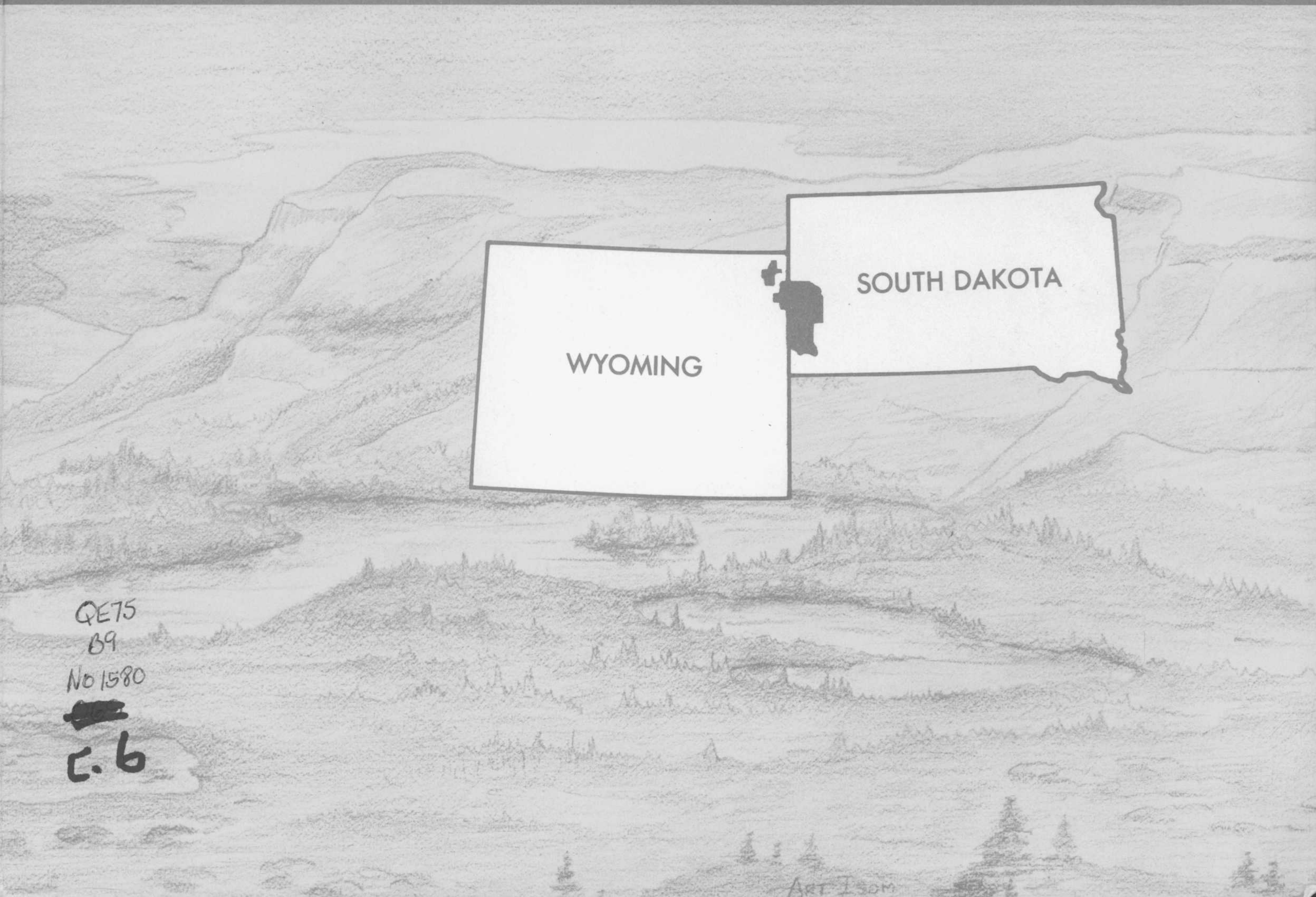
Mineral Resource Potential and Geology of the Black Hills National Forest, South Dakota and Wyoming

U.S. GEOLOGICAL SURVEY BULLETIN 1580



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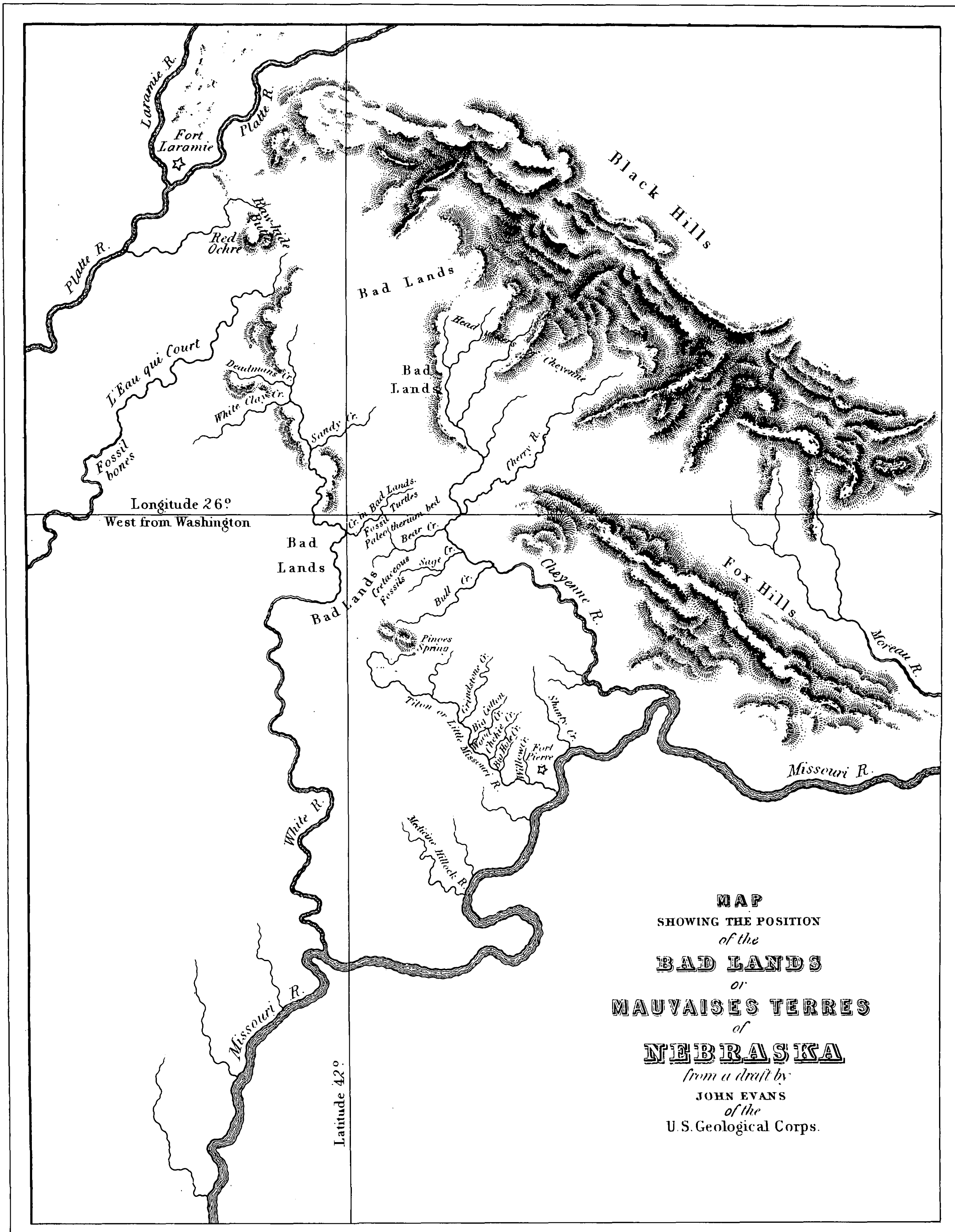

Frontispiece. The earliest known map of the Bad Lands and part of the Black Hills. From a report by John Evans contained in Owen (1852).

Mineral Resource Potential and Geology of the Black Hills National Forest, South Dakota and Wyoming

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U.S. GEOLOGICAL SURVEY BULLETIN 1580

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, *Secretary*

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SUMMARY

This assessment of the mineral resource potential of the Black Hills National Forest, South Dakota and Wyoming, was made to assist the U.S. Forest Service in fulfilling requirements of Title 36, Chapter 2, Part 219.22, Code of Federal Regulations, and to supply resource information and interpretations so that the mineral resources of this Forest can be considered with other resources in land use planning. Geologic, geochemical, and geophysical data were compiled at 1:100,000 and 1:250,000 scale, and all available information on mineral deposits and geology was used in assessing the mineral resource potential of the Forest, as of August 1985.

The Black Hills National Forest is endowed with a wealth of mineral resources. Mining and exploration in the Forest have played a central role in the history of the area and are active and ongoing interests. The world-famous Homestake mine, historically the largest producer of gold in the western hemisphere, is in the northern Black Hills. The southern Black Hills are known throughout the world for their rare-mineral pegmatite deposits. High-calcium limestone in the Black Hills is used to produce cement that is marketed in a nine-state region in the upper Midwest. Deposits in the Forest are currently producing gold, silver, base metals, pegmatite products, limestone, oil and gas, sand and gravel, and dimension stone. The Forest has produced uranium, vanadium, tungsten, gypsum, and industrial sand, and could again produce these commodities in addition to molybdenum, rare-earth elements, thorium, and fluorine. Active exploration programs by industry are seeking new deposits of base and precious metals, thorium, rare-earth elements, oil and gas, and other mineral resources. Economically important mineral production in the future seems assured.

CHARACTER AND GEOLOGIC SETTING

The Black Hills National Forest comprises 1,927 sq mi of rugged, timbered land in the Black Hills of South Dakota and Wyoming and the Bear Lodge Mountains of Wyoming. It extends southeast 115 mi from north of Sundance, Wyo., to south of Hot Springs, S. Dak. At its widest part from east to west the Forest extends for about 35 mi. Elevations within the Forest range from about 3,200 ft above sea level at Angostura Reservoir, south of Hot Springs, to 7,242 ft at the top of Harney Peak, north of Custer.

The rocks in the Forest range from those more than 2.5 billion years old to gravels being deposited in present-day stream bottoms. The earliest events in the geologic record are deposition of Precambrian silty and iron-rich sediments and their metamorphism and deformation sometime prior to 2.5 billion years ago. Granitic rocks intruded these ancient rocks about 2.5 billion years ago and were overlain by sandy, conglomeratic, and silty sediments that were intruded by mafic rocks about 2.2 billion years ago. More iron-rich sediments were deposited on top of these mafic rocks and were interbedded with sand, silt, mud, and minor volcanic rocks. All of the sediments were then metamorphosed, deformed, and intruded by a large body of granite about 1.7 billion years ago. That part of the geologic record from 1.7 billion years ago until about 550 million years ago is not represented in the Black Hills.

The Precambrian rocks had been extensively eroded and uplifted to the surface by about 550 million years ago. During Paleozoic time, from 550 until 250 million years ago, sandstone and limestone were deposited in the Black Hills area in a relatively stable marine environment. Mesozoic rocks, including shale, siltstone, and sandstone, overlie the Paleozoic rocks in a relatively uninterrupted sequence. Deformation of the Black Hills area from about 65 to 60 million years ago caused the region to be uplifted in an elliptical form and the Paleozoic and Mesozoic rocks to be partially stripped off the uplift, exposing the Precambrian rocks in the center of the Black Hills.

During Tertiary time, from about 60 to 50 million years ago, igneous rocks were emplaced in the northern Black Hills and caused local deformation of the older rocks. From about 40 to 35 million years ago the Black Hills again were partially covered by sediments derived from highlands to the west and from the Black Hills themselves. These sediments have been largely stripped from the uplift since 30 million years ago when the Black Hills area was again uplifted and the present landforms were largely shaped. Erosion continues to modify the landscape of the Black Hills locally.

MINERAL RESOURCES

Gold may have been discovered in the area of the Black Hills National Forest as early as 1834, but large-scale mineral production began in 1874 when gold was found in creek beds near Custer. The search for more gold led prospectors north from Custer to find other placer deposits in the central and northern Black Hills. Prospectors reached the Lead–Deadwood area by 1876, where they discovered the world-famous gold deposit that is now the Homestake mine. Shortly after the discovery of the Homestake deposit many of the Tertiary deposits in the Lead–Deadwood area were located. Pegmatite deposits containing rare metals were discovered in 1880 in both the Custer–Hill City–Keystone area and the Tinton area. Gypsum, lime, building stone, sand and gravel, cement materials, semiprecious and ornamental stones, clay, petroleum and natural gas, and uranium have been produced from the forest, and exploration for exotic commodities such as rare-earth elements continues today.

Mineral commodities extracted from the Black Hills National Forest or within 2 mi of its borders from 1874 until 1985 are worth more than $2.5 billion if the price for the commodity at the time of its production is used. If the 1983 price for the commodity is used, the value of mineral commodities extracted from the Forest and its immediately adjacent lands from 1874 until 1985 is more than $17 billion.

RESOURCE POTENTIAL

The assessment of mineral potential in this report is divided into three parts: locatable, leasable, and salable commodities. A summary of the resource potential for locatable and leasable commodities is presented in table 1. Listed in the table are the principal locatable and leasable commodities, the total area of the Forest having high, moderate, low, or unknown potential for each commodity, the types of deposits containing those commodities, and the total area having high, moderate, low, or unknown potential for each type of deposit. Note that the total area having high or moderate potential for all the deposits may be greater than the total area having high or moderate potential for all commodities. This case arises because areas having mineral potential for different types of deposits tend to overlap.

Table 1. Total area of lands having high, moderate, low, and unknown mineral resource potential in and adjacent to the Black Hills National Forest, S. Dak. and Wyo.

[Area of Black Hills National Forest is 1,927 sq mi; area of Forest and adjacent lands as shown in figures 1-3 and on plates 2 and 3 is 5,153 sq mi. Total areas for locatable, leasable, and salable resources shown at top of table cannot be added together because areas containing these three categories of resources overlap in figures 1-3 and on plates 2 and 3. The breakdown of locatable resources (A-Z) and leasable resources (CO, OG, and GE) may result in higher totals than for the summary at top of the table due to overlap of areas on plates 2 and 3 and in figures 15-24; REE, rare-earth elements; leaders (---) in "high," "moderate," and "unknown" columns indicate that no areas of high, moderate, or unknown potential are present; in "low" column, the leaders indicate that any areas of low potential that might be present are not discussed in the text and are not included in area totals]

	Resource potential of areas in Black Hills National Forest (in square miles, 1,927 sq mi maximum)				Resource potential of areas in Black Hills National Forest and adjacent lands (in square miles, 5,153 sq mi maximum)			
	High	Moderate	Low	Unknown	High	Moderate	Low	Unknown
Type of resource								
Locatable	667	858	38	45	1,287	1,532	41	54
Leasable	4	308	850	---	67	1,321	2,352	---
Salable	586	---	---	---	1,271	---	---	---
Locatable resources								
Type of deposit (commodities)								
A. Taconite (Fe)	4	4	7	---	4	5	7	---
B. Conglomerate (U)	---	3	---	---	---	3	---	---
C. Iron-formation (Au)	56	89	---	11	63	100	---	11
D. Vein (Au, Ag, Pb)	12	64	10	---	12	64	11	---
E-J. Pegmatite	258	58	1	---	260	150	1	---
K. Stratabound (Mica)	32	10	---	---	32	10	---	---
(Au, Ag, Zn)	---	---	---	43	---	---	---	43
L. Paleoplacer (Au)	---	3	27	---	---	9	36	---
(silica sand)	---	27	2	---	---	28	24	---
M. Limestone	126	577	---	---	392	648	---	---
N. Gypsum	20	13	---	---	233	1	---	---
O. Roll-front (U, V)	138	54	---	---	270	584	---	---
P. Bog-iron (Fe)	---	3	---	---	---	3	---	---
Q. Placer (Au)	---	23	19	---	---	34	23	---
R. Detrital (Fe)	---	2	3	---	---	2	3	---
S. Vein and replacement (Pb, Zn, Ag, Au).	7	2	6	---	7	---	6	---
T. Vein and replacement (Au, Ag, Pb, Zn).	12	30	4	---	15	42	5	---
U. Disseminated (Mo, Cu, Zn, Au, Ag).	2	5	1	2*	3	5	1	4*
V. Disseminated (Au, Ag, Mo, Cu).	7	13	2	---	7	17	2	---
W. Disseminated (Th)	20	5	---	3	20	5	---	18*
X. Disseminated (REE)	5	---	---	---	5	---	---	---
Y. Disseminated (Au, Ag)	4	---	1	---	4	---	1	---
Z. Vein (Ag, Pb, Au, Zn)	---	1	---	---	---	1	---	---
Leasable resources								
Type of deposit								
CO. Subbituminous coal	---	3	222	---	---	80	554	---
OG. Oil and gas	4	308	850	---	67	1,266	2,406	---
GE. Geothermal	---	---	1	---	---	---	8	---

*Includes areas UV1 and WXY1.

Locatable Commodities

Most metals and industrial minerals are included in the category of locatable commodities by the General Mining Law of 1872. The principal types of deposits considered in the assessment of mineral potential for locatable commodities in the Black Hills National Forest are listed below, and the metals found in each type of deposit and the principal areas of resource potential are briefly summarized. Letter symbols shown in the list below are used throughout this report to designate particular types of deposits. Areas having high, moderate, low, and unknown resource potential are shown in figure 1.

A. Taconitic iron-formation deposits that contain large amounts of iron and lesser amounts of titanium were formed in a submarine environment more than 2.2 billion years ago. The principal areas of high resource potential are in a northwest-trending belt centered near Nemo.

B. Quartz-pebble conglomerate deposits that contain uranium, thorium, and minor amounts of gold and chromium were formed in a shallow-water environment about 2.2 billion years ago. The principal area of moderate resource potential is a northwest-trending belt west of Nemo.

C. Iron-formation deposits rich in carbonate and sulfide minerals and containing gold and lesser amounts of silver were formed in a submarine environment about 1.8–2.1 billion years ago. The principal areas of high resource potential include the Lead–Deadwood region, the Rochford area, the Keystone area, and the Medicine Mountain region.

D. Veins and shear zones that contain gold and silver and lesser amounts of lead and zinc were formed about 1.6–1.9 billion years ago. The principal areas of moderate and high resource potential are in the central Black Hills near Keystone, near Hill City, northwest of Custer, near Silver City, in the Rochford area, and near Tinton.

E, F, G, H, I, J. Pegmatite bodies that contain tin, tungsten, lithium, beryllium, feldspar, and mica were formed in an igneous environment about 1.6–1.8 billion years ago. These deposits are classified according to whether they are rich in feldspar (type E), in tin and tungsten (type F), in lithium (type G), in potassium feldspar and mica (type H), or in mica (type I), or contain large amounts of beryllium (type J). The principal areas of high resource potential surround the Harney Peak Granite in the southern Black Hills on all sides, particularly on the south where the density of pegmatite bodies is greatest.

K. Schist that is rich in muscovite was formed in a near-surface environment about 1.7–2.0 billion years ago. The principal areas of high resource potential are in the central Black Hills near Hill City.

Pyrite-rich slate that possibly contains gold and silver and lesser amounts of zinc was formed about 1.7–2.0 billion years ago. The principal areas of resource potential are west of Hill City and south of Rochford.

L. Paleoplacers that contain gold were formed in a surface-weathering environment about 500 million years ago. Areas of moderate resource potential are in the Lead–Deadwood region.

Paleobeach deposits that contain very pure silica sand were formed in a marine environment about 500 million years ago. Areas of moderate resource potential are southwest of Deerfield, east of Nemo, and near Rockerville.

M. High-calcium limestone was formed in a shallow-water marine environment about 250–350 million years ago. Areas having high resource potential include the outcrop extent of the Minnekahta Limestone around the Black Hills uplift and small areas within the outcrop extent of the Pahasapa Limestone.

N. Gypsum was formed in a shallow-water marine and surface environment about 250 million years ago. Areas having high resource potential include the outcrop extent of the Spearfish Formation around the Black Hills uplift.

O. Roll-front deposits in Cretaceous rocks that contain uranium and vanadium were formed in a near-surface environment. Areas having high and moderate resource potential are in the southern Black Hills near Edgemont and in the northwestern Black Hills west of Sundance.

P. Bog-iron deposits were formed in the present-day surface-weathering environment. Principal areas having a moderate resource potential are concentrated around Rochford.

Q. Placers that contain gold and cassiterite are formed in a terrestrial environment by rivers and streams. Areas having moderate resource potential are scattered throughout the Black Hills from the Bear Lodge Mountains in the northwest to the Custer area in the southeast.

R. Colluvium that contains iron was formed in a surface-weathering environment about 500 million years ago. Areas having moderate resource potential are south of Deadwood and east of Keystone.

S, T. Vein and replacement deposits that contain base and precious metals were formed in an igneous environment about 50–60 million years ago. Type S are base-metal-rich deposits containing lead, zinc, and silver, and minor amounts of copper and gold; type T are precious-metal-rich deposits containing gold and minor amounts of silver, lead, zinc, and copper. Principal areas of high resource potential are west and south of Lead, near Galena, and in the Bear Lodge Mountains.

U, V. Disseminated and porphyry-type deposits that contain base and precious metals were formed in an igneous environment about 50–60 million years ago. Type U are base-metal-rich deposits containing molybdenum, lead, and minor amounts of silver and copper; type V are precious-metal-rich deposits containing gold, copper, and minor amounts of silver and lead. Areas having high and moderate resource potential are near Galena, west of Lead, and in the Bear Lodge Mountains.

W, X, Y. Disseminated and carbonatite deposits that contain base and precious metals and rare-earth elements were formed in an igneous environment about 50–60 million years ago. Type W are thorium-rich deposits containing thorium and manganese and minor amounts of uranium; type X are rare-earth-element-rich deposits containing lanthanum, cerium, other light rare-earth elements, lead, and minor amounts of thorium and uranium; and type Y are precious-metal-rich deposits containing gold, tellurium, and minor amounts of silver. Areas having high resource potential are in the Bear Lodge Mountains and near Tinton.

Z. Vein deposits that contain gold, silver, and lead formed in a tectonic environment about 65 million years ago. Areas having moderate resource potential are on the east edge of the Precambrian outcrop near Keystone.

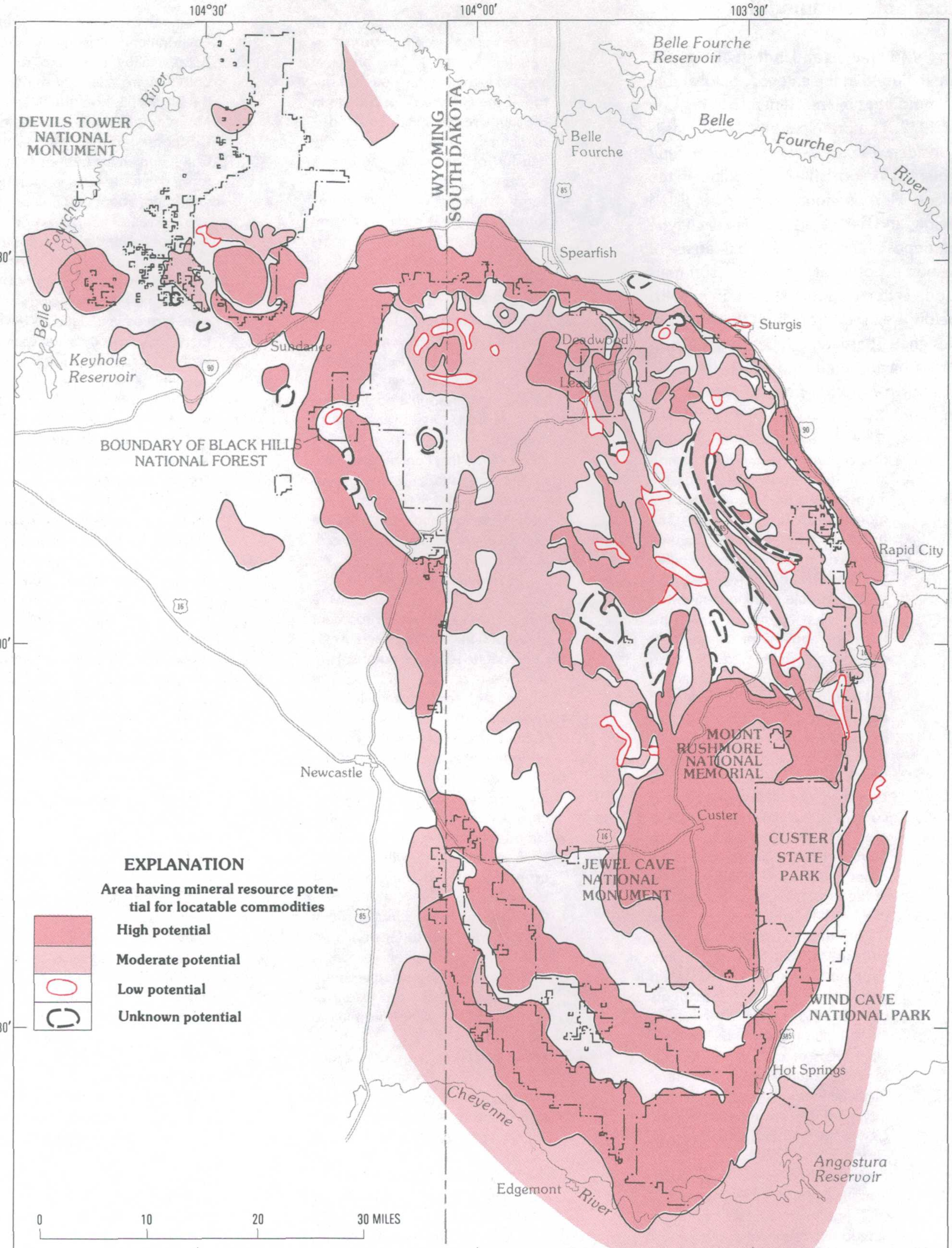


Figure 1. Mineral resource potential map for locatable commodities in the Black Hills National Forest and adjacent area, S. Dak. and Wyo.

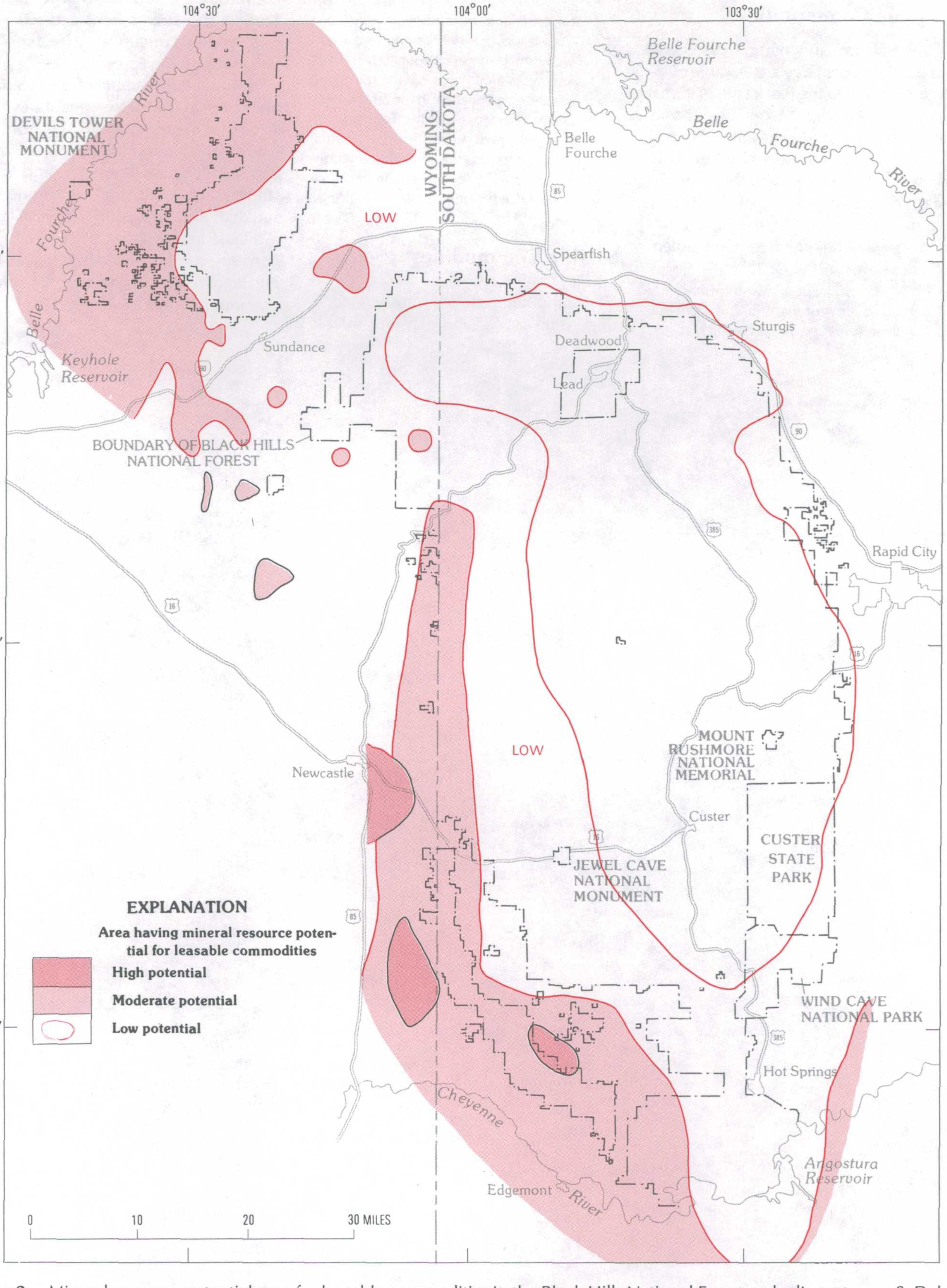


Figure 2. Mineral resource potential map for leasable commodities in the Black Hills National Forest and adjacent area, S. Dak. and Wyo.

Leasable Commodities

Petroleum and natural gas, coal, and geothermal energy are leasable commodities found in the Black Hills National Forest. The principal types of deposits considered in the assessment of mineral potential for leasable commodities in the Forest are listed below, and the principal areas of resource potential are briefly summarized. Areas having high, moderate, low, and unknown resource potential are shown in figure 2.

OG. Oil and gas deposits were formed in a marine environment about 100–400 million years ago. Areas having high and moderate resource potential are between Edgemont and Newcastle.

CO. Coal deposits were formed in a freshwater environment about 100–150 million years ago. Areas having moderate resource potential are in the far southern and western parts of the Forest.

GE. Geothermal deposits consist of thermal springs formed in a terrestrial environment at the present time. The only area of resource potential is near Hot Springs.

Salable Commodities

Sand and gravel, crushed rock, dimension stone, and clay are salable commodities found in the Forest. Modern-day stream beds and older terrace gravels contain most of the sand and gravel in the Forest. Crushed rock is available in large quantity from Paleozoic limestone and in lesser quantities from Tertiary igneous rocks in the northern Black Hills. Many Precambrian rock types, Paleozoic limestone and sandstone, and Mesozoic sandstone are suitable for dimension stone. Clay is available from Mesozoic sandstone that contains clay-rich interbeds. Areas having high resource potential for salable commodities are shown in figure 3.

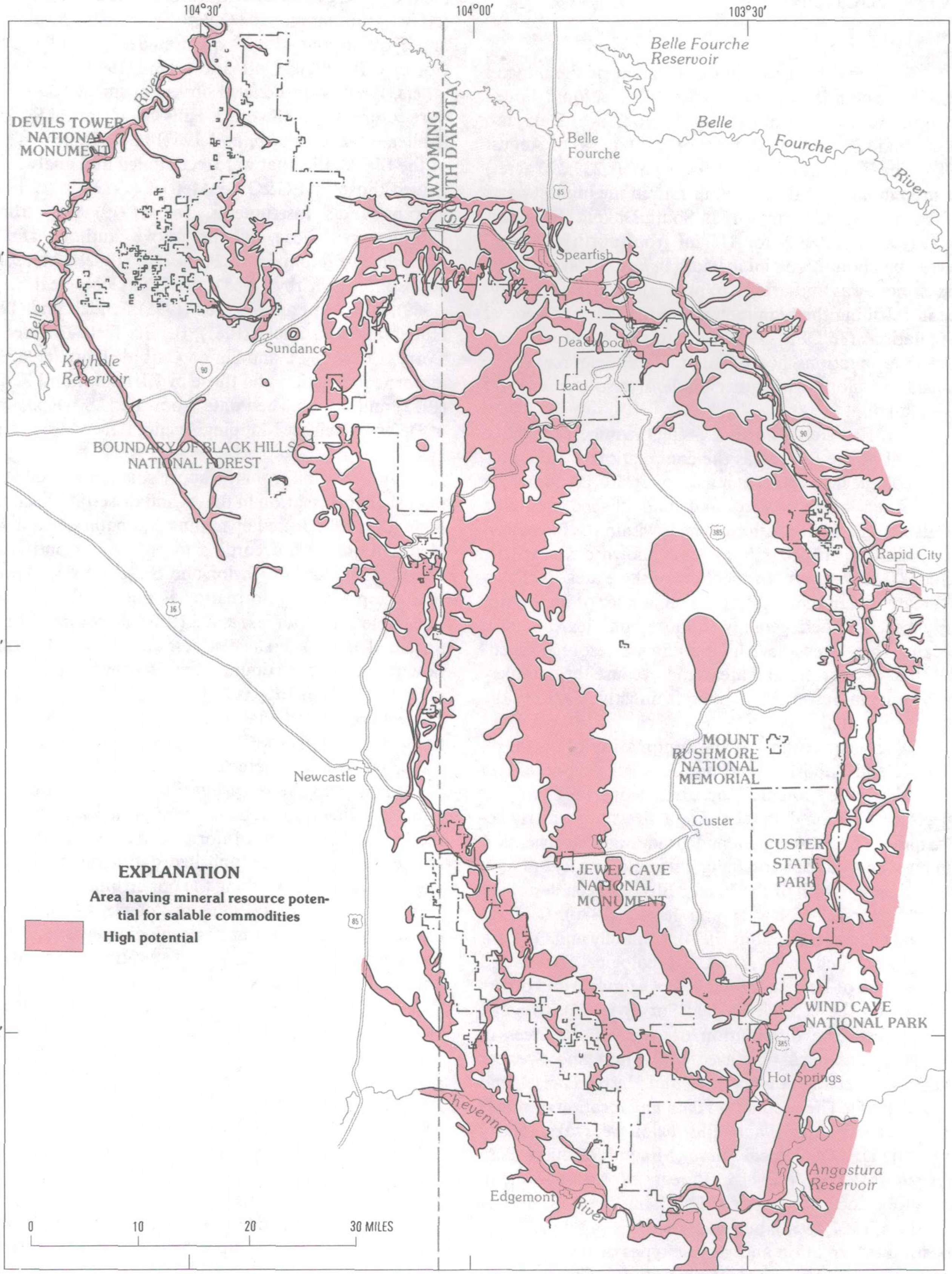


Figure 3. Mineral resource potential map for salable commodities in the Black Hills National Forest and adjacent area, S. Dak. and Wyo.

INTRODUCTION

This report presents an assessment of the mineral resource potential of the Black Hills National Forest (referred to as "the Forest" in this report), S. Dak. and Wyo., that is based on information available as of August 1985. The Forest consists of 1,927 sq mi (1,233,290 acres) of mountainous and forested terrain in the highest parts of the Black Hills, primarily in South Dakota. Irregularly shaped, it extends for 115 mi from north to south, averaging about 25–30 mi in width in South Dakota. This assessment was undertaken to assist the U.S. Forest Service in fulfilling the requirements of the Code of Federal Regulations (36 CFR 219.22) and to supply information and interpretations needed for mineral resources to be considered along with other kinds of resources in land use planning.

The first step toward assessing the mineral resource potential of the forest was the compilation of an up-to-date geologic map (pl. 1) at a scale of 1:250,000, for which we utilized all published and unpublished mapping available. In addition, selected areas within the forest having complex geologic relations are shown on page-size, 1:100,000-scale maps. The geology of these areas is shown in greater detail than that of the remainder of plate 1 not only because their geology is more complex, but also because these areas have higher mineral resource potential than do surrounding areas and because the complexity of mineral resource potential is directly related to the complexity of the geology.

The second step was the compilation of all maps, reports, and published and unpublished data regarding mineral resource potential, occurrence of mines and prospects, production data related to active and formerly active mines, stream-sediment and groundwater geochemical surveys, and radiometric, magnetic, and gravity surveys. The mineral wealth of the Black Hills has been described in publications by Newton and Jenney (1880), O'Harra (1902), Irving and Emmons (1904), Connolly and O'Harra (1929), Rothrock (1944), the U.S. Geological Survey and U.S. Bureau of Reclamation (1964), Osterwald and others (1966), and the U.S. Geological Survey (1975), to name only a few. The distribution of selected resources in Wyoming has been portrayed by Dolton and Spencer (1978), Hausel and others (1979), and Harris, Hausel, and Meyer (1985). The production data and location of mines and prospects in the Black Hills region were taken partly from the U.S. Geological Survey Mineral Resource Data System (MRDS), the U.S. Bureau of Mines Mineral Inventory Location System (MILS), and the U.S. Bureau of Mines (1954, 1955), but extensive revisions concerning location information and genetic types of deposits were made during the course of this study. The principal sources of stream-sediment and groundwater geochemical surveys were reconnaissance studies by the U.S. Department of Energy National Uranium Resource Evaluation (NURE) program for the Gillette, Newcastle, Rapid City, and Hot Springs 1°×2° quadrangles (Union Carbide Corp., 1979, 1980; Goff and others, 1980; Warren and others, 1980). More detailed surveys of smaller watersheds were completed by the Black Hills Geochemical Program (Miller, 1962, 1964a, b, and 1967). Geophysical surveys of the Black Hills that were recompiled and analyzed included those by EG&G geoMetrics (1979a, b, c, 1980a) and by Texas Instruments, Inc. (1979) for airborne radiometrics; those by the above authors and by Meuschke, Philbin, and Petrafeso (1962), Meuschke, Johnson, and Kirby (1963), the U.S. Geological Survey (1969), Kleinkopf and Redden (1975), Hildebrand (1981), Hildebrand and Kucks (1981), Bendix Field Engineering Corp. (1982a, b, c), and Union Carbide Corp. (1982) for airborne magnetics; and those by Kleinkopf and Redden (1975) and unpublished data from the U.S. Department of Defense, Defense Mapping Agency (DMA) for ground-based gravity.

Information from the above sources, as well as unpublished information in theses and dissertations and information volunteered by mining companies, was assembled and analyzed according to procedures outlined by Shawe (1981) and by Taylor and Steven (1983). Mineral resource potential information is portrayed on plates 2 (locatable commodities) and 3 (leasable commodities) at a scale of 1:250,000. Detailed resource potential information for locatable commodities is shown on page-size maps at a scale of 1:100,000. The areas of these maps coincide with those of the 1:100,000-scale geologic maps. Locations of mines in the Black Hills region are shown at 1:250,000 scale on plate 4.

This study relies primarily on information from published literature and on unpublished material from theses and dissertations. Information contained in reports in preparation and unpublished data from the authors were incorporated. Lacking the opportunity for new field studies, we did not fill gaps in knowledge; nor did we reconcile discrepancies among geologic, geochemical, and geophysical surveys made at different times or conducted under different circumstances. Recommendations for further studies indicate data needed for more adequate assessment of parts of the Forest.

Acknowledgments

Many individuals contributed data and ideas to this study. Among those that should be recognized are J. J. Norton for clarifications regarding Precambrian geology, pegmatite deposits, and economic conditions in the Black Hills region, A. L. Lisenbee for Laramide evolution of the region and unpublished data on mapping and composition of Tertiary igneous rocks in the northern Black Hills, and F. R. Karner for making unpublished data

available on the chemistry and petrography of Tertiary igneous rocks in Wyoming.

J. D. Hoffman, assisted by G. K. Lee, retrieved the NURE stream-sediment data from magnetic tape, edited and analyzed the information, and generated multi-element maps and factor analysis plots that were used in this study. J. S. Duval similarly retrieved NURE data and generated radiometric maps of the Black Hills area that show the surface distribution of uranium, thorium, and potassium. Vicky Bankey and M. D. Kleinkopf generated aeromagnetic and gravity maps of the Black Hills region from the NURE data and unpublished U.S. Department of Defense data.

J. E. Fox, G. L. Dolton, and F. V. Steece aided in the acquisition of information on oil and gas wells in the Black Hills area. Supplemental information was obtained from J. P. Gries.

Much of the preliminary bibliographic information was compiled by Rachel Barari. Velma Shelton, Rob Yambrick, Craig Bannister, Tom Johnson, D. E. Lane, P. M. Drouillard, and M. A. Clemensen assisted in various aspects of the study.

G. I. Selner, G. N. Green, and C. N. Gerlitz assisted in the computer plotting of plate 4.

An early version of the manuscript was improved by reviews from R. B. Taylor, F. S. Simons, and J. J. Norton.

GEOLOGY

The Black Hills National Forest is within the Black Hills uplift, a mountainous area of moderate relief that rises above the surrounding Great Plains. Much of the area is covered with coniferous forest, but the lowest slopes are open grasslands. The highest point in South Dakota, Harney Peak, at an elevation of 7,242 ft, is within the Forest, as are many peaks more than 6,000 ft. Terrain varies from mountainous in the central parts of the Forest to moderately steep slopes dissected by deep canyons on the flanks. Major streams in the Forest include Rapid Creek on the east and Spearfish Creek on the north. Local relief is generally not more than 1,500 ft and normally is less than 800 ft. The major center of commerce and transportation near the Forest is Rapid City, S. Dak.

Geologic Framework

The Black Hills uplift is an elongate dome or doubly plunging anticline that was formed during Laramide time (about 60–65 Ma) and exhumed from a cover of Oligocene sediments from 30 Ma to the present. Most of the rocks in the uplift were formed long before the Laramide and range in age from Cretaceous to Archean. Although small areas of Archean rocks exist, most of the Precambrian core consists of low- to high-grade Proterozoic metasedimentary rocks. Such rocks were deposited in an unstable marine environment similar to modern-day continental slopes and ocean bottoms. These rocks were deformed, metamorphosed, and intruded by a large body of relatively undeformed granite, the youngest Proterozoic rock in the uplift. The Precambrian rocks were then uplifted and eroded for a long period of time. In the Paleozoic a relatively thin sequence of marine limestone and sandstone was deposited on Precambrian rocks in a stable shelf environment. This Paleozoic shelf sequence was then succeeded by terrestrial red beds and sandstone of Mesozoic age. Overlying the sandstone is a thick sequence of marine black shale of late Mesozoic age. All the above rocks (shown in stratigraphic columns in fig. 4) were then domed into their present configuration during Laramide time (60–65 Ma). After the doming the Paleozoic and Mesozoic rocks in the northern Black Hills were intruded by a west-northwest-trending belt of stocks, laccoliths, dikes, and sills during early Tertiary time (50–60 Ma). Much of the area of the Black Hills was then covered by a thin sequence of Oligocene terrestrial sediments. Erosion since Oligocene time has uncovered the older rocks and has created the present form of the Black Hills.

The geologic map of the Black Hills (pl. 1) shows standard symbols for Paleozoic and younger rock units. All Precambrian rocks are shown on plate 1 as being either Early Proterozoic (X) or Late Archean (W), subdivided on the basis of published and unpublished isotopic-age-dating studies. Abbreviations for lithology or for the formation name, "Harney Peak," for example, are lower-case letters, such as Xsh for Early Proterozoic metamorphosed shale, Xgw for metamorphosed graywacke, Xq for metamorphosed quartzite, Xb for metamorphosed basalt, and Wgr for Late Archean granite. This lithologic classification was used for all Precambrian rocks. Furthermore, because the lithology of various units is directly related to their mineral resource potential, it is convenient to be able to assess resource potential in terms of established lithologic units.

Although the description that follows is based on lithology of the map units, most of the rock units in the Black Hills that are formally named are briefly mentioned in the text so the reader can understand which named units are contained in the various lithologic map units. The purpose of this description is not to propose new names, modify old names, or present new correlations, but rather to summarize the rock units on a lithologic basis. Much new information (Redden, unpub. mapping, 1975–1985) was incorporated in plate 1 and the page-size maps. Hence the reader will note revisions of existing maps, especially those that show the Precambrian of the Black Hills.

Western Black Hills

Unit	Thickness (Feet)	Symbol
Ogallala Formation and White River Group	0-200	Tw
Fox Hills Sandstone	125-250	Kfh
Pierre Shale	2,700	Kp
Niobrara Formation	125-225	Kng
Carlile Shale	520-600 (600 avg)	Kng
Greenhorn Limestone	70-275	Kng
Belle Fourche Shale	340-700	Kb

Northern Black Hills

Unit	Thickness (Feet)	Symbol
White River Group	0-200	Tw
Fox Hills Sandstone	125-250	Kfh
Pierre Shale	450-2,700	Kp
Niobrara Formation	80-225	Kng
Carlile Shale	400-620	Kng
Greenhorn Limestone	150-400	Kng
Belle Fourche Shale	400-850	Kb

Southern Black Hills

Unit	Thickness (Feet)	Symbol
White River Group	0 to >200	Tw
Pierre Shale	1,200	Kp
Niobrara Formation	175-300	Kng
Carlile Shale	345-450	Kng
Greenhorn Limestone	250-300	Kng
Belle Fourche Shale	150-400	Kb

Eastern Black Hills

Unit	Thickness (Feet)	Symbol
White River Group	10-40	Tw
Pierre Shale	>650	Kp
Niobrara Formation	>220	Kng
Carlile Shale	320 to >370	Kng
Greenhorn Limestone	215-360	Kng
Belle Fourche Shale	240	Kb

Mowry Shale	130-230	Kms
Newcastle Sandstone	0-100	
Skull Creek Shale	180-250	
Inyan Kara Group	150-570	KJim
Morrison Formation	0-150	
Sundance Formation	110-475	Jsg
Gypsum Spring Fm	0-125	
Spearfish Formation	450-600	TRPs
Minnekahta Limestone	25-50	Pmo
Opeche Shale	70-120	
Minnelusa Formation	700-1,000	PIPm
Pahasapa Limestone	300-630	MDpe
Englewood Formation	50	
Deadwood Formation	200	OCwd

Mowry Shale	180-230	Kms
Newcastle Sandstone	20-60	
Skull Creek Shale	240-270	
Inyan Kara Group	240-270	KJim
Morrison Formation	0-150	
Unkpapa Sandstone	0-40	
Sundance Formation	230-400	Jsg
Spearfish Formation	450-900	TRPs
Minnekahta Limestone	35-45	Pmo
Opeche Shale	25-120	
Minnelusa Formation	400-650	PIPm
Pahasapa Limestone	300-650	MDpe
Englewood Formation	35-50	
Whitewood Dolomite	35-150	OCwd
Winnipeg Formation	0-110	
Deadwood Formation	50-700	

Mowry Shale	125-175	Kms
Newcastle Sandstone	0-35	
Skull Creek Shale	150-250 (250 avg)	
Inyan Kara Group	255-670	KJim
Morrison Formation	0-125	
Unkpapa Sandstone	0-275	
Sundance Formation	230-400	Jsg
Spearfish Formation	355-600	TRPs
Minnekahta Limestone	35-50	Pmo
Opeche Shale	60-150	
Minnelusa Formation	500 to >1,050	PIPm
Pahasapa Limestone	300-650	MDpe
Englewood Formation	30-60	
Deadwood Formation	4-170	OCwd

Mowry Shale	125-140	Kms
Newcastle Sandstone	0-45	
Skull Creek Shale	190-260	
Inyan Kara Group	250 to >500	KJim
Morrison Formation	0-140	
Unkpapa Sandstone	60-250	
Sundance Formation	280	Jsg
Spearfish Formation	440	TRPs
Minnekahta Limestone	40	Pmo
Opeche Shale	110	
Minnelusa Formation	560-640	PIPm
Pahasapa Limestone	560-640	MDpe
Englewood Formation	33-37	
Deadwood Formation	150-300	OCwd

Figure 4. Stratigraphic sections of Phanerozoic rocks, Black Hills area, S. Dak. and Wyo. No correlations implied. Lance Formation and Tullock Member of Fort Union Formation not shown in western Black Hills section.

Archean Rocks

Rocks of Archean age (at least 2.5 Ga) are known to exist in three places in the Black Hills: Little Elk Creek, northeast of Nemo; Bear Mountain, northwest of Custer; and the Warren Peaks area, north of Sundance (pl. 1). At the first two locations, granite (unit Wgr, pl. 1) that has been isotopically dated intrudes older metasedimentary strata (unit Wos, pl. 1). At Warren Peaks, in the Bear Lodge Mountains, only granite is present. The granitic rocks northeast of Nemo have been deformed and have a gneissic fabric. Those in the Bear Mountain area are not uniformly gneissic but locally exhibit considerable evidence of deformation. Archean rocks may be present in the Tinton area (unit Xp) (Redden, unpub. data, 1985), but none has been dated. Archean rocks comprise less than 1 percent of the outcrop area of the Precambrian in the Black Hills; the other 99 percent consists of Early Proterozoic rocks. The following summary of the areas is condensed from work by Runner (1934), Woo (1952), Zartman and Stern (1967), Bayley (1972b), Ratté (1980), Redden (1980), and Staatz (1983).

Older Metasedimentary Rocks and Granite (Units Wos and Wgr)

The oldest Archean rocks in the Nemo area were coarse clastic sediments that are now feldspathic schist and gneiss (unit Wos, pl. 1 and fig. 5). These rocks are largely concealed by Paleozoic rocks or are too poorly exposed for thicknesses of the original strata to be estimated. These metasedimentary rocks are intruded by the Little Elk Granite (unit Wgr), which has a U-Th-Pb zircon date of 2.51 ± 0.7 Ga (recalculated from data in Zartman and Stern, 1967, using decay constants in Steiger and Jaeger, 1977).

The Little Elk Granite apparently underlies a relatively extensive area beneath the Phanerozoic cover east of Nemo as indicated by a prominent aeromagnetic low shown by Kleinkopf and Redden (1975) and by Bendix Field Engineering Corp. (1982c). The size of the aeromagnetic low suggests that the granite is a north to northwesterly elongate body at least 5 mi wide and 8 mi long. A prominent gravity low (Kleinkopf and Redden, 1975) that occupies a larger area than the magnetic low is tentatively interpreted to indicate a granitic body at least 10 mi long and 6 mi wide that extends beneath the Phanerozoic cover east of Little Elk Creek.

At Bear Mountain, in the Medicine Mountain area, relatively undeformed granitic rocks intrude biotite-plagioclase schist (Ratté, 1980) shown as unit Wos in figure 6. The total thickness of the schist is unknown because the lower contact is not exposed, but it must be at least 500 ft. South of Bear Mountain, in the Berne quadrangle, similar granitic rock and pegmatite intrude the basal part of the Vanderlehr Formation (Redden, 1968). The granitic rocks have a Rb-Sr whole-rock date of 2.40 ± 0.9 Ga (recalculated from Ratté and Zartman, 1970, using unpub. data by R. E. Zartman, 1985), which is interpreted as a minimum age. The Archean rocks at Bear Mountain apparently do not extend as a large body beneath the cover of Phanerozoic rocks to the west because no prominent magnetic or gravity anomalies are present.

The only Archean rock in the Bear Lodge Mountains (pl. 1, fig. 7) is granite that is exposed in large xenoliths or screens within Tertiary intrusive rocks. The granite has a U-Th-Pb zircon minimum age of about 2.63 Ga (Staatz, 1983).

Oldest Part of Iron-formation (Unit Xif)

Conformably(?) overlying unit Wos in the Nemo area is an interbedded schist-phyllite and banded chert-hematite taconite (unit Xif, pl. 1 and fig. 5), named the Nemo Iron-formation (Redden, 1981), that is about 150–450 ft thick and extends along strike for at least 3.5 mi; this unit is also present in isolated fault(?) segments. The taconitic portion is magnetic and can be traced beneath the Phanerozoic cover by following aeromagnetic (Redden and Kleinkopf, 1975; EG&G geoMetrics, 1980b) and ground-based magnetic highs (Bayley, 1972a). The Nemo Iron-formation is assumed to be older than the Little Elk Granite but is not intruded by it.

Proterozoic Rocks

Metasedimentary strata of Early Proterozoic age consisting mainly of metamorphosed graywacke, shale, and quartzite make up the great bulk of the Precambrian in the core of the Black Hills. Subordinate amounts of metabasalt and metagabbro are interbedded with the metasedimentary strata. All the rocks have been deformed and regionally metamorphosed and have been intruded by the coarse-grained to pegmatitic Harney Peak Granite. The following summary is condensed from work by Irving, Emmons, and Jaggar (1904), Paige (1913, 1924), Hosted and Wright (1923), Noble and Harder (1948), and Bayley (1972a) in the Lead–Deadwood area; by Berg (1946) and Bayley (1970a) in the Galena–Roubaix area; by Runner (1934), Bayley (1972b), and Redden (1980, 1981) in the Nemo area; by Bayley (1972c) in the Rochford area; by Redden (1968), Ratté and Wayland (1969), Ratté (1980), and Kuhl (1982) in the Medicine Mountain–Hill City area; by Norton (1976) in the Keystone area; by Redden, Norton, and McLaughlin (1982) and Redden (1963) in the Custer area; and by Darton and Paige (1925) in the intervening areas. Many of the maps cited above have been modified by Redden (unpub. mapping, 1975–1985) and are incorporated in plate 1 and in the page-size maps in this modified form.

Stratified Rocks

The oldest Early Proterozoic strata are in the Nemo and Medicine Mountain areas, where they unconformably overlie Archean metasedimentary rocks.

Metaconglomerate and Metaquartzite (Units Xcq and Xcqc)

The basal part of this sequence (unit Xcq, pl. 1; units Xcq and Xcqc, fig. 5) consists of conglomeratic and feldspathic schist, biotite schist, taconite, taconite conglomerate, and phyllite derived from conglomerate, arkose, siltstone, iron-formation, and shale. It is restricted to the Nemo area (fig. 5), where it consists of the Boxelder Creek Formation (Redden, 1981), which seems to be conformable in the exposed areas but very likely unconformably overlies the Nemo Iron-formation elsewhere. The unit originally was composed of quartzite, conglomerate with and without clasts of taconite, shale, and dolomite. Quartzite constitutes most of the formation and is as much as or more than 10,000 ft thick. Uraniferous and slightly auriferous fluvial conglomerate and quartzite tongues of the Boxelder Creek Formation containing detrital grains of pyrite are shown as unit Xcqc in figure 5. These tongues overlie fanglomerate marked by rapid facies and thickness changes. The fluvial tongues range between 100 and 500 ft in thickness.

Metaconglomerate (Unit Xc)

A thick sequence of conglomeratic rocks (unit Xc, pl. 1) unconformably overlies metaconglomerate and metaquartzite (unit Xcq) at Nemo and is also present at Medicine Mountain (fig. 6) and in large screens within the Harney Peak Granite (unit Xh, pl. 1) south of Harney Peak. In the Nemo area the conglomeratic unit is the Estes Formation (Redden, 1981), composed of low-grade, schistose rocks that originally were a fanglomerate deposit containing conglomerate, taconite conglomerate, quartzite, arkose, shale, and dolomite. It locally exceeds 6,000 ft in thickness. Similar conglomeratic strata unconformably overlying Archean biotite-plagioclase schist at Bear Mountain, in the Medicine Mountain area (unit Xc, fig. 6), were assigned by Ratté (1980) to basal members of the Vanderlehr Formation. Possibly equivalent units in the Bear Mountain area are apparently about 400 ft thick, but because the rocks have extremely tight folds, this thickness is only approximate. Some large country rock screens in the Harney Peak Granite south of Harney Peak (pl. 1; Keystone area, fig. 8) contain metamorphosed conglomerate, quartzite, arkose, and calc-silicate rocks in a stratigraphic sequence identical to that at Bear Mountain and are therefore placed in unit Xc.

Older Part of Iron-formation (Unit Xif)

Two types of iron-formation (unit Xif, pl. 1 and fig. 5) are common in the basal part of the Early Proterozoic sequence, an oxide-facies taconite represented by the Benchmark Iron-formation (Redden, 1981), and conglomeratic oxide-facies iron-formation bodies that are locally present within units Xcq and Xc. The Benchmark is similar in appearance and composition to the older Nemo Iron-formation, but it conformably overlies the Boxelder Creek Formation (unit Xcq) and is preserved only locally below unconformable younger deposits. Its thickness is irregular but is locally as much as 300 ft. The conglomeratic iron-formation within units Xcq and Xc, probably derived by erosion of both the Nemo and Benchmark Iron-formations, consists of fragments of oxide-facies iron-formation in a matrix of detrital hematite and quartz. These bodies are lens shaped and are thickest near paleotopographic highs, ranging in thickness from a feather edge to more than 500 ft.

Older Part of Metagabbro (Unit Xgb)

A 3,000-ft-thick, layered, gravity-differentiated, and metamorphosed gabbro sill named the Blue Draw Metagabbro (Redden, 1981) intrudes the Boxelder Creek Formation (unit Xcq, fig. 5) in the Nemo area. The gabbro (unit Xgb) is metamorphosed to amphibolite, greenstone, actinolite schist, and serpentinite and is shown as a northeast-trending, zig-zag-shaped body west of Nemo and as a north-trending body south of Steamboat Rock. The Blue Draw Metagabbro, the Boxelder Creek Formation, and the Benchmark Iron-formation are unconformably overlain by unit Xc (Estes Formation) and by younger strata. Preliminary U-Th-Pb zircon dating of the gabbro indicates that it is about 2.2 Ga (Z. E. Peterman, unpub. data, 1985). The Boxelder Creek Formation therefore must be between 2.2 and 2.5 Ga, and the Estes must be younger than 2.2 Ga. Other gabbro units shown in figure 5 are younger than the Blue Draw Metagabbro and constitute the younger part of unit Xgb, to be discussed later.

Metasedimentary Rocks (Unit Xd)

Metamorphosed dolomite and phyllite (unit Xd, pl. 1 and fig. 5) of the Roberts Draw Formation (Redden, 1981) conformably overlie the Estes Formation (unit Xc) in the Nemo area. The unit is about 60–300 ft thick where not thinned or thickened by folding. Rocks considered equivalent in age to unit Xd are marble and calc-silicate rocks overlying the coarse clastic metasediments in the basal part of the Vanderlehr Formation near Bear Mountain, south of Medicine Mountain (Redden, 1963; Ratté, 1980) and some of the large xenoliths within the Harney Peak Granite. The calcareous and carbonaceous strata (Poorman Formation, part of unit Xsc) beneath the Homestake Formation in the Lead area (fig. 9) also may be correlative with the dolomite and phyllite.

EXPLANATION

Tr — **Rhyolite (Eocene and Paleocene)**—Plugs and breccia pipes of rhyolite(?)

Tql — **Quartz latite(?) (Eocene and Paleocene)**—Sills and small laccoliths of hornblende-biotite quartz latite

TRPs — **Spearfish Formation (Triassic and Permian)**—Shale, siltstone, and gypsum

Pmo — **Minnekahta Limestone and Opeche Shale (Lower Permian)**—Minnekahta Limestone: slabby limestone. Opeche Shale: sandy shale

PIPm — **Minnelusa Formation (Lower Permian and Pennsylvanian)**—Sandstone, solution breccia (anhydrite in subsurface), limestone, and shale

MDpe — **Pahasapa Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)**—Pahasapa Limestone: cavernous dolomitic limestone. Englewood Formation: dolomitic limestone

O€wd — **Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**—Whitewood Dolomite: dolomite. Winnipeg Formation: shale and siltstone. Deadwood Formation: sandstone, shale and limestone

Xsh — **Metasedimentary rocks (Early Proterozoic)**—Phyllite, slate, and mica schist. Protoliths include shale, carbonaceous shale, and minor siltstone

Xgw — **Metagraywacke (Early Proterozoic)**—Siliceous mica schist and impure quartzite. Protoliths are turbidite deposits and include graywacke and mixed graywacke and shale. Includes Roubaix Formation

Xms — **Metasedimentary rocks (Early Proterozoic)**—Muscovite schist, muscovite phyllite. Protoliths include aluminous, tuffaceous shale and thin manganiferous chert-carbonate beds

Xsc — **Metasedimentary rocks (Early Proterozoic)**—Siliceous biotite phyllite, calcareous biotite phyllite, and schist. Protoliths include black shale and chert, calcareous and carbonaceous shale, and minor amount of siltstone. Younger part of unit. Includes Reausaw Slate, which intertongues with metabasalt

Xgb — **Metagabbro (Early Proterozoic)**—Amphibolite, greenstone, actinolite schist, and serpentinite. Protoliths include gabbro, norite, and quartz-rich gabbro sills of at least two different ages. Map unit includes both older and younger parts of unit described on plate 1. Includes Blue Draw Metagabbro. Sills that intrude units Xcq and Xcqc (Boxelder Creek Formation) are about 2.2 Ga; sills that intrude unit Xb (Hay Creek Greenstone), unit Xd (Roberts Draw Formation), and unit Xq (Buck Mountain Formation) are about 2.0 Ga (Z. E. Peterman, unpub. data, 1985)

Xch — **Metachert (Early Proterozoic)**—Cherty schist and siliceous schist. Protoliths include chert and iron-poor chert

Xb — **Metabasalt (Early Proterozoic)**—Amphibolite, greenstone, actinolite schist. Protoliths include basalt and minor bodies of gabbro. Interflow units include tuffaceous shale, black shale, massive chert, carbonate- and silicate-facies iron-formation, and mafic tuff. Map unit includes Hay Creek Greenstone

Xq — **Metaquartzite (Early Proterozoic)**—Quartzite, siliceous schist, and minor chert. Protoliths include quartzite containing interbedded siltstone and shale. Map unit includes Buck Mountain Formation and Gingrass Draw Slate

Xd — **Metasedimentary rocks (Early Proterozoic)**—Marble, phyllite, and calcareous phyllite. Protoliths are predominantly dolomite and shale and minor amounts of quartzite. Includes Roberts Draw Formation

Xc — **Metaconglomerate (Early Proterozoic)**—Conglomeratic, siliceous schist, feldspathic schist, and minor marble. Protoliths include conglomerate and quartzite containing minor amounts of arkose, limestone, and shale. Includes taconite conglomerate and is equivalent to parts of Estes Quartzite and Boxelder Creek Quartzite and all of Estes Formation

Xif — **Iron-formation (Early Proterozoic)**—Iron-formation, ferruginous chert, and minor mica schist. Protoliths include oxide-, carbonate-, silicate-, and sulfide-facies iron-formation and interbedded tuffaceous rocks. Map unit includes Nemo Iron-formation and Benchmark Iron-formation and unnamed younger iron-formations. Nemo Iron-formation may be Late Archean in age

Xcq — **Metaconglomerate and metaquartzite (Early Proterozoic)**—Conglomerate and feldspathic schist, biotite schist, taconite, and phyllite. Protoliths include quartzite and minor amounts of shale, dolomite, taconite conglomerate, pyritiferous fluvial conglomerate, and fanglomerate. Includes parts of Estes Conglomerate and Boxelder Creek Quartzite and all of Boxelder Creek Formation

Xcqc — **Metaconglomerate and metaquartzite (Early Proterozoic)**—Conglomeratic phyllite. Protoliths include uraniferous, pyritic conglomerate lenses within unit Xcq

Wgr — **Granite (Late Archean)**—Granite and gneissic granite. Includes Little Elk Granite (U-Th-Pb zircon age of 2.51±0.07 Ga; recalculated from data in Zartman and Stern, 1967)

Wos — **Older metasedimentary rocks (Late Archean)**—Phyllite and mica schist. Protoliths include siltstone and shale that lie beneath taconitic Nemo Iron-formation. These rocks are intruded by Little Elk Granite

Contact—Dashed where approximately located

Fault—Dashed where approximately located; dotted where concealed. Bar and ball on downthrown side; arrows show relative sense of displacement

SCALE 1:100,000

0 1 2 3 4 5 MILES

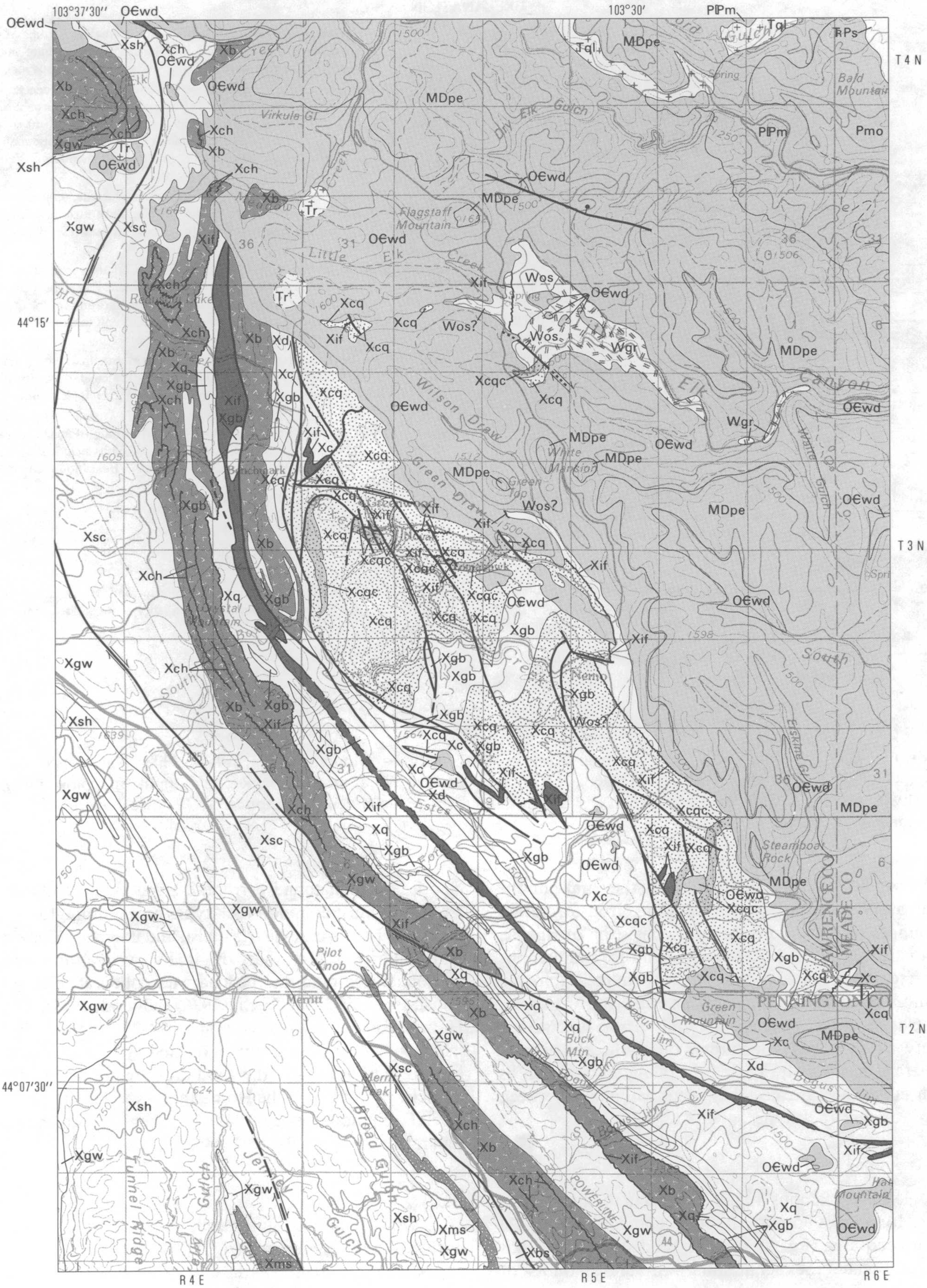
Figure 5 (above and facing page). Geologic map of the Nemo area, Black Hills National Forest, S. Dak. Geology from Redden (1981), Bayley (1970a), Bayley (1972a) as modified by Redden (unpub. mapping, 1985), J. J. Norton (unpub. mapping, 1985), Matthews (1979), and Redden (unpub. mapping, 1985). Base from U.S. Geological Survey, Rapid City, 1977.

Older Part of Metasedimentary Rocks (Unit Xsc)

Unit Xsc consists of two separate parts that differ in age. The older part is represented by the Poorman Formation (Hosted and Wright, 1923) in the Lead area (fig. 9). The oldest stratified unit in the Lead area, the Poorman consists of ankeritic phyllite, ankerite-mica schist, and interbedded chert and phyllite, all typically laminated or thin bedded and containing disseminated pyrite. It apparently was derived from a calcareous shale or shaly iron-rich dolomite that probably had considerable volcanogenic components. Minimum thickness is about 1,500 ft.

Younger Part of Iron-formation (Unit Xif)

Various facies of iron-formation are present in the Early Proterozoic strata of the Black Hills. Thick accumulations of oxide-facies iron-formation are restricted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Virkula Gl
Dry Elk Gulch
Flagstaff Mountain
Little Elk Creek
Wilson Draw
Green Draw
White Mansion
Green Top
Bald Mountain
Elk Canyon
Steamboat Rock
LAWRENCE CO
MEADE CO
PENNINGTON CO
Green Mountain
Pilot Knob
Merritt
Merritt Peak
Buck Mtn
Bogus Jim Cr
Broad Gulch
Tunnel Ridge
POWERLINE
Nemo
Estes
Benchmark

EXPLANATION

MЄpd **Pahasapa Limestone (Lower Mississippian), Englewood Formation (Lower Mississippian and Upper Devonian), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**—Pahasapa Limestone: massive, thick-bedded dolomitic limestone and dolomite. Cavernous in upper part. Englewood Formation: dolomitic limestone in upper part, shaly dolomite in lower part. Deadwood Formation: sandstone, shale, and limestone in upper part, sandstone and conglomerate in lower part

Xh **Harney Peak Granite (Early Proterozoic)**—Coarse-grained to pegmatitic muscovite granite and pegmatite containing accessory garnet, biotite, and tourmaline. Age (recalculated using decay constants recommended by Steiger and Jaeger, 1977) from Rb-Sr whole-rock isochron is 1,697±33 Ma (Riley, 1970)

Xsh **Metasedimentary rocks (Early Proterozoic)**—Phyllite, slate, and mica schist. Protoliths include shale, carbonaceous shale, and minor siltstone. Map unit includes part of Oreville Formation

Xms **Metasedimentary rocks (Early Proterozoic)**—Magnetite-ilmenite-rich muscovite schist, muscovite phyllite. Protoliths include aluminous, tuffaceous shale and thin manganiferous chert-carbonate beds. Map unit includes part of Oreville Formation

Xgw **Metagraywacke (Early Proterozoic)**—Siliceous mica schist and impure quartzite. Protoliths are proximal turbidite deposits that include graywacke and mixed graywacke and shale. Map unit includes Mayo Formation, Bugtown Formation, and part of Oreville Formation

Xgwm **Metagraywacke (Early Proterozoic)**—Micaceous schist and micaceous graywacke. Protoliths are distal turbidite deposits that include mixed shale and graywacke. Map unit includes Mayo Formation, Bugtown Formation, and part of Oreville Formation

Xbs **Metasedimentary rocks (Early Proterozoic)**—Biotite schist, biotite-muscovite schist. Protoliths include black shale (now pyrite rich), tuffaceous shale, and siltstone. Locally contains massive chert beds. Includes part of Loues Formation, part of Oreville Formation, and units east of Grand Junction fault in Berne quadrangle

Xif **Iron-formation (Early Proterozoic)**—Iron-formation, ferruginous chert, and minor mica schist. Protoliths include carbonate- and silicate-facies iron-formation and interbedded tuffaceous rocks

Xb **Metabasalt (Early Proterozoic)**—Amphibolite, greenstone, actinolite schist. Protoliths include basalt and minor bodies of gabbro. Interflow units include tuffaceous shale, black shale, massive chert, carbonate- and silicate-facies iron-formation, and mafic tuff. Map unit includes Crow Formation and members of Vanderlehr Formation

Xgb **Metagabbro (Early Proterozoic)** — Amphibolite, greenstone, actinolite schist, and serpentinite. Protoliths include gabbro, norite, and quartz-rich gabbro sills of at least two different ages

Xc **Metaconglomerate (Early Proterozoic)**—Conglomeratic, siliceous schist, feldspathic schist, and minor marble. Protoliths include conglomerate, quartzite, and minor amounts of arkose, dolomite, and shale. In Bear Mountain area map unit includes part of Vanderlehr Formation

Wgr **Granite (Late Archean)**—Granite of Bear Mountain which has Rb-Sr whole-rock age of 2.40±0.09 Ga (recalculated from Ratté and Zartman, 1970, using unpub. data of R. E. Zartman, 1985)

Wos **Older metasedimentary rocks (Late Archean)**—Phyllite, mica schist, and biotite-plagioclase schist. Protoliths include siltstone and shale that are intruded by granite of Bear Mountain

Contact—Dashed where approximately located

Fault—Dashed where approximately located. Bar and ball on downthrown side; arrows show relative sense of displacement

SCALE 1:100,000

0 1 2 3 4 5 MILES

Figure 6 (above and facing page). Geologic map of the Medicine Mountain area, Black Hills National Forest, S. Dak. Geology from Redden (1968), Ratté (1980), Ratté and Wayland (1969) as modified by Redden (unpub. mapping, 1985), Kuhl (1982), Redden (unpub. mapping, 1985), and DeWitt (unpub. mapping, 1985). Base from U.S. Geological Survey, Mount Rushmore, 1977).

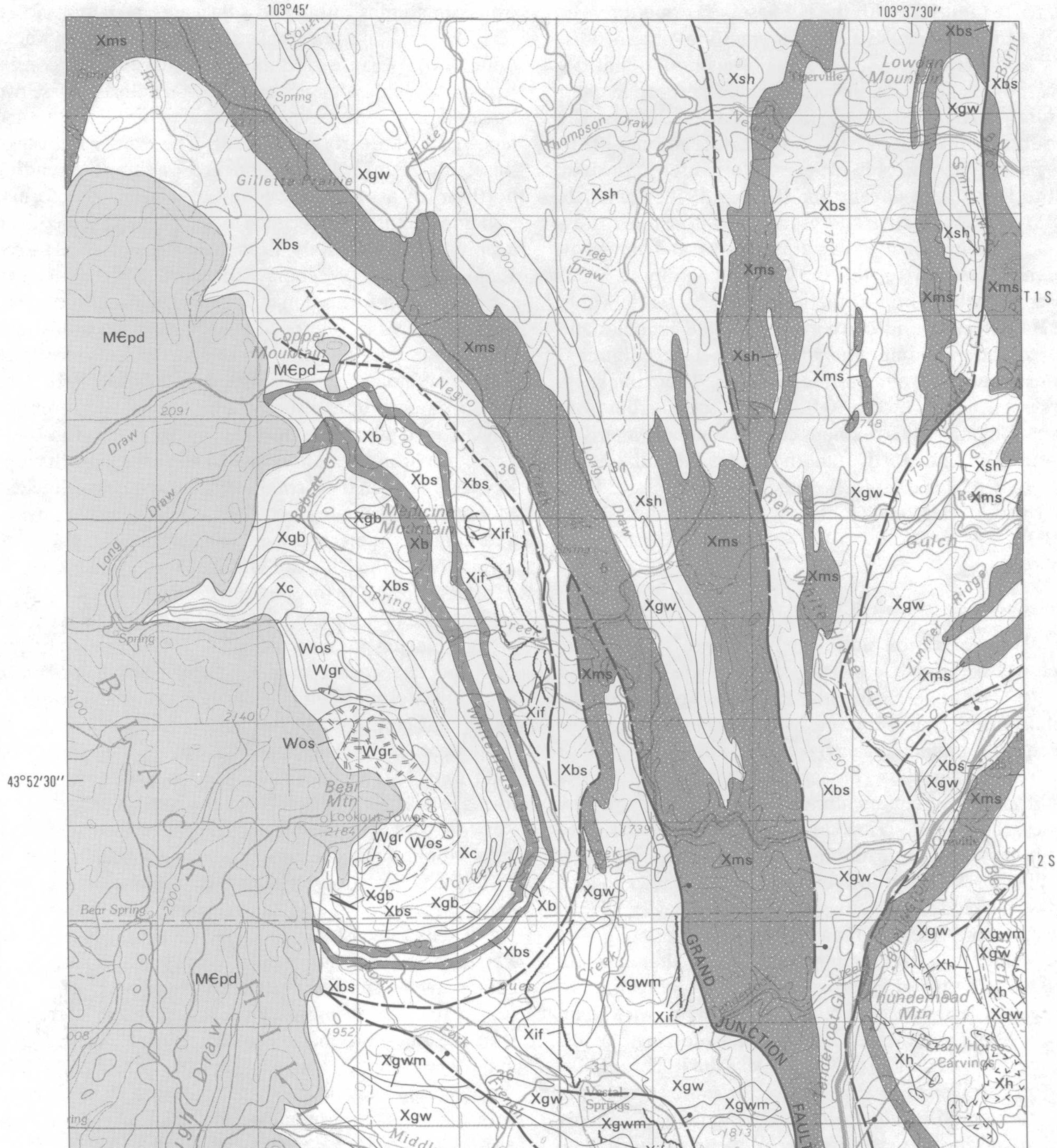
to older rocks of the Nemo area, where they make up the Nemo and Benchmark Iron-formations. Iron-formation in younger rocks is more variable, consisting of silicate, carbonate, sulfide, and oxide facies. Iron-formation units are present in the Lead–Deadwood area, in the Nemo and Rochford areas, and in the Keystone, Medicine Mountain, and Custer areas. They are spatially associated with a variety of rock types including quartzite, shale, conglomerate, and basalt. Their mineralogy and protoliths are discussed here because they occur within and between many younger rock types.

Lead–Deadwood Area

The most famous iron-formation in the Black Hills is the Homestake Formation (Hosted and Wright, 1923) in the Lead area (fig. 9), an interbedded chert and impure carbonate rock containing variable amounts of chlorite, cummingtonite, pyrrhotite, arsenopyrite, and electrum. The most common rock types are cummingtonite-quartz schist, ankerite-quartz schist, and interbedded chert and chlorite schist that originally were iron- and carbonate-rich mud interbedded with colloidal silica gel (Gustafson, 1933; McCarthy, 1976; Bidgood, 1977). The Homestake was originally perhaps 50–200 ft thick, but its thickness has been greatly modified by folding. Other iron-formation units in the Lead area are minor and are in rocks younger than the Homestake, especially the Flag Rock Formation (Dodge, 1942), but these are not shown separately in figure 9.

Nemo Area

Iron-formation units occur at three stratigraphic horizons in the Nemo area (fig. 5). Bayley (1972a) correlated the iron-formation at the base of the Buck Mountain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Xif
Xgwm
Xh
Wos
Wgr
MЄpd
GRAND JUNCTION FAULT
Gillette Prairie
Copper Mountain
Medicine Mountain
Bear Mtn
Lookout Tower
Round Mtn
Thunderhead Mtn
Crazy Horse Carvings
Lowden Mountain
Tigerville
Thompson Draw
Tree Draw
Long Draw
Sourdough Draw
Zimmer Ridge
Crown Mine
Vestal Springs
Atlantic Hill
Mile-high Hill
Toe Gulch
Bear Spring
Alkali Spring
Bull Spring
Spring
Middle
Creek
B L A C K   H I L L S

Quartzite (unit Xq) with the Homestake Formation. The Buck Mountain consists predominantly of interbedded chert and ferruginous schist containing minor quantities of carbonate minerals, magnetite, and interbedded chert and iron-carbonate beds or stilpnomelane-rich beds. The iron-formation is about 10-60 ft thick (Fantone, 1983). The predominantly oxide-facies iron-formation at the base of the Hay Creek Greenstone (Bayley, 1972b; unit Xb, fig. 5) is very siliceous and grades into ironstone. It extends for more than 15 mi along strike and ranges in thickness from 5 to 100 ft. The discontinuous chert horizons or 'lean' iron-formation (unit Xch, fig. 5) within the Hay Creek Greenstone contain hematite, limonite, and quartz, and minor amounts of stilpnomelane, cummingtonite, chamosite, and sulfide minerals. Their thickness does not generally exceed 50 ft. These discontinuous iron-formation units or ferruginous chert (essentially interflow subunits) extend north into the Galena–Roubaix area southeast of Lead (fig. 9), and rocks there have been described by Berg (1946), Bayley (1970a), and Krahulec (1981).

Rochford Area

Iron-formation units occur at three stratigraphic levels within unit Xsi in the Rochford area (pl. 1 and fig. 10). The uppermost is the Rochford Formation, the middle one is the Montana Mine Formation, and the lowest is an unnamed chert-grunerite unit at the base of the Irish Gulch Slate (Bayley, 1972c). (Unit Xsi in the Rochford area contains numerous rock units named by Bayley; these are described in the section about unit Xsi.) The upper two iron-formation units were correlated with the Flag Rock Formation (Dodge, 1942) in the Lead area and were included in the Flag Rock Group (Bayley, 1972c). The Rochford and Montana Mine Formations consist of interbedded chert-cummingtonite rocks that contain variable amounts of carbonate minerals, biotite, muscovite, garnet, carbonaceous material, and pyrite (McMillan, 1977). Where not thickened or thinned by folding, the formations range from 20 to 200 ft thick; the Rochford Formation can be traced along strike for more than 15 mi, the Montana Mine Formation for about 6 mi. The chert-cummingtonite unit near the base of the Irish Gulch Slate is similar in composition, thickness, and extent to the Rochford and Montana Mine Formations. South of Rochford near Castle Creek, the Rochford Formation exhibits a complicated refolded pattern that is discussed in the section on structure.

Keystone Area

Norton (1976) mapped two major areas of iron-formation near Keystone, one crossing Sheridan Lake and extending southeast across Bluelead Mountain, and another trending southeast through Keystone (fig. 8). Iron-formation is within and adjacent to metamorphosed conglomerate and graywacke (unit Xcg) and graywacke (unit Xgw). Because of lithologic similarities and consistent stratigraphic younging to the east-southeast, these two bodies of iron-formation are believed to be correlative and repeated by an early strike fault. The exact location of this fault is unknown, although it is shown extending north-northeast from Sheridan Lake. Other iron-formation units in the Keystone area include a large, folded, and deeply weathered body near Iron Mountain (Harrer, 1966), southeast of Mount Rushmore.

The iron-formation at Bluelead Mountain consists of grunerite schist interbedded with chert, both of which contain variable, but generally minor, amounts of biotite, garnet, actinolite, and carbonaceous material. Much of this iron-formation also contains pyritic slate, pyritic phyllite, and siliceous schist that is uncommon in other areas. The iron-formation that trends southeast through Keystone is similar in composition to that on Bluelead Mountain but contains less of the pyritic slate and phyllite and contains more massive grunerite schist. The iron-formation of the Bluelead and Keystone areas ranges in thickness from 20 to 500 ft where not duplicated by folding; the unit crossing Bluelead Mountain has an apparent thickness of more than 2,000 ft, but much of this thickness is accounted for by schist, phyllite, and slate. The Iron Mountain unit probably is dominantly sulfide facies, but contains much limonite and goethite due to deep weathering prior to the deposition of Cambrian sandstone. At present it is not certain if this iron-formation is the same as those in the belts passing through Keystone and Bluelead Mountain. The iron-formation at Iron Mountain appears to be about 80–400 ft thick.

Iron-formation units in the Keystone area appear to be somewhat younger than those associated with the Hay Creek Greenstone in the Nemo area. Much of the Keystone area iron-formation occurs within distinctive conglomerate and quartzite strata (unit Xcg, pl. 1 and fig. 8) that unconformably overlie quartzite correlated with the Buck Mountain Formation (unit Xq in figs. 5 and 8). However, farther west, in the central Black Hills, the conglomerate and quartzite conformably intertongue with thick graywacke units and gradually lose these distinctive lithologies. There are very pronounced facies changes of associated rocks toward the central Black Hills, so correlations are only tentative. However, it would seem that the iron-formation units in the Keystone area are about the same age as those in the Rochford area and hence correlate with the Flag Rock Formation in the Lead area. Iron-formation as old as the Homestake Formation apparently is not found in the Keystone area. If the sulfide-facies iron-formation at Iron Mountain does not correlate with the other iron-formation units to the north, it may be among the youngest in the Black Hills, inasmuch as it is within metamorphosed graywacke (unit Xgw, fig. 8).

Medicine Mountain Area

Redden (1968) mapped grunerite schist interbedded with chert in the Loues Formation and Ratté (1980) mapped the same lithology in the Vanderlehr Formation in the Medicine Mountain area. These iron-formation units shown on plate 1 and in figure 6 are within biotite schist (unit Xbs) that originally was pyrite-rich black shale and siltstone. The iron-formation units are composed of quartz, grunerite, carbonate minerals, biotite, carbonaceous material, and minor pyrite, are variable in thickness but do not exceed 50 ft, and are discontinuous along strike. Younger iron-formation units are within the Bugtown Formation (Redden, 1963), a graywacke lithology (unit Xgw, fig. 6) that structurally overlies unit Xbs but is separated from it by an inferred fault. Correlation of these iron-formation units with others in the Black Hills is uncertain because distinctive strata of the Nemo and Lead areas are not present in the Medicine Mountain area. The correlation problems are discussed in the section on the biotite schist (unit Xbs).

Custer Area

Iron-formation extends from near Stockade Lake east of Custer to Sanator, south of Custer (pl. 1), and probably is the extension of sulfide-facies iron-formation at Iron Mountain, south of Keystone (fig. 8). North of Custer the iron-formation is interbedded with conglomerate and graywacke lithologies (unit Xcg, pl. 1). Near Stockade Lake the iron-formation is composed of interbedded grunerite-rich and chert-rich strata that contain accessory biotite, garnet, and sulfide minerals. There, the iron-formation is about 250 ft thick, but this may be the result of unrecognized folding. To the south, in the southernmost exposures, the iron-formation consists of multiple grunerite-rich beds separated by mica-garnet schist.

Metachert (Unit Xch)

A unit consisting of metamorphosed chert is not shown on plate 1 because of scale limitations but is shown on the maps of the Nemo, Keystone, Lead, and Rochford areas (figs. 5, 8, 9, and 10). In all areas the unit is composed of siliceous schist and cherty schist that originally were iron-poor chert or 'lean' iron-formation. The chert occurs within a variety of other rock units, including metamorphosed basalt (unit Xb), conglomerate and graywacke (unit Xcg), and shale (unit Xsh). Most exposures of chert are lens shaped and discontinuous along strike, having maximum thicknesses of about 100 ft.

In the western part of the Nemo area (fig. 5) the thickest and laterally most continuous bodies of chert are within basalt (Hay Creek Greenstone). Thinner, less continuous chert lenses are noted in other units, especially in unit Xsc, but are not shown in figure 5. Large bodies of chert occur within conglomerate and quartzite (unit Xcg) in the Keystone area (fig. 8). Most large bodies of chert in the Galena–Roubaix area, southeast of Lead (fig. 9), are contained within basalt or near basalt and overlying rocks. Much chert in the Rochford area (fig. 10) is contained in rocks of mixed lithology in unit Xsi and at the contact of units Xsi and Xsh.

Metaquartzite (Unit Xq)

A unit composed predominantly of metamorphosed quartzite (unit Xq, pl. 1) is widespread in the Black Hills, where it is exposed at Lead, south and west of Nemo, in the Rochford area, and in a large and relatively unstudied terrane east and south of Custer. The quartzite in these various areas is thought to be of the same age.

Lead Area

The quartzite unit in the Lead area is the Ellison Formation (Hosted and Wright, 1923), which overlies the Homestake Formation (fig. 9). It is composed of phyllite, dark quartzite, micaceous quartzite, minor chert, and calcareous mica schist that originally were shale, impure siltstone, and sandstone. The Ellison is about 2,000–3,000 ft thick in relatively undeformed areas and may thin to the south.

Nemo Area

Quartzite, siliceous schist, and minor chert of the Buck Mountain Formation (Redden, 1981) and Gingrass Draw Slate (Bayley, 1972b) make up unit Xq in the Nemo area (fig. 5). Protoliths of the quartzite and related strata were clean sandstone, siltstone, and shale that were deposited conformably on the iron-formation. The quartzite unit pinches out to the north and thickens to the south toward Rapid City (pl. 1) and into the Keystone area (fig. 8). Where least affected by isoclinal folding, the unit ranges from less than 800 ft thick north of Benchmark to more than 5,000 ft thick south of Hat Mountain.

Rochford Area

Quartzite-rich strata in the Rochford area (fig. 10) include the Moonshine Gulch Quartzite, the oldest rock unit recognized there by Bayley (1972c), which consists of dark quartzite and laminated slate and schist that contain minor amounts of disseminated pyrite. Chert makes up a small part of the section. The strata originally were clean sandstone and impure siltstone and shale having a minimum thickness of about 1,000 ft. The quartzite occupies the core of a south-plunging anticlinorium, according to Bayley (1972c), that should, if the correlations with strata in the Lead area are correct, be underlain by the Homestake Formation.

Southeastern Black Hills Area

A large terrane south and east of Custer (pl. 1) is composed of quartzite, siliceous schist, and high-grade metamorphic rocks. Internal structure and stratigraphy of most of the terrane are unknown. NURE aerial radiometric surveys (Texas Instruments, Inc., 1979) show the terrane to contrast markedly with the Harney Peak Granite and surrounding graywacke. Although much of the area has not been mapped in detail, that which has been mapped (Redden, unpub. mapping, 1984; Christiansen, 1984) closely resembles the Buck Mountain Formation of the Nemo area and is considered to connect with that unit in areas covered by Paleozoic rocks along the eastern edge of the Precambrian core. The absence of the unit around the Bear Mountain and Harney Peak areas is interpreted to be the result of major faults, although unrecognized facies changes or unconformities could also account for the absence of the quartzite.

Metasedimentary Rocks (Unit Xsi)

A heterogeneous assemblage of slate, iron-formation, schist, and volcaniclastic rocks (unit Xsi, pl. 1) is present in both the Lead and Rochford areas. Metamorphosed basalt flows (unit Xb, pl. 1) are contained within the unit in both areas, and basalt flows of presumably about the same age are noted in the Nemo and Keystone areas.

In the Lead area (fig. 9) unit Xsi comprises the Northwestern Formation (Hosted and Wright, 1923) and the Flag Rock Formation (Dodge, 1942). The Northwestern (unit Xsi_2) conformably overlies the Ellison Formation and consists of phyllite, slate, and micaceous schist that originally were shale and siltstone. It attains its maximum thickness of about 1,500 ft east of Deadwood, thins to the north, and is truncated in the south by the overlying Flag Rock Formation (Noble and Harder, 1948). The Northwestern was correlated with the Irish Gulch Slate in the Rochford area by Bayley (1972c) but is not recognized in other areas of the Black Hills. It may not be a valid formation and possibly should be included within the Ellison or Flag Rock Formations.

The Flag Rock Formation (unit Xsi_1) unconformably(?) overlies the Northwestern and consists of phyllite and schist, pyritic and carbonaceous phyllite, chert, and carbonate-facies iron-formation that originally were impure shale having a high carbon content and carbonate-rich iron-formation containing cummingtonite and chlorite. Subsidiary rock types include metamorphosed basalt flows (described as part of unit Xb) and gabbro. Iron-formation units in the Flag Rock are impossible to tell from the Homestake Formation except that they tend to be thinner and are associated with different overlying and underlying rocks. The Flag Rock is more than 3,000 ft thick and may be thicker, but effects

EXPLANATION

Tw — **White River Group (Oligocene)**—Tuffaceous claystone and clay containing minor limestone lenses. Ogallala Formation of Miocene age mapped with White River

Tp — **Phonolite (Eocene and Paleocene)**—Dikes and small sills of analcime-rich phonolite

Tkf — **Potassium feldspar-rich alteration zones (Eocene and Paleocene)**—Alteration zones characterized by secondary potassium feldspar

Tbx — **Brecciated zones (Eocene and Paleocene)**—Fractured and brecciated zones cutting trachyte. Contain thin carbonatite dikes

Tt — **Trachyte (Eocene and Paleocene)**—Intrusive complex consisting of laccoliths, sills, and dikes of trachyte, trachyte porphyry, syenite, and other rocks rich in potassium

Tr — **Rhyolite (Eocene and Paleocene)**—Laccolith of leucocratic rhyolite. May be extrusive in part

KJim — **Inyan Kara Group (Lower Cretaceous) and Morrison Formation (Upper Jurassic)**

Inyan Kara Group—Fall River Sandstone: sandstone and minor siltstone. Lakota Formation: claystone and sandstone locally containing interbedded limestone and lignite lenses

Morrison Formation—Siliceous claystone and shale

Jsg — **Sundance Formation (Upper and Middle Jurassic) and Gypsum Spring Formation (Middle Jurassic)**—Sundance Formation: glauconitic sandstone and shale. Gypsum Spring Formation: massive gypsum and minor claystone

ƦPs — **Spearfish Formation (Triassic and Permian)**—Shale, siltstone, and gypsum

Pmo — **Minnekahta Limestone and Opeche Shale (Lower Permian)**—Minnekahta Limestone: slabby limestone. Opeche Shale: sandy shale

PIPm — **Minnelusa Formation (Lower Permian and Pennsylvanian)**—Sandstone, solution breccia (anhydrite in subsurface), limestone, and shale

MDpe — **Pahasapa Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)**—Pahasapa Limestone: cavernous dolomitic limestone. Englewood Formation: dolomitic limestone

OЄwd — **Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**—Whitewood Dolomite: dolomite. Winnipeg Formation: shale and siltstone. Deadwood Formation: sandstone, shale, and limestone

Wgr — **Granite (Late Archean)**—Granite east of Warren Peaks which has U-Th-Pb zircon minimum age of about 2.63 Ga (Staatz, 1983)

Contact

Fault—Dashed where approximately located; dotted where concealed. Bar and ball on downthrown side

Dome

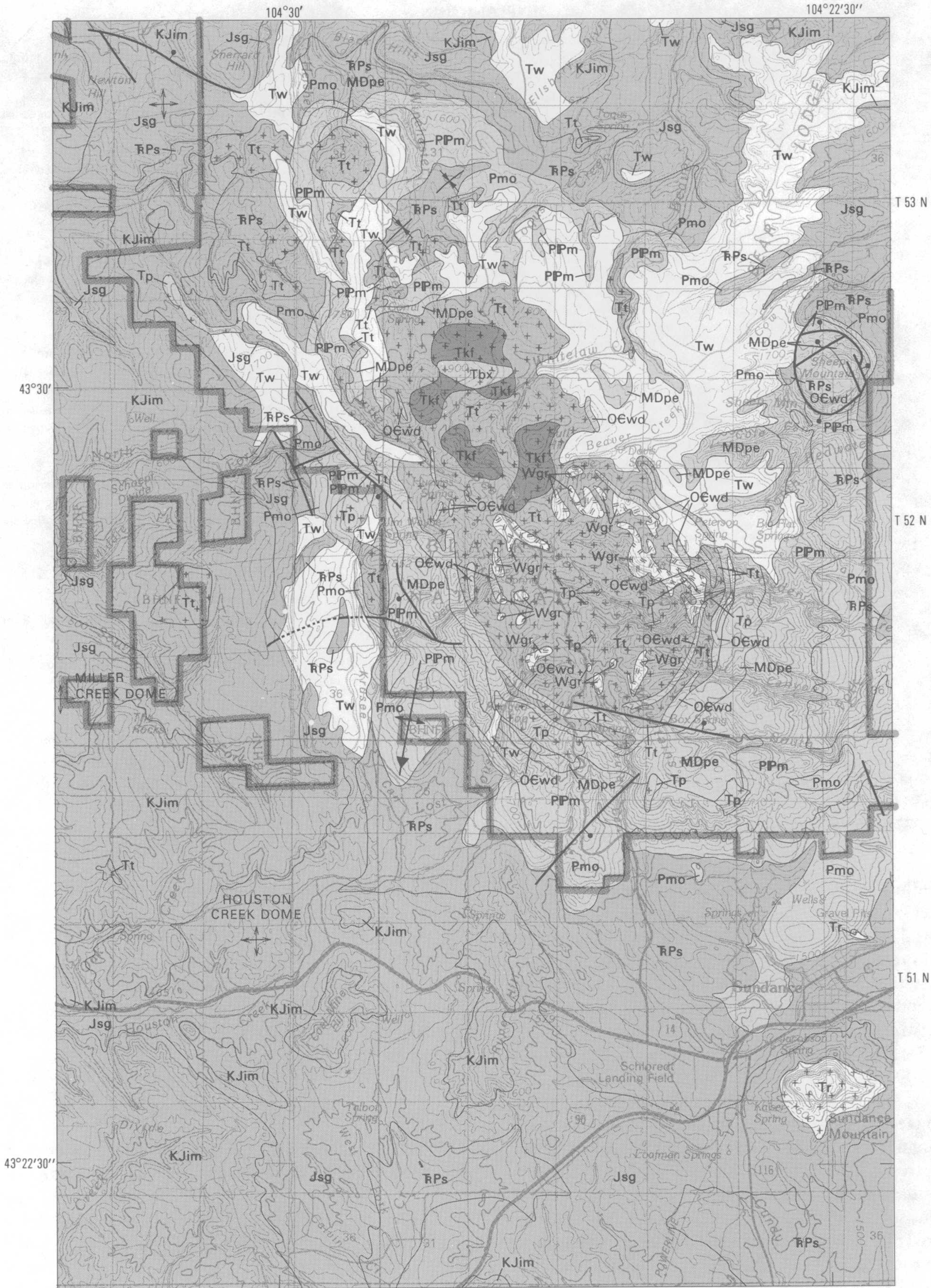
Anticline—Arrow shows direction of plunge

Syncline

SCALE 1:100,000

0 1 2 3 4 MILES

Figure 7 (above and facing page). Geologic map of the Bear Lodge Mountains area, Black Hills National Forest, Wyo. Geology from Staatz (1983), Pillmore and Mapel (1963), Robinson, Mapel, and Bergendahl (1964), Fashbaugh (1979), Jenner (1984), O'Toole (1981), White (1980), and Wilkinson (1982). Base from U.S. Geological Survey, Devils Tower and Sundance, 1979.



104°30′
104°22′30″
43°30′
43°22′30″
T 53 N
T 52 N
T 51 N
R 64 W
R 63 W
MILLER CREEK DOME
HOUSTON CREEK DOME
Sundance
Sundance Mountain
Schloredt Landing Field
Sherrard Hill
Newton Hill
Black Hills
Beaver Creek
Whitelaw Creek
Peterson Spring
Big Flat Spring
Sheep Mountain
Lost Cabin
Houston Creek
Divide
Loafman Springs
Kaiser Spring
Talbot Spring
Gravel Pits
Wells
POWERLINE
BHNF
KJim
Jsg
TRPs
Tw
Tt
Tp
Tkf
Tbx
Tr
PIPm
Pmo
MDpe
OЄwd
Wgr
90
14
116

EXPLANATION

Tw **White River Group (Oligocene)**—Tuffaceous claystone and clay containing minor limestone lenses

M€pd **Pahasapa Limestone (Lower Mississippian), Englewood Formation (Lower Mississippian and Upper Devonian), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**—Pahasapa Limestone: massive, thick-bedded dolomitic limestone and dolomite. Cavernous in upper part. Englewood Formation: dolomitic limestone in upper part, shaly dolomite in lower part. Deadwood Formation: sandstone, shale, and limestone in upper part, sandstone and conglomerate in lower part

Xh **Harney Peak Granite (Early Proterozoic)**—Coarse-grained to pegmatitic muscovite granite and pegmatite containing accessory garnet, biotite, and tourmaline. Age (recalculated using decay constants recommended by Steiger and Jaeger (1977) from Rb-Sr whole-rock isochron is 1697±33 Ma (Riley, 1970). Metasomatic alteration of country rocks common at contact. Massive texture except where flow foliation locally developed. Small granitic bodies and many pegmatite bodies not shown

Xms **Metasedimentary rocks (Early Proterozoic)**—Muscovite schist, muscovite phyllite. Protoliths include aluminous, tuffaceous shale and thin, manganiferous chert-carbonate beds

Xgw **Metagraywacke (Early Proterozoic)**—Siliceous mica schist and impure quartzite. Protoliths are proximal turbidite deposits that include graywacke and mixed graywacke and shale. Map unit includes basal and intermediate parts of unit described on plate 1.

Xbs **Metasedimentary rocks (Early Proterozoic)**—Biotite schist, biotite-muscovite schist. Protoliths include black shale (now pyrite rich), tuffaceous shale, and siltstone. Locally contains massive chert beds that are not shown. Includes part of Oreville Formation

Xif **Iron-formation (Early Proterozoic)**—Iron-formation, ferruginous chert, and minor mica schist. Protoliths include carbonate-, silicate-, and sulfide-facies iron-formation and interbedded tuffaceous rocks

Xgb **Metagabbro (Early Proterozoic)**—Amphibolite, greenstone, actinolite schist, and serpentinite. Protoliths include gabbro, norite, and quartz-rich gabbro sills of at least two different ages. Represents younger part of unit described on plate 1

Xch **Metachert (Early Proterozoic)**—Cherty schist and siliceous schist. Protoliths include chert and iron-poor chert

Xb **Metabasalt (Early Proterozoic)**—Amphibolite, greenstone, actinolite schist. Protoliths include basalt and minor bodies of gabbro. Interflow units include tuffaceous shale, black shale, massive chert, carbonate- and silicate-facies iron-formation, and mafic tuff

Xsc **Metasedimentary rocks (Early Proterozoic)**—Siliceous biotite phyllite, calcareous biotite phyllite, and schist. Protoliths include black shale and chert, calcareous and carbonaceous shale, and minor amounts of siltstone. Represents younger part of unit described on plate 1

Xcg **Metasedimentary rocks (Early Proterozoic)**—Conglomeratic biotite schist, siliceous biotite schist, mica schist, and iron-formation. Protoliths include debris flow conglomerate, quartzite, graywacke, ferruginous shale, and iron-formation

Xq **Metaquartzite (Early Proterozoic)**—Quartzite, siliceous schist, and minor chert. Protoliths include quartzite and interbedded siltstone and shale

Xc **Metaconglomerate(Early Proterozoic)**—Large xenoliths of conglomeratic, siliceous schist, feldspathic schist, and minor marble in Harney Peak Granite. Protoliths include conglomerate, quartzite, and minor amounts of arkose, dolomite, and shale

Contact—Dashed where approximately located; dotted where concealed

Fault—Dashed where approximately located. Bar and ball on downthrown side; arrows show relative sense of displacement

SCALE 1:100,000

0 1 2 3 4 5 MILES

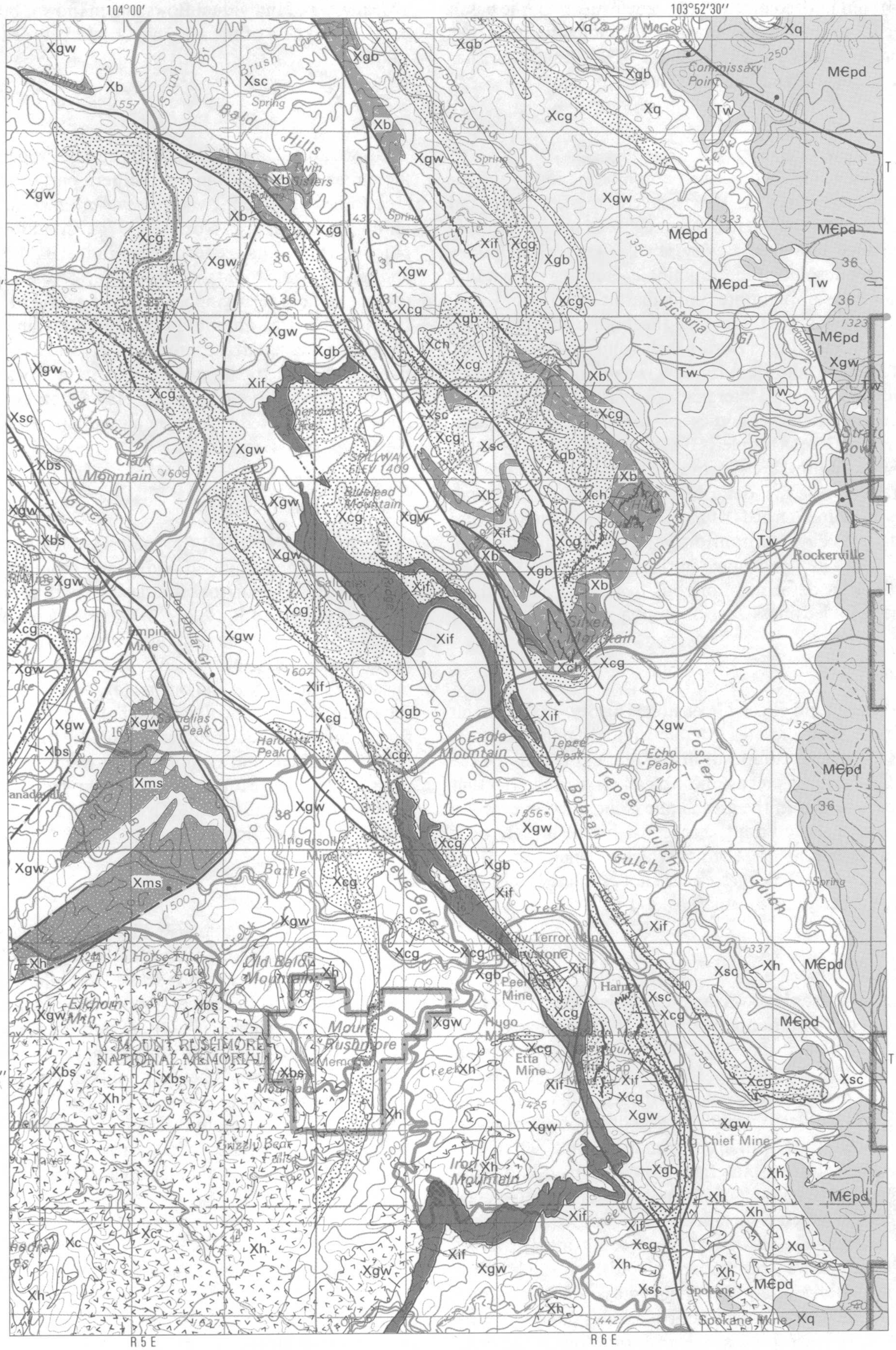
Figure 8 (above and facing page). Geologic map of the Keystone area, Black Hills National Forest, S. Dak. Geology from Norton (1976), Norton (unpub. mapping, 1985), Redden (unpub. mapping, 1985), P. H. Rahn (unpub. mapping, 1985), and Ratté and Wayland (1969) as modified by Redden (unpub. mapping, 1985). Base from U.S. Geological Survey, Mount Rushmore and Rapid City, 1977.

of folding are difficult to assess in a rock with so few marker beds. Units shown as Xsi west of Lead appear to be correlative with the Flag Rock, but have been mapped only in reconnaissance by Bayley (1972a). Rocks having lithologies similar to those in the Flag Rock are interpreted to extend southeast from Lead, under the cover of Cambrian strata, into the Roubaix area (fig. 9).

In the Rochford area unit Xsi comprises the Irish Gulch Slate, Nahant Schist, and Poverty Gulch Slate (Bayley, 1972c), which are composed of slate and phyllite, carbonaceous schist and phyllite, and biotite-garnet schist containing minor amounts of volcaniclastic-derived schist, respectively. Protoliths for this varied suite of rocks include shale, carbonaceous shale, impure siltstone, and tuffaceous sediment. The various units apparently conformably overlie the Moonshine Gulch Quartzite and have a composite thickness, which is poorly constrained, of at least 2,500 ft. Bayley (1972c) assigned the Nahant Schist to the Flag Rock Group, which included all rocks younger than the Irish Gulch Slate and older than the Poverty Gulch Slate. Unit Xsi defines the large, north-northwest-trending anticlinorium in the Rochford area and the complexly refolded east-trending anticlinorium north of Castle Creek. Metamorphosed basalt (unit Xb, fig. 10) within unit Xsi is described in the following section.

Metabasalt (Unit Xb)

Metabasalt (unit Xb, pl. 1) is a widespread rock type, occurring in the Lead and Rochford areas, the Nemo and Keystone areas, and in the Medicine Mountain and Custer areas. Although widespread, the basalt is minor in volume compared to metasedimentary rocks in the core of the Black Hills. Gabbroic sills (unit Xgb, pl. 1) are probably the subvolcanic equivalent of the basalt flows. Norby


104°00′
103°52′30″
44°00′
43°52′30″
T 1 N
T 1 S
T 2 S
R 5 E
R 6 E
Xgw
Xb
Xsc
Xcg
Xgb
Xq
MЄpd
Tw
Xif
Xch
Xbs
Xms
Xh
Xc
Commissary Point
Bald Hills
Twin Sisters
Victoria Gl
Clark Mountain
Bluelead Mountain
Silver Mountain
Rockerville
Eagle Mountain
Tepee Peak
Echo Peak
Hardesty Peak
Empire Mine
Ingersoll Mine
Old Baldy Mountain
Elkhorn Mtn
MOUNT RUSHMORE NATIONAL MEMORIAL
Mount Rushmore
Iron Mountain
Hugo Mine
Etta Mine
Peerless Mine
Holy Terror Mine
Keystone
Spokane Mine
Spokane
Chief Mine
Tepee Gulch
Foster Gulch
Battle Creek
Strato Bowl
Horse Thief Lake
Grizzly Bear Falls
SPILLWAY ELEV 4095

(1984) summarized much of the geochemistry of the basalt and gabbro units in the Black Hills, indicating that they are predominantly tholeiitic. None of the basalt flows has been isotopically dated.

Lead Area

Dodge (1942) described amphibolite in the formations younger than the Homestake in the Lead area and suggested that they were metamorphosed intrusive bodies of gabbro. However, Bayley (1972a) recognized pillow structures in some of the amphibolite and it is evident that much of the amphibolite is metabasalt. Wolfgram (1977) also suggested that some of the bodies are metamorphosed basalt flows. Both basalt (unit Xb) and gabbro (unit Xgb) are shown in figure 9 where originally studied by Dodge (1942) and later mapped by Bayley (1972a), west of Lead. Extensive bodies of metamorphosed basalt (Bayley, 1970a; Krahulec, 1981), as evidenced by relict pillow structures, are shown in the Roubaix area (fig. 9), where they were first described by Berg (1946). The basalt flows contain interbeds of mafic tuffaceous material and ferruginous chert or iron-formation (unit Xch on figs. 5, 8, and 9). The flows range in thickness from only a few feet thick in deformed horizons to at least 800 ft thick in the refolded mass east of Roubaix.

Rochford Area

The Rapid Creek Greenstone (Bayley, 1972c) is unit Xb in the Rochford area. Metamorphosed pillowed mafic flows of basaltic composition and mafic tuff beds are the protoliths for the greenstone. Volcaniclastic material that Bayley included in the greenstone is included in unit Xsi in figure 10. The basalt overlies Irish Gulch Slate or is within Nahant Schist, both of which are included in unit Xsi in figure 10. Thicknesses were not estimated by Bayley, but must range to as much as 300 ft.

Nemo Area

Metabasaltic rocks are more widespread in the area west of Nemo than in any other part of the Black Hills. Originally named the Hay Creek Greenstone by Bayley (1972b), unit Xb in this area consists of pillowed to massive flows of metabasalt, interbedded slate, chert, and mafic tuff, and associated sills and dikes of gabbro. Ferruginous chert or 'lean' iron-formation (unit Xch, fig. 5) occurs as interflow material, most of which is discontinuous. The basalt unit conformably overlies the Gingrass Draw Slate, which is included within unit Xq in figure 5. Near Benchmark, basalt apparently conformably overlies the Roberts Draw Formation (unit Xd), but the basalt is probably older than the main mass of Hay Creek Greenstone. In this area a fault separates the upper contact of this greenstone and iron-formation to the west. Thicknesses of individual flows are unknown, but the aggregate thickness of the unit must range between 200 and 1,000 ft.

Keystone Area

Metabasalt and metagabbro that are probably about the same age extend from the southern part of the Nemo area to near Keystone, where they were mapped as amphibolite bodies by Norton (1976). Metamorphosed pillowed flow units are recognized in the Bald Hills area and near Silver Mountain, where they contain interflow material rich in ferruginous chert and mafic tuff. Basalt flows in this area are interlayered with metamorphosed conglomerate, quartzite, and garnet schist (unit Xcg, fig. 8), whereas to the north these latter rocks clearly underlie the basalt flows of the Hay Creek Greenstone. Hence, it is believed that these basalts are younger than the Hay Creek Greenstone.

Medicine Mountain Area

Walawender (1967) first described the amphibolite in the Medicine Mountain and Bear Mountain areas as metasedimentary horizons interlayered with pelitic rocks. Redden (1968) and Ratté (1980) cited evidence that suggested the various amphibolite bodies included both metamorphosed gabbroic sills and basalt flows. Two metabasalt units (Xb) and one metagabbro unit (Xgb) are shown in figure 6. The units inferred to have been basalt flows could have been mafic tuff beds; they are about 150–200 ft thick and completely surround the exposed parts of the Bear Mountain dome. The basalt flows are within a biotite schist (unit Xbs, fig. 6) that is discussed in a following section.

Custer Area

The Crow Formation (Redden, 1963) west of Custer (pl. 1) is a heterogeneous assemblage of amphibolite, calc-silicate gneiss, cordierite-rich schist, and minor quartzite that is inferred to have been predominantly volcanic in origin. Protoliths include basalt, impure carbonate rocks, shale, and chert. The Crow is different from most basalt of unit Xb because it is between units of graywacke that are probably among the youngest strata in the Black Hills. Therefore, it may contain the youngest basaltic rocks in the region. The thickness of the Crow ranges from about 60 ft to more than 1,000 ft and increases from east to west.

Other Areas

Metabasalt in the Tinton area has been described by Norby (1984) as amphibolite of probable extrusive origin. These bodies are interbedded with mica schist and carbonaceous slate that originally were graywacke and organic-rich shale. The age of the amphibolite in the area is unknown, but Redden (unpub. data, 1985) believes that the enclosing graywacke, because its mineralogy differs considerably from other Proterozoic graywacke of the Black Hills, may be Archean.

Younger Part of Metagabbro (Unit Xgb)

Metamorphosed gabbroic sills intrude rocks as old as the Little Elk Granite in the Nemo area, as well as rocks as young as the graywacke (unit Xgw) shown on plate 1. The older part of the gabbro (Blue Draw Metagabbro) has been shown to be about 2.2 Ga in the Nemo area. The younger gabbro is of at least two different ages and possibly three. Gabbroic sills are closely associated with the metabasalt in the Nemo area (Hay Creek Greenstone) and are probably of equivalent age. Gabbro also cuts the graywacke above the Hay Creek Greenstone and may be younger. The third and youngest gabbro is that represented by parts of the Crow Formation. The gabbro is a volumetrically important rock unit in the Nemo, Keystone, and Medicine Mountain areas.

Runner (1934) first described the thick and extensive amphibolite horizons in the western part of the Nemo area and concluded that they were metamorphosed gabbroic sills. Bayley (1972b) mapped the sills as intruding the Hay Creek Greenstone, Gingrass Draw Slate, Buck Mountain Quartzite, Roberts Draw Limestone, and the Estes Quartzite. The largest ones are shown on plate 1 and in figure 5 as intruding units Xb, Xq, and Xd. They extend southeast from the Nemo area and continue into the Keystone area. The sills range in thickness from as little as 10 ft to about 1,000 ft. Fricke (1982) presented evidence that the sills were more differentiated in the direction that is stratigraphically younger, thus suggesting that the sills may be the same age as the overlying volcanic rocks.

Preliminary U-Th-Pb zircon dating of one sill east of Buck Mountain (southern part of Nemo area, fig. 5) indicates an age of about 2.0 Ga (Z. E. Peterman, unpub. data, 1985). This date suggests that the strata from the Hay Creek Greenstone through the Roberts Draw Formation are older than about 2.0 Ga and younger than about 2.2 Ga ('about' in this context should indicate an uncertainty of ± 0.1 Ga), the age of the oldest gabbro unconformably overlain by the Estes Formation. Further U-Th-Pb dating of the formations in the northern Black Hills is currently underway (Z. E. Peterman, oral commun., 1985).

If the regional correlations discussed in previous sections are correct, the approximate age of the younger part of the gabbro unit in the Nemo area constrains the age of strata elsewhere in the northern Black Hills. For instance, the Buck Mountain Formation (Redden, 1981) in the Nemo area is correlated with the Ellison Formation in the Lead area, and the iron-formation at the base of the Buck Mountain may be correlative with the Homestake Formation; therefore, the Homestake and Ellison are about 2.0–2.2 Ga. Also, the Rapid Creek Greenstone in the Rochford area appears to be younger than the Hay Creek Greenstone in the Nemo area (Redden, unpub. data, 1985), which suggests that the Rochford Formation and its probable equivalent, the Flag Rock Formation, is younger than about 2.0 Ga.

The extensive metamorphosed gabbroic sills in the Nemo area extend into the Keystone area (fig. 8), where they intrude quartzite, conglomerate, and graywacke (unit Xcg) and may intrude graywacke (unit Xgw). The large mass of gabbro shown north of Keystone is probably in part basalt.

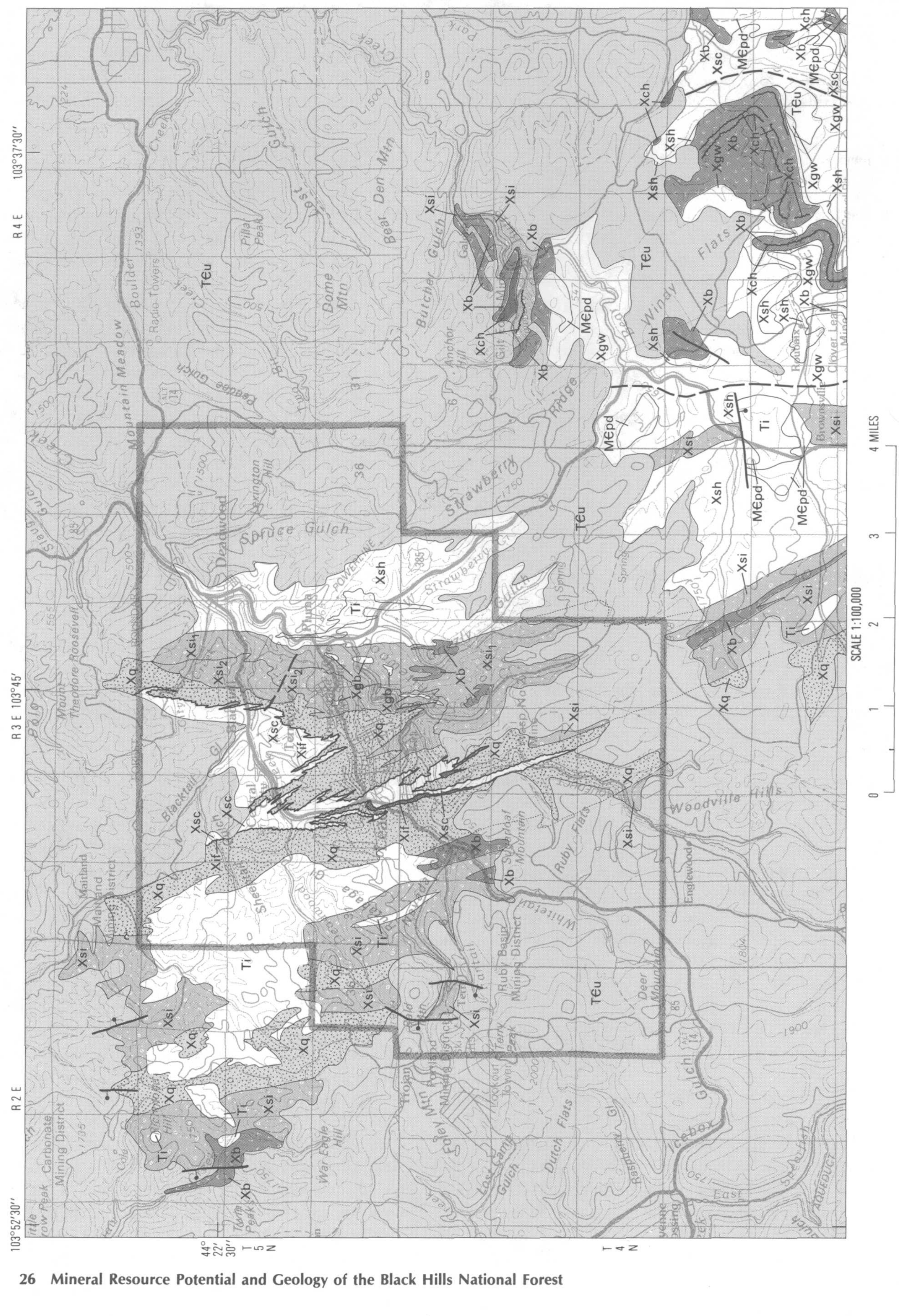
Only one unit of amphibolite in the Medicine Mountain area is inferred to have been a gabbro sill, although many smaller sills are present (Redden, unpub. data, 1985). The structurally deepest amphibolite on the flanks of the Bear Mountain dome may be a metamorphosed gabbro sill, but its age is unknown. The amphibolite appears to intrude unit Xc, which has been correlated with the Estes Formation in the Nemo area. If this relationship is valid, the gabbro most likely would be equivalent to the older part of the younger gabbro in the Nemo area, a conclusion based on the observation that the 2.2 Ga gabbro is unconformably overlain by the Estes Formation.

Redden (1968) showed many amphibolite bodies in the graywacke (unit Xgw) west of Custer, south of Medicine Mountain (pl. 1), and presented convincing evidence that they were derived from gabbroic intrusive rocks. These may be among the youngest gabbro bodies in the Precambrian of the Black Hills.

Younger Part of Metasedimentary Rocks (Unit Xsc)

The Reausaw Slate (Bayley, 1972b) west of Nemo (fig. 5) and extending into the Galena–Roubaix area southeast of Lead (fig. 9) is continuous with strata in the Bald Hills area northwest of Keystone (fig. 8). Rocks having lithologies similar to the Reausaw are thickest near Pactola Reservoir, west of Rapid City (pl. 1). The Reausaw intertongues with the Hay Creek Greenstone just north of Pactola Reservoir and consists largely of laminated carbonaceous phyllite, slate, and interbedded chert and slate that originally were organic-rich shale containing much chert. The thickness of the Reausaw is inferred to be greater than 2,500 ft, but the lack of internal marker lithologies, abundant folding, and generally poor exposures cause this estimate to be subject to major error.

To the south, in the Silver Mountain area northeast of Keystone (fig. 8), the map pattern suggests that unit Xsc either intertongues with conglomerate (unit Xcg) and basalt (unit Xb) or forms the core of a refolded anticline. Unit Xsc exposed southeast of Keystone is interpreted to correlate with the unit to the north on the opposite sides of an early fold axis. Unit Xsc is not recognized farther



R 2 E
R 3 E 103°45'
R 4 E
103°37'30''
103°52'30''
44° 22' 30''
T 5 N
T 4 N
SCALE 1:100,000
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1
2
3
4 MILES
Spruce Gulch
Deadwood
Strawberry Ridge
Windy Flats
Woodville Hills
Ruby Flats
Englewood
Bear Den Mtn
Dome Mtn
Lexington Hill
Mount Theodore Roosevelt
Deer Mountain
War Eagle Hill
Dutch Flats
Icebox Gulch
Lost Camp Gulch
Ruby Basin Mining District
Carbonate Mining District
Maitland Mining District
Butcher Gulch
Boulder
Mountain Meadow
Radio Towers
Brownsville
Clover Leaf Mtn
Anchor Hill

EXPLANATION

[Note: Many rock units younger than Precambrian are not shown on this map of the Lead-Deadwood area. Refer to figures 13 and 14 for distribution of those units.]

Ti — **Intrusive rocks (Eocene and Paleocene)**—Stocks, sills, dikes, laccoliths, breccias, and minor welded tuff units composed of alkali rhyolite, rhyolite, quartz trachyte, trachyte, latite, and phonolite

T€u — **Tertiary igneous rocks, Oligocene sedimentary rocks, Mesozoic sedimentary rocks, and Paleozoic sedimentary rocks**—Includes undivided Tertiary igneous and sedimentary rocks and all strata from Triassic and Permian Spearfish Formation to Ordovician and Cambrian Deadwood Formation

M€pd — **Pahasapa Limestone (Lower Mississippian), Englewood Formation (Lower Mississippian and Upper Devonian), Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**—Pahasapa Limestone: cavernous dolomitic limestone. Englewood Formation: dolomitic limestone. Whitewood Dolomite: dolomite. Winnipeg Formation: shale and siltstone. Deadwood Formation: sandstone, shale, and limestone

Xsh — **Metasedimentary rocks (Early Proterozoic)**—Phyllite, slate, and mica schist. Protoliths include shale, carbonaceous shale, and minor siltstone. Map unit includes Grizzly Formation

Xgw — **Metagraywacke (Early Proterozoic)**—Siliceous mica schist and impure quartzite. Protoliths are turbidite deposits and include graywacke and mixed graywacke and shale. Map unit includes Roubaix Formation

Xgb — **Metagabbro (Early Proterozoic)**—Amphibolite, greenstone, actinolite schist, and serpentinite. Protoliths include gabbro, norite, and quartz-rich gabbro sills of at least two different ages. Represents younger part of unit described on plate 1.

Xch — **Metachert (Early Proterozoic)**—Cherty schist and siliceous schist. Protoliths include chert and iron-poor chert

Xb — **Metabasalt (Early Proterozoic)**—Amphibolite, greenstone, actinolite schist. Protoliths include basalt and minor bodies of gabbro. Interflow units include tuffaceous shale, black shale, massive chert, carbonate- and silicate-facies iron-formation, and mafic tuff

Xsi — **Metasedimentary rocks (Early Proterozoic)**—Phyllite, slate, biotite schist, and minor chert and amphibolite. Protoliths include tuffaceous shale, siltstone, black shale, and volcaniclastic rocks, and minor carbonate- and silicate-facies iron-formation, and basalt. Locally intruded by thin sills of metagabbro. Includes Flag Rock Formation (Xsi_1) and Northwestern Formation (Xsi_2)

Xq — **Metaquartzite (Early Proterozoic)**—Quartzite, siliceous schist, and minor chert. Protoliths include quartzite containing interbedded siltstone and shale. Map unit includes Ellison Formation

Xif — **Iron-formation (Early Proterozoic)**—Iron-formation, ferruginous chert, and minor mica schist. Protoliths include carbonate-, silicate-, and sulfide-facies iron-formation and interbedded tuffaceous rocks. Map unit includes Homestake Formation

Xsc — **Metasedimentary rocks (Early Proterozoic)**—Siliceous biotite phyllite, calcareous biotite phyllite, and schist. Protoliths include black shale and chert, calcareous and carbonaceous shale, and minor amount of siltstone. Map unit includes Poorman Formation and Reausaw Slate that intertongues with basalt flows. Older and younger parts of unit described on plate 1

?— **Contact**—Dashed where approximately located; dotted where concealed; queried where uncertain

Fault—Dashed where approximately located. Bar and ball on downthrown side

Figure 9. Geologic map of the Lead area, Black Hills National Forest, S. Dak. Geology from Noble and Harder (1948), Bayley (1970a; 1972a), Krahulec (1981), and Redden (unpub. mapping, 1985). Base from U.S. Geological Survey, Rapid City, 1977.

west in the Hill City or Medicine Mountain areas, but may be correlative with carbonaceous biotite schist (unit Xbs, discussed below) in those areas.

Metasedimentary Rocks (Unit Xcg)

An unnamed heterogeneous assemblage of conglomeratic biotite phyllite, siliceous biotite phyllite, mica schist, quartzite, and iron-formation (unit Xcg, pl. 1) is restricted to the east-central and southeastern parts of the region, primarily the Keystone area (fig. 8), and extending south to the Custer area. The unit originally consisted of debris-flow conglomerate, graywacke, quartzite, ferruginous shale, and iron-formation. The iron-formation within the unit is described in the section on unit Xif, Keystone area.

In the far northeastern corner of the Keystone area (fig. 8) the unit contains clasts of the adjacent Buck Mountain Formation and unconformably(?) overlies unit Xq. Unit Xcg is older than the adjacent large body of graywacke to the southwest. In the north-central part of the area shown in figure 8 the unit conformably(?) overlies an older graywacke that in turn overlies basaltic rocks. In the far northwest corner of the area the unit is underlain and overlain by thick sections of graywacke. Unit Xcg apparently was derived from an eastern source and deposited on a steep submarine slope; it intertongues with graywacke turbidite in a westerly (distal) direction. The repeated Xcg and Xgw units at the lower and upper ends of Sheridan Lake (fig. 8) are characterized by a consistent direction of younging, east-southeast; such a pattern indicates that a major bedding-plane fault may repeat the section. The complex map pattern of unit Xcg is the result of two periods of tight folding, rapid facies changes in the unit itself, repetition by early faulting, and the fact that strata of the same lithology both overlie and underlie the unit.

In the Keystone area the unit ranges from 200 to more than 2,000 ft thick. It pinches out to the north, near the latitude of Rapid City (pl. 1), but probably continues south past Custer to the edge of Phanerozoic strata as a tectonically thinned layer. Only a thin layer is noted east of Hill City (pl. 1) and none of the unit has been identified in the Medicine Mountain area, so the unit must diminish abruptly in thickness west of Keystone.

Metasedimentary Rocks (Unit Xbs)

An unnamed assemblage of biotite schist, biotite-muscovite schist and pyritic biotite schist locally interbedded with massive chert (unit Xbs, pl. 1) is extensively exposed in the central Black Hills in the vicinity of Hill City, Medicine Mountain (fig. 6), and south to Custer. It originally was composed of black shale, pyritic and carbonaceous black shale, tuffaceous shale, and siltstone containing minor chert. Units Xbs and Xsc are

EXPLANATION

Tr — **Rhyolite (Eocene and Paleocene)**—Laccoliths and sills of rhyolite

M€pd — **Phasapa Limestone (Lower Mississippian), Englewood Formation (Lower Mississippian and Upper Devonian), and Deadwood Formation (Lower Ordovician and Upper Cambrian** — Pahasapa Limestone: massive, thick-bedded dolomitic limestone and dolomite. Cavernous in upper part. Englewood Formation: dolomitic limestone in upper part, shaly dolomite in lower part. Deadwood Formation: sandstone, shale, limestone, and conglomerate

Xsh — **Metasedimentary rocks (Early Proterozoic)**—Phyllite, slate, and mica schist. Protoliths include shale, carbonaceous shale, and minor siltstone. Map unit includes Swede Gulch Formation and large area of phyllite and schist in southern and eastern parts of area

Xms — **Metasedimentary rocks (Early Proterozoic)**—Muscovite schist, muscovite phyllite. Protoliths include aluminous, tuffaceous shale, and thin, manganiferous chert-carbonate beds

Xgw — **Metagraywacke (Early Proterozoic)**—Siliceous mica schist and impure quartzite. Protoliths are turbidite deposits that include graywacke and mixed graywacke and shale. Map unit includes Roubaix Formation. Apparently is uppermost part of unit as described on plate 1

Xgb — **Metagabbro (Early Proterozoic)**—Amphibolite, greenstone, actinolite schist, and serpentinite. Protoliths include gabbro, norite, and quartz-rich gabbro sills of at least two different ages. Represents younger part of unit described on plate 1

Xch — **Metachert (Early Proterozoic)**—Cherty schist and siliceous schist. Protoliths include chert and iron-poor chert

Xb — **Metabasalt (Early Proterozoic)**—Amphibolite, greenstone, actinolite schist. Protoliths include basalt and minor bodies of gabbro. Interflow units include tuffaceous shale, black shale, massive chert, carbonate- and silicate-facies iron-formation, and mafic tuff. Map unit includes Rapid Creek Greenstone

Xif — **Iron-formation (Early Proterozoic)**—Iron-formation, ferruginous chert, and minor mica schist. Protoliths include carbonate-, silicate-, and sulfide-facies iron-formation and interbedded tuffaceous rocks. Included in map unit are Rochford Formation and Montana Mine Formation

Xsi — **Metasedimentary rocks (Early Proterozoic)**—Phyllite, slate, biotite schist, and minor chert and amphibolite. Protoliths include tuffaceous shale, siltstone, black shale, and volcaniclastic rocks, and minor carbonate- and silicate-facies iron-formation and basalt. Locally intruded by thin sills of metagabbro. Includes Poverty Gulch Slate, Nahant Schist, and Irish Gulch Slate

Xq — **Metaquartzite (Early Proterozoic)**—Quartzite, siliceous schist, and minor chert. Protoliths include quartzite and interbedded siltstone and shale. Map unit includes Moonshine Gulch Quartzite

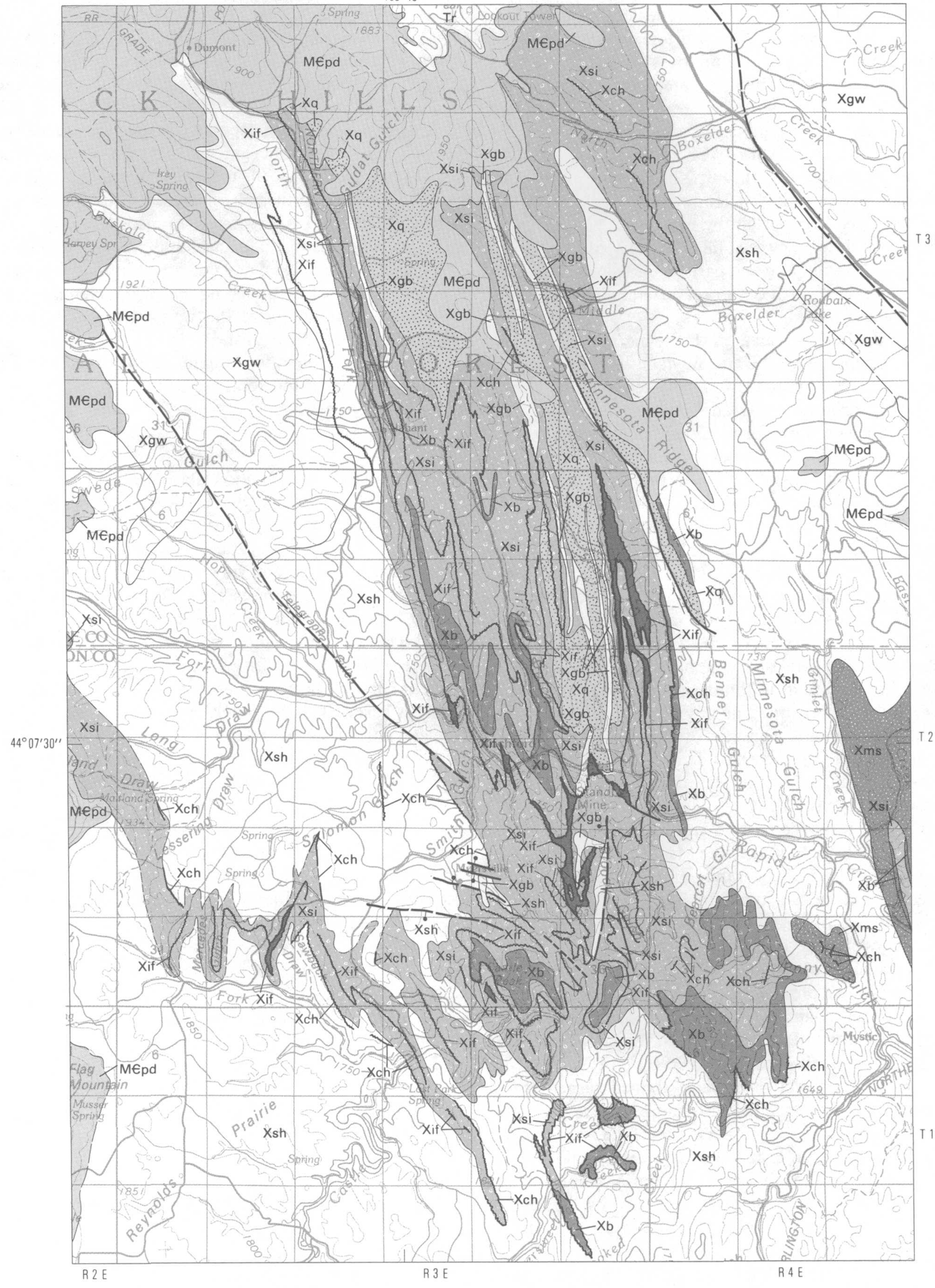
Contact—Dashed where approximately located; queried where uncertain

Fault—Dashed where approximately located. Bar and ball on downthrown side; arrows show relative sense of displacement

SCALE 1 100,000

0 1 2 3 4 MILES

Figure 10 (above and facing page). Geologic map of the Rochford area, Black Hills National Forest, S. Dak. Geology from Bayley (1972c) as modified by Redden (unpub. mapping, 1985), Bayley (1972a), Richard Cleath (unpub. mapping, 1984), and Redden (unpub. mapping, 1985). Base from U.S. Geological Survey, Rapid City, 1977.



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44°07′30″
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Xch
Xgw
Xif
Xq
Xgb
Xsh
Xb
Xms
Lookout Tower
Dumont
Irey Spring
Harvey Spr
Gudat Gulch
North Boxelder Creek
Middle Boxelder
Roubaix Lake
Minnesota Ridge
Swede Gulch
Hop Creek
Telegraph Gulch
Long Draw
Lessering Draw
Maitland Spring
Solomon Gulch
Smith Gulch
Standard Mine
Bennet Gulch
Minnesota Gulch
Gimlet Creek
Rapid Creek
Bearcat Gulch
Flag Mountain
Musser Spring
Prairie
Reynolds
Castle Creek
Lost Park Spring
Mystic
Spring

lithologically similar, and where only isolated masses of a pyritic biotite schist are exposed, the designation of that mass as unit Xbs or Xsc is uncertain. Also, because of the incompetent nature of the rock, several of the contacts of units Xbs and Xsc are probably faults or décollements.

As noted above, units Xsc and Xcg are not present west of Hill City. North of Hill City and southwest of Scruton Mountain (pl. 1), unit Xbs is underlain by unit Xgw and then by unit Xsc. However, at Medicine Mountain, unit Xbs is underlain by basalt and conglomerate (units Xb and Xc); between Hill City and Medicine Mountain, units Xsc and Xcg and part of unit Xgw are cut out. They may either pinch out or grade laterally into a thick mass of unit Xbs.

In the Hill City area (pl. 1) the biotite facies of the Oreville Formation (Ratté and Wayland, 1969) constitutes unit Xbs and is composed of carbonaceous biotite-garnet schist that originally was an iron- and potassium-rich shale. Unit Xbs is conformably underlain by metamorphosed graywacke (unit Xgw) and overlain by magnetite-rich schist (unit Xms). Farther north another tongue of graywacke (unit Xgw) separates the magnetite-rich muscovite schist from the Xbs unit. The minimum thickness of the unit is about 3,000 ft. North of Hill City the unit overlies unit Xsc; to the west near Medicine Mountain the unit may be laterally equivalent to unit Xsc.

In the eastern part of the area shown in figure 6, unit Xbs is composed of the Oreville Formation as mapped by Ratté (1980) and unnamed strata east of the Grand Junction fault in the Berne quadrangle (Redden, 1968). Lithologies are generally similar to those near Medicine Mountain. This part of unit Xbs can be traced continuously along the east side of the Grand Junction fault past Custer and to the edge of the Phanerozoic cover south of Pringle (pl. 1). It thins dramatically to the south, probably in response to high strain along the fault.

Unit Xbs in the Medicine Mountain area (fig. 6) is composed of part of the Vanderlehr Formation and the Loues Formation as mapped by Redden (1968) and part of the Vanderlehr Formation as mapped by Ratté (1980). Lithologies include carbonaceous biotite-garnet schist, carbonaceous schist and interbedded chert, laminated biotite schist and phyllite, biotite-feldspar schist, and iron-formation that originally were organic-rich shale, tuff, and interbedded chert. Total thickness of the unit is undetermined, but probably exceeds 4,000 ft.

Pyritic and graphitic coarse-grained garnetiferous schist tentatively correlated with unit Xbs occurs around the east, north, and southwest margins of the Harney Peak Granite (unit Xh, pl. 1) and as a large xenolith northwest of Harney Peak. The unit was domed during emplacement of the Harney Peak Granite, as suggested by the occurrence of rocks of the yet older unit Xc in the core of the pluton (pl. 1). For this reason the Xbs units at Bear Mountain and at Harney Peak are considered to be equivalent.

Metagraywacke (Unit Xgw)

Metamorphosed graywacke (unit Xgw, pl. 1) is the most widespread and volumetrically most common rock in the Proterozoic core of the Black Hills. It consists of siliceous mica schist and very impure quartzite that originally were turbidite deposits of mixed graywacke and shale. Locally, three main graywacke tongues or lenses can be distinguished above the major basalt unit in the Black Hills. However, in other places these tongues merge into single units and it is impossible to recognize individual tongues. The intermediate and basal graywacke tongues are generally the thickest and the most continuous laterally, but because of the pinching out of intervening rocks having different lithologies, the two tongues locally merge and cannot be distinguished. In a general way, all graywacke lenses tend to thicken and to consist of more proximal facies to the southeast.

Nemo and Roubaix Areas

The Roubaix Formation (Bayley, 1972b) is the main graywacke unit west of Nemo (pl. 1, fig. 5) and near Roubaix, southeast of Lead (fig. 9). It consists of mica schist, schistose metagraywacke, and slate that originally were impure siltstone and graywacke. In the Roubaix area it conformably(?) overlies metamorphosed shale and basalt correlated with the Flag Rock Formation (Berg, 1946; Bayley, 1970a); in the northwestern part of the Nemo area it is in fault contact with unit Xsc. Farther south, east of Merrit (fig. 5), the graywacke also conformably overlies basalt. This graywacke unit includes all three of the graywacke tongues and is a minimum of 1,500 ft thick.

Rochford Area

In the Rochford area, the graywacke unit constitutes part of the Swede Gulch Formation (Bayley, 1972b) west of Nahant (fig. 10). As at Roubaix, the unit consists of low-grade metamorphosed impure siltstone and graywacke having a minimum thickness of a few thousand feet. This graywacke apparently consists largely of the upper lens described above, but a facies change or fault must cut out the graywacke to the east near Nahant. The basal graywacke in the Roubaix area that overlies basaltic rocks is absent in the Rochford area.

Pactola Reservoir Area

All three graywacke units are present in the area west of Pactola Reservoir (pl. 1). The basal graywacke overlies unit Xsc west and south of Pactola Reservoir and is overlain, in ascending order, by unit Xbs, the intermediate tongue of graywacke, unit Xms, the upper graywacke unit, and metamorphosed shale (unit Xsh). In this area the basal graywacke is a minimum of 2,000 ft thick and the middle and upper units are about 600 ft and 1,500 ft thick, respectively.

Keystone Area

The basal and intermediate graywacke make up about 40 percent of the bedrock in the Keystone area. They are composed of micaceous schist containing abundant garnet and staurolite, and siliceous schist containing aluminosilicate minerals (Norton, 1976). The protoliths were impure siltstone and graywacke as in the Nemo area. The basal graywacke is exposed on the western edge of the area shown in figure 8, west of Sheridan Lake, where it underlies unit Xcg. The intermediate graywacke overlies unit Xcg north of Sheridan Lake and forms the large expanse of graywacke on the eastern edge of the area shown in figure 8, where it also overlies unit Xcg in the core of a syncline. The map pattern indicates the area has been extensively refolded, but the available evidence indicates a simple stratigraphic younging to the southeast. If correct, the iron-formation (unit Xif) and graywacke units on the east end of Sheridan Lake must be repeated by an early fault. This fault is inferred to follow the base (western contact) of unit Xif. Thicknesses of the graywacke units in the Keystone area have not been determined, but the lower unit is at least 3,000 ft thick and the intermediate unit has a comparable minimum thickness.

Medicine Mountain Area

On the northeast flank of the dome near Medicine Mountain (fig. 6) and along Zimmer Ridge and Lowden Mountain, the upper graywacke is exposed as a tongue between underlying magnetite-rich schist (unit Xms) and overlying metamorphosed shale (unit Xsh). Ratté (1980) considered this graywacke to be part of the Oreville Formation. Its thickness ranges to greater than 2,000 ft.

The southern part of the area shown in figure 6 contains both metagraywacke (unit Xgw) and micaceous metagraywacke (unit Xgwm) that are interpreted as proximal and distal facies, respectively. The Mayo and Bugtown Formations (Redden, 1963) constitute the graywacke unit west of the Grand Junction fault. The more proximal parts (Xgw) consist of quartz-mica-feldspar schist, whereas the more distal parts (Xgwm) are composed of alternating beds of quartz-mica-feldspar schist and minor micaceous schist containing garnet, staurolite, and aluminosilicate minerals. Within the area of figure 6, only about 2,000 ft of the Mayo Formation is exposed; farther south a minimum of 14,000 ft is present. The Bugtown Formation within the area of figure 6 is about 4,000–6,000 ft thick. East of the Grand Junction fault the graywacke consists of unnamed high-grade schist units of undetermined thickness.

The graywacke units south of the dome near Medicine Mountain do not fit into the rather simple threefold subdivision of graywacke units applicable elsewhere in the Black Hills. They are much thicker than graywacke units to the northeast and contain, in the middle of the sequence, the predominantly basaltic Crow Formation, a unit not recognized in other graywacke assemblages. Because these units are separated from the remaining rocks by the Grand Junction fault, it is possible that they are not at all correlative with the other graywacke units. However, we believe that this is unlikely.

East of the Medicine Mountain area, near Hill City (pl. 1), the graywacke is composed of parts of the Bugtown (Redden, 1963) and Oreville Formations as mapped by Ratté and Wayland (1969). The intermediate and upper graywacke units are exposed over much of the area, but they are not as thick as they are to the east and northeast. The composition and protoliths of the graywacke are similar to those described in the Keystone area. Thicknesses are not estimated for the graywacke units of the Hill City area due to their extreme deformation.

Tinton Area

Metamorphosed graywacke constitutes more than 90 percent of the Precambrian bedrock in the Tinton area (pl. 1, fig. 11). The unit is composed of feldspathic and micaceous schist and minor carbonaceous schist (Norby, 1984). This graywacke does not closely resemble other turbidite units in the central part of the Black Hills and may be Archean (Redden, unpub. data, 1985).

Metasedimentary Rocks (Unit Xms)

A magnetite-rich muscovite schist (unit Xms, pl. 1), present throughout much of the central core of the Black Hills, is a marker bed that reveals many of the major folds and facies variations that affect the Proterozoic strata. Parts of the Oreville Formation and unnamed units east of the Grand Junction fault are included in this unit, which originally was an iron-poor aluminous and tuffaceous shale. The schist contains disseminated magnetite and ilmenite in its western and central exposures near Medicine Mountain (fig. 6), but the amount of magnetite diminishes to the north near Rochford (fig. 10) and to the east toward the Harney Peak Granite (pl. 1 and fig. 8). The original thickness is difficult to estimate because of the deformed nature of the schist, but probably was between 1,000 and 3,000 ft. To the southeast the unit contains more turbidite beds and gradually loses its distinctive lithologic character. Consequently, the unit cannot be identified with certainty in the area east of Mount Rushmore or in the eastern turbidite belts. The unit is anomalously magnetic compared to adjacent strata and can be projected beneath the Phanerozoic cover to the west by the position of aeromagnetic highs (Kleinkopf and Redden, 1975; Bendix Field Engineering Corp., 1982a, c).

Metasedimentary Rocks (Unit Xsh)

The youngest stratified unit in the central part of the Black Hills is a metamorphosed shale (unit Xsh, pl. 1) that consists of phyllite, slate, and mica schist. The unit is exposed widely in the Rochford area and east, south, and west of Rochford. Correlative rocks extend into the Lead area.

The Grizzly Formation is unit Xsh in the Lead area (fig. 9), the easternmost and youngest stratified rock described by Noble and Harder (1948). According to Dodge (1942), it consists of an undetermined thickness, probably exceeding 2,000 ft, of micaceous phyllite that originally was an aluminous shale. The formation extends south under the cover of Cambrian sandstone into the Roubaix area.

In the Rochford area (fig. 10), part of the Swede Gulch Formation that consists of phyllite and mica schist is unit Xsh. A large area south and east of Rochford (pl. 1) consists of unnamed phyllite, slate, and mica schist units that are included in unit Xsh. Thickness estimates are approximate at best due to the homogeneous character and highly folded nature of the unit; a minimum of 5,000 ft is probably conservative.

Plutonic Rocks

The Archean and Early Proterozoic stratified metasedimentary and metavolcanic rocks are intruded by the Harney Peak Granite (unit Xh, pl. 1), a coarse-grained to pegmatitic peraluminous muscovite granite containing accessory garnet, biotite, and tourmaline (Huang and Wylie, 1981; Redden, Norton, and McLaughlin, 1982). The granite occupies a 40-sq-mi area between Custer and Keystone in which hundreds of dikes and sills coalesce into a coherent, but compositionally and texturally variable, intrusive body. Numerous bodies of pegmatite and small bodies of granite intrude the country rock for miles outside the main mass of the pluton. Outlying bodies of the Harney Peak Granite are noted northeast of Pringle and south of Hayward (pl. 1). The granite has a Rb-Sr whole-rock date of 1,697±33 Ma (recalculated from data in Riley, 1970), which is interpreted as the age of emplacement. Its initial $^{87}Sr/^{86}Sr$ ratio is about 0.7157, a very high value that indicates the granite was at least partially derived from sedimentary source material.

The Harney Peak Granite contains anomalous concentrations of uranium and potassium as compared to the metasedimentary wall rocks and can be outlined by airborne radiometric anomalies (Texas Instruments, Inc., 1979). Two pronounced thorium lows, one north of Sylvan Lake and the other near Elkhorn Mountain, may indicate zones within the granite that have anomalously low thorium concentrations. Gravity data (Kleinkopf and Redden, 1975) suggest that the granite may extend north beneath graywacke units between Hill City and Keystone.

EXPLANATION

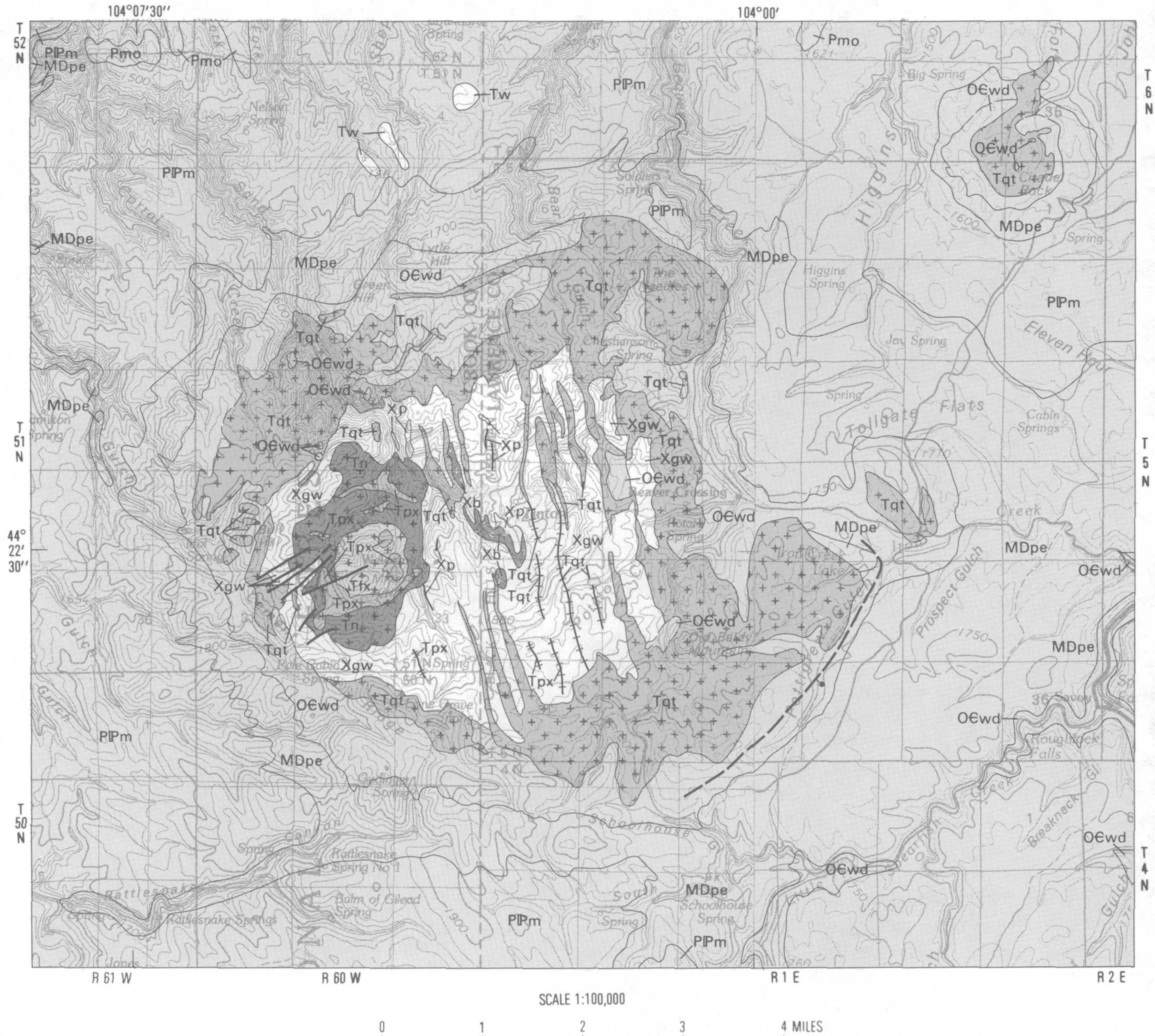
- **Tw** — **White River Group (Oligocene)**—Tuffaceous claystone and clay containing minor limestone lenses
- **Tfx** — **Feldspathoidal breccia (Eocene and Paleocene)**—Leucite-rich feldspathoidal intrusive breccia that forms core of ring dike complex
- **Tpx** — **Pyroxenite and diorite (Eocene and Paleocene)**—Plugs and intrusive sheets of pyroxenite and diorite that form incomplete ring surrounding feldspathoidal breccia
- **Tn** — **Nepheline syenite (Eocene and Paleocene)**—Outer ring dike of nepheline syenite that is intruded by diorite, pyroxenite, and feldspathoidal breccia
- **Tqt** — **Quartz trachyte (Eocene and Paleocene)**—Dikes and sills of latite-andesite, quartz latite, quartz trachyte, and trachyte
- **Pmo** — **Minnekahta Limestone and Opeche Shale (Lower Permian)**—Minnekahta Limestone: slabby limestone. Opeche Shale: sandy shale
- **PIPm** — **Minnelusa Formation (Lower Permian and Pennsylvanian)**—Sandstone, solution breccia (anhydrite in subsurface), limestone, and shale
- **MDpe** — **Pahasapa Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)**—Pahasapa Limestone: cavernous dolomitic limestone. Englewood Formation: dolomitic limestone
- **OЄwd** — **Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**—Whitewood Dolomite: dolomite. Winnipeg Formation: shale and siltstone. Deadwood Formation: sandstone, shale, and limestone
- **Xp** — **Pegmatite (Early Proterozoic?)**—Pegmatite bodies that may be Late Archean or may be age of Harney Peak Granite
- **Xb** — **Metabasalt (Early Proterozoic?)**—Amphibolite, greenstone, actinolite schist. Protoliths include basalt and minor bodies of gabbro
- **Xgw** — **Metagraywacke (Early Proterozoic?)**—Siliceous mica schist and impure quartzite. Protoliths are turbidite deposits that include graywacke and mixed graywacke and shale
- **Contact**—Dashed where approximately located
- **Fault**—Dashed where approximately located. Bar and ball on downthrown side

Figure 11 (above and facing page). Geologic map of the Tinton area, Black Hills National Forest, Wyo. and S. Dak. Geology from Smith and Page (1941), Welch (1974), Darton (1905), Fisher (1969), Darton and Paige (1925), and Norby (1984). Base from U.S. Geological Survey, Rapid City, 1977, and Sundance, 1979.

If the granite is present beneath the Phanerozoic cover, it most likely extends east toward Hayward.

Structure and Metamorphism

All the Precambrian rocks except the Harney Peak Granite have been variably deformed and metamorphosed. A detailed discussion of structure and metamorphism is beyond the scope of this paper. The structure of individual areas has been described by previous authors listed above in the sections about Archean and Proterozoic rocks, as well as by Noble, Harder, and Slaughter (1949),



Chinn (1969), Dheeradilok (1971), Luza (1972), Alkhazmi (1973), Atkinson (1976), McMillan (1977), Krahulec (1981), and Kuhl (1982), and the general structure has been described by Van Hise (1890), Darton and Paige (1925), Kleinkopf and Redden (1975), and Redden and Norton (1975). The following discussion is summarized from those works. Note that most structural symbols have been deleted from plate 1 and figures 5 through 14 in order to highlight the areal distribution of lithologic variations.

Folding

Incomplete exposures and facies changes make absolute correlation of stratified units, and hence structures, impossible at this time, but the most likely relationships of folding are summarized below. A synthesis of the structure is being prepared by Redden as an extension of the earlier descriptions by Redden and Norton (1975). The earliest documented folds trended east to northeast, were isoclinal, and were strongly refolded by northwest-trending folds. These early folds were overturned to the north-northwest and lacked any well-developed metamorphic fabric. The latter folding was sufficiently strong to warp many of the rocks into northwest trends, and a strong northwest-trending foliation developed. Although early analyses of the structure of the Black Hills emphasized the northwesterly trends (Van Hise, 1890; Noble, Harder, and Slaughter, 1949) as being the basic fabric, it is now evident that the two dominant trends in the stratified rocks resulted from two periods of folding. During a yet later deformation possibly related to emplacement of the Harney Peak Granite, a minor foliation trending north or northeast was locally developed.

Deformation related to emplacement of the Harney Peak Granite resulted in creation of a large domal structure surrounded by a few minor domes overlying subsidiary intrusions. These domal structures deformed earlier structures largely by plastic flow. A foliation was locally developed in both the wallrocks and some of the earlier phases of the granite during its emplacement. Because of the superposition of the late dome related to emplacement of the granite on pre-existing fold structures, the structure of the country rocks appears deceptively simple on the flanks of the large domes.

The overall structure of the Precambrian core of the Black Hills is a large synclinorium characterized by northeast- and northwest-striking exposures of rock units that are locally modified by northwest-trending domal axes (pl. 1). Archean rocks are exposed in the Nemo and Bear Mountain areas and, if not exposed, are inferred to be present at a shallow depth in the core of the dome near Harney Peak. The youngest Proterozoic stratified rocks are exposed in the center of the structure and are crossed by Castle Creek south of Rochford.

Although the major fold axes are not shown on plate 1, a major early synclinal axis follows the medial part of unit Xsh and trends northeasterly across the central Black Hills. An adjacent anticlinal axis follows unit Xbs northwest of Hill City. These early folds were dramatically deformed by younger northwest-trending folds that were in turn locally modified by such domal areas as Bear Mountain and Harney Peak. The oldest fold sets and east- to northeast-trending stratigraphy are revealed by strata older than unit Xd in the Nemo area (fig. 5) that strike northeast and dip steeply or are overturned but that display a prominent northwest-trending cleavage and schistosity. This older northeast-trending structural grain can be seen in the Roubaix area (southeastern part of area of fig. 9) by the northeast orientation of unit Xb, and in the Rochford area (fig. 10) by the east-trending orientation of units Xb and Xsi, both of which have been refolded about northwest-trending axes.

Near Hill City, the northeast trends of rock units are a combination of the early fold trends and the superposition of the younger domal structure related to emplacement of the Harney Peak Granite. Although the structure is not completely deciphered in the Hill City area, there is some evidence for northeast-trending nappe structures; it is not clear if these developed during the earliest folding or as a result of domal uplift of the Harney Peak area.

First- and second-generation folds plunge at various inclinations, many of them steeper than 40°. The orebodies in the Homestake mine have been mined to a depth of more than 8,000 ft on an anticlinorium that plunges southeast at about 45° (Slaughter, 1968). This anticlinorium resulted from northwest-trending folds formed during the second generation of folding.

Faulting

The earliest faults apparently were northeast-trending thrust faults that accompanied the earliest period of folding. These faults essentially parallel the lithologic contacts and were subsequently deformed by the superposed northwest-trending folds.

A number of large, northwest-trending faults having right-lateral separations of 1–5 mi cut the stratified rocks in the Pactola Reservoir, western Nemo, and Keystone areas (pl. 1 and figs. 5 and 8). Another northwest-trending fault that passes through Keystone has a movement sense opposed to this right-lateral separation, indicating that the area including Sheridan Lake is part of a block that has moved northwest relative to the Harney Peak and Nemo areas. These faults postdate, or are late in the development of, the Harney Peak domes. They contrast with the Grand Junction fault southwest of Harney Peak, which presumably preceded the final emplacement of the granite. Other inferred faults on the northwest side of the Harney Peak dome are also probably early, but their structural history has not been deciphered. Faults on the west side of the Harney Peak Granite have variable senses of displacement.

Metamorphism

Metamorphic grade in the stratified rocks ranges from greenschist facies in the central and northern parts to upper amphibolite facies in the south. An increase in metamorphic grade from low greenschist facies in the west to lower amphibolite facies in the east has been noted near Lead (Gustafson, 1933; Dodge, 1942; Noble and Harder, 1948). Metamorphic grade increases in a general way with proximity to the Harney Peak Granite (Darton and Paige, 1925; Redden, 1963, 1968; Ratté and Wayland, 1969; Redden and Norton, 1975), and uppermost amphibolite facies conditions are reached in isolated areas above the largest granitic masses. In pelitic rocks this increase in metamorphic grade is marked by the first occurrences of biotite, almandine garnet, staurolite, and sillimanite.

The distribution of pegmatite bodies closely parallels the increase in metamorphic grade adjacent to the main mass of the Harney Peak Granite. Virtually no pegmatite bodies are found in lower-greenschist-facies rocks or in pelitic rocks that do not contain staurolite, and the highest concentration of pegmatite bodies is in upper-amphibolite-facies rocks or pelitic rocks that contain sillimanite.

Phanerozoic Rocks

Strata of Cambrian to Cretaceous age were deposited on the Archean and Proterozoic rocks and now dip radially away from the core of the Black Hills (pl. 1). Intrusive rocks of early Tertiary age cut the Proterozoic and Phanerozoic rocks along a west-northwest-oriented belt in the northern Black Hills. Early Tertiary erosion of the Black Hills developed a relatively mountainous topography in the region that was covered by extensive Oligocene terrestrial deposits. These deposits have been largely removed over most of the area by post-Oligocene erosion. Quaternary sediments are restricted to valleys of modern streams.

The Phanerozoic rocks have been studied by many authors, and the stratigraphy, sedimentology, and tectonic setting have been well documented. This section will therefore be a review of many works, especially those by Hayden (1872), Newton and Jenney (1880), Darton (1902, 1904a, 1905, 1919), Darton and Smith (1904), Darton and O'Harra (1905, 1907, 1909), Darton and Paige (1925), Imlay (1947), Cobban (1952), Gries (1952, 1964, 1975), McCoy (1952), Waage (1959), Reeside and Cobban (1960), Gill and Cobban (1961), Robinson, Mapel, and Bergendahl (1964), Schultz (1965), Gott, Wolcott, and Bowles (1974), Harksen (1975), Merewether (1975), Rahn (1981), and numerous other authors.

Paleozoic Rocks

Paleozoic strata in the Black Hills consist of limestone and sandstone deposited in marine water on a relatively stable continental shelf. Thickness of Paleozoic rocks ranges from about 900 ft in the southern Black Hills to more than 2,200 ft in the northern Black Hills (fig. 4). For purposes of this report the Spearfish Formation is included with the Mesozoic rocks. The Paleozoic strata contain no distinctive trace-metal suites that could be detected by NURE stream-sediment sampling (Union Carbide Corp., 1979, 1980; Goff and others, 1980; Warren and others, 1980).

Deadwood Formation, Winnipeg Formation, and Whitewood Dolomite

The basal unit of the Paleozoic section is the Lower Ordovician and Upper Cambrian Deadwood Formation, a succession of sandstone, shale, and dolomite that locally contains a basal conglomerate. The Deadwood is a nearshore deposit that thickens notably from south to north (fig. 4), and may be as thin as 4 ft and as thick as 500 ft. Conformably overlying the Deadwood in the northern and central Black Hills is the Middle Ordovician Winnipeg Formation, a shale unit interbedded with minor amounts of siltstone and sandstone. The Winnipeg is absent in the southern Black Hills and thickens to about 110 ft near Deadwood. The Upper Ordovician Whitewood Dolomite conformably overlies the Winnipeg and consists of as much as 60 ft of dolomite in the northern Black Hills. Due to the unconformable upper contact, the unit is eroded to the south and is not known south of the approximate latitude of Nemo. The Ordovician and Cambrian strata are grouped on plate 1 as unit O€wd.

Englewood Formation and Pahasapa Limestone

Unconformably overlying the Ordovician or Cambrian strata is the Upper Devonian and Lower Mississippian Englewood Formation, an argillaceous dolomite that ranges in thickness from 35 to 60 ft. In the northern Black Hills the Englewood contains a basal shale horizon. The Englewood grades upward into the overlying Lower Mississippian Pahasapa Limestone, a cavernous dolomite that thickens from south to north, ranging in thickness from about 200 ft to more than 600 ft. The variation in thickness is largely due to a karst topography that developed on the Pahasapa before deposition of Pennsylvanian strata. These strata are combined on plate 1 as unit MDpe. In areas where the outcrops of Cambrian through Mississippian strata are complex or small, units from the Deadwood Formation through the Pahasapa Limestone are grouped as unit M€pd.

Minnelusa Formation

The Lower Permian and Pennsylvanian Minnelusa Formation (map unit PIPm, pl. 1) unconformably overlies the Pahasapa Limestone and consists largely of alternating units of sandstone and dolomite interbedded with lesser amounts of shale and chert. Anhydrite beds characteristic of the upper part of the formation in the subsurface become solution breccia in outcrop. The lower part of the formation consists of shale, dolomite, radioactive black shale, anhydrite, and sandstone. The upper part contains dolomite, anhydrite, aeolian sandstone, siltstone, and cherty dolomite. The Minnelusa is the oldest formation to thicken to the south, ranging in thickness from about 400 ft to more than 1,050 ft.

The Minnelusa Formation can be recognized on aerial radiometric maps of the area (EG&G geoMetrics, 1979a, b, c, 1980a; Texas Instruments, Inc., 1979) because it is slightly higher in uranium than are the strata above or below. Equivalent uranium concentrations of 2–4 ppm (parts per million) are indicated by the data; the source of the uranium probably is the black shale and sandstone near the base of the formation.

Opeche Shale and Minnekahta Limestone

The Lower Permian Opeche Shale overlies the Minnelusa and consists of 25–150 ft of red silty shale and discontinuous beds of gypsum or anhydrite. It is overlain by the Lower Permian Minnekahta Limestone, a 35- to 50-ft-thick thin-bedded, high-calcium limestone. The Minnekahta and Opeche are grouped as unit Pmo on plate 1.

Mesozoic Rocks

The Mesozoic strata in the Black Hills contrast markedly with the Paleozoic strata by being predominantly shale and sandstone that were deposited under shallow marine conditions in a relatively stable continental seaway. The strata range in thickness from about 2,800 ft in the southern and eastern Black Hills to more than 7,000 ft in the western and northern Black Hills (fig. 4). Many of the Mesozoic units, especially the black shale, contain distinctive trace-metal suites that were detected by NURE stream-sediment sampling.

Spearfish Formation

The Triassic and Permian Spearfish Formation (map unit ꞦPs) is included as the oldest Mesozoic unit even though the base of the formation is Permian. It consists of interbedded red siltstone, shale, and gypsum that thicken from south to north, ranging from about 325 ft in the south to more than 900 ft near Sturgis, on the northeast edge of the Black Hills.

The outcrop of the Spearfish can be delineated on airborne radiometric maps (EG&G geoMetrics, 1979a, b, c, 1980a; Texas Instruments, Inc., 1979) because it contains slightly more potassium and uranium than do the surrounding strata. Anomalous concentrations of strontium, presumably from gypsum beds, were noted by Goff and others (1980) in stream-sediment samples from the Spearfish, as were scattered lithium anomalies. The source of the lithium is unknown.

Gypsum Spring Formation and Sundance Formation

The Middle Jurassic Gypsum Spring Formation unconformably overlies the Spearfish. It consists of interbedded gypsum, siltstone, and shale and is as much as 125 ft thick. The unit thins to the southeast and is absent throughout much of South Dakota. Conformably overlying the Gypsum Spring is the Upper and Middle Jurassic Sundance Formation, a unit of alternating sandstone and shale that thickens from east to west. On the eastern side of the Black Hills it is only 250 ft thick; near Sundance it is more than 475 ft thick. The Sundance has been divided into six members, but it is not divided in this report. The Gypsum Spring and Sundance are grouped into unit Jsg on plate 1.

Unkpapa Sandstone, Morrison Formation, and Inyan Kara Group

The Upper Jurassic Unkpapa Sandstone conformably overlies the Sundance and underlies the Morrison on the eastern, northern, and southern flanks of the Black Hills, but is not present on the western flank, where it is replaced by the Morrison Formation. The Unkpapa consists of fine-grained sandstone and is as thick as 275 ft. The Upper Jurassic Morrison Formation conformably overlies the Sundance on the western side of the Black Hills and conformably overlies the Unkpapa on the eastern, northern, and southern sides. It consists of interbedded shale, sandstone, and minor limestone and is as thick as 150 ft. The Unkpapa is thickest where the Morrison is thinnest and the converse, the result being a rather constant thickness for the combination of the two units.

The Morrison is unconformably overlain by the Lower Cretaceous Inyan Kara Group, which consists of the Lakota Formation below and the Fall River Sandstone above. The Lakota is composed of sandstone, shale, and, locally, limestone, and ranges from 35 to more than 700 ft thick. The lower part of the Lakota contains channel-filling sandstone, thin lenses of conglomerate, and fossil wood. The upper part of the formation is composed of claystone and sandstone. Most of the formation accumulated in continental environments, most likely in river valleys and on flood plains. The Fall River Sandstone unconformably overlies the Lakota and consists of fine-grained sandstone, siltstone, and claystone that were deposited in shallow marine waters along the eastern shore of the Mesozoic seaway. The Fall River ranges from 100 to 200 ft thick. The Inyan Kara, Morrison, and Unkpapa are grouped in unit KJim on plate 1, but members of the Inyan Kara and overlying and underlying units are divided in figure 12.

On airborne radiometric maps (EG&G geoMetrics, 1979a, b, c, 1980a; Texas Instruments, Inc., 1979), the Inyan Kara Group can be delineated from the surrounding rock units by its high concentration of uranium and the somewhat surprisingly low concentration of potassium.

Skull Creek Shale, Newcastle Sandstone, and Mowry Shale

Conformably overlying the Fall River Sandstone is the Lower Cretaceous Skull Creek Shale, a dark-gray, concretion-bearing shale of marine origin that is about 170–270 ft thick. In the northwestern part of the Black Hills in Wyoming, a bentonite bed near the base of the Skull Creek has a K-Ar biotite date of 104.4 Ma (Obradovich and Cobban, 1978). The Lower Cretaceous Newcastle Sandstone conformably overlies the Skull Creek and consists of sandstone and lesser amounts of shale and bentonite. Biotite from a bentonite at the base of the sandstone has a K-Ar date of 99.6 Ma (Obradovich and Cobban, 1978). It ranges in thickness from 0 to 100 ft. On the eastern flank of the Black Hills, the Newcastle may have been deposited in a river or delta system; elsewhere it probably is marine in origin. The Newcastle is conformably overlain by the Lower Cretaceous Mowry Shale, a gray siliceous shale containing minor beds of bentonite, which have been dated in Wyoming as 94–98 Ma (Love and Christiansen, 1985). The Mowry is about 125–230 ft thick. The Mowry, Newcastle, and Skull Creek are grouped as unit Kms on plate 1.

All three rock units contain anomalously high concentrations of thorium and uranium as compared to the underlying strata, and can be delineated on airborne radiometric maps of the area (EG&G geoMetrics, 1979a, b, c, 1980a; Texas Instruments, Inc., 1979). Anomalous concentrations of lead and manganese were noted in stream-sediment samples from unit Kms (Warren and others, 1980). The heavy metals are presumed to be in black shale.

Belle Fourche Shale

The Upper Cretaceous Belle Fourche Shale (unit Kb) conformably overlies the Mowry Shale and consists of gray, concretion-bearing shale that contains beds of bentonite and minor limestone. It ranges in thickness from 300 to 850 ft and was deposited in an inland sea. Where the Belle Fourche, Mowry, Newcastle, and Skull Creek have not been mapped separately, the four units are included in map unit Kbs (pl. 1).

The Belle Fourche contains thorium and uranium anomalies comparable to those in the Mowry, Newcastle, and Skull Creek, and can be delineated on airborne radiometric maps. Anomalous concentrations of thorium, rubidium, hafnium, lanthanum, and lithium were reported in stream-sediment samples from the Belle Fourche by Union Carbide Corp. (1979, 1980) and by Goff and others (1980). These metals are presumed to be concentrated in bentonite layers. Also, anomalous concentrations of niobium, manganese, and chromium have been reported and are thought to be derived from the black shale.

Greenhorn Limestone, Carlile Shale, and Niobrara Formation

The Upper Cretaceous Greenhorn Limestone consists of interbedded calcareous shale and thin limestone that is about 225–400 ft thick. It conformably overlies the Belle Fourche Shale. The Upper Cretaceous Carlile Shale conformably overlies the Greenhorn and is composed of concretion-bearing gray shale, interbedded siltstone, shale, and sandstone, and dark shale containing calcareous concretions. It ranges in thickness from 400 to 620 ft. The Upper Cretaceous Niobrara Formation unconformably overlies the Carlile and ranges in thickness from about 80 to 300 ft. It is composed of calcareous shale, limestone, and thin beds of bentonite that have been dated in Wyoming as about 83 Ma (Love and Christiansen, 1985). The Niobrara, Carlile, and Greenhorn have been grouped as unit Kng on plate 1.

The Niobrara, Carlile, and Greenhorn contain anomalously high concentrations of thorium and uranium, similar to those in the Mowry through Belle Fourche strata. Anomalous concentrations of rubidium and lithium reported by Goff and others (1980) in stream-sediment samples from unit Kng are thought to come from bentonite beds. Anomalous concentrations of lead, vanadium, and antimony in the samples are thought to be derived from black shale. Soil developed on the Niobrara is also known to have high concentrations of selenium.

Pierre Shale

The Upper Cretaceous Pierre Shale (unit Kp) concordantly overlies and interfingers with the Niobrara Formation and consists of concretion-bearing gray shale containing bituminous shale, bentonite, sandstone, and calcareous shale. The bentonite beds in the Pierre in Wyoming have been dated as 72–78 Ma (Love and Christiansen, 1985). The Pierre ranges in thickness from as little as 1,200 ft near the Black Hills to an average of about 2,700 ft.

The Pierre can be delineated on airborne radiometric maps by its anomalously high potassium content (EG&G geoMetrics, 1979a, b, c, 1980a; Texas Instruments, Inc., 1979). Also, the basal part of the Pierre produces large local uranium anomalies without coincident thorium anomalies and can be mapped in places using the airborne radiometric data. The rest of the Pierre contains anomalously low concentrations of uranium and average to low concentrations of thorium.

The Pierre contains anomalous concentrations of a great variety of elements as indicated by stream-sediment samples from the unit (Union Carbide Corp., 1979, 1980; Goff and others, 1980). Rubidium, niobium, and lanthanum probably are contained in bentonite beds; zinc, cadmium, bismuth, vanadium, and antimony presumably are contained in black shale; manganese, nickel, chromium, and zinc are contained in concretion-rich horizons. Several horizons in the Pierre contain high concentrations of selenium.

Fox Hills Sandstone

Conformably overlying the Pierre Shale is the Upper Cretaceous Fox Hills Sandstone (unit Kfh). It consists of channel-filling sandstone and gray shale and is 125–250 ft thick near the western edge of the map area (pl. 1).

Lance Formation

The Upper Cretaceous Lance Formation conformably overlies the Fox Hills Sandstone in Wyoming on the western flank of the Black Hills and is composed of channel sandstone and minor lignite lenses. Near the western edge of the map area (pl. 1) in Wyoming, the basal part of the the Tullock Member of the Fort Union Formation of Paleocene age was mapped with the Lance. The Lance, as defined above, ranges in thickness from 2,000 to 3,400 ft.

Tertiary Rocks

Rocks of Tertiary age include fresh-water to terrestrial sedimentary deposits that partly covered the Black Hills uplift during Oligocene and later time, and shallowly emplaced igneous bodies in the northern Black Hills that range in age from Paleocene to Eocene.

Stratified Rocks

Fresh-water to terrestrial deposits of the Oligocene White River Group (unit Tw, pl. 1) unconformably overlie the Precambrian and Phanerozoic rocks, especially on the eastern flank of the Black Hills in South Dakota and on the eastern flank of the Bear Lodge Mountains in Wyoming. These strata consist of claystone, tuffaceous claystone, siltstone, and limestone contained in the Chadron and Brule Formations. Tropical conditions existed in the area during their deposition. During Oligocene time these strata covered much of the present Black Hills uplift. The White River Group attains a maximum thickness of about 250 ft on the eastern flank of the Black Hills near Fairburn.

Conglomeratic strata of the late Miocene Ogallala Formation are mapped with unit Tw in the Bear Lodge Mountains. Strata there include sandstone, conglomerate, and calcareous siltstone derived from the underlying Tertiary intrusive rocks. A minimum thickness of 50 ft of Ogallala Formation was measured by Staatz (1983).

Igneous Rocks

The northern Black Hills are cut by a west-northwest-trending belt of Tertiary igneous rocks of varied composition and form. Most of them were emplaced as laccoliths, sills, and small stocks into the Paleozoic and Mesozoic strata after Laramide uplift of the Black Hills (Darton and Paige, 1925; Shapiro, 1971). Their composition ranges from quartz-normative rhyolite to nepheline-normative phonolite; a tremendous number of igneous rock names have been applied to the various bodies. In order to simplify and standardize the nomenclature of these rocks, this report will use the chemical rock names suggested by De la Roche and others (1980) for those bodies for which major element analyses have been published. Bodies for which we have only petrologic descriptions will be assigned the chemical name followed by a query, such as "latite(?)."

The suite of rocks in the northern Black Hills ranges in SiO_2 content from about 50 percent (phonolite and trachy-phonolite) to about 70 percent (rhyolite and alkali rhyolite). Rocks having less than 50 percent SiO_2 (lamprophyre and pyroxenite) constitute a minor amount of the igneous suite. In a general sense the suite becomes more alkalic ($Na_2O + K_2O$) to the west. Peralkaline rocks do not occur because the Al_2O_3 content of the suite is everywhere too high. The suite is tholeiitic (iron-rich as opposed to magnesium-rich), although some of the easternmost rocks are calc-alkaline (magnesium-rich). Both peraluminous (molar Al_2O_3 greater than total molar $Na_2O + K_2O + CaO$) and metaluminous (molar Al_2O_3 less than total molar $Na_2O + K_2O + CaO$) rocks are noted in the suite. Those having the lowest SiO_2 contents are normally metaluminous, although peraluminous trachy-phonolite does occur; the rhyolite is commonly slightly peraluminous. Isotopic dating (Mukherjee, 1968; McDowell, 1971; Hill, Izett, and Naeser, 1975; Staatz, 1983) and strontium-isotope studies (Olson, 1976) indicate

EXPLANATION

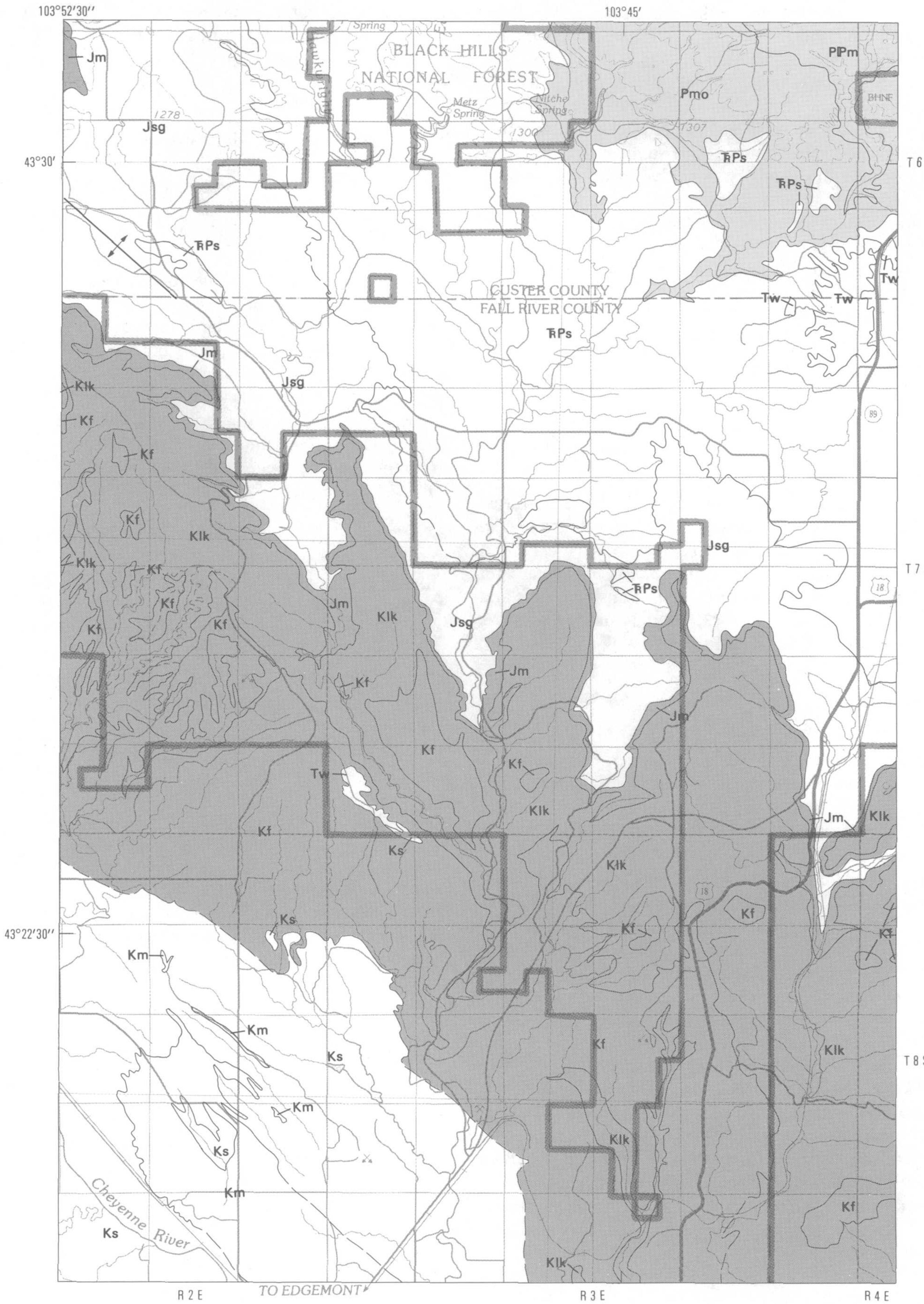
Tw	**White River Group (Oligocene)**—Tuffaceous claystone and clay containing minor limestone lenses
Km	**Mowry Shale (Lower Cretaceous)**—Siliceous shale interbedded with thin bentonite layers
Ks	**Skull Creek Shale (Lower Cretaceous)**—Black shale
Kf	**Fall River Sandstone (Lower Cretaceous)**—Sandstone and minor siltstone
Klk	**Lakota Formation (Lower Cretaceous)**—Claystone and sandstone locally interbedded with limestone and lignite lenses
Jm	**Morrison Formation (Upper Jurassic)**—Siliceous claystone and shale
Jsg	**Sundance Formation (Upper and Middle Jurassic) and Gypsum Spring Formation (Middle Jurassic)**—Sundance Formation: glauconitic sandstone and shale. Gypsum Spring Formation: massive gypsum and minor claystone
TRPs	**Spearfish Formation (Triassic and Permian)**—Shale, siltstone, and gypsum
Pmo	**Minnekahta Limestone and Opeche Shale (Lower Permian)**—Minnekahta Limestone: slabby limestone. Opeche Shale: sandy shale
PIPm	**Minnelusa Formation (Lower Permian and Pennsylvanian)**—Sandstone, solution breccia (anhydrite in subsurface), limestone, and shale.

Contact—Dashed where approximately located

Anticline

SCALE 1:100,000
0 1 2 3 MILES

Figure 12 (above and facing page). Geologic map of the Edgemont area, Black Hills National Forest, S. Dak. Geology from Gott and Schnabel (1963), Gott, Wolcott, and Bowles (1974), Ryan (1964), Bell and Post (1971), and Darton and Paige (1925). Base from U.S. Geological Survey, Hot Springs (advance edition), and Mount Rushmore, 1977.


103°52'30"
103°45'
43°30'
43°22'30"
T 6 S
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R 3 E
R 4 E
BLACK HILLS
NATIONAL FOREST
Metz Spring
Nitche Spring
CUSTER COUNTY
FALL RIVER COUNTY
Cheyenne River
TO EDGEMONT
Jm
Jsg
Pmo
PPm
TRPs
Tw
Klk
Kf
Ks
Km
1278
1300
1307

that most of the intrusive rocks were emplaced 50–60 Ma and were probably derived from primitive material, most likely upper mantle or lower crust.

The Tertiary igneous rocks are described here in somewhat more detail than the Phanerozoic stratified rocks because of their genetic relation to major ore deposits and the fact that no other summary of the bodies deals with their chemistry. Intrusive rocks will be summarized from east to west as they appear on plate 1, where they are shown as either quartz-normative (unit Tq) or nepheline-normative (unit Tn). Both types are shown further subdivided on page-size maps. Unless otherwise noted, all the rocks are porphyritic and have a fine-grained groundmass. The following discussion is greatly condensed from summary papers by Irving (1899), Jaggar (1901), Darton and Paige (1925), Armour (1975), Karner (1981), and Lisenbee (1981). Individual works are referenced in the following sections.

Bear Butte

The small stock or laccolith at Bear Butte, northeast of Sturgis (pl. 1), is composed of rhyolite (included in map unit Tq, pl. 1) containing phenocrysts of oligoclase and biotite in a fine-grained groundmass of potassium feldspar. It intrudes and strongly deforms Paleozoic and Mesozoic strata (DeWitt, 1973). Biotite from the stock has a K-Ar date of 52.1±1.5 Ma (McDowell, 1971).

Vanocker Laccolith

The Vanocker laccolith, south of Sturgis and east of Galena (pl. 1, fig. 13), is composed of two main rock types, quartz latite(?) shown as unit Tql in figure 13 and trachyte(?) shown as unit Tt in figure 13. The quartz latite(?) is composed of phenocrysts of oligoclase, biotite, and amphibole in a fine-grained groundmass of potassium feldspar and minor quartz (Anna, 1973; Rockey, 1974; and Matthews, 1979) and occurs in a laccolith, as much as 1,300 ft thick, that intrudes strata from the Deadwood Formation through the Pahasapa Limestone. Biotite from the quartz latite(?) has a K-Ar date of 57.2±1.7 Ma (McDowell, 1971). An initial $^{87}Sr/^{86}Sr$ ratio of 0.7058 was determined for a sample of the quartz latite(?) by Olson (1976).

Trachyte(?) intrudes the quartz latite(?) as two small stocks on the northwestern edge of the laccolith and is composed of phenocrysts of oligoclase and amphibole in a groundmass of potassium feldspar and minor quartz. A small magnetic low (Meuschke, Philbin, and Petrafeso, 1962) above the western trachyte(?) body could be due to reverse magnetization of the trachyte, minor alteration, or a low magnetite content compared to the quartz latite(?).

Darton and Paige (1925) showed the two intrusive bodies along Deadman Gulch north of the main Vanocker laccolith as monzonite, but they are subdivided into quartz latite(?) and trachyte(?) in this report.

Gilt Edge Mine Area

The oldest Tertiary intrusive rocks in the Gilt Edge mine area west of Galena (fig. 13) are trachy-andesite, latite, and quartz latite(?) described by Mukherjee (1968), Grunwald (1970), and Beck (1976). These rocks are not separated in figure 13, all being shown as unit Tl. The trachy-andesite consists of andesine and hornblende phenocrysts in a matrix of plagioclase, hornblende, and potassium feldspar. The latite and quartz latite(?) consist of phenocrysts of oligoclase, sanidine, and hornblende in a fine-grained matrix of potassium feldspar and minor quartz and plagioclase. Hornblende and biotite from different parts of the trachy-andesite have K-Ar dates of 61.9±3.0 and 60.3±1.8 Ma, respectively (Mukherjee, 1968; McDowell, 1971). A sample of one of the above rock types from the Gilt Edge mine area has an initial $^{87}Sr/^{86}Sr$ ratio of 0.7059 if an age of 60 Ma is assumed for the body (Olson, 1976).

The quartz latite(?) underlying Dome Mountain and Pillar Peak (map unit Tql) north of Galena is a laccolithic sheet that is 120–640 ft thick and intrudes rocks from the Deadwood Formation to the Minnelusa Formation. An east-northeast-trending band of trachyte (unit Tt) that intrudes the quartz latite(?) consists of phenocrysts of oligoclase, sanidine, and minor quartz in a fine-grained groundmass of potassium feldspar. At the western end of the band of trachyte, near the Gilt Edge mine, two small rhyolite(?) stocks (unit Tr) intrude the trachyte and quartz latite(?). The stocks are extensively hydrothermally altered and contain disseminated auriferous pyrite.

Phonolite (unit Tp, fig. 13) sills that intrude the quartz latite(?) and Deadwood Formation and Pahasapa Limestone along Two Bit Creek (Kirchner, 1971) are the easternmost exposed phonolite in the northern Black Hills. The phonolite contains phenocrysts of anorthoclase and aegirine-augite in a groundmass of potassium feldspar, nepheline, analcime, and various alteration products. Trachy-basalt dikes that may be related to these phonolites cut all rock units in the Galena area but are not shown in figure 13.

Whitewood Peak Area

Sills and discordant masses of rhyolite (unit Tr, fig. 13) and quartz trachyte (unit Tqt, fig. 13) intrude the Ordovician and Cambrian strata at Whitewood Peak and strata as young as the Minnelusa Formation farther east (Boyd, 1975). The rhyolite consists of very sparse albite phenocrysts in a fine-grained matrix of albite, quartz, and potassium feldspar. It contains anomalously high barium concentrations, many greater than 1,200 ppm. The quartz trachyte consists of phenocrysts of anorthoclase in a matrix of potassium feldspar and minor quartz and plagioclase. It contains 140–500 ppm rubidium and 70–90 ppm thorium.

One sill-like mass of phonolite (unit Tp) containing phenocrysts of aegirine-augite, andesine and minor nepheline and sphene in a groundmass of plagioclase and orthoclase intrudes the Pahasapa Limestone south of Whitewood Peak (fig. 13).

Roubaix Area

Northwest of Roubaix, a small area shown with map symbol Tr (fig. 13) contains intrusive rhyolite(?), flow breccia, lithic tuff beds, and obsidian (Darton, 1909; Runner, 1957; Drake, 1967; and Kirchner, 1977) that have been variously interpreted as evidence for a major volcano or a volcanic pipe having collapse features. Potassium-argon and fission-track dating by Redden and others (1983) reveal that the obsidian is 56–60 Ma and that the volcaniclastic rocks probably formed in a collapsed pipe during Paleocene to Eocene intrusive activity.

The largest magnetic low in the Black Hills, a north-northwest-trending asymmetric feature that is 1,500 gammas lower than the surrounding terrane, extends south from the volcanic pipe for more than 4 mi (Meuschke, Philbin, and Petrafeso, 1962). The magnetic low cannot be explained by the surface exposures of Precambrian schist, but part of the eastern side of the negative anomaly coincides with a fault that juxtaposes metamorphosed shale on the west and metamorphosed graywacke on the east. Kleinkopf and Redden (1975) indicate a very small gravity high in the northern part of the magnetic low, but no large gravity anomalies over the rest of the magnetic low. The magnetic and gravity features could be explained by a large, reversely polarized or highly altered Tertiary or Precambrian pluton in the subsurface whose density would be similar to the schist at the surface.

Englewood Area

Rhyolite(?), latite(?), and phonolite intrude the Deadwood Formation in the area near Englewood (fig. 14) and to the north and east as sills and a small laccolith. The rhyolite(?) forms a large sill in the southeastern part of the area shown in figure 14 (map unit Tr) and is in contact with latite(?) west of the Gilt Edge mine (fig. 13). South of the area of figure 14 the rhyolite(?) forms a laccolith as much as 600 ft thick in the Woodville Hills (Usiriprisan, 1979). It consists of phenocrysts of orthoclase replaced by quartz, sanidine, strongly resorbed quartz, oligoclase, and biotite, with accessory garnet, in a fine-grained groundmass. The replacement of feldspar by quartz is similar to alteration noted in alkali rhyolite in the Bald Mountain–Ragged Top Mountain area that is discussed in a following section.

The Woodville Hills appear to be underlain by a conduit that fed the laccolith and much of the sill to the northeast. A magnetic dipole over the laccolith (Meuschke, Philbin, and Petrafeso, 1962) inverts to a small magnetic low when the aeromagnetic data are reduced to the modern-day pole (M. D. Kleinkopf, unpub. data, 1985). The small low suggests that the rhyolite contains very little magnetite, has been reversely magnetized, or is altered in its source conduit.

North of Englewood, the latite(?) forms a 100-ft-thick sill in the Deadwood Formation east of Sugarloaf Mountain (Jumnongthai, 1979). It consists of phenocrysts of oligoclase, potassium feldspar, quartz, and biotite in a groundmass of plagioclase and potassium feldspar.

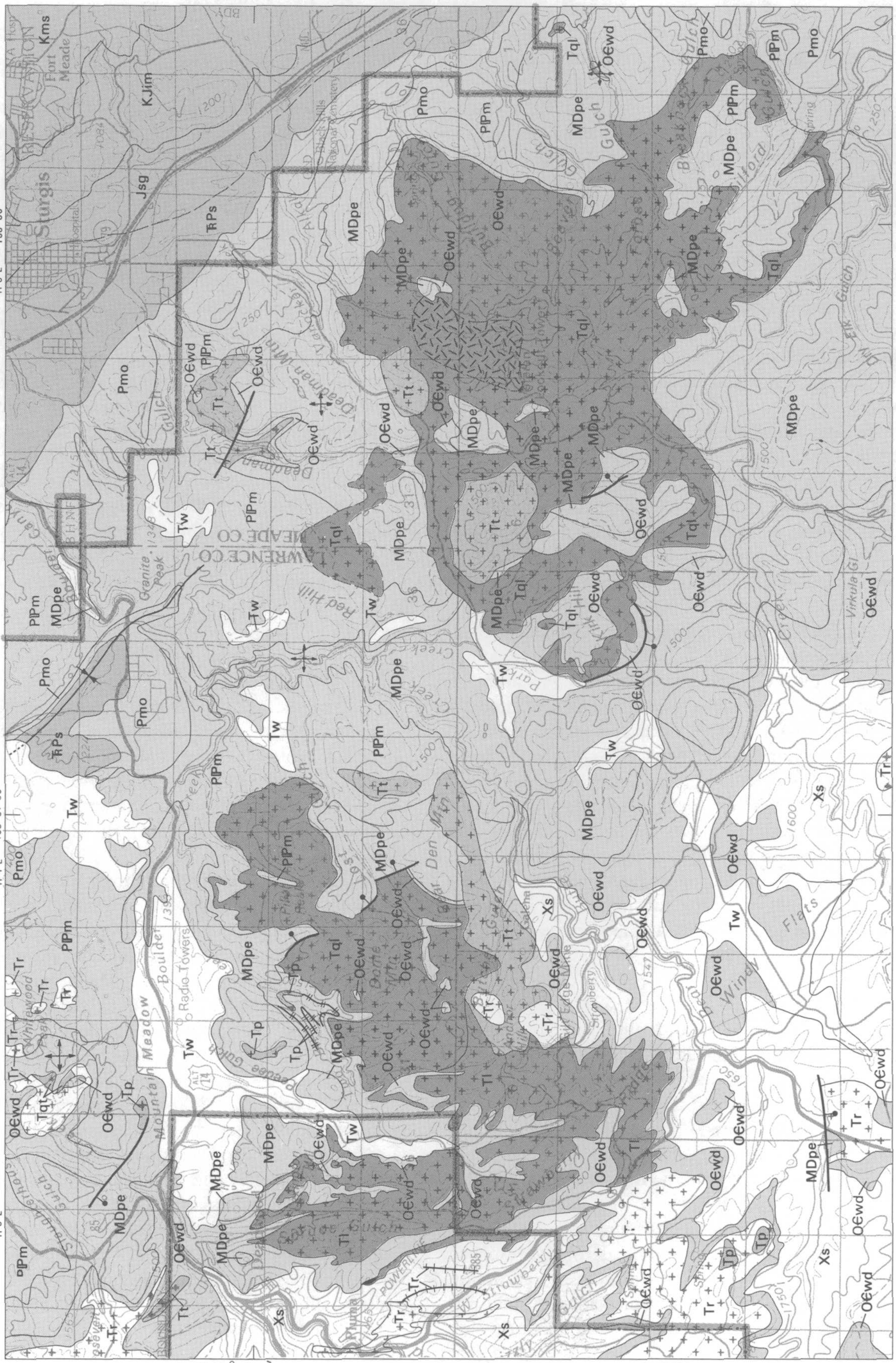
On Sugarloaf Mountain and extending to the south is a discontinuous sheet of phonolite that intrudes the Deadwood. The sheet ranges in thickness from 255 ft to less than 90 ft and cuts down-section to the north into the Proterozoic basement. The phonolite contains phenocrysts of orthoclase, aegirine, nepheline, and leucite in a groundmass of alkali feldspar, aegirine, various feldspathoids, albite, and sphene. Sill-like bodies of phonolite have also been noted south of Whitewood Creek near Kirk and in the far southeastern corner of the area of figure 14.

Bald Mountain–Ragged Top Mountain Area

This area has the greatest diversity of Tertiary igneous rocks in the Lead–Deadwood region, containing phonolite, latite, trachyte(?), quartz trachyte, and alkali rhyolite. Phonolite sills (unit Tp, fig. 14) intrude the Deadwood Formation and Ordovician strata along Squaw Creek and Annie Creek and at Green Mountain (Kirchner, 1971). The Squaw Creek sill is 50–150 ft thick, the five sills along Annie Creek total about 600 ft in thickness, and the Green Mountain sill is about 120 ft thick. A phonolitic laccolith having a minimum thickness of 370 ft was emplaced in the Pahasapa Limestone at Ragged Top Mountain. These rocks are similar mineralogically to other bodies of phonolite described above. The phonolite sills at Green Mountain, near Trojan (fig. 14), have initial $^{87}Sr/^{86}Sr$ ratios that range between 0.7051 and 0.7055 (Olson, 1976).

Latite (map unit Tl) was emplaced as a discordant body into Cambrian through Mississippian strata northeast of Ragged Top Mountain, where it consists of phenocrysts of andesine, orthoclase, biotite, and hornblende in a groundmass of plagioclase and minor quartz (Irving, 1899). The latite most closely resembles latite(?) and trachy-andesite near the Gilt Edge mine described by Mukherjee (1968). Other bodies of latite intrude the Deadwood as sills south of Bald Mountain (fig. 14).

Quartz trachyte (map unit Tqt) is the most widespread rock type between Bald Mountain and Twin Peaks. It intrudes the Deadwood as one to three sill-like


Sturgis
Fort Meade
Red Hill
Granite Peak
Boulder
Deadman
Dead Man Mtn
Bulldog Gulch
Flats
Radio Towers
MEADE CO
LAWRENCE CO
R 3 E
R 4 E
R 5 E
103°37'30"
103°30'
T 5 N
T 4 N
44° 22' 30"
0
1
2
3
4
5 MILES

EXPLANATION

Tw — **White River Group (Oligocene)**—Tuffaceous claystone and clay containing minor limestone lenses

Tp — **Phonolite (Eocene and Paleocene)**—Sills, laccoliths, and dikes of analcime-rich phonolite

Tr — **Rhyolite (Eocene and Paleocene)**—Dikes, plugs, sills, and laccoliths of quartz-rich rhyolite

Tqt — ***Quartz trachyte (Eocene and Paleocene)***—Sills, laccoliths, and dikes of quartz trachyte

Tql — **Quartz latite(?) (Eocene and Paleocene)**—Sills and laccoliths of hornblende quartz latite(?) and biotite quartz latite(?). Pattern indicates area containing hydrothermally altered material. Large body in eastern part of map area is Vanocker laccolith

Tl — **Latite (Eocene and Paleocene)**—Sills of hornblende latite

Tt — **Trachyte(?) (Eocene and Paleocene)**—Sills, dikes, and plugs of trachyte and trachyte porphyry

Kms — **Mowry Shale, Newcastle Sandstone, and Skull Creek Shale (Lower Cretaceous)**—Mowry Shale: siliceous shale containing thin bentonite layers. Newcastle Sandstone: sandstone and siltstone containing beds of bentonite and lignite. Skull Creek Shale: black shale

KJim — **Inyan Kara Group (Lower Cretaceous) and Morrison Formation (Upper Jurassic)**

Inyan Kara Group—Fall River Sandstone: sandstone and minor siltstone. Lakota Formation: claystone and sandstone containing locally interbedded limestone and lignite lenses

Morrison Formation—Siliceous claystone and shale

Jsg — **Sundance Formation (Upper and Middle Jurassic) and Gypsum Spring Formation (Middle Jurassic)**—Sundance Formation: glauconitic sandstone and shale. Gypsum Spring Formation: massive gypsum and minor claystone

ŦPs — **Spearfish Formation (Triassic and Permian)**—Shale, siltstone, and gypsum

Pmo — **Minnekahta Limestone and Opeche Shale (Lower Permian)**—Minnekahta Limestone: slabby limestone. Opeche Shale: sandy shale

PIPm — **Minnelusa Formation (Lower Permian and Pennsylvanian)**—Sandstone, solution breccia (anhydrite in subsurface), limestone, and shale

MDpe — **Pahasapa Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)**—Pahasapa Limestone: cavernous dolomitic limestone. Englewood Formation: dolomitic limestone

O€wd — **Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**—Whitewood Dolomite: dolomite. Winnipeg Formation: shale and siltstone. Deadwood Formation: sandstone, shale, and limestone

Xs — **Metasedimentary and metavolcanic rocks (Early Proterozoic)**—Undivided Ellison Formation, Flag Rock Formation, Grizzly Formation, and unnamed age-equivalent strata

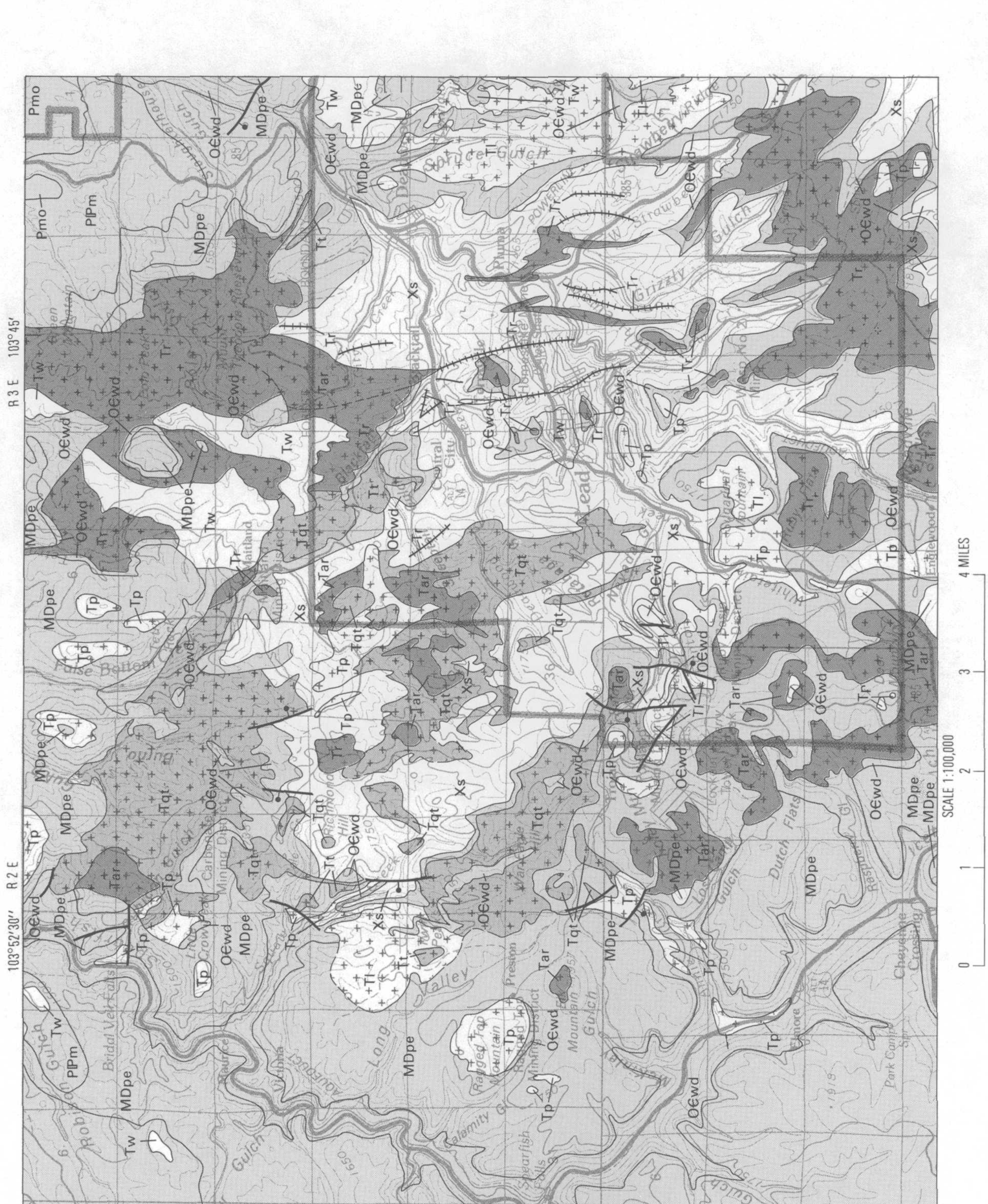
Contact—Dashed where approximately located

Fault—Bar and ball on downthrown side

Syncline—Axis dotted where concealed

Dome

Figure 13. Geologic map of the Galena area, Black Hills National Forest, S. Dak. Geology from Darton and Paige (1925), Beck (1976), Matthews (1979), Anna (1973), Rockey (1974), Gasser (1981), G. M. French (unpub. mapping, 1984), Mukherjee (1968), Boyd (1975), Bayley (1972a), and Lisenbee (1985). Base from U.S. Geological Survey, Rapid City, 1977.



R1E
R2E
R3E
103°52'30''
103°45'
T5N
T4N
44° 22' 30''
SCALE 1:100,000
0
1
2
3
4 MILES
Lead
Central City
Long Valley
False Bottom Creek
Spruce Gulch
Strawberry Ridge
Grizzly
Dutch Flats
Eleven Mile
Prospect Gulch
Breakneck Gl
Timber
Cheyenne Crossing
Englewood
Spearfish Falls
Roughlock Falls
Ragged Top Mountain
Cabin Springs
Jay Spring
Tollgate Flats
Robinson Gulch
Bridal Veil Falls
Calamity Gulch
Squaw Creek
Tinton

EXPLANATION

Tw	**White River Group (Oligocene)**—Tuffaceous claystone and clay containing minor limestone lenses
Tp	**Phonolite (Eocene and Paleocene)**—Sills, laccoliths, and dikes of analcime-rich phonolite
Tar	**Alkali rhyolite (Eocene and Paleocene)**—Sills, laccoliths, and dikes of aegirine-bearing alkali rhyolite
Tr	**Rhyolite (Eocene and Paleocene)**—Dikes, plugs, sills, and laccoliths of leucocratic rhyolite
Tl	**Latite (Eocene and Paleocene)**—Dikes, plugs, and small stocks of biotite latite
Tqt	**Quartz trachyte (Eocene and Paleocene)**—Sills, laccoliths, and dikes of quartz trachyte
Tt	**Trachyte (Eocene and Paleocene)**—Sills, dikes, and plugs of trachyte, trachyte porphyry, and syenite
Pmo	**Minnekahta Limestone and Opeche Shale (Lower Permian)**—Minnekahta Limestone: slabby limestone. Opeche Shale: sandy shale
PIPm	**Minnelusa Formation (Lower Permian and Pennsylvanian)**—Sandstone, solution breccia (anhydrite in subsurface), limestone, and shale
MDpe	**Pahasapa Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)**—Pahasapa Limestone: cavernous dolomitic limestone. Englewood Formation: dolomitic limestone
O€wd	**Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**—Whitewood Dolomite: dolomite. Winnipeg Formation: shale and siltstone. Deadwood Formation: sandstone, shale, and limestone
Xs	**Metasedimentary and metavolcanic rocks (Early Proterozoic)**—Undivided Poorman Formation, Homestake Formation, Ellison Formation, Northwestern Formation, Flag Rock Formation, Grizzly Formation, and unnamed age-equivalent strata

Contact—*Dashed where approximately located*

Fault—Bar and ball on downthrown side

Figure 14. Geologic map of the Bald Mountain area, Black Hills National Forest, S. Dak. Geology from Darton and Paige (1925), Irving (1899), Noble, Harder, and Slaughter (1949), Heidt (1977), Sofranoff (1979), Usiriprisan (1971), Jumnongthai (1979), Larsen (1977), Shapiro and Gries (1970), Fisher (1969), G. M. French (unpub. mapping, 1984), Kirchner (1971), and Lisenbee (1985). Base from U.S. Geological Survey, Rapid City, 1977.

masses that split and coalesce to form a composite sill ranging in thickness from 100 to more than 150 ft. The rock consists of phenocrysts of sanidine, microcline, and albite in a groundmass of quartz, orthoclase, and biotite. Quartz is normally strongly resorbed. One small area of trachyte(?) (unit Tt) at Twin Peaks, northeast of Ragged Top Mountain, appears to have been emplaced as a sill-like body in the latite.

Alkali rhyolite (map unit Tar) constitutes the volumetrically largest intrusive in the area. It was emplaced as a composite sill-like mass that intrudes the upper parts of Deadwood, the Ordovician strata, and the Pahasapa Limestone on Foley Mountain, Terry Peak, and Deer Mountain (fig. 14). The sill-like mass is a minimum of 90 ft thick, and exceeds 400 ft in thickness in a few places. The alkali rhyolite consists of phenocrysts of sanidine and orthoclase in all stages of replacement by quartz, aegirine-augite, and minor quartz in a groundmass of quartz, alkali feldspar partially replaced by quartz, aegirine-augite, and albite. Aegirine from near Terry Peak has a K-Ar date of 58.5±4.3 Ma (McDowell, 1971).

A magnetic dipole (Meuschke, Philbin, and Petrafeso, 1962) located over an area 0.5 mi south of Richmond Hill (fig. 14, near center) reverts to a prominent magnetic low when the magnetic data are reduced to the modern-day pole (M. D. Kleinkopf, unpub. data, 1985). The low probably is not caused by Proterozoic metabasaltic units that normally are associated with small magnetic highs. Rather, it may be caused by a small stock in the subsurface that is reversely magnetized or highly altered.

Carbonate Area

Quartz trachyte (Tqt) is the most common intrusive rock in the Carbonate area (fig. 14), where it is flanked by sills of phonolite on the west and north and by a body of alkali rhyolite(?) north of Rubicon Gulch. The quartz trachyte is a sill-like mass that intrudes the Deadwood Formation on its south side and the Pahasapa Limestone on the north. It is composed of anorthoclase, orthoclase, perthite, aegirine, quartz, and minor biotite in a groundmass of alkali feldspar (Parkhill, 1976; Sofranoff, 1979), similar to quartz trachyte in the War Eagle Hill area 4 mi to the south. Parkhill (1976) indicates that the quartz trachyte contains anomalously high concentrations of barium (1,600–2,000 ppm) and zirconium (390–700 ppm).

The body of alkali rhyolite north of Rubicon Gulch is similar to the aegirine-bearing alkali rhyolite in the Terry Peak region 6 mi to the south. The phonolite at Little Crow Peak, southwest of Rubicon Gulch, is a 200-ft-thick sill-like body in the Pahasapa. Spearfish Peak appears to be underlain by a phonolitic laccolith that has a minimum thickness of about 600 ft. A phonolite sill less than 100 ft thick intrudes the Pahasapa between Burno Gulch and False Bottom Creek (fig. 14, north-central part of area). All bodies of phonolite have mineralogies similar to those described above.

Upper False Bottom Creek Area

The intrusive rocks in this area west of Lead (fig. 14) are known collectively as the Cutting stock (Noble, Harder, and Slaughter, 1949). The stock is not coherent but rather consists of myriad dikes and sills that coalesce to create a complex intrusive body of quartz trachyte, alkali rhyolite, and phonolite.

Quartz trachyte is the oldest and most extensive rock unit (Larsen, 1977); it is compositionally similar to quartz trachyte in the Carbonate and War Eagle Hill area, but appears to contain 5–10 percent primary amphibole that is extensively replaced by alteration products. The quartz trachyte contains anomalous concentrations of rubidium (300–400 ppm), barium (900–4,600 ppm), and zirconium (as much as 460 ppm), and moderately high concentrations of niobium (40–60 ppm).

Alkali rhyolite that intrudes quartz trachyte is mineralogically similar to alkali rhyolite in the Terry Peak area but contains less aegirine-augite and traces of biotite. Concentrations of rubidium, barium, and zirconium are slightly above average for the rocks of rhyolitic composition, but are not as anomalous as in the quartz trachyte.

A northwest-trending dike and sill complex of phonolite that intrudes both of the above rock types has a composition and mineralogy similar to other bodies of phonolite. Olson (1976) determined an initial $^{87}Sr/^{86}Sr$ ratio of 0.7048 for the body. The phonolite has high strontium concentrations (2,800–3,200 ppm) as compared to values of 800–1,500 ppm for the phonolite at Green Mountain.

A prominent magnetic low (Meuschke, Philbin, and Petrafeso, 1962) over the eastern margin of the Cutting stock may be due partly to the emplacement of Tertiary bodies at depth and partly to the presence of the Ellison Formation, a presumed nonmagnetic basement rock unit.

Maitland Area

The region northeast of Maitland (north of Lead) contains the greatest amount of rhyolite(?) in the Lead-Deadwood area (fig. 14). Lesser amounts of quartz trachyte, trachyte(?), and phonolite also are present. Near Maitland and north of Central City the rhyolite(?) intrudes the middle part of the Deadwood Formation as a laccolithic body composed of three or more sills (Heidt, 1977), but to the north it cuts up section into the Minnelusa Formation. The three sills have a minimum thickness of about 1,000 ft; the laccolith probably was 1,500 ft thick. The rhyolite(?) body south of Mount Theodore Roosevelt is shown to be in contact with a body of alkali rhyolite(?). The rhyolite(?) contains sparse phenocrysts of altered alkali feldspar, plagioclase, and biotite in a sericitized groundmass of alkali feldspar, plagioclase, and quartz. Biotite from one of these rhyolite bodies has a K-Ar date of 50.6±1.5 Ma (McDowell, 1971). A sample of alkali rhyolite from near Mount Theodore Roosevelt has an initial $^{87}Sr/^{86}Sr$ ratio of 0.7059 and an anomalously high Rb/Sr ratio of 4.52 (Olson, 1976).

Quartz trachyte forms two small laccoliths about 400–600 ft thick along False Bottom Gulch northwest of Maitland and along Blacktail Creek southeast of Maitland. Both bodies intrude the basal part of the Deadwood Formation. Mineralogy of the quartz trachyte is similar to that of bodies in the Carbonate area to the west, except that the quartz trachyte contains more plagioclase and traces of biotite. Trachyte(?) is exposed in a 150-ft-thick sill in the basal part of the Deadwood Formation north of Central City. Phonolite sills that are a minimum of 300 ft thick intrude the Pahasapa Limestone at Tetro Rock, northwest of Maitland.

A small magnetic high that trends north from Blacktail toward Polo Peak could be due in part to a magnetite-rich phase of the rhyolite(?) or to basement rocks older than the Poorman Formation.

Homestake Mine Area

Noble (1948) described both low-potassium and high-potassium siliceous dikes in the Homestake mine at Lead (fig. 14) that are rhyolite and alkali rhyolite, respectively. The alkali rhyolite contains 10–12 percent K_2O and very little Na_2O; the rhyolite contains between 5 and 6 percent K_2O and 2–4 percent Na_2O. Both types of rhyolite are shown with map symbol Tr on figure 14. Similar high-potassium dikes were noted on the eastern margin of the Cutting stock (Parkhill, 1976). Phonolite dikes cut both varieties of rhyolite dikes. Slightly altered biotite from a phonolite dike in the Homestake mine has a K-Ar date of 58.2±1.7 Ma (McDowell, 1971).

Tinton Area

Precambrian schist and lower Paleozoic rocks in the Tinton area (fig. 11) are intruded by north-northwest-trending dikes and a sill or laccolith complex of latite-andesite, quartz latite, quartz trachyte, and trachyte, all of which are shown as quartz trachyte (unit Tqt). The laccolith complex intruded the basal part of the Deadwood Formation near the center of the area, but reached nearly into the Minnelusa Formation on the northeast side of the uplift. Thickness of the laccolith varies considerably, but is a maximum of about 400 ft. The basement rocks were uplifted in a domal fashion, leading Ray (1979) to conclude that the area may be underlain by a stock. The quartz trachyte contains phenocrysts of oligoclase to andesine, altered amphibole, and minor biotite and aegirine-augite in a groundmass of orthoclase and minor quartz (Welch, 1974; Ray, 1979). The most evolved rocks in the area sampled by Ray (1979) are trachyte found 1 mi west of Tinton.

Centered around Welcome, 2 mi southwest of Tinton, is a zoned ring-dike complex (Welch, 1974) that appears to intrude the quartz trachyte. The ring complex is composed of an outer shell of nepheline syenite (unit Tn), an incomplete inner ring of pyroxenite and diorite (unit Tpx), and a central area of feldspathoidal breccia (unit Tfx). The entire ring complex is slightly less than 2 mi in diameter. The nepheline syenite consists of equal amounts of sanidine-orthoclase and pyroxene, lesser amounts of nepheline, variable amounts of plagioclase, and accessory amphibole, garnet, sphene, biotite, and hauyne. The pyroxenite consists of pyroxene and accessory ilmenite-magnetite, apatite, biotite, and nepheline. The diorite consists of phenocrysts of plagioclase, amphibole, and pyroxene in a groundmass of plagioclase. The feldspathoidal breccia contains leucite, pyroxene, nepheline, hauyne, garnet, and a variety of accessory minerals.

A very large magnetic dipole (Union Carbide Corp., 1982) is centered over the ring-dike complex. Much of the dipole remains after the magnetic data are reduced to the modern-day pole (M. D. Kleinkopf, unpub. data, 1985). Concentrations of ilmenite-magnetite in the pyroxenite are believed to cause the positive part of the dipole.

At Citadel Rock, in the northeastern part of the area of figure 11, a quartz trachyte(?) intruded the basal part of the Deadwood Formation and locally cut into the Minnelusa Formation on its northeast side (Fisher, 1969). The quartz trachyte(?) is composed of phenocrysts of albite and altered amphibole in a groundmass of orthoclase and quartz.

Black Buttes Area

Three rock types occur as laccoliths and sills in the Black Buttes area, southeast of Sundance (pl. 1). Trachyte(?) is shown on plate 1 as unit Tq, and nepheline syenite and phonolite are shown as unit Tn. The trachyte(?) is a composite laccolith that intrudes the upper part of the Deadwood Formation and up section into the Minnelusa Formation (Elwood, 1979). Smaller bodies of trachyte(?), some containing as much as 95 percent alkali feldspar, intrude rocks as young as the Spearfish Formation. Nepheline syenite and phonolite cut the trachyte(?) and form small laccoliths in the Spearfish and in the older dikes and sills. The trachyte(?) bodies contain anomalous concentrations of thorium and potassium as indicated by airborne radiometric surveys (EG&G geoMetrics, 1979a, b). Augite from one phonolite body has a K-Ar date of 55.6±2.2 Ma (McDowell, 1971).

Inyan Kara Mountain

A stock-like mass of trachyte(?) intrudes rocks as young as the Inyan Kara Group at Inyan Kara Mountain, southwest of Black Buttes (pl. 1) and strongly deforms the sedimentary cover. The trachyte(?) is composed of phenocrysts of oligoclase partially mantled by orthoclase, aegirine-augite, and altered hornblende in a groundmass of alkali feldspar and quartz. Anomalous concentrations of uranium, thorium, and potassium were noted over the intrusive by airborne radiometric surveys (EG&G geoMetrics, 1979a, b).

Bear Lodge Mountains Area

Trachyte, high-potassium trachyte, quartz trachyte, phonolite, and minor rhyolite and carbonatite occur as sills, laccoliths, dikes, and possibly as stocks in the Bear Lodge Mountains, north of Sundance (pl. 1, fig. 7). The outlying parts of the area will be described first, followed by the intrusive core of the range.

Sundance Mountain, just south of Sundance, was originally interpreted to be a laccolith that intrudes the Jurassic Sundance Formation (Darton, 1905). However, Fashbaugh (1979) suggested that the rhyolitic rocks (unit Tr, fig. 7) that make up the mountain are extrusive in origin, and are most likely welded tuff beds. The rhyolite consists of phenocrysts of oligoclase in a fine-grained groundmass.

On the west side of the Bear Lodge Mountains (pl. 1) are several sills that intrude rocks as young as the Cretaceous Fall River Sandstone (Pillmore and Mapel, 1963). The largest sill is a trachyte(?) shown in figure 7 as unit Tt and composed of phenocrysts of alkali feldspar, sanidine, aegirine-augite, and nepheline in a groundmass of alkali feldspar.

Closer to Warren Peaks, along Kruse Canyon and Houston Creek, (fig. 7), sills of phonolite and trachyte intrude the Paleozoic strata (Fashbaugh, 1979; O'Toole, 1981; Wilkinson, 1982). The phonolite (unit Tp) contains phenocrysts of sanidine, aegirine-augite, sodalite, and sphene in a groundmass of orthoclase and aegirine. The trachyte contains the same phenocrysts and groundmass minerals, but it contains melanite garnet instead of sodalite.

On the northwest side of the Bear Lodge Mountains, between Hershey and Winchester Creeks, White (1980) noted sills of trachyte and phonolite intruding rocks ranging in age from the Pahasapa Limestone to the Sundance Formation. The phonolite sills are similar to those at Warren Peaks described by O'Toole (1981). The trachyte sills, however, contain the iron-rich amphibole ferrohastingsite, in addition to the usual phenocrysts of sanidine, oligoclase, anorthoclase, and aegirine.

The core of the Bear Lodge Mountains has been studied by Staatz and others (1979), Wilkinson (1982), Staatz (1983), and Jenner (1984), who indicate that the intrusive rocks are predominantly trachyte, high-potassium trachyte, and minor amounts of carbonatite, all of which are cut by late phonolite dikes. The core may have a slightly more calcic rim on the southwest side and may grade into a latitic composition as suggested by Wilkinson (1982). Elsewhere the core consists of trachyte (unit Tt, fig. 7) containing phenocrysts of sanidine, albite, altered hastingsite, and salite in a groundmass of sanidine, albite, and anorthoclase. The high-potassium trachyte (shown approximately by the distribution of unit Tkf, fig. 7) has been suggested by Jenner (1984) to be a product of potassic alteration, or fenitization. It has the same mineralogy as the trachyte, but contains more sanidine and accessory strontian calcite, fluorite, barite, brookite, pyrite, pyrrhotite, and chalcopyrite. Locally, the groundmass of the high-potassium trachyte consists of as much as 15 percent carbonate minerals.

Carbonatite dikes not shown in figure 7 cut the trachyte and high-potassium trachyte and consist of strontian calcite, strontianite, barite, siderite, other accessory minerals of the high-potassium trachyte, and a suite of rare-earth-rich fluocarbonate minerals that includes bastnaesite, synchysite, ancylite, burbankite, and carbocernaite. Calcite from the carbonatite dikes has carbon and oxygen isotope ratios typical of primary igneous carbonatites (Jenner, 1984).

McDowell (1971) dated two mixtures of hornblende and pyroxene from trachyte near Warren Peaks that have K-Ar dates of 39.7 ± 2.1 and 50.1 ± 1.6 Ma. Staatz (1983) reported three K-Ar sanidine dates ranging from 48.8 ± 1.7 to 50.5 ± 1.2 Ma for trachyte and dikes that cut trachyte in the core of the Bear Lodge Mountains. If these three dates of 49–50 Ma are correct, the 39.7-Ma date reported by McDowell must be in error. Staatz also reported a K-Ar sanidine date of 38.3 ± 0.6 Ma for a phonolite along Bear Den Canyon. This date appears to be anomalously young.

The entire core of the Bear Lodge Mountains contains anomalous concentrations of thorium, potassium, and uranium that have been mapped by Staatz (1983) and have been detected by airborne radiometric surveys (EG&G geoMetrics, 1979a, b).

Gravity data for the vicinity of the Bear Lodge Mountains are sparse (U.S. Dept. of Defense, Defense Mapping Agency, unpub. data, 1985); the raw data show a large gravity high east of Warren Peaks, but M. D. Kleinkopf (written commun., 1985) suggests that the data may be in error. A small gravity high outlines the dome between Hershey and Winchester Creeks (fig. 7).

Aeromagnetic data (Union Carbide Corp., 1982) indicate that the entire Bear Lodge Mountains uplift is coincident with a large aeromagnetic high that has a minimum amplitude of 300 gammas. This high is the southern end of a very large area of magnetic highs (Bendix Field Engineering Corp., 1982d) that trends south from lat 46°30′ (50 mi north of the Montana state line) and terminates at the latitude of Sundance. Much of the anomaly must be a response to Proterozoic and Archean basement rocks, but some may be related to both buried and exposed Tertiary intrusive rocks rich in magnetite.

Devils Tower and Missouri Buttes

The spectacular Devils Tower, west of the Bear Lodge Mountains (pl. 1), has been interpreted to be an erosional remnant of a laccolith or a volcanic neck (Jaggar, 1901; Halvorson, 1980). Devils Tower consists of phonolite containing phenocrysts of anorthoclase, aegirine-augite, and sphene in a groundmass of albite, microcline, analcime, aegirine, nepheline, and nosean. A breccia at the base of the tower, described by Jaggar as an agglomerate and by Halvorson as an alloclastic breccia, contains rocks of diverse lithology, from Precambrian basement to Cretaceous sedimentary rocks, in a matrix of glass and fine-grained igneous material. Bassett (1961) determined a 41.5±1.6 Ma date for alkali feldspar from Devils Tower. Hill, Izett, and Naeser (1975) determined a fission-track date of 53.3±6.8 Ma for sphene from the phonolite, which probably is a better estimate for the age of the intrusive.

Missouri Buttes, west of Devils Tower (pl. 1), appear to be eroded volcanic necks composed of phonolite and trachy-phonolite similar in mineralogy to the phonolite at Devils Tower (Halvorson, 1980). Alloclastic breccia is also present at Missouri Buttes and 0.5 mi west of the buttes. Its composition is similar to the breccia at the base of Devils Tower, but it also contains xenoliths of carbonatite(?). McDowell (1971) determined a K-Ar date of 50.8±1.7 Ma for aegirine from Missouri Buttes. Hill, Izett, and Naeser (1975) determined a fission-track date of 55.5±7.1 Ma for sphene from one of the intrusive bodies at Missouri Buttes. Missouri Buttes stands out as a thorium, potassium, and uranium radiometric high relative to the surrounding sedimentary rocks (EG&G geoMetrics, 1979a, b).

Quaternary Rocks

Deposits of Quaternary age include alluvial material in stream bottoms, terrace deposits of gravel, landslide material, and minor deposits of windblown sand. Only the alluvial material is shown on plate 1, as unit Qu. Terrace gravel and landslide material are not shown on plate 1, but terrace gravel is included in unit QTu on plates 2 and 3. The alluvial material consists of gravel, sand, and silt deposited in stream beds throughout the Black Hills. The thickest accumulations (as much as 150 ft) are commonly in large streams that overlie rocks of Mesozoic or younger age. Older strata tend to form deep, sinuous canyons that do not collect large amounts of alluvium. However, streams draining all rock types in the Black Hills, from Archean to Tertiary, contain some alluvial material. Terrace gravel of Quaternary age is most common on the eastern flank of the Black Hills, where it overlies Cretaceous shale on most east-trending drainage divides (pls. 2 and 3). Landslide material is common on steep slopes underlain by rocks of Cretaceous age, particularly the Inyan Kara Group. Windblown sand is restricted to the area south of Edgemont and the area near Oelrichs.

Structure

The Black Hills uplift, 175 mi long and 90 mi wide, is an anticlinal upwarp in the continental interior province. The uplift was formed in Laramide time (about 60–65 Ma) and has been exhumed from a thin cover of sediments (White River Group) since late Oligocene time. The uplift is nearly flat on top and is bounded by monoclines on the west and east (Darton, 1902, 1904a, 1905; Darton and Smith, 1904; Darton and O'Harra, 1907, 1909; and Darton and Paige, 1925). Noble, Harder, and Slaughter (1949) and Shapiro (1971) noted that the uplift actually consists of a western, structurally lower block, and an eastern, structurally higher, block separated by the Fanny Peak monocline (pl. 1). The two most recent and comprehensive reviews of the Phanerozoic structural history of the region are by Lisenbee (1978, 1985), from which much of this summary is taken.

Western Block

The western block is bounded on the west by the Black Hills monocline, a flexure that has an average amplitude of 3,500 ft. The monocline extends from north of Moorcroft (pl. 1) to near Newcastle, where it terminates against the Fanny Peak monocline, the eastern boundary of the western block. A maximum of 4,000 ft of additional structural relief is gained on the western block east of the Black Hills monocline, the highest structural point being near the Wyoming–South Dakota state line in the vicinity of Buckhorn. The maximum structural relief on the western block is about 9,000 ft.

Subsidiary structures on the western block consist of domes caused by emplacement of Eocene-Paleocene igneous rocks, and anticlines and synclines of relatively minor importance. Structural uplift around intrusive centers is greatest in the Bear Lodge Mountains (pl. 1), which have about 2,400 ft of structural relief. The structural uplift around Tinton is about 2,000 ft. Much smaller domes, such as those in the Black Buttes and at Green Mountain, typically have less than 500 ft of structural relief. A great number of small domes, only a few of which are shown on plate 1, are present northwest of the Bear Lodge Mountains, between the Belle Fourche and Little Missouri Rivers. These are thought to be underlain by small Tertiary intrusive bodies similar to those near Sundance.

Eastern Block

The eastern block is bounded by the Fanny Peak monocline on the west, a flexure that increases in amplitude from north to south. Near Buckhorn, on the Wyoming-South Dakota state line, the monocline has only about 500 ft of structural relief. Near Newcastle, the amplitude increases to about 1,700 ft, and about 30 mi south of Newcastle the amplitude is at least 3,400 ft. The eastern boundary of the eastern block is a homoclinal dip slope interrupted by small, discontinuous monoclines and anticlines. A maximum of an additional 7,000 ft of structural relief is gained on the eastern block east of the Fanny Peak monocline. Maximum structural relief on the eastern block is about 10,000 ft.

The northern and southern margins of the eastern block are characterized by north-trending paired anticlines and synclines not found on the western block. The anticline is consistently on the east side of the syncline and normally has a greater amplitude than does the syncline. Most anticlines are asymmetric, having steep western limbs and more gently dipping eastern limbs. These structures have been described by Lisenbee (1978) as monoclines opposed to the regional dip of the eastern block. Paired anticline-synclines (all synclines are unnamed) on the northern margin (from west to east) are the LaFlamme anticline, the Belle Fourche anticline, and the Whitewood anticline. Paired anticline-synclines on the southern margin (from west to east) are the Old Woman anticline, the Mule Creek anticline and Mule Creek–Bush Creek syncline, the Chilson anticline, the Cascade anticline, and the Dudley anticline. The northern anticlines are 20–40 mi long and have maximum amplitudes of 400 to about 1,200 ft. The southern anticlines have comparable lengths but slightly greater amplitudes of 1,000–2,000 ft, although the Dudley anticline has only a 500-ft amplitude.

Subsidiary structures in the eastern block include domes formed by intrusion of Tertiary igneous bodies and monoclines on the eastern flank of the block. Domes in the eastern block have less structural relief than those in the western block. The relief on the dome in the Lead-Deadwood area is only about 1,000 ft, and that on the Vanocker laccolith only about 900 ft. Smaller domes, such as those at Bear Butte and Elkhorn Mountain, have structural relief comparable to the small domes in the western block. The two most prominent monoclines on the eastern flank of the eastern block are the Whitegate and Buffalo Gap monoclines, both of which have about 1,500 ft of structural relief.

Timing and Deformational Processes

Laramide deformation of the Black Hills occurred after deposition of the Upper Cretaceous Lance Formation and before intrusion of the Tertiary igneous rocks in the northern Black Hills. The Lance is about 63–66 Ma (Obradovich and Cobban, 1975; Lanphere and Jones, 1978), and the oldest dated intrusives are about 60 Ma. Paleocene clastic sediments in the Powder River Basin were derived from the rising Black Hills uplift (Love, 1960). Most of the uplift must therefore have taken place between 60 and 65 Ma.

The process that formed the uplift was described by Lisenbee (1978) as predominantly vertical uplift and drape folding (Stearns, 1971), but the large-scale features described above, especially the paired anticline-synclines on the northern and southern margins of the eastern block, suggest horizontal compression and low-angle faulting of the basement. Such low-angle faulting has been suggested by Berg (1962, 1981) and proven for the Laramide deformation of the Wind River Range in Wyoming (Smithson and others, 1979; Lynn, Quam, and Thompson, 1983) and has been proposed for the Laramie Mountains in Wyoming (Brewer and others, 1982; Johnson and Smithson, 1985). The Black Hills may well have been formed by low-angle faulting that was manifested at the surface by monoclinal flexures and asymmetric anticline-syncline pairs. If so, the asymmetry of these features suggests that major low-angle faults beneath the Black Hills would dip to the east.

MINERAL RESOURCES—LOCATABLE COMMODITIES

Locatable commodities include all minerals and products subject to exploration, development, and production under the Federal General Mining Law of 1872. Most metals and industrial minerals are included in this group and are considered in this section.

History of Mining and Exploration

Some prospecting and minor production of placer gold may have begun as early as 1834 in the northern Black Hills, but large-scale placer operations and the location of the first lode claims did not take place until 1874, when gold was discovered along French Creek near Custer, S. Dak. Since then, mines of diverse kinds have produced metallic and nonmetallic products from the Black Hills that are valued at more than $17 billion at 1983 prices (Norton, 1975a; Aase, 1977, 1980, 1981, 1982, 1983; Aase and LaTour, 1981; Aase and Steece, 1978, 1979; Aase and Wallace, 1978; Aase, West, and Steece, 1981).

Placer gold has been produced from present-day stream beds and from Tertiary gravel deposits throughout the Black Hills area, and possibly from Cambrian sandstone. Few mining districts were established in the area of placer deposits, the most famous being the Rockerville district northeast of Keystone, the Hurricane district on

Sand Creek northwest of Tinton, and part of the Deadwood district on Whitewood Creek northeast of Deadwood (Hill and Lindgren, 1912). Most of the placer operations have been discontinued either because of marginal operating profits or because of negative environmental impacts on the streams. Gold and cassiterite are sporadically produced from small placer workings in the northern Black Hills near Deadwood and Tinton.

Small vein deposits of Early Proterozoic age containing gold, silver, and minor amounts of base metals were discovered in the central Black Hills soon after the discovery of placer deposits. Mining districts that included these vein deposits were concentrated northwest of Custer, near Hill City and Keystone, east of Rochford, and in the Roubaix area southeast of Deadwood, and included the Junction, Chilkoot, Hill City, Keystone, Redfern, Silver City, and Mystic districts. Most vein deposits ceased production of metallic products in the 1930's, but exploration continues for these deposits in areas of poor outcrop and in environments not previously considered favorable.

Lode gold was discovered in the Lead area in 1876 in what was to be recognized as the Western Hemisphere's largest deposit in the Homestake mine. The Lead mining district was established soon after this discovery. Gold and minor amounts of silver have been produced from Early Proterozoic iron-formation for more than 100 years at Homestake. Other smaller deposits similar to the Homestake were subsequently discovered in the Keystone and Rochford areas, in the Keystone and Rochford (Amphibolite) districts, respectively, but none of the deposits is currently producing precious metals. Exploration for auriferous iron-formation is very active in the Black Hills area.

Pegmatite deposits containing tin, tantalum, beryl, lithium, feldspar, mica, and other commodities were discovered as early as 1880 in the Tinton and Harney Peak regions. Mining districts including the Harney Peak, Keystone, Hill City, Custer, and Pringle districts that produced pegmatite products literally surrounded Harney Peak, from Keystone on the east to Hill City on the north to Custer on the south. Although only minor amounts of tin and tantalum have been produced from the pegmatite deposits, major amounts of feldspar, mica, and lithium have been produced, most actively during the First and Second World Wars. Feldspar is currently produced from several mines in the area. Within the last 15 years the pegmatite deposits have been increasingly utilized for their semiprecious gemstones and mineral specimens.

Vein and replacement deposits associated with Tertiary intrusive rocks in the area around Lead were discovered in the late 1870's, soon after the deposit in the Homestake mine was located. The largest established mining districts west of Lead included Maitland, Carbonate, Ragged Top, Portland (Bald Mountain), and Ruby Basin. Districts east of Lead and near Deadwood included Yellow Creek, Deadwood, and Two Bit. Farther southeast, near Galena, the Galena and Strawberry Gulch districts were established. In the Black Hills, production of precious metals from these deposits is second only to that from the Homestake mine. Much ore had been produced from these deposits by the 1920's, but the largest mines continued to produce precious metals until the late 1960's. Small mines continue to produce gold and silver from such deposits, and exploration for low-grade, porphyry-type deposits is very actively pursued in the northern Black Hills.

Paleozoic limestone in the area was a source of lime and a flux for smelters during the late 1890's and early 1900's, and later was recognized as a raw material for the production of cement. The South Dakota State Cement Plant at Rapid City has for 60 years produced cement that is made from high-calcium limestone quarried in the Black Hills.

Gypsum has been mined from the area since the late 1880's, but only a small amount has been produced, principally for plaster of paris and an additive in cement. The State Cement Plant at Rapid City is the principal producer of gypsum in the Black Hills.

Iron has been known in the Black Hills area since the early 1890's but little has been produced since the late 1920's. Iron occurs as detrital accumulations in the basal Paleozoic rocks, in taconitic iron-formation, and in bog-iron deposits in modern stream bottoms. The largest producer of iron in the Black Hills area is the State Cement Plant, which uses the iron as an additive in the production of cement.

Uranium was discovered in the southern Black Hills in the early 1950's and in the far northwestern Black Hills soon after that. The Edgemont mining district was organized in the late 1950's and most of the uranium and vanadium produced in the Black Hills area through the middle 1970's was produced from that district. Uranium was discovered in Early Proterozoic rocks in the Nemo area in 1977 but none has been produced from that area.

Thorium and uranium were known to occur in the Bear Lodge Mountains by the middle 1950's, but rare-earth elements were not discovered in the area until later, and their occurrence was not well documented until the early 1980's. Presently, exploration for carbonatite-related deposits containing base and precious metals and rare-earth elements is active in the northern Black Hills.

Metals

The Black Hills area has a great variety of deposits that contain base, precious, and ferrous metals. Types of deposits and metals contained in them are briefly summarized below. A letter designation (A, B, and so on) for various types of deposits is used in the following section on resource potential and on plate 2.

A. Archean(?) and Proterozoic taconitic iron-formation are stratiform metasedimentary deposits that were formed in a submarine environment about 2.2–2.5 Ga. Iron and silica were concentrated in sedimentary rocks by volcanic or chemical processes.

B. Proterozoic quartz-pebble conglomerate bodies are stratiform metasedimentary accumulations that were formed in a shallow-water fluvial environment about 2.2 Ga. Uranium, thorium, and minor amounts of gold and chromium were concentrated in sedimentary rocks by sedimentologic processes and movement of low-temperature fluids.

C. Proterozoic carbonate-, silicate-, and sulfide-facies iron-formation units are syngenetic stratiform deposits formed in a submarine environment about 1.8–2.1 Ga. Gold and arsenic and minor amounts of silver were concentrated in sedimentary and volcaniclastic rocks by biologic, sedimentologic, or hydrothermal processes.

D. Proterozoic veins and shear zones are discordant deposits formed in a metamorphic and tectonic environment about 1.6–1.9 Ga. Hydrothermal solutions concentrated gold, silver, lead, and minor amounts of zinc, copper, and arsenic in metasedimentary rocks.

F, G, J. Proterozoic pegmatite bodies were formed in an igneous and metamorphic environment about 1.6–1.8 Ga. Late-stage magmatic products of the Harney Peak Granite concentrated lithium, beryllium, tin, tungsten, and tantalum in the surrounding metamorphic rocks and the granite. Large deposits of feldspar and muscovite-rich rock were similarly formed in the granite. Type F deposits are pegmatite bodies rich in tin and tungsten, type G deposits are rich in lithium, and type J are rich in beryllium.

K. Proterozoic pyrite-rich slate is a possible stratabound deposit formed in a reducing environment about 1.7–2.0 Ga. Iron and carbon, and possibly gold and silver and minor amounts of vanadium, zinc, and copper, were concentrated in deep-water mud and silt.

L. Cambrian paleoplacers are bedded sedimentary deposits formed in a surface-weathering environment about 500 Ma. Rivers concentrated heavy detrital minerals, especially gold, along stream channels.

O. Roll-front deposits in Cretaceous rocks are stratabound accumulations of uranium and vanadium that were formed in a near-surface, locally reducing environment. Low-temperature, sodium sulfate- or sodium bicarbonate-rich fluids containing minor amounts of selenium and molybdenum moved down-dip through the host rocks and precipitated ore minerals in carbon-rich horizons.

P. Bog-iron deposits are colluvial concentrations of iron-rich material found in stream bottoms and along canyon walls that are being formed in the present-day surface-weathering environment. Cool, moist conditions and locally reducing environments concentrate the iron and minor manganese.

Q. Tertiary and Holocene placers are bedded sedimentary deposits formed in a terrestrial environment by rivers and streams transporting and concentrating heavy minerals, especially gold and cassiterite, in stream channels.

R. Cambrian colluvium is a stratabound deposit formed in a surface-weathering environment about 500 Ma. Extensive weathering and minimal transport of the underlying Proterozoic rocks resulted in iron-rich accumulations of debris and fine-grained material near the base of the Cambrian strata.

S, T. Vein and replacement deposits occur predominantly in Paleozoic strata as discordant to concordant bodies containing base and precious metals. Mineralization took place in an epithermal environment about 50–60 Ma by hydrothermal alteration and metallization of wall rocks near Tertiary intrusive bodies. Type S deposits are rich in base metals, containing lead, zinc, silver, and minor amounts of copper and gold. Type T deposits are rich in precious metals, containing gold and minor amounts of silver, lead, zinc, and copper.

U, V. Disseminated and porphyry-type deposits are fracture-filling, vein, and disseminated concentrations of base and precious metals formed in a plutonic to subvolcanic environment about 50–60 Ma. Fracturing and hydrothermal alteration of Tertiary quartz-normative igneous rocks resulted in precipitation of sulfide minerals rich in base and precious metals. Type U deposits are rich in base metals, containing molybdenum, lead, and minor amounts of silver and copper. Type V deposits are rich in precious metals, containing gold, copper, and minor amounts of silver and lead.

W, X, Y. Disseminated and carbonatite deposits are fracture-filling, vein, and disseminated concentrations of base, precious, and rare-earth-element metals formed in a plutonic to subvolcanic environment about 50–60 Ma. Fracturing and metasomatic alteration of Tertiary alkalic igneous complexes and associated carbonatite resulted in precipitation of sulfide and carbonate minerals. Type W deposits are rich in thorium, containing thorium, manganese, and minor amounts of uranium. Type X deposits are rich in rare-earth elements, containing lanthanum, cerium, other light rare-earth elements, lead, barium, strontium, and minor amounts of thorium and uranium. Type Y deposits are rich in precious metals, containing gold, tellurium, and minor amounts of silver.

Z. Phanerozoic vein deposits are discordant to concordant concentrations of base and precious metals formed in a tectonic environment about 65 Ma. Hydrothermal fluids rich in lead, zinc, and silver, and containing minor amounts of gold, deposited sulfide minerals in fissures created by uplift of the Black Hills.

Industrial Minerals

Pegmatite minerals, principally feldspar and mica, and high-calcium limestone and gypsum are found in the Black Hills area in the types of deposits described below. Because many pegmatite bodies contain both metallic and industrial minerals, they are included in this section as well. As was the case for metals described in the previous section, a letter designation (E, H, K, and so on) is used for various types of deposits.

E, H, I. Proterozoic pegmatite bodies were formed in an igneous and metamorphic environment about 1.6–1.8 Ga. Late-stage magmatic products of the Harney Peak Granite concentrated lithium, beryllium, tin, and tungsten in the surrounding metamorphic rocks and the granite. Large deposits of feldspar- and muscovite-rich rock were similarly formed in the granite. Type E deposits are rich in potassium feldspar; type H deposits are rich in potassium feldspar and mica; and type I deposits contain large amounts of mica.

K. Proterozoic schist is a bedded metamorphic deposit containing large amounts of muscovite. It was formed in a near-surface environment about 1.7–2.0 Ga by extreme weathering and leaching of metals in a subtropical to tropical setting. Aluminum was concentrated in a shale protolith that later was metamorphosed by the Harney Peak Granite. Volcanic contributions may have enriched the shale in potassium.

L. Cambrian paleobeach deposits are accumulations of bedded sedimentary material formed in a surface marine environment about 500 Ma. Wave action created concentrations of very clean, well-rounded silica sand.

M. High-calcium limestone is a bedded sedimentary deposit formed in a shallow-water marine environment about 250–350 Ma. Precipitation of calcium carbonate from seawater and accumulation of organisms rich in calcium carbonate created the deposits.

N. Gypsum is a bedded sedimentary evaporite deposit formed in shallow-water marine and surface environments about 250 Ma. Restricted basins of seawater evaporated in an arid climate to form deposits of salt, related minerals, and gypsum.

Resource Potential—Locatable Commodities

The resource potential of the Black Hills National Forest for locatable minerals was evaluated for 18 deposit types in rocks that range in age from Archean to Holocene (pl. 2, table 2). Table 2 is also reproduced in the text as an aid in following the discussion of each deposit type. In this section the characteristics of known and inferred deposits are briefly summarized and specific areas in and adjacent to the Forest having high, moderate, low, or unknown mineral resource potential are reviewed.

Table 2. Description of areas having mineral resource potential for locatable
[REE, rare-earth elements; level of potential/level of certainty explained in figure 25, Appendix 1; commodities listed

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
A1	High------	H/D	Fe (Ti)-------------------	Large, stratiform sedimentary.
A2	Moderate--	M/D	Fe (Ti)-------------------	Medium, stratiform sedimentary.
A3	Moderate--	M/D	Fe (Ti)-------------------	Medium, conglomeratic sedimentary.
A4	High------	H/D	Fe (Ti)-------------------	Large, conglomeratic sedimentary.
A5	Low-------	L/D	Fe (Ti, Au, Ag)-----------	Small, stratiform sedimentary.
A6	Low-------	L/D	Fe (Mn, Au, Ag, Cu)-------	Medium, stratiform sedimentary.
A7	High------	H/D	Fe (Mn, Ti)---------------	Medium, stratiform sedimentary.
A8	Low-------	L/D	Fe (Ti, Au)---------------	Small, stratiform sedimentary.
B1	Moderate--	M/D	U (Au)--------------------	Small-medium, conglomeratic sedimentary stratiform.
C1	High------	H/D	Au (Ag, As)---------------	Large, syngenetic stratiform.
C2	Moderate--	M/D	Au (Ag, As)---------------	Large, syngenetic stratiform.
C3	Moderate--	M/D	Au (Ag, As)---------------	Medium, syngenetic stratiform.
C4	Moderate--	M/D	Au (Ag, As)---------------	Large, syngenetic stratiform.
C5	Moderate--	M/D	Au (Ag, As)---------------	Small-medium, syngenetic stratiform.
C6	Unknown---	U/A	Au (Ag)-------------------	Size unknown, syngenetic stratiform.
C7	High------	H/D	Au (Ag, As)---------------	Medium, syngenetic stratiform.
C8	Moderate--	M/C	Au (Ag, As)---------------	Large, syngenetic stratiform.
C9	Moderate--	M/C	Au (Ag, Cu, As)-----------	Small, syngenetic stratiform.
C10	Moderate--	M/C	Au (Ag, As)---------------	Medium, syngenetic stratiform.
C11	Unknown---	U/A	Au (Ag, As)---------------	Medium-small, syngenetic stratiform.
C12	High------	H/D	Au (Ag, As, Cu, Mo)-------	Medium, syngenetic stratiform.
C13	Moderate--	M/C	Au (Ag, Cu)---------------	Small-medium, syngenetic stratiform.
C14	High------	H/C	Au (Ag, As)---------------	Small-medium, syngenetic stratiform.
C15	Moderate--	M/C	Au (Ag, As)---------------	Small, syngenetic stratiform.
C16	Moderate--	M/C	Au (Ag, As)---------------	Small-medium, syngenetic stratiform.
D1	Moderate--	M/D	Au, Ag (Cu)---------------	Small, vein or shear zone.
D2	Moderate--	M/D	Au, Ag, Pb (Zn, As)-------	Small-medium, vein.
D3	Low-------	L/C	Au, Ag--------------------	Small, vein or shear zone.
D4	Moderate--	M/D	Au, Ag (Zn)---------------	Small-medium, vein.
D5	Moderate--	M/C	Au, Ag (Pb, Sb)-----------	Small, vein or shear zone.
D6	Moderate--	M/C	Au, Ag (Cu)---------------	Small, vein.
D7	Moderate--	M/D	Au, Ag (As, Zn)-----------	Small, vein.
D8	Low-------	L/B	Au, Ag--------------------	Small, vein or shear zone.
D9	Moderate--	M/C	Au, Ag--------------------	Small, vein.
D10	High------	H/D	Au, Ag (As, Pb, Zn)-------	Small-medium, vein or shear zone.
D11	Low-------	L/D	Au, Ag--------------------	Small, vein.
EFGHIJ1	Moderate--	M/D	Feldspar, mica (pegmatite commodities).	Medium-small, pegmatite.
EFGHIJ2	Moderate--	M/C	Pegmatite commodities-----	Medium-small, pegmatite.
EGHIJ1	High------	H/D	Pegmatite commodities----- except Sn.	Small-medium, pegmatite.
EGHI1	High------	H/D	Feldspar, mica, Li-------- (pegmatite commodities except Sn, Be).	Small, pegmatite.
EGHJ1	High------	H/D	Pegmatite commodities----- except Sn and mica.	Small-medium, pegmatite.
EHIJ1	High------	H/D	Feldspar, mica, Be-------- (pegmatite commodities except Sn, Li).	Small, pegmatite.
F1	Low-------	L/D	W (Sn)--------------------	Small, skarn or vein.
FG1	High------	H/D	Sn, Li (W, Ta, pegmatite commodities).	Small, pegmatite.
FG2	High------	H/D	Sn, Li (W, Ta, Nb,-------- pegmatite commodities).	Small, pegmatite or quartz vein.
FG3	Moderate--	M/C	Sn, Li (pegmatite--------- commodities, W, Ta).	Small, pegmatite.
FGH1	Moderate--	M/D	Sn, Li, feldspar (W, Ta, pegmatite commodities).	Small, pegmatite.
K1	High------	H/D	Muscovite (magnetite,----- ilmenite).	Large, bedded metamorphic.
K2	Moderate--	M/C	Muscovite (magnetite,----- ilmenite).	Large, bedded metamorphic.
K3	Unknown---	U/A	Au, Ag, V, Cu-------------	Large, stratabound.
K4	Unknown---	U/A	Au, Ag, V, Cu-------------	Medium-small, stratabound or vein.
L1	Low-------	L/C	Au------------------------	Small-medium, paleoplacer.
L2	Moderate--	M/D	Au------------------------	Small, paleoplacer.
L3	Low-------	L/C	Au------------------------	Small, paleoplacer.
L4	Low-------	L/C	Au------------------------	Small, paleoplacer.
L5	Moderate--	M/D	Hydrafrac sand------------	Medium, paleobeach.
L6	Low-------	L/C	Hydrafrac sand------------	Medium, paleobeach.

resources in and adjacent to the Black Hills National Forest, S. Dak. and Wyo.
in order of relative importance; where variable sizes of deposits are shown, the most probable size is listed first]

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
M1	Moderate--	M/D	High-calcium limestone----	Medium, bedded sedimentary.
M2	High------	H/D	High-calcium limestone----	Large, bedded sedimentary.
M3	Moderate--	M/D	High-calcium limestone----	Large-medium, bedded sedimentary.
N1	High------	H/D	Gypsum--------------------	Medium, bedded sedimentary.
N2	Moderate--	M/D	Gypsum--------------------	Medium, bedded sedimentary.
O1	High------	H/C	U, V----------------------	Medium, stratabound.
O2	Moderate--	M/C	U, V----------------------	Medium-small, stratabound.
O3	High------	H/D	U, V----------------------	Medium, stratabound.
O4	Moderate--	M/B	U, V----------------------	Small-medium, stratabound.
O5	Moderate--	M/C	U, V----------------------	Medium-large, stratabound.
P1	Moderate--	M/D	Fe (Au)-------------------	Small-medium, colluvium.
Q1	Moderate--	M/C	REE, Mn, Th, Ti (Au,------ Pb, U).	Small-medium, placer.
Q2	Moderate--	M/D	Au, Sn, W, Ta-------------	Small, placer.
Q3	Moderate--	M/D	Au------------------------	Medium-small, placer.
Q4	Low-------	L/D	Au------------------------	Small-medium, placer.
Q5	Moderate--	M/D	Au------------------------	Small-medium, placer.
Q6	Moderate--	M/D	Au (Sn, Ta)---------------	Small, placer.
Q7	Low-------	L/C	Au------------------------	Small, placer.
Q8	Low-------	L/C	Au (Sn, W)----------------	Small-medium, placer.
R1	Moderate--	M/D	Fe------------------------	Medium-small, stratabound.
R2	Low-------	L/D	Fe------------------------	Small, stratabound.
S1	High------	H/D	Pb, Ag, Zn, Au (W)--------	Small-medium, vein or replacement.
S2	Low-------	L/C	Pb, Ag (Zn, Au)-----------	Small, replacement or vein.
S3	Moderate--	M/D	Pb, Zn (Ag, Au)-----------	Small, replacement.
S4	High------	H/D	Pb, Ag, Zn (Au)-----------	Medium-small, replacement or vein.
S5	Low-------	L/D	Pb, Zn (Ag)---------------	Small, replacement or vein.
T1	Low-------	L/B	Au, Ag (Th, U)------------	Small, vein.
T2	High------	H/D	Au, Ag, Mn, REE, Pb, Th--- (Ba, U).	Small-medium, vein or replacement.
T3	Moderate--	M/D	Au, Ag (Te, Cu)-----------	Small, vein or replacement.
T4	High------	H/D	Au, Ag (As, F, Te)--------	Medium, vein or replacement.
T5	Moderate--	M/D	Au, Ag (Te, As)-----------	Medium-small, vein or replacement.
T6	Moderate--	M/D	Au, Ag, W (As)------------	Small-medium, vein or replacement.
T7	Moderate--	M/C	Au, Ag (As, Te)-----------	Medium-small, vein or replacement.
T8	Low-------	L/B	Au, Ag (Pb, Zn)-----------	Small, vein or replacement.
T9	Moderate--	M/C	Au, Ag (Cu)---------------	Small, vein.
U1	High------	H/D	Mo, Cu (Ag, W, Pb)--------	Medium, disseminated or porphyry.
U2	Moderate--	M/C	Mo, Ag (Pb)---------------	Medium-small, disseminated.
U3	Moderate--	M/C	Mo, Cu (Ag, Pb, Zn)-------	Medium, disseminated.
U4	Moderate--	M/B	Mo, Cu (Ag, Pb, Zn)-------	Medium, disseminated.
U5	Low-------	L/B	Mo, Cu (Ag, Pb)-----------	Medium-small, disseminated.
UV1	Unknown---	U/A	Mo, Cu (Ag, Pb)-----------	Size unknown, vein or disseminated.
V1	Moderate--	M/B	Au, Ag (Th, U)------------	Medium-small, disseminated.
V2	High------	H/D	Au, Ag (Cu)---------------	Medium, disseminated or porphyry.
V3	High------	H/D	Au, Ag--------------------	Medium-small, disseminated or porphyry.
V4	Moderate--	M/C	Au, Ag (Cu)---------------	Small, disseminated or porphyry.
V5	Moderate--	M/D	Au, Ag (Pb, Zn)-----------	Medium-small, disseminated or porphyry.
V6	High------	H/D	Au, Ag (Pb, Te, F)--------	Medium, disseminated or porphyry.
V7	Moderate--	M/C	Au, Cu (REE)--------------	Small-medium, disseminated.
V8	Low-------	L/C	Au, Ag (Cu, Zn)-----------	Small, disseminated.
V9	Low-------	L/C	Au, Ag--------------------	Small, disseminated or breccia pipe.
W1	High------	H/D	Th, REE, Ba, Mn (U, P,---- Au, F, Ag).	Large, disseminated.
W2	Moderate--	M/B	Th, REE (Au)--------------	Small, disseminated.
WXY1	Unknown---	U/A	REE, Th, U, Au, Ag--------	Size unknown, disseminated or vein.
X1	High------	H/D	REE, Th, Ba, Mn (U, P,---- Au, F, Ag).	Large, disseminated.
Y1	High------	H/D	Au, Cu, Ag (REE)----------	Medium, disseminated or breccia pipe.
Y2	Low-------	L/C	Au, REE-------------------	Small, disseminated.
Y3	High------	H/D	Au, Fe, Cu (Ti, Mn)-------	Medium-small, disseminated.
Z1	Moderate--	M/D	Pb, Zn, Ag (Au, Cu)-------	Small, vein.

Definitions of terminology used, specifically the meaning of the several levels of resource potential, are in Appendix 1.

Specific areas having high, moderate, low, or unknown mineral resource potential are given a letter-number designation. As an example, all areas that have a resource potential for Archean(?) stratabound deposits, specifically iron-formation, are shown with a letter A and a number following the letter, such as A1, A2, A3, and so on. Each combined letter-number designation (A2, for example) indicates that the area has a specific resource potential (low, moderate, or high) for a restricted set of commodities occurring in a certain size and type of deposit. Sizes of deposits (small, medium, and large) are shown in table 4, Appendix 2. Area A1 therefore has a different potential than do areas A2, A3, and so on. All areas designated A1 have the same resource potential.

Plate 2 presents the information regarding high, moderate, low, and unknown resource potential for the entire Forest and adjacent area. However, where relationships are too complex to be portrayed at the scale of plate 2, detailed information is shown on one of the page-size maps that are shown as insets on plate 2 (figs. 15–24). The assessment sections in the following discussion direct the reader either to plate 2 or to one of the page-size maps for the most accurate portrayal of the mineral resource potential.

On plate 2, areas having high potential are shown in red, and areas having moderate potential are shown in pink. Areas of low potential that are discussed in the text are shown in red outline, and areas having unknown potential are shown by heavy, black dashed outlines. All other areas have been assigned low potential.

Archean(?) Stratabound Deposits

Banded Iron-Formation (A)

Commodities; Byproducts; and Trace Metals

Iron; byproduct titanium; trace manganese.

Host Rocks

Deposits are in Archean(?) taconitic banded iron-formation (map unit Xif, pl. 2), principally the Nemo Iron-formation. The most favorable units are those containing hematite, magnetite, limonite, goethite, and quartz. Less favorable units of iron-formation are those composed of iron-rich silicate minerals and sulfide minerals. Iron probably was deposited in the layers as colloidal gels rich in hematite; these were metamorphosed to iron-rich oxide and silicate minerals.

Structural Control

The thickness and extent of the iron-rich beds were determined by sedimentologic processes. The distribution of the iron-formation is strongly influenced by the isoclinal folding of the strata, which has also locally thickened or thinned the deposits.

Age

The metasedimentary rocks beneath the taconitic Nemo Iron-formation in the Nemo area are apparently intruded by the Little Elk Granite, which has been dated at 2.51±0.07 Ga (recalculated from data in Zartman and Stern, 1967). The Nemo Iron-formation is younger than the underlying strata but is inferred to be older than 2.51 Ga. All other iron-formation units in the Nemo area are apparently Proterozoic.

Deposit Description

Deposits range in size from thin beds that are only tens of feet thick and hundreds of feet long to the deposit in the Nemo Iron-formation east of Nemo that in places is more than 300 ft thick and extends along strike for more than 3 mi (Harrer, 1966; Redden, 1980). Ore minerals are predominantly hematite and magnetite and lesser amounts of limonite and goethite. Gangue includes quartz and various phyllosilicate minerals. Iron-rich silicate minerals, predominantly cummingtonite-grunerite, and sulfide minerals make up the iron-formation in areas assigned low mineral potential. Harrer (1966) estimated that more than 500 million tons of ore having an average iron content of 30 percent are present in the Nemo area. His estimate included all iron deposits of Archean and Proterozoic age. One-fourth to one-third of his total is probably contained in the Nemo Iron-formation.

Geochemical Signature

Samples of the taconitic iron-formation contain highly anomalous amounts of iron and slightly anomalous amounts of titanium (Harrer, 1966). The samples are not particularly enriched in manganese. The taconite contains very minor quantities of sulfur and phosphorus. Sample localities in the NURE (National Uranium Resource Evaluation Program) stream-sediment survey (Union Carbide Corp., 1980) are too widely spaced to be of help in the resource assessment. Many beds of iron-formation were oxidized during Cambrian or Tertiary time; these were among the sources of iron in residual concentrations in the basal units of the Deadwood Formation or in present-day creek bottoms.

Geophysical Signature

Most of the iron-formation, and especially the magnetite-rich taconite, contains enough magnetite to be magnetically anomalous with respect to the surrounding rocks. The taconite can be traced under the Phanerozoic cover in the Nemo area by following aeromagnetic highs (Kleinkopf and Redden, 1975; EG&G geoMetrics, 1980a, b; Bendix Field Engineering Corp., 1982c), but it does not contain anomalous concentrations of potassium, uranium, or thorium, so it is not locatable by aerial radiometric surveys (EG&G geoMetrics, 1980a).

Assessment Criteria

1. Presence of iron-formation in either oxide-, sulfide-, silicate-, or carbonate-facies rocks. Rocks of the oxide facies have the highest resource potential; rocks of the other facies can grade to the oxide facies along strike or down dip.

2. Presence of airborne and ground magnetic highs in areas of poor outcrop may suggest the presence of iron-formation.

3. Aeromagnetic anomalies having amplitudes too high to be due to metamorphosed basalt, gabbro, or magnetite-rich schist may indicate taconite deposits buried beneath Phanerozoic cover.

Assessment

Area A1.—This area (pl. 2 and fig. 15) contains the Nemo Iron-formation east of Nemo and has a high resource potential for large deposits containing iron and byproduct titanium (table, fig. 15). The Nemo Iron-formation is traceable for more than 3 mi along strike and has a probable thickness of 150–300 ft. Samples collected throughout this thickness average 30–40 percent iron (Harrer, 1966). The assignment of high resource potential is based on the presence of thick taconitic iron-formation and the past production of iron ore from the region (Nemo Iron Ore Company).

Area A2.—The probable extension of the known taconite deposits of area A1 under the Phanerozoic cover is shown as area A2 in figure 15. This area has been outlined by following aeromagnetic highs ascribed to the Nemo Iron-formation beneath the section of rocks from the Deadwood Formation through the Pahasapa Limestone. The area has a moderate potential for mediumsize deposits of iron in taconitic iron-formation.

Economic Significance

Taconite deposits are the major source of iron ore in the world and are expected to remain the major source for many years. The deposits in the Nemo Iron-formation have been used as a source of iron for the South Dakota State Cement Plant in Rapid City and contain about 25–33 percent of the iron resources in the Nemo area. Exploration and development of undiscovered deposits in area A2 will be more difficult and costly than in area A1 due to the overburden of sedimentary rocks.

Proterozoic Stratabound Deposits

Banded Iron-Formation (A)

Commodities; Byproducts; and Trace Metals

Iron; titanium; manganese, gold, copper, and molybdenum.

Host Rocks

Deposits are in Proterozoic banded iron-formation (map unit Xif, pl. 2) within the Boxelder Creek Formation and including the Benchmark Iron-formation (part of unit Xcq, pl. 1), the Estes Formation (part of unit Xc, pl. 1), the Rochford and Montana Mine Formations (within unit Xsi, pl. 1), and unnamed iron-formation in the Keystone and Custer areas. Deposits within the Benchmark are oxide-facies taconite similar to that in the Nemo Iron-formation, but are only locally preserved below an unconformity at the base of the Estes Formation. Those in the Boxelder Creek and Estes are conglomeratic taconite containing clasts of iron-formation in a matrix of iron-rich detritus. Deposits in the other units are in oxide-, silicate-, or sulfide-facies iron-formation. The most favorable units are those that contain hematite, magnetite, limonite, goethite, and quartz. Less favorable units of iron-formation are composed of iron-rich silicate minerals and sulfide minerals.

Structural Control

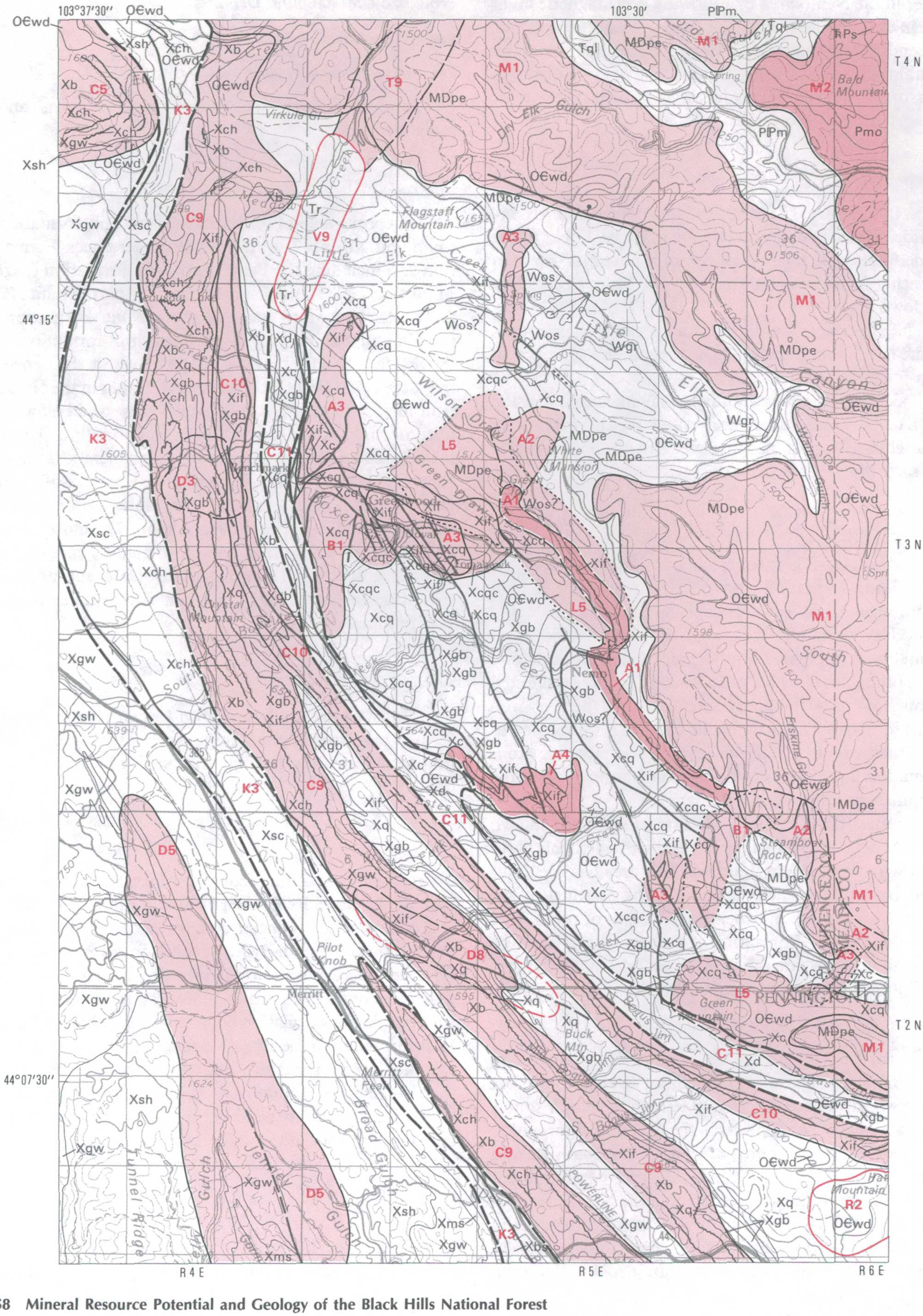
Most of the Proterozoic iron-formation is more deformed than the older taconite; isoclinal folding of the iron-formation has locally thickened or thinned the deposits.

Age

The oldest Proterozoic iron-formation, near the base of the Boxelder Creek Formation (unit Xcq, pl. 1), is a conglomeratic deposit composed of taconite clasts derived from the underlying Nemo Iron-formation. The Boxelder Creek Formation is intruded by gabbroic sills that are about 2.2 Ga, which places the age of the oldest Proterozoic iron-formation between 2.2 and about 2.5 Ga. Iron-formation in the Estes is younger than the gabbroic sills that intrude the Boxelder Creek Formation but older than the regional metamorphism in the Black Hills area, which is regarded to be about 1.7 Ga. The other Proterozoic iron-formation units in the Black Hills are regarded as between 1.7 and 2.2 Ga.

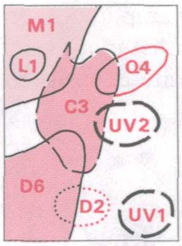
Deposit Description

Deposits range in size from thin beds that are tens of feet thick and thousands of feet long to ones that are



103°37'30''
103°30'
44°15'
44°07'30''
T 4 N
T 3 N
T 2 N
R 4 E
R 5 E
R 6 E
OЄwd
Xsh
Xch
Xb
C5
K3
Xgw
Tr
Xsc
C9
Xif
C10
Xq
Xgb
Xc
Xd
Xcq
A3
C11
D3
B1
Xcqc
T9
V9
M1
M2
MDpe
Tql
PIPm
Pmo
Bald Mountain
Virkula Gl
Flagstaff Mountain
Little Elk Creek
Little Elk Canyon
Wos
Wos?
Wgr
L5
A2
A1
A4
White Mansion
Green Draw
Wilson Draw
Greenwood
Tomahawk
Benchmark
Crystal Mountain
Nemo
South Boxelder Creek
Pilot Knob
Merritt
Merritt Peak
D5
D8
Buck Mtn
Steamboat Rock
LAWRENCE CO
MEADE CO
PENNINGTON CO
Green Mountain
Hat Mountain
R2
Broad Gulch
Jenney Gulch
Tunnel Ridge
POWERLINE
Xms
Xbs
Erskine Gl

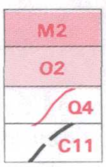
EXPLANATION



Areas having mineral resource potential—Boundaries are dashed or dotted where necessary to show limits of overlapping areas. Areas are labeled by letter and number corresponding to entries in the table below. Where two or more overlapping areas have different levels of potential, the overlapping area is colored to show the highest potential determined.

In the example at left C3 is an area of high mineral resource potential that is overlapped on the right by Q4, an area of low potential, and by UV2, an area of unknown potential. Area M1, which has moderate potential, overlaps area C3 and also contains an area of low potential, L1. Area D6, which has high potential, overlaps C3 and is overlapped by area D2, which has low potential. Area UV1 is an area of unknown potential.

The map must be used together with the table to interpret correctly the potential of overlapping areas



High mineral resource potential

Moderate mineral resource potential

Low mineral resource potential

Unknown mineral resource potential

Levels of resource potential

H High mineral resource potential

M Moderate mineral resource potential

L Low mineral resource potential

U Unknown mineral resource potential

Levels of certainty

D Data define geologic environment and level of resource potential and indicate resource-forming processes in all or part of the area

C Data partially define geologic environment and indicate a resource potential and indicate resource-forming process in some of the area

B Data partially define geologic environment and suggest level of resource potential

A Available data not adequate for evaluation of resource potential

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
A1	High------	H/D	Fe (Ti)--------------------	Large, stratiform sedimentary.
A2	Moderate--	M/D	Fe (Ti)--------------------	Medium, stratiform sedimentary.
A3	Moderate--	M/D	Fe (Ti)--------------------	Medium, conglomeratic sedimentary.
A4	High------	H/D	Fe (Ti)--------------------	Large, conglomeratic sedimentary.
B1	Moderate--	M/D	U (Au)---------------------	Small-medium, conglomeratic sedimentary stratiform.
C5	Moderate--	M/D	Au (Ag, As)----------------	Small-medium, syngenetic stratiform.
C9	Moderate--	M/C	Au (Ag, Cu, As)------------	Small, syngenetic stratiform.
C10	Moderate--	M/C	Au (Ag, As)----------------	Medium, syngenetic stratiform.
C11	Unknown---	U/A	Au (Ag, As)----------------	Medium-small, syngenetic stratiform.
D3	Low-------	L/C	Au, Ag---------------------	Small, vein or shear zone.
D5	Moderate--	M/C	Au, Ag (Pb, Sb)------------	Small, vein or shear zone.
D8	Low-------	L/B	Au, Ag---------------------	Small, vein or shear zone.
K3	Unknown---	U/A	Au, Ag, V, Cu--------------	Large, stratabound.
L5	Moderate--	M/D	Hydrafrac sand-------------	Medium, paleobeach.
M1	Moderate--	M/D	High-calcium limestone-----	Medium, bedded sedimentary.
M2	High------	H/D	High-calcium limestone-----	Large, bedded sedimentary.
R2	Low-------	L/D	Fe-------------------------	Small, stratabound.
T9	Moderate--	M/C	Au, Ag (Cu)----------------	Small, vein.
V9	Low-------	L/C	Au, Ag---------------------	Small, disseminated or breccia pipe.

LIST OF MAP UNITS

Tr Rhyolite (Eocene and Paleocene)

Tql Quartz latite(?) (Eocene and Paleocene)

ŦPs Spearfish Formation (Triassic and Permian)

Pmo Minnekahta Limestone and Opeche Shale (Lower Permian)

PIPm Minnelusa Formation (Lower Permian and Pennsylvanian)

MDpe Pahasapa Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)

O€wd Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)

Xsh Metasedimentary rocks (Early Proterozoic)

Xgw Metagraywacke (Early Proterozoic)

Xms Metasedimentary rocks (Early Proterozoic)

Xsc Metasedimentary rocks (Early Proterozoic)

Xgb Metagabbro (Early Proterozoic)

Xch Metachert (Early Proterozoic)

Xb Metabasalt (Early Proterozoic)

Xq Metaquartzite (Early Proterozoic)

Xd Metasedimentary rocks (Early Proterozoic)

Xc Metaconglomerate (Early Proterozoic)

Xif Iron-formation (Early Proterozoic)

Xcq Metaconglomerate and metaquartzite (Early Proterozoic)

Xcqc Metaconglomerate and metaquartzite (Early Proterozoic)

Wgr Granite (Late Archean)

Wos Older metasedimentary rocks (Late Archean)

Contact—Dashed where approximately located

Fault—Dashed where approximately located; dotted where concealed. Bar and ball on downthrown side; arrows show relative sense of displacement

SCALE 1:100,000

Figure 15 (above and facing page). Mineral resource potential map for locatable commodities in the Nemo area, Black Hills National Forest, S. Dak. Geology shown alone in figure 5. Base from U.S. Geological Survey, Rapid City, 1977.

as much as 500 ft thick and 1–2 mi long. Bayley (1970b) described in detail the taconite in the Benchmark Iron-formation and conglomeratic iron-formation in the Boxelder Creek Formation south-southwest of Nemo. He did not publish a tonnage for the deposit, but a conservative calculation based on his figures would indicate a minimum size of 150 million tons. Ore minerals are predominantly hematite and magnetite and lesser amounts of limonite and goethite. Gangue includes quartz and various phyllosilicate minerals. Iron-rich silicate minerals, predominantly cummingtonite-grunerite, sulfide and minor oxide minerals make up the iron-formation in areas assigned low mineral potential.

Geochemical Signature

Samples of the taconitic and conglomeratic iron-formation contain highly anomalous amounts of iron and slightly anomalous amounts of titanium (Harrer, 1966). The samples are not particularly enriched in manganese. The taconite contains very minor quantities of sulfur and phosphorus. Gold, arsenic, and rare molybdenum occur in some of the iron-formation. Sample localities in the NURE stream-sediment survey (Union Carbide Corp., 1980) are too widely spaced to be of help in the resource assessment. Many beds of iron-formation were oxidized during Cambrian or Tertiary time; these were among the sources of residual concentrations of iron in the basal units of the Deadwood Formation or in the present-day creek bottoms.

Geophysical Signature

Most of the Proterozoic iron-formation, and especially the magnetite-rich taconite, contain considerable magnetite and hence are magnetically anomalous with respect to the surrounding rocks. Because the Proterozoic deposits tend to be smaller than the Archean(?) deposits, however, the resulting magnetic anomalies may be smaller. Iron-formation can be traced under the Phanerozoic cover or through areas of poor outcrop by following aeromagnetic highs (Kleinkopf and Redden, 1975; EG&G geoMetrics, 1980a, b; Bendix Field Engineering Corp., 1982c). The taconite does not contain anomalous concentrations of potassium, uranium, or thorium so is not locatable by aerial radiometric surveys (EG&G geoMetrics, 1980a).

Assessment Criteria

1. Presence of iron-formation in either oxide-, sulfide-, silicate-, or carbonate-facies rocks. Rocks of the oxide facies have the highest resource potential; rocks of the other facies may grade to the oxide facies along strike or down dip.
2. Presence of airborne and ground magnetic anomalies in areas of poor outcrop may suggest iron-formation in the subsurface.
3. Aeromagnetic anomalies having amplitudes too high to be due to metamorphosed basalt, gabbro, or magnetite-rich schist may indicate taconite deposits in areas of poor outcrop.

Assessment

Area A3.—Five areas that have a moderate potential for medium-size conglomeratic iron-formation deposits containing iron are shown in figure 15. The areas are (1) on the western side of the Little Elk Granite, (2) north and east of Benchmark, (3) west of Tomahawk, (4) southwest of Steamboat Rock, and (5) southeast of Steamboat Rock.

Outcrops of conglomeratic iron-formation in the area along the western side of the Little Elk Granite indicate that units of iron-formation in the Boxelder Creek Formation may be 30–100 ft thick and extend for at least 1 mi along strike and even farther underneath cover of Phanerozoic rocks.

The area north and east of Benchmark contains both the Benchmark Iron-formation and conglomeratic iron-formation in the Estes Formation. The conglomeratic unit is folded and thickened in a northeast-plunging, overturned anticline. The combined thickness of both units ranges from 135 to more than 800 ft. Iron-formation is continuously exposed for about 2 mi along strike and in faulted slices.

West of Tomahawk the Boxelder Creek Formation contains conglomeratic iron-formation units that range in thickness from 100 to 500 ft. The iron-formation has been tightly to openly folded and plunges steeply.

Southwest of Steamboat Rock, conglomeratic iron-formation within the Boxelder Creek Formation ranges in thickness from 100 to more than 400 ft and can be traced along strike for about one-third of a mile.

In the area southeast of Steamboat Rock, conglomeratic iron-formation in the Estes Formation is about 100 ft thick and projects beneath Phanerozoic cover to the north and south.

Area A4.—South-southwest of Nemo and north of Estes Creek (fig. 15), the Benchmark Iron-formation is overlain by conglomeratic iron-formation in the Estes Formation (Redden, 1980). Bayley (1970b) described the distribution of iron-rich rocks and concluded that the area contained a large deposit of iron ore. The combined thickness of taconite and conglomeratic taconite in the area varies from 100 to 900 ft. The easternmost outcrop of iron-formation covers an irregularly shaped area about 1,200 ft by 1,700 ft. Conservative estimates of the amount of iron ore in the area, based on Bayley's (1970b) data, suggest a minimum amount of 150 million tons. The area has a high potential for a large deposit of iron.

Area A5.—This area in the Rochford region (pl. 2

and fig. 16) is assigned a low potential for a small deposit of iron. The one identified low-grade deposit occurs in the highly folded nose of an anticline in the Rochford Formation, in silicate- and sulfide-facies iron-formation. The area is assigned a low resource potential due to the difficulty of beneficiating iron contained in silicate minerals.

Area A6.—South of Sheridan Lake (pl. 2, fig. 17), area A6 has a low potential for a medium-size deposit. The iron-formation in the region is mostly sulfide and silicate facies; it contains anomalous concentrations of copper, silver, gold, and molybdenum (Raymond, King, and Norton, 1975; Raymond, 1981), which might be byproducts of iron production.

Area A7.—This area, southeast of Mount Rushmore (fig. 17), contains a large unit of oxidized sulfide-facies iron-formation that has been studied by Harrer (1966). He estimated that iron-formation in the vicinity of Iron Mountain contains about 750,000 tons of ore averaging 30–60 percent iron. Most of the iron is contained in limonite, hematite, and goethite, but some is contained in sulfide minerals within the iron-formation. The oxidation is largely a result of Cambrian or Tertiary weathering of sulfide-facies iron-formation and the unit covers a relatively large area; however, it probably does not extend to great depths. This area has a high potential for a medium-size deposit.

Area A8.—Iron-formation in an area east of Custer (pl. 2) has a low potential for an iron resource in a small deposit. The iron-formation in this area is chiefly composed of silicate- and sulfide-facies rocks.

Economic Significance

Iron deposits within the Proterozoic rocks contain approximately the same amount of hematite and magnetite as do the older taconite deposits. Harrer's (1966) estimate of more than 500 million tons of iron ore in the Nemo area indicated that about one-half to two-thirds of that total would be in the Proterozoic deposits described above. These deposits can be expected to be a potential major source of iron for many years. The deposits containing silicate-, sulfide-, and carbonate-facies iron-formation are much less valuable because the iron cannot be economically recovered with present technology. The iron deposit in area A7 is within sight of Mount Rushmore National Memorial, and it is doubtful whether this deposit would ever be utilized.

Quartz-Pebble Conglomerate Deposits (B)

Commodities; Byproducts; and Trace Metals

Uranium; gold; thorium and chromium.

Host Rocks

Deposits are stratabound in Proterozoic metamorphosed conglomerate, fanglomerate, and shale of the Boxelder Creek Formation (unit Xcq, pls. 1 and 2). Uranium, thorium, gold, and detrital minerals are concentrated in certain conglomerate units. Uraniferous conglomerate is restricted to lenses within the Boxelder Creek Formation and is not found in the younger Estes Formation as originally thought (Bayley, 1972b; Hills, 1977).

Structural Control

The uraniferous lenses or tongues of the Boxelder Creek Formation have been folded and intensely faulted, but the mineralized material has not been leached from its original stratabound position nor redistributed along faults. Faulting has offset and thinned many of the units of the Boxelder Creek Formation, so that exploration for deposits is difficult.

Age

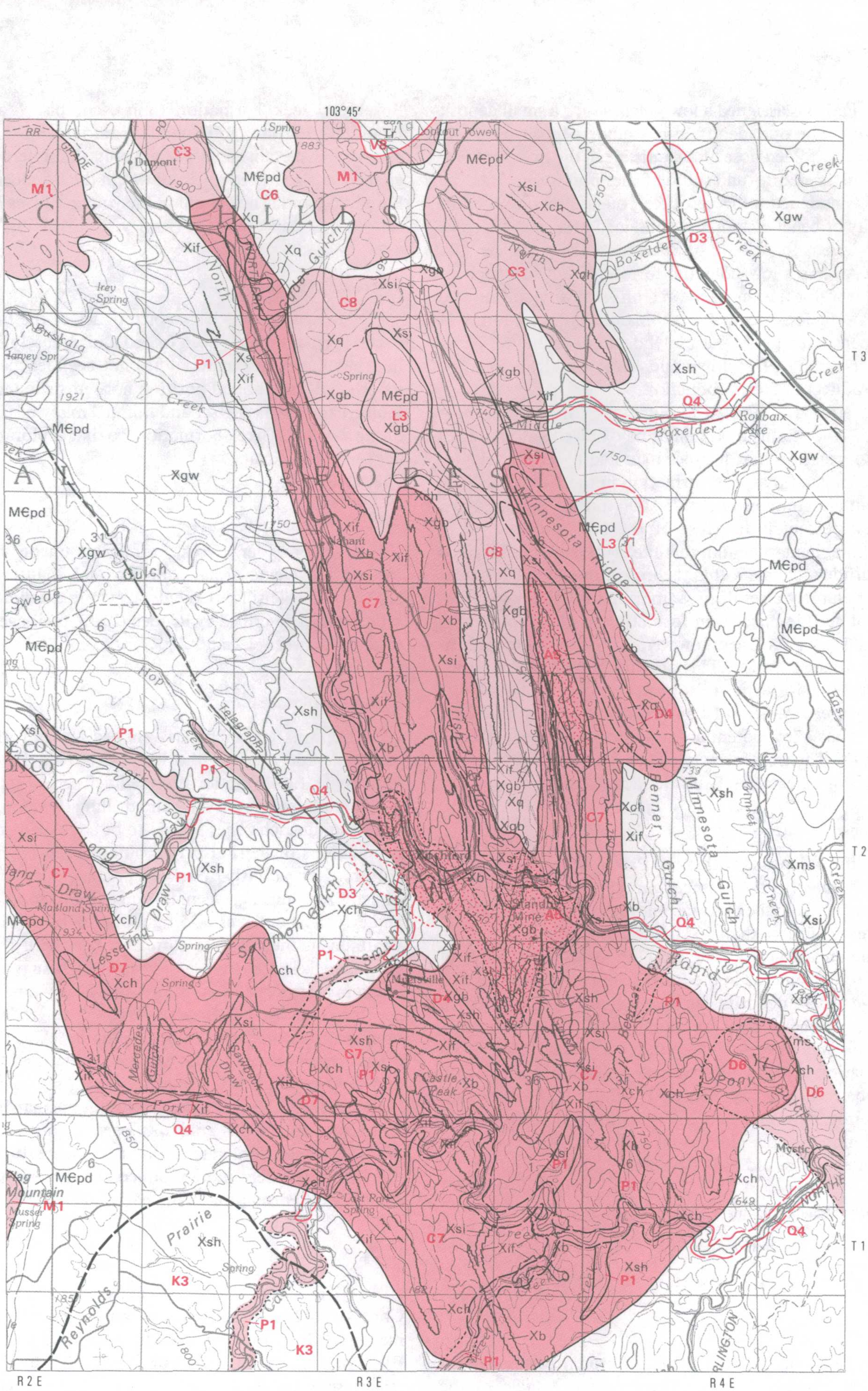
The Boxelder Creek Formation unconformably overlies the Nemo Iron-formation and is intruded by 2.2-Ga gabbroic sills. If the deposits are detrital or late syngenetic as described by Redden (1980), their age is constrained between 2.2 and 2.5 Ga.

Deposit Description

Deposits are irregularly shaped lenses within the conglomeratic units of the Boxelder Creek Formation (unit Xcqc, fig. 15) in an area well defined by mapping, ground radiometric surveys, and drilling (Redden, 1980). The uranium-rich zones appear to be coincident with accumulations of detrital pyrite, blue quartz, zircon, and chromite in tightly packed pebble conglomerate. Mineralized fluvial gravel units range from 3 to 65 ft thick and extend as much as 0.25 mi along strike (Kim, 1979). Uranium in the deposits correlates best with thorium, cobalt, nickel, and iron, a relation which suggests that uranium is associated with the detrital, heavy-mineral suite dominated by pyrite (Redden, 1980). The grade of the uranium deposits is low, not commonly exceeding 200 ppm. Very few ore minerals have been identified because much of the uranium is apparently very fine grained and is associated with iron oxide minerals in the matrix of the conglomerate. Placer gold has been identified in the uraniferous conglomerate (Hills, 1977; Kim, 1979), and the Safe Investment mine produced gold from the Boxelder Creek Formation in the early 1900's.

Geochemical Signature

NURE stream-sediment analyses (Union Carbide Corp., 1980) revealed uranium anomalies near the Benchmark and Greenwood localities (northwestern part of area B1, shown in fig. 15) noted by Redden (1980). Detailed stream-sediment sampling and rock-chip geochemistry


103°45′
44°07′30″
T 3 N
T 2 N
T 1 N
R 2 E
R 3 E
R 4 E
Dumont
Lookout Tower
Irey Spring
Nahant
Rochford
Standard Mine
Castle Peak
Mystic
Flag Mountain
Musser Spring
Lost Pair Spring
Minnesota Ridge
Telegraph Gulch
Boxelder
Roubaix Lake
Rapid
Prairie
Reynolds
C3
M1
C6
V8
C8
D3
P1
L3
Q4
C7
A5
D4
D7
D6
K3
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Xch
Xgw
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Xq
Xgb
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Xms
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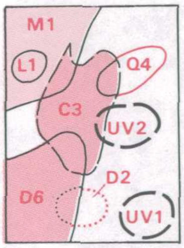
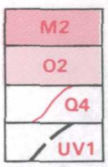
EXPLANATION



Areas having mineral resource potential—Boundaries are dashed or dotted where necessary to show limits of overlapping areas. Areas are labeled by letter and number corresponding to entries in the table below. Where two or more overlapping areas have different levels of potential, the overlapping area is colored to show the highest potential determined.

In the example at left C3 is an area of high mineral resource potential that is overlapped on the right by Q4, an area of low potential, and by UV2, an area of unknown potential. Area M1, which has moderate potential, overlaps area C3 and also contains an area of low potential, L1. Area D6, which has high potential, overlaps C3 and is overlapped by area D2, which has low potential. Area UV1 is an area of unknown potential.

The map must be used together with the table to interpret correctly the potential of overlapping areas



High mineral resource potential

Moderate mineral resource potential

Low mineral resource potential

Unknown mineral resource potential

Levels of resource potential

H	High mineral resource potential
M	Moderate mineral resource potential
L	Low mineral resource potential
U	Unknown mineral resource potential

Levels of certainty

D	Data define geologic environment and level of resource potential and indicate resource-forming processes in all or part of the area
C	Data partially define geologic environment and indicate a resource potential and indicate resource-forming process in some of the area
B	Data partially define geologic environment and suggest level of resource potential
A	Available data not adequate for evaluation of resource potential

NOTE: Some map areas are patterned to show them more clearly

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
A5	Low-------	L/D	Fe (Ti, Au, Ag)-----------	Small, stratiform sedimentary.
C3	Moderate--	M/D	Au (Ag, As)---------------	Medium, syngenetic stratiform.
C6	Unknown---	U/A	Au (Ag)-------------------	Size unknown, syngenetic stratiform.
C7	High------	H/D	Au (Ag, As)---------------	Medium, syngenetic stratiform.
C8	Moderate--	M/C	Au (Ag, As)---------------	Large, syngenetic stratiform.
D3	Low-------	L/C	Au, Ag--------------------	Small, vein or shear zone.
D4	Moderate--	M/D	Au, Ag (Zn)---------------	Small-medium, vein.
D6	Moderate--	M/C	Au, Ag (Cu)---------------	Small, vein.
D7	Moderate--	M/D	Au, Ag (As, Zn)-----------	Small, vein.
K3	Unknown---	U/A	Au, Ag, V, Cu-------------	Large, stratabound.
L3	Low-------	L/C	Au------------------------	Small, paleoplacer.
M1	Moderate--	M/D	High-calcium limestone----	Medium, bedded sedimentary.
P1	Moderate--	M/D	Fe (Au)-------------------	Small-medium, colluvium.
Q4	Low-------	L/D	Au------------------------	Small-medium, placer.
V8	Low-------	L/C	Au, Ag (Cu, Zn)-----------	Small, disseminated.

LIST OF MAP UNITS

Tr	**Rhyolite (Eocene and Paleocene)**
M€pd	**Pahasapa Limestone (Lower Mississippian), Englewood Formation (Lower Mississippian and Upper Devonian), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**
Xsh	**Metasedimentary rocks (Early Proterozoic)**
Xms	**Metasedimentary rocks (Early Proterozoic)**
Xgw	**Metagraywacke (Early Proterozoic)**
Xgb	**Metagabbro (Early Proterozoic)**
Xch	**Metachert (Early Proterozoic)**
Xb	**Metabasalt (Early Proterozoic)**
Xif	**Iron-formation (Early Proterozoic)**
Xsi	**Metasedimentary rocks (Early Proterozoic)**
Xq	**Metaquartzite (Early Proterozoic)**

Contact—Dashed where approximately located; queried where uncertain

Fault—Dashed where approximately located. Bar and ball on downthrown side; arrows show relative sense of displacement

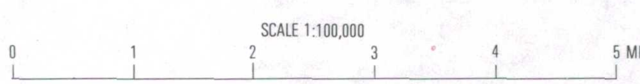
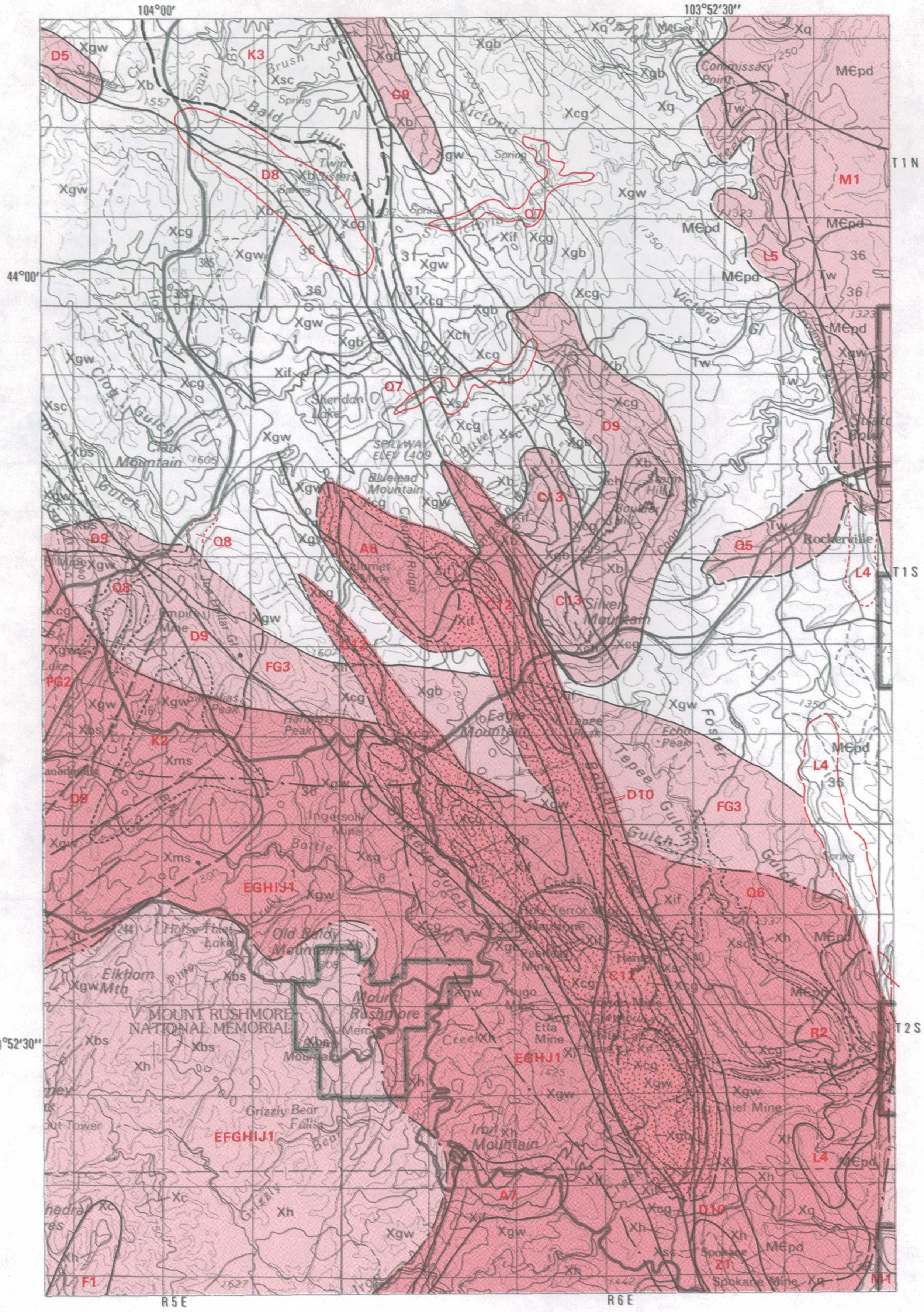


Figure 16 (above and facing page). Mineral resource potential map for locatable commodities in the Rochford area, Black Hills National Forest, S. Dak. Geology shown alone in figure 10. Base from U.S. Geological Survey, Rapid City, 1977.


104°00′
103°52′30″
44°00′
43°52′30″
T1N
T1S
T2S
R5E
R6E
MOUNT RUSHMORE NATIONAL MEMORIAL
Sheridan Lake
Rockerville
Silver Mountain
Bluelead Mountain
Clark Mountain
Harney Peak
Elkhorn Mtn
Old Baldy Mountain
Iron Mountain
Eagle Mountain
Horse Thief Lake
Grizzly Bear Falls
Commissary Point
Victoria
Tapee Gulch
Foster Gulch
Ingersoll Mine
Empire Mine
Etta Mine
Hugo Mine
Chief Mine
Spokane Mine
Holy Terror Mine
Keystone
Spillway Elev 1409
D5
K3
Q9
D8
Q7
M1
L5
D9
C13
Q8
A6
C12
Q5
L4
FG2
FG3
K2
D10
EGHIJ1
Q6
C11
R2
EFGHIJ1
A7
Z1
F1
Xgw
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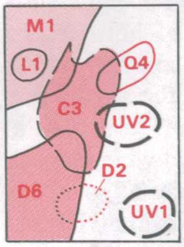
MЄpd
Tw
Xif
Xch
Xbs
Xms
Xh
Xc

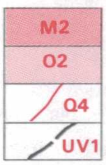
EXPLANATION



Areas having mineral resource potential—Boundaries are dashed or dotted where necessary to show limits of overlapping areas. Areas are labeled by letter and number corresponding to entries in the table below. Where two or more overlapping areas have different levels of potential, the overlapping area is colored to show the highest potential determined.

In the example at left C3 is an area of high mineral resource potential that is overlapped on the right by Q4, an area of low potential, and by UV2, an area of unknown potential. Area M1, which has moderate potential, overlaps area C3 and also contains an area of low potential, L1. Area D6, which has high potential, overlaps C3 and is overlapped by area D2, which has low potential. Area UV1 is an area of unknown potential.

The map must be used together with the table to interpret correctly the potential of overlapping areas



High mineral resource potential

Moderate mineral resource potential

Low mineral resource potential

Unknown mineral resource potential

Levels of resource potential

- H High mineral resource potential
- M Moderate mineral resource potential
- L Low mineral resource potential
- U Unknown mineral resource potential

Levels of certainty

- D Data define geologic environment and level of resource potential and indicate resource-forming processes in all or part of the area
- C Data partially define geologic environment and indicate *a resource potential and indicate resource-forming* process in some of the area
- B Data partially define geologic environment and suggest level of resource potential
- A Available data not adequate for evaluation of resource potential

NOTE: Some map areas are patterned to show them more clearly

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
A6	Low-------	L/D	Fe (Mn, Au, Ag, Cu)----------------------	Medium, stratiform sedimentary.
A7	High------	H/D	Fe (Mn, Ti)------------------------------	Medium, stratiform sedimentary.
C9	Moderate--	M/C	Au (Ag, Cu, As)--------------------------	Small, syngenetic stratiform.
C12	High------	H/D	Au, Ag (As, Cu, Mo)----------------------	Medium, syngenetic stratiform.
C13	Moderate--	M/C	Au (Ag, Cu)------------------------------	Small-medium, syngenetic stratiform.
D5	Moderate--	M/C	Au, Ag (Pb, Sb)--------------------------	Small, vein or shear zone.
D8	Low-------	L/B	Au, Ag-----------------------------------	Small, vein or shear zone.
D9	Moderate--	M/C	Au, Ag-----------------------------------	Small, vein.
D10	High------	H/D	Au, Ag (As, Pb, Zn)----------------------	Small-medium, vein or shear zone.
EFGHIJ1	Moderate--	M/D	Feldspar, mica (pegmatite commodities)---	Medium-small, pegmatite.
EGHIJ1	High------	H/D	Pegmatite commodities except Sn----------	Small-medium, pegmatite.
EGHJ1	High------	H/D	Pegmatite commodities except Sn and mica-	Small-medium, pegmatite.
F1	Low-------	L/D	W (Sn)-----------------------------------	Small, skarn or vein.
FG2	High------	H/D	Sn, Li (W, Ta, Nb, pegmatite commodities)	Small, pegmatite or quartz vein.
FG3	Moderate--	M/C	Sn, Li (pegmatite commodities, W, Ta)----	Small-medium, pegmatite.
K2	Moderate--	M/C	Muscovite (magnetite, ilmenite)----------	Large, bedded metamorphic.
K3	Unknown---	U/A	Au, Ag, V, Cu----------------------------	Large, stratabound.
L4	Low-------	L/C	Au---------------------------------------	Small, paleoplacer.
L5	Moderate--	M/D	Hydrafrac sand---------------------------	Medium, paleobeach.
M1	Moderate--	M/D	High-calcium limestone-------------------	Medium, bedded sedimentary.
Q5	Moderate--	M/D	Au---------------------------------------	Small-medium, placer.
Q6	Moderate--	M/D	Au (Sn, Ta)------------------------------	Small, placer.
Q7	Low-------	L/C	Au---------------------------------------	Small, placer.
Q8	Low-------	L/C	Au (Sn, W)-------------------------------	Small-medium, placer.
R2	Low-------	L/D	Fe---------------------------------------	Small, stratabound.
Z1	Moderate--	M/D	Pb, Zn, Ag (Au, Cu)----------------------	Small, vein.

LIST OF MAP UNITS

- Tw **White River Group (Oligocene)**
- M€pd **Pahasapa Limestone (Lower Mississippian), Englewood Formation (Lower Mississippian and Upper Devonian), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**
- Xh **Harney Peak Granite (Early Proterozoic)**
- Xms **Metasedimentary rocks (Early Proterozoic)**
- Xgw **Metagraywacke (Early Proterozoic)**
- Xbs **Metasedimentary rocks (Early Proterozoic)**
- Xif **Iron-formation (Early Proterozoic)**
- Xgb **Metagabbro (Early Proterozoic)**
- Xch **Metachert (Early Proterozoic)**
- Xb **Metabasalt (Early Proterozoic)**
- Xsc **Metasedimentary rocks (Early Proterozoic)**
- Xcg **Metasedimentary rocks (Early Proterozoic)**
- Xq **Metaquartzite (Early Proterozoic)**
- Xc **Metaconglomerate (Early Proterozoic)**

Contact—Dashed where approximately located; dotted where concealed

Fault—Dashed where approximately located. Bar and ball on downthrown side; arrows show relative sense of displacement

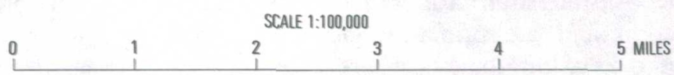


Figure 17 (above and facing page). Mineral resource potential map for locatable commodities in the Keystone area, Black Hills National Forest, S. Dak. Geology shown alone in figure 8. Base from U.S. Geological Survey, Mount Rushmore and Rapid City, 1977.

should indicate anomalously high amounts of uranium, thorium, chromium, and iron in the conglomerate lenses.

Geophysical Signature

The uranium deposits were discovered by ground traverses using a handheld scintillometer (Hills, 1977). This technique was also used to outline uraniferous conglomerate lenses within the Boxelder Creek Formation (Redden, 1980). Aerial radiometric surveys (EG&G geoMetrics, 1980a) detected uranium and thorium anomalies over the Steamboat Rock and Steamboat West localities (southeastern part of area B1, shown in fig. 15) discussed by Redden (1980).

Assessment Criteria

1. Presence of conglomeratic units that contain tightly packed, pyrite-rich accumulations of detrital material.
2. Anomalous concentrations of uranium and thorium, or areas of anomalous radioactivity.

Assessment

Area B1.—This area (pl. 2), which is subdivided into two major areas shown in figure 15, has a moderate potential for uranium in small to medium-size deposits. Redden (1980) has discussed the geologic setting and mineralized conglomerate lenses in the region. The area is assigned a moderate potential, rather than a high potential, due to the low grade of all deposits that have been investigated and drilled.

Economic Significance

Known deposits probably will not be exploited in the near future because of their low grade. Additional exploration may reveal other mineralized areas within the Boxelder Creek Formation, but those probably will have similar characteristics and be of little immediate interest.

Syngenetic Stratiform Deposits (C)

Commodities; Byproducts; and Trace Metals

Gold and silver; arsenic and manganese; mercury and zinc.

Host Rocks

The precious-metal deposits are stratiform bodies in Proterozoic iron-formation and are primarily in carbonate- and sulfide-facies rocks of the Homestake Formation, Montana Mine Formation, and Rochford Formation (units Xif on pls. 1 and 2). Other deposits are in unnamed iron-formation units of similar facies in the Keystone, Medicine Mountain, and Custer areas. The auriferous zones within the iron-formation apparently have been controlled by the location of hot springs, biologic action, or sedimentation that contributed the gold, arsenic, and minor base metals to the strata (Rye, Doe, and Delevaux, 1974). Auriferous iron-formation at the Homestake mine is a deposit of world-wide renown, having yielded more than 37 million ounces of gold. The Homestake mine has accounted for well over 50 percent of the value of mineral resources produced from the Black Hills area.

Structural Control

The auriferous zones and the iron-formation have been complexly folded and cross-folded (Noble and Harder, 1948; Noble, Harder, and Slaughter, 1949; Noble, 1950; Bayley, 1972b). This deformation has greatly thinned and thickened the gold-bearing zones, but has not particularly increased the chances for deposits being localized in the hinge zones of major folds. Noble and Harder (1948) thought that cross-folding locally enhanced the grade of ore in some areas. Although isotopes of sulfur and oxygen have migrated tens of feet to possibly hundreds of feet near major structures (Rye and Rye, 1974), deformation has not redistributed the gold to any great extent. Quartz veining in the areas of greatest deformation has locally modified the location of high-grade gold ore.

Age

The auriferous iron-formation deposits in the Black Hills are older than 1.7 Ma, the apparent end of regional metamorphism, but are younger than the Boxelder Creek Formation and gabbros that intrude it, about 2.2 Ga. Preliminary U-Th-Pb zircon dating of some of the iron-formation units in the northern Black Hills (Z. E. Peterman, written commun., 1985) indicates an age of about 1.9–2.1 Ga.

Deposit Description

Deposits are restricted to specific stratigraphic intervals within the iron-formation units. Although stratiform on the scale of an individual lithologic unit, the mineralized areas may crosscut units in areas of intense quartz veining. Most deposits are within carbonate- and sulfide-facies host rocks, and many are restricted to zones of magnesian metasomatism that formed hydrothermal chlorite. The chief ore mineral is electrum having a low silver content; minor amounts of auriferous pyrrhotite and arsenopyrite are present in some places. The gangue includes major amounts of arsenopyrite, pyrrhotite, chlorite, carbonate minerals, and quartz, and minor amounts of pyrite and phyllosilicate minerals.

Geochemical Signature

Bidgood (1977) showed that the syngenetic stratiform deposit at the Homestake mine, in addition to having anomalous concentrations of gold, silver, and arsenic, contains very low concentrations of copper, lead, zinc, cobalt, nickel, and mercury, and only slightly anomalous amounts of manganese. He also found no statistically valid correlations between any of the above elements and gold. Bayley (1970a; 1970c) showed that iron-formation in the Roubaix and Rochford areas has highly anomalous concentrations of arsenic. Fantone (1983), in a study of iron-formation in the Nemo area, noted that gold correlates best with arsenic, even though the correlation is weak.

NURE stream-sediment sampling is inadequate for detecting auriferous zones in the iron-formation because the detection limits for gold, silver, arsenic, and other trace elements in the NURE studies are too high. Stream-sediment sampling programs would help to delineate areas of potential for auriferous iron-formation, but the sampling network would have to be substantially more detailed and the analytical techniques more sensitive than those used in the NURE studies.

Geophysical Signature

Most of the auriferous iron-formation contains enough magnetite and pyrrhotite to stand out as magnetic highs on aeromagnetic maps (Kleinkopf and Redden, 1975; EG&G geoMetrics, 1980a; Bendix Field Engineering Corp., 1982c) or can be detected readily in detailed ground-based aeromagnetic surveys. Because it is not as magnetic as the taconite, the auriferous iron-formation cannot be traced as far beneath the Phanerozoic cover as can the taconite. The iron-formation units have no aerial radiometric signature because they are not enriched in potassium, uranium, or thorium.

Assessment Criteria

1. Presence of iron-formation.
2. Presence of carbonate- or sulfide-facies strata is favorable, but not required, as the facies may change along strike or down dip.
3. Lack of high-energy sedimentary strata (conglomerate, sandstone) and presence of low-energy strata (shale, calcareous strata).

Assessment

Area C1.—The outcrop extent of the Homestake Formation (unit Xif, fig. 18), the host rock for the gold deposits at the Homestake mine, is within area C1 near Lead. This area has a high potential for large deposits containing gold and silver.

Area C2.—This area north of Lead and Deadwood (fig. 18) contains the subsurface extension of the Homestake Formation beneath the cover of Phanerozoic rocks. It has a moderate potential for a large deposit similar to the one in the Homestake mine, but exploration for such a deposit would have to penetrate the cover of lower Paleozoic strata.

Area C3.—Five small areas west, south, and east of Lead (fig. 18) have a moderate potential for gold and silver in a medium-size deposit. This region contains iron-formation within the Flag Rock Formation, a unit whose correlative strata in the Rochford area are known to contain gold (Bayley, 1972b). The Flag Rock Formation is less favorable for gold than is the Homestake Formation because of its smaller historic production.

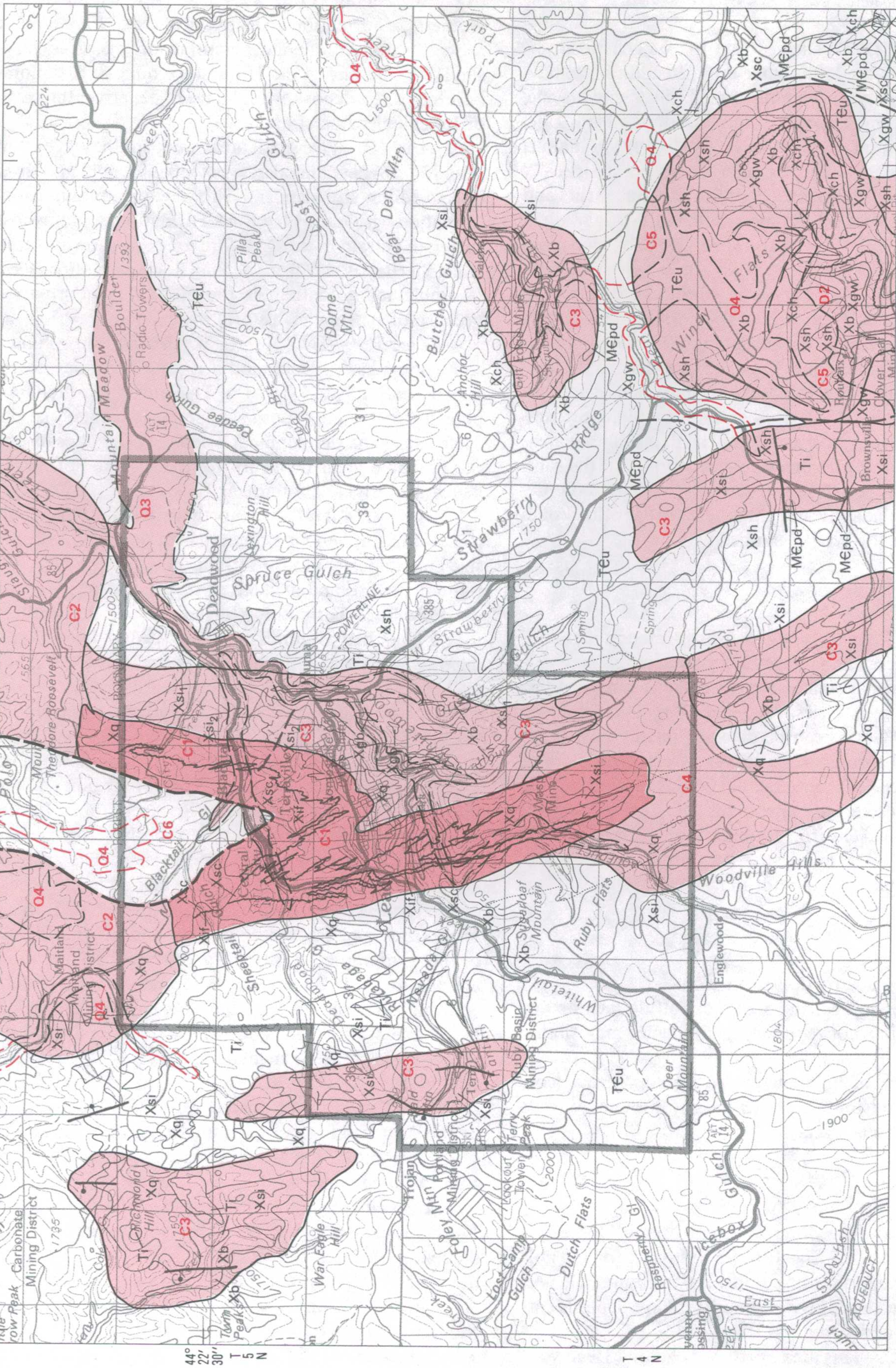
Area C4.—The Homestake Formation plunges south-southeast at Lead, and it is present in the subsurface beneath area C4 (fig. 18). This area has a moderate potential for a large deposit similar to the Homestake, but exploration and development would be costly because of the probable great depth to the Homestake Formation beneath overlying Proterozoic rocks.

Area C5.—This area north and east of Roubaix (fig. 18) has a moderate potential for small to medium-size gold deposits in iron-formation within phyllite, ferruginous schist, and metabasalt that are correlative with the Flag Rock Formation (Bayley, 1970a). Mineralized rock is abundant as shown by Bayley (1970a), but expected deposits would be smaller than those in areas C1, C2, and C4 because they would be predominantly within volcanic rocks rather than within sedimentary rocks deposited in low-energy environments.

Area C6.—Two areas designated C6 are shown in the northern Black Hills, one in the Rochford region and one north of Lead. The C6 area near Rochford (pl. 1, fig. 16) has an unknown potential for gold and silver in syngenetic stratiform deposits within iron-formation. The area has an unknown potential because the favorable host rocks of the Homestake(?) Formation are covered by younger Proterozoic and Phanerozoic rocks and because details of the stratigraphy and structure of the subsurface rocks are unknown. The Homestake Formation, or its lateral equivalent, should underlie this area at depth and might be an exploration target for Homestake-type deposits. Present knowledge is inadequate to assess the resource potential.

The C6 area near Lead (fig. 18, pl. 2) is underlain by the Poorman Formation, a unit older than the Homestake Formation, but which is chemically similar to it. Iron-formation may well be present, as suggested by slight magnetic highs in the area (Meuschke, Philbin, and Petrafeso, 1962), but present knowledge is inadequate for prediction. Area C6 therefore is assigned an unknown potential for gold deposits like the one in the Homestake mine.

Area C7.—Both the Rochford Formation and the Montana Mine Formation—carbonate-, silicate- and sulfide-facies iron-formation—underlie large parts of this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4 MILES
R 2 E
R 3 E 103°45'
R 4 E 103°37'30"
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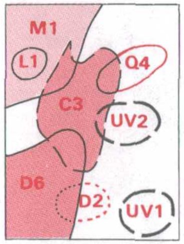
T 5 N
T 4 N
Deadwood
Englewood
Woodville Hills
Strawberry Ridge
Windy Flats
Ruby Flats
Dutch Flats
Spruce Gulch
Butcher Gulch
Dome Mtn
Bear Den Mtn
Deer Mountain
War Eagle Hill
Maitland Mining District
Carbonate Mining District
Ruby Basin Mining District
Portland Mining District

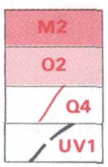
EXPLANATION



Areas having mineral resource potential—Boundaries are dashed or dotted where necessary to show limits of overlapping areas. Areas are labeled by letter and number corresponding to entries in the table shown at right. Where two or more overlapping areas have different levels of potential, the overlapping area is colored to show the highest potential determined.

In the example at left C3 is an area of high mineral resource potential that is overlapped on the right by Q4, an area of low potential, and by UV2, an area of unknown potential. Area M1, which has moderate potential, overlaps area C3 and also contains an area of low potential, L1. Area D6, which has high potential, overlaps C3 and is overlapped by area D2, which has low potential. Area UV1 is an area of unknown potential.

The map must be used together with the table to interpret correctly the potential of overlapping areas



High mineral resource potential

Moderate mineral resource potential

Low mineral resource potential

Unknown mineral resource potential

Levels of resource potential

H	High mineral resource potential
M	Moderate mineral resource potential
L	Low mineral resource potential
U	Unknown mineral resource potential

Levels of certainty

D	Data define geologic environment and level of resource potential and indicate resource-forming processes in all or part of the area
C	Data partially define geologic environment and indicate a resource potential and indicate resource-forming process in some of the area
B	Data partially define geologic environment and suggest level of resource potential
A	Available data not adequate for evaluation of resource potential

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
C1	High------	H/D	Au (Ag, As)----	Large, syngenetic stratiform.
C2	Moderate--	M/D	Au (Ag, As)----	Large, syngenetic stratiform.
C3	Moderate--	M/D	Au (Ag, As)----	Medium, syngenetic stratiform.
C4	Moderate--	M/D	Au (Ag, As)----	Large, syngenetic stratiform.
C5	Moderate--	M/D	Au (Ag, As)----	Small-medium, syngenetic stratiform.
C6	Unknown---	U/A	Au (Ag)--------	Size unknown, syngenetic stratiform.
D2	Moderate--	M/D	Au, Ag, Pb----- (Zn, As).	Small-medium, vein.
Q3	Moderate--	M/D	Au-------------	Medium-small, placer.
Q4	Low-------	L/D	Au-------------	Small-medium, placer.

Note: Only mineral resources related to Proterozoic deposits and placers derived from Proterozoic deposits are shown on this map of the Lead-Deadwood area. Refer to figures 23 and 24 for the distribution of mineral resources related to Phanerozoic deposits.

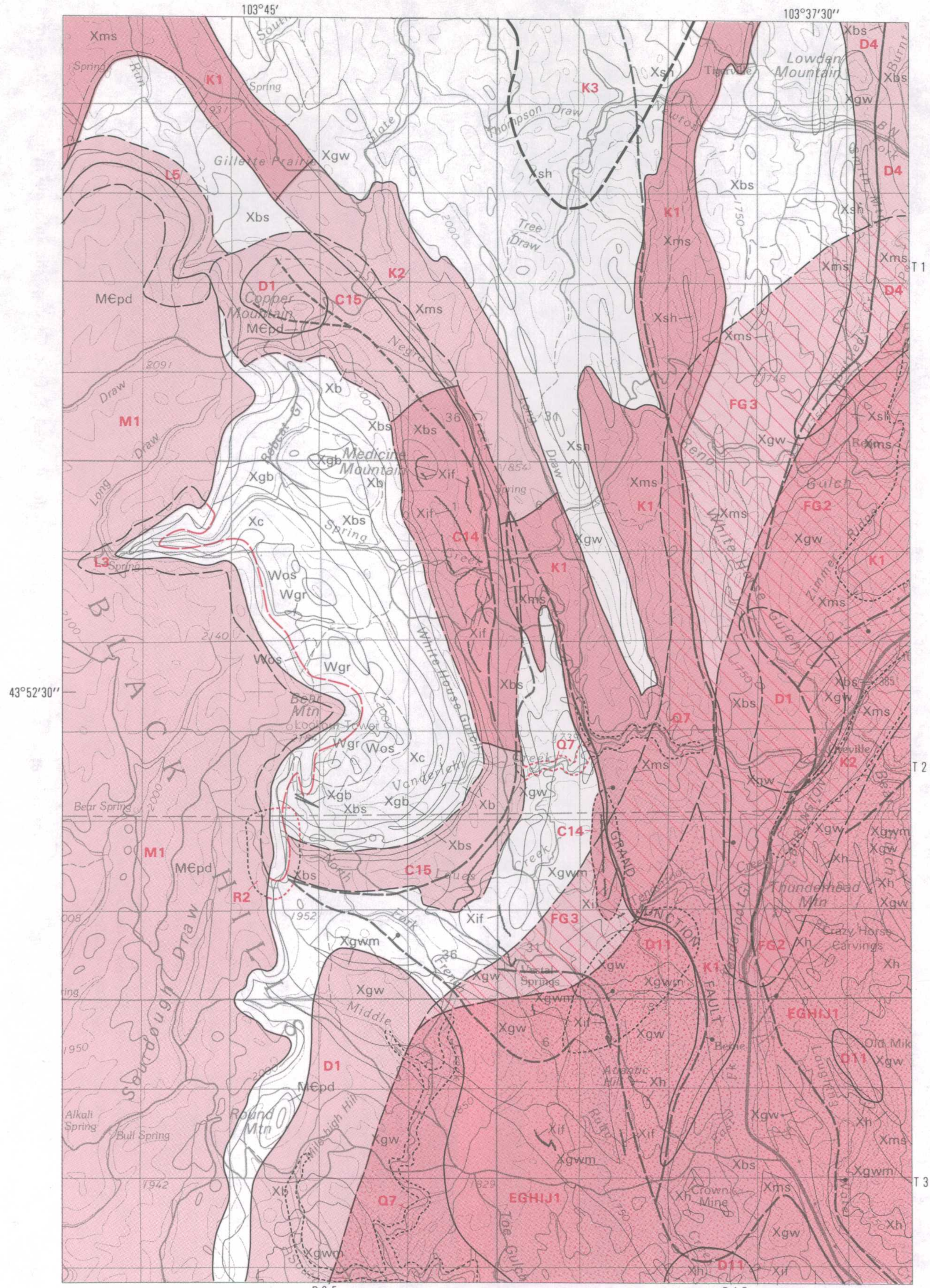
LIST OF MAP UNITS

Ti	**Intrusive rocks (Eocene and Paleocene)**
T€u	**Tertiary igneous rocks, Oligocene sedimentary rocks, Mesozoic sedimentary rocks, and Paleozoic sedimentary rocks**
M€pd	**Pahasapa Limestone (Lower Mississippian), Englewood Formation (Lower Mississippian and Upper Devonian), Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**
Xsh	**Metasedimentary rocks (Early Proterozoic)**
Xgw	**Metagraywacke (Early Proterozoic)**
Xgb	**Metagabbro (Early Proterozoic)**
Xch	**Metachert (Early Proterozoic)**
Xb	**Metabasalt (Early Proterozoic)**
Xsi	**Metasedimentary rocks (Early Proterozoic)**
Xq	**Metaquartzite (Early Proterozoic)**
Xif	**Iron-formation (Early Proterozoic)**
Xsc	**Metasedimentary rocks (Early Proterozoic)**

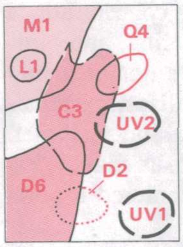
Contact—Dashed where approximately located; dotted where concealed; queried where uncertain

Fault—Dashed where approximately located. Bar and ball on downthrown side

Figure 18. Mineral resource potential map for locatable commodities in the Lead area, Black Hills National Forest, S. Dak. Geology shown alone in figure 9. Base from U.S. Geological Survey, Rapid City, 1977.


103°45′
103°37′30″
43°52′30″
T 1 S
T 2 S
T 3 S
R 3 E
R 4 E
K1
K2
K3
L5
L3
D1
D4
D11
C14
C15
M1
R2
Q7
FG2
FG3
EGHIJ1
Xms
Xbs
Xgw
Xsh
Xb
Xgb
Xc
Xif
Xh
Xgwm
Wos
Wgr
M€pd
Copper Mountain
Medicine Mountain
Lowden Mountain
Thunderhead Mtn
Round Mtn
Bear Mtn
Lookout Tower
Gillette Prairie
Thompson Draw
Tree Draw
White Horse Gulch
Reno Gulch
Vanderlehr Creek
Spring Creek
Tenderfoot Gulch
Crazy Horse Carvings
Crown Mine
Old Mike
Berne
Keystone
Tigerville
Hill City
Atlantic Hill
Middle Fork
North Fork
Long Draw
Sourdough Draw
Bear Spring
Alkali Spring
Bull Spring
Mile-high Hill
Toe Gulch
Laughing Water
GRAND JUNCTION FAULT
BLACK HILLS

EXPLANATION



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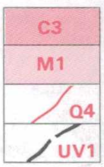

High mineral resource potential

Moderate mineral resource potential

Low mineral resource potential

Unknown mineral resource potential

Levels of resource potential

H High mineral resource potential

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Levels of certainty

D Data define geologic environment and level of resource potential and indicate resource-forming processes in all or part of the area

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B *Data partially define geologic environment and suggest* level of resource potential

A Available data not adequate for evaluation of resource potential

NOTE: Some map areas are patterned to show them more clearly

Map area	Resource Potential	Level of resource potential/ level of certainty	Commodities (by-products)	Size, type of deposit
C14	High------	H/C	Au (Ag, As)---------------	Small-medium, syngenetic stratiform.
C15	Moderate--	M/C	Au (Ag, As)---------------	Small, syngenetic stratiform.
D1	Moderate--	M/D	Au, Ag (Cu)---------------	Small, vein or shear zone.
D4	Moderate--	M/D	Au, Ag (Zn)---------------	Small-medium, vein.
D11	Low-------	L/D	Au, Ag--------------------	Small vein.
EGHIJ1	High------	H/D	Pegmatite commodities except Sn.	Small-medium, pegmatite.
FG2	High------	H/D	Sn, Li (W, Ta, Nb, pegmatite commodities.	Small, pegmatite or quartz vein.
FG3	Moderate--	M/C	Sn, Li (pegmatite commodities, W, Ta).	Small-medium, pegmatite.
K1	High------	H/D	Muscovite (magnetite-ilmenite, Cu).	Large, bedded metamorphic.
K2	Moderate--	M/C	Muscovite (magnetite-ilmenite, Cu).	Large, bedded metamorphic.
K3	Unknown---	U/A	Au, Ag, V, Cu-------------	Large, stratabound.
L3	Low-------	L/C	Au------------------------	Small, paleoplacer.
L5	Moderate--	M/D	Hydrafrac sand------------	Medium, paleobeach.
M1	Moderate--	M/D	High-calcium limestone----	Medium, bedded sedimentary.
Q7	Low-------	L/C	Au------------------------	Small, placer.
R2	Low-------	L/D	Fe------------------------	Small, stratabound

LIST OF MAP UNITS

M€pd **Phasapa Limestone (Lower Mississippian), Englewood Formation (Lower Mississippian and Upper Devonian), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**

Xh **Harney Peak Granite (Early Proterozoic)**

Xsh **Metasedimentary rocks (Early Proterozoic)**

Xms **Metasedimentary rocks (Early Proterozoic)**

Xgw **Metagraywacke (Early Proterozoic)**

Xgwm **Metagraywacke (Early Proterozoic)**

Xbs **Metasedimentary rocks (Early Proterozoic)**

Xif **Iron-formation (Early Proterozoic)**

Xgb **Metagabbro (Early Proterozoic)**

Xb **Metabasalt (Early Proterozoic)**

Xc **Metaconglomerate (Early Proterozoic)**

Wgr **Granite (Late Archean)**

Wos **Older metasedimentary rocks (Late Archean)**

Contact—Dashed where approximately located

Fault—Dashed where approximately located. Bar and ball on downthrown side; arrows show relative sense of displacement

SCALE 1:100,000

0 1 2 3 4 5 MILES

Figure 19 (above and facing page). Mineral resource potential map for locatable commodities in the Medicine Mountain area, Black Hills National Forest, S. Dak. Geology shown alone in figure 6. Base from U.S. Geological Survey, Mount Rushmore, 1977.

area in the Rochford region (fig. 16) and give it a high resource potential for precious metals in medium-size deposits. The area contains numerous small mines, such as the Standby, Montana, and Cochrane, that have produced gold and silver ore.

Area C8.—This area covers a north-trending zone within area C7 northwest of Rochford (fig. 16) that has a moderate potential for a large deposit like that at the Homestake mine. Favorable rocks underlie this area at a moderate depth and constitute a target for deep drilling (Bayley, 1972c). The type of deposit expected in this area would be considerably larger than that expected in area C7 because the deposit would be located within the Homestake Formation, not the Rochford Formation or Montana Mine Formation.

Area C9.—This area west of Nemo (fig. 15) is assigned a moderate potential for gold in small syngenetic stratiform deposits. The tectonic setting of area C9 is similar to area C5 near Roubaix, but gold mineralization is less well documented (Fantone, 1983). Much of the iron-formation in the area follows the eastern contact of the main metabasalt (unit Xb, pl. 1) and is oxide facies. It therefore also has a low resource potential for taconite-type deposits similar to those described for the Nemo Ironformation. However, the iron-formation deposits in C9 are much thinner and lower in iron content than those in the Nemo Iron-formation.

Area C10.—This area west of Nemo (fig. 15) contains carbonate- and silicate-facies iron-formation at the base of the Buck Mountain Formation (part of unit Xq, pl. 1). Fantone (1983) sampled the iron-formation and noted that it contained trace amounts of gold. Area C10 is assigned a moderate potential for medium-size deposits containing gold and silver, on the basis of the anomalous content of gold in certain rocks. Much of the area is concealed by colluvium and its resource potential is less well constrained than is that in previous areas. If the Buck Mountain Formation is equivalent to the Ellison Formation at Lead, this iron-formation would be equivalent to the gold-bearing Homestake Formation.

Area C11.—The Roberts Draw Formation (unit Xd, pl. 1) crops out in area C11 west of Nemo (fig. 15) and is composed of carbonaceous phyllite and dolomitic marble. Such lithologies are similar to those in the Poorman Formation (part of unit Xsc, pl. 1) which underlies the Homestake Formation at the Homestake mine. No geochemical data are published for the Roberts Draw Formation; therefore this area is classified as having an unknown potential for medium to small deposits.

Area C12.—The major carbonate-, silicate-, and sulfide-facies iron-formation units at the surface in the Keystone area (fig. 17) are contained within area C12 and indicate a high resource potential for medium-size syngenetic stratiform deposits. Mines in the central and southern parts of C12 include the Bismark, Ida-Florence, and Bullion, which contain deposits similar to those at Rochford. In the northern part, sulfide-facies iron-formation within slate contains anomalous concentrations of copper and molybdenum (Raymond, King, and Norton, 1975; Raymond, 1981), two elements not normally associated with the gold and silver mineralization. Mines in the northern area include the Dakota and Calumet. Both base- and precious-metal-rich deposits may be expected in the northern part in an area centered around Bluelead Mountain.

Area C13.—The area northeast of Keystone (fig. 17) contains silicate- and carbonate-facies iron-formation within flow units of metamorphosed basalt or associated volcaniclastic rocks. The area is tectonically similar to area C9. Isolated high-grade quartz veins near Silver Mountain contain gold that may have been remobilized from iron-formation. Area C13 is therefore assigned a moderate potential for gold in small to medium-size deposits.

Area C14.—The central part of the Medicine Mountain area contains several silicate- and carbonate-facies iron-formation units (unit Xif, fig. 19) within metamorphosed shale and siltstone (unit Xbs). This area has a high potential for small to medium-size deposits containing gold and silver. Cook (1975) has documented mineralized material in iron-formation and related units in the area. Another similar but smaller area, also designated C14, is located to the southeast (fig. 19); it contains the Grand Junction mine and also has a high resource potential.

Area C15.—Both north and south of C14 the iron-formation decreases in thickness although adjacent metamorphosed tuffaceous units continue, and metamorphosed shale increases. These northern and southern extensions of area C14 are designated C15 and assigned a moderate potential for precious metals in small deposits.

Area C16.—In this area east of Custer (pl. 2), an unnamed silicate- and sulfide-facies iron-formation is a favorable host for a small to medium-size deposit containing precious metals. The area is assigned moderate resource potential. The geologic relations are similar to those in the Keystone area, although mineralization is not as well documented.

Economic Significance

Gold deposits within carbonate-, silicate-, and sulfide-facies iron-formation are major sources of precious metals both in the Black Hills and in Precambrian terranes around the world. The Homestake mine has produced more than 37 million oz of gold in its 109 years of production and probably will produce ore for many years to come. Iron-formation units in the Black Hills are therefore premier exploration targets for deposits of precious metals and will remain as such for the foreseeable future.

Proterozoic Vein and Shear-Zone Deposits (D)

Commodities; Byproducts; and Trace Metals

Gold and silver; lead and zinc; copper and antimony.

Host Rocks

These deposits are in veins that cut all Archean and Proterozoic rock units except the Harney Peak Granite. Some veins are in simple fractures filled by quartz and a variety of sulfide minerals; others are in anastomosing shear zones that contain very little quartz and few sulfide minerals.

Structural Control

Most vein and shear zone deposits are more structurally controlled than any of the other types of deposits. In many instances the deposits are on or near major fault zones; in other instances no major structures are apparent in the vicinity of the deposit. Examples also exist of major fault systems that show no evidence of mineralization although sheared, brecciated, and altered material is present.

Age

The quartz veins and shear zones are difficult to date because most do not contain datable minerals and many are not in contact with rocks younger than 1.7 Ga. Some of the vein deposits discussed in this section could be much younger than their postulated Proterozoic age. In the southern Black Hills some of the veins are cut by pegmatite bodies related to the Harney Peak Granite and thus are known to be older than about 1.7 Ga. However, in the same area other veins associated with faults are younger than regional metamorphism.

Deposit Description

The ore deposits are in veins or shear zones that cut Archean and Proterozoic metamorphic rocks. They range from simple quartz veins having well-defined walls and thicknesses of 1 in. to 10 ft to compound and complex shear zones containing anastomosing quartz stringers, indefinite walls, and highly variable thicknesses. The mineralogy of the veins is independent of the form and structure of the deposit. Electrum, native silver, pyrite, sphalerite, galena, arsenopyrite, and traces of chalcopyrite are the major primary minerals, and quartz and carbonate minerals are the major gangue minerals (Irving and Emmons, 1904; Connolly and O'Harra, 1929). Where the veins have been oxidized, the primary minerals have been converted into various oxides and carbonates of iron, zinc, lead, and copper, such as limonite, smithsonite, cerrusite, malachite, azurite, and so on.

Geochemical Signature

Veins contain highly anomalous amounts of gold, silver, and lead, and minor amounts of arsenic, zinc, and other trace metals. Stream-sediment samples from streams that drain mineralized areas should contain anomalous amounts of precious and base metals, and such trace elements as bismuth, cadmium, arsenic, and mercury.

NURE stream-sediment sampling is inadequate for detecting most quartz veins and shear-zone deposits because the samples are too widely spaced and the analytical techniques employed cannot detect precious metals at low enough concentrations. Prospectors located most of the known deposits by panning for gold in the creeks and following the anomalies upstream. Most of the deposits containing free-milling gold (electrum) that crop out at the surface in the Black Hills probably have been discovered. However, additional shear zones containing very fine grained electrum or gold associated with sulfide minerals may have been overlooked.

Geophysical Signature

All quartz veins and shear zones are too small to detect by geophysical techniques such as gravity, magnetic, or radiometric surveys. Ground surveys, such as induced polarization or electromagnetics, possibly could locate such deposits if the alteration of the country rock were extensive and if the vein contained a significant quantity of sulfide minerals.

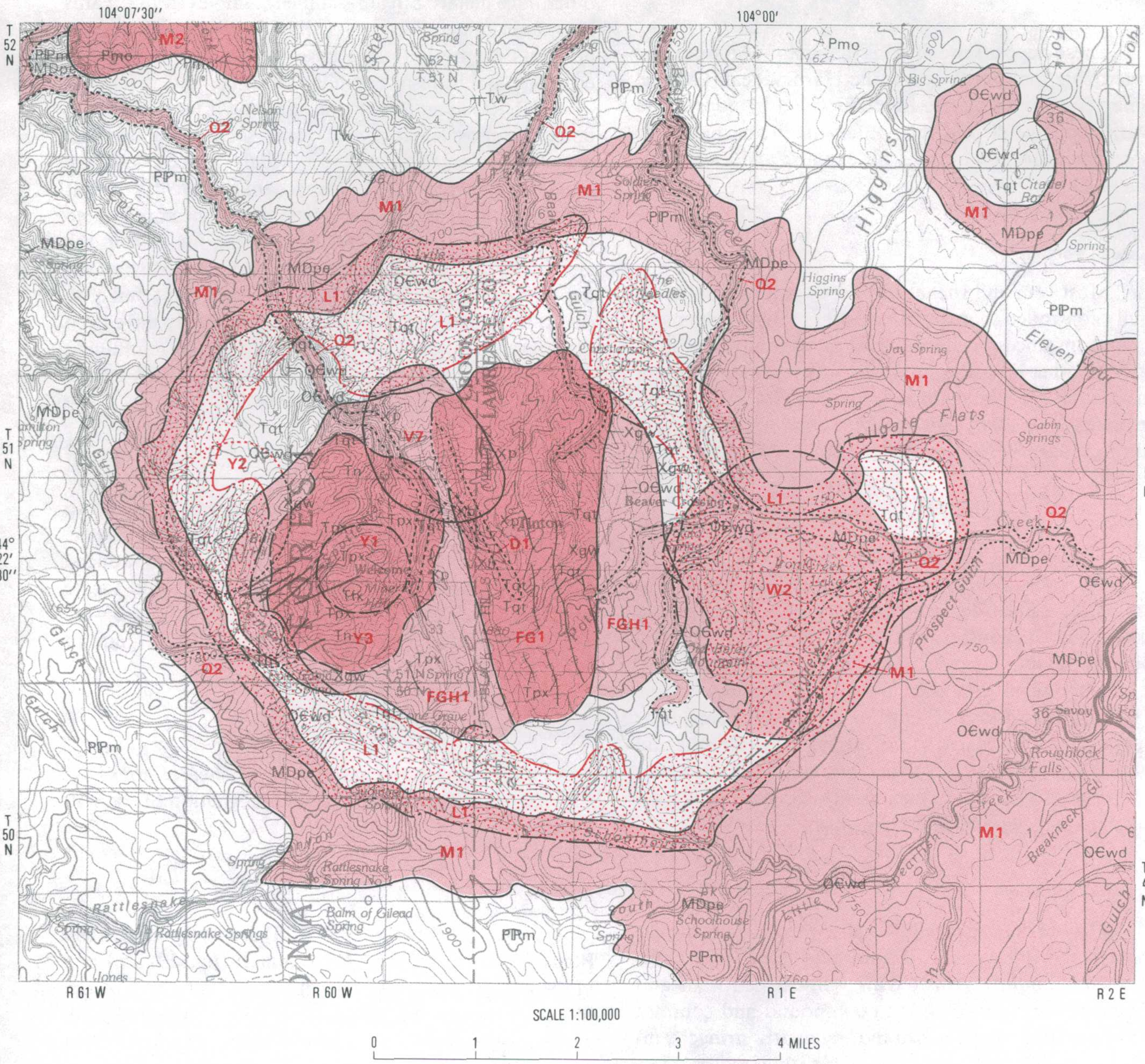
Assessment Criteria

1. Presence of quartz veins or sheared rocks.
2. Silicification or pyrite-impregnation of the wall rocks.

Assessment

Area D1.—Four areas (all D1) are designated in the Black Hills, one in the Tinton region (fig. 20) and one in the northern part and two in the southern part of the Medicine Mountain region (fig. 19). All areas have moderate potential for precious metals and copper in small veins or shear zones. The D1 area at Tinton contains quartz veins that cut metabasalt. The Rusty mine produced gold from this area (Norby, 1984). The D1 area north of Medicine Mountain has documented copper occurrences with a postulated precious metal association (Ratté, 1980). The two D1 areas south of Medicine Mountain contain deposits similar to those in the Saginaw, Hard Scrabble, and Penobscot mines (Connolly and O'Harra, 1929; Allsman, 1940; Redden, 1968).

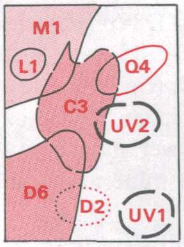
Area D2.—The Clover Leaf mine, in the Roubaix area (pl. 2 and fig. 18), is within area D2. This deposit has been described as a "saddle reef," quartz vein, or shear zone (Irving and Emmons, 1904; Allsman, 1940) and could be any of these or a mineralized body of chert. The Clover Leaf mine was developed in ferruginous schist and phyllite correlative with the Flag Rock Formation (Bayley,



LIST OF MAP UNITS

Tw	White River Group (Oligocene)
Tfx	Feldspathoidal breccia (Eocene and Paleocene)
Tpx	Pyroxenite and diorite (Eocene and Paleocene)
Tn	Nepheline syenite (Eocene and Paleocene)
Tqt	Quartz trachyte (Eocene and Paleocene)
Pmo	Minnekahta Limestone and Opeche Shale (Lower Permian)
PIPm	Minnelusa Formation (Lower Permian and Pennsylvanian)
MDpe	Pahasapa Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)
O€wd	Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)
Xp	Pegmatite (Early Proterozoic?)
Xb	Metabasalt (Early Proterozoic?)
Xgw	Metagraywacke (Early Proterozoic?)
	Contact—Dashed where approximately located
	Fault—Dashed where approximately located. Bar and ball on downthrown side

EXPLANATION



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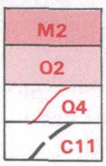
The map must be used together with the table to interpret *correctly the potential of overlapping areas*



High mineral resource potential

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Levels of certainty

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A Available data not adequate for evaluation of resource potential

NOTE: Some map areas are patterned to show them more clearly

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
D1	Moderate--	M/D	Au, Ag (Cu)-----------	Small, vein or shear zone.
FG1	High------	H/D	Sn, Li (W, Ta, pegmatite commodities).	Small, pegmatite.
FGH1	Moderate--	M/D	Sn, Li, feldspar------ (W, Ta, pegmatite commodities).	Small, pegmatite.
L1	Low-------	L/C	Au--------------------	Small-medium, paleoplacer.
M1	Moderate--	M/D	High-calcium limestone	Medium, bedded sedimentary.
M2	High------	H/D	High-calcium limestone	Large, bedded sedimentary.
Q2	Moderate--	M/D	Au, Sn, W, Ta---------	Small, placer.
V7	Moderate--	M/C	Au, Cu, REE-----------	Small-medium, disseminated.
W2	Moderate--	M/B	Th, REE (Au)----------	Small, disseminated.
Y1	High------	H/D	Au, Cu, Ag (REE)------	Medium, disseminated or breccia pipe.
Y2	Low-------	L/C	Au, REE---------------	Small, disseminated.
Y3	High------	H/D	Au, Fe, Cu (Ti, Mn)---	Medium-small, disseminated.

Figure 20 *(above and facing page). Mineral resource potential map for locatable commodities in the Tinton area, Black Hills* National Forest, Wyo. and S. Dak. Geology shown alone in figure 11. Base from U.S. Geological Survey, Sundance, 1979, and Rapid City, 1977.

1970a) and contained the largest vein deposit in the Black Hills (Connolly, 1929; Allsman, 1940). The deposit furnishes a part of the evidence leading to assignment of moderate potential to this area for precious metals in small to medium-size vein deposits that contain substantial amounts of lead, zinc, and arsenic.

Area D3.—Areas with this designation have a low potential for precious metals in small vein or shear-zone deposits. The areas lack signs of precious metals despite quartz veining. The region along North Boxelder Creek in the Rochford area (fig. 16) is located at a large bend in a strike-slip(?) fault separating metamorphosed shale from graywacke. The area just west of Rochford is located along a strike-slip(?) fault that offsets volcaniclastic rocks and associated iron-formation. The region west of Benchmark, in the Nemo area (fig. 15), contains quartz veins that cut metabasalt. The area east of Pactola Dam (pl. 2) is along a strike-slip(?) fault that cuts metabasalt.

Area D4.—Three areas designated D4 have moderate resource potential for gold in vein deposits; two are in the Rochford region (fig. 16) and one is north of Hill City, partly in the Medicine Mountain area (fig. 19). The northernmost area in the Rochford region contains the Minnesota Ridge mine and is along a strike-slip fault that cuts iron-formation, quartzite, volcaniclastic rocks, and carbonaceous schist. The southernmost area, south of Rochford, is along a strike-slip fault that cuts similar rock types. The area that extends north from Hill City is along a contact zone where metagraywacke and the adjacent schist appear to be sheared and impregnated with minor amounts of sulfide minerals. The localization of deposits in this area may have been partially controlled by anomalous detrital gold content of the graywacke.

Area D5.—This area trends northwest from south of Silver City (pl. 2) and includes vein and shear-zone deposits localized along strike-slip faults that cut metagraywacke and schist. The area is geochemically unique for this type of deposit in the Black Hills because it contains minor amounts of antimony and possibly some mercury (Connolly and O'Harra, 1929; Larson, 1971). Productive but presently inactive mines in the area include the Homelode and the Diana (Allsman, 1940). The unusual chemistry and mineralogy of mineralized rock in this area may indicate that the deposits are younger than the postulated Proterozoic age. The area has a moderate potential for precious metals, lead, and antimony in small vein or shear-zone deposits.

Area D6.—This area near Mystic (pl. 2, fig. 16) has a moderate potential for vein deposits similar to those at the Inca mine (Allsman, 1940). Small quartz veins contain precious metals and minor amounts of copper.

Area D7.—Two areas near Rochford (fig. 16) designated D7 have a moderate potential for small vein deposits. Veins having low dips and rich in arsenic and base metals cut iron-formation at the Golden West mine and the Bee lode.

Area D8.—Two areas are designated D8 (pl. 2), one in the southern part of the Nemo area (fig. 15), and one in the northern part of the Keystone area (fig. 17). Both have a low potential for precious metals in small vein or shear zone deposits. The area is given a level of certainty of "B" due to the lack of documented mineralization along the faults.

Area D9.—A large area east of Hill City that extends into the Keystone area (pl. 2) has a moderate resource potential for precious metals in small vein deposits such as those at the Empire and Golden Summit mines (Connolly and O'Harra, 1929; Allsman, 1940, Ratté and Wayland, 1969). Another area of similar potential is noted around Silver Mountain, northeast of Keystone (fig. 17), where quartz veins that cut metabasalt contain small amounts of gold and silver.

Area D10.—The central and southern parts of the Keystone area (fig. 17) contain the second-largest auriferous quartz vein in the Black Hills, the deposit occurring in the Holy Terror mine (Connolly, 1925; Connolly and O'Harra, 1929; Allsman, 1940), and many smaller mines such as the Keystone and Columbia. Many veins in this area cut iron-formation and may have extracted some of their precious metals by leaching these rocks. The area has a high potential for small to medium-size vein or shear-zone deposits containing precious metals, arsenic, and minor amounts of lead and zinc. Mineralization in the area may be younger than the presumed Proterozoic age.

Area D11.—Three areas designated D11, one in the southeastern part of the Medicine Mountain region (fig. 19), one east of Custer (pl. 2), and the other southwest of Custer (pl. 2) have a low resource potential for small vein deposits containing precious metals. In the areas shown in figure 19, narrow quartz veins cut metagraywacke. The area east of Custer contains the old Chilkoot mining district, where small quartz veins cut metaquartzite. The Bebington and Roberta mines (Allsman, 1940; Redden, 1963) are southwest of Custer; quartz veins in this area cut metagraywacke and metabasalt.

Economic Significance

Most quartz veins and shear-zone deposits are small exploration targets that produce limited quantities of precious metals. The two largest deposits in the Black Hills, those at the Clover Leaf mine and the Holy Terror mine, would be profitable today. Deposits of this type will continue to be a viable exploration target for precious metals, but will contribute much less ore and metals than either the iron-formation or the Tertiary replacement and disseminated deposits that are discussed later in this report.

Proterozoic Pegmatite Deposits—Potassium Feldspar (E); Tin and Tungsten (F); Lithium (G); Potassium Feldspar and Mica (H); Mica (I); Beryllium (J)

Commodities; Byproducts

Potash feldspar, tin, tungsten, lithium, sheet mica, scrap mica, beryllium, semiprecious gem stones, and quartz; tantalum and uranium.

Host Rocks

Most deposits are in pegmatite and coarse-grained granitic phases of the Harney Peak Granite. Tin and tungsten deposits are in quartz veins associated with pegmatite, and tungsten has been noted in skarn deposits within marble xenoliths. The pegmatite ranges from simple, unzoned bodies to complex, zoned intrusions surrounded by metasomatic alteration halos in the adjacent schist.

Structural Control

The pegmatite bodies are spatially related to the Harney Peak Granite: the density of bodies decreases away from the main body of the granite to the north, east, and west, but remains rather constant on the south (Norton, 1975b; Redden, Norton, and McLaughlin, 1982). Some pegmatite intruded the foliation of the country schist, but many bodies are concordant with the layering in the schist. The margins of pegmatite bodies parallel the foliation in the schist in some places and then cut up and across the foliation; examples include the mass of Harney Peak Granite at Mount Rushmore and the spires of granite and pegmatite along the Needles Highway.

Age

A 10-point Rb-Sr whole-rock isochron for the Harney Peak Granite (Riley, 1970) indicates an age of 1,697±33 Ma for its emplacement. Mineral dates for lepidolite and uraninite from the pegmatite are slightly younger, but those that can be interpreted as emplacement dates are in the range of 1,630–1,700 Ma. Both the Harney Peak Granite and its cogenetic pegmatite bodies were emplaced during the waning stages of regional metamorphism and deformation of the Archean and Proterozoic rocks. The granite produced a noticeable thermal aureole characterized by unoriented potassium feldspar porphyroblasts in the schist 2–5 mi from the main granitic mass.

Deposit Description

Deposits range from small, simple bodies consisting largely of quartz and feldspar through unzoned pegmatite consisting of quartz, perthite, plagioclase, and muscovite, to large zoned bodies having a central core containing lithium minerals and surrounded by concentric zones of quartz and varied percentages of potassium feldspar with or without spodumene and amblygonite and an outer shell of plagioclase, quartz, and muscovite (Norton, 1975b, 1983a). The pegmatite bodies are linear, elliptical, or keel-shaped, and the largest ones are as much as 1,500 ft long and 400 or more ft thick.

The unzoned pegmatite bodies commonly have the simplest mineralogy, consisting of quartz, potassium feldspar, plagioclase, and muscovite. Accessory minerals include tourmaline, apatite, garnet, and biotite. The zoned pegmatite bodies normally have a more complex mineralogy that includes the above-listed minerals and also beryl, spodumene, amblygonite, lepidolite, pollucite, cassiterite, and a host of rare phosphate and oxide minerals (Page and others, 1953; Roberts and Rapp, 1965).

Quartz veins containing tin and tungsten cut across or parallel foliation in the older schist. Some veins occupy fractures in the schist and are highly irregular in thickness and extent. Skarn deposits containing tungsten are restricted to marble beds in xenoliths within the Harney Peak Granite.

Geochemical Signature

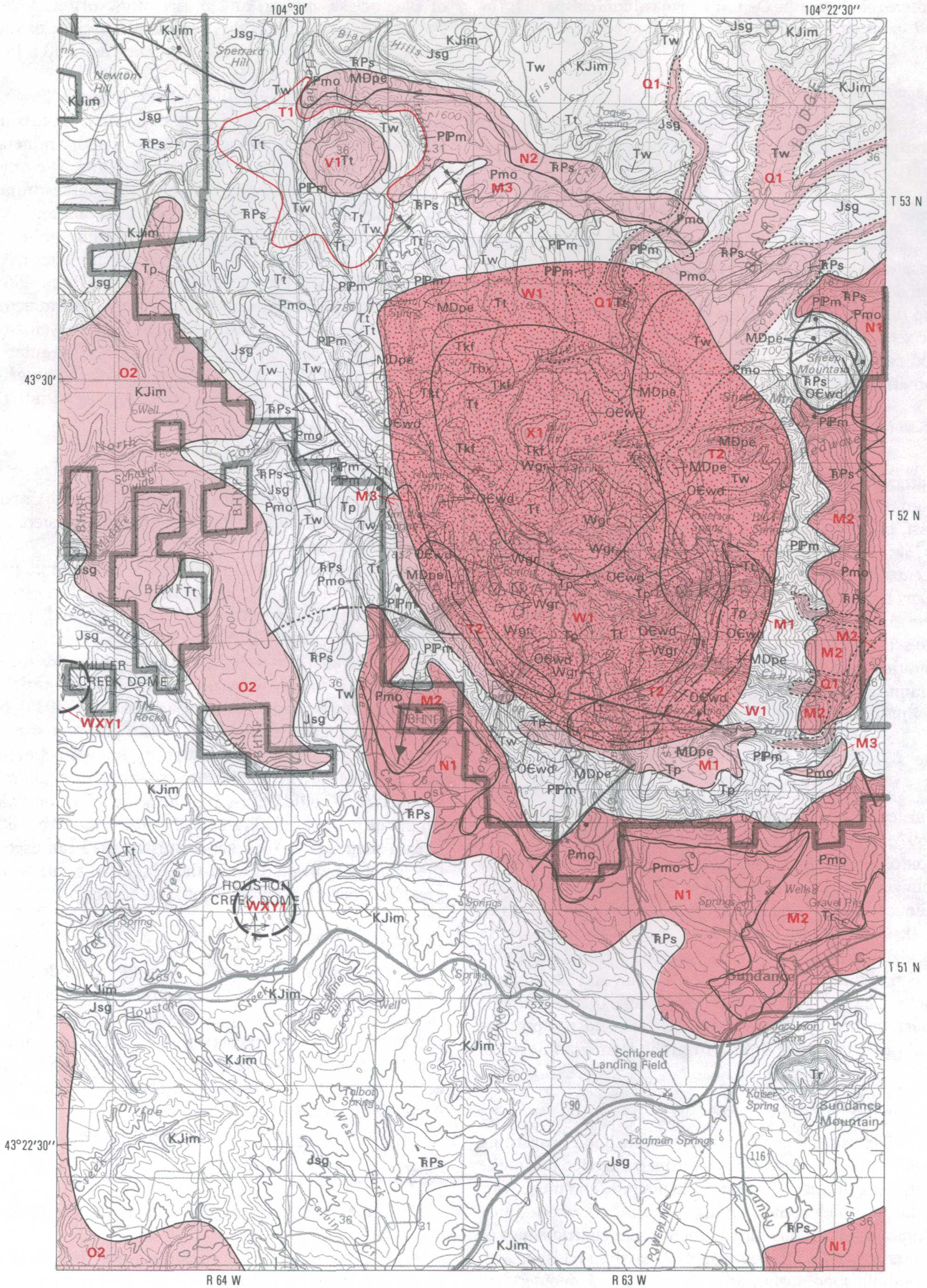
The pegmatite deposits are anomalous in their concentration of lithium, beryllium, boron, tin, tungsten, and in some minor trace elements. Many large, zoned pegmatite bodies exhibit metasomatic halos containing lithium, rubidium, and cesium that extend for varying distances into the country rocks (Schearer and others, 1983; Tuzinski, 1983). The Harney Peak Granite and the surrounding area in which pegmatite is common is shown on the NURE stream-sediment maps as a region enriched in lithium and uranium (Union Carbide Corp., 1979), but the sample density is much too low to pinpoint specific targets for exploration or to identify known pegmatite deposits. More detailed stream-sediment and rock geochemistry could be used in the search for concealed pegmatite bodies, as indicated by Norton (1984). Very little stream-sediment or rock geochemistry has been used in the search for pegmatites in the Black Hills due to the great number of exposed pegmatite bodies.

Geophysical Signature

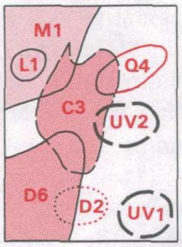
The pegmatite bodies are virtually excluded from geophysical exploration by virtue of their small size, a density similar to the rocks they intrude, and their lack of highly radioactive or magnetic minerals. The most useful geophysical technique to employ in the exploration for concealed pegmatite bodies would be ground-based magnetic surveys, which might be able to detect buried bodies by a low magnetic response as compared to the host rocks.

Assessment Criteria

1. Presence of pegmatite bodies, quartz-feldspar veins, and marble units.
2. Lithium, cesium, rubidium, and boron metasomatism of the host schist.


104°30′
104°22′30″
43°30′
43°22′30″
T 53 N
T 52 N
T 51 N
R 64 W
R 63 W
Sherrard Hill
Newton Hill
Tw
KJim
Jsg
TRPs
Tt
Tp
Pmo
PIPm
MDpe
OEwd
Wgr
Tkf
Tbx
Tr
T1
T2
V1
X1
W1
N1
N2
M1
M2
M3
O2
Q1
WXY1
HOUSTON CREEK DOME
BHNF
Sheep Mountain
Sundance
Sundance Mountain
Schloredt Landing Field
Jacobson Spring
Kaiser Spring
Loafman Springs
POWERLINE
90
116

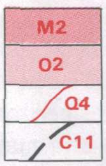
EXPLANATION



Areas having mineral resource potential—Boundaries are dashed or dotted where necessary to show limits of overlapping areas. Areas are labeled by letter and number corresponding to entries in the table below. Where two or more overlapping areas have different levels of potential, the overlapping area is colored to show the highest potential determined.

In the example at left C3 is an area of high mineral resource potential that is overlapped on the right by Q4, an area of low potential, and by UV2, an area of unknown potential. Area M1, which has moderate potential, overlaps area C3 and also contains an area of low potential, L1. Area D6, which has high potential, overlaps C3 and is overlapped by area D2, which has low potential. Area UV1 is an area of unknown potential.

The map must be used together with the table to interpret correctly the potential of overlapping areas



High mineral resource potential

Moderate mineral resource potential

Low mineral resource potential

Unknown mineral resource potential

Levels of resource potential

- H **High mineral resource potential**
- M **Moderate mineral resource potential**
- L **Low mineral resource potential**
- U **Unknown mineral resource potential**

Levels of certainty

- D **Data define geologic environment and level of resource potential and indicate resource-forming processes in all or part of the area**
- C **Data partially define geologic environment and indicate a resource potential and indicate resource-forming process in some of the area**
- B **Data partially define geologic environment and suggest level of resource potential**
- A **Available data not adequate for evaluation of resource potential**

NOTE: Some map areas are patterned to show them more clearly

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
M1	Moderate--	M/D	High-calcium limestone----	Medium, bedded sedimentary.
M2	High------	H/D	High-calcium limestone----	Large, bedded sedimentary.
M3	Moderate--	M/D	High-calcium limestone----	Large-medium, bedded sedimentary.
N1	High------	H/D	Gypsum--------------------	Medium, bedded sedimentary.
N2	Moderate--	M/D	Gypsum--------------------	Medium, bedded sedimentary.
O2	Moderate--	M/C	U, V----------------------	Medium-small, stratabound.
Q1	Moderate--	M/C	REE, Mn, Th, Ti----------- (Au, Pb, U).	Small-medium, placer.
T1	Low-------	L/B	Au, Ag (Th, U)------------	Small, vein.
T2	High------	H/D	Au, Ag, Mn, REE, Pb, Th--- (Ba, U).	Small-medium, vein or replacement.
V1	Moderate--	M/B	Au, Ag (Th, U)------------	Medium-small, disseminated.
W1	High------	H/D	Th, REE, Ba, Mn----------- (U, P, Au, F, Ag).	Large, disseminated.
WXY1	Unknown---	U/A	REE, Th, U, Au, Ag--------	Size unknown, disseminated or vein.
X1	High------	H/D	REE, Th, Ba, Mn----------- (U, P, Au, F, Ag).	Large, disseminated.

LIST OF MAP UNITS

- Tw **White River Group (Oligocene)**
- Tp **Phonolite (Eocene and Paleocene)**
- Tkf **Potassium feldspar-rich alteration zones (Eocene and Paleocene)**
- Tbx **Brecciated zones (Eocene and Paleocene)**
- Tt **Trachyte (Eocene and Paleocene)**
- Tr **Rhyolite (Eocene and Paleocene)**
- KJim **Inyan Kara Group (Lower Cretaceous) and Morrison Formation (Upper Jurassic)**
- Jsg **Sundance Formation (Upper and Middle Jurassic) and Gypsum Spring Formation (Middle Jurassic)**
- ŦPs **Spearfish Formation (Triassic and Permian)**
- Pmo **Minnekahta Limestone and Opeche Shale (Lower Permian)**
- PIPm **Minnelusa Formation (Lower Permian and Pennsylvanian)**
- MDpe **Pahasapa Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)**
- O€wd **Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**
- Wgr **Granite (Late Archean)**

Contact

Fault—Dashed where approximately located; dotted where concealed. Bar and ball on downthrown side

Dome

Anticline—Arrow shows direction of plunge

Syncline

SCALE 1:100,000

0 1 2 3 4 5 MILES

Figure 21 (above and facing page). Mineral resource potential map for locatable commodities in the Bear Lodge Mountains area, Black Hills National Forest, Wyo. Geology shown alone in figure 7. Base from U.S. Geological Survey, Devils Tower and Sundance, 1979.

3. Regional distribution around the Harney Peak Granite: tin and tungsten deposits appear to be restricted to the north and northwest side of the granite (originally the top of the pluton?); large deposits of feldspar are more likely to be found on the southeast, southwest, and south sides of the granite, not on the north.

Assessment

The assessment of the pegmatite deposits follows a slightly different outline from that used for the previous deposit types. Because so many of the different types of pegmatite (E–J) occur together, it is not feasible to discuss types E through J separately. Rather, large areas around the Harney Peak Granite appear to have a resource potential for a group of deposit types. Therefore, most of the areas discussed have compound letter designations, for example EGHJ, which indicates that the entire area has a resource potential for E (potassium feldspar), G (lithium), H (potassium feldspar and mica) and J (beryllium).

Area EFGHIJ1.—This area (pl. 2), which constitutes the main mass of the Harney Peak Granite, has a moderate potential for medium to small pegmatite bodies containing virtually all pegmatite commodities (E–J). Feldspar and scrap mica would be the major commodities because most pegmatite bodies within the granite are rich in feldspar.

Area EFGHIJ2.—The area of Custer State Park (pl. 2) is assigned a moderate potential for medium to small pegmatites containing virtually all pegmatite commodities. This region has been closed to exploration since the creation of the park, but old prospects and small mines exist within the area. The concentration of pegmatite bodies is similar to that of other areas south of the Harney Peak Granite, and there is no reason to doubt that the area contains commercial pegmatite deposits similar to those south of Custer.

Area EGHIJ1.—This belt surrounding the Harney Peak Granite (pl. 2, figs. 17 and 19) is assigned a high potential for small to medium-size pegmatite deposits containing all pegmatite commodities except tin. Many of the largest potassium feldspar pegmatite bodies, such as the Big Chief, Hugo, and Dan Patch (Norton and others, 1964; Norton, 1975b), are within this zone. Tin is the only commodity not listed for this area, but even it should be found in trace amounts in the predominantly feldspar-rich pegmatite bodies.

Area EGHI1.—A large area south of Custer that is approximately centered on Cicero Peak (pl. 2) appears to lack beryllium-rich pegmatites normally found in area EGHIJ1. Area EGHI1 corresponds to a region having a concentration of pegmatites lower than normal for the area south of Custer. Area EGHI1 therefore has a high potential for small pegmatite bodies that contain all pegmatite commodities except tin and beryllium. Deposits in this area would be predominantly potassium feldspar-mica bodies (H) such as the Dakota Feldspar, Greene, Elkhorn, and Bull Moose pegmatite bodies (Norton, 1975b; Redden, Norton, and McLaughlin, 1982). Large pegmatite bodies that contain significant beryllium, such as the Smith and Black Diamond-Beecher Number 3, border the area on the south and west, respectively.

Area EHIJ1.—Another large area southwest of Custer appears to lack lithium-rich pegmatite bodies normally found in area EGHIJ1. Area EHIJ1, west of area EGHI1, has a high potential for all pegmatite commodities except tin and lithium. Deposits in this area would be predominantly mica-rich bodies (I) such as the New York, Buster, and White Spar pegmatite bodies (Norton, 1975b). Interestingly, this area contains the highest number of pegmatite bodies per square mile in the region (Norton, 1975b, p. 138) and may be a large-scale equivalent of the core of a zoned pegmatite, which is commonly rich in muscovite and poor in lithium.

Area F1.—Large inclusions or xenoliths of metamorphic rock (unit Xc, pl. 1) in the Harney Peak Granite southwest of Keystone (fig. 17) contain disseminated scheelite that is restricted to marble beds (Kernaghan and Garske, 1969). The area therefore has a low potential for small skarn or vein deposits containing tungsten. No production from the area is known. This locality is also notable for its decorative stone derived from the marble.

Area FG1.—The only region in the Black Hills outside the Harney Peak area that has produced pegmatite commodities is near Tinton (pl. 2, fig. 20). This area including the Giant-Volney and the Rough and Ready pegmatite bodies (Hess and Bryan, 1938; Smith and Page, 1941) has a high potential for small pegmatite deposits that contain tin, lithium, plagioclase, and minor amounts of tungsten, but it lacks potassium feldspar-rich pegmatite.

Area FGH1.—The area surrounding FG1 (fig. 20) has a moderate potential for small pegmatite deposits containing tin, lithium, plagioclase, potassium feldspar, and minor amounts of tungsten and muscovite. The major potassium feldspar pegmatite in this area is Tantalum Hill (Smith and Page, 1941).

Area FG2.—A belt outside EGHIJ1 and extending from east of Keystone to south of Medicine Mountain (pl. 2) has pegmatite deposits that contain tin, lithium, and other pegmatite commodities; this is the major tin belt in the Harney Peak region. Part of this belt is composed of area FG2, centered on Hill City and extending to the southwest into the Medicine Mountain area (fig. 19) and to the east into the Keystone area (fig. 17). It has a high potential for small pegmatite or quartz-muscovite vein deposits containing tin, lithium, beryllium, tungsten, tantalum, scrap mica, and most other pegmatite commodities. All the commercial tin produced from the Harney Peak area has come from this belt, from deposits such as the Cowboy mine (Ratté, 1975).

Area FG3.—A belt outside FG2 (pl. 2), but within the area containing between 1 and 50 pegmatite bodies per square mile (Norton, 1975b, p. 138), has a moderate potential for small pegmatite deposits containing tin, lithium, and other pegmatite commodities. This belt is peripheral to the known distribution of tin-bearing pegmatite bodies and veins, but evidence suggests the possibility of the presence of tin-bearing pegmatite in the subsurface. The restriction of tin-bearing pegmatite to only the northwest side of the Harney Peak Granite suggests that this is the top of a dome subsidiary to the main body of the granite.

Economic Significance

Pegmatite deposits in the Black Hills have been important sources of strategic and critical minerals, minerals for the ceramics and electronics industry, and, most recently, semiprecious gems and mineral specimens. Pegmatite bodies will continue to be exploited for potassium feldspar and scrap mica, but will not be important sources of lithium or beryllium unless the market for these commodities changes dramatically, such as in case of national emergency or war. The market for semiprecious gems and mineral specimens from pegmatite has been increasing for the last 15 years and shows no sign of decreasing.

Much of the Harney Peak Granite (area EFGHIJ1) is contained within state parks, national monuments, wildlife preserves, or wilderness areas and is excluded from mineral exploration. A large part of the southeastern pegmatite district (area EFGHIJ2) is within Custer State Park and is excluded from mineral exploration.

Miscellaneous Proterozoic Deposits (K)

Bedded Metamorphic Deposits

Commodities; Byproducts; and Trace Metals

Muscovite (scrap mica); magnetite and ilmenite; copper.

Host Rocks

Deposits are muscovite-rich schist (unit Xms, pl. 2) that was originally aluminous shale derived in part from tuff. The entire unit contains abundant muscovite and biotite; certain stratigraphic intervals, 150–300 ft thick, within the unit contain more than 50 percent muscovite. The distribution of muscovite in the unit was controlled by sedimentation.

Structural Control

Isoclinal folding locally thickened and thinned the muscovite-rich strata. In places where the thickening was profound the resource potential was increased; where the unit was thinned the potential was diminished. Almost everywhere the unit crops out it is thick enough to be considered a resource, but because of varied metamorphic grade along strike, the grain size of the product mica varies and the mica may have a different usage or value.

Age

The muscovite schist unit is undated but must be older than the Harney Peak Granite and younger than the stratified rocks in the Medicine Mountain region. If the metamorphosed basaltic and gabbroic rocks at Medicine Mountain are approximately the same age as dated rocks in the Nemo area (Redden, 1981; Z. E. Peterman, written commun., 1985), the muscovite schist unit is between 1.7 and 2.2 Ga.

Deposit Description

The deposits within the schist unit are basically any muscovite-rich strata that are thick enough to be mined. Several subunits are 150–300 ft thick and extend along strike for several miles. Hence, reserves of scrap mica are very large. The unit crops out in the Medicine Mountain 7½-minute quadrangle (Ratté, 1980), the Berne 7½-minute quadrangle (Redden, 1968), the Hill City 7½-minute quadrangle (Ratté and Wayland, 1969), and in smaller areas in the core of the Black Hills (pls. 1 and 2). Because the scrap mica is used for various products, various sizes and purities of mica can be produced. At present, only the mica of highest metamorphic grade (higher grade than the first occurrence of staurolite in pelitic rocks) has been mined, but uses for the finer grained mica may be developed in the future.

Thirty modal analyses of the muscovite-rich schist by Redden (1968) indicate an average muscovite content of 31 volume percent and a range from 20 to 60 percent. The rock contains an average of 17 volume percent biotite, the remainder of the rock being quartz or plagioclase.

Geochemical Signature

The muscovite-rich schist contains anomalous amounts of chromium and copper (Redden, 1968). NURE stream-sediment sampling shows the anomalous character of the unit for copper, and possibly for chromium (Union Carbide Corp., 1979, 1980). More detailed sampling would be necessary to distinguish metal concentrations in muscovite-rich schist as opposed to concentrations from other sources of mineralized rock.

Geophysical Signature

Most of the muscovite-rich schist unit in the Medicine Mountain, Berne, and Hill City quadrangles contains anomalous concentrations of magnetite and ilmenite, and, where the dip is steep, is detectable on aerial magnetic surveys (Kleinkopf and Redden, 1975; EG&G geoMetrics, 1980a; Texas Instruments, Inc., 1979; Bendix Field Engineering Corp., 1982a, c) as aeromagnetic highs. The schist unit loses the magnetite at higher metamorphic grades to the east and south and has a diminished magnetite content to the north in the Silver City and Rochford areas by virtue of a facies and composition change. The unit is not detectable by aerial radiometric surveys because its content of uranium, thorium, and potassium is similar to surrounding rocks.

Assessment Criteria

1. Presence of muscovite-rich units and beds.
2. Copper mineralization and chromium anomalies in muscovite-rich schist.
3. Magnetic response in many cases, but this characteristic not necessary for high concentrations of muscovite.

Assessment

Area K1.—Regions east and north of Medicine Mountain (pl. 2, fig. 19) contain the greatest amount of muscovite-rich schist. These regions in the Medicine Mountain area and extending east into the Hill City and Keystone areas and north into the Deerfield Lake area have a high potential for large bedded metamorphic deposits of muscovite, accessory magnetite and ilmenite, and trace amounts of copper. The K1 areas are those that contain exposures of the muscovite-rich schist that are thickest and contain the most mica.

Area K2.—These areas in the same general region as K1 have a moderate potential for large bedded metamorphic deposits of muscovite containing accessory magnetite and ilmenite and trace amounts of copper. The K2 areas have a lower resource potential than do the K1 areas primarily because of their lesser stratigraphic thickness.

Economic Significance

Muscovite from the schist can be utilized for lower quality scrap mica than can the muscovite from pegmatite deposits. Because it is such an extensive unit, the schist can be exploited by surface excavation, and much of it contains at least 50 volume percent muscovite; the muscovite schist affords a virtually limitless supply of scrap mica at favorable market conditions. Pacer Corp., Custer, S. Dak., is currently producing muscovite from the unit along Tenderfoot Creek southwest of Oreville (fig. 19).

Stratabound Deposits

Commodities

Gold, silver, vanadium, and copper.

Host Rocks

Hypothetical deposits may be in metamorphosed carbonaceous and pyritic shale (units Xsh and Xbs, pl. 1). Some of these units are associated with beds of metamorphosed chert and thin units of basalt, indicating a possible volcanogenic origin. All of unit Xbs is carbonaceous and pyritic; only certain zones in unit Xsh contain organic(?) remains. The pyritic zones in both units appear to be stratiform and represent original sulfur- and carbon-rich beds; the pyrite therefore appears to be syngenetic.

Structural Control

Isoclinal folding of both units had little effect on the distribution of pyrite-rich zones. There appears to be no large-scale structural control of the hypothetical deposits.

Age

The black shale (unit Xbs, pl. 1) is older than unit Xms discussed above, and the shale (unit Xsh, pl. 1) is younger than unit Xms. Unit Xsh is the youngest stratified rock in the core of the Black Hills and must be older than about 1.7 Ga. Both rock units are probably between 2.2 and 1.8 Ga.

Deposit Description

Actual deposits in the two units are not proven. If deposits do exist, they would be stratiform lenses within pyrite-rich zones. Black shale commonly is enriched in zinc, copper, manganese, vanadium, nickel, and cobalt, and may contain minor amounts of gold and silver. No analyses of the two pyrite-rich units are published that would show whether these units contain anomalous amounts of such elements. Precious metals, if they exist here, may be present as fine-grained inclusions within pyrite or carbonaceous material. The exact mineralogy of the deposits is not known.

Geochemical Signature

The NURE stream-sediment sampling for the core of the Black Hills (Union Carbide Corp., 1979, 1980) is much too widely spaced to define metal-rich areas in either of the two shale units. The limited sample coverage does suggest, however, that both units are slightly enriched in zinc. The NURE information does not contain quantitative data for either gold or silver.

Geophysical Signature

The pyritic units are not amenable to detection by standard airborne geophysical techniques but might be defined by induced polarization or electromagnetic ground surveys. The pyritic units contain no abnormal concentrations of radioactive elements or magnetite.

Assessment Criteria

1. Presence of pyrite-rich units and beds.
2. Presence of carbonaceous units may be favorable, but probably is not necessary.
3. Presence of surface mineralization indicates favorable environment, but the deposit type (containing fine-grained precious metals) may have been overlooked by early prospectors.

Assessment

Area K3.—Five regions in the central Black Hills are designated K3, all of which have an unknown potential for large stratabound deposits that would be syngenetic concentrations of precious and base metals. The five areas include a zone along the west side of the Nemo area (pl. 2 and fig. 15), one area southeast and one area southwest of Pactola Reservoir (pl. 2), an area in the southwestern part of the Rochford region (fig. 16) that extends south into the Deerfield Lake area, a small area in the northern part of the Medicine Mountains region (fig. 19), and a small area north of Hill City (pl. 2). The K3 area west of Nemo includes the outcrop extent of the Reausaw Slate. The area southeast of Pactola Dam is in rocks similar to the Reausaw Slate. The Rochford and Medicine Mountain areas are contained within unit Xsh (pl. 1), and the Hill City area includes part of the Oreville Formation, unit Xbs, shown on plate 1.

Area K4.—Whereas the K3 areas are in zones of low metamorphic grade, the K4 area on the west side of the Harney Peak Granite (pl. 2) is in rocks that contain sillimanite and are highly deformed. This increased metamorphic grade makes redistribution of any base and precious metals more likely in area K4 than in K3. Accordingly, the K4 area is assigned an unknown potential for medium to small stratabound or vein deposits containing precious and base metals.

Economic Significance

Deposits in this category are speculative, but if they exist they would be large deposits that could be exploited by surface and underground methods.

Phanerozoic Stratabound Deposits

Cambrian Paleoplacer Deposits (L)

Commodities; Byproducts

Gold and silica sand; silver.

Host Rocks

Deposits are in the basal part of the Deadwood Formation, a transgressive conglomeratic beach deposit that locally contains detrital gold where the beach was eroding Proterozoic auriferous iron-formation (Irving and Emmons, 1904). Some gold may have been eroded(?) from some quartz-vein and shear-zone deposits. The basal and, uncommonly, higher units in the Deadwood contain accumulations of rounded, well-sorted silica sand derived from Proterozoic quartzite. The Deadwood crops out continuously around the core of the Black Hills.

Structural Control

Gold-bearing deposits appear to be concentrated in areas of paleobedrock highs and through-going channels (Devereux, 1882; G. M. French, unpub. mapping, 1984) where the detrital gold was not transported far from its source. Subsequent deformation and intrusion of Tertiary sills and stocks did not modify this depositional geometry.

Age

Gold in the deposits was derived from Proterozoic iron-formation and possibly from quartz veins and shear zones. The gold was deposited during the Cambrian as was well-rounded silica sand and other detrital components.

Deposit Description

Deposits are placer accumulations of detrital gold and well-rounded silica sand. The gold is in the form of smooth, partly flattened and rounded grains and nuggets. Detrital gold produced from mines in the Lead area contained less silver than did ore from the Homestake mine (Devereux, 1882; Irving and Emmons, 1904). The ore was extensively oxidized and the gold grains were surrounded and cemented by iron oxides. Devereux (1882) proposed oxidation of the gold during transport as a mechanism to account for the low silver content of the placer gold. Noble (1950) disagreed with the theory of paleoplacer gold, but none of the mines was accessible for him to collect more specimens and evaluate the validity of the observations of Devereux or of Irving and Emmons.

The silica-sand deposits are locally coincident with associated paleoplacer gold deposits, but more commonly are found without extensive placer gold (Ching, 1973). These deposits consist of well-rounded and well-sorted quartz grains in a poorly cemented matrix of quartz and carbonate minerals. Thicknesses of the sand-rich beds range from 2 to 40 ft, and individual beds may extend along strike for at least 0.5 mile and probably more (Ching, 1973). All the silica-sand deposits are in areas where the underlying Proterozoic rocks are quartzite. The rounded sand grains were derived from disaggregated quartzite prior to deposition of the Deadwood Formation.

Geochemical Signature

The paleoplacer gold and silica-sand deposits are too small to be detected by NURE stream-sediment geochemistry. Also, the only geochemical tracer for the gold deposits is the gold itself, an element not determined by NURE. Similarly, the silica-sand deposits are characterized by their nearly total lack of trace metals. Geochemical data for soil downhill from the outcrop of the Deadwood Formation might indicate areas of paleoplacer gold deposits. Delineation of areas of Proterozoic quartzite would indicate where the Deadwood may contain potential silica-sand deposits.

Geophysical Signature

Neither the gold nor the silica-sand deposits are amenable to detection by geophysical techniques. The deposits are too small to be detected and contain too few of the metals or minerals to give the deposits an anomalous character.

Assessment Criteria

1. Presence of Deadwood Formation close to areas of gold mineralization in the underlying Proterozoic iron-formation.
2. Presence of the Deadwood above or along areas containing Proterozoic quartzite, such as the Ellison, Boxelder Creek, or Buck Mountain Formations.
3. Presence of anomalously thick channel-filling deposits and basal conglomerate.

Assessment

Area L1.—The Tinton area produced a larger amount of gold from Holocene placer deposits than would have been expected from the number of quartz-vein deposits in the area. Irving and Emmons (1904) and Norby (1984) proposed that this enhanced Holocene placer potential is due to the Deadwood Formation containing paleoplacer gold that has been reworked by Holocene placers. Area L1 near Tinton (pl. 2, fig. 20) is therefore assigned a low potential for small to medium-size paleoplacer deposits containing precious metals.

Area L2.—This area near Lead (pl. 2, fig. 18) is the only region from which paleoplacer gold in the Deadwood Formation has been produced (Devereux, 1882; Irving and Emmons, 1904). Consequently the resource potential for such deposits in this area is higher than for other areas in the Black Hills. The L2 area has a moderate potential for small paleoplacer deposits that contain gold and minor amounts of silver. Most of the deposits, such as those at the Monitor and Hidden Treasure mines, were largely mined out during the early days of the district. All paleoplacer deposits were within 2 mi of the Homestake deposit, the presumed source of the placer gold.

Area L3.—Three areas in the Black Hills are designated L3. All have a low potential for small paleoplacer deposits containing gold. One L3 area surrounds the L2 region near Lead (fig. 23). No mines are known to have produced placer gold from the Deadwood in this area, but the sedimentologic characteristics of the basal part of the Deadwood suggest that gold might be found in this area in a setting similar to that in area L2. Another L3 area is northeast of Rochford along Minnesota Ridge (fig. 16). This area could have received placer gold not only from Proterozoic iron-formation deposits but also from vein and shear-zone deposits. The third L3 area is west of Medicine Mountain (fig. 19), where gold might have been derived from iron-formation to the east. Neither of the latter two areas have historic production of gold from paleoplacer deposits in the Deadwood, but both have environments favorable for the accumulation of such deposits.

Area L4.—A narrow, north-trending area northeast of Keystone (fig. 17) has a low potential for small paleoplacer deposits containing gold. Gold in this area would have been derived from iron-formation and quartz-vein sources to the west and southwest. The richness of the Rockerville placers (Connolly, 1933) suggests that the Deadwood Formation may have contained small amounts of paleoplacer gold that subsequently were concentrated in the Rockerville placers during weathering of the Deadwood in Tertiary and Holocene times.

Area L5.—The three areas in the Black Hills that have a moderate potential for the production of silica-sand deposits are near the Nemo area, south of Deerfield Lake, and southeast of Pringle. In all these areas the sand is sufficiently rounded and coarse enough to be used as hydrafrac (hydraulic fracturing) sand in the recovery of oil. The Nemo area (pl. 2, fig. 15) has a moderate potential for medium-size deposits of silica sand in the Deadwood Formation in three subareas, one northwest of Nemo, one north of Bogus Jim Creek (fig. 15), and one south of Norris Peak (pl. 2). Ching (1973) noted that sandstone beds in the lower part of the Deadwood in these subareas contain well-rounded, very clean quartz grains suitable for hydrafrac sand and, at the locality south of Norris Peak, possibly suitable for low-quality glass sand. The Deadwood Formation south of Deerfield Lake (pl. 2) has been quarried as a source of industrial silica sand along the south fork of Castle Creek and along Ditch Creek. This L5 area has a moderate resource potential for all types of industrial silica sand, including possible high-quality glass sand (Ching, 1973). Exposures of the Deadwood southeast of Pringle (pl. 2) also have a moderate potential for medium-size deposits of all types of industrial silica sand except glass sand.

Area L6.—One long and narrow area extending from southeast of Pringle to near Grace Coolidge Creek (pl. 2) has a low potential for medium-size deposits of silica suitable for hydrafrac sand. This area has a lower potential than does area L5 because the Deadwood Formation is thinner here and the quartz grains are not so well rounded (Ching, 1973).

Economic Significance

Paleoplacers probably will not be an important source of precious metals in the Black Hills in the foreseeable future. The potential for gold deposits in iron-formation, quartz veins, shear zones, and Holocene placer deposits is greater, and the cost of production from the paleoplacer deposits is too high to make the latter deposit type viable in the future.

Silica-sand deposits in the Deadwood that are suitable for hydrafrac sand use by the oil industry could be an important resource in the Black Hills area because no other deposits are known that are closer to the major oil fields in North Dakota, Montana, and parts of Canada. Hydrafrac sand has been produced from mines in the Deerfield area. In recent years several companies in the Black Hills region have shown considerable interest in hydrafrac sand deposits. To date, however, no deposit has been developed, although holes were drilled in the Deerfield area to test the continuity of sand horizons in the Deadwood.

Paleozoic High-Calcium Limestone Deposits (M)

Commodities; Byproducts

High-calcium limestone; dimension stone and gravel.

Host Rocks

Deposits are in some of the limestone- and dolomite-rich strata of the Phanerozoic section, particularly in the Minnekahta Limestone (part of unit Pmo, pl. 1) and Pahasapa Limestone (most of unit MDpe, pl. 1). The Minnekahta is by far the more important of the two. Other limestone-rich strata include the Whitewood Dolomite and the Englewood Formation, but because of their limited thickness or high magnesium content, their resource potential is limited. The Minnekahta and Pahasapa are exposed continuously around the core of the Black Hills. The Pahasapa ranges in thickness from about 200 ft in the south to more than 600 ft in the north. The Minnekahta remains a rather constant 30–50 ft thick throughout the area.

Structural Control

The Pahasapa and Minnekahta Limestones crop out at the surface because of deformation during the Laramide uplift of the Black Hills. The resource potential for limestone is high where the dip is low and the beds form extensive dip slopes along strike; the potential is lower where the dip is steep.

Age

The Pahasapa Limestone is Mississippian in age; the Minnekahta Limestone is Permian.

Deposit Description

Deposits in the Pahasapa Limestone consist of calcium-rich and magnesium-poor zones within the generally dolomite-rich limestone (Barnum, 1973; Schneider, 1973). No particular horizon within the Pahasapa is rich in calcium, and only 5- to 15-ft thicknesses of the Pahasapa are normally low enough in magnesium to be considered resources for high-calcium limestone (Gries, 1975). Harrer (1966) notes that high-calcium limestone in the Pahasapa is most common in outcrops in the southern and southwestern Black Hills. All of the Pahasapa, except those areas with karst development, is a source for general aggregate and road material.

Deposits in the Minnekahta Limestone are restricted to an upper pure zone and a lower pure zone that average 20–25 ft thick (Gries, 1975). Throughout this thickness the magnesium content is less than 1 percent and the insoluble-residue content is very low. Material from the Minnekahta constitutes a high-calcium limestone resource that has been utilized in the preparation of cement and for the production of lime in Rapid City. The Minnekahta also is quite resistant to abrasion and hence is widely used for aggregate for cement, road metal, or rough dimension stone.

Geochemical Signature

Both the Minnekahta and Pahasapa are characterized by their lack of trace metals. Their outcrop extent is well known and no stream-sediment geochemical data are needed to define their extent.

Geophysical Signature

Geophysical techniques would not be of help in determining the extent, depth, or thickness of the Pahasapa and Minnekahta Limestones suitable for quarrying. Karst features along the upper contact of the Pahasapa possibly may be detected by surface geophysical techniques such as seismic-reflection profiling.

Assessment Criteria

1. Presence of Minnekahta or Pahasapa Limestones.
2. Low-dipping strata have a higher resource potential than do strata that dip steeply.

Assessment

Area M1.—This area around the Black Hills (pl. 2) includes the outcrop extent of the Pahasapa Limestone and is assigned a moderate potential for high-calcium limestone in medium-size, bedded sedimentary deposits. Due to the great thickness of the Pahasapa and its tendency to weather into cliffs, almost all outcrops could be utilized for aggregate and building materials. Areas in the southern and southwestern Black Hills contain the greatest amount of high-calcium limestone. Even in the northern Black Hills, in areas of moderate hydrothermal alteration associated with Tertiary igneous activity, the Pahasapa contains abundant unaltered material for use as aggregate and building materials.

Area M2.—The gently dipping outcrop extent of the Minnekahta Limestone is assigned a high potential for large, bedded sedimentary deposits of high-calcium limestone. Many quarries in this area produce limestone for a variety of uses in the Black Hills and surrounding areas.

Area M3.—The steeply dipping outcrop extent of the Minnekahta is assigned a moderate potential for large to medium-size deposits of high-calcium limestone.

Economic Significance

Most of the limestone in the Pahasapa is not a high-calcium variety suitable for chemical or metallurgical use (Schneider, 1973). However, Harrer (1966) does indicate that the Pahasapa contains low-magnesium beds in some quarries in the Black Hills. The best known of these occurs as reef-like deposits in the upper part of the unit in the Tilford area northwest of Rapid City. All of the Pahasapa is suitable for road metal, riprap, lime for sugarbeet processing, flux, and aggregate in concrete. The vast quantities of the Pahasapa will serve as a virtually limitless supply of limestone in the future.

Most of the Minnekahta Limestone is a high-calcium variety suitable for chemical and metallurgical uses. The South Dakota State Cement Plant in Rapid City utilizes the limestone from the Minnekahta to produce their cement products. The Minnekahta is also used for road metal, production of lime, aggregate, and building stone, and has a variety of other uses in the Black Hills area. The Minnekahta will continue to be a source of high-calcium limestone for many years to come.

Evaporite Deposits (N)

Commodities

Gypsum.

Host Rocks

Deposits are in the lower part of the Spearfish Formation and the lower part of the Gypsum Spring Formation (unit ₰Ps and, locally, part of unit Jsg, pl. 1). Most of the gypsum has been produced from beds in the lower 200–250 ft of the Spearfish where the gypsum beds range in thickness from 6 ft to more than 75 ft (Bowles and Redden, 1975). The lower part of the Gypsum Spring also contains a 25- to 30-ft-thick gypsum bed, but this thins to the south and is not present in the southern Black Hills. The underlying Opeche Shale and Minnelusa Formation also contain beds of gypsum, but they rarely exceed 10 ft in thickness and are interbedded with shale and siltstone. The Minnelusa contains as much as 200 ft of evaporite in beds in the subsurface around the Black Hills region, but these cannot be exploited at the present time.

Structural Control

Structural control of the gypsum deposits is similar to that of the Paleozoic limestone units; steeply dipping outcrops of gypsum have a lower resource potential than do gently dipping outcrops. Most of the Spearfish Formation dips away from the central Black Hills at a low angle, and the resource potential therefore does not vary greatly from place to place.

Age

The Spearfish Formation ranges in age from Permian to Triassic; the Gypsum Spring Formation is Jurassic.

Deposit Description

Deposits are massive, undulating beds of gypsum within shale and siltstone of the Spearfish and Gypsum Spring Formations. No other evaporite minerals are known to exist in the deposits, although the gypsum appears to grade into anhydrite in the subsurface. Individual gypsum beds in the southeastern Black Hills, near Hot Springs, are as thick as 50 ft and are continuous for miles along strike. Analyses in Bowles and Redden (1975) indicate that the gypsum contains only minor amounts of iron, magnesium, and silica.

Geochemical Signature

The Spearfish and Gypsum Spring Formations could be delineated by their sulfur and sulfate content, but, because the outcrop extent of the two formations is well known, such characterization is unnecessary. The NURE stream-sediment geochemistry is of little help in delineating areas that have abundant gypsum.

Geophysical Signature

On aerial radiometric maps the Spearfish Formation stands out as a potassium and thorium high as compared to the adjacent strata, the Minnekahta Limestone and Sundance Formation (EG&G geoMetrics, 1979a, b, c, 1980a; Texas Instruments, Inc., 1979). The Spearfish also contains areas with slight uranium anomalies, not exceeding 2–5 ppm equivalent uranium. The shale and siltstone in the formation appears to be the source of these slight metal enrichments, not the gypsum beds.

Assessment Criteria

1. Presence of Spearfish Formation or Gypsum Spring Formation.
2. Gypsum beds at the surface are preferred, but not necessary, because facies changes are rapid and large bodies of gypsum could be encountered at depth but not be indicated at the surface.

Assessment

Area N1.—Gently dipping strata of the Spearfish and Gypsum Spring Formations in area N1 are assigned a high potential for medium-size, bedded sedimentary deposits of gypsum (pl. 2). This high potential is assigned for most of the two formations around the entire Black Hills except in areas of steep dip or limited exposure.

Area N2.—Within area N2 the steeply dipping beds of the Spearfish and Gypsum Spring Formations have a lower potential than they do in area N1. Area N2 is assigned a moderate potential for medium-size deposits of gypsum (pl. 2).

Economic Significance

Gypsum currently is produced from the Black Hills region only by the South Dakota State Cement Plant for use in the production of various cement products. A major use for the gypsum in the region could be in building products, particularly plaster and dry-wall, but demand for the products is apparently not high enough for it to be used this way at the present.

Roll-Front Deposits in Cretaceous Rocks (O)

Commodities; Trace Metals

Uranium and vanadium; selenium and arsenic.

Host Rocks

Deposits are found throughout the Inyan Kara Group, which consists of the Lakota Formation and the Fall River Sandstone, preferentially in channel-sandstone lenses. Minor occurrences of uranium are known in many Paleozoic and Mesozoic rocks in the Black Hills area, but commercial uranium has been produced only from the Inyan Kara Group, both in the southern and northwestern Black Hills. Other units, especially the Minnelusa Formation, contain abundant breccia pipes and collapse features that could host deposits of uranium; they should not be excluded from consideration as areas of resource potential. In the southern Black Hills the Inyan Kara Group ranges from 255 to 670 ft in thickness; it thins slightly to the west and north and is only 200–400 ft thick in the northwestern Black Hills. The Inyan Kara Group is composed of nonmarine units of sandstone, siltstone, and minor shale characterized by rather rapid lateral facies changes.

Structural Control

The localization of uranium ore apparently has been controlled by the direction of groundwater movement through the stratigraphic section. Gott, Wolcott, and Bowles (1974), among others, suggested that the uplift of the Black Hills in Laramide time led to the development of artesian flow through the Paleozoic and Mesozoic rocks flanking the uplift. They suggested that basement fractures, fault zones in the Phanerozoic rocks, channel systems in the Inyan Kara Group, and evaporite beds and solution-collapse features in the underlying rocks have controlled the movement and deposition of uranium. Structural features, in their view, have controlled much of the ore deposition process. Until the uranium deposits have been accurately dated, their age and the role of structure in their formation are unsure.

Age

The uranium deposits in the Inyan Kara Group of the Black Hills region are younger than the Inyan Kara Group. Uranium deposits in the southern Black Hills have not been radiometrically dated, but could be considerably younger than their enclosing strata. Until more precise dating of the deposits is undertaken their age will remain unknown.

Deposit Description

Deposits are lens-shaped bodies having a characteristic roll-front geometry (Bidgood, 1973). The roll front itself is an interface between oxidized and unoxidized material and usually forms one side of the deposit. Other sides are diffuse zones where ore-grade material grades into the host rock. The roll front is presumed to represent the interface of an advancing groundwater system in which unoxidized host rock is present on the leading side and oxidized and mineralized material is present behind the front. Mineralized material is commonly in the form of an irregularly shaped lens that is stratiform but not confined to a specific bed. Abundant carbonaceous material is typically associated with the deposits and may have caused the precipitation of the uranium and vanadium. The deposits are tabular and many times longer and wider than they are thick. Individual roll-front deposits may be 10–50 ft thick and as much as 1,000 ft in lateral extent.

Common ore minerals are uraninite and coffinite in unoxidized deposits, and carnotite, autunite, uranophane, and tyuyamunite in oxidized deposits. A large number of rare and secondary uranium- and vanadium-bearing minerals have been identified. Vanadium-uranium ratios range from 4:1 to 1:4 (Gott and Schnabel, 1963). Gangue consists of pyrite, carbonate minerals, carbonaceous matter, silica, and iron oxide minerals.

Geochemical Signature

In addition to the uranium and vanadium, the deposits contain anomalous concentrations of selenium, arsenic, and molybdenum, and minor amounts of manganese and strontium (Butz and others, 1980; C. H. Maxwell, unpub. data, 1985). Regional reconnaissance of the Hot Springs 1°×2° quadrangle (Union Carbide Corp., 1979) detected the main uranium-producing district north of Edgemont and showed it to be an area of anomalous uranium in stream-sediment samples. That sampling did not detect anomalies for the trace metals in the deposits noted above. Regional reconnaissance of the northwestern Black Hills (Warren and others, 1980) detected uranium anomalies near some of the major uranium mines but again failed to pinpoint other known mineralized districts. Much of the failure of the NURE regional reconnaissance geochemical surveys was due to the low sample density over the region.

Detailed stream-sediment sampling of the Edgemont area (Butz and others, 1981) and the western part of the Hot Springs 1°×2° quadrangle (Butz and others, 1980) indicated a much better agreement between the distribution of known uranium deposits and that of areas anomalous in uranium, selenium, scandium, arsenic, and chromium. Stream-sediment sampling did not reveal a good correlation between presence of molybdenum and areas of uranium mineralization, as might have been expected.

Detailed sampling of ground water in the Edgemont area revealed a good correlation between areas of uranium mineralization and anomalous concentrations of uranium and arsenic in the water. A much poorer correlation was noted between molybdenum and scandium in the water. Both of these techniques were utilized in the assessment of mineral resource potential.

Geophysical Signature

Aerial radiometric maps (EG&G geoMetrics, 1979a, b, c, 1980a; Texas Instruments, Inc., 1979) define the areas of known production much better than do the regional stream-sediment surveys. Both the southern and northwestern Black Hills uranium districts have prominent airborne uranium anomalies and high ratios of uranium to thorium. These maps have been utilized in assessing the resource potential in the following sections.

Other geophysical techniques, such as magnetic and gravity surveys, would be much less helpful in determining areas of resource potential because the deposits are not characterized by anomalous concentrations of magnetic minerals nor by rocks of anomalous density.

Assessment Criteria

1. Presence of the Inyan Kara Group in outcrop; either the Lakota Formation or the Fall River Sandstone or both are favorable host rocks. Other rock units, such as the Minnelusa Formation, contain uranium in stratabound horizons and in breccia pipes, but none of these has been proven to contain economic concentrations of uranium or vanadium.
2. Alteration and oxidation of the host rocks, specifically the channel sandstone within the units.
3. Presence of carbonaceous material that could act as a reductant to trap uranium and vanadium.
4. Anomalous surface radioactivity would reveal shallow surficial deposits but would not be helpful in locating buried deposits.
5. Presence of such rare gases as helium, radon, and tritium (Bowles and others, 1980) may be helpful in determining the location of buried uranium deposits.

Assessment

Area O1.—Two areas are labeled O1, one east of Carlile in the northwestern Black Hills, and one northeast of Burdock, near Edgemont (pl. 2). Both have a high potential for medium-size stratabound roll-front deposits containing uranium and vanadium. The northern area near Carlile contains the Carlile mine, the second-largest uranium producer in the northwestern Black Hills. Only the Hauber mine, north of Missouri Buttes, has produced more uranium ore (U.S. Dept. of Energy, unpub. data, 1985). This area contains favorable channel-sandstone stratigraphy (Robinson, Mapel, and Bergendahl, 1964; Maxwell, 1974) and has airborne radiometric uranium anomalies and a high ratio of uranium to thorium (EG&G geoMetrics, 1979b). Reconnaissance stream-sediment sampling by Warren and others (1980) reveals minor uranium anomalies in this area.

The O1 area near Burdock contains the Freezeout and Triangle mines and has airborne radiometric uranium anomalies and a high ratio of uranium to thorium. In addition, stream sediments from this area contain anomalous concentrations of uranium, arsenic, vanadium, and scandium (Butz and others, 1980).

Area O2.—Eight areas labeled O2 have a moderate potential for medium to small stratabound deposits in the Inyan Kara Group. One area east of Hulett (pl. 2) has no known mines but contains airborne radiometric uranium anomalies that suggest the presence of mineralized material near the surface.

An area north of Aladdin contains four small mines, has favorable stratigraphy, and has airborne uranium anomalies and a high ratio of uranium to thorium. This region is just north of the small coal fields at Aladdin and possibly could produce subbituminous coal as a byproduct of uranium mining.

An area northeast of Carlile, adjoining area O1 on the west, has stratigraphy similar to that of the known uranium mines near Carlile and has larger airborne uranium anomalies than does area O1 to the east. Warren and others (1980) reported slightly anomalous uranium concentrations in stream-sediment samples from this area.

On the west slope of the Bear Lodge Mountains, west of Warren Peaks (pl. 2, fig. 21), is an area of Inyan Kara Group that has a large airborne radiometric uranium anomaly. The anomaly is not due to the Tertiary intrusive rocks to the east, which are known to be radioactive (Staatz, 1983), but appears to be directly over the Lakota Formation in the Nefsy Divide quadrangle. This area is assigned a moderate potential for uranium deposits in the base of the Lakota.

The Houston Creek area, southwest of Sundance (pl. 2), is characterized by a large zone of modest radiometric uranium anomalies (EG&G geoMetrics, 1979a, b). It contains no uranium mines but is assigned a moderate potential because of favorable stratigraphy, reconnaissance stream-sediment anomalies (Warren and others, 1980), and the radiometric anomalies.

Southwest of Inyan Kara Mountain is an O2 area of moderate potential within the Lakota Formation and Fall River Sandstone. Uranium deposits are known a short distance to the south, and this area contains moderately large airborne radiometric uranium anomalies and high ratios of uranium to thorium. It is therefore assigned a moderate potential.

North of Newcastle and east of the Cambria coal field is a small area of the Lakota Formation that is characterized by modest airborne radiometric uranium anomalies (EG&G geoMetrics, 1979b, c). Only a small part of the Lakota Formation is present in this area, and the airborne anomaly may be due, in part, to anomalous radioactivity from the underlying Spearfish Formation.

The last area having moderate potential is a small region north of Burdock that borders the O1 area described previously. The only difference between this O2 area and the O1 area is that stream-sediment geochemical data from Butz and others (1980) show no sizeable anomalies in this area. The surrounding area of Inyan Kara Group therefore has a moderate potential as opposed to a high potential.

Area O3.—Two areas in the southern Black Hills designated O3 have a high potential for medium-size roll-front uranium deposits, one east of Clifton, near the Wyoming–South Dakota state line (pl. 2), and one that includes the Edgemont mining district (fig. 22, pl. 2). The one east of Clifton contains the Wicker-Baldwin mine and the Alray prospect, has extensive airborne radiometric uranium anomalies showing high ratios of uranium to thorium, and has favorable stratigraphy in the Inyan Kara Group. Additionally, Butz and others (1980) detected anomalies in both stream sediments and groundwater collected from the area. Uranium, molybdenum, arsenic, and scandium were present in anomalous amounts in the samples.

The Edgemont mining district (fig. 22, pl. 2) has produced most of the uranium ore in the southern Black Hills (Schnabel, 1975). Production has come from a number of mines, the largest of which are the Gould, Triangle, and Runge (U.S. Dept. of Energy, unpub. data, 1985). All of the mining district and additional land to the east and west is assigned a high potential for medium-size uranium deposits. Extensive airborne radiometric uranium anomalies (Texas Instruments, Inc., 1979), anomalous concentrations of uranium, vanadium, molybdenum, arsenic, and selenium in stream sediments and groundwaters (Butz and others, 1980; Truesdell, Daddazio, and Martin, 1982), and the presence of favorable stratigraphy in the Inyan Kara Group rocks give this area its high potential.

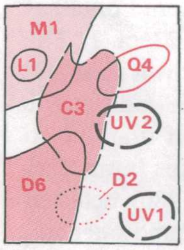
Area O4.—Four areas that have moderate potential are identified in the Black Hills. One area, north of Clifton (pl. 2), is the northern extension of one area O3 discussed above. It has stratigraphy very similar to the area having high potential but lacks airborne radiometric anomalies and stream-sediment anomalies, and hence is assigned a moderate potential for roll-front uranium deposits.

A large area north of Angostura Reservoir (pl. 2) on the east flank of the Cascade anticline also has a moderate potential. Stratigraphy in the region is similar to that in the Edgemont mining district to the west, but this area lacks the airborne radiometric anomalies and stream-sediment anomalies common in that district. The outcrops of the Inyan Kara may have been leached and the original uranium transported down-dip into area O5, which is discussed in a following section.

South of Rapid City is a small outcrop area of Inyan Kara Group rocks (pl. 2) that shows an airborne radiometric uranium anomaly having a high ratio of uranium to thorium. The anomaly is close to outcrops of the Tertiary White River Group, which may have contributed to the size of the anomaly. This area has a moderate resource potential.

The last O4 area is west of Fairburn in a region where the Inyan Kara Group changes from nonmarine strata in the south to marine strata in the north (Dandavati, 1981; Dandavati and Fox, 1981; Truesdell, Daddazio, and Martin, 1982). Airborne radiometric

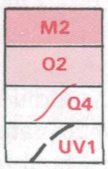
EXPLANATION



Areas having mineral resource potential—Boundaries are dashed or dotted where necessary to show limits of overlapping areas. Areas are labeled by letter and number corresponding to entries in the table below. Where two or more overlapping areas have different levels of potential, the overlapping area is colored to show the highest potential determined.

In the example at left C3 is an area of high mineral resource potential that is overlapped on the right by Q4, an area of low potential, and by UV2, an area of unknown potential. Area M1, which has moderate potential, overlaps area C3 and also contains an area of low potential, L1. Area D6, which has high potential, overlaps C3 and is overlapped by area D2, which has low potential. Area UV1 is an area of unknown potential.

The map must be used together with the table to interpret correctly the potential of overlapping areas



High mineral resource potential

Moderate mineral resource potential

Low mineral resource potential

Unknown mineral resource potential

Levels of resource potential

- **H** High mineral resource potential
- **M** Moderate mineral resource potential
- **L** Low mineral resource potential
- **U** Unknown mineral resource potential

Levels of certainty

- **D** Data define geologic environment and level of resource potential and indicate resource-forming processes in all or part of the area
- **C** Data partially define geologic environment and indicate a resource potential and indicate resource-forming process in some of the area
- **B** Data partially define geologic environment and suggest level of resource potential
- **A** Available data not adequate for evaluation of resource potential

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
M2	High------	H/D	High-calcium limestone----	Large, bedded sedimentary.
N1	High------	H/D	Gypsum--------------------	Medium, bedded sedimentary.
O3	High------	H/D	U, V----------------------	Medium, stratabound.
O5	Moderate--	M/C	U, V----------------------	Medium-large, stratabound.

LIST OF MAP UNITS

Tw	**White River Group (Oligocene)**
Km	**Mowry Shale (Lower Cretaceous)**
Ks	**Skull Creek Shale (Lower Cretaceous)**
Kf	**Fall River Sandstone (Lower Cretaceous)**
Klk	**Lakota Formation (Lower Cretaceous)**
Jm	**Morrison Formation (Upper Jurassic)**
Jsg	**Sundance Formation (Upper and Middle Jurassic) and Gypsum Spring Formation (Middle Jurassic)**
T̄RPs	**Spearfish Formation (Triassic and Permian)**
Pmo	**Minnekahta Limestone and Opeche Shale (Lower Permian)**
PIPm	**Minnelusa Formation (Lower Permian and Pennsylvanian)**

Contact—Dashed where approximately located

Anticline

SCALE 1:100,000

0 1 2 3 MILES

Figure 22 (above and facing page). Mineral resource potential map for locatable commodities in the Edgemont area, Black Hills National Forest, S. Dak. Geology shown alone in figure 12. Base from U.S. Geological Survey, Hot Springs (advance edition), and Mount Rushmore, 1977.

uranium anomalies in this area of the Lakota Formation and Fall River Sandstone have high ratios of uranium to thorium and do not appear to be affected by any White River Group rocks. The area has a moderate potential for marine-type roll-front deposits similar to those described for central and western Texas (Galloway, 1978; Goldhaber, Reynolds, and Rye, 1978).

Area O5.—A large region extending from near Clifton on the west to north of Hermosa on the east (pl. 2) has a moderate potential for medium to large roll-front uranium deposits that could be exploited by underground solution mining. Sampling of well water and deep borings by Truesdell, Daddazio, and Martin (1982) revealed the presence of anomalous concentrations of uranium, sulfur, arsenic, and selenium in the buried Inyan Kara Group and overlying Cretaceous shale. Uranium deposits may be forming at the present time in this environment as artesian waters pass downward through the Inyan Kara Group from their recharge zones around the flank of the Black Hills uplift.

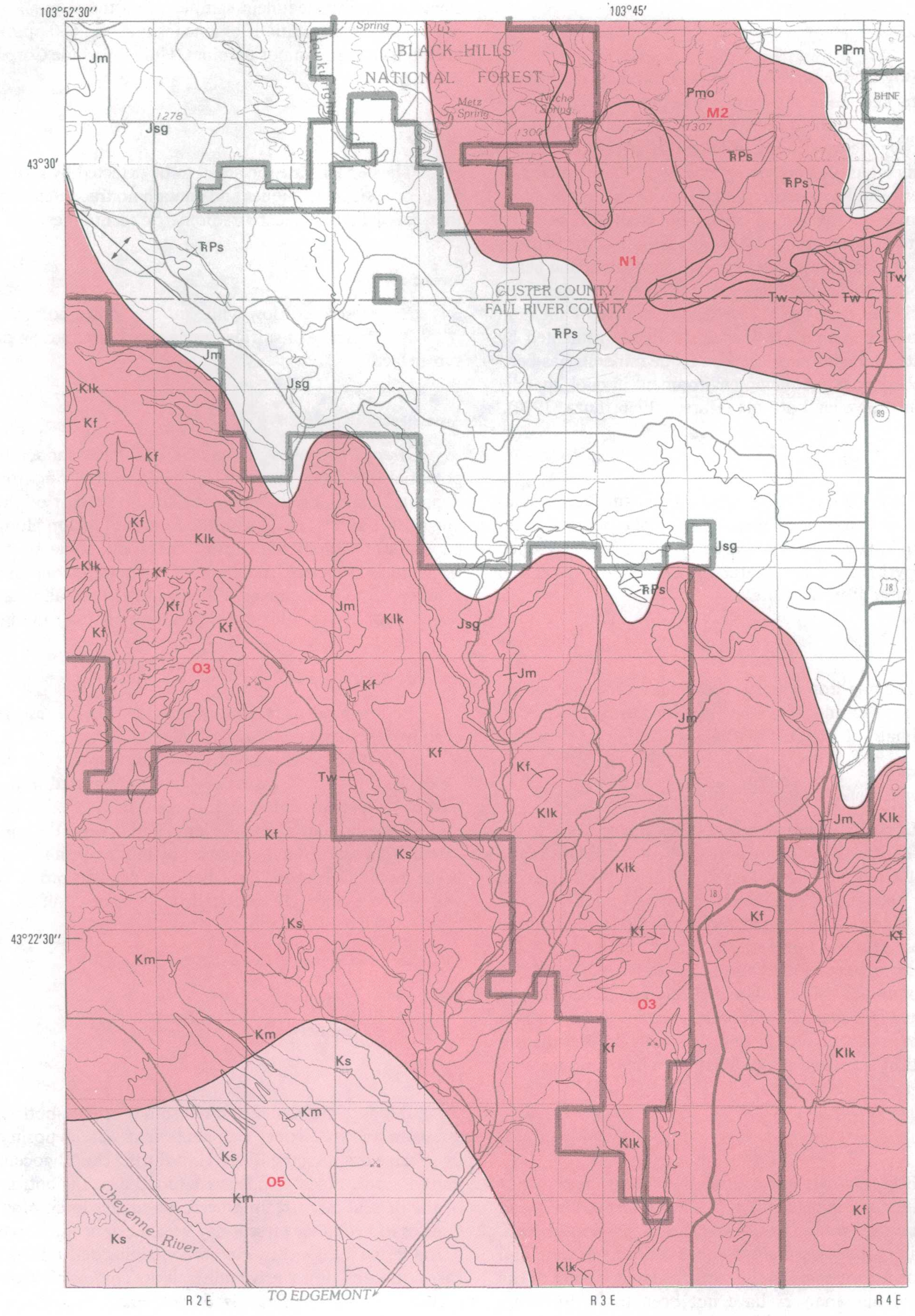
Economic Significance

Nearly all the uranium produced in the Black Hills has come from rollfront deposits in the northwest and southern regions. Although the quantity of uranium produced from the Black Hills is small compared to that from the Colorado Plateau, the deposits will remain important sources and exploration targets for the foreseeable future.

Quaternary Bog-Iron Deposits (P)

Commodities; Byproducts

Iron; gold.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103°45'
43°30'
43°22'30''
T6S
T7S
T8S
R2E
R3E
R4E
BLACK HILLS
NATIONAL FOREST
BHNF
Spring
Metz Spring
Spring
CUSTER COUNTY
FALL RIVER COUNTY
Cheyenne River
TO EDGEMONT
M2
N1
O3
O3
O5
Jm
Jsg
TRPs
Pmo
PIPm
Tw
Klk
Kf
Ks
Km
89
18

Host Rocks

Bog-iron deposits are found in modern-day stream bottoms and along canyon walls in the west-central core of the Black Hills, near Rochford. The deposits are formed by the weathering of Proterozoic iron-formation, slate, metabasalt, and metagraywacke. These units contain pyrite and pyrrhotite, which oxidize to form limonite and goethite, the major ore minerals of the bog-iron deposits. However, most of the iron sulfides occur in zones within black graphitic slate and iron-formation, and hence the bog-iron deposits develop preferentially where the bedrock is of these types. The deposits consist of alluvium and colluvium that are loosely to firmly cemented by limonite. Deposition of the iron oxide minerals has been controlled by the reducing environment in cool, marshy bogs in the valley bottoms (Harrer, 1966; Luza, 1970).

Structural Control

Steep, sinuous valleys contain very small accumulations of bog iron; wide, meandering flood plains contain large and thick deposits. The deposits are best developed above pyritic slate, but weathering of iron-formation also yields large iron deposits.

Age

The bog-iron deposits are of Holocene to Pliocene age and are forming and being modified today in the cool, wet climate of the central Black Hills.

Deposit Description

Deposits are lens-shaped bodies that conform to the shape of the valley floor and walls. Most deposits are many times longer than they are wide or thick (Harrer, 1966). The largest bogs are as much as 1.5 mi long and 500 ft wide and have a maximum thickness of about 20 ft. Most deposits range in thickness from 3 to 10 ft, in width from 200 to 300 ft, and in length from 300 to 2,000 ft. Colluvium of weathered Proterozoic bedrock is cemented by a matrix of limonite, goethite, and other iron oxide minerals. Rarely, the bog lacks colluvial detritus and consists of organic-rich mud that has a high limonite content (Harrer, 1966; Luza, 1970).

Geochemical Signature

Bog-iron deposits contain anomalous amounts of iron, titanium, manganese, and sulfur (Harrer, 1966), and some contain minor concentrations of precious metals, including gold. Anomalous concentrations of zinc and uranium are expected in the reducing environment of the deposits, but analyses have not been made for these elements. Stream-sediment samples from the bogs show anomalous concentrations of zinc (as much as 600 ppm), cobalt, nickel, and minor uranium (Union Carbide Corp., 1980).

Geophysical Signature

The deposits are too small to be detected by standard geophysical techniques and contain no trace elements that could be detected by radiometric techniques.

Assessment Criteria

1. Presence of low-lying, marshy valley bottoms.
2. Presence of sulfide-bearing rocks in outcrop or subsurface.

Assessment

Area P1.—Areas designated P1 have moderate potential for iron in small to medium-size bog-iron deposits containing limonite and goethite. Most of the areas (pl. 2 and fig. 16) are in the Rochford region along tributaries to Rapid and Castle Creeks, but some are as far south as Deerfield Lake. Some of the bog-iron deposits near Rochford were derived from iron-formation and may contain gold extractable as a byproduct of iron mining.

Economic Significance

Bog-iron deposits contain the third-largest reserve of iron in the Black Hills, estimated at more than 500,000 tons of material averaging 25–56 percent iron (Harrer, 1966). Iron produced from the deposits was used in the past as an additive in the manufacture of cement at the South Dakota State Cement Plant, Rapid City. Because the environmental damage caused by mining iron is high in the mountain meadows, the bog-iron deposits probably will not be extensively exploited in the near future.

Quaternary and Tertiary Placer Deposits (Q)

Commodities; Byproducts

Gold; cassiterite.

Host Rocks

Deposits are found in modern-day stream-bottom alluvium and in Tertiary sediments that were deposited by streams draining the Black Hills during the Oligocene and Miocene. Placer deposits are found near the bottom of the present-day stream gravels, on higher level, older terraces related to the present-day streams, or near the base of the Tertiary sediments. Placers containing detrital gold, cassiterite, and other heavy minerals are commonly close to their source of mineralized rock; most placer gold can be traced back to lode-gold sources in Proterozoic rocks, although some may have received a minor contribution from the weathering of precious-metal deposits in Tertiary intrusive rocks and their Paleozoic wall rocks. Other placers may be derived, at least in part, from paleoplacers in the basalt part of the Cambrian Deadwood Formation.

Structural Control

Structure has controlled the localization of placer deposits very little. The flow patterns in streams are the primary controls for the deposition of detrital minerals, the heaviest minerals being deposited on the inside of oxbows and in pools cut into the bedrock.

Age

Placer deposits range in age from Oligocene to Holocene. Most of the gold produced has been recovered from Holocene gravels in modern-day stream valleys. Gold, cassiterite, and other heavy minerals could be concentrated in paleostream deposits in Tertiary rocks as well.

Deposit Description

Deposits are irregularly shaped placer accumulations of heavy minerals (for example, gold, cassiterite, columbite, magnetite, zircon). An entire drainage basin is usually prospected, but the heaviest minerals are restricted to thin units near the bottom of the alluvium and gravel. The deposits are laterally more extensive than they are thick, but individual "paystreaks" in the sediment may be almost any shape.

Geochemical Signature

All placer deposits in the Black Hills contain anomalous amounts of iron (magnetite), titanium (ilmenite), and zirconium (zircon), but only certain ones contain gold, tin, tantalum, niobium, and other rare metals. Because concentrations of all heavy minerals in placer deposits are rather low (less than 20 percent), panning of the stream sediment is usually necessary to concentrate the anomalous elements sufficiently for chemical analysis. Conventional stream-sediment analysis as conducted by the NURE sampling program on less-than-100-mesh samples is usually ineffective in detecting anomalous concentrations of trace metals in placer deposits. As an example, known gold placer deposits along Whitewood Creek north of Deadwood were not detected by Union Carbide Corp. (1980). The NURE geochemical data generally do not outline areas of precious-metal concentrations in the placers because the detection limits for gold and silver are too high. However, reconnaissance sampling by Warren and others (1980) detected tin, titanium, and lithium anomalies in the placer deposits along Sand Creek northwest of Tinton (pl. 1, fig. 20), indicating that rich placer deposits might be detected by the conventional analyses.

Geophysical Signature

The ore deposits are much too small to be detected by any geophysical techniques and contain no concentrations of trace elements that could be detected by radiometric techniques. The total thicknesses of placer gravels can be determined by seismic refraction or reflection profiles.

Assessment Criteria

1. Presence of modern-day stream gravels or gravel deposits in Tertiary sediments.
2. Anomalous concentrations of titanium, iron, or base and precious metals.

Assessment

Area Q1.—This area on the east side of the Bear Lodge Mountains (pl. 2, fig. 21) has a moderate potential for rare-earth minerals and gold in small to medium-size placer deposits in present-day stream channels and in conglomeratic strata of the Miocene Ogallala Formation and Oligocene White River Group (Staatz, 1983). Possible recoverable commodities include gold and detrital minerals rich in rare-earth elements, manganese, thorium, titanium, lead, and uranium. Stream sediments from the area contain anomalous concentrations of thorium, manganese, cerium, lanthanum, lead, and barium (Warren and others, 1980), which reflect the very large concentrations of rare-earth elements that are associated with the Tertiary intrusive rocks of the area.

Area Q2.—Streams that drain the Tinton area (pl. 2, fig. 20) have a moderate potential for gold, tin, tungsten, and tantalum in small placer deposits. Native gold and cassiterite have been produced from the beds of Sand Creek, Bear Gulch, and Potato Creek (Connolly, 1933; Norby, 1984). Some of the largest gold nuggets in the Black Hills have been recovered from the Tinton area placers (O'Harra, 1931). Stream sediments in the area contain anomalous concentrations of tin, titanium, iron, copper, vanadium, lithium, scandium, manganese, cerium, calcium, and beryllium (Warren and others, 1980). The tin, lithium, scandium, cerium, and beryllium are probably derived from Precambrian pegmatite, and the iron, titanium, copper, and manganese are probably derived from the Tertiary intrusive center discussed in a later section.

Area Q3.—The Lead-Deadwood area produced the largest amount of placer gold in the Black Hills region (O'Harra, 1931; Connolly, 1933), principally from

Whitewood Creek and its tributaries. Accordingly, the area (pl. 2, fig. 18) is assigned a moderate potential for gold in medium to small placer deposits in the modern-day stream gravels and in gravel horizons within the White River Group. NURE stream-sediment sample localities are too widely spaced to evaluate the potential of the area, and Whitewood Creek is so contaminated by trace metals from the tailings of the Homestake mine that samples would be almost meaningless for a placer evaluation.

Area Q4.—A number of areas designated Q4 are assigned a low potential for small placer accumulations of gold, including the False Bottom Creek and Bear Butte Creek areas (fig. 18), Middle Boxelder Creek above Roubaix Lake, the channels of Rapid Creek and Castle Creek above Silver City (pl. 2, fig. 16), and French Creek upstream and downstream from Stockade Lake, east of Custer (pl. 2).

The False Bottom Creek area includes outcrops of the White River Group northwest of Lead and modern-day stream beds along False Bottom Creek. Very minor placer production is known from False Bottom Creek and none is documented from the White River Group. There are no NURE stream-sediment analyses for this area.

The Bear Butte Creek area also has a low placer potential in the present-day stream bed and in gravels of the White River Group that were deposited by paleostreams draining to the east. The only sample collected from Bear Butte Creek (Union Carbide Corp., 1980) contains highly anomalous concentrations of copper, lead, zinc, thorium, and uranium, all of which are suspected of being derived from the disseminated gold deposit at the Gilt Edge mine and replacement deposits in the Deadwood Formation along Bear Butte Creek.

Middle Boxelder Creek above Roubaix Lake has a low potential for gold in small placer deposits because the stream drains areas containing gold-bearing iron-formation. There are no geochemical data from the area.

The stream channels of Rapid Creek and Castle Creek have yielded small amounts of placer gold, presumably derived from weathering of gold-bearing iron-formation and quartz veins. NURE stream-sediment sample localities are too widely spaced to aid the resource assessment.

The last area having a low potential for small placer deposits is along French Creek east of Custer. Gold was first discovered in the Black Hills by the Custer Expedition of 1874 along French Creek, and a small amount of gold was produced from gravels in the creek. NURE stream-sediment geochemical data are of little help in the assessment of the area.

Area Q5.—This area northeast of Keystone (pl. 2, fig. 17), which includes the placer deposits near Rockerville, has a moderate potential for gold in small to medium-size deposits in both modern-day stream systems and the White River Group sediments. The placers at Rockerville produced the second largest amount of detrital gold in the Black Hills after the Lead–Deadwood placers (Connolly, 1929). Gold in the placers probably was derived from small quartz veins and iron-formation in the vicinity of Silver Mountain and also from reworking of detrital gold in the basal Deadwood Formation. No stream-sediment geochemical data are available for the area.

Area Q6.—Two areas designated Q6, one east of Keystone (pl. 2, fig. 17) and one southwest of Custer (pl. 2), have moderate potential for gold from small placer deposits. The region east of Keystone along Battle Creek and its tributaries has yielded a moderate amount of placer gold, presumably derived from weathering of gold-rich iron-formation and quartz veins in the Keystone area. Small amounts of tin and tantalum have been produced from the placers, both metals presumably being derived from pegmatites in the Keystone area. NURE geochemical surveys did not detect anomalous gold in the sediments from this area, primarily because of the high detection limit for gold in the NURE studies.

The other Q6 area of moderate potential is along Lightning Creek and its tributaries southwest of Custer, where small amounts of placer gold presumably derived from small quartz veins in metabasalt have been produced. NURE geochemical data indicate anomalous concentrations of copper and zinc in one sample from this stream, but are of little help in assessing the placer gold potential of the area.

Area Q7.—Four areas, two in the Keystone region (fig. 17) and two in the Medicine Mountain region (fig. 19), are assigned low potential for gold in small placer deposits. The two areas north of Keystone are along Spring Creek downstream from Sheridan Lake and along South Victoria Creek. Both areas are downstream from areas containing small quartz veins in pyritic slate and metabasalt. Placer gold apparently has not been produced from these streams in the past, but geologic conditions are favorable for its concentration in the streams mentioned.

The two Q7 areas in the Medicine Mountain region are along Spring Creek downstream from iron-formation exposed to the west and along the North Fork of French Creek and its tributaries (fig. 19). Placer gold has been produced from the latter place but not the former. Gold along French Creek apparently has been derived from weathering of quartz veins that cut metagraywacke. Stream sediments (Union Carbide Corp., 1979) in this area contain slightly anomalous concentrations of zinc.

Area Q8.—One area in the central Black Hills, east of Hill City (pl. 2, fig. 17), has a low potential for gold and byproduct tin and tungsten from small placer deposits. Cassiterite has been produced from gravels along Spring Creek and its tributaries (Connolly, 1929). NURE stream-sediment geochemical data are of little help in the assessment of potential because Union Carbide Corp. (1980) did not analyze samples for tin, tungsten, or tantalum.

Economic Significance

The Black Hills will continue to produce much more gold from lode deposits than from placers. However, the placer deposits can be worked by individuals or small mining concerns, whereas only large mining firms have the capital to invest in lode-gold deposits. Undesirable environmental effects from placer mining can be diminished through prudent mining practices. If this is done, the placers can be a source of gold and tin for some years into the future.

Miscellaneous Phanerozoic Deposits

Detrital Deposits in the Deadwood Formation (R)

Commodities

Iron.

Host Rocks

Deposits are in the basal part of the Deadwood Formation or at its contact with the underlying Proterozoic units. The Deadwood crops out continuously around the core of the Black Hills, but detrital iron deposits have been found in only a few places.

Structural Control

Detrital iron deposits appear to have formed in proximity to bedrock highs that were a source of iron during deposition of the Deadwood Formation.

Age

Iron in the deposits was derived from Proterozoic rock units rich in hematite, pyrite, pyrrhotite, and magnetite. Weathering and enrichment of the iron took place prior to deposition of the Deadwood Formation, but the final deposition of the detrital iron minerals in the Deadwood took place in Middle Cambrian time.

Deposit Description

Deposits are irregularly shaped, detrital or reconstituted bodies of primary and secondary hematite and limonite in the basal part of the Deadwood Formation. Iron occurs in well-rounded grains of hematite, in hematitic residue around other detrital grains, and in hematite and limonite cement between the grains. Deposits are lens shaped and are seldom thicker than 20 ft; most are 4–10 ft thick. Few deposits have been defined by drilling, but most are thought to be less than 500–1,000 ft across. Harrer (1966) estimated that the deposits on Strawberry Ridge and near Hayward (described in following sections) contain about 100,000 tons of ore that averages 34–45 percent iron. Detrital iron deposits are generally not coincident with paleoplacer deposits because the reducing environment for preserving detrital hematite differs from the oxidizing environment of the well-sorted, clean gravel bars of the paleoplacers.

Geochemical Signature

The detrital iron deposits are too small to have been detected by NURE stream-sediment geochemical surveys. The only geochemical tracers for the iron deposits are iron and manganese, two elements showing high concentrations in almost all streams that drain Proterozoic rocks and bog-iron deposits. Geochemical data for soil downhill from the outcrop of the Deadwood Formation might indicate areas enriched in iron.

Geophysical Signature

The detrital iron deposits are too small to be detected by most geophysical techniques. Their lack of magnetite makes them undetectable by magnetic surveys, and they contain no radioactive elements that could be detected by airborne radiometric surveys.

Assessment Criteria

1. Presence of Deadwood Formation close to areas of hematite-, magnetite-, or sulfide-mineral-rich Proterozoic slate or iron-formation.
2. Presence of iron staining in the basal beds of the Deadwood or hematite-rich clasts in the basal conglomerate.

Assessment

Area R1.—The largest deposit of detrital hematite in the Deadwood Formation is on Strawberry Ridge, southeast of Deadwood (pl. 2, figs. 23 and 24). This area has a moderate potential for iron in a medium to small deposit. The area has two mines that have supplied iron ore for the South Dakota State Cement Plant in Rapid City (Harrer, 1966).

Area R2.—Two areas designated R2, one east of Keystone near Hayward (fig. 17) and one south of Bear Mountain (fig. 19), have a low resource potential for iron in small deposits in the basal part of the Deadwood. The area east of Keystone has been described by Harrer (1966) as containing detrital hematite concentrations at the base of the Deadwood Formation. One small mine has produced several hundred tons of iron ore from the area. The area south of Bear Mountain has not produced ore, but core drilling (Harrer, 1966) indicates that detrital hematite deposits at the base of Deadwood have a thickness of 3–13 ft and are continuous for at least 100 ft across strike.

Economic Significance

The detrital hematite deposits constitute a high-grade, easily extractable resource that can be utilized in local industries, especially the production of cement. The deposits on Strawberry Ridge probably will remain a small source of iron for the near future.

Phanerozoic Igneous-Related Deposits

Base-Metal-Rich Replacement and Vein Deposits in Paleozoic Rocks (S)

Commodities; Byproducts; and Trace Metals

Lead, zinc, and silver; gold and copper; bismuth and cadmium.

Host Rocks

Deposits are most common in the Deadwood Formation and the Pahasapa Limestone and are restricted to the northern Black Hills. Shapiro and Gries (1970) pointed out that nearly all the Paleozoic section in the northern Black Hills has been mineralized, but economic production has been restricted to the Deadwood and Pahasapa. The Deadwood in the northern Black Hills ranges between 350 and 500 ft thick and averages 400 ft. It thickens slightly to the north and west, being 350 ft thick in the east at Galena and more than 430 ft thick west of Deadwood. Staatz (1983) reports that the Deadwood Formation in the Bear Lodge Mountains north of Sundance is more than 700 ft thick. The Deadwood is composed of a basal quartz-pebble conglomerate and overlying siltstone, shale, sandstone, limestone, and dolomite (Kulik, 1965; Shapiro and Gries, 1970).

The Winnipeg Formation, Whitewood Dolomite, and Englewood Formation occur between the Deadwood and overlying Pahasapa in the northern Black Hills. All the units are predominantly limestone and dolomite with lesser amounts of shale and siltstone. Their aggregate thickness is about 180 ft.

The Pahasapa Limestone in the northern Black Hills varies between 300 and 630 ft thick and averages 550 ft in thickness. It is generally low dipping and is predominantly a massive, cliff-forming dolomite modified by abundant caves and solution breccias that are related to the disconformity at the top of the unit.

Structural Control

Almost all of the base-metal-rich deposits in the northern Black Hills are controlled by the orientation of major joint systems cutting the low-dipping beds. Each deposit normally consists of replaced units along bedding planes and "verticals" that may or may not be connected to replacement ore (Irving and Emmons, 1904; Shapiro and Gries, 1970). Most of the ore is concentrated in the flat-lying replaced beds. The verticals are actually ore-filled joints and fractures. The major verticals in each district in the Lead–Deadwood area have a characteristic strike, and commonly at least two verticals are well developed. Most of the main verticals are oriented northeast and dip at a high angle. Minor verticals are oriented at a high angle to the regionally important verticals. Many orebodies at the intersection of the two verticals are quite large and high grade.

Age

Throughout most of the northern Black Hills the replacement deposits in Paleozoic rocks are younger than, or the same age as, trachytic to rhyolitic sills emplaced in the strata and older than cross-cutting phonolite bodies. Where dated, the rhyolite and phonolite are approximately the same age. McDowell (1971) obtained a K-Ar biotite date of 58.2 ± 1.7 Ma for a phonolite dike in the Homestake mine and a K-Ar biotite date of 60.3 ± 1.8 Ma for rhyolite from the Gilt Edge mine. Thus the ore appears to have formed in late Paleocene time, or about 59 Ma.

Deposit Description

Deposits are replacements of favorable beds along flat channelways and replacements and open-space fillings along verticals in the Deadwood Formation. In the Pahasapa Limestone the ore forms irregular replacement masses and veins along verticals (Irving and Emmons, 1904; Shapiro and Gries, 1970). Replacement deposits in the Deadwood can occur at any stratigraphic level but are concentrated in the dolomitic strata and at the contacts of dolomite with shale and sandstone. Two horizons have been extensively mineralized throughout the northern Black Hills, the upper part of the Deadwood in the "upper contact zone" and the lower part of the Deadwood in the "lower contact zone" (Connolly, 1927; Connolly and O'Harra, 1929).

In the Galena area deposits are located in both the lower and upper contact zones of the Deadwood and occur largely as flat-lying replacement deposits in dolomite and sandy dolomite. Individual deposits in the lower contact zone range in thickness from an inch or two to more than 2 ft and are as much as 20 ft in width. The deposits are discontinuous along strike and down dip, but have been traced for as much as 3,000 ft in their longest dimension. Deposits in the upper contact zone are generally 18–30 in. thick and are irregular in extent along strike and down dip (Connolly, 1927; Connolly and O'Harra, 1929).

Primary ore minerals include argentiferous galena, loellingite, sphalerite, and minor amounts of chalcopyrite (Irving and Emmons, 1904; Connolly and O'Harra, 1929). Also, Garske (1968) identified arsenopyrite, pyrrhotite, and tetrahedrite in samples from the Double Rainbow mine, which contains the largest deposits in the Galena area. Grunwald (1970) indicated that, in addition to the above minerals, freibergite is an ore mineral. Primary gangue includes pyrite, siderite, calcite, and quartz. Most of the silver apparently is contained in galena. Secondary, or oxidized, ore minerals include oxides and carbonates of lead, cerargyrite, native silver, argentocorkite, argentojarosite, and minor covellite and acanthite.

Replacement deposits in the Pahasapa Limestone, which differ markedly from those in the Deadwood Formation, consist of unoriented mineralized fractures and breccia masses that have been extensively silicified (Irving and Emmons, 1904). In addition, there are smaller, flat-lying replacement bodies along bedding planes in the Pahasapa as well as nearly vertical mineralized fractures that persist downward for as much as 300 ft in some places. The Carbonate district contains most of these deposits (Shapiro and Gries, 1970).

The mineralogy of these replacement deposits in the Pahasapa also differs from those in the Deadwood Formation near Galena. Ore minerals consist of carbonates of lead, galena, cerargyrite, gold, and tellurium-bearing minerals (Connolly and O'Harra, 1929). Primary gangue consists of abundant jasper, considerable fluorite, and minor carbonate minerals. Secondary ores contain cerussite, cerargyrite, matlockite, wulfenite, pyromorphite, atacamite, and other minerals. The mineralogy of these deposits closely resembles the precious-metal-rich replacement ores in the Deadwood, which are discussed in a following section.

Geochemical Signature

The base-metal-rich deposits contain anomalous amounts of lead, zinc, arsenic, silver, gold, and vanadium (Shapiro and Gries, 1970), and probably contain significant quantities of bismuth, cadmium, and other trace metals commonly associated with lead and zinc deposits. NURE stream-sediment geochemical data (Union Carbide Corp., 1980) are of little help in assessing the resource potential because of the wide sample-locality spacing of that study. Because trace-element concentrations in present-day stream sediments in the northern Black Hills have been significantly modified by tailings and debris from past mining ventures, sampling of those streams probably would locate only the old mines and prospects. An example of this is provided by lead anomalies on Bear Butte Creek east of Bear Butte (pl. 2) that probably are due to mining operations at the Double Rainbow mine nearly 20 mi to the west. Shapiro and Gries (1970) have indicated that rock-chip geochemistry of the Deadwood and other units in the area is able to delineate geochemically anomalous areas related to mineralization.

Geophysical Signature

The replacement deposits in Paleozoic strata are too small and irregularly shaped to be detected by most geophysical techniques. Ground-based electromagnetic surveys might be able to detect the shallow, more massive, pyrite- and galena-rich deposits, but these are normally buried beneath too much overburden. Alteration near the deposits, primarily in the form of silicification and dolomitization, cannot be detected by airborne radiometric surveys but might be detectable by luminescence studies if the heavy forest cover did not render the study impossible.

Assessment Criteria

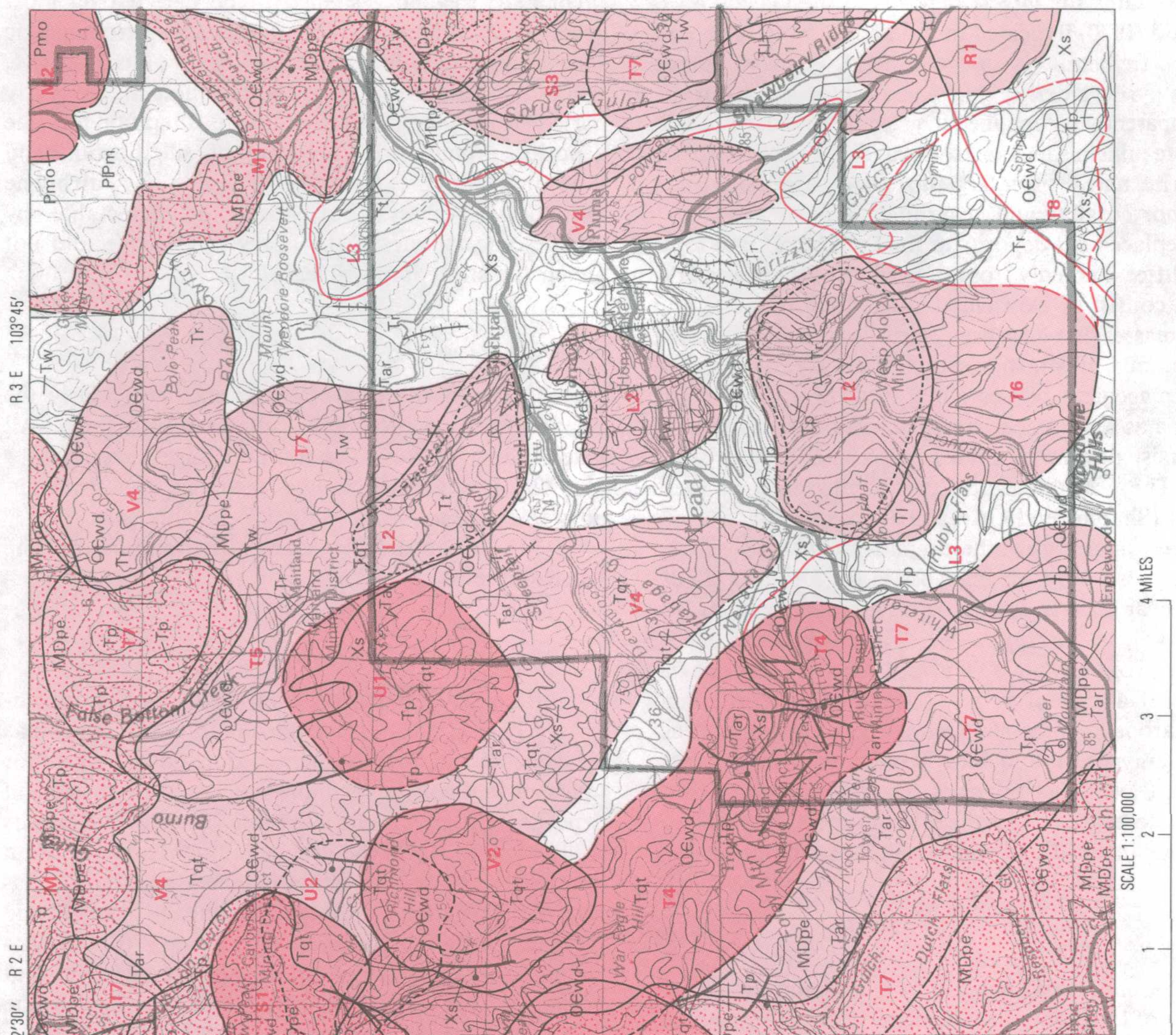
1. Presence of favorable strata, particularly the Deadwood Formation and Pahasapa Limestone. All Paleozoic strata could contain mineralized material.
2. Spatial association of favorable strata with Tertiary trachytic to rhyolitic stocks and sills.
3. Dolomitization and silicification of the Paleozoic rocks.

Assessment

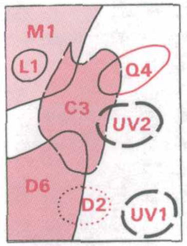
Area S1.—The mining camp of Carbonate, northwest of Lead (fig. 23), is included in this area, which has a high potential for lead, silver, zinc, gold, and minor tungsten in small to medium-size vein or replacement deposits, primarily in the Pahasapa Limestone. Deposits could occur in any of the Paleozoic strata, however, from the Deadwood Formation through the Minnelusa Formation. Principal mines in the area include the Iron Hill and the Seabury-Calkins (Shapiro and Gries, 1970). Deposits are primarily in northeast-striking, high-angle veins that presumably are related to Tertiary intrusive rocks to the south.

Area S2.—Two areas designated S2 in the northern Black Hills have a low potential for base metals in small vein or replacement deposits in Paleozoic strata. One area surrounds S1 and extends to the west of Carbonate (fig. 23), and the other is on the southeastern border of the Vanocker laccolith, west of Tilford (pl. 2; fig. 24). The area west of Carbonate is assigned a low potential for small vein or replacement deposits in Paleozoic strata. Stratigraphy, structure, and the fracture system in this area are similar to those in area S1. Very little ore has been produced from area S2, but the region could contain blind orebodies not detected by surface sampling (Shapiro and Gries, 1970). The S2 area west of Tilford is in a similar tectonic setting, where the Pahasapa Limestone is intruded by a hornblende quartz latite phase of the Vanocker laccolith. There are no mines in this area, but mineralized material may be present at depth.

Area S3.—This area includes the deposit at the Belle Eldridge mine south-southeast of Deadwood (pl. 2, figs. 23 and 24) and has a moderate potential for lead and zinc and minor amounts of precious metals and arsenic


R 1 E
R 2 E
R 3 E
103°52'30''
103°45'
T 5 N
T 4 N
44° 22' 30''
SCALE 1:100,000
0 1 2 3 4 MILES
Note: Only mineral resources related to Phanerozoic deposits are shown on this map of the Bald Mountain area. Refer to figure 18 for the distribution of mineral resources related to Proterozoic deposits. Some map areas are patterned to show them more clearly.

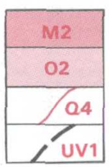
EXPLANATION



Areas having mineral resource potential—Boundaries are dashed or dotted where necessary to show limits of overlapping areas. Areas are labeled by letter and number corresponding to entries in the table shown at right. Where two or more overlapping areas have different levels of potential, the overlapping area is colored to show the highest potential determined.

In the example at left C3 is an area of high mineral resource potential that is overlapped on the right by Q4, an area of low potential, and by UV2, an area of unknown potential. Area M1, which has moderate potential, overlaps area C3 and also contains an area of low potential, L1. Area D6, which has high potential, overlaps C3 and is overlapped by area D2, which has low potential. Area UV1 is an area of unknown potential.

The map must be used together with the table to interpret correctly the potential of overlapping areas



High mineral resource potential

Moderate mineral resource potential

Low mineral resource potential

Unknown mineral resource potential

Levels of resource potential

H High mineral resource potential
M Moderate mineral resource potential
L Low mineral resource potential
U Unknown mineral resource potential

Levels of certainty

D ***Data define geologic environment and level of resource potential and indicate resource-forming processes in all or part of the area***

C **Data partially define geologic environment and indicate a resource potential and indicate resource-forming process in some of the area**

B **Data partially define geologic environment and suggest level of resource potential**

A **Available data not adequate for evaluation of resource potential**

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
L1	Low-------	L/C	Au-------------	Small-medium, paleoplacer.
L2	Moderate--	M/D	Au-------------	Medium-small, paleoplacer.
L3	Low-------	L/C	Au-------------	Small, paleoplacer.
M1	Moderate--	M/D	High-calcium--- limestone.	Medium, bedded sedimentary.
M2	High------	H/D	High-calcium--- limestone.	Large, bedded sedimentary.
R1	Moderate--	M/D	Fe-------------	Medium-small, stratabound.
S1	High------	H/D	Pb, Ag, Zn, Au (W).	Small-medium, vein or replacement.
S2	Low-------	L/C	Pb, Ag (Zn, Au)	Small, replacement or vein.
S3	Moderate--	M/D	Pb, Zn (Ag, Au)	Small, replacement.
T3	Moderate--	M/D	Au, Ag (Te, Cu)	Small, vein or replacement.
T4	High------	H/D	Au, Ag (As, F, Te).	Medium, vein or replacement.
T5	Moderate--	M/D	Au, Ag (Te, As)	Medium-small, vein or replacement.
T6	Moderate--	M/D	Au, Ag, W (As)	Small-medium, vein or replacement.
T7	Moderate--	M/C	Au, Ag (As, Te)	Medium-small, vein or replacement.
T8	Low-------	L/B	Au, Ag (Pb, Zn)	Small, vein or replacement.
T9	Moderate--	M/C	Au, Ag (Cu)----	Small, vein.
U1	High------	H/D	Mo, Cu (Ag, W, Pb).	Medium, disseminated or porphyry.
U2	Moderate--	M/C	Mo, Ag (Pb)----	Medium-small, disseminated.
V2	High------	H/D	Au, Ag (Cu)----	Medium, disseminated or porphyry.
V3	High------	H/D	Au, Ag---------	Medium-small, disseminated or porphyry.
V4	Moderate--	M/C	Au, Ag (Cu)----	Small, disseminated or porphyry.
W2	Moderate--	M/B	Th, REE (Au)---	Small, disseminated.

LIST OF MAP UNITS

Tw **White River Group (Oligocene)**
Tp **Phonolite (Eocene and Paleocene)**
Tar **Alkali rhyolite (Eocene and Paleocene)**
Tr **Rhyolite (Eocene and Paleocene)**
Tl **Latite (Eocene and Paleocene)**
Tqt **Quartz trachyte (Eocene and Paleocene)**
Tt **Trachyte (Eocene and Paleocene)**
Pmo **Minnekahta Limestone and Opeche Shale (Lower Permian)**
PIPm **Minnelusa Formation (Lower Permian and Pennsylvanian)**
MDpe **Pahasapa Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)**
O€wd **Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**
Xs **Metasedimentary and metavolcanic rocks (Early Proterozoic)**

Contact—Dashed where approximately located
Fault—Bar and ball on downthrown side

Figure 23. *Mineral resource potential map for locatable commodities in the Bald Mountain area, Black Hills National Forest, S. Dak. Geology shown alone in figure 14. Base from U.S. Geological Survey, Rapid City, 1977.*

(Allsman, 1940) in small replacement deposits. The deposits in this area may be genetically related to an intrusive complex to the southeast near the Gilt Edge mine (Mukherjee, 1968).

Area S4.—This region near Galena (fig. 24) includes the eastern part of the Galena mining district and has a high resource potential for lead, silver, and zinc in medium to small replacement or vein deposits that also contain very minor amounts of gold (Irving and Emmons, 1904; Connolly and O'Harra, 1929; Grunwald, 1970). The Galena area was a major producer of lead and silver, but production statistics are not available (Irving and Emmons, 1904). The largest mines in the area, the Double Rainbow, Florence, and Horseshoe-Comet, produced ore from both the lower contact and upper contact zones in the Deadwood. Some of the mines may have closed because of litigation regarding ownership, rather than because of depletion of ore. Drilling would be necessary to explore for blind ore deposits in the Galena area. Replacement deposits may be related to the intrusive complex to the west at the Gilt Edge mine, but this is unproven.

Area S5.—A small area on the northeast side of Black Buttes, southwest of Tinton (pl. 2), contains galena and sphalerite in small veins within the Pahasapa Limestone (Elwood, 1979). This area has a low resource potential for small replacement or vein deposits in Paleozoic strata. The veins are probably related to the Tertiary syenite and trachyte laccoliths that intrude the Pahasapa on the south and west.

Economic Significance

Base-metal-rich deposits in Paleozoic rocks produced ore primarily before 1885 and during the two World Wars when the demand for lead and zinc was high. The silver content of the ore made the mines profitable. New orebodies to be found in the areas probably would be blind, that is, unexposed at the surface, and exploration would be based on rock geochemistry and drilling. The high grade of silver found in most of the mines and the comparative ease of refining the ores make these replacement and vein deposits viable future exploration targets. The largest deterrent to exploration is the expected small size of deposits.

Precious-Metal-Rich Replacement and Vein Deposits in Paleozoic Rocks (T)

Commodities; Byproducts; and Trace Metals

Gold, silver (rare-earth elements, thorium, and lead in the Bear Lodge Mountains), and tungsten in selected areas; uranium and manganese in the Bear Lodge Mountains; arsenic, fluorine, and tellurium.

Host Rocks

Deposits are most common in the two contact zones of the Deadwood Formation, but are found in the Pahasapa Limestone as well. Minor replacement and vein deposits are noted in the basal conglomerate and in shale of the Deadwood (Irving and Emmons, 1904). Most rock units older than the Minnelusa probably contain some mineralized material. Veins in the Bear Lodge Mountains occur in all Paleozoic rocks older than the Pahasapa Limestone (Staatz, 1983; Jenner, 1984). Thicknesses and lithologies of the Pahasapa and older units have been reviewed above.

Structural Control

Almost all of the precious-metal-rich deposits in the Lead–Deadwood area were controlled by the orientation and abundance of verticals as was the case with the base-metal-rich deposits. Each deposit normally consisted of replacement bodies along bedding planes and along ore-bearing verticals that may or may not have connected the replacement horizons. The Portland mining district west of Lead was characterized by a major vertical system oriented north-northeast; the Ruby Basin district southwest of Lead had a major north-northwest-trending system of verticals (Irving and Emmons, 1904; Connolly, 1927; Connolly and O'Harra, 1929). Orebodies at the intersection of major and minor verticals were commonly quite large and high grade.

Structural control of vein systems in the Bear Lodge Mountains does not appear to be as important as that in the Lead–Deadwood area.

Age

As was the case with the base-metal-rich deposits, the precious-metal deposits in the Lead–Deadwood area appear to be younger than, or the same age as, trachytic to rhyolitic sills emplaced in the Deadwood and younger strata and older than crosscutting phonolite bodies. Some trachytic and rhyolitic sills and dikes do cut the replacement ores; however, no fragments of ore have been found within the sills. In the Lead–Deadwood area, where dated, the felsic dikes and sills and phonolite bodies are approximately the same age, about 60 Ma (McDowell, 1971). The igneous body closest to most of the old mining districts is the alkali rhyolite (grorudite) sheet at Terry Peak, which has a K-Ar aegirine date of 58.5 ± 4.3 Ma. The ore in the Lead–Deadwood area appears to have formed in late Paleocene time.

Mineralization in the Bear Lodge Mountains is not as well dated. McDowell (1971) reports K-Ar dates from mixtures of augite and hornblende that range from 40 to 50 Ma. Likewise, Staatz (1983) reports K-Ar dates from sanidine and orthoclase(?) that range from 38 to 50 Ma. As reviewed in the section on geology of the Tertiary intrusive rocks of the Bear Lodge Mountains, the mineralization probably took place closer to 50 Ma than to 40 Ma.

Deposit Description

Deposits in the Lead–Deadwood area are replacements along flat channelways and veins along verticals in the Deadwood Formation and Pahasapa Limestone (Irving and Emmons, 1904; Shapiro and Gries, 1970; Norton, 1983b). Most of the deposits in the Ruby Basin district southwest of Lead are in the lower contact zone; those in the Portland district are mainly in the upper contact zone. Deposits in the Ragged Top district, west of the Portland district, are in the Pahasapa Limestone.

Replacement orebodies in both the lower and upper contact zones range in thickness from 3 to 20 ft and probably average 12–15 ft (Connolly and O'Harra, 1929). Their lengths and widths are highly variable, ranging from 10 to more than 500 ft. The deposits are elongated parallel to the strike of the verticals related to the major fracture systems. Replacement deposits in the Pahasapa Limestone are irregularly shaped lenses, pods, and fractures similar to those in the base-metal-rich deposits.

The deposits contained both "red ore" and "blue ore," the former being oxidized material from which much of the gold and silver could be retrieved, and the latter being unoxidized material from which precious-metal recovery was extremely difficult, either by a cyanide process or by smelting. Recovery of precious metals from the blue ore seldom exceeded 35 percent (Irving and Emmons, 1904; Connolly and O'Harra, 1929). Much of the blue ore was left unmined because the gold and silver could not be recovered.

The blue ore occurs in silicified zones within dolomitic beds of the Deadwood. It is banded, brittle, hard, and fine grained, and contains from a trace to several percent sulfide minerals, predominantly pyrite. Primary ore minerals include minor amounts of auriferous pyrite, sylvanite, possibly other telluride minerals, arsenopyrite, and trace amounts of galena and sphalerite. The gangue is made up of jasper, quartz, fluorite, and barite (Irving and Emmons, 1904). Connolly and O'Harra (1929) estimated that the ores average nearly 5,000 ppm arsenic. In those deposits containing tungsten, additional primary ore minerals are wolframite, huebnerite, and scheelite. The silver-to-gold ratios of blue ores throughout the northern Black Hills are rather constant and range between 1.5:1 and 2.0:1. No primary silver minerals have been identified; much of the silver is thought to be in auriferous pyrite.

The red ores in the Deadwood Formation contain some of the primary ore minerals and the secondary suite of limonite, gypsum, kaolinite, pyrolusite, and minor amounts of wulfenite, pyromorphite, malachite, azurite, and chrysocolla.

Replacement deposits in the Pahasapa Limestone in the Lead–Deadwood area differ from those in the Deadwood in that they consist largely of irregularly oriented and mineralized fractures and breccia masses that have been extensively silicified. Smaller, flat-lying replacement bodies along bedding planes in the Pahasapa also have been noted. The Ragged Top district contains most of these replacement deposits (Shapiro and Gries, 1970).

The mineralogy of these replacement deposits differs slightly from those in the Deadwood Formation. The deposits are silicified masses of Pahasapa Limestone containing quartz, chalcedony, minor auriferous pyrite, unidentified telluride minerals, and accessory fluorite. The ratio of silver to gold in the Ragged Top district is the lowest in the region, ranging from 1:4 to 1:15 (Irving and Emmons, 1904).

The deposits in the Bear Lodge Mountains are entirely in veins that appear to have no preferred orientation (Staatz, 1983). The veins cut Paleozoic units older than the Pahasapa Limestone and are regarded to be genetically related to the Tertiary alkalic intrusives in the core of the range. Individual veins are narrow and short, not commonly exceeding 2 ft in width or 500 ft in length. Oxidization has affected most of the veins, altering the primary minerals to differing degrees. Ore minerals consist of manganese oxide minerals, brockite, bastnaesite, monazite, and galena. Gangue consists of quartz, hematite, sanidine, barite, rutile, dolomite, fluorite, anatase, and zircon. Staatz (1983) included no analyses for precious metals; nor did he mention the occurrence of gold in any of the veins. Darton (1905), however, showed most of the veins in the area as gold prospects.

Geochemical Signature

The precious-metal-rich deposits in the Lead–Deadwood area contain anomalous amounts of gold, silver, arsenic, fluorine, tellurium, and barium in all deposits and, additionally, tungsten in some deposits. Most deposits probably contain significant quantities of other trace metals commonly associated with precious-metal deposits. NURE stream-sediment geochemical data (Union Carbide Corp., 1980) are of little help in assessing the resource potential because of the wide sample-locality spacing in that study. Also, present-day streams in the northern Black Hills have been significantly contaminated by tailings and debris from past mining ventures, and sampling of those streams would face the same problem as was discussed in the preceding section on base-metal-rich deposits.

Veins in the Bear Lodge Mountains contain anomalous concentrations of thorium, rare-earth elements, uranium, barium, copper, lead, manganese, molybdenum, and zinc (Staatz, 1983). NURE stream-sediment geochemical surveys (Warren and others, 1980) detected many of these elements, but sample localities are too widely spaced to assist assessment of resource potential for these areas.

Geophysical Signature

The replacement deposits in Paleozoic strata in the

Lead–Deadwood area are too small and irregularly shaped to be detected by most geophysical techniques. Ground-based electromagnetic surveys might be able to detect the more massive, pyrite-rich deposits, but normally they are buried beneath too much overburden. Alteration near the deposits, primarily silicification and dolomitization, cannot be detected by airborne radiometric surveys but might be detectable by luminescence studies if the forest cover is not too thick.

The vein deposits in the Bear Lodge Mountains contain enough radioactive elements to be detected both by airborne radiometric surveys (EG&G geoMetrics, 1979a, b) and ground-based surveys (Staatz, 1983). They might contain enough magnetite to be detected by ground-based magnetic traverses.

Assessment Criteria

1. Presence of favorable strata, particularly the Deadwood Formation and Pahasapa Limestone. All Paleozoic strata could contain mineralized material, however.
2. Spatial association of Tertiary trachytic to rhyolitic felsic sills or stocks.
3. Dolomitization and silicification of the Paleozoic strata in the Lead–Deadwood area and radioactive veins in the Bear Lodge Mountains area.

Assessment

Area T1.—In area T1 north of Sundance (pl. 2, fig. 21), Paleozoic and Mesozoic strata are folded into the Hershey Creek dome, northwest of Warren Peaks in the Bear Lodge Mountains, and may contain small vein deposits of precious metals, thorium, and uranium. The core of the Hershey Creek dome is composed of an alkalic, ferrohastingsite-bearing trachyte (White, 1980), a rock type commonly associated with gold mineralization (Giles, 1982). No mines are known in the area, but the region has not been extensively prospected for precious metals. Accordingly, the area is assigned a low potential for precious metals in small deposits, primarily in the Pahasapa Limestone adjacent to the trachyte.

Area T2.—The west, south, and east margins of the Tertiary intrusive core of the Bear Lodge Mountains (pl. 2, fig. 21) have a high potential for small to medium-size vein or replacement deposits containing precious and base metals, rare-earth elements, uranium, and thorium. The veins, their mineralogy, and geochemistry have been described by Staatz (1983). The area has been explored during the last 5 years for deposits in carbonatite bodies (Wilkinson, 1982). The Deadwood Formation and the overlying Ordovician rocks are the most favorable strata for this type of deposit.

Area T3.—Deposits in the Ragged Top mining district west of Lead (fig. 23) are included in area T3; it is assigned a moderate potential for precious metals in small vein or replacement deposits in the Pahasapa Limestone, and possibly in the underlying strata. The largest production from the area came from mines operated by the Spearfish Gold Mining Company and from the Deadwood Standard mine (Allsman, 1940; Shapiro and Gries, 1970). Precious metals are contained in verticals that cut the Pahasapa Limestone and in silicified replacement deposits that crosscut and parallel bedding. Ores in the area contained the highest ratios of gold to silver in the northern Black Hills (Shapiro and Gries, 1970). The best exploration targets would be northeast-striking fracture zones in all strata and mineralized features of the karst near the top of the Pahasapa.

Area T4.—The main parts of the Portland, Ruby Basin, and Elk Mountain mining districts, west of Lead, are included in area T4 (fig. 23), which is assigned a high resource potential for precious metals in medium-size replacement and vein deposits contained in the Deadwood Formation. Gold and silver are the main commodities of importance in the district, but minor amounts of base metals, arsenic, and fluorine might be produced as byproducts. The largest production in the Tertiary deposits of the northern Black Hills came from the Portland district, primarily from the Bald Mountain group of mines (Allsman, 1940; Shapiro and Gries, 1970). Other large producers in the district included the Imperial, Reliance, Dakota, and Ofer mines. Most of the production in the Ruby Basin district came from the Golden Reward and Great Mogul mines, with subsidiary production from the Lundberg, Dorr, and Wilson properties. Area T4 yielded about 1,400,000 oz of gold and 3,400,000 oz of silver from 1887 until the late 1960's. Deposits are predominantly silicified replacements in the lower and upper contact zones of the Deadwood. The most likely targets for undiscovered deposits would be in the down-dip extension of the Deadwood and in the middle dolomitic member of the Deadwood.

Area T5.—Area T5 is north of Lead, in the vicinity of Maitland (fig. 23), and includes the Garden and Maitland mining districts. It is assigned a moderate resource potential for medium to small veins or replacement deposits containing precious metals and minor amounts of tellurium and arsenic. The largest producer in the area was the Penobscot mine of the Maitland Company, which extracted ore from silicified replacement deposits in the Deadwood. The greatest potential for undiscovered deposits in the area would be in the down-dip extension of the Deadwood beneath trachytic to rhyolitic sills to the north and east, and in the overlying Paleozoic rocks.

Area T6.—Most of the tungsten production in the Black Hills has come from area T6 south of Lead, near the Wasp gold mine (fig. 23). This area has a moderate potential for precious metals and tungsten in small to medium-size replacement and vein deposits in the Deadwood Formation. Why tungsten is restricted to this area is not fully understood; its occurrence may indicate that the T6 area was mineralized by a major hydrothermal system related to an underlying metal-rich pluton.

Area T7.—Seven areas designated as T7 have moderate potential for precious metals in medium to small vein or replacement deposits. The three shown in figure 24 will be discussed first.

The first area is west and north of Galena, extending from near the Gilt Edge mine on the southeast to near the Belle Eldridge mine on the northwest (fig. 24). Small mines in the area produced gold and silver from replacement deposits in the Deadwood. The mineralization is probably genetically related to emplacement and alteration of rhyolite bodies at the Gilt Edge mine, and undiscovered deposits are probable in the area.

The second area is north of Dome Mountain (fig. 24) and contains small mines (Mascot and Black Diamond) that produced gold and silver ore from siliceous replacement deposits in the Deadwood. Multiple sills intrude the Deadwood in this area, and undiscovered small deposits similar to those at the Mascot or Black Diamond may well be present.

The third area is north of Deadman Mountain (fig. 24) where a quartz latite laccolith intrudes the Paleozoic strata. No mines are known in the area, but the geologic relations are similar to those in the Galena area.

The remaining four T7 areas are near Lead (pl. 2, fig. 23). All have a moderate potential for precious metals in medium to small vein or replacement deposits. One area, northwest of Carbonate (fig. 23), is peripheral to base-metal-rich areas S1 and S2; there, precious-metal deposits in Paleozoic host rocks might be present. A zonal relationship of precious-metal-rich deposits peripheral to base-metal-rich deposits is typical in porphyry environments, and the Carbonate area may have potential for buried porphyry deposits as discussed in following sections.

A second T7 area is west of Carbonate, north of Maitland (fig. 23). The resource potential of this area is lower than the potential in the adjoining T5 area because the strata most likely to be mineralized, the Deadwood Formation, are largely concealed or intruded by Tertiary igneous bodies (Heidt, 1977). The northeast trend of major verticals in area T5 suggests that mineralization may have extended into this T7 area.

The largest T7 area near Lead is south and west of the Portland, Ruby Basin, and Elk Mountain mining districts, between Ragged Top Mountain and Deer Mountain (fig. 23). This area is assigned a moderate potential for replacement and vein deposits in the Deadwood and younger Paleozoic strata. The northeast trend of major verticals in much of the T4 area to the northeast suggests that mineralized rock may be present at depth in this area.

The last area near Lead (pl. 2) is the southern extension of the T7 area near Deer Mountain discussed above. It also has a moderate potential for medium to small replacement or vein deposits in the Pahasapa Limestone and older Paleozoic rocks.

Area T8.—Two small areas designated T8 in the Lead-Deadwood region have a low potential for small vein or replacement deposits in Paleozoic rocks. The first area, southeast of Lead (fig. 23), adjoins on the east the only area to have produced tungsten (T6). The stratigraphy of the Deadwood and type and number of sills that intrude the Deadwood in T8 are similar to those of area T6.

The second area is near Whitewood Peak (fig. 24), where the Minnelusa Formation is intruded by rhyolite and quartz trachyte (Boyd, 1975). No precious metals are known to have been produced from the area, but the chemistry of the intrusive rocks and the nature of the host rocks makes this area worth considering for possible vein and replacement deposits in Paleozoic rocks.

Area T9.—Two areas designated T9 have a moderate potential for precious metals in small vein deposits in Paleozoic rocks. One area is north of Galena (fig. 24), on the eastern contact of the Tertiary intrusive body at the Gilt Edge mine. The Pahasapa Limestone and older Paleozoic strata are in contact with various phases of the intrusive body, creating a favorable geologic setting for vein and replacement deposits containing precious metals. The area has no known production.

The second area extends northeast from Virkula Gulch in the Nemo area (fig. 15) toward the Vanocker laccolith (fig. 24) and straddles a fault zone in the Pahasapa Limestone along which small rhyolitic breccia pipes have been emplaced (Gasser, 1981). The area has no known production, but the geologic setting is favorable for vein deposits related to the emplacement of the breccia pipes.

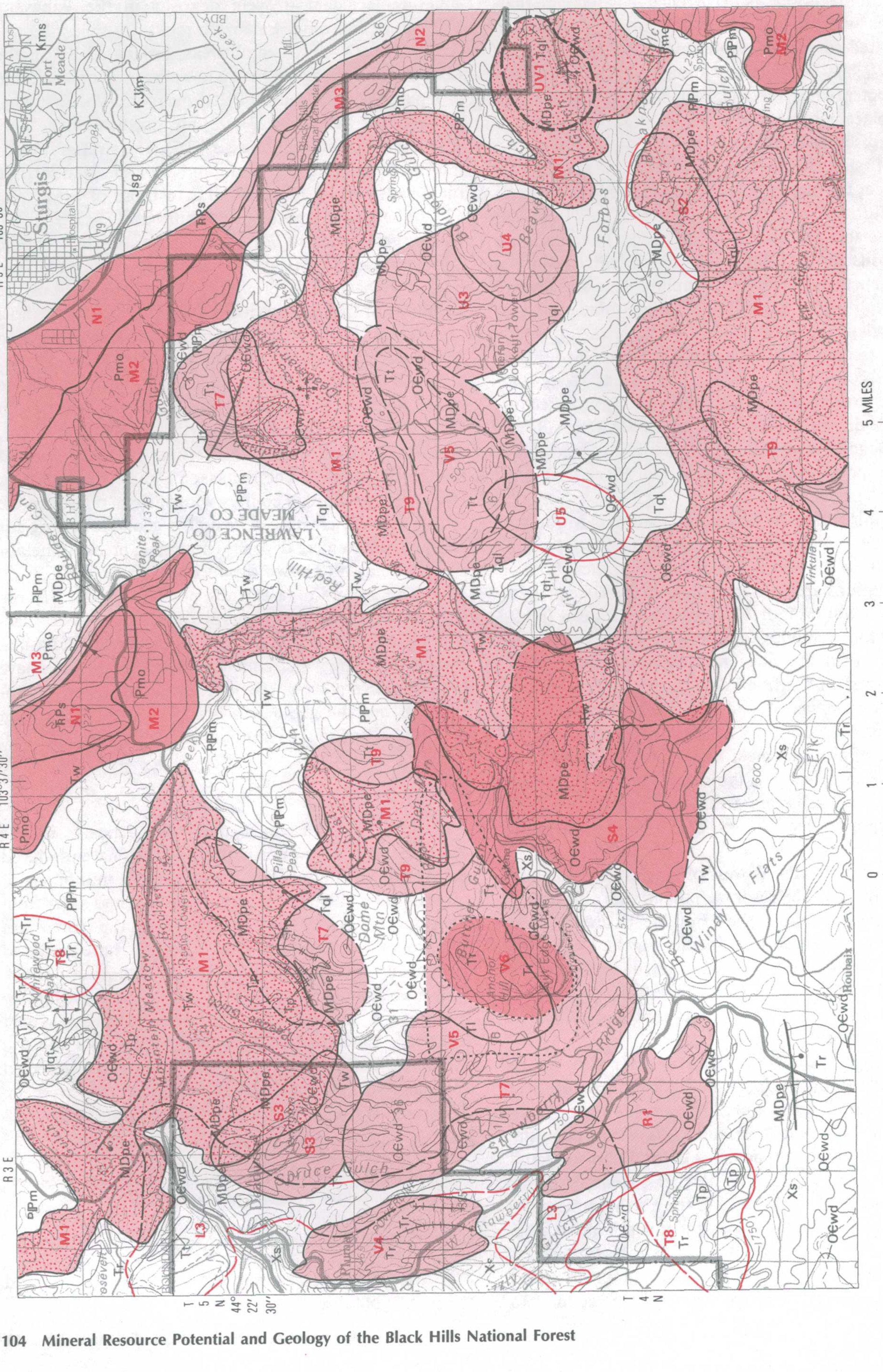
Economic Significance

Tertiary replacement and vein deposits in the Paleozoic strata of the northern Black Hills have produced more than 2.1 million oz of gold and 3.8 million oz of silver (Norton, 1983b). Production of gold and silver from these deposits is second only to that from the Homestake mine, and the fact that the Tertiary deposits have produced more than 1 million oz of gold makes the northern Black Hills a world-class epithermal gold district. Active mining ventures in the area include operations by Wharf Resources, Vancouver, British Columbia, near Ragged Top Mountain, west of Lead. Active exploration for concealed deposits (Norton, 1974) similar to those that have been discovered will continue for the foreseeable future.

Base-Metal-Rich Disseminated and Vein Deposits in Tertiary Quartz-Normative, Subalkalic to Alkalic Igneous Rocks (U)

Commodities; Byproducts; and Trace Metals

Molybdenum and copper; silver, lead, zinc, and tungsten; gold.


Sturgis
Fort Meade
MEADE CO
LAWRENCE CO
R 5 E
103°30'
R 4 E
103°37'30"
R 3 E
T 5 N
44° 22' 30"
T 4 N
0
1
2
3
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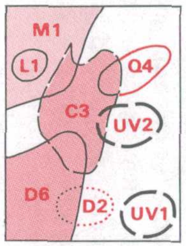
5 MILES

EXPLANATION

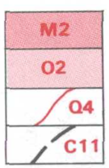


Areas having *mineral resource potential*—Boundaries are dashed or dotted where necessary to show limits of overlapping areas. Areas are labeled by letter and number corresponding to entries in the table shown at right. Where two or more overlapping areas have different levels of potential, the overlapping area is colored to show the highest potential determined.

In the example at left C3 is an area of high mineral resource potential that is overlapped on the right by Q4, an area of low potential, and by UV2, an area of unknown potential. Area M1, which has moderate potential, overlaps area C3 and also contains an area of low potential, L1. Area D6, which has high potential, overlaps C3 and is overlapped by area D2, which has low potential. Area UV1 is an area of unknown potential.

The map must be used together with the table to interpret correctly the potential of overlapping areas

Note: Only mineral resources related to Phanerozoic deposits are shown on this map. Refer to figure 18 for the distribution of mineral resources related to Proterozoic deposits. Some map areas are patterned to show them more clearly.



High mineral resource potential

Moderate mineral resource potential

Low mineral resource potential

Unknown mineral resource potential

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
L3	Low-------	L/C	Au------------	Small, paleoplacer.
M1	Moderate--	M/D	High-calcium--- limestone.	Medium, bedded sedimentary.
M2	High------	H/D	High-calcium--- limestone.	Large, bedded sedimentary.
M3	Moderate--	M/D	High-calcium--- limestone.	Large, bedded sedimentary.
N1	High------	H/D	Gypsum---------	Medium, bedded sedimentary.
N2	Moderate--	M/D	Gypsum---------	Medium, bedded sedimentary.
R1	Moderate--	M/D	Fe-------------	Medium-small, stratabound.
S2	Low-------	L/C	Pb, Ag--------- (Zn, Au).	Small, replacement or vein.
S3	Moderate--	M/D	Pb, Zn (Ag, Au)	Small, replacement.
S4	High------	H/D	Pb, Zn, Ag (Au)	Medium-small, replacement or vein.
T7	Moderate--	M/C	Au, Ag (As, Te)	Medium-small, vein or replacement.
T8	Low-------	L/B	Au, Ag (Pb, Zn)	Small, vein or replacement.
T9	Moderate--	M/C	Au, Ag (Cu)----	Small, vein.
U3	Moderate--	M/C	Mo, Cu (Ag, Pb, Zn).	Medium, disseminated.
U4	Moderate--	M/B	Mo, Cu (Ag, Pb, Zn).	Medium, disseminated.
U5	Low-------	L/B	Mo, Cu (Ag, Pb)	Medium-small, disseminated.
UV1	Unknown---	U/A	Mo, Cu (Ag, Pb)	Size unknown, vein or disseminated.
V4	Moderate--	M/C	Au, Ag (Cu)----	Small, disseminated or porphyry.
V5	Moderate--	M/D	Au, Ag (Pb, Zn)	Medium-small, disseminated or porphyry.
V6	High------	H/D	Au, Ag (Pb, Te, F).	Medium, disseminated or porphyry.

Levels of resource potential

- **H** High mineral resource potential
- **M** Moderate mineral resource potential
- **L** Low mineral resource potential
- **U** Unknown mineral resource potential

Levels of certainty

- **D** Data define geologic environment and level of resource potential and indicate resource-forming processes in all or part of the area
- **C** Data partially define geologic environment and indicate a resource potential and indicate resource-forming process in some of the area
- **B** Data partially define geologic environment and suggest level of resource potential
- **A** Available data not adequate for evaluation of resource potential

LIST OF MAP UNITS

- Tw **White River Group (Oligocene)**
- Tp **Phonolite (Eocene and Paleocene)**
- Tr **Rhyolite (Eocene and Paleocene)**
- Tqt **Quartz trachyte (Eocene and Paleocene)**
- Tql **Quartz latite(?) (Eocene and Paleocene)**
- Tl ***Latite (Eocene and Paleocene)***
- Tt **Trachyte(?) (Eocene and Paleocene)**
- Kms **Mowry Shale, Newcastle Sandstone, and Skull Creek Shale (Lower Cretaceous)**
- KJim **Inyan Kara Group (Lower Cretaceous) and Morrison Formation (Upper Jurassic)**
- Jsg **Sundance Formation (Upper and Middle Jurassic) and Gypsum Spring Formation (Middle Jurassic)**
- ℞Ps **Spearfish Formation (Triassic and Permian)**
- Pmo **Minnekahta Limestone and Opeche Shale (Lower Permian)**
- PℙPm **Minnelusa Formation (Lower Permian and Pennsylvanian)**
- MDpe **Pahasapa Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)**
- O€wd **Whitewood Dolomite (Upper Ordovician), Winnipeg Formation (Middle Ordovician), and Deadwood Formation (Lower Ordovician and Upper Cambrian)**
- Xs **Metasedimentary and metavolcanic rocks (Early Proterozoic)**

Contact—Dashed where approximately located

Fault—Bar and ball on downthrown side

Syncline—Axis dotted where concealed

Dome

Figure 24. Mineral resource potential map for locatable commodities in the Galena area, Black Hills National Forest, S. Dak. Geology shown alone in figure 13. Base from U.S. Geological Survey, Rapid City, 1977.

Host Rocks

Hypothetical deposits would be within Tertiary stocks that are quartz normative, have a high total alkali content (sodium plus potassium), and are rhyolitic to quartz latitic in composition. Expected deposits should resemble porphyry copper or porphyry molybdenum stockwork and disseminated deposits in which base-metal-rich sulfide minerals would be dispersed throughout the stock and concentrated in veins within the stock. The intensity of hydrothermal alteration and fracturing would be local guides to ore. Low concentrations of precious metals, primarily silver, would be expected in the altered and mineralized stocks.

Structural Control

These deposits would be expected only in the belt of Tertiary intrusive rocks that crosses the northern Black Hills region along a west-northwest trend (pls. 1 and 2). Inside the stocks the fracturing, intensity of alteration, and position of orebodies may be controlled by local structures. The presence or absence of mineralized rock would be controlled by the chemistry and localization of intrusive bodies.

Age

All of the intrusive bodies in the South Dakota portion of the Black Hills that have been dated are Paleocene to early Eocene (50–60 Ma; Mukherjee, 1968; McDowell, 1971; Redden and others, 1983). Base-metal-rich deposits genetically related to these intrusive bodies likewise would be 50–60 Ma.

Deposit Description

Base-metal-rich deposits in Tertiary quartz-normative, subalkalic to alkalic intrusive bodies have not been mined in the northern Black Hills, but numerous geologic features indicate that they may exist in the subsurface. The mineralization discussed in the preceding section that has affected the Paleozoic rocks must be genetically related to emplacement of the voluminous sills, dikes, and stocks in the area. The deposition of metals must be related to the Tertiary intrusive rocks and their associated hydrothermal systems. Some areas that contain vein and replacement deposits in the Paleozoic strata may be underlain by porphyry-type deposits in Tertiary plutons that contain molybdenum and (or) copper.

Such deposits would be similar to known porphyry copper and porphyry molybdenum systems in which a stock with varying textural phases is emplaced, fractured, and hydrothermally altered, and sulfide minerals, primarily pyrite, chalcopyrite, and molybdenite, are deposited within the stock and in veins cutting the intrusive body. The shapes and sizes of the deposits are controlled by the size of the intrusive body, the extent of hydrothermal alteration, and the type and composition of host rocks that are intruded. Typically, the deposits are irregularly shaped zones within the stock and at its contact with the wall rocks. Grades of base metals in the porphyry-type deposits are lower than in vein and replacement deposits, but the tonnage of ore in the porphyry-type is much larger. Oxidation of the primary ore minerals may enrich the deposit in base and precious metals.

Geochemical Signature

Base-metal-rich porphyry-type deposits are typically enriched in molybdenum, copper, and silver, and contain slightly anomalous concentrations of zinc, lead, and gold. The stock and its alteration products may be enriched in barium and fluorine. Even the small porphyry-type systems commonly have extensive hydrothermally altered areas that surround the stock or intrusive center. Rock-chip and stream-sediment geochemical data are usually able to define the altered areas.

NURE stream-sediment geochemical surveys for the northern Black Hills (Union Carbide Corp., 1980) have sample localities too widely spaced to be of help in assessing the potential of the area for porphyry-type deposits. Stream-sediment sampling by Miller (1962, 1964a, b, 1967) disclosed a molybdenum anomaly near Spearfish Creek west of Lead that led to exploratory drilling of a concealed, low-grade porphyry molybdenum deposit. Interpretation of the data from the stream-sediment sampling program in the northern Black Hills is generally hampered by the obvious contamination of the streams from mining of the replacement-type orebodies in the Paleozoic rocks. A survey of rock-chip geochemistry similar to that carried out by Larsen (1977) is generally necessary to better define areas of resource potential.

Geophysical Signature

Of all deposit types considered here, the base- and precious-metal deposits associated with the Tertiary intrusive rocks in the northern Black Hills have the greatest likelihood for being detected by airborne and ground-based geophysical surveys. One important aerial technique would be a magnetic survey similar to those conducted by Meuschke, Philbin, and Petrafeso (1962), Kleinkopf and Redden (1975), Bendix Field Engineering Corp. (1982a, b, c), and Union Carbide Corp. (1982). Porphyry deposits are associated with felsic intrusive rocks that are normally more magnetic than the Paleozoic and Mesozoic strata that they intrude. Therefore, unaltered Tertiary stocks that are normally magnetized may cause aeromagnetic highs; altered stocks associated with porphyry-type deposits have abnormally low magnetic signatures as compared to unaltered stocks. Many actual base-metal deposits and their alteration zones are too small to be detected by reconnaissance aeromagnetic surveys, but ground-based magnetic surveys can be employed to obtain detailed information.

Felsic Tertiary stocks in the northern Black Hills contain anomalous concentrations of radioactive elements such as potassium, uranium, and thorium. Exposed stocks appear as radiometric highs as compared to the strata they intrude (EG&G geoMetrics, 1979a, b, c, 1980a; Texas Instruments Inc., 1979). All of the areas containing voluminous intrusive rocks in the northern Black Hills can be delineated on such airborne radiometric maps. The various stocks differ in their concentrations of these radioactive elements; stocks associated with base-metal deposits do not contain as much thorium or potassium as those associated with precious-metal- and rare-earth-rich deposits. The mineral deposits associated with the stocks, however, are too small to be detected by airborne techniques. Staatz (1983) has shown that ground-based radiometric surveys can delineate areas of hydrothermal alteration and unusual enrichment in radioactive elements.

Other ground-based geophysical techniques that may be employed in the exploration for porphyry deposits include gravity surveys and induced polarization and electromagnetic surveys. The gravity surveys are designed to locate buried plutons by virtue of their density contrast with the rocks they intrude. Unfortunately, in areas of complex geology, the density contrasts between dissimilar basement rocks may overwhelm the subtle contrasts expected between buried plutons and the Paleozoic and Mesozoic cover rocks; such is the case in the northern Black Hills (Kleinkopf and Redden, 1975). Induced polarization and electromagnetic surveys may reveal buried or near-surface stocks and altered plutons by virtue of the electrical conductivity of the intrusive rocks. As mentioned above, base-metal-rich deposits normally are associated with porphyry-type plutons that contain sulfide minerals. Concentrations of these minerals can be detected by the different electrical response of the plutons and their wall rocks as compared to the barren rocks some distance from the plutons. Unfortunately, no published surveys of this kind are available.

Assessment Criteria

1. Presence of Tertiary intrusive bodies, particularly stocks and shallow plutons having rhyolitic to quartz latitic compositions.
2. Known or inferred hydrothermal alteration, fracturing, or brecciation.
3. Mineralized material, particularly silver-rich veins and replacement deposits, in the Paleozoic and Mesozoic strata surrounding the stocks and plutons.
4. Aeromagnetic lows (destruction of magnetite indicating hydrothermal alteration) and radiometric highs (uranium and potassium highs indicating hydrothermal alteration and creation of clay minerals) over known or inferred Tertiary plutons.
5. Anomalous concentrations of base and precious metals in stream-sediment or rock-chip samples over a relatively large area may indicate buried intrusive bodies.

Assessment

Area U1.—Southwest of Maitland, area U1 (fig. 23) has a high potential for a medium-size disseminated or porphyry-type deposit containing molybdenum, copper, and minor amounts of silver, lead, and tungsten. The deposit might be present in what has been referred to as the Cutting stock, a complex igneous body composed of dikes and small stocks (Darton, 1909; Darton and Paige, 1925; Larsen, 1977). A variety of rock compositions are noted, predominantly alkali rhyolite, quartz trachyte, and phonolite; a disseminated deposit, if present, would be located in alkali rhyolite or quartz trachyte. Stream-sediment and rock-chip geochemical data (Larsen, 1977) define two large areas of anomalous concentrations of molybdenum and copper in altered and fractured rhyolitic rocks. Many vein and replacement deposits flank the area to the northeast, and vein deposits are noted cutting rhyolite and quartz trachyte (Irving and Emmons, 1904; Shapiro and Gries, 1970).

The entire area of the Cutting stock is enhanced in potassium and thorium relative to the surrounding rocks (EG&G geoMetrics, 1980a). Area U1 contains anomalously high uranium concentrations with respect to the rest of the Cutting stock and is situated at the north end of a concave-westward magnetic low (Meuschke, Philbin, and Petrafeso, 1962) located over the eastern margin of the Cutting stock. This low could be interpreted as indicating altered and mineralized material at depth in this part of the stock. Drilling in the area encountered stockwork veins containing molybdenum similar to that in porphyry deposits, but the grade of the material was marginal.

Area U2.—North and west of Richmond Hill (fig. 23) is area U2, which is assigned a moderate potential for molybdenum in porphyry deposits. This area is flanked by the lead-silver replacement deposits of the Carbonate district to the north and could contain medium to small disseminated deposits of molybdenum, silver, and minor amounts of lead in the porphyry. Stocks and sills of alkali rhyolite and quartz trachyte are present on the south and east borders of area U2 (Sofranoff, 1979).

Stream geochemical data of Miller (1962, 1964a, b, 1967) as reviewed by Allcott (1975) indicates molybdenum anomalies in Squaw Creek, which drains the western half of area U2. A magnetic dipole (Meuschke, Philbin, and Petrafeso, 1962) in the western half of U2 becomes a prominent magnetic low when the data are reduced to the present-day magnetic pole (M. D. Kleinkopf, unpub. data, 1985), the low indicating that a buried stock may be present beneath the Deadwood Formation in the area of

Squaw Creek. Area U2 is on the western edge of prominent potassium, thorium, and uranium airborne radiometric anomalies (EG&G geoMetrics, 1980a) centered on the Cutting stock. Drilling in the area encountered the stockwork veins containing molybdenum, but the grade of mineralized material found to date has been marginal.

Area U3.—This area just east of Veteran Lookout covers the east-central part of the Vanocker laccolith (fig. 24). Matthews (1979) described an area along Alkali Creek in which the host intrusive was altered and pyrite and molybdenite were introduced. Propylitic and argillic alteration of primary minerals were observed, and minor silicification and quartz veining were noted. The altered area described by Matthews is in the northwestern part of area U3. Alteration may not be restricted to the area described by Matthews: radiometric anomalies (EG&G geoMetrics, 1980a) showing enhanced levels of thorium, uranium, and potassium are present southeast of Matthews' altered area. Area U3 was drawn to include Matthews' area and extended to cover the radiometric anomalies. Area U3 has a moderate resource potential for molybdenum and copper in medium-size disseminated deposits.

Area U4.—This area is southeast of U3; it is drawn to cover the region of radiometric anomalies (EG&G geoMetrics, 1980a) that lack the characteristic hydrothermal alteration of U3. Area U4 is assigned a moderate potential for medium-size disseminated deposits rich in base metals, principally molybdenum and copper. The area has a lower level of certainty than does area U3 because of the lack of documented alteration.

Area U5.—Area U5 covers a part of the Vanocker laccolith southeast of Kirk Hill (fig. 24). It is defined principally by an airborne radiometric anomaly that indicates high uranium levels relative to the rest of the laccolith. Area U5 is on the south edge of a small aeromagnetic low (Meuschke, Philbin, and Petrafeso, 1962) that could be related to hydrothermal alteration and destruction of magnetite at depth. This area has a low potential for medium to small disseminated deposits containing molybdenum and copper.

Economic Significance

Porphyry-type deposits are the world's leading source of copper and molybdenum and will remain so for many years to come. Although ore grades are low, many deposits are very large and metals can be produced at low cost relative to underground mining of vein and replacement deposits. No production from porphyry molybdenum or copper deposits in the Black Hills is recorded, but the geologic environment is especially suited for low-grade porphyry molybdenum deposits containing minor amounts of silver.

Precious-Metal-Rich Disseminated and Vein Deposits in Tertiary Quartz-Normative, Subalkalic to Alkalic Igneous Rocks (V)

Commodities; Byproducts; and Trace Metals

Gold and silver; copper, uranium, and thorium; tellurium.

Host Rocks

Deposits are in Tertiary rhyolitic stocks that are quartz normative and are subalkalic to alkalic (high total-alkali content). Typically, the deposits resemble porphyry copper stockwork and disseminated deposits in which sulfide minerals are dispersed throughout the stock and concentrated in veins within the stock. Precious metals are normally contained in the sulfide minerals or in telluride minerals dispersed in the stock. The intensity of hydrothermal alteration and fracturing are guides to mineralized rock and ore. The base-metal contents of the stocks are typically lower than in the previously described molybdenum and copper porphyry systems.

Structural Control

Deposits are restricted to the belt of Tertiary intrusive rocks that crosses the northern Black Hills along a west-northwest trend (pls. 1 and 2). The fracturing and intensity of alteration and the ore deposits are controlled by local structures, but the presence or absence of mineralized rock is thought to be controlled by the chemistry and localization of intrusive bodies.

Age

All of the intrusive bodies in the northern Black Hills are probably in the age range of 50–60 Ma. However, none of the stocks that contain disseminated precious-metal deposits has been dated. The rhyolite at the Gilt Edge mine, which is host to precious-metal deposits, intrudes hornblende-bearing sills that have K-Ar hornblende and biotite dates of about 61 Ma and 57 Ma, respectively (Mukherjee, 1968; McDowell, 1971).

Deposit Description

Precious-metal deposits in Tertiary quartz-normative, subalkalic to alkalic intrusive bodies at the Gilt Edge mine have been described by Irving and Emmons (1904), Connolly and O'Harra (1929), and Mukherjee (1968). The deposit consists of veins and disseminations of auriferous pyrite and chalcopyrite in small stocks, breccia pipes, and country rock cut by the intrusive rock. The stocks are extensively fractured and hydrothermally altered, and have alteration zones like those typically associated with porphyry deposits. Oxidation has enriched the upper levels of the stocks and breccia pipes in gold, which is contained principally in auriferous limonite. Alunite has been reported from one locality northwest of the Gilt Edge mine (Connolly and O'Harra, 1929).

Geochemical Signature

The precious-metal-rich porphyry-type deposits are enriched in gold, silver, and copper, and contain anomalous concentrations of mercury, arsenic, and minor amounts of molybdenum (Connolly and O'Harra, 1929; Mukherjee, 1968). If the deposits resemble other epithermal gold deposits, they also should contain anomalous concentrations of fluorine, tellurium, and possibly barium.

As was the case for base-metal-rich porphyry deposits, NURE stream-sediment geochemical data are of little help in assessing the potential for precious-metal-rich porphyry-type deposits. Stream-sediment geochemical data given by Miller (1962, 1964a, b, 1967) are more helpful but do not cover all drainage basins in the northern Black Hills. Data on the geochemistry of rock-chip or soil samples, as completed by Mukherjee (1968) for the Gilt Edge mine area, would be necessary to define precisely areas of potential.

Geophysical Signature

Most of the aerial and ground geophysical techniques discussed in the section on base-metal-rich porphyry deposits are applicable to assessment of the precious-metal deposits. Rhyolitic stocks that are altered and mineralized are generally less magnetic than their wallrocks or adjacent, unaltered igneous rocks. Stocks associated with these deposits contain anomalous concentrations of uranium, thorium, and potassium (EG&G geoMetrics, 1979b, 1980a), and altered areas within the stocks may contain highly anomalous concentrations of potassium and uranium. Most rhyolitic stocks can be detected on reconnaissance airborne radiometric maps, but more detailed ground-based radiometric surveys would be needed to identify the smaller, intensely altered zones. Staatz (1983) identified highly potassic zones within the intrusive rocks in the Bear Lodge Mountains by this technique.

Assessment Criteria

1. Presence of Tertiary intrusive bodies, particularly stocks and shallow plutons having rhyolitic compositions.
2. Known or inferred hydrothermal alteration, fracturing, or brecciation.
3. Mineralized material, particularly gold-rich veins and replacement deposits, in the Paleozoic and Mesozoic strata surrounding the stocks and plutons.
4. Aeromagnetic lows (destruction of magnetite indicating hydrothermal alteration) and radiometric highs (uranium and potassium highs indicating hydrothermal alteration and creation of clay minerals) over known or inferred Tertiary plutons.
5. Anomalous concentrations of precious metals, arsenic, and mercury in areas not known to contain igneous rocks may indicate buried stocks at depth.

Assessment

Area V1.—The Hershey Creek dome in the northwestern Bear Lodge Mountains (pl. 2, fig. 21) has a core of ferrohastingsite-bearing alkalic trachyte (White, 1980), a rock type genetically associated with gold mineralization in tectonic settings similar to the Black Hills (Giles, 1982). The area is assigned a moderate potential for gold in medium to small disseminated deposits containing precious metals and minor amounts of thorium and uranium. This assessment is based on the favorable rock type, even though no gold production from the intrusive rock is recorded.

Area V2.—This area is centered on Richmond Hill, west of Lead (fig. 23), where two or possibly three rhyolitic to quartz trachytic stocks containing breccia pipes are located (Darton and Paige, 1925; Shapiro and Gries, 1970). The area has a high potential for medium-size disseminated or porphyry deposits containing precious metals and copper. Precious-metal-rich replacement deposits in the Pahasapa Limestone probably are related to one of the stocks in the area. A prominent uranium high over the area is shown on airborne radiometric maps (EG&G geoMetrics, 1980a).

Area V3.—This area includes the Ragged Top district west of Lead (fig. 23); it has a high potential for gold and silver in medium to small disseminated or porphyry deposits. The replacement and vein deposits in Pahasapa Limestone in this district are thought to be genetically related to a possible rhyolitic to quartz trachytic stock at depth. Existing geochemical and geophysical data are inadequate to aid in an assessment of the area.

Area V4.—Much of the region northwest of Lead and contained within the Cutting stock (fig. 23) has a moderate potential for small disseminated or porphyry deposits containing precious metals and copper. The area contains numerous dikes and irregularly shaped intrusive bodies that range in composition from rhyolite to quartz trachyte (Parkhill, 1976; Larsen, 1977). The magnetic low mentioned in the above discussion of area U1 trends south from U1 through the southern part of V4 and could be the surface expression of altered and mineralized zones in the subsurface; however, it also could be partly a response from a basement of nonmagnetic quartzite in the Ellison Formation. More detailed geophysical information is needed from the area. All of area V4 contains rocks rich in uranium, thorium, and potassium, but more detailed surveys than that of EG&G geoMetrics (1980a) are needed to define hydrothermally altered zones.

Another V4 area having a moderate potential for small disseminated deposits containing precious metals is near Polo Peak, northeast of Maitland (fig. 23). A rhyolitic intrusive body in the area (Darton and Paige, 1925; Heidt, 1977) may contain areas of alteration or radioactive element enrichment that would be favorable for the occurrence of precious-metal deposits. No mines are known to have produced gold ore from the area, and undiscovered deposits probably would have to be detected by drilling and geophysical techniques.

The last V4 area is south of Deadwood (figs. 23, 24) and includes a large rhyolitic dike that cuts the Precambrian rocks and probably was a feeder for sills in the lower part of the Deadwood Formation. A magnetic low northeast of this dike (Meuschke, Philbin, and Petrafeso, 1962) may represent altered material at depth along the dike, or the low could be a response from a basement of nonmagnetic units in the Grizzly Formation. No mines are known to have produced gold ore from the area. The area has a moderate potential for precious-metal deposits, most probably in veins related to the dike.

Area V5.—North and west of Galena (fig. 24), area V5 includes an elongate region centered on the Gilt Edge mine that is assigned a moderate potential for precious metals, lead, and zinc in medium to small disseminated or porphyry deposits. Mines in the area include the Monarch and Golden Crest (Connolly and O'Harra, 1929; Allsman, 1940). Known deposits consist of disseminated auriferous pyrite in rhyolitic stocks and sills, brecciated masses of intrusive rock containing auriferous pyrite and limonite, and base-metal-rich veins and fracture fillings. The area corresponds to a large radiometric anomaly indicating high concentrations of thorium, uranium, and potassium. A rather large magnetic low (Meuschke, Philbin, and Petrafeso, 1962) is just southwest of the area, in the vicinity of Strawberry Ridge, but its relation to the porphyry-type deposits is questionable.

Another area designated as V5, having moderate resource potential, is on the northeast side of the Vanocker laccolith, between Kirk Hill and Deadman Mountain (fig. 24). Here, Matthews (1979) mapped two trachyte stocks intruding the older hornblende-bearing quartz latite that forms much of the laccolith. Darton and Paige (1925) had referred to the stocks as rhyolite. Although no gold ore has been produced from the trachyte, the composition and setting of the stocks in an area of multiple intrusions suggests that unexposed plutons might contain precious metals.

Area V6.—This area west of Galena (fig. 24), around the Gilt Edge and Anchor Mountain mines, is assigned a high potential for medium-size disseminated or porphyry deposits containing precious metals, lead, and minor amounts of tellurium and fluorine. Both disseminated and breccia-pipe deposits are known to exist in the area (Mukherjee, 1968), and the Gilt Edge and surrounding mines have been extensively investigated and drilled in the last 10 years. The mines of the area have produced gold ore from auriferous pyrite and limonite, sylvanite, and possibly other telluride minerals (Connolly and O'Harra, 1929). Classic porphyry-type alteration zones are developed at the Gilt Edge mine, where an outer propyllitic zone grades inward to a zone of argillic alteration and then to a quartz-veined potassic core containing disseminated pyrite and trace amounts of chalcopyrite (Mukherjee, 1968). Mineralization appears to be related to the emplacement of rhyolitic stocks that intrude 60 Ma hornblende-bearing sills.

Area V7.—A hydrothermally altered area northwest of Tinton (pl. 2, fig. 20) has a moderate potential for small to medium-size disseminated deposits containing gold and copper. Ray (1979) suggested that the alteration, which is superimposed on a quartz trachyte sill complex, was related to an underlying intrusive body. Such an intrusive body may well contain disseminated copper and gold-bearing minerals; hence the assignment of a moderate potential for the area. Aerial radiometric surveys (EG&G geoMetrics, 1979b, 1980a) do not show uranium or potassium anomalies over the zone of alteration and indicate only a small thorium anomaly.

The alteration assemblage noted by Ray (1979) in area V7 is calcite-chlorite-epidote-pyrite, not the typical clay-mica-feldspar assemblage noted in most potassic systems such as porphyry copper and molybdenum deposits. Ray's assemblage seems more likely to have been caused by intrusion and alteration of the quartz trachyte by the nearby ring-dike complex of pyroxenite-syenite-feldspathoidal breccia (Welch, 1974). An undersaturated, mafic suite of intrusive rocks such as this could produce the type of alteration assemblage noted by Ray. If so, area V7 would have a moderate potential for small disseminated deposits containing gold, copper, and rare-earth elements. The lack of uranium and potassium anomalies in the altered area, as noted above, is consistent with the assemblage noted by Ray and with the above interpretation that the alteration was caused by the emplacement of the ring dike.

Another area designated V7, south of Lead and east of Englewood (pl. 2), has a moderate potential for small to medium-size disseminated deposits containing gold and copper. Rhyolite sills that intrude the Deadwood Formation south of Lead appear to have been derived from an intrusive body in the Woodville Hills (Usiriprisan, 1979). A small magnetic dipole (Meuschke, Philbin, and Petrafeso, 1962) coincides with the source conduit identified by Usiriprisan, strengthening the interpretation that the Woodville Hills are underlain by a small stock of rhyolite. EG&G geoMetrics (1980a) aerial radiometric surveys show both uranium and potassium anomalies coinciding with the rhyolite in the Woodville Hills.

Area V8.—This small area of low potential for small disseminated deposits containing precious metals, copper, and zinc surrounds the rhyolite body underlying Custer

Peak, south of Englewood (pl. 2). The assignment of low potential is due to the interpretation that the rhyolite is a laccolith that could be situated over a very small plug. The rhyolite exhibits uranium and potassium anomalies (EG&G geoMetrics, 1980a) and a very small magnetic low coincides with Custer Peak (Meuschke, Philbin, and Petrafeso, 1962). No mines are known in the area.

Area V9.—Northwest of Nemo (pl. 2), near Virkula Gulch (fig. 15), area V9 is assigned a low resource potential for precious metals in small disseminated or breccia-pipe deposits. Darton and Paige (1925) and Gasser (1981) mapped the breccia pipes that intrude the Deadwood Formation and Pahasapa Limestone, but noted little mineralized rock in the area. The pipes are too small to be detected by normal aerial radiometric surveys, but ground-based surveys and geochemical sampling could aid in the resource assessment of the area.

Area UV1 (Combined Base- and Precious-Metal Deposits).—Three areas that have an unknown potential for vein or disseminated deposits of unknown size containing base and precious metals include Elkhorn Peak, west of Whitewood (pl. 2); Crook Mountain, south of Whitewood (pl. 2); and an area south-southeast of Sturgis along Forbes Gulch (fig. 24). All areas are situated over domes presumed to be underlain by rhyolitic to quartz latitic stocks or laccoliths that could contain base- and precious-metal deposits. The Elkhorn Peak dome coincides with a magnetic dipole (Meuschke, Philbin, and Petrafeso, 1962) that indicates the presence of an igneous rock near the surface. Crook Mountain may exhibit a slight magnetic dipole, but a more detailed survey would be necessary to verify this. No magnetic surveys cover the dome at Forbes Gulch. This deposit type (UV) is restricted to the central and eastern part of the belt of Tertiary intrusive rocks in the northern Black Hills.

Economic Significance

Disseminated or porphyry-type gold deposits are becoming an increasingly important exploration target because of the low cost of mining the deposits, the use of heap-leach extraction techniques, and the relatively high and stable price of precious metals. Mineralized areas in the northern Black Hills will continue to be sampled and drilled, and deposits such as those at the Gilt Edge mine probably could produce ore in the next 5 years.

Thorium-Rich (W) and Rare-Earth-Element-Rich (X) Disseminated and Vein Deposits in Tertiary Nepheline-Normative or Alkalic Igneous Rocks

Commodities; Byproducts; and Trace Metals

Thorium and rare-earth elements; barium, gold, silver, fluorine, and uranium; phosphorus and manganese.

Host Rocks

Deposits are in Tertiary stocks that are composed of trachyte, trachyphonolite, and high-potassium trachyte, are alkalic, and may be nepheline-normative. Typically, the ore minerals are disseminated in the stock or in veins that cut the stock. The intensity of hydrothermal alteration, especially of potassium metasomatism and introduction of carbonate minerals, and fracturing are guides to mineralized material. The base-metal contents of the stocks are typically slightly higher than the previously described precious-metal deposits in porphyry-type systems.

Structural Control

Deposits are restricted to the western part of the belt of Tertiary intrusive rocks that crosses the northern Black Hills (pls. 1 and 2) and are predominantly in Wyoming. The fracturing, intensity of alteration, and ore deposits are controlled by local structures, but the presence or absence of mineralization is thought to be primarily related to the chemistry of intrusive bodies.

Age

The alkalic complexes are the least well dated of all intrusive bodies in the northern Black Hills. No isotope dates are available from the ring-dike complex at Tinton (Welch, 1974). The alkalic complex in the Bear Lodge Mountains has K-Ar sanidine and hornblende-augite dates that range from about 40 to 50 Ma (McDowell, 1971; Staatz, 1983). In all probability, the range in dates reflects poor retention of argon in the minerals dated and does not reflect a 10-Ma time interval during which the intrusive rocks were emplaced and the ore deposits formed.

Deposit Description

Deposits in the Bear Lodge Mountains are irregularly shaped zones within alkalic stocks composed of trachyte that are cut by carbonatite dikes. The deposits are best developed where hydrothermal alteration, potassium metasomatism, and carbonate veining have been the most intense. The character and chemistry of the igneous rocks, nature and mineralogy of the veins and disseminated deposits, and description of the hydrothermal alteration products have been noted by Staatz (1983) and Jenner (1984). Deposits typically consist of high-grade veins and low-grade disseminations of brockite, bastnaesite, monazite, synchysite, ancylite, burbankite, carbocernaite, other rare-earth fluocarbonate minerals, galena, and chalcopyrite in a gangue of strontian calcite, limonite, psilomelane, fluorite, barite, quartz, and a variety of minor alteration products. The greatest concentration of both thorium and rare-earth elements is found in carbonatite dikes. Trachyte that is intruded by the carbonatite dikes is enriched in potassium, thorium, rare-earth elements, uranium, and base metals.

Geochemical Signature

Vein and disseminated deposits in the Bear Lodge Mountains contain anomalous concentrations of thorium, rare-earth elements, uranium, barium, copper, lead, manganese, molybdenum, and zinc (Staatz, 1983). NURE stream-sediment geochemical surveys (Warren and others, 1980) detected many of these elements in the few samples from localities in the Bear Lodge Mountains. Staatz (1983) did not report precious-metal contents of his samples. Anomalous concentrations of fluorine, zirconium, and potassium are expected from the vein mineralogy. Alteration related to emplacement of the trachyte bodies and carbonatite dikes is widespread in the Bear Lodge Mountains, and the geochemical signature of such alteration should be detectable far from the intrusive center.

Geophysical Signature

Aerial and ground-based geophysical techniques are applicable to exploration for deposits rich in thorium and rare-earth elements. Aerial radiometric surveys are particularly good at detecting the anomalous amounts of uranium, thorium, and potassium associated with the deposits (EG&G geoMetrics, 1979a, b). Ground-based radiometric surveys (Staatz, 1983) can delineate areas of extreme alteration, potassium metasomatism, and abundance of thorium-rich rare-earth minerals.

Aeromagnetic surveys may be helpful in detecting altered areas within host igneous rocks by the depletion of magnetite. In the case of the Bear Lodge Mountains, the host trachyte apparently does not contain much more magnetite than does the altered trachyte. Ground-based magnetic surveys would supply more information than would airborne data. The altered rocks in the core of the Bear Lodge Mountains contain enough disseminated pyrite to be delineated by induced polarization surveys.

Assessment Criteria

1. Presence of Tertiary intrusive bodies, particularly stocks and shallow plutons containing high levels of potassium, thorium, and uranium. Trachytic and carbonatitic compositions are highly favorable.
2. Known or inferred hydrothermal alteration, fracturing, or brecciation.
3. Mineralized material, particularly thorium-rich veins and disseminated deposits, may be indicators of rare-earth-element-rich deposits at depth.
4. Aeromagnetic lows (destruction of magnetite indicating hydrothermal alteration) and radiometric highs (potassium and thorium highs indicating hydrothermal alteration) over known or inferred Tertiary plutons.

Assessment

Area W1.—Much of the central part of the Bear Lodge Mountains north of Sundance (fig. 21) has a high potential for large disseminated deposits containing thorium, rare-earth elements, and the other elements listed above. The outcrop extent of all of the Tertiary trachytic intrusive rocks is included in area W1. The area is delineated by airborne radiometric surveys as a uranium, thorium, and potassium anomaly (EG&G geoMetrics, 1979a, b), and by aeromagnetic surveys as a pronounced magnetic high (Union Carbide Corp., 1982). The relationship between the magnetic anomaly and the Tertiary intrusive rocks that contain deposits rich in thorium and rare-earth elements is not clear. Staatz (1983) and Jenner (1984) documented mineralization genetically related to emplacement of carbonatite dikes in area X1 near the center of area W1 (area X1 is discussed below).

Area W2.—This area east of Tinton, designated W2, near the Wyoming state line (pl. 2, fig. 20) has a moderate potential for small disseminated deposits containing thorium, rare-earth minerals, and minor amounts of gold. The area is in the eastern part of a quartz trachyte sill that intrudes Paleozoic strata (Darton and Paige, 1925; Smith and Page, 1941). The chemical composition and petrology of the sill to the west have been investigated by Ray (1979). Area W2 contains a uranium and thorium anomaly detected by airborne radiometric surveys (EG&G geoMetrics, 1979a, b, 1980a). No large magnetic highs or lows characterize the area. The Mineral Hill ring-dike complex (Welch, 1974) intrudes similar rocks just 4 mi to the west but has none of the radiometric or magnetic characteristics of this area (pyroxenite and breccia of the ring dike are highly magnetic and contain virtually no concentrations of radioactive elements). The deposits that may be in the subsurface of area W2 thus appear to have more in common with those in the Bear Lodge Mountains than they do with the precious-metal deposits in the Mineral Hill area.

Area X1.—This area in the Bear Lodge Mountains, centered on the headwaters of Beaver Creek (fig. 21), has a high potential for large disseminated or carbonatite-related deposits containing rare-earth elements, thorium, and the elements listed in the section on deposit description above. Deposits are in high-potassium trachyte and carbonatite dikes. The zone of extensive alteration and brecciation and of elevated potassium content is included in this area. Subsurface mineralization related to emplacement of carbonatite dikes was documented by Jenner (1984) from study of diamond-drill core.

Economic Significance

Staatz (1983) predicted that the central Bear Lodge Mountains contain large resources of thorium and considerable amounts of rare-earth elements. Carbonatite dikes found in the subsurface indicate that the potential for a rare-earth-element deposit similar to the one at Mountain Pass, Calif., or the one at Magnet Cove, Ark., is high. Because carbonatite bodies are a major source of rare-earth elements, uranium, gold, copper, and other valuable metals, exploration for these deposits in the Bear Lodge Mountains is expected to continue and mining is possible in the future.

Precious-Metal-Rich Disseminated and Vein Deposits (Y) in Tertiary Nepheline-Normative or Alkalic Igneous Rocks

Commodities; Trace Metals

Gold, copper, and titanium; silver, rare-earth elements, iron, and manganese.

Host Rocks

Deposits are in Tertiary intrusive rocks that are nepheline-normative, have mafic to intermediate compositions, and may or may not be associated with carbonatite. The known deposit at Mineral Hill, west of Tinton, is in a steep-sided ring-dike complex (Darton, 1905; Welch, 1974) containing pyroxenite, nepheline syenite, and feldspathoidal breccia. Typically, the ore minerals are disseminated in the pyroxenite or breccia. Commonly, the breccia is hydrothermally altered and veined, and parts may be replaced by carbonate minerals. Base-metal contents are moderate and variable.

Structural Control

The only known deposit is restricted to the central breccia unit of the Mineral Hill ring-dike complex; other deposits conceivably may be found in other structural settings. The gas-charged emplacement of the central breccia unit of the ring dike may have facilitated hydrothermal alteration and rapid precipitation of metals from a vapor-rich solution. If so, then other breccia-pipe systems might be favorable for precious-metal-related deposits. A mafic, silica-undersaturated composition of the mineralized intrusive material appears to be the most favorable.

Age

The Mineral Hill ring-dike complex has not been isotopically dated. Because all other intrusive centers in the northern Black Hills appear to be between 50 and 60 Ma, the Mineral Hill system is probably also Paleocene or Eocene in age.

Deposit Description

The deposit at Mineral Hill is localized in the central two rock units, an outer ring of pyroxenite and diorite, and an inner pipe of feldspathoidal breccia (Welch, 1974). Native gold(?), chalcopyrite, titaniferous magnetite, and minor galena are disseminated in the breccia and in veins that cut the pyroxenite and breccia. Mines in the area that have produced gold from the pyroxenite or breccia include the Treadwell and the Interocean. A detailed study of the primary or oxidized mineralogy is not available, nor are data on rare-earth elements or radioactive elements. Due to a lack of analyses of the existing core samples, the geometry of gold-bearing zones in the pyroxenite and breccia is unknown.

Geochemical Signature

The ring-dike complex contains anomalous concentrations of iron, titanium, copper, gold, lead, and possibly phosphorus (apatite in pyroxenite), as reported by Welch (1974). The concentration of many trace metals, including rare-earth elements and radioactive elements, is unknown. NURE data on stream sediments from the Tinton area (Warren and others, 1980) show anomalous concentrations of tin, titanium, iron, copper, vanadium, lithium, scandium, manganese, cerium, calcium, and beryllium. The tin, lithium, cerium, and beryllium probably are derived from Precambrian pegmatite bodies, but the iron, titanium, copper, calcium, and manganese probably are derived from the ring-dike complex. Scandium may be derived either from the pegmatite (associated with tin) or from the pyroxenite (associated with apatite or ferromagnesian minerals).

Geophysical Signature

The pyroxenite in the Mineral Hill area is presumed to be the cause of a large magnetic dipole shown by aeromagnetic surveys (Union Carbide Corp., 1982). Gravity stations in the area are too widely spaced to indicate the size or shape of the pyroxenite or ring-dike complex in the subsurface. Data from both detailed ground-based magnetic and gravity surveys would be useful in assessment of the area. Apparently, the ring-dike complex contains no anomalous concentrations of uranium, thorium, or potassium, as airborne radiometric surveys (EG&G geoMetrics, 1979a, b) show no anomalies over Mineral Hill.

Assessment Criteria

1. Presence of Tertiary intrusive bodies, particularly ring dikes and breccia pipes. Mafic and silica-undersaturated compositions are favorable.
2. Mineralized material, principally in breccia systems or as veins cutting brecciated material.
4. Aeromagnetic or gravity highs indicating unexposed mafic rocks. If no mafic rocks are present but breccia pipes are, magnetic and gravity surveys would be of little help.

Assessment

Area Y1.—Area Y1, west of Tinton (fig. 20), has a high resource potential for gold, copper, silver, and possibly rare-earth elements in medium-size disseminated or breccia-pipe deposits. The area includes the outcrop extent of feldspathoidal breccia that Welch (1974) considered to be the most favorable rock type for gold mineralization. Gold is known to have been produced from three small mines in the breccia, and the area has been explored and drilled over the last 10 years.

Area Y2.—Area Y2 is west of area Y1 (fig. 20) and has a low potential for gold and possibly rare-earth elements in small disseminated deposits. This area is defined principally by airborne radiometric anomalies (EG&G geoMetrics, 1979a, b) that show elevated levels of thorium and potassium not present over the rest of the quartz trachyte sill of the Tinton area. No mafic rocks crop out at the surface, and the presence of thorium and potassium anomalies does not match the geochemical data for the mafic rocks at Mineral Hill. Low potential is assigned to area Y2 because it may be underlain by a small breccia pipe or alkalic plug that would be favorable for gold mineralization.

Area Y3.—This area surrounds Y1 (fig. 20) and includes the pyroxenite and outer zone of nepheline syenite in the Mineral Hill ring-dike complex (Welch, 1974). It has a high potential for medium to small disseminated deposits containing gold, iron, copper, and accessory titanium and manganese. Both rock types are known to contain gold, but iron, copper, titanium, and manganese are restricted to concentrations of magnetite and ilmenite in the pyroxenite.

Area WXY1 (Combined Thorium, Rare-Earth Element, and Precious-Metal Deposits.—Areas designated WXY1 have an unknown potential for disseminated deposits of unknown size containing all of the elements listed for deposit types W, X, and Y. The areas are coincident with domes (pl. 2) that are believed to be underlain by small stocks, plugs, or laccoliths in which the igneous material is less than 500 ft from the surface. The igneous material is predicted to resemble intrusive bodies in the Bear Lodge Mountains and at Tinton (potassic trachyte, pyroxenite, phonolite, and minor carbonatite) and be different from intrusive centers farther east in South Dakota (UV1 areas on pl. 2). From west to east the areas are (1) Miller Creek dome west of Warren Peaks; (2) Houston Creek dome southwest of Warren Peaks (fig. 21); (3) Lime Buttes dome and (4) Gypsum Buttes dome southeast of Sundance; (5) Green Mountain east of Sundance; (6) Soldier Creek dome and (7) an unnamed dome north of the Soldier Creek dome, both located south of Black Buttes; (8) Bald Mountain dome southwest of Tinton; and (9) the dome on the northern end of Crow Peak west of Spearfish.

Economic Significance

The geologic environment in which the Mineral Hill ring-dike system formed is not markedly different from that in which carbonatite dikes were emplaced in the Bear Lodge Mountains. Therefore, concentration of some of the metals, principally gold and rare-earth elements, can be expected in both areas. Ring dikes and breccia pipes that contain commodities having a high unit value (gold and rare-earth elements) are attractive exploration targets. Exploration of domes underlain by igneous rocks is not expected in the near future.

Miscellaneous Phanerozoic Igneous-Related Vein Deposits (Z)

Commodities; Trace Metals

Lead, zinc, and silver; gold and copper.

Host Rocks

Deposits are in veins that parallel foliation in Precambrian rocks and possibly cut pegmatite bodies related to the Harney Peak Granite. Veins may also cut across foliation in the country rock, but the only proven Phanerozoic vein does not.

Structural Control

Veins are concordant to foliation in Precambrian rocks. The extent of the veins is limited, and mines in which the veins are exposed are inaccessible. The degree of structural control by the Precambrian fabric is conjectural.

Age

Kulp and others (1956) determined lead-isotope ratios from galena collected at the Spokane mine, southeast of Keystone. The ratios indicate that the galena is probably younger than 200 Ma and may be Tertiary, especially if the galena incorporated minor amounts of Proterozoic lead from the schistose wallrocks during its formation. The lead-isotope data show that the vein cannot be Proterozoic in age.

Deposit Description

The deposit dated as Phanerozoic in age is the lead-zinc-silver vein at the Spokane mine, southeast of Keystone (pl. 2, fig. 17). The vein concordantly cuts metamorphosed graywacke and shale and a small pegmatite (U.S. Bureau of Mines, 1955). Ore minerals include pyrite, sphalerite, galena, and minor amounts of chalcopyrite (Connolly and O'Harra, 1929). Most of the silver and gold apparently are associated with galena. The gangue consists of quartz and muscovite. Arsenopyrite is abundant in the wallrocks, but only small amounts occur in the vein. The vein varies from a few inches to 25 ft in width and has been traced on the surface for more than 700 ft.

Geochemical Signature

The deposit contains anomalous concentrations of lead, silver, zinc, gold, and probably arsenic. Other trace elements such as bismuth and cadmium probably are present in anomalous amounts. NURE stream-sediment geochemical data (Union Carbide Corp., 1979) are of little help in assessing the resource potential of the area because the sample localities are too widely spaced.

Geophysical Signature

The vein deposits are very small and could not be detected by aerial geophysical surveys. They probably contain enough sulfide minerals to be delineated by ground-based electromagnetic surveys.

Assessment Criteria

1. Presence of quartz veins cutting rock units of any age.
2. Mineralized material, particularly base-metal-rich veins.

Assessment

Area Z1.—An area southeast of Keystone, centered about the Spokane mine (pl. 2, fig. 17), has a moderate potential for small vein deposits containing lead, zinc, silver, and minor amounts of gold and copper. This is the only area south of the latitude of Nemo known to contain Phanerozoic vein deposits. Other areas that might contain such deposits probably would be located along faults with Laramide or younger movement.

Economic Significance

Small base-metal-rich deposits containing very little gold are not promising exploration targets in the Black Hills. Unless larger deposits similar to that at the Spokane mine are located, these kinds of deposits will not contain important resources.

Miscellaneous Commodities

A few commodities or mineral deposits of lesser importance than the types previously described are present in the Forest and the adjacent lands. These are not of sufficient economic significance to be assessed in the same way as the major types, but are briefly described below.

Utilization of Mine Tailings

Tailings from old mining operations are widespread in the Black Hills, particularly in the Lead-Deadwood area, the region between Keystone and Custer, and the area near Edgemont. Typically, the tailings have resulted from mining of precious metals in the first area, pegmatite deposits in the second, and uranium in the third area. As early as the 1920's, attempts were made to reprocess the tailings and recover metals that were lost in the early days of inefficient recovery. Recently, Fredlund and Cope (1968), Roberts and Cope (1968), and Lindgard and Roberts (1970) suggested ways in which the tailings could be utilized. Tailings derived from base- and precious-metal and uranium mining can be heap-leached to recover some metals, but the tailing cannot be used for other purposes such as road-fill, earthen embankments, fill-dirt, and the like because of the relatively toxic metals remaining in the tailings. Many tailings piles in the northern Black Hills have been investigated in the last 10 years, and some have been heap-leached with cyanide solutions to recover the precious metals. Tailings derived from pegmatite mining may be used for road-fill, gravel, and similar uses if high concentrations of radioactive elements are not present. The only drawback to the use of pegmatite tailings for road surfacing is the high mica content, which invariably creates locally dusty conditions.

Aluminum

Many of the trachytic, syenitic, and phonolitic Tertiary intrusive rocks in the northern Black Hills contain between 18.0 and 22.0 weight percent Al_2O_3 and in the past have been considered possible sources of aluminum. Such a source would have to contain very little iron and magnesium to be considered a resource. Some of the leucocratic intrusive rocks, such as nepheline syenite and amphibole-poor phonolite, could constitute an aluminum resource, but the limited demand for aluminum in the Black Hills region would hinder any production.

Bentonite

Bentonite has been produced from Cretaceous strata in western South Dakota and eastern Wyoming for more than 70 years, but none has come from the Forest. The Clay Spur Bentonite Bed of the Mowry Shale (Reeside and Cobban, 1960) has been a major source of swelling bentonite mined in the Belle Fourche area, north of the Forest (Knechtel and Patterson, 1962; Patterson and Harksen, 1975). In that area the F bed of the Belle Fourche Shale also contains swelling bentonite. South of the Forest, in Fall River County, the Ardmore Bentonite Bed, near the base of the Pierre Shale, has been a source of low-swelling bentonite.

The Mowry Shale crops out in the far southeastern part of the Forest near Angostura Reservoir, where it contains thin beds of bentonite, none of which have been mined. The southwestern boundary of the Forest, from Edgemont to near Newcastle, is within 1 or 2 mi of outcrops of the Mowry. The Pierre Shale does not crop out within the Forest, but is within 2 mi of the boundary, near Angostura Reservoir.

MINERAL RESOURCES—LEASABLE COMMODITIES

The Mineral Leasing Act of 1920 removed oil and gas, oil shale, potash, sodium, native asphalt, bitumen or bituminous rock, phosphate, and coal from the provisions of the General Mining Law of 1872 and set up laws to control the right to explore for, develop, and produce specific minerals through a system of prospecting permits and leases. These commodities are sometimes referred to as "leasing act minerals" but are called "leasable commodities" in this report. The Geothermal Steam Act of 1970 added geothermal energy to the list of leasable commodities.

The occurrence of oil in the Black Hills was known from seeps in the Newcastle area as early as 1880. An exploratory well first produced a minor amount of oil in the area of the Barker Dome field, northwest of Edgemont, in 1929, but the first production from the area was not until the middle 1950's. The largest field in the area, the Newcastle-Clareton field, west of Newcastle, was discovered in 1948–49 and has produced oil and gas continuously since its discovery. Numerous test wells have been drilled outside the Forest, but few have tested the potential of strata within the Forest.

Small amounts of coal have been known in the Black Hills region since the early 1880's (Darton, 1904c), when it was used for heating and as a source of power in some of the early mines. Most of this coal was produced from the Cambria coal field in Lakota Formation north of Newcastle, Wyo. The only coal produced within the Forest came from an area east of Edgemont along the Cheyenne River. No coal is now produced from the Black Hills area.

Thermal springs have been known in the Hot Springs area since the early 1900's. The springs have been used for business and residential heating, for recreation, and therapeutic purposes.

No oil shale, potash or sodium, asphalt, or phosphate resources are known in the Forest or the adjacent lands.

The types of deposits that contain coal, oil and natural gas, and geothermal resources are outlined below. Letter designations (OG, CO, and GE) for the various types of deposits are given in the following section on resource potential and are used on plate 3.

OG. Oil and gas deposits in Mesozoic and Paleozoic rocks are stratabound accumulations of organic remains that formed in a marine environment about 100–400 Ma. Organic substances, including animal and plant remains, were modified into kerogen and petroleum-related matter by compaction and heat.

CO. Coal deposits in the Cretaceous Inyan Kara Group are stratabound accumulations of organic remains that formed in a fresh-water environment about 100–150 Ma. Organic substances, mostly plant remains, were modified into subbituminous coal and carbon-rich sedimentary rocks.

GE. Geothermal deposits consist of thermal springs formed in a terrestrial environment at the present time. Groundwaters are heated at depth and returned to the surface along fractures and fissures in the crust.

Resource Potential—Leasable Commodities

The Black Hills National Forest and adjacent lands were evaluated for three leasable commodities, oil and gas, coal, and geothermal resources (pl. 3, table 3). Table 3 also is reproduced in the text as an aid in following the discussion of each deposit type. In this section the characteristics of known and inferred deposits are briefly summarized and specific areas in and adjacent to the Forest having high, moderate, or low potential are reviewed. Definitions of terminology used, specifically the several levels of resource potential, are provided in Appendix 1.

On plate 3, areas having high potential are shown in red, and areas having moderate potential are shown in pink. Areas of low potential that are discussed in the text are shown in red outline. All other areas have been assigned low potential.

Oil and Gas in Mesozoic and Paleozoic Rocks (OG)

Commodities; Byproducts

Oil and gas; petroleum byproducts.

Host Rocks

Deposits are in Mesozoic and Paleozoic rocks, primarily the Permian and Pennsylvanian Minnelusa Formation and the Cretaceous Inyan Kara Group. Favorable strata for the accumulation of oil and natural gas (that is, reservoir rocks) include the above-mentioned units, Ordovician limestone and dolomite, Mississippian limestone and dolomite, and Cretaceous and Jurassic sandstone. Strata younger than the Cretaceous Inyan Kara Group are unfavorable for the accumulation of oil because of their predominant shale lithologies. An exception to this rule is the Cretaceous Newcastle Sandstone, which is the producing unit in the oil fields near Newcastle, Wyo. Shale units younger than the Inyan Kara Group may be unfavorable for the accumulation of oil and natural gas (reservoir rocks), but they are excellent sources (source rocks) of hydrocarbon material because of their high organic contents, trace-metal enrichment, and thickness.

Oil and natural gas may accumulate in reservoir rocks because of original sedimentary variations that trap the oil in favorable strata (sedimentary traps).

Structural Control

Oil and natural gas deposits are controlled to a high degree by the structural configuration of the reservoir beds. Oil, being lighter than water, migrates into structurally high areas such as anticlines and domes and therefore may be restricted to structural traps. All the oil and natural gas production from the Forest has come from structural traps.

Age

Oil and natural gas deposits are very difficult to date, and very few have been dated. All deposits have to be the same age or younger than both their surrounding reservoir rocks and structures. However, deposits can be tens of millions to hundreds of millions of years younger than their host rocks, and deposits can be forming today in rocks that are 500 million years old. Most of the anticlines and domes that act as structural traps for the oil and natural gas deposits formed about 60–65 Ma in response to Laramide deformation of the Black Hills (Lisenbee, 1978).

Deposit Description

Deposits are within irregularly shaped zones in the sedimentary strata. Most oil has been produced from limestone and sandstone units in which the petroleum is present as intergranular films on clastic grains and in pore spaces. The sedimentary units and the deposits are relatively thin, commonly less than 100 ft thick, but may extend for miles along and across strike. Oil fields such as those near Newcastle, Wyo., may be as much as 40 sq mi in surface extent or larger.

Geochemical Signature

Geochemical signature is not generally used to prospect for oil and natural gas deposits. However, most oil fields are characterized by anomalous concentrations of base metals, primarily lead and zinc, sulfur, complex organic compounds, and gases such as methane and hydrogen sulfide. Conventional stream-sediment and groundwater geochemical surveys are of little help in assessing resource potential for oil and natural gas. Unconventional techniques such as rare-gas detection (for example, methane, hydrogen sulfide, helium) and isotopic analyses (carbon, oxygen, hydrogen, and sulfur) of brines in groundwater and drill holes may be used as exploration tools.

Geophysical Signature

In the past, most oil fields have been discovered through a combination of knowledge of surface geology and geophysical exploration, primarily seismic refraction and reflection profiling. These techniques can be used to reconstruct an approximate subsurface configuration of the favorable strata. The accuracy of such a reconstruction is usually indirectly related to the complexity of the structure; areas of simple structure can be reconstructed quite accurately, those having complicated structure normally cannot be done as accurately.

Assessment Criteria

1. Presence of favorable reservoir rocks in subsurface. All of the Paleozoic rocks and Mesozoic units older than the Newcastle Sandstone are favorable.
2. Presence of favorable source rocks in subsurface. Organic-rich strata in the Black Hills area are favorable source rocks, especially the Cretaceous shale.
3. Presence of stratigraphic and structural traps.
4. Lack of igneous and hydrothermal activity.

Assessment

Area OG1.—A large area northwest of a line extending from Houston Creek southwest of Sundance to Aladdin, Wyo. (pl. 3), has a moderate potential for medium to large deposits of oil and gas. Oil has been produced from the Minnelusa Formation 5 mi east-northeast of Hulett, Wyo., a location only 2 mi west of the Forest boundary (Stephenson, VerPloeg, and Chamberlain, 1984). The southwest part of area OG1 extends into the Barton, Soap Creek, and Pine Ridge oil fields, from which oil and gas in the Inyan Kara Group, Morrison Formation, and Triassic strata have been produced (Petroleum Information Corp., 1984). Oil and gas in this area would be primarily restricted to sedimentary traps in the favorable strata. Only two test wells have been drilled on Forest lands in the entire area west and north of Sundance.

Area OG2.—A small area between Sundance and Beulah, Wyo. (pl. 3), has a moderate potential for small oil and gas deposits. This area, along Rocky Ford Creek, produced a minor amount of oil from the Minnelusa Formation in structural traps created by a small, northwest-trending anticline (Petroleum Information Corp., 1984). The oil was of low quality and was last produced in the 1960's.

Area OG3.—A very large area around the Black Hills uplift (pl. 3), which includes most of the Paleozoic strata except those affected by Tertiary igneous activity in the Black Hills, has a low potential for small to medium-size deposits of oil and gas, primarily in stratigraphic traps.

Table 3. Description of areas having mineral resource potential for leasable resources in and adjacent to the Black Hills National Forest, S. Dak. and Wyo.

[Level of potential/level of certainty explained in figure 25, Appendix 1; where variable sizes of deposits are shown, the most probable size is listed first]

Map area	Resource potential	Level of potential/ level of certainty	Commodities (by-products)	Size, type of deposit
CO1	Low-------	L/C	Subbitumimous coal----	Small, bedded sedimentary.
CO2	Moderate--	M/D	Subbituminous coal----	Small, bedded sedimentary.
OG1	Moderate--	M/C	Oil and gas-----------	Medium-large, stratabound.
OG2	Moderate--	M/D	Oil and gas-----------	Small, stratabound.
OG3	Low-------	L/B	Oil and gas-----------	Small-medium, stratabound.
OG4	Moderate--	M/C	Oil and gas-----------	Small, stratabound.
OG5	Moderate--	M/B	Oil and gas-----------	Large, stratabound.
OG6	High------	H/D	Oil and gas-----------	Large, stratabound.
OG7	High------	H/D	Oil and gas-----------	Small, stratabound.
OG8	Moderate--	M/D	Oil and gas-----------	Medium, stratabound.
GE1	Low-------	L/D	Geothermal water------	Small, water.

Area OG4.—A number of domes near Sundance (pl. 3) have a moderate potential for small deposits of oil and gas. As discussed in the section on locatable commodities, the domes are inferred to be underlain by Tertiary igneous rocks. Intense heating from intrusion of such rocks would not be conducive to retaining oil in structural traps, but the contact metamorphism normally related to such intrusive rocks in the Lead-Deadwood area is so minor that the domes shown as OG4 on plate 3 are believed to have a moderate potential for oil and gas deposits.

Structures having a moderate potential include the Houston Creek dome on the southwest flank of the Bear Lodge Mountains, west of Sundance; the Gypsum Buttes dome south of Sundance; the dome north of the Soldier Creek dome, south of Black Buttes; and the Bald Mountain dome southwest of Tinton (pl. 3). The Miller Creek, Green Mountain, Lime Buttes, and Elkhorn Mountain domes are not assigned a moderate potential because all either have been drilled and have not been found to contain oil and natural gas, or are too close to surface outcrops of low-grade metamorphic rocks.

Area OG5.—The Fanny Peak monocline, on the southwestern side of the Black Hills uplift and surrounding region, is contained within area OG5 (pl. 3). This area has a moderate potential for large deposits of oil and natural gas that previously have not been investigated or explored. If the Fanny Peak monocline is caused by a low-angle thrust fault instead of a high-angle reverse fault, as suggested by Lisenbee (1978), Phanerozoic rocks could be encountered at depth in area OG5 beneath an overhanging wedge of Precambrian rocks. This geometry would be similar to other Laramide uplifts in the Wyoming province (Berg, 1962; Stearns, 1971), such as the Wind River Mountains and the Laramie Mountains (Berg, 1981), both of which have steep monoclinal flexures on one side of an uplift. In the ranges mentioned, one side of the uplift has been shown to be bounded by a low-angle thrust fault that places allochthonous Precambrian rocks on top of Phanerozoic strata below.

The Fanny Peak monocline increases in structural separation from north to south, and has 3,500 ft of separation near the Weston County–Niobrara County line (pl. 3). A major structure such as this could have more than 5 mi of lateral offset if it were a low-angle fault that steepens at the surface. No seismic information is published, nor are any drill holes in the area deep enough to test this hypothesis. Therefore, the area is assigned a level of certainty of "B" and a moderate potential for large deposits.

Area OG6.—The Newcastle-Clareton oil field is contained within area OG6 (pl. 3), which has a high potential for large deposits of oil and gas. The field is apparently terminated by the Fanny Peak monocline along its eastern side. However, if the hypothesis above concerning the monocline is correct, the field could extend beneath the structure to the northeast. Even if that hypothesis is not correct, areas adjacent to the Forest near Newcastle have a high potential for oil and gas deposits similar to those in the Newcastle-Clareton oil field.

Area OG7.—The only oil production in the Forest is from the Barker Dome field, northwest of Edgemont (pl. 3), which is contained within area OG7. This area has a high potential for small deposits of oil and gas in structural traps associated with monoclinal flexures and anticlines. The Barker Dome field has produced oil from the Minnelusa Formation since 1955 (Steece, 1975).

Area OG8.—A large region in the southern Black Hills, generally south of a line from Newcastle, Wyo., to Hot Springs, S. Dak., has a moderate potential for medium-size deposits of oil and gas in all subsurface Phanerozoic strata. Only 13 test wells have been completed within the Forest in this area.

Economic Significance

Oil and gas are two of the main energy sources for the United States. Although very little oil or natural gas is currently produced from the Forest and its adjacent lands, the exploration for these deposits will not diminish in the future. Oil fields in Wyoming on the periphery of the Forest indicate that the Forest lands have a potential for similar deposits.

Coal in the Cretaceous Inyan Kara Group (CO)

Commodities

Subbituminous coal.

Host Rocks

Deposits are restricted to strata of the Inyan Kara Group of Early Cretaceous age, and, within the group, largely to the Lakota Formation. The lower 100 ft of the Lakota commonly contains coal beds 1-7 ft in thickness; the overlying Fall River Sandstone also contains beds of coal, but they are much thinner, not generally exceeding 3 ft. No other Phanerozoic rocks within or adjacent to the Forest contain coal beds that can be considered to have a resource potential. Beds of lignite coal as much as 90 ft in thickness are known to be present in Tertiary strata west of the Black Hills, but those strata are not present in the Forest. Coal deposits have formed by the decomposition and alteration of organic remains in the sedimentary strata.

Structural Control

Deposits of coal have not been controlled by structural deformation. In areas of monoclinal flexures the coal has been thinned or thickened to a minor degree, but not enough to enhance or diminish the resource potential.

Age

All coal deposits in and adjacent to the Forest are Early Cretaceous in age. The actual age of modification of the original organic material in the host strata to subbituminous coal in the Lakota Formation is unknown, and this difference in age has not been dated.

Deposit Description

Deposits are thin layers within the basal units of the Lakota Formation. Thin lenses of coal in the Inyan Kara Group are widespread, but laterally persistent beds of consistent thickness are restricted to the lower 100 ft of the Lakota. Coal beds normally do not exceed 5 ft in thickness and do not persist for more than 1-2 mi in any one direction. The largest deposits in the Black Hills region, those at Cambria, north of Newcastle (Darton, 1904c), average 5-7 ft thick and are as much as 9 ft thick. That coal-bearing area occupies an oval region of about 15 sq mi. Gold has been reported in the ash from coal in the Cambria region, but it cannot be considered a resource because of its low concentration. Areas described below have a lesser thickness of coal and are not as laterally continuous as the deposits at Cambria.

Geochemical Signature

Coal deposits are seldom prospected for by geochemical techniques. However, most coal does contain anomalous concentrations of heavy metals, particularly uranium, selenium, molybdenum, gold, zinc, and sulfur. Conventional stream-sediment or groundwater geochemical surveys would be of little help in assessing the mineral potential of coal deposits.

Geophysical Signature

Geophysical techniques are of little help in exploration for or assessment of coal deposits. Drilling and sedimentologic studies are necessary to accurately define areas underlain by coal.

Assessment Criteria

1. Presence of the Lakota Formation; most of the favorable beds are in the lower 100 ft of the formation.
2. Presence of slag-like residue above coal beds, which has formed by combustion of coal at the surface.

Assessment

Area CO1.—Three areas designated CO1 have a low potential for small, bedded sedimentary deposits containing subbituminous coal. The first area, a large region west, north, and northeast of Sundance, Wyo. (pl. 3), consists of outcrops of the Lakota Formation that are known to contain coal beds similar to the deposits at Aladdin, Wyo. (Darton, 1904c). The deposits at Aladdin are too far outside the Forest boundary to include on plate 3.

The second CO1 area, southwest of Inyan Kara Mountain (pl. 3), also has a low potential for small coal deposits. Darton (1905) described beds of coal as much as 5 ft thick in the basal part of the Lakota Formation.

The third CO1 area extends south of a line from near Newcastle on the west to Edgemont on the south, and back northeast to near Buffalo Gap, S. Dak. (pl. 3). This area also has a low potential for small deposits of subbituminous coal and is delineated by the outcrop extent of the Inyan Kara Group. The coal deposits at Cambria, north of Newcastle, are not shown on plate 3, even though they would be contained within area CO1, because they are too far outside the Forest boundary.

Area CO2.—Four small areas designated CO2 have a moderate potential for small, bedded sedimentary deposits containing subbituminous coal. The first is located west and south of Sundance (pl. 3), where Darton (1905) described small coal mines in the basal part of the Lakota Formation. Coal produced from this area has been utilized by local businesses and ranches for heating purposes.

The second CO2 area is southwest of Inyan Kara Mountain (pl. 3) in the Lakota Formation, where coal beds as much as 6 ft thick have been described by Darton (1904c, 1905). Coal produced from this area has also been utilized for local heating purposes.

The third and fourth CO2 areas are east and northwest of Edgemont, respectively (pl. 3). The area to the east, along the Cheyenne River, has produced subbituminous coal from two small mines (Darton, 1904c). Coal in this area averages about 5 ft thick and has been used for local heating. Coal from the area northwest of Edgemont has been produced from one small mine and has also been utilized by local ranches for heating.

Economic Significance

Coal is one of the major energy sources in the United States, but very little of this coal is mined from the area of the Black Hills National Forest. Extensive reserves of lignite coal in Tertiary strata are known to the west and north of the Black Hills; these reserves are being mined and will produce orders of magnitude more coal than any produced from the Lakota Formation. However, the coal in the Lakota will continue to be utilized on a small scale by farmers, ranchers, and local businesses in the area.

Geothermal Resources in Hot Springs (GE)

Commodities

Hot water.

Host Rocks

In and adjacent to the Forest, surface springs having elevated temperatures discharge from rocks ranging in age from Triassic to Early Cretaceous. The largest springs are in the vicinity of Hot Springs and Cascade Springs, S. Dak.

Structural Control

Caves in the Pahasapa Limestone and collapse structures in the Minnelusa Formation apparently capture stream flow and infiltrated surface water from the highest elevations of the Black Hills and direct the water through Paleozoic acquifers and along underground fracture systems. Subsurface water along the eastern flank of the Black Hills flows generally in a southeastern direction, as documented by dye tests (Rahn and Gries, 1973). Discharge areas, or springs, are generally located where aquifers dip below the outcrops of the Spearfish Formation. The subsurface flow intersects the Spearfish Formation, a relatively impermeable unit (an aquatard) that prevents upward migration of water from the aquifers. Because the near-surface flow on the edge of the Black Hills is relatively large, the aquifers are saturated and the excess infiltrated water must escape as springs.

Age

Springs having elevated temperatures obviously are heated by some mechanism operating today. Either there is a local source of heat, such as a magma, or the water is penetrating to great depths in the Earth's surface and is then returning to upper levels where the water is hotter than would be expected from the geothermal gradient. The relatively high lithium content of wells in the Minnelusa Formation in the Edgemont area (Carda, 1975) suggests that the latter explanation may be correct.

Deposit Description

The hot springs range from small trickles of low-temperature water to large-volume flows, such as the spring at Evan's Plunge in Hot Springs, S. Dak., which has a temperature of about 90°F (Gott and Schnabel, 1963). The total discharge from all thermal springs in the Hot Springs area is about 23 cubic feet per second (Rahn and Gries, 1973), or approximately 9,900 gallons per minute. Cascade Spring, south of Hot Springs, has a constant temperature of 70°F and a discharge of 8.5 cubic feet per second, or about 3,900 gallons per minute (Rahn and Gries, 1973). The springs discharge into or form small creeks.

Geochemical Signature

Thermal springs in the Black Hills do not contain levels of total dissolved solids or cations significantly different from those of springs and wellwater of average temperature. Evan's Plunge contains 250 ppm calcium, 51 ppm magnesium, and 86 ppm sodium (Gott and Schnabel, 1963); the mean values for nonthermal springs and wellwater in the Hot Springs 1°×2° quadrangle is 128 ppm calcium, 48 ppm magnesium, and 148 ppm sodium

(Union Carbide Corp., 1979). Likewise, the sulfate, bicarbonate, and chlorine levels of the hot springs are similar to or only slightly above the mean value for nonthermal springs.

Geophysical Signature

Geophysical techniques are of little help in exploration for, or assessment of, hot springs or geothermal resources.

Assessment Criteria

1. Presence of springs having elevated temperatures.

Assessment

Area *GE1*.—The only area in the Forest that has a potential for geothermal resources is situated at Hot Springs, S. Dak. (pl. 3). This area contains Evan's Plunge, the largest thermal spring in the Black Hills. The area has a low potential for small deposits of hot water that could be used for heating purposes or for recreation. The surface water temperature of the springs is too low for generating steam. Wells east of Hot Springs have bottom-hole temperatures of about 100–150°F (Schoon and McGregor, 1974) at depths of 1,500–2,000 ft, but these temperatures also are too low for steam generation. The thermal spring to the south at Cascade Springs is not included as an area of geothermal resources because its temperature is too low.

Economic Significance

Evan's Plunge has been used for many years for both recreation and therapeutic purposes. Thermal springs in the area cannot be expected to be utilized for power generation, but can provide recreational and health benefits for the foreseeable future.

MINERAL RESOURCES—SALABLE COMMODITIES

By John S. Dersch, U.S. Forest Service

The Federal Materials Act of 1947, as amended by the Multiple Surface Use Act of 1955, removed petrified wood, common varieties of sand and gravel, stone, pumice, volcanic cinders (including scoria), and some clay from acquisition by either location or lease. These commodities may be acquired from the U.S. Government only by purchase and are referred to as salable commodities. Several exceptions to the salable category are block pumice, gem stones, including quartz crystals, and such forms of dimension stone as high-quality marble and travertine. Determination that a particular mineral is a salable commodity must be reviewed on a case-by-case basis in light of past legal decisions. Salable commodities generally have low unit value (value per ton); their exploitation is dependent on easy access to transportation, and generally they are used near the site of production. Some of the following information is from summaries by Rothrock (1944), Osterwald and others (1966), and Roberts (1975).

Sand and gravel deposits are in many different places within the Forest. The uses are varied, but include road-fill, base-course, concrete aggregate, final surfacing, and other construction uses. The principal source is outwash gravel deposited in the major streams and larger tributaries that ring the Black Hills uplift. Currently, there are 14 sites active in the Forest and 5 known source areas. Local needs can create short-term demand for road-fill and construction uses.

Sources of crushed rock for railroad ballast, road-fill and metal, filter beds, riprap, and concrete blocks are found throughout the Forest. These materials come from limestone and feldspar porphyry. There are 17 active sites and 4 known sources in the Forest.

Dimension stone for interiors and exteriors of buildings, monuments, paving blocks and curbing material, crushed stone for driveways and gardens, and flagging have been quarried from several pits within the Forest. Granite from the Harney Peak area provides a good building and polishing rock but is not suitable for intricate monument carving due to the coarse and irregular crystal sizes. Three active slate quarries being worked for local uses are on Slate Creek and Skull Gulch north of Hill City. A dike of green granite in Rapid Creek has been quarried for ornamental uses. A dark quartzite in Rapid Canyon has been sold commercially as "pearl granite" for decorative purposes. The quartzite contains a sprinkling of small, bluish, pearl-like quartz pebbles. A dolomitic marble about 40 ft thick (Kernaghan and Garske, 1969) has been quarried south of Harney Peak. Considerable marble was blocked out around the turn of the century but none was shipped. Three zones are present, including a unit mottled with light- and dark-gray specks and particles of serpentine, a phlogopite marble, and a pure-white marble. The Minnekahta Limestone has been excavated where thin bedded for retaining walls, culverts, patios, and building facings. The upper part of the Deadwood Formation is a uniformly grained sandstone suitable for building-block material. The Fall River

Sandstone has been the source of stone used to construct numerous buildings in the Hot Springs area (Rothrock, 1944). That stone has been mined at Evans quarry, immediately adjacent to the Forest. The outcrops are easily mined, creating blocks several feet thick that are generally a light gray with a delicate pink tinge.

Clay has been mined from the Fuson Member of the Lakota Formation, which encircles the Forest. Along the southern boundary of the Forest the clay that is used for refractory bricks is marginal in quality. Mining has been very limited as a result.

Resource Potential—Salable Commodities

The mineral resource potential for sand and gravel, crushed rock, dimension stone, and clay is evaluated in this section. The distribution of areas having high mineral resource potential for any of the following commodities is shown in figure 3. Income from the sale of these mineral commodities will vary according to accessibility, unit value and cost, and production rate. Environmental factors are not considered in this assessment.

Sand and Gravel

Sand and gravel are available in sufficient quantities for road construction. The majority of the bedrock units weather to form materials suitable for construction needs. Several units that contain shale and many of the Cretaceous units (units Kp, Kb, Kms, pl. 1) contain too much clay to make them useful construction materials. The unconsolidated deposits (Qu, pl. 1; QTu, pl. 2) are the most commonly used sources of sand and gravel. These deposits occur around the fringes of the Black Hills uplift. Due to the 1:250,000 scale of this appraisal, the deposits have been depicted in a general way in figure 3, and some small economical areas may not be shown.

Crushed Rock

Crushed rock is available in larger quantities in the Forest than are sand and gravel. The principal sources are the Lower Permian Minnekahta Limestone (part of unit Pmo, pls. 1 and 2) and the Lower Mississippian Pahasapa Limestone (most of unit MDpe, pl. 1). These units encircle the main core of the Black Hills, forming a low but conspicuous escarpment. The thicknesses of the units and the relatively shallow dip will provide easily accessible material in sufficient quantity and at reasonable production costs. On the basis of thicknesses of units, one may conclude that the Pahasapa would provide a larger volume of minable material than would the Minnekahta. A Tertiary-age feldspar porphyry useful for construction materials is exposed in the Lead area, along Whitewood Creek at Green Mountain north of Polo Peak, and at Custer Peak and is included in unit Tq, plate 1. Many of these sources of crushed rock are shown in figure 3.

Dimension Stone

Sources of dimension stone, including granite, slate, quartzite, marble, limestone, and sandstone, which are shown on plate 1 as units Xh, Xsh and Xbs, Xq, Xd and part of Xc, part of Pmo, and part of O€wd, respectively, are located in various places in the Forest. Each material is quarried for a specific local use, and the production rate would be determined by the demand and the cost. The stone must be aesthetically pleasing, free from cracks, easy to quarry, and reasonably strong. Detailed assessments cannot be made for each rock type at a 1:250,000 scale, but most areas having high potential are shown in figure 3.

Clay

Clay suitable for production of refractory brick comes from the Fuson Member of the Lakota Formation. This unit is present at the southern end of the Forest. The mineralogy and chemical composition of the clay control its physical properties and its suitability for commercial use. Large amounts of clay of suitable quality probably would be exploited where available if the needs were present. Larger outcrops of higher quality clay are present outside the Forest. The distribution of the clay cannot be shown well at 1:250,000 scale, but is included in unit Kms, shown on plate 1.

RECOMMENDATIONS FOR FUTURE STUDIES OF MINERAL RESOURCE POTENTIAL

Parts of the Black Hills National Forest and adjacent lands possess rich mineral resources and, accordingly, have been extensively mined and prospected. Because much of the mining activity took place before modern geologic mapping and investigative techniques had been developed, our understanding of the processes responsible for the formation of selected mineral deposits is limited and needs to be improved before adequate assessments of mineral resource potential are available for all commodities and deposit types.

Of particular interest are the Proterozoic iron-formation units and their stratiform, syngenetic gold deposits. The deposit at the Homestake mine, the largest producer of gold in the Western Hemisphere, has been studied and mined for more than 100 years, yet the mechanism or mechanisms responsible for deposition of the precious metals is poorly understood. At present we do not know if the gold was deposited from volcanic emanations, was trapped by biologic or bacterial organisms, or was introduced into the strata by heated ground water. Additional stable-isotope studies, careful study of the chemistry of layers within the iron-formation, and detailed mapping and understanding of the stratigraphic setting of the deposits are needed before we can accurately assess the resource potential of much of the Proterozoic core of the Black Hills.

Vein and shear-zone deposits of presumed Proterozoic age need to be studied and dated in order to determine whether or not significant numbers of deposits are younger than Proterozoic and thus possibly related to Laramide uplift and deformation of the Black Hills. If all the deposits are indeed Proterozoic, knowing their age would help us to understand better their environment of formation and hence to determine their possible distribution in the subsurface or in areas of poor outcrop.

Pegmatite deposits have been extensively exploited, but very few studies have been conducted to determine their possible distribution in the subsurface. Modern techniques should be employed to determine how many pegmatite bodies might be found in the Black Hills within 300 ft of the surface. Also, additional studies of the genesis and absolute age of the pegmatites should be conducted to understand more fully their pattern of zoning on a district-wide scale.

Metamorphosed Proterozoic black shale should be investigated by modern chemical and petrologic techniques to assess the possibility of containing precious- and base-metal deposits. These strata in the Black Hills are, in reconnaissance, similar to other black shale units in the world that contain significant deposits of base metals.

The question of whether or not the Cambrian Deadwood Formation contains paleoplacer deposits of gold derived from Proterozoic lode deposits can be answered only by investigation of old mines or by modern drilling programs. In view of the number of areas in the Deadwood that could contain detrital accumulations of gold, this question needs to be answered in order for the resource potential for this deposit type to be assessed accurately.

One of the more important, and unanswered, questions regarding roll-front deposits of uranium in Cretaceous rocks is that of their absolute age. Paleotectonic reconstructions are especially important in the search for such deposits, and the timing of the mineralization must be known before such reconstructions can be useful in the search for ore deposits.

The northern Black Hills contains a world-class epithermal gold district comprising numerous small and large deposits. However, many of the deposits were mined before the ore deposits could be studied adequately. Compared to our understanding of the formation of other precious-metal, epithermal gold districts in the Western United States, our knowledge of the northern Black Hills deposits is very poor. Modern drilling programs, chemistry studies, and investigations of stable and radioactive isotopes need to be made of these deposits before we can accurately assess their mineral resource potential.

The realization that there could be carbonatite-related deposits in the northern Black Hills has come only within the last 5 years. Studies similar to those being conducted in the Bear Lodge Mountains north of Sundance need to be made for all alkalic, mafic, or undersaturated intrusive centers in the northern Black Hills in order for the resource potential of this area to be properly evaluated for rare commodities.

The Black Hills probably never have been evaluated for such rare commodities as diamonds, yet the possibility of finding diamonds in breccia pipes and diatremes related to the alkalic intrusive rocks is not totally unlikely, especially in view of the extensive cover by coniferous forest.

The deep oil and gas potential of the Fanny Peak monocline has not been addressed by shallow test wells in and adjacent to the Forest. Although it admittedly is a speculative hypothesis, the possibility of large amounts of oil-bearing Phanerozoic strata being trapped beneath crystalline Precambrian rock along the monocline should be tested if possible.

In order for most of the above recommendations to be carried out, additional geologic mapping of the Forest and its adjacent lands is necessary. A great wealth of mineral deposits is found in Precambrian rocks in the Black Hills, and a further understanding of those deposits will be advanced the most by detailed geologic field studies of the complexly deformed terrane. Detailed geologic maps at 1:24,000 scale are available for only some of the areas in the Precambrian that have, in this study, been assessed as having a moderate or high mineral resource potential. Likewise, extensive areas in the northern Black Hills that include many Tertiary epithermal deposits and the Proterozoic gold-bearing iron-formation at the Homestake mine, near Lead, need to be mapped at 1:24,000 scale.

Stream-sediment and groundwater geochemical data of a reconnaissance nature are available for the Forest and adjacent lands from the NURE surveys, but sample localities for those studies are too widely spaced to be of much help in resource assessment in many areas. Basic data from the studies appear to be reliable, but need to be augmented by additional samples and analyses for elements such as gold, silver, mercury, arsenic, bismuth, cadmium, and other elements that are directly related to mineral deposits in the area.

The entire Forest and adjacent lands are covered by airborne radiometric surveys from the NURE program at a flight-line spacing of about 2–3 mi. This spacing is adequate to differentiate many sedimentary rock units from one another and to differentiate the Tertiary intrusive units from other rocks, but it is not sufficient to separate rock types within the intrusive bodies nor to accurately map altered or mineralized areas within such bodies. Radiometric surveys flown at a spacing of about 1 mi would be able to detect such differences and would greatly aid in the assessment of mineral resource potential for the areas in the northern Black Hills.

Aeromagnetic and gravity data are adequate for the South Dakota part of the Forest and adjacent lands, but not for that part of the Forest in Wyoming, particularly the area of the Bear Lodge Mountains and the region surrounding Tinton. Additional magnetic and gravity data would greatly aid the assessment of the extent of mafic ring dikes and carbonatite bodies.

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APPENDIXES 1 AND 2

APPENDIX 1. DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

Mineral resource potential is defined as the likelihood of the presence of mineral resources in a defined area; it is not a measure of the amount of resources or their profitability.

Mineral resources are concentrations of naturally occurring solid, liquid, or gaseous materials in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.

Levels of resource potential are denoted by letters H, M, L, U (fig. 25):

H. High mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resources, where interpretations of data indicate a high likelihood for resource accumulation, where data support occurrence and(or) genetic models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential requires positive knowledge that resource-forming processes have been active in at least part of the area; it does not require that occurrences or deposits be identified.

M. Moderate mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable chance for resource accumulation, and where an application of genetic and(or) occurrence models indicates favorable ground.

L. Low mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment in which the existence of resources is unlikely. This level of potential embraces areas of dispersed mineralized rock as well as areas having few or no indications of mineralization. Assignment of low potential requires specific positive knowledge; it is not used as a catchall for areas where data are inadequate.

U. Unknown mineral resource potential is assigned to areas where the level of knowledge is so inadequate that classification of the area as high, moderate, or low would be misleading. The phrase "no mineral resource potential" applies only to a specific resource type in a well-defined area. This phrase is not used if there is the slightest possibility of resource occurrence; it is not used as the summary rating for any area.

Expressions of the certainty of the mineral resource assessment incorporate a consideration of (1) the adequacy of the geologic, geochemical, geophysical, and resource data base available at the time of the assessment; (2) the adequacy of the occurrence or genetic model used as the basis for a specific evaluation; and (3) an evaluation of the likelihood that the expected mineral endowment of the area is, or could be, economically extractable.

Levels of certainty of assessments are denoted by letters A–D (fig. 25):

A. The available data are not adequate to determine the level of mineral resource potential. This level is used with an assignment of unknown mineral resource potential.

B. The available data are adequate to suggest the geologic environment and the level of mineral resource potential, but either the evidence is insufficient to establish precisely the likelihood of resource occurrence or the occurrence and(or) genetic models are not well enough known for predictive resource assessment.

C. The available data give a good indication of the geologic environment and the level of mineral resource potential, but additional evidence is needed to establish precisely the likelihood of resource occurrence. The extent or degree of the resource-forming processes or existing occurrence and(or) genetic models are minimal for predictive applications.

D. The available data clearly define the geologic environment and the level of mineral resource potential, and indicate the extent or degree of resource-forming processes. Key evidence to interpret the presence or absence of specified types of resources is available, and occurrence and(or) genetic models are adequate for predictive resource assessment.

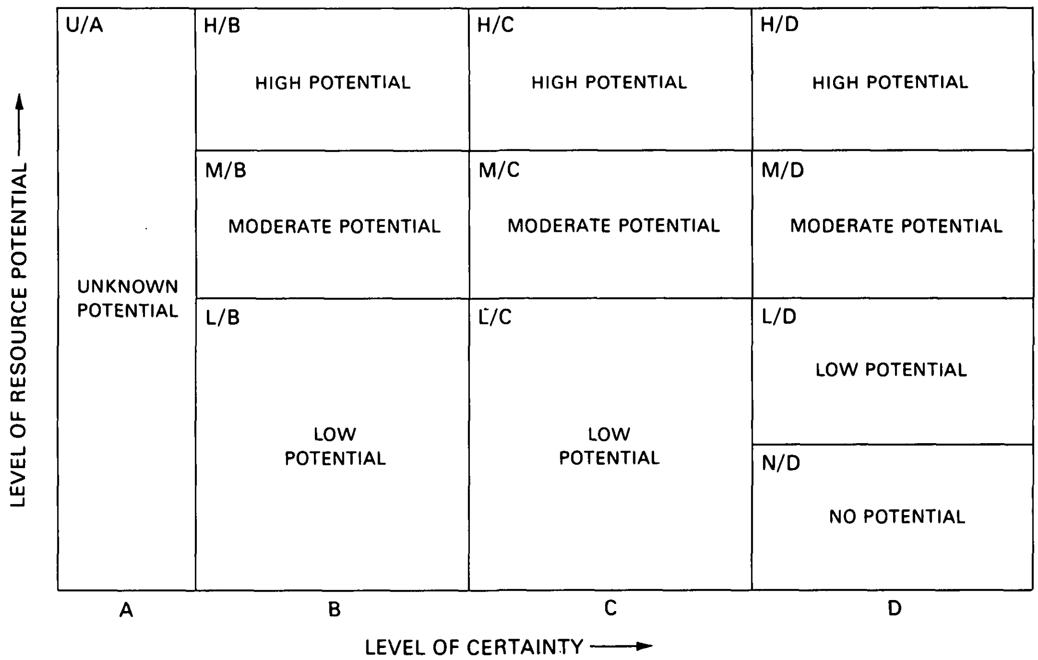

Figure 25. Diagram showing relationships between levels of resource potential and levels of certainty.

APPENDIX 2. SIZE CLASSIFICATION OF DEPOSITS

Various sizes of deposits are discussed throughout the text. Table 4, below, lists the sizes of various deposits (small, medium, large) for locatable commodities (A-Z) and leasable commodities (CO, OG, and GE).

Table 4. Size classification of deposits discussed in text
[>, greater than; <, less than; BBL, barrels of oil; MCF, million cubic feet of gas]

Type of deposit (commodities)	Size of deposit (short tons) Small	Medium	Large
A. Taconite (Fe)	<1,000,000	1,000,000-75,000,000	>75,000,000
B. Conglomerate (U)	<10,000	10,000-50,000	>50,000
C. Iron-formation (Au)	<1,000,000	1,000,000-10,000,000	>10,000,000
D. Vein (Au, Ag, Pb)	<10,000	10,000-250,000	>250,000
E-J. Pegmatite	<30,000	30,000-2,000,000	>2,000,000
K. Stratabound (Mica, Au, Ag, Zn)	<1,000,000	1,000,000-5,000,000	>5,000,000
L. Paleoplacer (Au, silica sand)	<10,000	10,000-100,000	>100,000
M. Limestone	<100,000	100,000-10,000,000	>10,000,000
N. Gypsum	<100,000	100,000-1,000,000	1,000,000
O. Roll-front (U, V)	<10,000	10,000-50,000	>50,000
P. Bog-iron (Fe)	<10,000	10,000-100,000	>100,000
Q. Placer (Au)	<1,000	1,000-20,000	>20,000
R. Detrital (Fe)	<10,000	10,000-100,000	>100,000
S. Vein and replacement (Pb, Zn, Ag, Au)	<20,000	20,000-2,000,000	2,000,000
T. Vein and replacement (Au, Ag, Pb, Zn)	<10,000	10,000-500,000	>500,000
U. Disseminated (Mo, Cu, Zn, Au, Ag)	<10,000,000	10,000,000-50,000,000	50,000,000
V. Disseminated (Au, Ag, Mo, Cu)	<200,000	200,000-10,000,000	10,000,000
W. Disseminated (Th)	<100,000	100,000-2,000,000	>2,000,000
X. Disseminated (REE)	<50,000	50,000-500,000	>500,000
Y. Disseminated (Au, Ag)	<100,000	100,000-1,000,000	>1,000,000
Z. Vein (Ag, Pb, Au, Zn)	<10,000	10,000-250,000	>250,000
CO. Subbituminous coal	<50,000	50,000-1,000,000	>1,000,000
OG. Oil and gas	<1,000,000 BBL	1,000,000-20,000,000 BBL	>20,000,000 BBL
	<400,000 MCF	400,000-5,000,000 MCF	>5,000,000 MCF
GE. Geothermal		Adequate supply of water at	
	<100°F	100-180°F	>180°F

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