have been flown for the Hot Springs NTMS Quadrangle for the NURE Program. The report on this area indicates "significant" anomalies in rock units of Jurassic, Triassic, and Cretaceous age. These anomalies appear to follow the known mining district (Texas Instruments, Inc., 1979).

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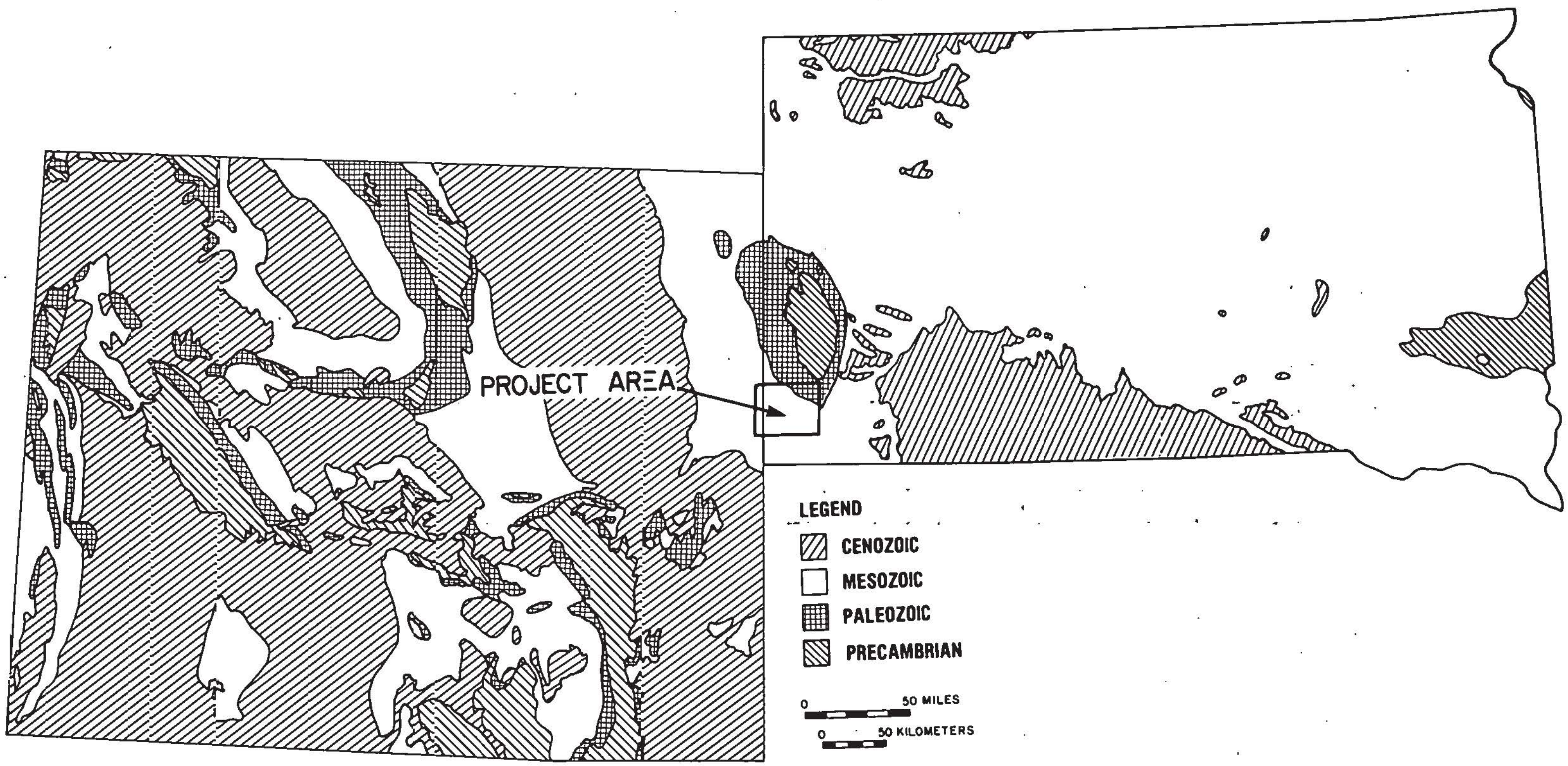


Figure 2

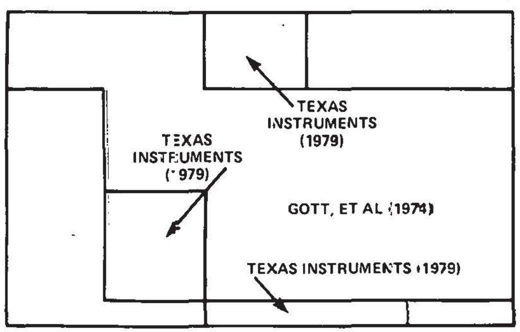
GENERALIZED GEOLOGIC MAP OF SOUTH DAKOTA WITH LOCATION
OF THE EDGEMONT DETAILED GEOCHEMICAL SURVEY, SOUTH DAKOTA; WYOMING
(AFTER KING, ET AL, 1974)

STRATIGRAPHIC COLUMN OF THE EDGEMONT DETAILED GEOCHEMICAL SURVEY

ERA	SYSTEM	GEOLOGIC MAP CODE	GEOLOGIC GROUP	GEOLOGIC FORMATIONS	GEOLOGIC MEMBER	MAXIMUM THICKNESS METERS	FEET
CENOZOIC	QUATERNARY	QAL		ALLUVIUM, TERRACE DEPOSITS			
MESOZOIC	CRETACEOUS	KNC		NIOBRARA MARL AND CARLILE SHALE, UNDIVIDED		76	250
		KGCG		GREENHORN LIMESTONE		76	250
		KGDS	GRANEROS GROUP	BELLE FOURCHE SHALE, MOWRY SHALE, NEWCASTLE SANDSTONE, AND SKULL CREEK SHALE		265	870
		KFL	INYAN KARA GROUP	FALL RIVER FORMATION		201	660
				LAKOTA FORMATION	FUSON MEMBER MINNEWASTE MEMBER CHILSON MEMBER		
	JURASSIC	JMOR		UNKPAPA SANDSTONE AND MORRISON FORMATION, UNDIVIDED		113	370
		JRSU		SUNDANCE FORMATION		122	400
	TRIASSIC	TRSP		SPEARFISH FORMATION		169	556
PALEOZOIC	PERMIAN	PEMO		MINNEKAHTA LIMESTONE AND OPECHE SHALE		41	135
	PENNSYLVANIAN	PMIN		MINNELUSA FORMATION		305	1,000
	MISSISSIPPIAN			PAHASAPA FORMATION		76	250

SOURCES:

1. GOTT, G. B., WOLCOTT, D. E., AND BOWLES, C. G., "STRATIGRAPHY OF THE INYAN KARA GROUP AND LOCALIZATION OF URANIUM DEPOSITS, SOUTHERN BLACK HILLS, SOUTH DAKOTA AND WYOMING," U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 763 (1974).
2. KEENE, J. R., "GROUNDWATER RESOURCES OF THE WESTERN HALF OF FALL RIVER COUNTY, SOUTH DAKOTA," SOUTH DAKOTA GEOLOGICAL SURVEY, REPORT OF INVESTIGATIONS NO. 109 (1973).
3. POST, E. V., "GEOLOGY OF THE CASCADE SPRINGS QUADRANGLE, FALL RIVER COUNTY, SOUTH DAKOTA," U.S. GEOLOGICAL SURVEY BULLETIN 1063-L (1967).
4. TEXAS INSTRUMENTS CORPORATION, "GEOLOGIC MAP OF THE HOT SPRINGS QUADRANGLE" (1979).



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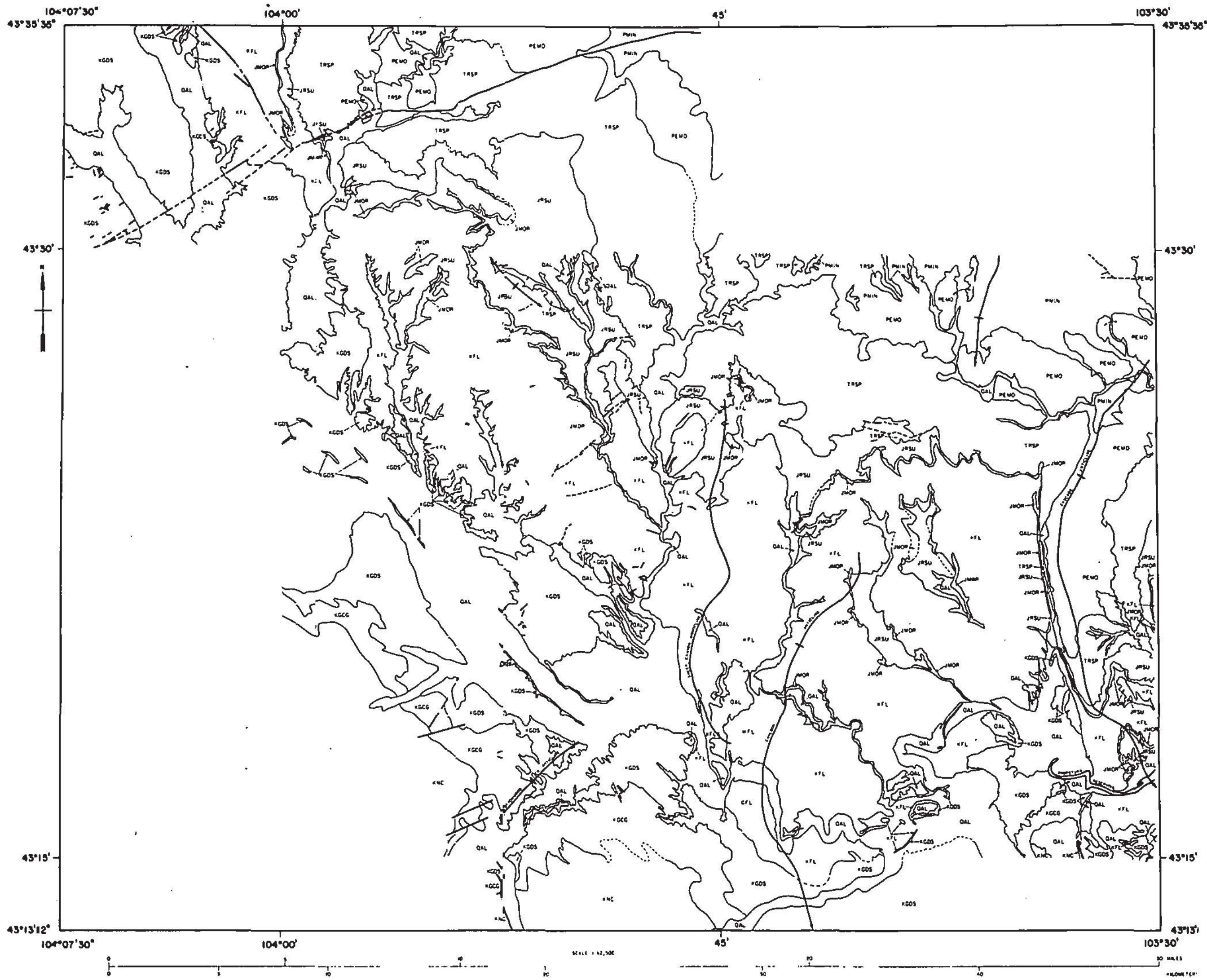

Figure 3

GENERALIZED GEOLOGIC MAP OF THE EDGEMONT DETAILED GEOCHEMICAL SURVEY, SOUTH DAKOTA; WYOMING

Reconnaissance geochemical sampling for the Hot Springs NTMS Quadrangle was completed in 1979 by UCC-ND for the NURE Program. Groundwater data show signficant amounts of uranium from the same units described as being anomalous by the aerial gamma ray and magnetic surveys (Uranium Resource Evaluation Project, December 1979).

GEOLOGY

STRATIGRAPHY

Pennsylvanian and Permian units crop out in and to the north of the area sampled. Mesozoic shales, sandstones, marls, and limestones are the predominant units in the project area. They include the Permo-Triassic Spearfish Formation, the Jurassic Sundance Formation, and the Unkpapa Sandstones and Morrison Formation. Lower Cretaceous units cover the largest area and include the Inyan Kara Group and units of the Graneros Group (Skull Creek Shale, Newcastle Sandstone, and Mowry Shale). Upper Cretaceous units are the Belle Fourche Shale of the Graneros Group, Greenhorn Limestone, Niobrara Marl, and Carlile Shale, all of which crop out in the southern part of the project area. Alluvium from the Cheyenne River covers the Graneros and Inyan Kara Groups in the central section of the project area.

Although the Pahasapa Formation of Mississippian age does not crop out in the project area, it is reported here because of its potential as an aquifer in the project area. It is a gray to buff, massive limestone with thin layers of chert and laterite. The Pahasapa Formation is as much as 12,400 m (4,000 ft) below the surface within the project area.

The Minnelusa Formation is Pennsylvanian to Permian in age. An extensive red mudstone locally called the "Red Marker" is considered the division between the two systems. Below the "Red Marker" bed, the Minnelusa Formation is composed of limestone, dolomite, shale, and sandstone. The upper unit consists of alternating beds of anhydrite, sandstone, and dolomite. Approximately 1,000 ft of the Minnelusa Formation is present within the project area (Braddock, 1963).

The Opeche Shale crops out in the northern section of the area sampled in Hell Canyon. It is primarily a red mudstone with several thin gypsum beds. Overlying the Opeche Shale is the Minnekahta Limestone. The Minnekahta Limestone is composed of beds of fossiliferous, pure to argillaceous limestone, and reddish-brown to reddish-gray limestone.

The Spearfish Formation is a nonresistant series of red siltstones, red sandstones, and gypsum with some carbonate beds. Within the project area, three units of the Spearfish Formation have been mapped by Braddock (1963) and Post (1967). The lower two units contain the gypsum beds. In age determinations, correlations have been made with units in Wyoming, and the top of the Permian has been placed in the middle unit of the Spearfish Formation at the uppermost gypsum bed. The age of the Spearfish Formation is considered to be Late Permian and Triassic. Subsurface logs indicate that the Spearfish Formation can be up to 169 m (556 ft) thick within the project area (Keene, 1973).

The Sundance Formation lies unconformably on the Spearfish Formation. This erosional unconformity represents part of the Triassic and all of the Early and Middle Jurassic. The Sundance Formation is Late Jurassic in age. The thickness of the formation in its outcrop area ranges from 91 to 122 m (300 to 400 ft). It consists of orange-red fine-grained sandstones, olive-gray fossiliferous shales, argillaceous siltstone with some thin limestone beds, and glauconitic sandstones. According to Braddock (1963), the Sundance Formation was deposited in a marine shelf environment that extended northwestward between the Williston Basin in North Dakota and the Twin Creek Trough in southwestern Wyoming.

Overlying the Sundance Formation throughout most of the project area is the Morrison Formation of Late Jurassic age. The Morrison Formation is poorly exposed throughout the project area, but has been measured up to 37 m (120 ft) in the western part (Post, 1967). The Morrison Formation is nonmarine and principally a gray-green mudstone with thin discontinuous beds of limestone. Braddock (1963) suggests that owing to the lack of channel sandstones and the abundance of clay and limestone that the Morrison was deposited in an area of poor drainage and abundant ponds. The Morrison Formation thins out in the eastern section of the survey area.

The Unkpapa Sandstone has a limited extent within the survey area. It is considered Late Jurassic due to its stratigraphic position beneath the Morrison Formation in a few locations. The Unkpapa Sandstone consists of a fine-grained, orange-red sandstone with indistinct crossbeddding, very fine-grained maroon to yellow-orange siltstone, and an upper unit of varicolored argillaceous siltstone and claystone. This upper unit is not always present owing to a pre-Lakota period of erosion. The entire unit has been measured up to 77 m (250 ft) thick within the project area. The Unkpapa Sandstone is considered terrestrial in origin. Post (1967) suggests that it represents a transition from an eolian to a paludal environment.

The Inyan Kara Group is of Early Cretaceous age. The group contains two formations, the Lakota and Fall River, which reach a combined thickness of up to 205 m (660 ft) in the project area. The Lakota Formation consists of these three members: Chilson, Minnewaste, and Fuson. The Chilson Member is primarily composed of two fluvial units and consists of a series of sandstones, shales, siltstones, and mudstones laid down as stream and floodplain deposits. Carbonized plant remains are common in the lower unit. The Minnewaste Member overlies these fluvial units. It grades from an almost pure limestone in its thickest section to a calcareous sandstone at the margins of the deposit. This, along with its limited distribution and presence of fresh water sponge spicules, indicates that the Minnewaste Member is lacustrine in origin (Gott, et al, 1974). The Fuson Member in the project area is primarily a mudstone. The lower part interfingers with a conglomeratic sandstone and channels at the top are filled with a fluvial sandstone. The Fall River Formation is a group of carbonaceous siltstones and fine-grained sandstones cut and overlain by two separate fluvial units. Petrographic studies made by Gott, et al (1974) show a change of sediment source areas over the period of deposition of the Inyan Kara Group. The first two fluvial units from

the Lakota Formation had a western source area, which included ash and tuff from volcanic activity. The fluvial units in the Fuson Member show a transition from a western source area to an eastern source of sediment by the middle of Fall River time.

The Graneros Group is a name given to four units that are Early to Late Cretaceous in age by the South Dakota Geological Survey. According to Keene (1973), they may be up to 265 m (870 ft) thick in the western half of Fall River County, South Dakota where most of the project area lies. The oldest unit is the Skull Creek Shale, which is a gray to black marine shale locally interbedded with siltstone and sandstone. Calcareous concretions and thin limestone beds with cone-in-cone structure are present within the unit. The Skull Creek Shale has a gradational contact with the underlying Inyan Kara Group. Stratigraphically above the Skull Creek Shale is the Newcastle Sandstone. The Newcastle apparently does not overlie the Skull Creek Shale everywhere within the project area. Where it is described, it appears to be thin discontinuous beds of sandstone. The Mowry Shale overlies the Skull Creek Shale in most of the project area and is considered to be the last of the Early Cretaceous units in the Black Hills. The contact between the Mowry and Skull Creek is marked by the Clay Spur bentonite bed. The Mowry Shale is a medium to dark gray shale that typically weathers to light gray or silver in outcrop. The Mowry Shale is also characterized by numerous sandstone dikes. Overlying the Mowry Shale is the Belle Fourche Shale, a Late Cretaceous black marine shale with some beds of bentonite and zones of iron-manganese carbonate concretions.

The Greenhorn Limestone (Late Cretaceous) is a prominent ridge former in the southern Black Hills. It is approximately 77 m (250 ft) thick and includes a lower thick section of olive gray to yellow brown shales and an overlying limestone unit. Overlying the Greenhorn Limestone, in the southern part of the project area, is the Carlile Shale of Late Cretaceous age. The Carlile Shale is a sequence of sandstone and gray shales with limestone concretions. A measured section east of the survey area indicates the Carlile Shale is up to 77 m (250 ft) thick (Post, 1967). Above the Carlile Shale is the Niobrara Marl (Late Cretaceous), which is 62 to 77 m (200 to 250 ft) of gray to yellow marl and chalk (Keene, 1973).

Quaternary alluvial deposits in the project area include terrace deposits and alluvium. Terrace deposits along the Cheyenne River and larger stream basins are often composed of older Paleozoic and Precambrian rocks north of the project area (Gott and Schnabel, 1963). Other terrace deposits include sediments from the nearby Cretaceous rocks, and Ryan (1964) suggests that this represents a reworking of the earlier gravels by the Cheyenne River. Alluvial deposits of sand and silt are extensive on the floodplain of the Cheyenne River and are variable in thickness.

STRUCTURE

The project area lies on the southern end of the Black Hills Uplift, a north-northwest trending dome that probably formed during Laramide time.

Two south-plunging anticlines dominate the eastern part of the project area. The Cascade Anticline is the largest with an amplitude of 3,900 m (1,300 ft) (Gott, et al, 1974) and a steeply dipping western flank with a mildly dipping eastern flank. It forms topographic highs where the resistant Inyan Kara Group crops out. The Chilson Anticline is approximately 12.9 km (8 mi) west of the Cascade Anticline. It also forms ridges along its axis in the Inyan Kara Group. Other anticlines in the project area have little or no surface expression.

In the northwestern part of the project area, two major monoclines border the Dewey Structural Terrace (Brobst, 1961). The Fanny Peak Monocline on the western side of the terrace only extends slightly into the project area, but is a major structure in the region as it separates the Black Hills Uplift and the Powder River Basin to the west. The gently western dipping beds of the Black Hills Monocline are the strata in which the Elk Mountains are cut. The south-plunging Sheep Canyon Monocline (Gott, et al, 1974) lies 4 km (2.5 mi) east of Edgemont. This monocline is bounded on the east by the Livingston Terrace and on the west by the Edgemont Terrace.

Two structural zones extend from the western to the central part of the project area. The Dewey Structural Zone is a fault zone of steeply dipping to vertical normal faults. The northern side of the faults are upthrown with as much as 155 m (500 ft) of displacement (Gott, et al, 1974). The Long Mountain Structural Zone is not as well defined as the Dewey. It consists of many small northeast-trending normal faults. Breccia pipes and collapse structures are numerous in the project area and are formed by the solution of beds of gypsum, anhydrite, dolomite, and limestone in artesian waters. Breccia pipes slope upward for hundreds of meters from the Pahasapa Formation into the overlying formations. These pipes appear to be structurally controlled by zones of intense fracturing and faulting. They are commonly located in the Dewey and Long Mountain Structural Zones.

HYDROLOGY

The principal aquifers of the project area are the Fall River and Lakota Formations of the Inyan Kara Group. The Fall River Formation is the larger producing aquifer. Both produce artesian water and a large number of the wells drilled into these formations flow.

Recharge of the Inyan Kara aquifers does not occur where it is exposed at the surface. Gott, et al (1974) cites studies indicating imperceptible stream loss to the Inyan Kara Group. These aquifers are recharged instead by artesian waters from the Minnelusa Formation which move upward through collapse and breccia pipes and along fault zones. These waters change in composition during their migration from a calcium-sulfate type as it rises through the various structures into the Inyan Kara Group to a sodium-sulfate type as it moves basinward through the permeable zones of the Inyan Kara Group. This change is interpreted as a natural base exchange which softens the water (Gott, et al, 1974). A further alteration occurs locally where the sodium-sulfate type water is changed to a sodium-bicarbonate type. This process occurs due to reduction of sulfate

to hydrogen sulfide by bacteria present in carbonaceous materials within the Inyan Kara Group. According to Keene (1973), hydrogen sulfide in well water is concentrated in areas where a transformation over a short distance from calcium-sulfate water to sodium-bicarbonate water is made. This is due to two factors. The first is a decrease in permeability of the rock which slows movement of the water and allows time for the cation exchange needed to make the change to a sodium-sulfate water. The second factor is confinement and reaction with carbonaceous material which produces a reducing environment which reduces sulfate to sulfide resulting in sodium-bicarbonate waters.

Other aquifers in the project area include alluvium, the Sundance Formation, and the Pahasapa Formation.

Keene (1973) considers the water from the Pahasapa Formation to be some of the best water in Fall River County and to have excellent potential as an aquifer. However, in the project area, the Pahasapa Formation can be as much as 12,400 m (4,000 ft) below the surface and can be up to 59°C (139°F) in temperature. Its use is not widespread.

The Sundance Formation produces water in the southern Black Hills in areas where it crops out. Water downdip has proved to be brackish with high amounts of dissolved solids.

Shallow wells are drilled in alluvium along major streams and the Cheyenne River. They are usually hand dug or rotary drilled and have concrete casing.

The Graneros Group, Morrison Formation, Unkpapa Sandstone, and Spearfish Formation yield small amounts of very poor-quality water. The Minnelusa Formation is thought to be the source of a number of springs in the project area, notably those at Cascade Springs (Keene, 1973).

URANIUM OCCURRENCES

Uranium was first discovered in the southern Black Hills in 1951. Extensive mining operations throughout the area, along with a detailed mapping study and evaluation of the ore deposits, took place during the 1950's and early 1960's. The mining district stretches from the Elk Mountains in Wyoming southeastward through Custer and Fall River Counties, South Dakota, passing north of Edgemont and ending west of the Angostura Reservoir.

Ore deposits were found to be restricted to four stratigraphic units within the Inyan Kara Group. They are the lower unit of the Fall River Formation, the fluvial sandstone Unit 5 in the Fall River Formation, the fluvial Unit 4 in the Fuson Member of the Lakota Formation, and the fluvial Unit 1 in the Chilson Member of the Lakota Formation (Gott, et al, 1974). Principal ore minerals are carnotite, tyuyamunite, corvusite, and rauvite.

Controls on the placement of ore bodies are varied. Permeability, water chemistry, and all structures play a part in ore deposition. Increased

permeability of channel sandstones allows rapid flow of large volumes of aqueous solutions through these fluvial units. Impermeable units, such as the various mudstones and siltstones that interfinger with the channel sandstones, slow this flow, and according to Keene (1973) produce reducing zones. Braddock (1957), Cuppels (1962), and Bell, et al (1955) note uranium deposits at the interface of these rock types. The mineralizing solutions are considered to have been the calcium-sulfate water that recharges the Inyan Kara Group from the Minnelusa Formation (Gott, et al, 1974). Three sources of the uranium in the waters have been suggested. They are (1) Precambrian granites exposed to the north of the project area, (2) sedimentary rocks of the Paleozoic and Mesozoic, and (3) the Tertiary White River Group which contains volcanic ash and which supposedly overlaid this area at one time. There is an apparent decrease in the uranium concentration in groundwaters as they move basinward and the calcium-sulfate water is modified to a sodium-sulfate and sodium-bicarbonate water. This decrease in uranium in solution is interpreted by Gott, et al (1974) as a result of precipitation of uranium. According to studies made by Gott, et al (1974), calcium-sulfate waters in the Inyan Kara Group having high uranium values also have high redox and pH values, indicating an oxidized zone. Sodium-sulfate and sodium-bicarbonate waters with low uranium values have low redox and pH values, indicating a reducing zone.

Uranium deposits are found as both oxidized and reduced ore. Bell, et al (1955) notes the deposits that he studied are located in areas of sudden changes in dip or along margins of structural terraces. Braddock (1957) indicates uranium occurrences on Long Mountain, South Dakota are between two faults. These faults could serve as conduits for mineralizing solutions as breccia pipes do elsewhere in the project area. Calcium-carbonate cement has long been recognized as being spatially related to the ore deposits. Numerous calcite cemented breccia pipes indicate the upwelling Minnelusa Formation waters as the source for the calcite cement as well as the uranium.

SAMPLE COLLECTION

CHRONOLOGY OF THE SURVEY

Sampling for the Edgemont detailed geochemical survey took place during August 1979. Laboratory analysis and compilation and verification of the field and laboratory data base used to prepare the statistical and areal distribution of uranium and other related variables for this report were completed in February 1980.

FIELD PROCEDURES

Field sampling was performed by personnel of the South Dakota Geological Survey. A total of 109 groundwater and 419 stream sediment samples was collected within the survey area. Spring water and well water samples are combined and reported as groundwater. Plates 1 and 4 show sample locations for groundwater and stream sediment sites, respectively. Drainage basins are drawn in on Plate 4 to indicate the area represented

by the stream sediment samples. Due to the sparse population and an accompanying lack of wells, sample coverage for groundwater is limited.

Detailed information regarding techniques in sample collection, recording site data, field equipment, and field measurements may be found in the following reports: "Hydrogeochemical and Stream Sediment Reconnaissance Procedures for the Uranium Resource Evaluation Project" (Arendt, et al, December 1979); "Procedures Manual for Groundwater Reconnaissance Sampling" (Uranium Resource Evaluation Project, March 1978); and "Procedures Manual for Stream Sediment Reconnaissance Sampling" (Uranium Resource Evaluation Project, May 1978). Field observations were recorded on the field form shown in Table C-2 and are included in the microfiche in Appendix D.

CONTAMINATION

Precautions were taken to avoid the possibility of collecting contaminated samples. Wells which were affected by any chlorination, water-softening, or filtering devices were not sampled if a sample could not be taken before the water passed through such devices. Any well that had not been pumped recently was allowed to run long enough to flush the system, and the fact that it had no recent use was noted on the field form. Since the possibility for contamination is high in dug wells, these were noted on the field form. Any wells that the sampler had reason to suspect might be contaminated were noted as such on the field form.

Sediment samples were collected upstream from road crossings, where possible. Visible signs of contamination upstream from a sample site were noted on the field form.

Uranium mining has been a major industry throughout most of the survey area for the past 30 years. Active exploration is being carried on presently by a number of mining firms. Old mines are both pit and shaft operations. These mines have not been filled or reclaimed. Some drill holes have not been properly cased or plugged (Keene, 1973) and may be a possible source of contamination. A uranium mill was operated in the town of Edgemont during the 1950's. Tailings from this mill were buried around several local communities and a survey by the Environmental Protection Agency and U.S. AEC in 1972 showed 49 radioactive anomalies (Nuclear Fuel, 1980).

CHEMICAL ANALYSIS

All samples collected in the field geology program were returned to the URE Project laboratory in Oak Ridge, Tennessee for preparation and analysis. The elements determined and the analytical techniques used along with the appropriate detection limits are given in Table 1. These detection limits are considered the best average during normal operation; however, some variables have values reported below these limits. All water samples were received in 250-ml polyethylene bottles and were filtered through 0.45-μm cellulose acetate paper. Stream sediment sam-

Table 1

DETECTION LIMITS OF VARIABLES DETERMINED IN WATER AND SEDIMENT SAMPLES

Variable	Method	Detection Limit Sediment (ppm)	Detection Limit Water (ppb)
U-FL	Fluorometry	0.25	0.2
U-MS	Mass Spectrometry-Isotope Dilution	--	0.02
U-NT	Neutron Activation-Delayed Neutron Count	0.02	--
As	Atomic Absorption	0.1	0.5
Se	Atomic Absorption	0.1	0.2
Ag	Plasma Source Emission Spectrometry	2	2
Al	Plasma Source Emission Spectrometry	0.05[a]	10
B	Plasma Source Emission Spectrometry	10	8
Ba	Plasma Source Emission Spectrometry	2	2
Be	Plasma Source Emission Spectrometry	1	1
Ca	Plasma Source Emission Spectrometry	0.05[a]	0.1[b]
Ce	Plasma Source Emission Spectrometry	10	30
Co	Plasma Source Emission Spectrometry	4	2
Cr	Plasma Source Emission Spectrometry	1	4
Cu	Plasma Source Emission Spectrometry	2	2
Fe	Plasma Source Emission Spectrometry	0.05[a]	10
Hf	Plasma Source Emission Spectrometry	15	--
K	Plasma Source Emission Spectrometry	0.05[a]	0.1[b]
La	Plasma Source Emission Spectrometry	2	--
Li	Plasma Source Emission Spectrometry	1	4
Mg	Plasma Source Emission Spectrometry	0.05[a]	0.1[b]
Mn	Plasma Source Emission Spectrometry	4	2
Mo	Plasma Source Emission Spectrometry	4	4
Na	Plasma Source Emission Spectrometry	0.05[a]	0.1[b]
Nb	Plasma Source Emission Spectrometry	4	--
Ni	Plasma Source Emission Spectrometry	2	4
P	Plasma Source Emission Spectrometry	5	40
Sc	Plasma Source Emission Spectrometry	1	1
Si	Plasma Source Emission Spectrometry	--	0.1[b]
Sr	Plasma Source Emission Spectrometry	1	2
Th	Plasma Source Emission Spectrometry	2	--
Ti	Plasma Source Emission Spectrometry	10	2
V	Plasma Source Emission Spectrometry	2	4
Y	Plasma Source Emission Spectrometry	1	1
Zn	Plasma Source Emission Spectrometry	2	4
Zr	Plasma Source Emission Spectrometry	2	2
SO_4	Spectrophotometry	--	5[b]
Cl	Spectrophotometry	--	10[b]

[a] Detection limits expressed in percent.
[b] Detection limits expressed in ppm.

ples were dried overnight at 85°C and sieved to collect the <150-μm fraction. Part of the sediment sample was dissolved in 10 ml of 1:1 nitric-hydrofluoric acid. The analytical procedures which were used have been described by Cagle (1977) and Arendt, et al (December 1979). All observed data from all samples are included in the microfiche in Appendix D.

QUALITY CONTROL

MEASUREMENTS CONTROL

The procedures used to analyze URE Project samples require that calibration standards, check samples, and blanks be analyzed along with normal samples to ensure the validity of the reported results. A measurements control program provides information concerning precision and reliability of these measurements. Control samples of two water batches and two sediment batches are submitted anonymously along with routine samples on a daily basis. A statistical summary of results reported on control samples, which were analyzed along with the samples included in this survey, is given in Table 2. Results of uranium analysis of water and sediment control samples obtained from the Ames Laboratory as part of the Multilaboratory Analytical Quality Control for the HSSR Program are reported by D'Silva, et al (1979).

PRINCIPAL COMPONENT ERROR ANALYSIS

A principal component analysis of data from well water and stream sediment samples was used to produce an ordered list of samples using the eigenvalue statistics as described by Kane, et al (1977), where the most extreme samples were listed first. Additional unusual samples were identified if single-element measurements were outside a three standard deviation confidence interval around the mean. The laboratory and field data from the unusual samples identified by this procedure were reviewed. Two well water samples (405357 and 406443) and four stream sediment samples (404881, 405081, 405234, and 405324) which appeared to be the most unusual were submitted for reanalysis. The original results were compared to the results from reanalysis. Of the more than 150 individual analyses that were compared, the only results which were considered to be in error in the original analysis and thus require corrections were multielement values for Water Sample 406443 and a uranium fluorometric value for Sediment Sample 405324. This low error rate for the unusual samples indicates a high level of reliability for the laboratory measurements.

GEOCHEMICAL RESULTS

GEOCHEMICAL DISTRIBUTIONS IN GROUNDWATER

The sample site locations for groundwater samples collected in the Edgemont detailed geochemical survey are shown on Plate 1. Symbol plots for uranium and specific conductance are presented on Plates 2 and 3 and

Table 2

SUMMARY OF MEASUREMENTS CONTROL RESULTS OBTAINED WITH SAMPLES FROM THE EDGEMONT DETAILED GEOCHEMICAL SURVEY, SOUTH DAKOTA; WYOMING

		Measurements Control Results for Water							
		Batch L-4				Batch H-4			
Element	Method	No. of Samples	Mean (ppb)	Standard Deviation (ppb)	Coefficient of Variation	No. of Samples	Mean (ppb)	Standard Deviation (ppb)	Coefficient of Variation
U	MS[(a)]	1	0.52	0.0	0.0	3	9.92	0.496	0.05
U	FL[(b)]	29	0.68	0.234	0.35	25	10.30	0.632	0.06
As	AA[(c)]	33	3.5	0.72	0.20	41	0.7	0.29	0.42
Se	AA	37	1.2	0.17	0.14	41	0.8	0.31	0.38
Al	PS[(d)]	30	96.0	17.6	0.18	30	350.0	21.4	0.06
B	PS	28	1,584.0	71.2	0.04	32	71.0	4.0	0.06
Ba	PS	28	139.0	5.2	0.04	32	32.0	1.4	0.04
Ca	PS	30	10,200.0	540.0	0.05	30	98,500.0	4,310.0	0.04
Co	PS	31	20.0	2.7	0.13	30	95.0	4.6	0.05
Cr	PS	26	95.0	6.0	0.06	34	19.0	3.6	0.19
Cu	PS	30	64.0	18.6	0.29	33	208.0	20.3	0.10
Fe	PS	31	86.0	21.7	0.25	30	984.0	49.5	0.05
K	PS	30	1,910.0	324.0	0.17	34	20,100.0	2,383.0	0.12
Li	PS	31	17.0	2.1	0.12	33	102.0	8.5	0.08
Mg	PS	28	9,300.0	390.0	0.04	30	72,400.0	3,160.0	0.04
Mn	PS	31	20.0	1.7	0.08	30	103.0	4.8	0.05
Mo	PS	28	34.0	7.2	0.21	33	6.0	5.7	0.90
Na	PS	30	1,600.0	220.0	0.14	33	44,800.0	3,780.0	0.08
Ni	PS	28	192.0	8.8	0.05	32	38.0	4.6	0.12
P	PS	31	109.0	21.2	0.19	34	4,790.0	404.2	0.08
Sc	PS	28	62.0	3.8	0.06	31	11.0	0.7	0.06
Si	PS	26	920.0	80.0	0.09	34	7,960.0	912.0	0.11
Sr	PS	30	54.43	3.702	0.07	30	5,155.77	170.646	0.03
Ti	PS	28	113.0	7.0	0.06	32	40.0	2.2	0.05
V	PS	26	10.0	3.0	0.27	30	41.0	5.0	0.12
Y	PS	31	9.0	1.1	0.12	32	47.0	2.0	0.04
Zn	PS	28	498.0	30.4	0.06	23	48.0	22.3	0.46

		Measurements Control Results for Stream Sediment							
		Batch R-3				Batch S-2			
Element	Method	No. of Samples	Mean (ppm)	Standard Deviation (ppm)	Coefficient of Variation	No. of Samples	Mean (ppm)	Standard Deviation (ppm)	Coefficient of Variation
U	FL	52	4.15	0.400	0.10	30	9.93	0.871	0.09
U	NT[(e)]	61	4.86	0.136	0.03	40	10.26	0.276	0.03
As	AA	38	3.6	0.53	0.15	24	9.8	0.98	0.10
Se	AA	40	0.4	0.24	0.53	27	0.8	0.28	0.36
Al	PS	53	31,900.0	2,450.0	0.08	32	55,800.0	4,470.0	0.08
B	PS	57	12.0	6.1	0.48	32	49.0	9.7	0.20
Ba	PS	50	416.0	16.1	0.04	35	381.0	20.3	0.05
Be	PS	56	1.0	2.3	1.64	35	2.0	0.6	0.27
Ca	PS	57	2,700.0	440.0	0.16	36	3,500.0	470.0	0.13
Ce	PS	49	62.86	10.815	0.17	32	83.19	22.161	0.27
Co	PS	55	13.0	2.3	0.17	34	22.0	4.1	0.18
Cr	PS	53	27.0	1.7	0.06	34	60.0	4.3	0.07
Cu	PS	53	21.0	2.7	0.13	33	45.0	2.9	0.06
Fe	PS	53	17,700.0	1,150.0	0.06	32	33,600.0	1,580.0	0.05
K	PS	53	9,800.0	810.0	0.08	30	19,400.0	1,580.0	0.08
Li	PS	55	22.0	1.5	0.07	34	34.0	3.4	0.10
Mg	PS	53	2,100.0	130.0	0.06	34	5,300.0	330.0	0.06
Mn	PS	53	1,898.0	112.4	0.06	32	761.0	38.4	0.05
Mo	PS	56	2.0	1.2	0.47	34	27.0	2.4	0.09
Na	PS	55	1,500.0	130.0	0.08	34	2,100.0	200.0	0.10
Nb	PS	57	12.0	3.8	0.31	35	10.0	5.3	0.50
Ni	PS	57	18.0	2.4	0.13	34	56.0	3.3	0.06
P	PS	53	1,808.0	251.0	0.14	32	808.0	88.3	0.11
Sc	PS	55	5.0	0.6	0.10	32	11.0	0.7	0.06
Sr	PS	51	54.39	2.899	0.05	35	79.94	5.693	0.07
Th	PS	57	7.0	4.3	0.60	36	8.0	2.6	0.32
Ti	PS	53	3,197.0	281.1	0.09	36	2,955.0	267.7	0.09
V	PS	53	52.0	4.6	0.09	30	157.0	10.7	0.07
Y	PS	55	19.0	1.6	0.08	34	28.0	1.4	0.05
Zn	PS	51	88.0	7.6	0.09	32	100.0	6.2	0.06
Zr	PS	51	131.0	8.9	0.07	32	112.0	5.9	0.05

[(a)] Mass spectrometry.
[(b)] Fluorometric analysis.
[(c)] Atomic absorption.
[(d)] Plasma source emission spectroscopy.
[(e)] Neutron activation delayed neutron count.

Figures A-1b and A-2b, respectively. A map of samples noted as having hydrogen sulfide odor at the time of sampling is presented in Figure 4. With the exception of four samples, all groundwater samples are from the Inyan Kara aquifer. Samples 405328, 409507, and 409520 were produced from the Sundance Formation and Sample 406438 was reported as being produced from the alluvium. The number of samples from each of the major geologic and lithologic units in the project area is presented in Table 3.

Observed data for the variables arsenic, calcium, magnesium, molybdenum, pH, selenium, specific conductance, sulfate, total alkalinity, vanadium, and uranium are listed in Table A-3. The figures in Appendix A present log frequency, lognormal probability, percentile, and areal symbol plots for arsenic, calcium, magnesium, molybdenum, pH, selenium, specific conductance, sulfate, total alkalinity, uranium, boron, lithium, potassium, sodium, strontium, uranium/specific conductance, and uranium/sulfate.

Uranium

Uranium concentrations in groundwater above the 84th percentile (7.35 ppb) are present in scattered clusters throughout the area sampled. The largest concentration of these clusters is in the northwest of the area sampled where uranium values above the 84th percentile are found in groundwaters from wells within and around the community of Dewey, south of Dewey along Beaver Creek in Custer and Fall River Counties, and southeast of Dewey at the Doran Ranch. A large cluster of uranium values occurs in the north central portion of the area sampled. These samples are from the groundwaters along Driftwood Creek and Driftwood Canyon approximately 4.8 km (3 mi) north to northwest of the town of Edgemont. The three highest uranium values for groundwater are located apart from the main body of groundwater samples in the southeastern section of the area sampled. They are from wells located at the Marty Ranch on the east side of Chilson Canyon and a spring located in Deadhorse Canyon. Two of these samples were taken from holding tanks in which large amounts of algae were noted. A final high uranium value is isolated in the far southeastern corner of the study area along the Cheyenne River. Some of the groundwaters which were high in uranium were taken from wells and springs located near old uranium mines. These include Samples 405089, 405311, 405356, 405357, 405379, 406468, and 409510. All of the preceding groundwaters are produced from the Inyan Kara Group. One uranium value greater than 84th percentile is from a well drilled into the Sundance Formation. It is located in the northern part of the survey area within the Black Hills National Forest.

The 16th percentile for uranium values in groundwater is below the detection limit of 0.20 ppb for uranium. The 25th percentile is 0.22 ppb for all uranium values. Most of the low uranium values are located in the central to south central section of the area sampled. These groundwaters are produced predominantly from the Inyan Kara Group. There are two probable reasons for low uranium values in a geologic unit which also

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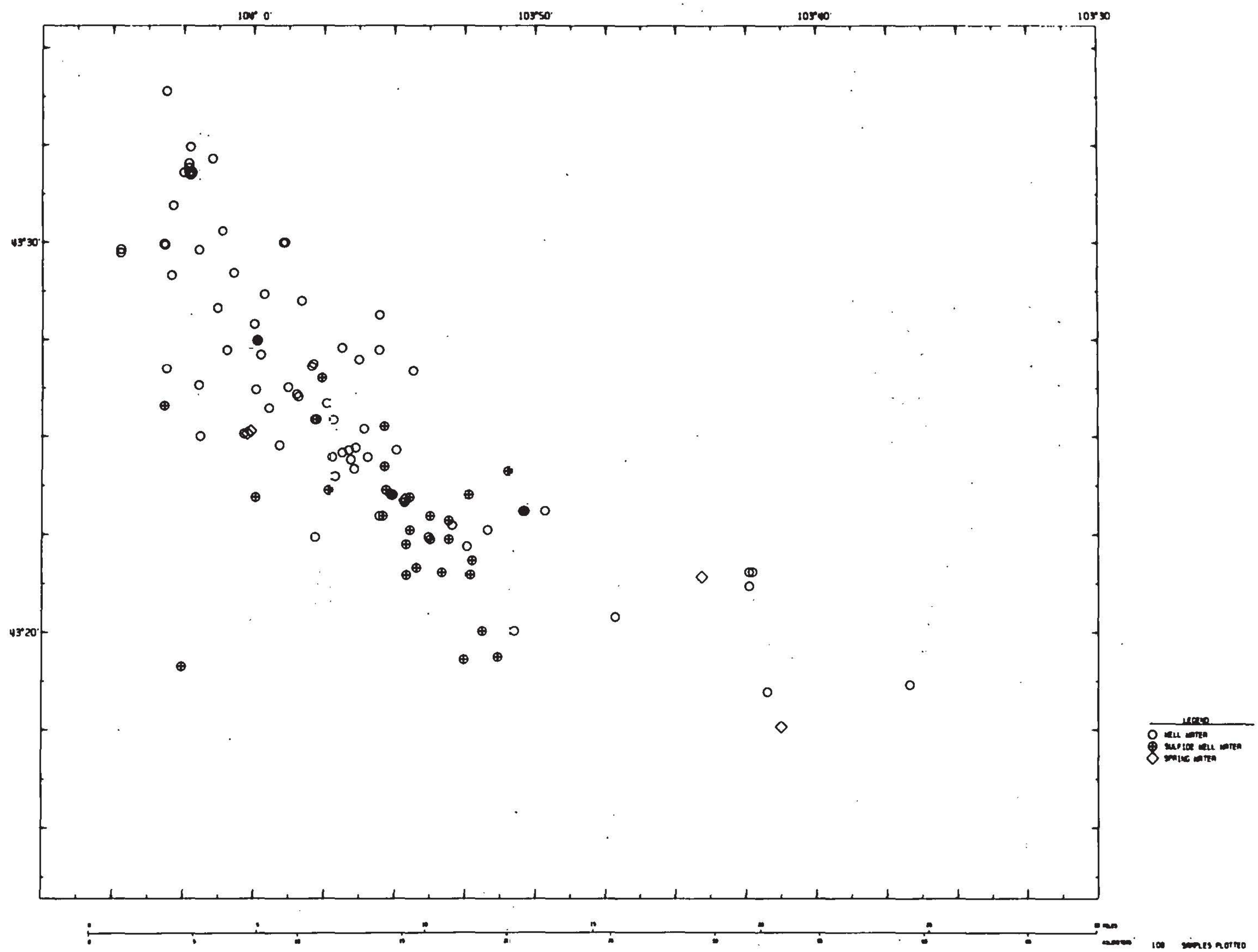

Figure 4

SULFIDE WELL LOCATION MAP FOR GROUNDWATER
OF THE EDGEMONT DETAILED GEOCHEMICAL SURVEY, SOUTH DAKOTA; WYOMING