# United States Gold Terranes—Part I

U.S. GEOLOGICAL SURVEY BULLETIN 1857–B

U.S. DEPARTMENT OF THE INTERIOR
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Chapter B

# United States Gold Terranes—Part I

## Geographic Distribution of Gold Mining Regions and Types of Deposits in the United States

By EDWIN W. TOOKER

## Patterns of Gold Mineralization in Nevada and Utah

By WILLIAM C. BAGBY

## Gold-Silver Deposits Associated with the Trans-Challis Fault System, Idaho

By THOR H. KIILSGAARD, FREDERICK S. FISHER, and EARL H. BENNETT

## Geologic Setting and Potential Exploration Guides for Gold Deposits, Black Hills, South Dakota

By JACK A. REDDEN and GREGORY McN. FRENCH

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GEOLOGY AND RESOURCES OF GOLD IN THE UNITED STATES

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# United States Gold Terranes—Part I

## Geographic Distribution of Gold Mining Regions and Types of Deposits in the United States

*By* Edwin W. Tooker

### Abstract

Early settlement and westward expansion of the geographic borders of the United States commonly were accompanied by a search for gold, as chronicled by the discovery dates of the classic western mining districts. This search still continues in known gold-producing regions as well as in other areas now known to contain the geologic environments favorable to gold occurrence. The geographic distribution of gold is related fundamentally to the geologic structures and lithologies of discrete parts of craton or accreted crustal terranes. Numerous gold-producing areas occur in the outer craton platform and shelf, generally in favorable Precambrian and Phanerozoic host rocks along or overlying basement suture zones, whereas gold deposits are rare in the mid-continent craton platform. Gold also occurs locally along accretionary fault contacts or zones in favorable host rocks in the accreted terranes, generally at an angle to the basement zones in the cratonal terranes. Several types of primary or byproduct gold occurrences, such as quartz lodes, polymetallic veins and replacements, skarns, porphyries, bonanza deposits, disseminated types, massive sulfide deposits, iron-formation deposits, and placers are equally distributed between the outer craton and the accreted terranes of the Appalachian and Rocky Mountain cordillera. The most economically minable type at present in the eastern and western cordilleran regions is the disseminated deposit. Commonly production and reserves of disseminated deposits have surpassed those of the other types that may have been mined previously in a terrane. Several types of gold deposits may occur within large complex mining districts, such as Bingham, Utah.

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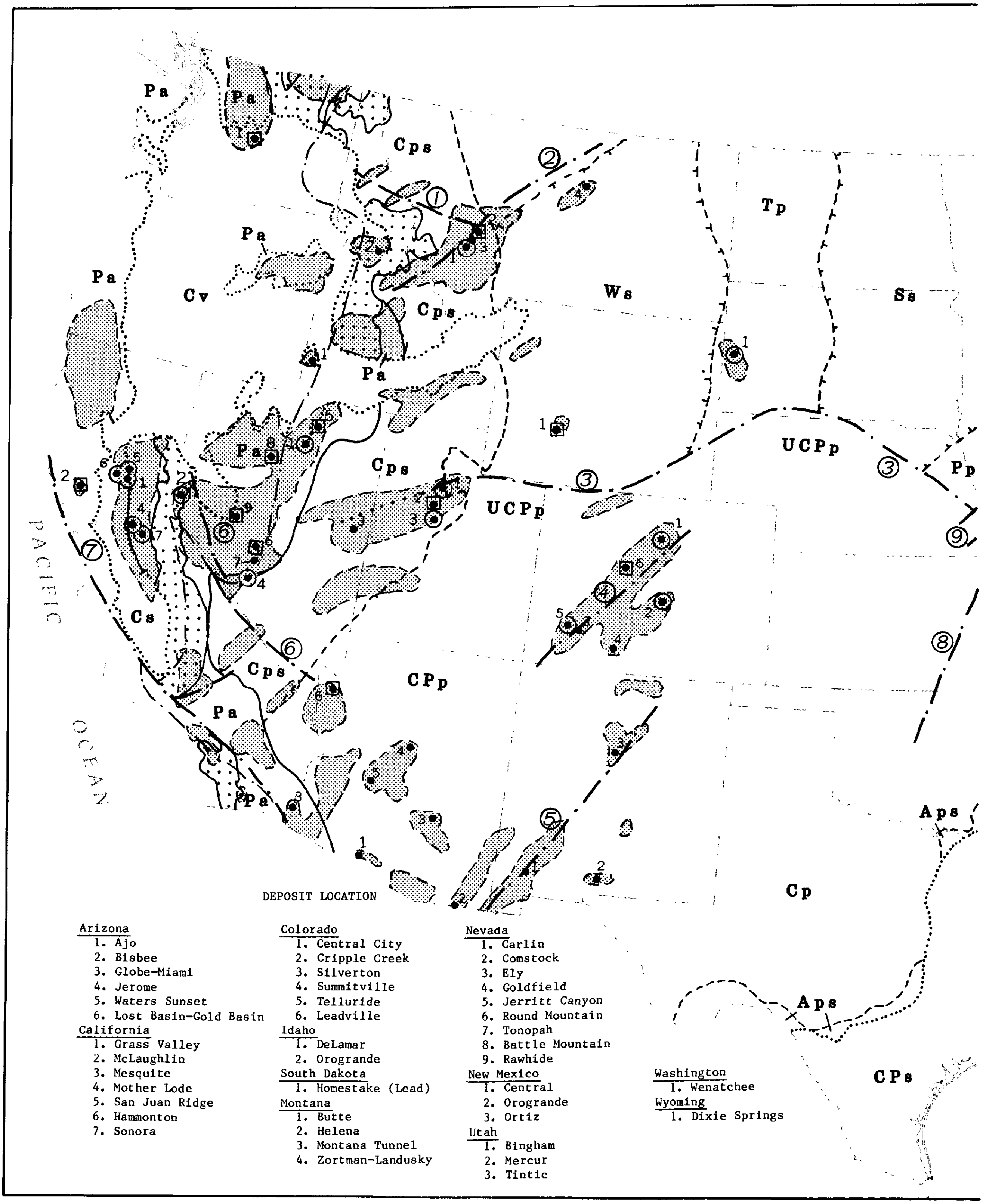
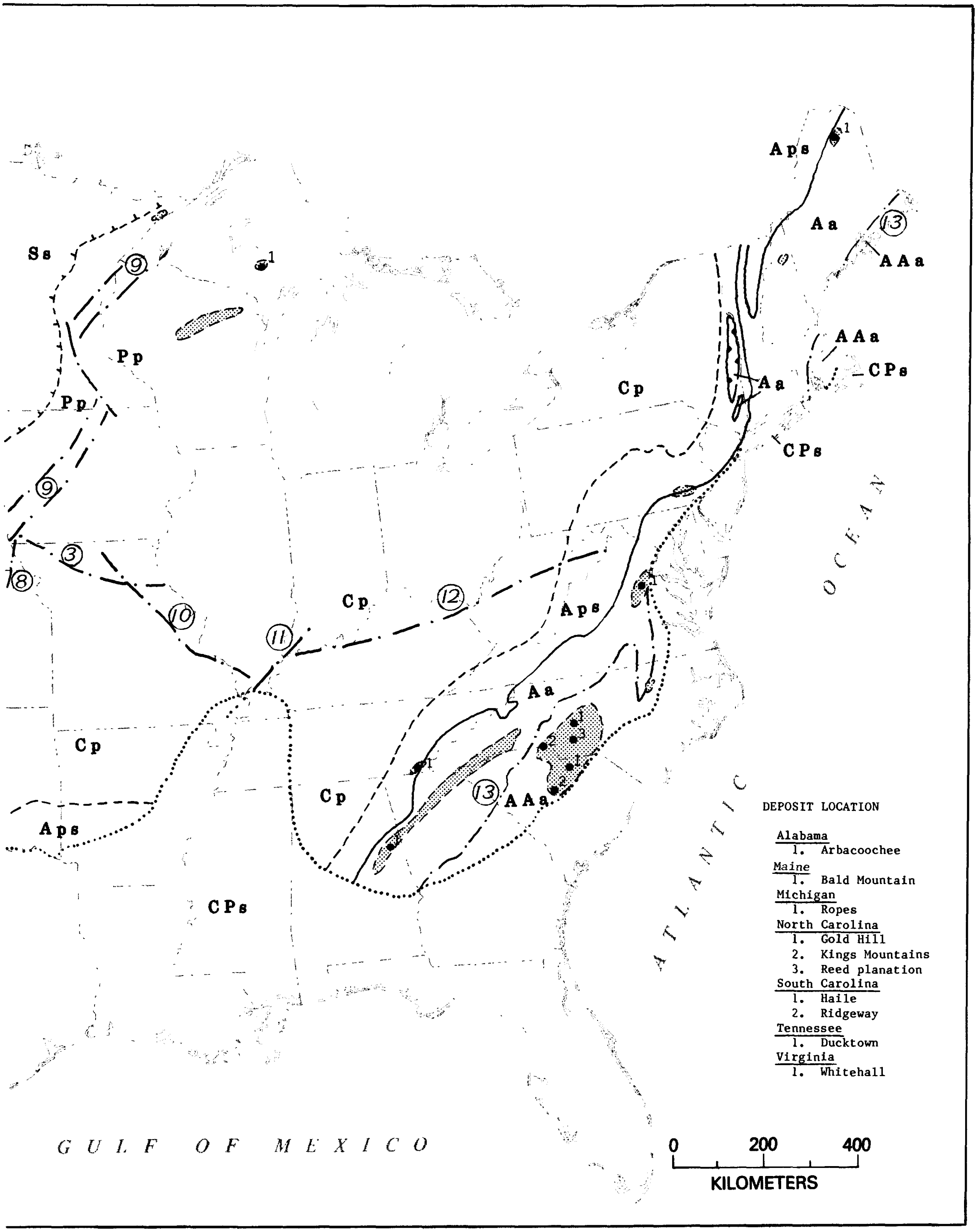
## INTRODUCTION

Knowledge of the geographic distribution of gold deposits in the United States has grown as the nation expanded westward. Beginning with the first settlers along the Atlantic Coast as early as 1607, the quest for gold was one of the incentives that led inexorably to the westward exploration and settlement of the continent. In the West, gold had been recovered from placers by the Spanish and Mexicans as early as 1775 (Clark, 1970), but exploration for it there remained localized until the arrival of Americans in the mid-nineteenth century. Interest in gold was motivated first by the intrinsic value and mystique of the metal itself, and was quickened by the apparent ease of its early discovery and recognition in a variety of deposits, some originally developed for metals other than gold.

The geographic distribution of gold-bearing regions, in part at least, may be correlated with geologic terranes.[1] The range of types of gold deposits and their locations in terranes of the conterminous United States have been compiled by Tooker and Vercoutere (1986), and those in Alaska by Berg and others (1964). These data are summarized in figures B1 and B2.

[1]A terrane is here considered to be a geographic region having a singular geologic history that differs from that in adjoining regions and is separated from its neighbor terrane by major faults, fault zones, or other geologic discontinuities.


Pa
Cps
Cv
Cs
Ws
Tp
Ss
UCPp
Pp
CPp
Cp
Aps
CPs
PACIFIC
OCEAN
DEPOSIT LOCATION
Arizona
1. Ajo
2. Bisbee
3. Globe-Miami
4. Jerome
5. Waters Sunset
6. Lost Basin-Gold Basin
California
1. Grass Valley
2. McLaughlin
3. Mesquite
4. Mother Lode
5. San Juan Ridge
6. Hammonton
7. Sonora
Colorado
1. Central City
2. Cripple Creek
3. Silverton
4. Summitville
5. Telluride
6. Leadville
Idaho
1. DeLamar
2. Orogrande
South Dakota
1. Homestake (Lead)
Montana
1. Butte
2. Helena
3. Montana Tunnel
4. Zortman-Landusky
Nevada
1. Carlin
2. Comstock
3. Ely
4. Goldfield
5. Jerritt Canyon
6. Round Mountain
7. Tonopah
8. Battle Mountain
9. Rawhide
New Mexico
1. Central
2. Orogrande
3. Ortiz
Utah
1. Bingham
2. Mercur
3. Tintic
Washington
1. Wenatchee
Wyoming
1. Dixie Springs


Aps
Aa
13
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Pp
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3
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11
12
Cp
Aps
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Cp
13
AAa
Cp
Aps
CPs
OCEAN
ATLANTIC
DEPOSIT LOCATION
Alabama
1. Arbacoochee
Maine
1. Bald Mountain
Michigan
1. Ropes
North Carolina
1. Gold Hill
2. Kings Mountains
3. Reed planation
South Carolina
1. Haile
2. Ridgeway
Tennessee
1. Ducktown
Virginia
1. Whitehall
GULF OF MEXICO
0
200
400
KILOMETERS

**Figure B1** (on preceding pages). Known geographic distribution of some major gold deposits in the conterminous United States (in fine stipple). The larger gold districts are numbered and named on the map as well as discussed in the text. The patterned areas, outlined by light dashed lines, contain additional smaller gold mining districts and areas of known resources. Generalized geologic terranes (after Beck and others, 1980), outlined by heavy solid, dash (including ticked-dash), or dot boundaries, are identified as follows: *Cratonal terranes*—Ws, Wyoming shield; Ss, Superior shield; Tp, Trans-Hudson platform; Pp, Penokean platform; UCPp, Uinta-Central Plains platform; CPp, Colorado Plateau platform; Cp, craton platform, undivided; Cps, Cordilleran platform shelf; Aps, Appalachian platform shield. *Accreted terranes*—Aa, Atlantic, composite; AAa, Atlantic Avalon; Pa, Pacific, composite. *Overlapped (covered) areas*—CPs, Coastal Plain sedimentary rocks; Cv, Cenozoic volcanics; Cs, Cenozoic sedimentary rocks. Circled numbers and heavy dash-dot lines indicate basement fault or lineament zones: 1, Lewis and Clark; 2, Trans-Challis; 3, Uinta-Central Plains; 4, Precambrian shear (Colorado mineral belt); 5, New Mexico mineral belt; 6, Walker Lane belt; 7, San Andreas; 8, Nemaha Ridge; 9, Midcontinent rift; 10, Northeast Missouri-St. Genevieve; 11, Mississippi embayment; 12, Thirty-eighth parallel; 13, Avalon accretion zone. Coarse stippled areas are sites of major batholiths. Western edge of the craton is shown by a light-weight dash-dot line extending through Washington, Idaho, Nevada, and southern California. Circled dots indicate districts that have produced more than 3 million oz (93.3 t (metric tons)) of gold; squared dots are districts whose production and announced reserves exceed 3 million oz (93.3 t) of gold. Data from Tooker and Vercoutere (1986).

## PATTERN OF GROWTH OF KNOWN GEOGRAPHIC DISTRIBUTION OF GOLD IN THE UNITED STATES

Knowledge of the geographic distribution of gold deposits has developed gradually and continues to broaden, the cumulative result of the chance discoveries of placers and the "rushes" to explore the new areas, the subsequent diligent search for the source lodes, and a variety of technologic and economic factors that have spurred exploration for lower grade deposits. These factors include new mining and extraction techniques, periodic urgent national need for gold, and legislation to deregulate the price of gold. Although the broad pattern of gold distribution in the United States largely had been established by the early 1900's, new areas containing gold-bearing deposits are still being identified.

A chronology of dates of discovery (and in some cases rediscovery) of gold districts parallels the territorial expansion of the United States. Spurred by earlier Spanish successes at exploiting precious metal resources in the New World, the English settlers of early 1600's began to look for gold. A "feverish hunt" in Virginia by Capt. John Smith's group (Rabbitt, 1979) proved unsuccessful, and the necessity to survive the harsh climate in New England slowed the pace of exploration in that region, but the search continued in coastal areas. The French and English governments vied for control of the lands and potential resources west of the Appalachians during the territorial wars that preceded the American Revolution. Following the Revolutionary War, individual States created geological surveys that gradually began systematic investigations of the lands and their resources. Placer gold was reported in Virginia in about 1782, followed by the discovery of additional placers and their source lodes in several of the southeastern States. Notable examples (located on fig. B1) include:

| | |
|---|---|
| Reed plantation, North Carolina | 1799 |
| Gold Hill, North Carolina | 1824 |
| Haile, South Carolina | 1827 |
| Arabacoochee, Alabama | 1830 |
| Kings Mountain, North Carolina | 1834 |
| Whitehall, Virginia | 1836 |
| Ducktown, Tennessee | 1850 |

Production from these and other small districts in the region was sufficient to establish a branch of the U.S. mint in Dahlonega, Ga., in 1838 (Rabbitt, 1980). The southeastern States remained an important source of domestic production until 1859. Spanish explorers searching for silver discovered and worked placer deposits in southern Arizona and southern California as early as 1775 (Moore, 1969; Clark, 1970), but American entry to develop the gold resources of the western region was delayed until after 1848.

The lure of the western territories led President Thomas Jefferson to send the Lewis and Clark expedition in 1805 to survey the resources of the lands comprising the Louisiana Purchase. Lewis and Clark's report encouraged further exploration of western territories. However, it was the chance discovery of easily mined placer gold in the Sierra Nevada foothills in 1848 that launched the massive gold rush in California and shifted the focus of attention of gold-seekers to the West. The search soon broadened throughout the Cordilleran region and led to the discovery of many placer and vein lode mining districts. Subsequently, the pace of search increased with discovery close to the turn of the century of a new type of deposit, the celebrated epithermal bonanzas in the volcanic terranes of Nevada and Colorado. The wide geographic distribution of high-grade deposits recognized during this period is illustrated by the dates of discovery in the following districts (fig. B1):

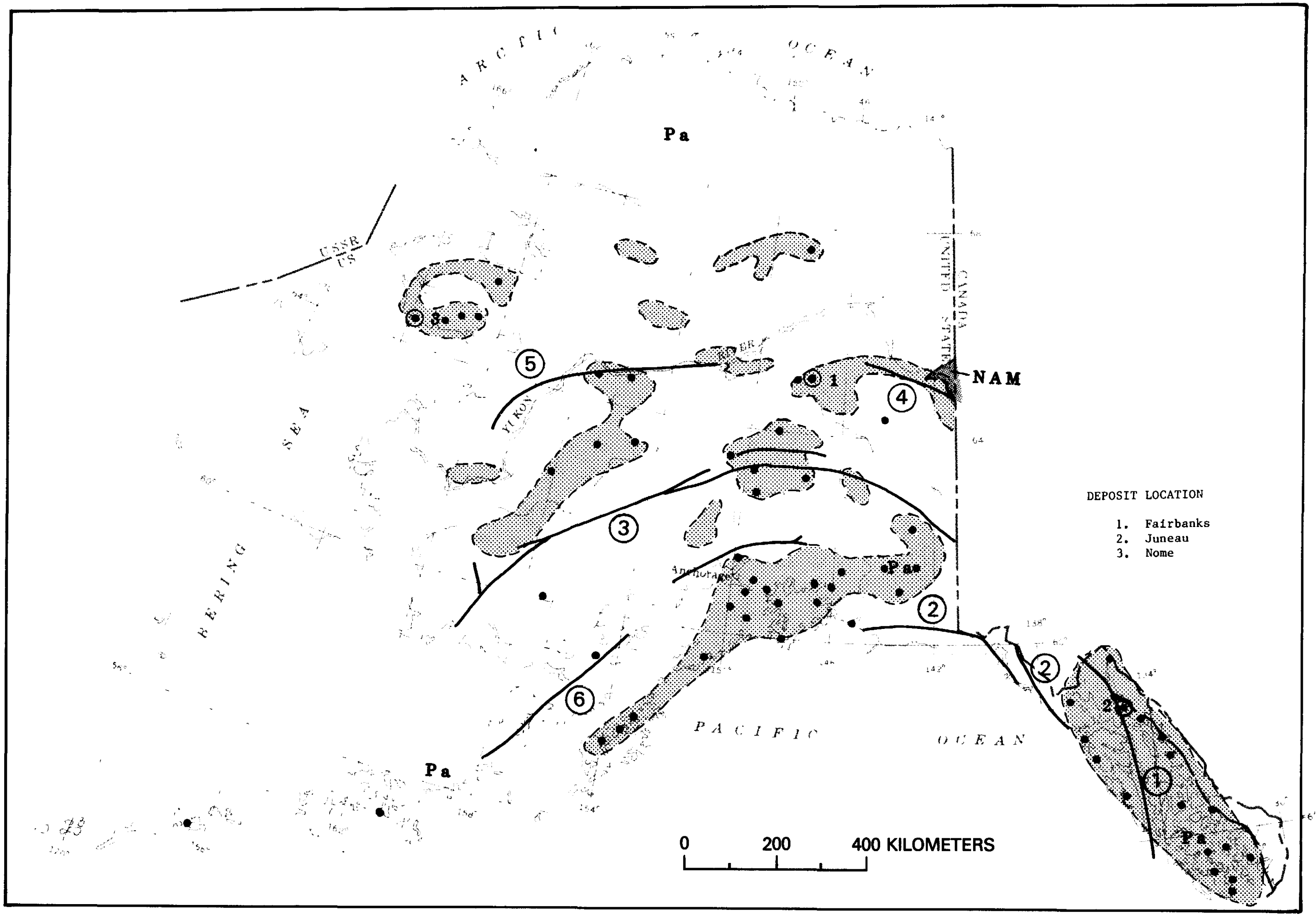


**Figure B2.** Known geographic distribution of some major lode and placer gold deposits in Alaska (in fine stipple). Numbered districts, located and named on the map, are noted in the text, and areas enclosed by dashes contain additional smaller gold mining districts and known gold resources in Alaska; generalized geologic terrane and structural framework elements include: *Cratonal terrane*—NAM, North American plate (medium-gray shaded); *accreted terrane*—Pa, Pacific, composite. Circled numbers identify basement fault or lineament zones (solid lines): 1, Fairweather; 2, Chugach-St. Elias; 3, Denali; 4, Tintina; 5, Kaltag; 6, Bruin Bay. Circled dots locate districts that have produced more than 3 million oz (93.3 metric tons) of gold. Data from Berg and others (1964).

| | |
|---|---|
| Mother Lode, California | 1849 |
| Grass Valley, California | 1850 |
| Comstock Lode, Nevada and Central City, Colorado | 1859 |
| Bingham Canyon, Utah | 1860 |
| Helena and Butte, Montana | 1864 |
| Summitville and Silverton, Colorado | 1872 |
| Lead (Homestake), South Dakota | 1875 |
| Cripple Creek, Colorado | 1892 |
| Tonopah, Nevada | 1900 |
| Goldfield, Nevada | 1902 |

The geographic range of the search for gold was enlarged in 1853 by the Gadsden Purchase of the southwestern United States and in 1867 by the purchase of Alaska. The search also was intensified by the economic and political demands of the American Civil War (1861–1865). Completion of the transcontinental railroad in 1869 stimulated further exploration and discovery by providing much-needed access to mining camps in the mountainous regions of the West.

Gold was discovered in Alaska as early as 1848, but the first mining in southeastern Alaska began in 1869. The Juneau lode was discovered in 1880, and Nome placer production began in 1897. The Klondike discovery and subsequent rush of 1896 in neighboring Canada also broadened the geographic focus of gold exploration along the extensive river systems in Alaska.

The development of new mining technology also had an impact on the discovery of new gold-bearing regions or extensions in known regions. Placers, which had been the chief sources of gold until 1873, were gradually displaced by lode production, even though brief periods of resurgence in placer mining occurred as large dredges began to operate in California (1896) and at Fairbanks, Alaska (around 1900). Technology for the recovery of dispersed low-grade, fine-grained gold from porphyry copper deposits in the early 1900's resulted in byproduct production of gold in a number of well-established base- and precious-metal mining districts in the West and Southwest, such as these:

| Mining district | Original mining began | Mining of porphyry deposits began |
|---|---|---|
| Bingham, Utah | 1860 | 1904 |
| Globe-Miami, Arizona | 1874 | 1904 |
| Central, New Mexico | 1804 | 1906 |
| Ely, Nevada | 1873 | 1908 |
| Ajo, Arizona | 1750 | 1917 |
| Butte, Montana | 1864 | 1955 |

By 1945, more than 50 percent of U.S. gold production was derived from deposits of this type. Most mining devoted exclusively to gold production ceased during World War II and production fell drastically. Acceleration in the production of base metals from porphyry copper deposits during the war, however, resulted in continued although low production of gold (Stowe, 1975).

In the early 1960's, very fine grained, low-grade, bulk-minable, epithermal gold disseminated in sedimentary and volcanic rocks was recognized at Carlin, Cortez, and Round Mountain, Nev. These discoveries, together with the earlier recognized disseminated deposits at Getchell and Gold Acres, Nev., led to an awareness of the significance of this gold deposit type. As a result, the western and subsequently the Appalachian cordilleran regions were reopened to a renewed search for gold in previously mined areas as well as in new geographic areas that contained the geologic and economic characteristics of disseminated (bulk minable) type deposits (Tooker, 1985). The broad geographic distribution of disseminated gold ores in some old as well as new mining areas is shown by the following examples:

| | Early production began | Mining of disseminated deposits began |
|---|---|---|
| Waters Sunset, Arizona | none | 1984 |
| McLaughlin, California | 1862 (mercury) | 1986 (gold) |
| Mesquite, California | none | 1986 |
| Summitville, Colorado | 1870 | 1986 |
| DeLamar, Idaho | 1863 | 1977 |
| Orogrande, Idaho | 1857 | 198? |
| Bald Mountain, Maine | none | 1986 |
| Ropes, Michigan | 1880 | 1985 |
| Montana Tunnels, Montana | none | 1987 |
| Zortman-Landusky, Montana | 1884 | 1980 |
| Carlin, Nevada | 1900 | 1965 |
| Round Mountain, Nevada | 1906 | 1977 |
| Jerritt Canyon, Nevada | none | 1971 |
| Ely, Nevada | 1867 | 1987 |
| Orogrande, New Mexico | 1905 | 1981 |
| Ortiz, New Mexico | 1828 | 1981 |
| Haile, South Carolina | 1827 | 1986 |
| Ridgeway, South Carolina | none | 1986 |
| Lead, South Dakota | 1877 | 1986 |
| Mercur, Utah | 1870 | 1981 |
| Bingham, Utah | 1960 | [1]1987 |

[1]Discovery of Barney's Canyon reported, but mining had not begun (British Petroleum Company, 1986).

## GEOLOGIC BASIS FOR THE GEOGRAPHIC DISTRIBUTION OF GOLD

Although gold occurs in at least 40 States (Tooker and Johnson, 1980) and in more than 1,000 mining districts, major United States production and significant reserves are located in relatively few restricted geographic regions (Tooker and Vercoutere, 1986). The geographic distribution of gold (figs. B1 and B2) seems to be closely related to specific parts of the continental framework composed of a craton and peripherally accreted host rock terranes. Distribution of gold districts in these terranes differs, and generally gold is abundant in only parts of a terrane (Tooker, 1979).

Favorable host regions for the occurrence of gold, shown in figures B1 and B2, contain concentrations of deposits that are the sites for major U.S. production (from Tooker and Vercoutere, 1986). Deposits in the accreted terranes, which were attached to the craton during Phanerozoic time, occur as clusters along recognized accretionary structures or in favorable lithologic units. Those deposits that formed locally in favorable Precambrian and Phanerozoic units on the craton commonly seem to be grouped geographically in the outer craton platform and shelf along persistent Precambrian basement suture zones rather than along the structures or rock units in the overlying Phanerozoic cover rocks. Cratonal terrane districts are clustered mainly along the outer edges of the western platform and shelf. Few gold districts are known in the central part of the craton. The shield areas (Ss and Ws, fig. B1) are not major U.S. gold-producing regions, whereas in Canada the Archean Superior shield hosts most of the productive deposits (Boyle, 1979; Cameron, 1988). The Wyoming shield has some districts characterized by small lode and disseminated gold deposits, and a potentially large (Dixie Springs) placer district, whose source lode is as yet poorly identified. Most of the Precambrian gold deposits in the United States are hosted in Proterozoic platform terranes, close to the shield-platform boundaries (Ropes, Mich., and Homestake, S. Dak.). Potential byproduct gold also is known in the Duluth Gabbro in northeast Minnesota, and in metamorphosed sedimentary rocks such as the Crandon-type massive sulfide deposits in north-central Wisconsin. Important sources of gold in the Rocky Mountain region occur in Precambrian and Phanerozoic rocks composing the craton platform and shelf terranes. These regions appear to be aligned along northeast-trending zones that may intersect and cross the exposed structural fabric of the Phanerozoic cover rocks. Some evidence suggests that major controls for this pattern of distribution are basement shear zone structures, such as those in the mineral belt in central Colorado, Trans-Challis in southwestern Montana, the Uinta-Cortez trend in north-central Utah, and probably the New Mexico mineral belt. In contrast, the central craton platform of the midcontinent region and the Colorado Plateau region lack igneous intrusions and the structural deformation that characterize the outer craton platform and shelf regions of the Rocky Mountain and Appalachian cordillera.

The gold-producing regions in the accreted terranes are closely aligned with Phanerozoic structural features such as Sierra foothills and Klamath belts in California, Southeast Alaska, and Atlantic Avalon and Arabacoochee belts in the Appalachian terranes (figs. B1 and B2). This relation is well shown in the eastern U.S. (AAa and Aa) and Alaskan (Pa) accreted terranes, and is also repeated in the accreted terranes in western Washington, Oregon, and California.

The geographic distribution of gold districts in north-central Nevada seems not exclusively related to the geologic features of the host accreted terranes. Here rocks of oceanic origin have been obducted onto continental crust of the craton shelf. The resulting distribution and magnitude of gold deposition may reflect contributions from both terranes.

## GEOGRAPHIC DISTRIBUTION OF GOLD DEPOSIT TYPES

Assessment of the geographic distribution of types of gold deposits is made difficult because no generally accepted genetic classification of them exists, and gold deposits in a single mining district may consist of more than one type. A number of gold classifications emphasize features such as temperature-pressure (depth) of formation (Lindgren, 1933), host rocks and structures (Boyle, 1979), or a combination of genetic and descriptive features (Ashley, in press). Furthermore, some types of gold deposits are more amenable to one system of classification than to another, and commonly types overlap, even within a single deposit. A tentative descriptive classification of types is shown in the following tabulation, based mostly on the compilation of gold data by Tooker and Vercoutere (1986).

*General classification of types of primary and byproduct gold deposits:*

1. *Skarn.* Irregular replacement of fractured carbonate rock adjacent to granitic intrusives (contact metamorphism) to form gold-bearing calc-silicate mineralized rock; gold may be a primary product or a byproduct of base metals.
2. *Dispersed (porphyry).* Large-volume, low-grade, vein and disseminated sulfides in sheeted zone or stockwork of an associated subvolcanic porphyry; gold may be a primary product or a byproduct of base metal sulfides.
3. *Polymetallic vein and replacement.* Sulfide-rich fissure and replacement deposit in sedimentary or igneous host; gold may be a primary product or a byproduct of base and other precious metals.

4. *Quartz lode.* Vein and shear zone deposit generally in regionally metamorphosed sedimentary and igneous rocks and composed primarily of gold with quartz-pyrite gangue; a lode may contain minor base metal sulfides.
5. *Disseminated sediment- and volcanic-hosted.* Large-volume, low-grade, bulk-minable, generally epithermal deposit of primary gold, which may or may not be associated with intrusive rocks. The disseminated type also has been applied to bulk-minable parts of quartz lode, stockwork, bonanza, and other types.
6. *Bonanza.* Exceptionally rich ore shoot of primary and oxidized epithermal gold generally in a volcanic host, but also as an enriched quartz lode, replacement, stockwork, or breccia pipe.
7. *Massive sulfide.* Irregular peneconformable concentration of sulfide minerals in volcanic, metavolcanic, and metasedimentary rocks of mobile belts or accreted terranes; gold occurs mostly as a byproduct of base metals.
8. *Iron-formation.* Local concentration of primary gold in stratabound stringers and fracture fillings of "banded" (layered) marine metasedimentary and volcaniclastic rocks that contain more than 15 percent iron, abundant chert, and fine-grained quartz segregations.
9. *Placer.* Eluvial, alluvial, and colluvial modern and fossil local accumulation of free gold, the result of surface erosion of other types of deposits (types 1–8) and mechanical concentration of gold by stream or wave action.
10. *Saprolite.* Secondary enriched deposit of gold in place, localized in decomposed soft clay-rich igneous or metamorphic rocks by chemical weathering.

This classification is similar to the classification adopted by Shawe (1988) for grouping ore deposits in the various chapters of this Bulletin series. That classification consists of gold deposits in metamorphic rocks (including some quartz lodes and massive sulfide deposits), mesozonal gold deposits (including polymetallic replacements and veins, porphyry copper systems, and intermediate level gold-quartz veins), epizonal gold deposits (including bonanza-type and disseminated gold deposits), and placer gold deposits. In Shawe's classification, skarn deposits are considered part of porphyry copper systems, iron-formation deposits are grouped under deposits in metamorphic rocks, and saprolite deposits are not considered.

Tooker and Vercoutere (1986) arbitrarily placed a deposit in a class on the basis of the main ore type produced; they also indicated associated types where present. In some cases, the literature did not provide sufficient information for them to distinguish between a quartz vein (lode), which contained only minor base metal sulfides, and a polymetallic vein, in which the base metal value generally exceeded that of gold. This fact may account for the significant variation in the proportions of lode and polymetallic veins in the craton and accreted terranes shown in the following table.

| Types of gold occurrence | Cratonal (percent) | Accreted (percent) |
|---|---|---|
| Skarn, bonanza, iron-formation, and massive sulfide | 5 | 6 |
| Porphyry | 5 | small |
| Polymetallic veins and replacement | 50 | 25 |
| Quartz lode | 6–10 | 30 |
| Disseminated | 5–10 | 14 |
| Placer | 20 | 25 |

Analysis of the geographic distribution of deposit types in this classification indicates that non-vein types are distributed nearly equally in cratonal and accreted terranes. However, the Tooker and Vercoutere (1986) data suggest that certain types are characteristic of, but not confined to, specific geographic regions. Massive sulfide and saprolitic deposits predominate in Appalachian accreted terranes; iron-formation deposits are concentrated in South Dakota, polymetallic vein and replacement deposits predominate in the Colorado Front Range, quartz lodes and placers are most abundant in the Sierra foothills of California (placers are also abundant in Alaska), and disseminated gold deposits are most numerous in Nevada.

Most geographic regions, and even individual districts, contain a mix of deposit types. The table on page B9 illustrates some of the diversity to be expected.

However, as these generalizations suggest, the "disseminated" category in particular may include parts of virtually all lode deposit types (for example, Sierra foothills Mother Lode), carbonate-hosted (Carlin), arkosic-hosted (Wenatchee), volcanic-hosted (Round Mountain), and bonanza (Goldfield) types. Their common thread is that most are considered to be of epithermal origin and are bulk-minable; the Mother Lode is mesothermal, and moreover, in places (Bingham, for example) gold seems to have been introduced in several stages of the ore-forming process. At Bingham the copper-gold-molybdenum stage was an early high-temperature dispersed (porphyry) system in which the gold was deposited from a saline solution as fine-grained particles in veinlets and permeable altered zones in fractured wall rock (Roedder, 1971). Skarn copper-gold-silver deposits in the limestone beds adjacent to the porphyry intrusives were formed at the same time as the dispersed ores (Cameron and Garmoe, 1987). Locally rich concentrations of gold in peripheral base-metal-silver veins and replacement deposits are coarser grained and were deposited from lower-temperature, low-salinity

| Geographic areas and typical districts | Prominent types of deposits |
|---|---|
| Western Washington (Wenatchee). | Disseminated, and polymetallic veins. |
| Sierra foothills, California (Mother Lode). | Placer, quartz lode (and disseminated). |
| Central Nevada (Carlin). | Disseminated, bonanza, polymetallic vein and replacement. |
| Western Montana (Butte, Montana Tunnels). | Polymetallic vein, porphyry (disseminated). |
| Central Utah (Bingham, Tintic). | Porphyry, quartz lode, polymetallic vein and replacement, skarn, disseminated. |
| Western Arizona-Southwest California (Mesquite). | Disseminated. |
| South-central Arizona (Jerome). | Massive sulfide, polymetallic vein and replacement. |
| Southwest Oregon. | Quartz lode, polymetallic vein and replacement, placer. |
| Colorado Front Range (Central City). | Polymetallic vein and replacement, placer. |
| Western South Dakota (Homestake). | Iron-formation, quartz lode, disseminated. |
| South Carolina (Haile). | Disseminated, massive sulfide, placer. |
| Southeast Alaska (Juneau). | Quartz lode, placer. |

fluids (Rubright and Hart, 1968; Bowman and others, 1987). The gold that originated in these early stages apparently was the source of placer gold in Bingham Canyon (Boutwell, 1905). Just north of the Bingham porphyry intrusives, along a prominent north-northeast-trending fault, altered carbonate sedimentary rocks contain epithermal low-temperature fine-grained disseminated gold (British Petroleum Co., 1986) that is presumed to be derived from the hydrothermal system active at Bingham.

The timing of deposition stages is not fully known at present, neither at Bingham nor elsewhere. Most of the deposits in the major terranes are post accretionary, but some deposits such as the massive sulfide bodies were formed early. Much recycling or remobilization and concentration of gold in the cratonal terranes is suspected, but is not as yet well documented.

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# Patterns of Gold Mineralization in Nevada and Utah

*By* William C. Bagby

**Abstract**

The distribution of gold-producing districts in Nevada and Utah is controlled by a combination of interacting regional geologic features. Spatial associations between gold-producing districts and aeromagnetic anomalies, certain types of tectono-stratigraphic terranes, plutonic and volcanic rocks of certain chemical affinities, and regional tectonic, stratigraphic, and structural features have provided a context for research and exploration for gold. Maps showing the distribution of mining districts that have produced at least 10 ounces of gold give the appearance of scatter diagrams; however, gold-producing districts are twice as abundant in accreted terranes as they are in cratonal terranes. Reasonably distinct patterns appear on maps drawn to show major districts that have produced more than 1,000 ounces of gold. These patterns reinforce the association of gold with accreted terranes but also indicate a preferred localization of the districts in accreted terranes along northwesterly lineaments. Major districts that occur in cratonal terranes form east-trending patterns. Both the northwest and east trends of major gold-producing districts also contain intrusive and volcanic rocks, major faults and folds, and, in some cases, coincide with aeromagnetic anomalies. Although ages of gold mineralization are mixed in the pattern analysis, certain conclusions may be drawn regarding the genetic significance of the patterns. The conclusions are (1) that districts that produce gold are twice as likely to occur in accreted terranes as in cratonal terranes and (2) that deep-seated regional structures are major controls of the locations of these districts. The deep-seated structures are also the loci of magmatic and fault activity.

## INTRODUCTION

The distribution of gold-producing districts in Nevada and Utah apparently is controlled by a combination of interacting regional geologic features. Several investigators have examined the spatial distribution of gold and other types of ore deposits within the framework of known regional geologic features in an attempt to understand and to define metallogenic controls in Utah and Nevada. For example, Ferguson (1929) recognized two metallogenic provinces in Nevada: (1) a western province that contains mostly gold, silver, mercury, and antimony, and (2) an eastern province that is dominated by base metal deposits with peripheral precious metal ore bodies. Roberts (1966) expanded on Ferguson's metallogenic provinces and identified a series of 11 mineral belts in Nevada that are defined by alignments of ore deposits along structural trends. Jerome and Cook (1967) discussed the spatial distribution of mineral deposits and their regional tectonic, sedimentary, and igneous host environments in the Western United States. Silberman and others (1976) noted the similarity of ages among Tertiary volcanic rocks, precious metal deposits, and regional structural trends in Nevada and proposed a genetic association. Shawe and Stewart (1976), Shawe (1977), Stewart and others (1977), and Shawe and others (1978) interpreted the distribution patterns of precious and base metal deposits in Nevada and Utah in terms of aeromagnetic patterns, the ages and distribution of intrusive rocks, and regional structural trends, including the possible influence of plate interactions along the western margin of North America.

These examples represent a classical approach to the problem of explaining the distribution of ore deposits. Recently, the occurrence of mineral deposits related to tectono-stratigraphic terranes has been considered. For example, Albers (1983) and Tooker (1983) suggested that a genetic association is possible between tectono-stratigraphic terranes and ore deposits. Tooker (1983) showed that cobalt, chrome, and platinum group metals predominate in accreted terranes, and that gold and copper occur abundantly in both accreted terranes and over cratonic basement in the northwestern United States. On the other hand, lead, zinc, tin, and tungsten are predominantly concentrated in or along the margins of the craton. Likewise, Albers (1983) noted that some types of ore deposits are restricted to certain accreted terranes throughout the Western United States.

The success of applying the terrane concept to the location of ore deposits in general suggests that the concept should be considered as a factor in explaining the distribution patterns of gold-producing districts in Nevada and Utah. These patterns are examined herein and interpreted in light of the temporal and spatial relations between gold districts and the associated structural, magnetic, and igneous trends noted by earlier workers.

## TERRANES OF NEVADA AND UTAH

The Nevada-Utah region contains a diverse assemblage of geologic terranes. For example, the areas of central and western Nevada are composed of a collage of tectono-stratigraphic terranes accreted to, and in part, overlying cratonic basement which underlies eastern Nevada (Silberling and others, 1984). In contrast, Utah contains no accreted terranes, but instead consists of a complex of older cratonic basement terranes, different parts of which may have experienced different geologic histories.

The definition of a geologic terrane, as used in this report, is one that was proposed by the Penrose Conference on microplate tectonics: "a fault-bounded geologic entity characterized by a distinctive stratigraphic sequence and/or a structural history differing markedly from those of adjoining neighbors" (Beck and others, 1980, p. 454). This definition is most commonly used with reference to accreted terranes, those that are interpreted to have formed in a different geographic location from that in which they now occur. Thus, oceanic terranes may be accreted to a craton by either collision or transform tectonics. This definition may also extend to areas that may or may not have moved but that have experienced unique geologic histories: such terranes may be identified as cratonal terranes because they formed over cratonic basement and have not moved from their original site. Also, the definition is broadened to include basement terranes of distinctive rock units that, owing to high-grade metamorphism, cannot strictly be interpreted as stratigraphic sequences.

The distribution of accreted and cratonal terranes in Nevada and Utah (Silberling and others, 1984; Hilpert, 1964) is shown in figure B3. Allochthonous terranes underlie the central and western parts of Nevada and include the Paleozoic Roberts Mountains allochthon (Poole and others, 1977); the middle to upper Paleozoic Golconda allochthon (Silberling and Roberts, 1962), and the upper Paleozoic to lower Mesozoic Sonomia terrane (Speed, 1977; 1979). The latter of these three major terranes is a composite of several island arc and ocean floor terranes, including: (1) the upper Paleozoic to Middle Triassic Black Rock terrane (Ketner and Wardlaw, 1981), (2) the lower Mesozoic Jackson terrane (Russell, 1984), (3) the lower Mesozoic Jungo terrane (Silberling and others, 1984), and (4) the lower Mesozoic Walker Lake terrane which is divided into the Paradise and Pine Nut subterranes (Silberling and others, 1984). The separate terranes that together compose Sonomia are delineated in figure B3. Cenozoic rocks cover large parts of the accreted terranes in western and northern Nevada. A boundary that is generally used to define the easternmost extent of outcrops of lower Paleozoic oceanic siliceous assemblage rocks (the Roberts Mountains allochthon) in Nevada separates accreted oceanic and island arc terranes to the west from cratonal terranes to the east (fig. B3).

The lower Paleozoic Roberts Mountains allochthon is the oldest accreted terrane in Nevada, and as such, is farthest inboard and overlaps both Paleozoic miogeoclinal sedimentary rocks and Precambrian crystalline basement. The approximate amount of overlap is shown in figure B3 by the location of isograds marking initial strontium isotope ratios of 0.7060 and 0.7080 in Mesozoic and Tertiary intrusives. The 0.7060 strontium isotope line is commonly accepted as the western edge of Precambrian crystalline basement in Nevada (Kistler and Peterman, 1978; Kistler, 1983). Farmer and DePaolo (1983), however, have suggested that the 0.7080 line, which is based also on Nd isotope systematics, is a better location for that boundary. The amount of overlap of the cratonic block by the Roberts Mountains allochthon is approximately 100–200 km east of the 0.7060 line or 50 km east of the 0.7080 line. Thus, Precambrian crystalline basement may underlie a significant portion of both the Roberts Mountains allochthon and the younger, overlying middle to upper Paleozoic Golconda allochthon.

Eastern Nevada and all of Utah are underlain by cratonal terranes of continental origin (fig. B3). These include the Rocky Mountains, Colorado Plateaus, and miogeoclinal shelf terranes. The miogeoclinal terrane is further subdivided into the Sevier orogenic belt and its hinterland, the Mesozoic metamorphic belt. These terranes overlap due to superimposed deformation events. For example, the Mesozoic metamorphic belt affected parts of the area overlain by the Roberts Mountains allochthon. Likewise, younger Laramide deformation associated with the formation of the Rocky Mountains overlapped part of the Sevier orogenic belt in northeastern Utah. Despite these superimposed events, cratonal terranes are herein defined by the dominant type of deformation style, or lack thereof, in order to simplify the terrane picture.

Miogeoclinal sediments were deposited in shallow epicontinental basins and on the continental shelf in eastern Nevada and western Utah. During the Late Jurassic to Late Cretaceous, the eastern half of the sedimentary pile was folded as well as thrusted during the Sevier orogeny (Armstrong, 1968), whereas the western hinterland of the Sevier orogenic belt (Misch and Hazzard, 1962; Armstrong, 1968; Snoke, 1980) was metamorphosed but not strongly deformed. On this basis, these areas are separated into two different cratonal

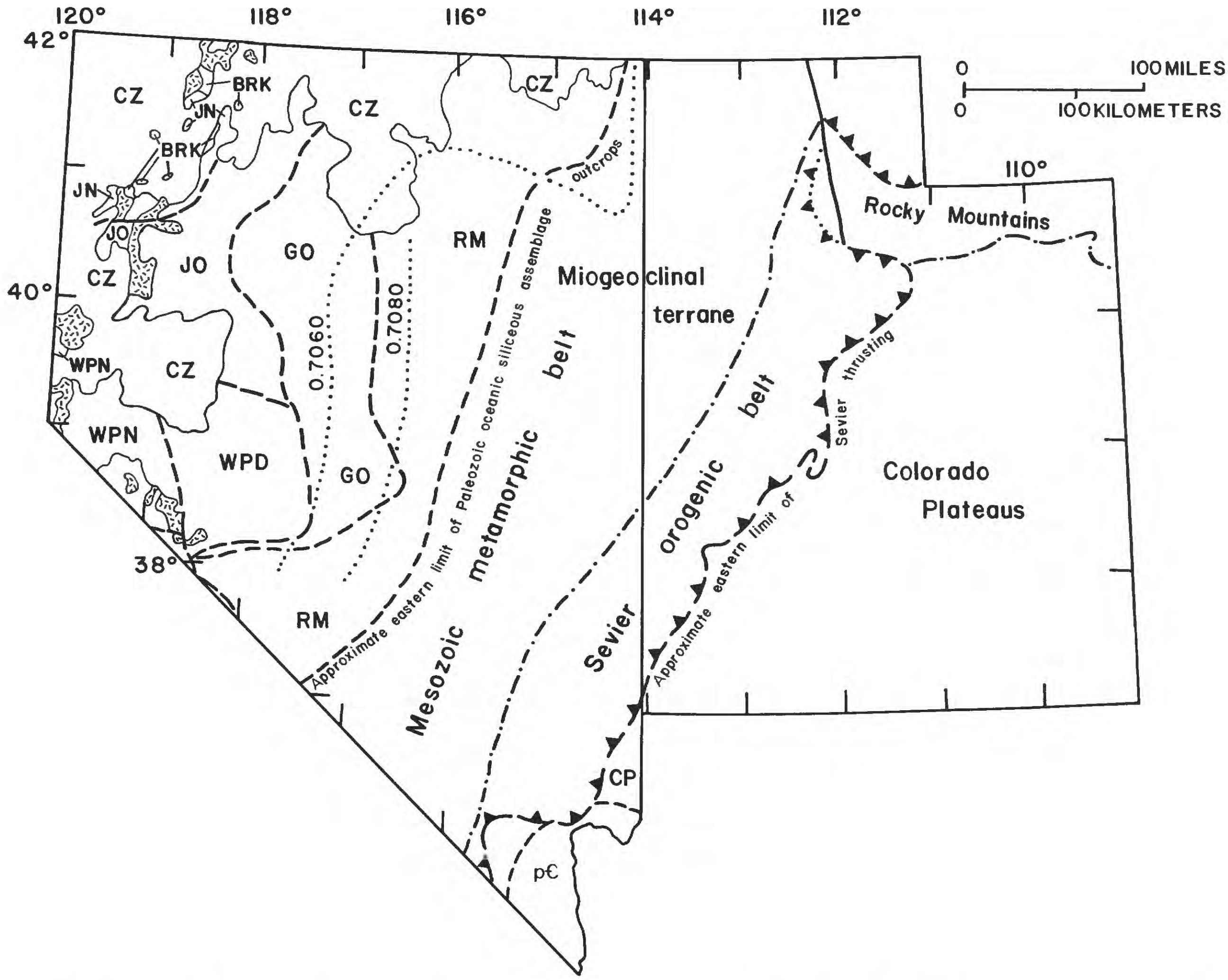


**Figure B3.** Geologic terranes of Nevada and Utah. Cratonal terranes (various dash and dash-dot outlines): Colorado Plateaus (CP), Rocky Mountains, Precambrian basement (p-€), and miogeoclinal terrane, divided into the Mesozoic metamorphic and Sevier orogenic belts (Hilpert, 1964; Armstrong, 1968; and Tooker, 1983). Accreted terranes (dashed outlines): Roberts Mountains allochthon (RM); Golconda allochthon (GO); and the terranes that compose Sonomia: Jungo (JO), Black Rock (BRK), Jackson (JN), Walker Lake–Paradise (WPD), Walker Lake–Pine Nut (WPN) (Silberling and others, 1984). Cenozoic cover (solid outline; CZ) is postaccretionary; patterned areas indicate Mesozoic intrusions. The 0.7060 and 0.7080 initial strontium isotopic lines (dotted) are from Kistler and Peterman (1978) and Farmer and DePaolo (1983), respectively.

subterranes, even though their geologic histories are similar. Clastic debris shed to the east off the Sevier highlands formed a sedimentary pile on a lower Phanerozoic basement that has not been strongly deformed, the Colorado Plateaus terrane. This terrane acted as an undisturbed block during Laramide (Late Cretaceous to early Tertiary) deformation that resulted in Precambrian basement uplifts and the formation of the Rocky Mountains terrane.

The southeastern corner of Nevada, south of the Colorado Plateaus terrane, is dominated by Early and Middle Proterozoic rocks (Stewart, 1980). Paleozoic or Mesozoic sedimentary rocks that may have covered the area have been eroded. Mesozoic and Cenozoic igneous rocks intrude the Precambrian. This area is considered herein as Precambrian basement terrane.

## PATTERNS OF GOLD-PRODUCING DISTRICTS IN NEVADA AND UTAH

Gold-producing districts in Nevada and Utah (Bonham, 1976; Bergendahl, 1964) are shown in figure B4 together with accreted and cratonal terranes and strontium isotope isograds. The types and sizes of gold-producing districts are not discriminated. For example, predominantly gold producing districts (for example, Carlin, Jerritt Canyon) are included with predominantly base metal producing districts (for example, Bingham Canyon, Ely) that have produced more than 10 ounces of gold. For some of these base metal districts, the current and the future gold production may actually be more important economically than base metal production.

The distribution of gold-producing districts shown in figure B4 gives the impression of a scatter diagram that indicates no correlation between either accreted or cratonal terranes and the locations of gold-producing districts. However, gold-producing districts are about twice as abundant in accreted terranes (about 170) as they are in cratonal terranes (about 70), the two regions being of roughly comparable area. Gold-producing districts located in cratonal terranes are limited predominantly to the miogeoclinal terrane with a sparse scattering of deposits in the other cratonal terranes. Although areas of postaccretionary Cenozoic cover in western and northern Nevada contain notable precious metal deposits such as Comstock and Jarbidge, gold-producing districts are sparse in this cover compared to occurrences in the accretionary and cratonal terranes.

In order to clarify the distribution of gold-producing districts in terms of substantial production, I have defined "important" districts as those that have produced, or have reserves of, more than 1,000 oz of gold and plotted them in figure B5. This distribution shows that a higher proportion (again, about 2:1) of deposits of this size occur in the accreted terranes, especially along northwest-trending lineaments, and it enhances the perception that gold is more abundant in accreted terranes than it is in cratonal terranes. The northwesterly trends are easier to discern in figure B6 where the important gold districts are plotted together with different regional structural trends. Important gold districts in cratonal terranes seem to define (1) broad east-trending patterns that cut across the north- to

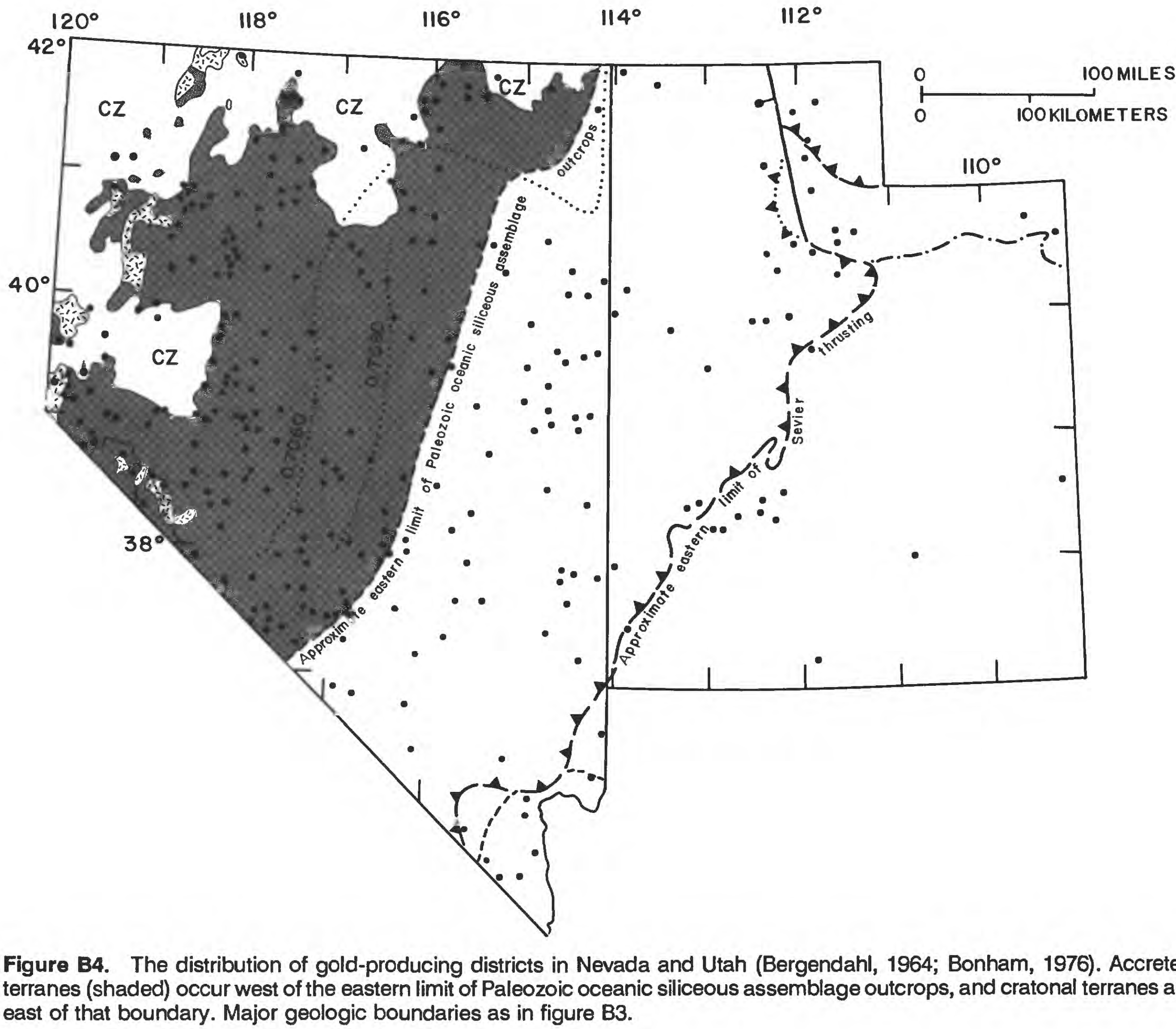


**Figure B4.** The distribution of gold-producing districts in Nevada and Utah (Bergendahl, 1964; Bonham, 1976). Accreted terranes (shaded) occur west of the eastern limit of Paleozoic oceanic siliceous assemblage outcrops, and cratonal terranes are east of that boundary. Major geologic boundaries as in figure B3.

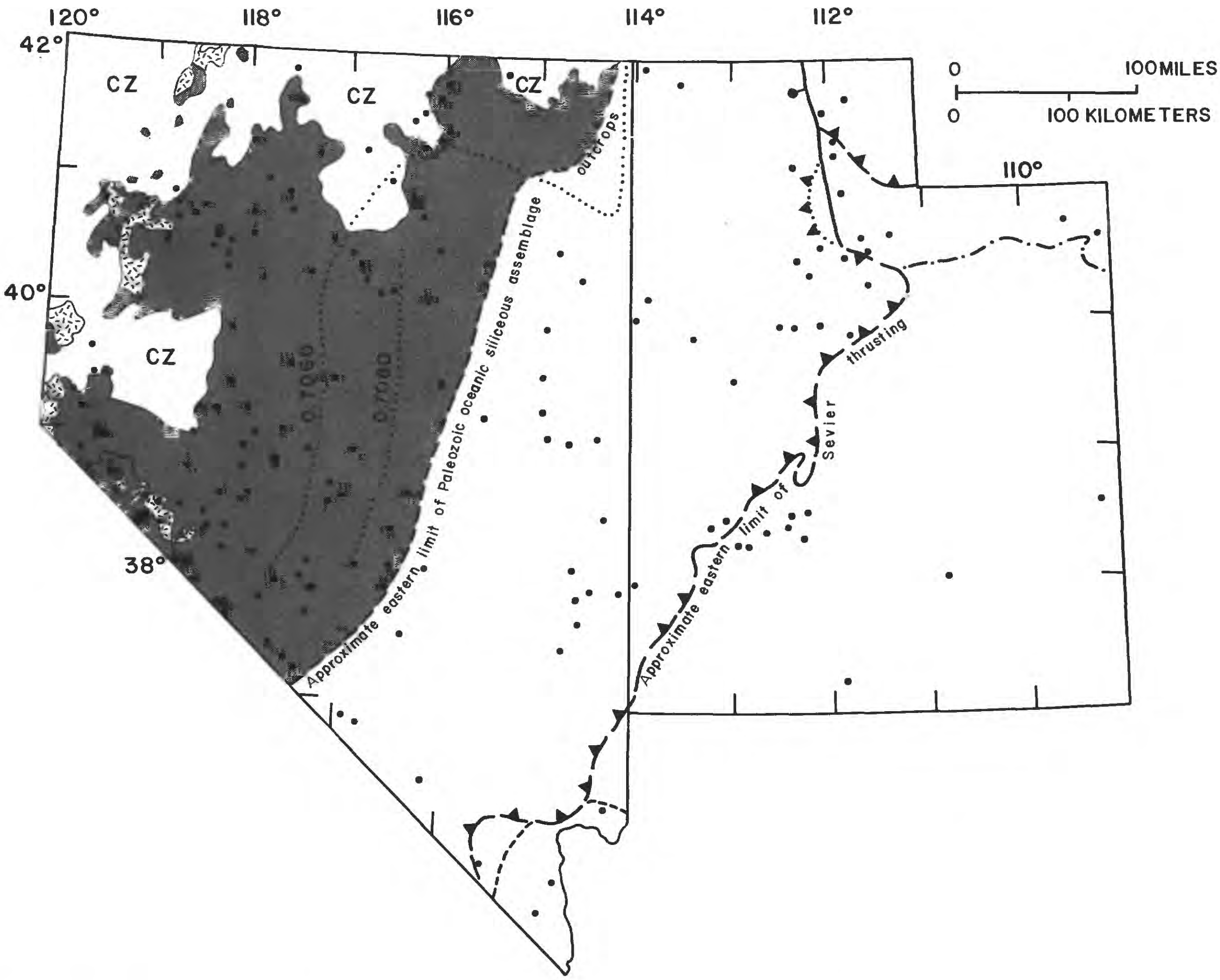


**Figure B5.** The distribution of gold-producing districts in Nevada and Utah that either have produced or have reserves of more than 1,000 oz of gold (Bergendahl, 1964; Bonham, 1976). Geologic boundaries and terrane patterns from figure B4.

northeast-striking geologic fabric of the Sevier orogenic belt and (2) a north-trending belt of deposits along the boundary of the Rocky Mountain and Sevier terranes in northern Utah.

The east-trending patterns of gold-producing districts in cratonal terranes in Utah and eastern Nevada coincide with prominent belts of Tertiary calc-alkalic intrusions. These east-trending belts of ore deposits associated with intrusive and volcanic rocks in Utah have been termed the Park City–Bingham, Tintic–Deep Creek, and Marysvale–Pioche belts (Butler and others, 1920; Morris and Lovering, 1961; Hilpert and Roberts, 1964; Tooker, 1971). These belts also have strong positive aeromagnetic signatures that are possibly related to concealed, near-surface intrusive rocks (Shawe and Stewart, 1976; Stewart and others, 1977).

Comparison of the distribution of significant gold-producing districts in Nevada and Utah with igneous rocks of comparable age also suggests a close genetic relationship between gold deposits and igneous rocks. Silberman and others (1976) illustrated the close spatial association of the following deposits with igneous rocks of comparable age:

| | |
|---|---|
| Tuscarora, Battle Mountain, Bullion, Cortez, Bingham, Park City | early Oligocene igneous rocks (fig. B7) |
| Tintic district and Round Mountain | late Oligocene (fig. B8) |
| Pyramid, Wonder, Tonopah, Goldfield, Gold Mountain | early Miocene (fig. B8) |
| Comstock, Rawhide, Camp Douglas, Silver Dyke, Manhattan, Divide, Seven Troughs, Ten Mile, Adelaide, Midas, Jarbidge, Buckhorn, Marysvale, Deer Trail | middle Miocene (fig. B9) |
| Talapoosa, Monitor, Aurora, Bodie, Gilbert, Bull Frog, Silver Peak | late Miocene (fig. B9) |

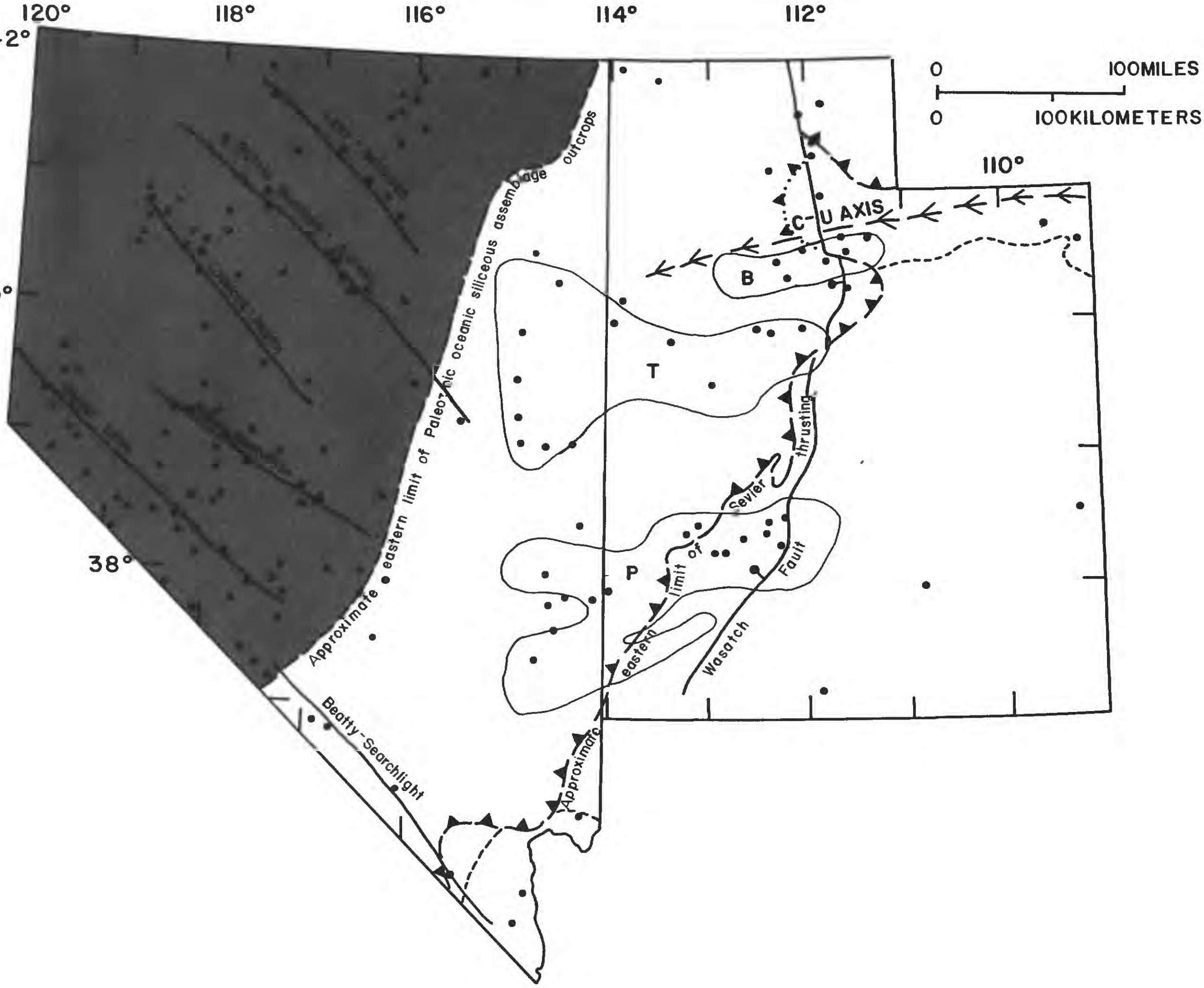


**Figure B6.** Distribution of gold districts in Nevada and Utah that either have produced or have reserves of more than 1,000 oz of gold (fig. B3), together with various mineral belts and named structural trends. East-trending mineral belts: Marysvale–Pioche (P), Tintic–Deep Creek (T), and Park City–Bingham (B), from Stewart and others (1977). The locations of the Cortez–Uinta axis (C–U axis) and the Wasatch fault are from Tooker (1983). Mineral belts in Nevada are from Roberts (1966). Other geologic boundaries as in figure B4.

Another important spatial association is that the Park City–Bingham zone lies along the flanks of the Cortez–Uinta axis. In the Rocky Mountains and miogeoclinal terranes in Utah, episodic uplift has occurred along this axis beginning in the Precambrian and extending through the Paleozoic. Roberts (1966) and Tooker (1971, 1983) proposed that the Cortez–Uinta axis extends west of the Rocky Mountains uplift as a basement structural zone beneath the Sevier orogenic belt terrane. Such a deep, through-going structural zone of Precambrian age could serve to localize Tertiary intrusive rocks.

There is a diffuse northerly alignment of very small gold-producing districts in Utah, north of the Park City–Bingham mineral belt. The alignment extends away from the north flank of the Cortez–Uinta axis, suggesting that some other regional geologic feature is responsible for the formation of deposits along this trend. Three important gold districts are isolated in the southern part of the Colorado Plateaus terrane. These are spatially associated with intrusions, suggesting some temporal and thus, probably, a genetic association. Two districts lie in the eastern part of the Rocky Mountain cratonal terrane in Utah. These are presumably related to Laramide deformation. The Precambrian basement terrane in southeastern Nevada hosts three known important gold-producing districts. Each of these is located along contacts between Precambrian and either Mesozoic or Tertiary intrusive rocks.

Gold-producing districts in the accreted terranes of Nevada have a more scattered distribution than do those in the cratonal terranes of Utah and eastern Nevada.

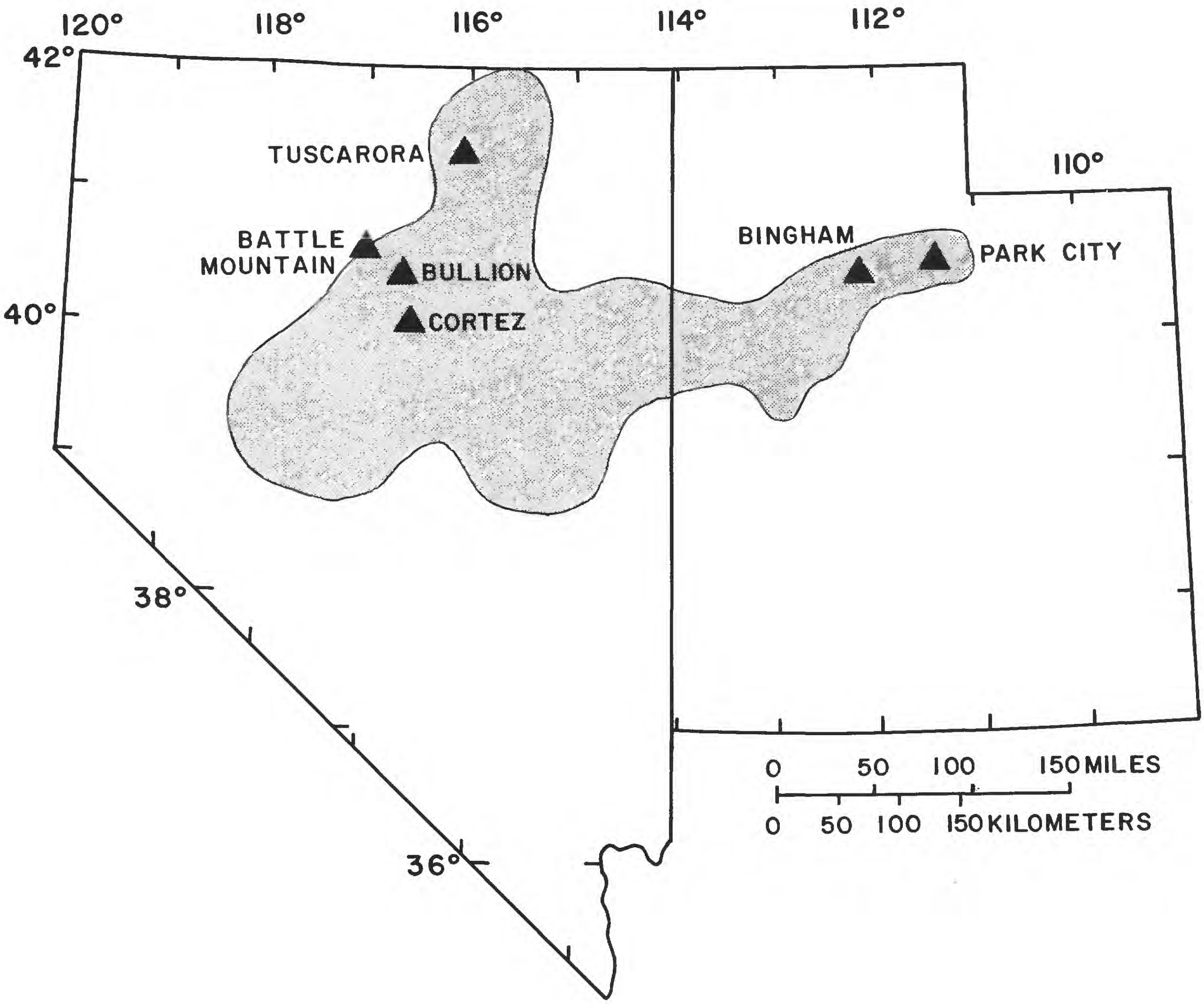


**Figure B7.** General outline of upper Eocene and lower Oligocene igneous rocks in Nevada and Utah and locations of gold-producing districts that have early Oligocene ages. Modified from Silberman and others (1976).

Despite this scatter, a preferred alignment of some districts nevertheless exists along northwest-striking mineral belts (fig. B6). These belts have been identified and discussed by Roberts (1966), Shawe and Stewart (1976), and Silberman and others (1976). Although Roberts (1966) attributed these belts to older structural zones beneath allochthonous terranes, recent work indicates that these belts crosscut the northerly fabric of the accreted terranes and are thus younger, probably of Mesozoic age (R.J. Madrid, oral commun., 1984). If this is true, it is still possible that older, buried structures guided later deformation by serving as zones of weakness, at least in areas where deformation affected thin-skinned, allochthonous terranes.

Consideration of the distribution of gold districts in light of the terrane concept in Nevada and Utah must take into account that the deposits shown on the map are not all the same age. Thus the distribution appears scattered, and some gold belts are poorly defined because of the scatter. The well-defined east-west gold belts that cross the Utah-Nevada border are all of Tertiary age. In contrast, mixing of deposit ages in Nevada results in more diffuse patterns.

## DISCUSSION

The significant patterns that emerge from the distribution of gold-producing districts in Nevada and Utah are that (1) deposits that have produced at least 10 ounces of gold are broadly scattered, with the majority of the districts occurring in accreted terranes of Nevada, (2) gold districts are sparse in the postaccretionary Cenozoic cover of western and northern Nevada and in

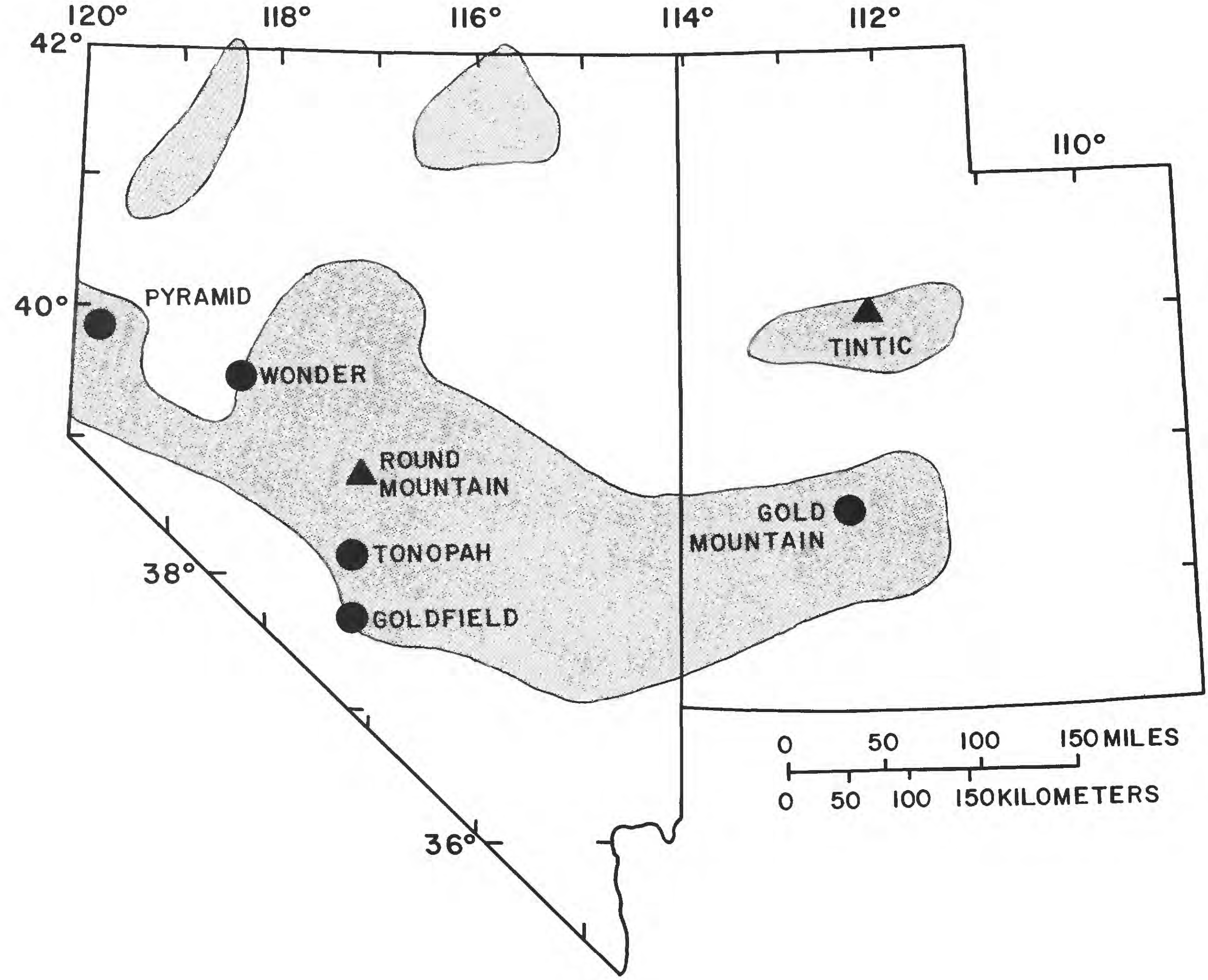


**Figure B8.** General outline of upper Oligocene and lower Miocene igneous rocks in Nevada and Utah and locations of gold-producing districts that have ages of mineralization within the same time frame. Solid triangle, district of late Oligocene age; solid circle, early Miocene. Modified from Silberman and others (1976).

the cratonal Colorado Plateaus terrane of Utah, and (3) gold-producing districts with greater than 1,000 oz of contained or produced gold occur predominantly in accreted terranes, coincide in position and in age with particular igneous rock assemblages, and are spatially associated with major structural trends.

Albers (1983) noted that gold districts throughout the Western United States seem to be preferentially associated with accreted terranes of oceanic affinity. This is borne out by the gold distribution patterns for Nevada and Utah and suggests that accreted oceanic terranes in Nevada may have served not only as a host environment for gold, but also as the source for gold and associated metals (such as arsenic, antimony, mercury) in these districts. For example, Keays and Scott (1976) suggested that pillow basalts are possible source rocks for gold because gold is concentrated in easily leachable mineralogical sites on pillow margins. In addition, black shales also may be source rocks due to possible enrichment of gold in the shales during diagenesis (Boyle, 1979). Thus, it is permissive to consider the presence of high contents of easily leachable gold in oceanic terranes as an explanation for the number of gold districts that occur in these accreted terranes. However, other geologic factors may be as important if not more so. For example, Shawe and Stewart (1976) noted a close spatial association of precious metal deposits with Cretaceous and Tertiary intrusions in Nevada, and Silberman and others (1976) noted both a spatial and temporal association between some precious metal districts and intrusive rocks. Thus, the intrusions in accreted terranes may have acted as more than heat engines to drive circulating hydrothermal systems; they may also have served as sources of gold. This is a viable alternative,

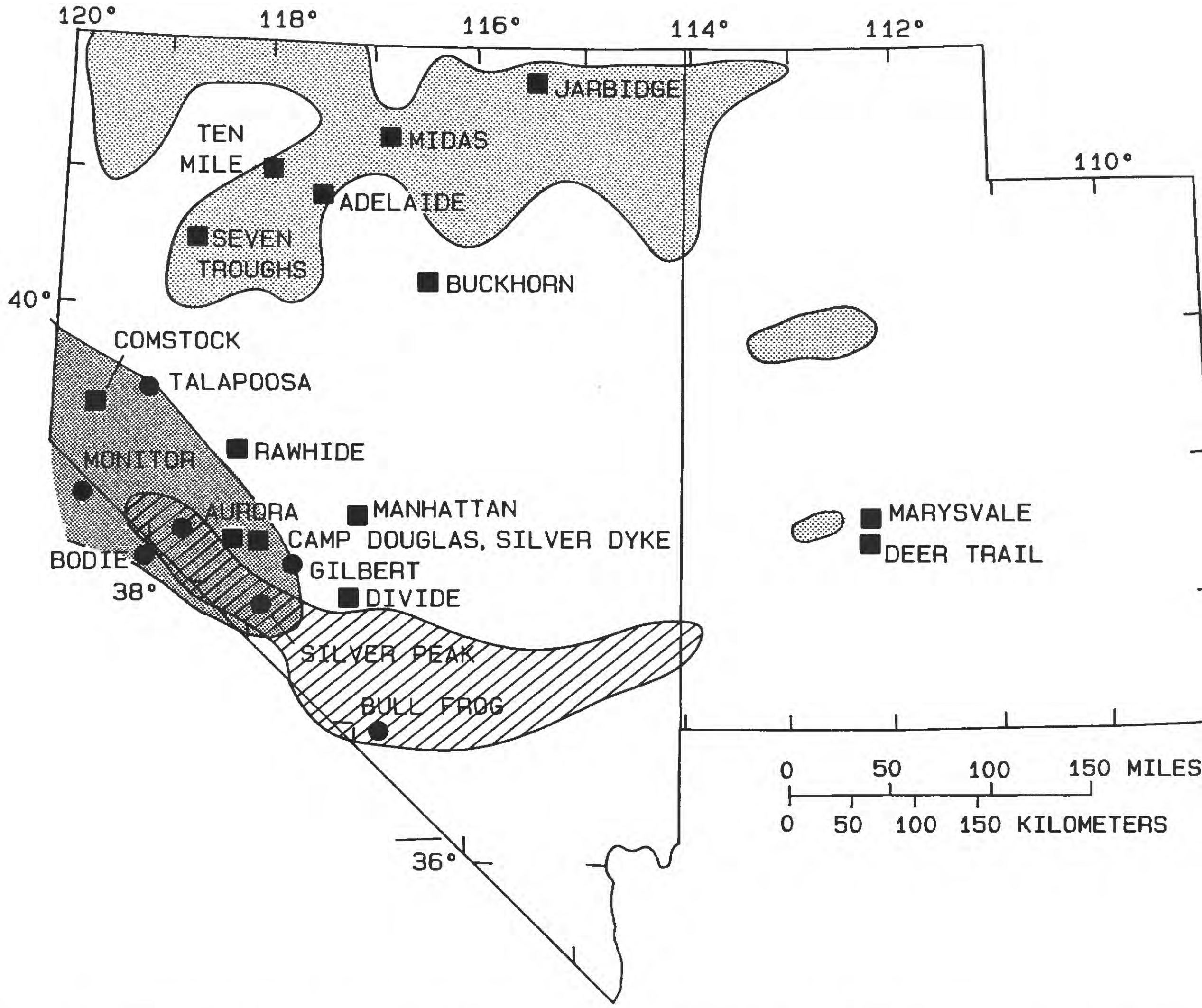


**Figure B9.** General outline of middle and upper Miocene igneous rocks in Nevada and Utah and locations of gold-producing districts that have ages of mineralization within the same time frame. Medium screen, intermediate volcanic rocks; light screen, basalt, silicic tuff, and rhyolite; cross lined, mostly silicic tuff. Solid square, district corresponding to middle Miocene age rocks; solid circle, late Miocene. Modified from Silberman and others (1976).

because Farmer and DePaolo (1983) showed that intrusions west of the 0.7080 strontium isotope isograd (in the accreted oceanic terrane province) contain a major mantle component, whereas the intrusions east of the line show a major crustal component. Thus, gold in the upper mantle could have been concentrated by partial melting and introduced into the upper crust of accreted terranes by intrusive activity.

Although the postaccretionary Cenozoic cover of western and northern Nevada contains notable precious metal deposits (for example, Jarbidge and Comstock), the lack of numerous gold-producing districts in that terrane compared to accretionary terranes invites speculation as to what may exist beneath that cover. Based on the observation that most gold-producing districts of Nevada occur in exposed accreted terranes, major gold deposits possibly occur in accreted terranes that likely underlie the Cenozoic volcanic cover. In fact, since most of the Cenozoic cover is volcanic, it is entirely possible that the magmas responsible for the volcanism also were responsible for either generating mineral leaching-transporting-depositing hydrothermal systems, or providing gold, or both. The cratonal Colorado Plateaus terrane, like this Cenozoic-covered area of Nevada, contains few important gold districts. Those that are exposed are either associated with the Marysvale–Pioche mineral and intrusive belt (fig. B6) or are spatially associated with isolated intrusions. Note, however, that the Precambrian terrane in southeastern Nevada and northwestern Arizona contains several important gold districts (Theodore and others, 1982). Thus, the absence of numerous gold districts in the Colorado Plateaus terrane of Utah may simply reflect younger sedimentary cover over gold-bearing Precambrian terrane.

The association of gold districts with igneous provinces and (or) structural trends in both accreted and cratonal terranes suggests that deep-seated structures may be the ultimate control on the alignments of gold districts. These structures most likely served as conduits not only for intrusive activity but also for hydrothermal circulation. As discussed previously for accreted terranes, the gold in these mineral belts may be either leached from the sedimentary pile or introduced by intrusive activity. At this point it is virtually impossible to determine the relative importance of these possible gold sources.

In summary, the distribution of gold-producing districts in Nevada and Utah seems to be controlled by deep-seated regional structures. That these structures cut across both cratonal and accreted terranes suggests that the structures, and not the terranes, are the most important regional controls on the distribution of gold-producing districts. This interpretation suggests several lines of research that need to be followed on a detailed, district-by-district basis within the different mineral belts. For example, Shawe and Stewart (1976) discussed the en echelon faults in the Pioche and Manhattan mineral belts and their orientation relative to those belts. However, we don't have a clear idea as to the nature of these faults at depth; for that reason, seismic and other geophysical studies oriented perpendicular to the different belts would be most illuminating. In addition, it would be important to compare the geochemistry and ages of mineralization in the different belts in hopes of identifying a mantle source for gold west of the 0.7080 strontium isotope line and a crystalline basement source for gold east of that line, for those districts that can unequivocally be related to igneous activity. If these data are collected by detailed geologic mapping and integrated over the length of the mineral belts, answers should begin to appear regarding the origin of gold and associated metals in these deposits, and distribution patterns of the important gold-producing districts in Nevada and Utah should become clearer.

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# Gold-Silver Deposits Associated with the Trans-Challis Fault System, Idaho

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## Abstract

Many gold-silver deposits in central Idaho, including those of the productive Boise Basin, are located near or along northeast-trending faults of the trans-Challis fault system. Some of the deposits are hosted in granitic rocks of the Idaho batholith of Late Cretaceous age, but many are along or partially within Tertiary dikes. Other deposits are in Tertiary plutonic rocks, or in dikes that cut Tertiary plutonic rocks. In the northeast part of the Challis 1°×2° quadrangle, several gold-silver deposits of the trans-Challis fault system are related to bodies of Tertiary rhyolite, whereas others are in Precambrian sedimentary rocks, in Paleozoic and Precambrian roof pendants in the Idaho batholith, and in pyroclastics and lavas of the Challis Volcanics. The northeast-trending belt of regional faults, Tertiary intrusive rocks, and mineral deposits extends at least 270 kilometers across Idaho and probably into Montana. The extent and linearity of the northeast-trending fault system, the grabens and cauldrons aligned along the faults, the igneous rocks of Tertiary age that have been intruded along the fault system, many of them also aligned along the faults, and postintrusive adjustment along the faults indicate a major zone of rifting and crustal extension that has guided emplacement of the mineral deposits.


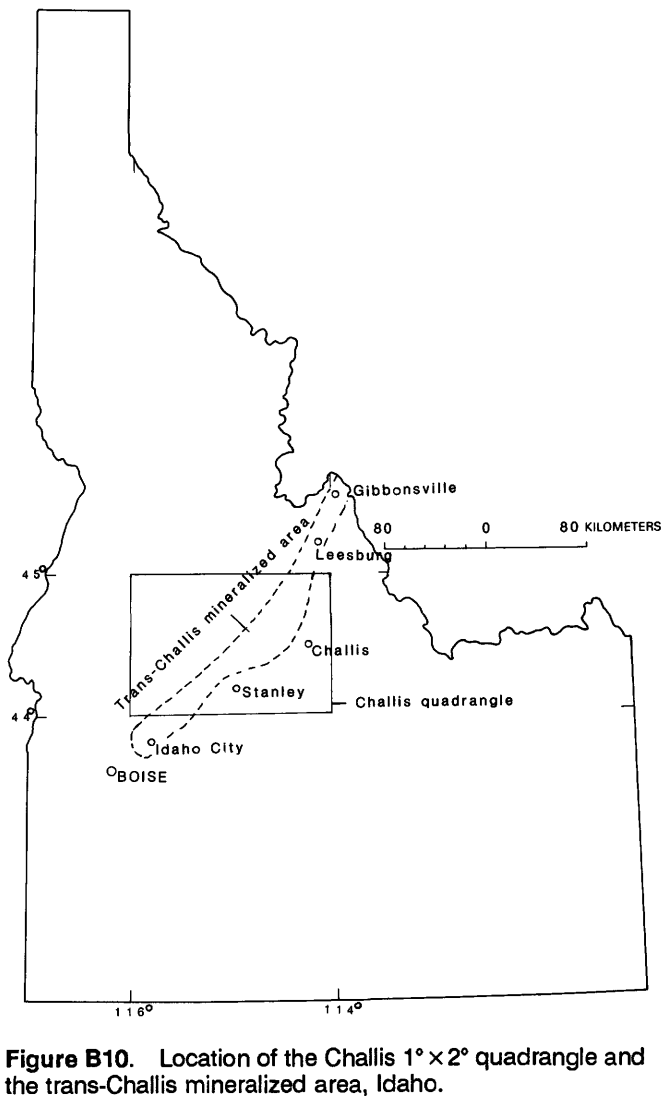


**Figure B10.** Location of the Challis 1°×2° quadrangle and the trans-Challis mineralized area, Idaho.

## INTRODUCTION

A broad system of northeast-trending, subparallel, high-angle faults, aligned grabens and eruptive centers, and roughly aligned intrusive rocks of Tertiary age extends across the Challis 1°×2° quadrangle (Fisher and others, 1983). This broad structural system, identified as the trans-Challis fault system (Bennett, 1984; Kiilsgaard and Lewis, 1985, p. 20–42), has been traced from the vicinity of Idaho City in the Boise Basin northeastward to beyond Leesburg, a distance of at least 270 km (fig. B10), and has exerted structural control on the location of gold-silver deposits in the area. The system is aligned with and appears to be a continuation of the Great Falls lineament, projected by O'Neill and Lopez (1985) northeast from Idaho across Montana.

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## TRANS-CHALLIS FAULT SYSTEM

Faults of the trans-Challis fault system have been mapped in the Boise Basin (fig. B11; Kiilsgaard, unpub. mapping, 1985). The faults are particularly evident along Mores, Elk, Grimes, Big Muddy, Little Muddy, and West Fork Clear Creeks, and across Wild Goat Creek and Rattlesnake Creek (Pioneerville, Placerville, Idaho City, and Warm Springs Point 7½-minute quadrangles). A northeast-trending shear zone described by Ballard (1924) as being half a mile or more wide near the Gold Hill mine in the Boise Basin (fig. B11) is the westernmost known fault of the system. That fault defines the western edge of the most intensively mineralized part of the Boise Basin mineralized area. Southwest of Idaho City, several faults of the system pass beneath an embayment of basalt of the Snake River Group of Pleistocene age. Northeast-trending faults in the vicinity of Idaho City are mentioned by Lindgren (1898) and Anderson (1947).

The northeast-trending faults are well exposed about 30 km west of Stanley in the upper reaches of Warm Springs, Eightmile, and Cat Creeks (Fisher and others, 1983). Some fault zones in this area are more than 500 m wide, and the sheared and pulverized granitic rocks of the Idaho batholith within the zones are so altered that their original composition is difficult to determine (Luthy, 1981). Tertiary granite and dioritic rock, in part elongate along the fault system and in part fault bounded, are exposed in the faulted area, as are swarms of Tertiary dikes that are elongate along the system. Locally, the Tertiary plutonic rocks are offset in a left-lateral sense along the faults. Many of the dikes also have been offset by post-dike fault movement.

A gap in the fault system appears northeast of Casto (fig. B11). Adjacent to and southeast of the gap are the Custer graben and the Twin Peaks caldera, which are considered to be part of the fault complex, although not aligned within it. The Van Horn Peak cauldron complex (Fisher and others, 1983) also occupies part of the gap. Within the gap and in the Custer graben and the Panther Creek graben are numerous quartz porphyry and rhyolite dikes, pods, irregular plugs, and domes, many of which are linear and coincident with the trans-Challis fault system. The rhyolites were emplaced at high levels in the crust, and several vented to the surface. Most of the plugs and domes are small (less than 2.5 $km^2$); however, one complex rhyolitic stock is exposed over about 129 $km^2$ (Hardyman and Fisher, 1985). The rhyolites range in age from 48 to 39 Ma (Fisher and others, 1983) and can be shown locally to have been emplaced along preexisting faults of the trans-Challis fault system. In places the rhyolites have been offset by younger faulting.

The Panther Creek graben, similar to the Custer graben, is bounded on the southeast side by faults of great displacement (McIntyre and others, 1982), which continue on to the northeast, where Bunning and Burnet (1981) have identified the zone as the Panther Creek fault. The fault is aligned with a broad set of northeast-trending faults that are exposed west of Stanley. Other northeast-trending faults are exposed near Shoup and Gibbonsville (fig. B11).

Three major northwest-trending faults, Sawtooth, Bear River–Montezuma, and Deer Park, terminate against the trans-Challis fault system (Kiilsgaard and Lewis, 1985). The northwest-trending faults do not appear to have been truncated and displaced by the trans-Challis faults, as no evidence of them has been found northwest of that system. Instead, the trans-Challis faults appear to be older and the northwest-trending faults simply terminated at intersections with the older faults. In the eastern part of the Challis quadrangle, many north-trending faults also appear to terminate against the trans-Challis fault system (Fisher and others, 1983), further evidence of the controlling effect of the system.

### Age of Faulting

Field evidence indicates that movement along the trans-Challis fault system may have been recurrent from Precambrian to Holocene time. According to Lopez (1981), the Panther Creek fault offsets the contact between the Early and Middle Proterozoic Yellowjacket Formation and 1,370 Ma plutonic rock southwest of Leesburg. At the contact locality, the Panther Creek fault is defined, in part, by tight isoclinal folds in the Yellowjacket Formation; truncation of the folds by the 1,370 Ma plutonic rocks indicates Precambrian movement along the fault (O'Neill and Lopez, 1985). Hughes (1983) described northeast-trending transverse faults in the vicinity of Blackbird and noted how movement along these faults imposed damming effects on turbidity currents that deposited sediments of the Proterozoic Yellowjacket Formation. The northeast transverse faults fit in the trans-Challis fault system. Faults of the system clearly displace granitic rocks of the Idaho batholith of Late Cretaceous age and have guided emplacement of Eocene plutonic rocks and rhyolites and younger dikes. Subsequent movement along the faults has displaced the Eocene rocks. Stream terraces that contain glacial erratics of probable Pleistocene age have been displaced by Holocene faults. A dense concentration of recent earthquake epicenters (Breckenridge and others, 1984) in the area north and northwest of Stanley is indicative of continuing movement along the trans-Challis fault system.

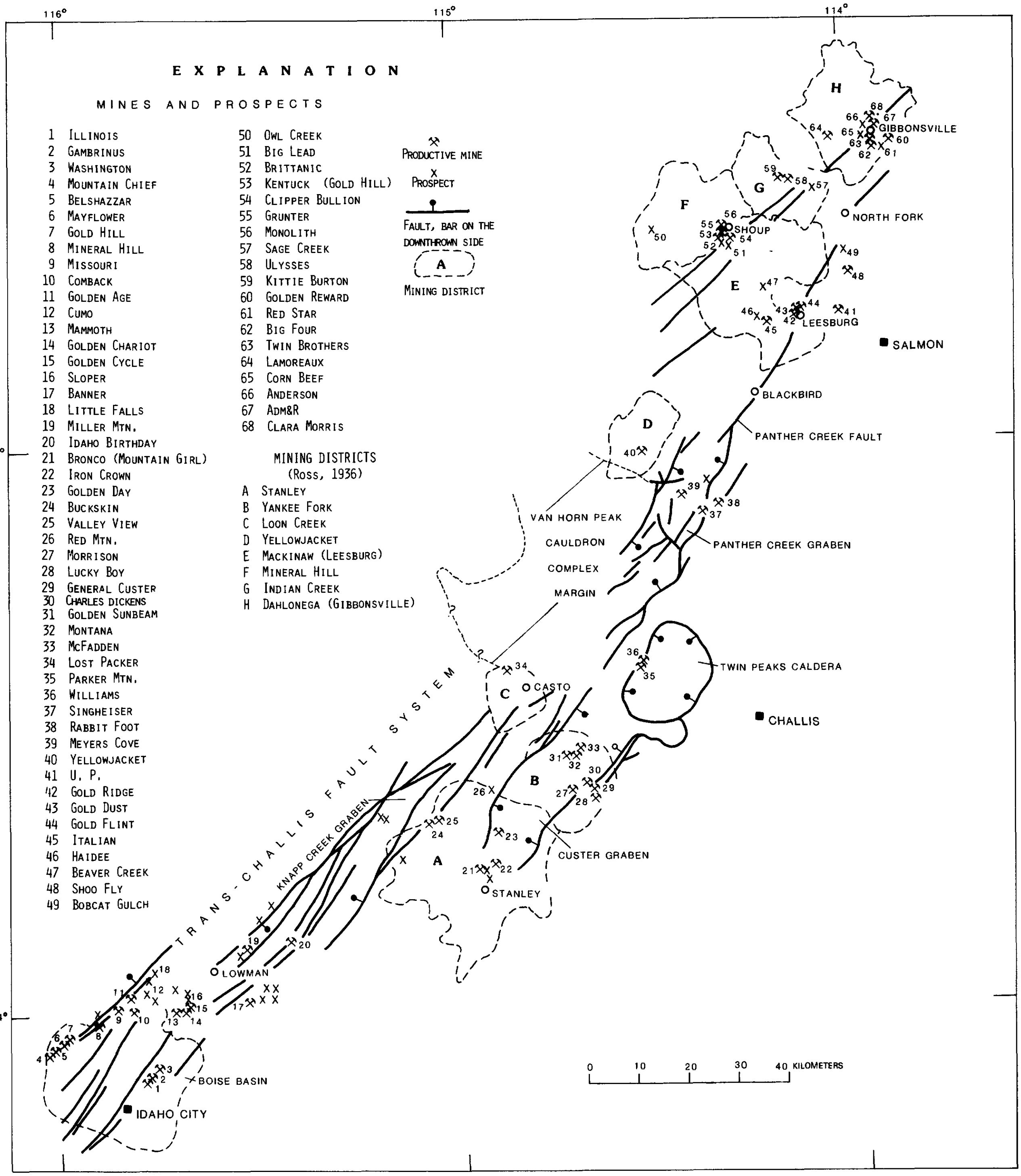


**Figure B11.** The trans-Challis fault system and location of associated gold-silver deposits.

## MINERALIZED LOCALITIES ASSOCIATED WITH THE TRANS-CHALLIS FAULT SYSTEM

Many mineral deposits in central Idaho show a spatial relation to the trans-Challis fault system (fig. B11), and they appear to be genetically related to structures of the system and to Tertiary rocks that have been intruded along it (Kiilsgaard and Bennett, 1985). The deposits form a belt that consists, for the most part, of gold-silver deposits, in many of which silver output has exceeded that of gold but in which gold has been the principal metal in terms of value. Byproduct metals produced include lead, zinc, and copper. Several molybdenum-copper deposits in the faulted area have been explored, but none have been brought into production. Fluorspar has been mined from deposits in the Panther Creek graben and uranium from deposits at the southwest end of the Custer graben. Productive gold-silver deposits and some prospects along the fault system are shown in figure B11. They include mines in the vicinity of Gibbonsville and Leesburg in the northeast part, deposits in the Panther Creek graben, the Twin Peaks caldera, and the Yankee Fork mining district in the central part, and those in the Boise Basin and nearby localities in the southwest part. Of these mineralized localities, the Boise Basin has been, by far, the largest gold producer.

## Southwest Part

### Boise Basin

More gold has been produced from the Boise Basin than any other mining locality in Idaho. The basin, a physiographic feature, is in the southwest part of the trans-Challis fault system (fig. B11). Within the basin are the Pioneerville, Centerville, Quartzburg, Mores Creek, and Gambrinus mining districts (Ross, 1936). (For purposes of this report the Grimes Pass and Summit Flat mining districts also are included even though parts of these latter districts are topographically north of the basin.)

Boise Basin is underlain by granitic rocks of the Idaho batholith of Late Cretaceous age. Intrusive into these granitic rocks are northeast-trending Tertiary stocks (fig. B12) and dikes, the emplacement of which has been guided by faults of the trans-Challis system. Depiction of the distribution of dikes on figures B11 and B12 is precluded by the small scales of the maps. Near Idaho City the Payette Formation of Miocene age is more than 200 meters thick; basalt is intercalated in the Payette. Northwest and southwest of Placerville, similar basalt, identified as the Weiser Basalt of the Columbia River Basalt Group (Kiilsgaard and Lewis, 1985), rests unconformably on an eroded surface of Idaho batholith. Two patterns of gold-bearing quartz veins, one trending northeast and the other northwest, crop out in the basin. Erosion of the veins has formed placer deposits that have yielded about 75 percent of the gold produced from the basin.

#### History and Production

Placer gold was discovered near the present site of Centerville (fig. B12) in 1862 and lode deposits were discovered soon thereafter. The Gold Hill lode deposit (fig. B11), discovered in 1863, was worked almost continuously until 1938 (Anderson, 1947). In 1867 and 1868 at least 10 stamp mills in Boise Basin were treating free-milling oxidized gold ore, but after a period of activity and considerable production many of these were dismantled, in part because ore bodies were exhausted but also because deeper sulfide ores could not be treated by the stamp-amalgamation process (Jones, 1916). Aside from the Gold Hill mine, most lode mining in Boise Basin has been sporadic. A spurt of mining activity in the 1920's resulted in the discovery of at least one significant gold producer, the Comeback mine, and in the expanded output of others; but mining was curtailed in 1931 by a forest fire that destroyed the surface plants of several mines in the northwest part of the basin. Lode mining since World War II has consisted of small-scale sporadic efforts at several mines and prospects, but no significant production of gold. No mines were being worked in 1988, and most mine workings were caved or otherwise inaccessible.

More placer gold was produced from the Boise Basin in the 9 years following discovery (Lindgren, 1898) than during any other similar length of time. Placer mining led directly to lode discoveries, with some rich placers being mined up to the vein outcrop, as at the Illinois vein, north of Idaho City, where rich placer gold was sluiced from surface material at the vein outcrop (Lindgren, 1898). No rich placers have been found upstream from presently known vein outcrops. Early-day placer mining was by sluicing, although hydraulic mining was employed on higher bench gravels. The largest deposit to be mined by hydraulic jets is about 1 km north of Idaho City, where auriferous gravel was reported by Ballard (1924) to have an average depth of 60 feet, a value per cubic yard of $0.0979, at a gold price of $20.67 per troy oz, and a ratio of gold to silver in bullion of about 8:1. According to Ballard (1924) gold dredging started near Placerville in 1898. Early-day dredgable placer ground was richer in gold than was placer gravel dredged in later years. Placer gravel near Placerville, dredged from 1905 to 1909, is reported to have averaged 30 feet in depth and $0.30 per cubic yard (gold at a price of $20.67/oz) (U.S. Geological Survey, 1909). Dredged gravel along Mores and Grimes Creeks in the 1940's ranged in value from $0.11 to $0.22/yd$^3$ (U.S. Bureau of Mines, 1942–1948), with gold at a price of $35.00/oz. Bullion obtained from dredging in the 1940's had an average gold-silver ratio of 4.3:1. Dredging in the basin terminated in 1951.

The total amount of gold produced from the Boise Basin is a subject of dispute because of incomplete early-day records, because of the difficulty of separating gold produced from Boise Basin from that produced at other localities in Boise County, and because some of the gold that was mined was not reported. Lindgren (1898) used U.S. Mint reports and other sources of data to prepare gold production statistics for the years 1863–1896. Jones (1916) updated production statistics from

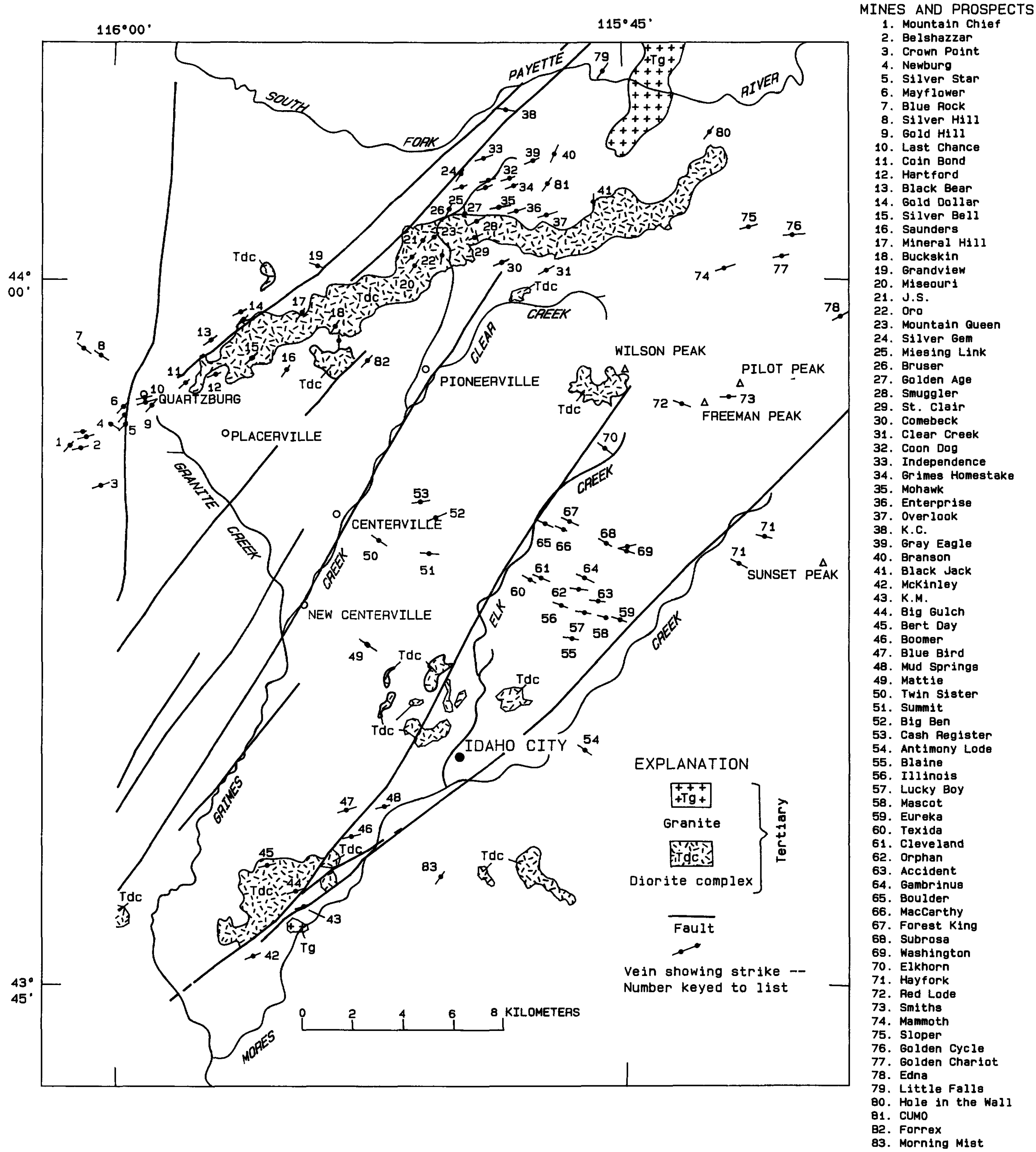


**Figure B12.** Boise Basin, Idaho, showing locations of gold-silver veins (identified by mines and prospects) with respect to faults of the trans-Challis fault system and to stocks of Tertiary age (modified in part from Anderson, 1947).

1863 to 1914, and Anderson (1947) further updated gold production statistics.

Table B1, based on production statistics from Anderson (1947) for the years 1863–1940 and U.S. Bureau of Mines data for subsequent years, updates gold production in Boise County (principally Boise Basin) to 1982. Gold-silver production from 1941 to 1982 is shown in table B2. The accumulated output of 2,818,596 oz of gold makes Boise Basin the largest gold producer in Idaho.

**Table B1.** Gold production from Boise County (principally Boise Basin), Idaho, 1863–1982

[Production statistics 1863–1940 from Anderson (1947); other statistics from U.S. Bureau of Mines Minerals Yearbooks (1932–1983) and unpublished data. Annual production figures from 1953 to 1980 commonly available only as combined lode and placer (see table B2) and are summarized in this table as total gold. From 1911 to 1970, 98 percent of the gold produced in Boise County came from deposits in Boise Basin. A similar percentage probably holds for gold produced in Boise County from 1863 to 1910. Value is based on the price of gold at the time of production; for the period 1968–1980, value is based on the average annual price of gold; data from U.S. Bureau of Mines (1924–31; 1932–83). Leaders (- -), no production or no data available]

| Year | Lode gold | | Placer gold | | Total gold | |
|---|---|---|---|---|---|---|
| | Troy ounces | Value | Troy ounces | Value | Troy ounces | Value |
| **Boise County** | | | | | | |
| 1863- 70 | 151,414 | $ 3,130,000 | 1,362,724 | $28,170,000 | 1,514,138 | $31,300,000 |
| 1871- 80 | 133,166 | 2,752,780 | 247,307 | 5,112,306 | 308,473 | 7,865,086 |
| 1881- 90 | 106,737 | 2,206,452 | 87,330 | 1,805,279 | 194,067 | 4,011,731 |
| 1891-1900 | 93,143 | 1,925,444 | 62,096 | 1,283,630 | 155,239 | 3,209,074 |
| | 484,460 | $10,014,676 | 1,759,457 | $36,371,215 | 2,171,917 | $46,385,891 |
| **Boise Basin** | | | | | | |
| 1901- 10 | 46,351 | $ 958,155 | 67,673 | $1,398,932 | 114,024 | $ 2,357,087 |
| 1911- 20 | 84,033 | 1,737,122 | 120,629 | 2,493,625 | 204,662 | 4,230,747 |
| 1921- 30 | 64,463 | 1,332,571 | 14,094 | 291,350 | 78,557 | 1,623,921 |
| 1931- 40 | 54,079 | 1,732,584 | 109,580 | 3,783,530 | 163,659 | 5,516,114 |
| 1941- 50 | 6,421 | 224,735 | 72,539 | 2,538,865 | 78,960 | 2,763,600 |
| 1951- 55 | 305 | 10,675 | 4,929 | 172,515 | 5,711 | 199,885 |
| | 255,652 | $ 5,995,842 | 389,444 | $10,678,817 | 645,096 | $16,674,659 |
| **Boise County** | | | | | | |
| 1956- 60 | 16 | $560 | 185 | $6,475 | 512 | $17,920 |
| 1961- 70 | 513 | 18,653 | 19 | 665 | 932 | 33,940 |
| 1971- 80 | -- | -- | -- | -- | 139 | 35,600 |
| 1981- 82 | -- | -- | -- | -- | -- | -- |
| | 529 | $ 19,213 | 204 | $7,140 | 1,583 | 87,460 |
| TOTAL--- | 740,641 | $16,029,731 | 2,149,105 | $47,057,172 | 2,818,596 | $63,148,010 |

Almost as much silver as gold was produced from Boise County, from 1863 to 1914 (Jones, 1916). If gold-silver production from 1942 to 1980 (table B2) is indicative, the amount of silver mined from Boise Basin lode deposits exceeds the amount of gold.

#### Lode Deposits

Two groups of veins in the Boise Basin have been described by Anderson (1947). Veins of one group are found only in rock of the Idaho batholith, they generally strike west and northwest, they are chiefly quartz with a scanty content of sulfide minerals, and they show feeble wall-rock alteration. These veins are chiefly north of Idaho City (fig. B12), were productive only to shallow depths, and produced gold valued at perhaps less than $2,000,000; but they probably contributed most of the placer gold mined from Mores Creek and some of its tributaries. The veins formed at shallow depths and were

**Table B2.** Gold-silver production from Boise County (principally from Boise Basin), Idaho, 1941–1982

[Data from U.S. Bureau of Mines (1924–31; 1932–83). Leaders (--), no production or no data available. Gold values 1968–1980 based on the average annual price of gold]

| Year | Lode gold | | Placer gold | | Total gold | | Silver | |
|---|---|---|---|---|---|---|---|---|
| | Troy ounces | Value | Troy ounces | Value | Troy ounces | Value | Troy ounces Lode | Troy ounces Placer |
| **Boise Basin** | | | | | | | | |
| 1941 | 2,302 | $80,570 | 20,758 | $726,530 | 23,060 | $807,100 | 34,484 | 5,504 |
| 1942 | 1,597 | 55,895 | 13,112 | 458,920 | 14,709 | 514,815 | 33,795 | 3,250 |
| 1943 | 370 | 12,950 | 35 | 1,225 | 405 | 14,175 | 5,573 | 10 |
| 1944 | 361 | 12,635 | 65 | 2,275 | 426 | 14,910 | 6,819 | 17 |
| 1945 | 329 | 11,515 | 1,635 | 57,225 | 1,964 | 68,740 | 1,644 | 391 |
| 1946 | 198 | 6,930 | 7,706 | 269,710 | 7,904 | 276,640 | 1,734 | 1,750 |
| 1947 | 260 | 9,100 | 7,864 | 275,240 | 8,124 | 284,340 | 116 | 1,453 |
| 1948 | 694 | 24,290 | 11,733 | 410,655 | 12,427 | 434,945 | 1,991 | 2,528 |
| 1949 | 106 | 3,710 | 4,789 | 167,615 | 4,895 | 171,325 | 3,107 | 1,243 |
| 1950 | 204 | 7,140 | 4,842 | 169,470 | 5,046 | 176,610 | 1,033 | 1,212 |
| 1951 | 84 | 2,940 | 4,926 | 172,410 | 5,010 | 175,350 | 73 | 1,306 |
| 1952 | 57 | 1,995 | 3 | 105 | 60 | 2,100 | 771 | -- |
| 1953 | -- | -- | -- | -- | 326 | 11,410 | 268 | -- |
| 1954 | 164 | 5,740 | -- | -- | 164 | 5,740 | 2,392 | -- |
| 1955 | -- | -- | -- | -- | 151 | 5,285 | 957 | -- |
| **Boise County** | | | | | | | | |
| 1956 | -- | -- | -- | -- | 15 | 525 | 5 | -- |
| 1957 | -- | -- | -- | -- | 93 | 3,255 | 1,174 | -- |
| 1958 | -- | -- | -- | -- | 175 | 6,125 | 3,529 | -- |
| 1959 | -- | -- | -- | -- | 28 | 980 | 1,294 | -- |
| 1960 | 16 | 560 | 185 | 6,475 | 201 | 7,035 | 14 | 41 |
| 1961 | -- | -- | -- | -- | -- | -- | -- | -- |
| 1962 | 113 | 3,955 | 19 | 665 | 132 | 4,620 | 757 | 2 |
| 1963 | -- | -- | -- | -- | 79 | 2,765 | 1,734 | -- |
| 1964 | 13 | 455 | -- | -- | 13 | 455 | 513 | -- |
| 1965 | 21 | 735 | -- | -- | 21 | 735 | 761 | -- |
| 1966 | -- | -- | -- | -- | 175 | 6,125 | 1,155 | -- |
| 1967 | 162 | 5,670 | -- | -- | 162 | 5,670 | 55 | -- |
| 1968 | -- | -- | -- | -- | 146 | 5,732 | -- | -- |
| 1969 | 81 | 3,362 | -- | -- | 81 | 3,362 | 848 | -- |
| 1970 | 123 | 4,476 | -- | -- | 123 | 4,476 | 89 | -- |
| 1971 | -- | -- | -- | -- | -- | -- | -- | -- |
| 1972 | -- | -- | -- | -- | -- | -- | -- | -- |
| 1973 | -- | -- | -- | -- | -- | -- | -- | -- |
| 1974 | -- | -- | -- | -- | 80 | 12,779 | -- | -- |
| 1975 | -- | -- | -- | -- | 28 | 4,746 | -- | -- |
| 1976 | -- | -- | -- | -- | -- | -- | -- | -- |
| 1977 | -- | -- | -- | -- | -- | -- | -- | -- |
| 1978 | -- | -- | -- | -- | -- | -- | -- | -- |
| 1979 | -- | -- | -- | -- | 3 | 923 | -- | -- |
| 1980 | -- | -- | -- | -- | 28 | 17,152 | 335 | -- |
| 1981 | -- | -- | -- | -- | -- | -- | -- | -- |
| 1982 | -- | -- | -- | -- | -- | -- | -- | -- |
| Total-- | 7,255 | $254,623 | 77,672 | $2,718,520 | 86,254 | $3,050,945 | 107,020 | 18,707 |

considered by Anderson (1947) to be of questionable early Tertiary age. The second group, the Miocene veins of Anderson (1947), are in or near porphyry dikes and stocks of Tertiary age, and they generally strike northeast more or less parallel to dikes and faults in a mineralized belt that trends northeast across the basin. They are characterized by distinctive sulfide mineral assemblages, and widespread and conspicuous wall-rock alteration effects. These veins have produced most of the lode gold mined in the area.

Quartz is the principal gangue mineral in the veins, and three stages of quartz were described by Anderson (1947), the last two in breccias of earlier quartz. The youngest and most abundant quartz is rather coarsely crystalline and somewhat drusy, and it commonly shows comb structure. Locally, it contains grains of native gold and auriferous pyrite and is considered the most important guide to ore.

Veins of the northeast-trending mineralized belt probably are genetically related to dikes (Ballard, 1924). The principal veins extend along northeast-trending shears; they may parallel dikes, be within dikes, or may crosscut dikes at acute angles. Some mineralized shears are in the hydrothermally altered granitic country rock, but some of the more productive ore bodies occurred at the intersections of mineralized shears and dikes. According to Ballard (1924) the Gold Hill vein, the most productive vein in the basin, is in a northeast-trending shear zone half a mile or more wide that cuts across numerous rhyolite dikes. Near the surface, the productive segments of the vein cut granitic rock of the Idaho batholith and dacite- and rhyolite-porphyry dikes. At depth most of the ore came from shear zones oblique to the Gold Hill vein, at intersections of the shear zones and rhyolite dikes. The shear zones in hydrothermally altered granitic rock were gouge-filled, tight, and impermeable. At intersections with the brittle rhyolite dikes, the shears resolved into countless seams and fractures which were more permeable to mineralizing solutions than was the impermeable clay-enriched granitic country rock. Mineralized quartz veins along the shears rarely extended more than a meter or so away from the shattered dikes.

Veins in the Boise Basin vary in size, but most of them are small. They range from a few centimeters to 2 m in thickness and are as much as a few hundred meters in length. The largest vein, the Gold Hill, had a developed length of about 1,070 m and a maximum width of about 2 m. On the 400 level, where the bottom of the productive part of the Gold Hill vein was reached, the stope length of the vein had decreased to 305 m (Anderson, 1947). Gold Hill ore shoots at dike-fault intersections were from 1 to 12 m wide, and had stope lengths of more than 30 m and vertical dimensions ranging from 30 to 245 m. The ore shoots persisted to the 1100 level, but ore of minable grade was not found on the 1250 level, and the mine was closed. The Mountain Chief, Belshazzar, Mayflower, and Golden Age mines, all in the northeast-trending belt, were developed extensively and mined to about 120 m below the surface. Other lodes in the basin were mined to shallower depths.

#### Tenor of Ore

The grade of ore in Boise Basin lode mines was richer in oxidized parts of the veins than in the underlying sulfide zone. Early-day ore at the Gold Hill mine averaged about 1.0 oz Au/ton (Lindgren, 1898), but 230,100 tons of ore produced from deeper levels of the mine, from 1911 to 1923, had an average grade of 0.41 oz Au/ton (Ballard, 1924). A total of 30,256 tons of ore produced in 1930–1931 had an average grade of 0.379 oz Au/ton (Minerals Yearbooks of the U.S. Bureau of Mines). The average grade of Gold Hill ore appears to have been comparable to that of other mines, which apparently ranged from 0.2 to 0.5 oz Au/ton. The grade of ore in all the mines was irregular, and small pockets and stringers of rich ore commonly were interspersed in large volumes of low-grade material.

#### Mineralogy

Complex mineral suites from Boise Basin lode deposits were described by Anderson (1947), Ballard (1924), and Ross (1937). According to Ballard, auriferous pyrite is the predominant sulfide in the lode deposits. The gold is disseminated as minute particles and in varied quantities in the pyrite. At the Belshazzar mine, pyrite in vein quartz consistently assayed 0.50 oz Au/ton or more, whereas pyrite elsewhere along the vein assayed 0.10–0.20 oz Au/ton (Ballard, 1924). Ross (1937) described a sample of pyrite taken from a seam on the 100 level of the Gold Hill mine, away from the stoped area, as containing 0.205 oz Au/ton and 4.33 oz Ag/ton. Arsenopyrite also occurs in small amounts in various lode deposits, and a sample of it taken 76 m below the surface at the Mountain Chief mine assayed 0.55 oz Au/ton.

In oxidized parts of veins, gold particles were coarser in size than was gold recovered from underlying sulfide zones. Nuggets found in placers near vein outcrops also were far larger than particles of gold found in veins. The larger sizes suggest mobilization and accretion of gold during the process of oxidation and supergene enrichment (Lesure, 1971; J.C. Antweiler, oral commun., 1984). Ballard (1924) recognized this fact, and he described gold-bearing iron oxide sludge that collected on the wall of a crosscut at the Gold Hill mine. Two samples of the iron-oxide sludge assayed 0.12 oz Au/ton. A sample of similar material that collected on mine timbers in the Belshazzar mine assayed 0.10 oz Au/ton. Ross (1927) also described supergene-enriched gold ore bodies in Tertiary lavas of central Idaho.

Galena, sphalerite, chalcopyrite, and tetrahedrite are common minerals in the lode deposits, particularly those in the northern part of the basin, in the area north of Pioneerville (fig. B12). However, these minerals do not occur in sufficient quantity to be mined solely for their base metal content.

According to Ballard (1924) the gold of Boise Basin invariably was associated with bismuth. At Gold Hill, where ore shoots formed at the intersections of faults and rhyolite dikes, the highest content of gold was found with bismuth minerals. Several bismuth minerals were found in veins in the vicinity of Quartzburg (fig. B12), including bismuthinite, beegerite, cosalite, lillianite, galenobismutite, and tetradymite (Ballard, 1924; Ross, 1937). Anderson (1947) recognized native bismuth in the Gold Hill mine and matildite at the nearby Mayflower mine. All three authors called attention to the association of native gold and bismuth minerals. Silver-bearing minerals identified in vein deposits include miargyrite, pyrargyite, tetrahedrite, argentite, andorite, electrum, and native silver (Anderson, 1947); they were most abundant in the northern part of the basin. The volume of silver produced from mines in that locality was 14 times that of gold. Stibnite occurs in a few of the veins but in minor amounts.

#### Molybdenum-copper Deposits

Although gold and silver generally have been the metals sought in Boise Basin, principal mineral exploration in the area in the late 1970's and early 1980's was directed at two molybdenum-copper deposits, in the northeast-trending belt of veins (fig. B12). At the CUMO deposit, extensive diamond drilling by the AMAX Corp. and other companies indicated that Tertiary rhyolite porphyry dikes and contiguous Cretaceous biotite granodiorite contain veinlets and disseminations of molybdenite and chalcopyrite. The deposit is cut by a post-mineral rhyolite dike. D.J. Baker (oral commun., 1985) estimated the CUMO deposit to contain 1 billion tons of material, the average grade of which is 0.10 percent $MoS_2$. A swarm of rhyolite dikes crop out in the vicinity of the CUMO deposit and continue on to the northeast. The Little Falls molybdenum deposit is in the dike swarm, about 5.5 km northeast of the CUMO deposit. Veinlets of molybdenite cut rhyolite dikes at the Little Falls deposit, and also occur in contiguous Cretaceous biotite granodiorite of the Idaho batholith. Fission-track dating of zircon from a rhyolite dike at the deposit gave an age of 29.3±1.7 Ma (P.A.M. Andriessen, written commun., 1982). Molybdenite veinlets that cut the rhyolite dike, therefore, are younger. Abella Resources drilled the deposit extensively in 1978–1981. About 2,500 m of core from the Abella drill holes gave a weighted average grade of 0.05 percent $MoS_2$.

### Banner Mine

The Banner mine and nearby prospects are in Boise County, Idaho, about 30 km northeast of Idaho City. Veins at the Banner mine were discovered in 1866, and during the height of production, from 1878 to 1906, the mine produced more than 3,000,000 oz of silver (M.G. Hansen, unpub. data, 1935). Bullion from the mine had a gold:silver ratio, in dollar value, of 0.4:1 (Anderson and Rasor, 1934). Mining activity at the Banner mine declined in 1906, and little ore has been produced since then.

The Banner mine area is underlain by biotite granodiorite of the Idaho batholith. Cutting the granodiorite are a number of rhyolite dikes of Tertiary age that follow northeast-trending shear zones of the trans-Challis fault system. Twelve en echelon veins crop out in the vicinity of the Banner mine. The veins follow the northeast-striking faults and dikes, although at least one vein is known to crosscut a rhyolite porphyry dike. A rhyolite dike cuts what is probably the northeast extension of the Crown Point vein, and a mafic dike along the vein system is younger than the mineralized veins (Anderson and Rasor, 1934). The veins are of fissure-filling origin and range in width from a few centimeters to a meter or so; ore values vary widely. The Banner vein, a principal producer, ranged from 1.5 to 3 cm in width on the lowest drift level, which was 160 m below the outcrop, whereas the Crown Point vein averaged about 1 m in width, was characterized by erratic ore values, and was not mined below the 450 level (Anderson and Rasor, 1934).

Principal silver-ore minerals, according to Anderson and Rasor (1934), were pyrargyrite and owyheeite, with lesser proustite, miargyrite, and tetrahedrite. Additional silver-bearing minerals in oxidized parts of the Banner veins include argentite, stephanite, native silver, polybasite, and cerargyrite (Shannon, 1926). Galena, sphalerite, and chalcopyrite occurred in the veins but not in sufficient quantities to be minable by themselves. On the lowest level of the Banner mine, the ore minerals formed faint narrow parallel bands in quartz, which was drusy and showed comb structure. Some ore minerals were brecciated by recurrent movement along the fissures during mineralization (Anderson and Rasor, 1934).

Attitudes and dike associations of the Banner veins are similar to those of the Boise Basin. The character of the ore minerals and accompanying quartz and the nature of the veins suggest they are epithermal.

## Central Part

### Stanley District

#### History and Production

Placer gold was discovered in the Stanley district in 1863, and most placer mining activity was in the 1870's and 80's, with a resumption of placer mining during the 1930's. The total amount of gold produced from placers in the district is unknown. Placer gold mined prior to 1900, calculated from reported dollar values, amounted to about 20,800 oz, whereas reported production since 1900 totaled 6,716 oz (Fisher, 1987, tables 10 and 11). A number of small lode mines and prospects are known, of which the Valley Creek, Buckskin, and Bronco (Mountain Girl) mines (fig. B11) are the only gold-silver producers of record. These three mines, worked intermittently from 1904 to 1942, yielded 5,284 tons of ore from which was recovered 1,583 oz gold, 33,949 oz silver, 2,053 lbs copper and 73,050 lbs lead (Van Noy and others, 1986, table 20).

#### Lode Deposits

Gold-silver lode deposits in the Stanley district are chiefly small discontinuous quartz veins and mineralized shears that cut granodiorite of the Idaho batholith. The Iron Crown, Golden Day, and Bronco (Mountain Girl) deposits, and many small prospects, are within or at the southwest end of the Custer graben (fig. B11). The larger Valley Creek and Buckskin deposits lie near a main strand of the trans-Challis fault system (fig. B11). The Valley Creek and Buckskin mines also are along a belt of northeast-trending Tertiary dikes that range from latite to more commonly rhyolite in composition. At the two mineralized deposits, granodiorite country rock of the Idaho batholith is intensely altered and brecciated. The Valley Creek deposit consists of near-vertical mineralized shears and quartz veins that range from 0.3 to 1.4 m in thickness in a fracture zone that trends N. 70°–85° E., has a maximum observed thickness of about 18 m, and may be traced on the surface for more than 600 m. The deposit has been explored by 630 m of adits and drifts on eight different levels and by surface workings that include a large open pit. No free gold or sulfide minerals were seen in the oxidized surface material.

Four quartz veins crop out at the Buckskin mine, which is 2 km southwest of the Valley Creek mine. The veins are 0.3–1 m thick, vuggy, and iron stained, but they also contain pyrite, which in places makes up as much as 20 percent of the vein material. Galena occurs sparingly in the veins. Tertiary dikes are exposed near the veins in the altered granodiorite country rock. Three adits at the Buckskin deposit explore a shear zone that strikes N. 80° E., is as much as 1.5 m wide, and contains stringers and lenses of quartz, some of which are enriched in pyrite. Samples of the mineralized zone and dumps averaged 0.04 oz Au/ton and 2.6 oz Ag/ton; however, a sample of pyrite-rich vein quartz contained 0.583 oz Au/ton and 6.38 oz Ag/ton, which suggests that the precious metals are associated with the pyrite (Van Noy and others, 1986).

The Bronco (Mountain Girl) mine workings explore a northeast-trending brecciated quartz vein that averages about 0.5 m in thickness. No sulfide minerals were seen in the vein by Choate (1962), although a composite sample chipped across the vein by him contained 0.41 oz Au/ton and 2.46 oz Ag/ton. Twenty-two tons of ore shipped from the mine contained 17 oz gold and 83 oz silver (Van Noy and others, 1986). Small shipments of gold-silver ore also have been made from narrow, northeast-striking quartz veins at the Golden Day mine.

The Iron Crown mine consists of three adits on different levels, all of which explore a Tertiary dike of rhyolite porphyry. Quartz-pyrite veinlets in the rhyolite porphyry contain free gold as irregular-shaped blebs and as wire gold intimately intergrown with pyrite (Choate, 1962).

#### Gold-bearing Resources

Eleven placer deposits in the Stanley district have been estimated to contain about 26.8 million yd$^3$ of gravel in which the average gold content ranges from a trace to 605 mg/yd$^3$ (Van Noy and others, 1986, table 37). Veins in the district are estimated to contain from 295,000 to 410,000 tons, with average grades ranging from 0.06 to 0.25 oz Au/ton and 1.8 to 4.12 oz Ag/ton (Van Noy and others, 1986). Substantial volumes of placer and lode material in the district are probably of minable grade, but future mining of the resources will be hampered by the fact that they are within the Sawtooth National Recreation Area, which is withdrawn from mineral entry under the 1872 mining laws, subject to valid existing rights, and where restrictive regulations are enforced to guard against impairment of the scenic features of the area.

### Custer Graben

The Custer graben, in the central part of the trans-Challis fault system, is northeast of the town of Stanley, Idaho (fig. B11). The graben is an Eocene volcanotectonic structure that subsided partly in response to the eruption of latitic ash-flow tuffs and partly owing to crustal extension (McIntyre and Johnson, 1985). It has little or no present-day physiographic expression. Northeast-trending normal faults are the most common structures within the graben. Most of these faults have dip-slip displacements of several tens to several hundreds of meters. Some have strike-slip displacements of several hundreds of meters to 2 km.

Two principal groups of rocks underlie the graben: siltite, argillite, quartzite, and limestone of the Permian Grand Prize Formation, and granitic rocks of the Late Cretaceous Idaho batholith. Volcanic rocks in and adjacent to the graben include andesitic lavas and pyroclastics erupted about 50 Ma, just prior to graben subsidence, and quartz latite to rhyolite ash-flow tuffs, lavas, and pyroclastics deposited during graben subsidence about 48 to 47 Ma. Locally, several hundred meters of lake sediments were deposited on lower parts of the graben floor.

Several types of Tertiary intrusive rocks are present in or near the graben. Andesitic dikes and plugs are found near vent areas of the andesite lavas. A small granodiorite–quartz monzonite stock is exposed near the south-central edge of the graben. Numerous dikes, domes, and irregular masses of rhyolite are present throughout the graben. Several of the domes vented to the surface, and many were probably emplaced at very shallow depths (Hardyman and Fisher, 1985). Ore deposits are genetically related to both the granodiorite–quartz monzonite stock and to several rhyolite intrusions.

Numerous gold mines and prospects are scattered near and within the central part of the trans-Challis fault system. However, within the Challis quadrangle (fig. B11), except for the Yankee Fork mining district, only two lode mines (the Yellowjacket mine, in the Yellowjacket mining district, and the Lost Packer mine, in the Loon Creek mining district) and one placer area (Loon Creek placers, in the Loon Creek mining district) have produced more than a few thousand ounces of gold each. Individual production from all the other mines has been small, and at a maximum has ranged from a few tens to a few hundreds of ounces.

### Yankee Fork District

#### History and Production

Placer gold was discovered in the Yankee Fork district near the mouth of Jordan Creek in the early 1870's. The first lode discovery was at the Charles Dickens property in 1875, and by 1877 most of the lodes in the district were located. The ores were very rich, ranging from $350 to several thousand dollars in silver-gold values per ton (Anderson, 1949). The district was most productive during the 1880's and 1890's, whereas by 1905 many mines had shut down. The Golden Sunbeam mine produced ore from 1907 to 1911; the Montana mine was reopened and in production from 1914 to 1917, and the Lucky Boy mine was a notable producer from 1933 to 1942. Activity at most properties in the district, however, has waxed and waned with only minor production recorded from the lode mines since the turn of the century. Placer deposits were worked intermittently, and from the 1930's to 1960, dredging was conducted at various times on the Yankee Fork of the Salmon River and on Jordan Creek. Total production from the placer deposits is unknown. Umpleby (1913a) estimated the value of placer production to be about $50,000 prior to the date of his report. U.S. Bureau of Mines unpublished records list total placer production since 1901 at 38,272 oz gold and 22,299 oz silver. The bulk of the placer production between 1940 and 1962 came from dredging on the Yankee Fork of the Salmon River and on Jordan Creek, and it totaled 29,356 oz gold and 21,037 oz silver. Production values (mostly at $20.67/oz of gold, and various prevailing silver prices) from the major lode mines are: General Custer ($8,000,000), Lucky Boy ($2,200,000), Charles Dickens ($600,000), Golden Sunbeam ($400,000), Montana ($350,000), McFadden ($200,000), and Morrison ($100,000) (Anderson, 1949). Most of these values were produced prior to 1901, as total lode production from the district between 1901 and 1982, according to unpublished U.S. Bureau of Mines records, amounted to only 41,650 oz gold and 433,269 oz silver.

#### Character of the Lode Deposits

Nearly all the lode production from the district has come from epithermal silver-gold veins. Veins in the northwestern part of the district are hosted in silicic tuff and intrusive rhyolite, whereas those in the southeastern part of the district are in andesite. All the rocks are of Eocene age. The veins formed at shallow depths and ore occurred along the veins in rich bonanza shoots. Silver was much more abundant than gold, and in some deposits the ratio of silver to gold was 80 or 90:1. Only ore from the upper workings of the Montana mine and from the Golden Sunbeam produced higher ratios of gold to silver. With the exception of the Charles Dickens mine, base metals are not abundant in the district, and only a few mines have recorded minor production of byproduct lead and copper. In the Charles Dickens the base metals were present in chalcopyrite, covellite, galena, and sphalerite; the 1983 operators of the property reported that the highest gold values were associated with chalcopyrite.

Northeast- and northwest-trending faults and fractures controlled location of the ore deposits, and mineralization was most intense in two areas, one in the Golden Sunbeam–Estes Mountain area and the other in the Charles Dickens–General Custer–Lucky Boy area. Rocks around these two mineralized areas are characteristically depleted in $^{18}O$ (Criss and others, 1985). The deposits occur as simple fracture-filling veins, filled breccia veins, shear zones, and stockworks. Some veins are an aggregate of small fracture zones, whereas others are simple structures with well-defined walls. The exposed strike length of the veins ranges from a few hundred meters to as much as 1,000 m. The average width of the veins is about 1 m, but they range from a few centimeters to a maximum of 5–6 m wide. Productive parts of the veins decrease rapidly with depth, and in most mines the veins are barren below 150–200 m.

Since 1975 exploration activity has focused on large-tonnage, lower grade gold-silver deposits associated with high-level rhyolite intrusions and also broad areas of pervasively altered rock adjacent to some of the major veins (Hardyman and Fisher, 1985; McIntyre and Johnson, 1985). The principal exploration targets have been at the Golden Sunbeam and General Custer mines. Rocks that host the deposits are extensively shattered and intensely altered to clay minerals and quartz. They contain disseminated gold and silver. Gold values are in the range of 0.02 to 0.03 oz/ton.

#### Mineralogy and Geochemistry

Cryptocrystalline to fine-grained, laminar, vuggy, drusy, white to dark-gray quartz is the main gangue mineral in the veins. Lesser amounts of chalcedony, calcite, barite, and adularia also are present. Pyrite is ubiquitous; however, it commonly has been oxidized. The other metallic minerals, fine grained and in most cases sparse, include chalcopyrite, sphalerite, tetrahedrite, galena, arsenopyrite, enargite, stephanite, miargyrite, pyrargyrite, argentite, electrum, and gold (Anderson, 1949). Anderson (1949) also reported gold and silver selenides; however, the presence of these minerals cannot be confirmed by the present authors. In the low-grade disseminated deposits, the ore is essentially indistinguishable (except by assay) from the barren altered country rock. These rocks are bleached and silicified, and clay minerals are common in them. Fine-grained disseminated pyrite is sparse, and other metallic minerals are rare.

Stream sediments from the district are enriched in gold, silver, copper, and molybdenum (Callahan and others, 1981; McIntyre and Johnson, 1985). Arsenic, molybdenum, beryllium, zirconium, and barium are commonly enriched in the altered rocks near the ore bodies, and these elements may provide useful prospecting guides (Hardyman and Fisher, 1985).

#### Wall-rock Alteration

Hydrothermally altered rocks are common in the Yankee Fork district. Alteration was most intense in the Golden Sunbeam–Estes Mountain area, Charles Dickens–General Custer–Lucky Boy area, and in the Red Mountain area, where altered zones range from several hundred to a thousand meters in width and length. Propylitized rocks are widespread, and silicification and argillization were more intense near the central controlling fractures and faults. Oxidation of the ubiquitous pyrite has stained and bleached many areas to shades of red, orange, and yellow. $^{18}O/^{16}O$ ratios are lowest in the intensely altered and mineralized zones, and the zones of $^{18}O$ depletion extend well beyond the areas of visibly altered rocks (Criss and others, 1985).

#### Age of Mineralization

Ages of ore formation are not well known. Zircon from hydrothermally altered rhyolite at the Golden Sunbeam mine yielded a fission-track age of 45.8±2.3 Ma (P.A.M. Andriessen, written commun., 1982), and sericite from the General Custer vein yielded K-Ar ages ranging from 48.4 to 44.0 Ma. These ages suggest that mineralization was associated with hydrothermal events that occurred after the main graben subsidence had been completed (McIntyre and Johnson, 1985).

#### Ore Controls and Resources

Structures are the principal ore controls in the district. Most of the richer lodes are on northeast- or northwest-trending faults or fracture systems. Richer ore shoots are commonly found near intersections of the main veins with cross faults. Lodes nearer the surface tend to be richer than those at depth. Most veins are barren at depths of more than about 200 m from the surface. Finally, undulations in strike and dip of the veins appear to have enhanced ore deposition in some lodes (Anderson, 1949). In some mines richer ore is associated with base metals if they are present; however, in most mines the youngest quartz commonly contains the highest values.

Undoubtedly a few high-grade pockets of bonanza ore are still present in the district, but they are likely to be small and to constitute no significant resource. Likewise small amounts (a few hundred to perhaps a maximum of 1,000 oz) of gold and silver may be produced from placers, mainly along Jordan Creek and the Yankee Fork of the Salmon River. The greatest resources in the district are most likely contained in the lower grade disseminated deposits associated with the high-level rhyolite domes (for example, the Golden Sunbeam and Red Mountain areas) and with the areas of extensive fracturing that hosted widespread alteration and mineralization (such as the extensive altered zone adjacent to the General Custer vein). Resources from these zones will be low grade (about 0.02 to 0.03 oz Au/ton). Millions of tons of this low-grade material may be present in the district.

### Loon Creek District

The Loon Creek district (fig. B11) is west of the Custer graben and at the extreme northeast end of the

Knapp Creek graben. The only significant gold production has come from the Lost Packer lode mine and the Loon Creek placers. The few other lode mines in the district have had little development and essentially no production. Rocks underlying the district consist of the Idaho batholith of Late Cretaceous age, metamorphosed Precambrian and Paleozoic sedimentary rocks (roof pendants in the Idaho batholith), dacitic and granitic stocks of Eocene age, and extrusive lavas and pyroclastic rocks of the Eocene Challis Volcanics (Fisher and others, 1983).

#### Loon Creek Placers

The Loon Creek placers were discovered in 1869 and reached their greatest development and production during the next 10 years (Ross, 1934). There has been little activity since 1880 and only minor production. The placers extend about 7 km northeast from the abandoned townsite of Casto (fig. B11). They average about 300 m in width and comprise the flood plain and higher terraces along Loon Creek. The gravel is as much as 10 m thick but more commonly is about 5 m thick. The gold was generally coarse, and nuggets weighing more than 1 oz were not uncommon (Umpleby, 1913c). Gold produced from the placers was estimated by Umpleby (1913c) to be valued at between $500,000 and $2,000,000.

#### Lost Packer Mine

The Lost Packer mine was discovered in 1902, and most development and mine production was between then and 1927. Umpleby (1913c) estimated the total production to 1911 to be valued at $500,000, with gold accounting for $350,000 and copper $150,000. Ross (1934) reported an additional $100,000 in metal values that were produced between 1911 and 1927. Unpublished records of the U.S. Bureau of Mines show that the mine produced 19,791 oz gold, 48,451 oz silver, 1,797,786 lbs copper, and 8,038 lbs lead between 1903 and 1937. There has been essentially no production of ore since 1937.

The Lost Packer lode is in quartzose, micaceous, and calcareous metasedimentary rocks of Precambrian or possibly Paleozoic age. Mica schist and dark micaceous quartzite are common. These rocks have been intruded by Cretaceous rocks related to the Idaho batholith and by Tertiary dacite, dacite porphyry, and granophyre dikes. The ore appears to be younger than the Cretaceous aplite dikes and older than the Tertiary granophyres.

The Packer vein extends along the Packer fault, which strikes N. 10° E., dips steeply northwest, and exhibits left-lateral displacement of only a few meters. The vein is a narrow structure formed chiefly by fissure filling; it consists mostly of quartz and is generally sparse in sulfides. Ore was produced from three major shoots along the vein—the north, south, and main shoots. These shoots had vertical dimensions of about 50–100 m, and ranged from about 1 to 2 m in thickness.

Gangue minerals include abundant quartz and siderite, smaller amounts of pyrite and pyrrhotite, and minor amounts of calcite and barite. Ore minerals are chalcopyrite, tetrahedrite, bornite, native copper, and gold. The high-grade ore consisted mostly of gold-bearing massive chalcopyrite, which according to Umpleby (1913c) ran about $80–$90 per ton in gold, silver, and copper values. The chalcopyrite commonly assayed 2½ to 3 oz Au/ton, and quartz from some ore shoots was equally rich in gold (Umpleby, 1913c). Jennings (1906) estimated that the high-grade ore averaged 15 percent Cu and contained 2–20 oz Au/ton and only minor amounts of silver.

Exploration of the property has continued sporadically; high-grade chalcopyrite-gold ore was discovered in 1983 and was being evaluated in 1984. Small high-grade shoots may be present, but large reserves of high-grade ore are unlikely. An unknown tonnage of lower grade material is present.

### Other Mines and Prospects

Many other gold mines and prospects occur within and adjacent to the central part of the trans-Challis mineral belt within the Challis quadrangle (fig. B11). Most of these deposits are small veins or placers with no recorded production and very low future potential. However, some of these occurrences, notably the Singheiser, Rabbit Foot, and Parker Mountain deposits, have produced a few hundred ounces each and may offer targets for large-tonnage, low-grade type operations. All three of these occurrences are associated with high-level rhyolite intrusions (Hardyman and Fisher, 1985) and have similarities to the disseminated deposit at the Golden Sunbeam mine in the Yankee Fork district. Numerous other rhyolite intrusions occur along the central part of the trans-Challis fault system (Fisher and others, 1983), and several are known to be mineralized (Hardyman and Fisher, 1985). A sum total of probably millions of tons of low-grade (0.01–0.02 oz Au/ton) resources may be associated with the high-level rhyolites.

### Yellowjacket District

The Yellowjacket mine (fig. B11) is just north of the northwestern edge of the Panther Creek graben, an asymmetric volcanotectonic structure that subsided partly owing to regional rifting and partly owing to magma withdrawal associated with the eruption of rhyolite tuffs (Fisher and others, 1983). It is similar to the Custer graben. The Panther Creek graben is a tilted block whose bounding faults on the southeast side have displacements of about 4,000 m, whereas northwest-side bounding faults have maximum displacements of a few tens to a few hundreds of meters (McIntyre and Johnson, 1985; Fisher and others, 1983).

Total production from the Yellowjacket district is unknown because prior to 1893 no records were kept. Umpleby (1913b) estimated total gold production to 1910 to be valued at about $450,000. Between 1902 and 1949, the district produced 3,855 oz gold, 5,608 oz silver, 20,792 lbs copper, and 17,175 lbs lead. The biggest producer of precious metals, by far, was the Yellowjacket mine, which accounted for 3,003 oz gold and 3,397 oz silver (Anderson, 1953). The Yellowjacket lode was discovered in 1868 and was extensively developed in the 1880's and 1890's. By 1900, however, mining activity had slowed, and since then development and production have been sporadic. Placer mining in the district has not been extensive, but production from placers is unknown and probably minor (Anderson, 1953).

The district is underlain by argillaceous and calcareous quartzite of the Yellowjacket Formation and by the Hoodoo Quartzite, both formations of Early and Middle Proterozoic age. A wide variety of igneous rocks has intruded the Precambrian metasedimentary rocks. Stocks, dikes, and irregular plugs of gabbro, diabase, olivine gabbro, diorite, lamprophyre, granite porphyry, and granophyre have been emplaced at various (but uncertain) times from the Precambrian to the Tertiary (Anderson, 1953; Fisher and others, 1983).

The Precambrian sedimentary rocks in the district have been repeatedly deformed since Early Proterozoic time. They are complexly folded and fractured. Most of the mineralized fractures in the district strike about N. 60° E. or N. 15°–20° W. Dips of the northeast set range from 35° to 80° NW., and those of the northwest set dip steeply to the southwest (Anderson, 1953). Major regional faults mostly of northeast trend and less commonly of northwest trend also cross the district. Dip-slip movement on these faults has been as much as 1,000 m.

The deposits are mainly fracture-filling veins with minor replacement. Gold is the most important metal followed by silver, copper, and lead. Base metals are sporadic in their occurrence, and the veins may be classed as gold-base metals, silver-copper, and silver-lead deposits. Most of the individual veins are narrow (a few centimeters to a meter wide) and are not persistent along strike. Lodes generally contain numerous veins, and the entire zone may be several tens of meters wide and hundreds of meters long. In places the mineralized rock has a stockwork character. Gangue minerals include quartz, calcite, siderite, barite, and pyrite, of which quartz is by far the most abundant. Ore minerals include chalcopyrite, sphalerite, tetrahedrite, galena, and gold. Secondary minerals are chalcocite, covellite, cuprite, malachite, azurite, and native copper. The gold is very fine grained and is most commonly associated with the quartz (Anderson, 1953).

#### Yellowjacket Mine

The Yellowjacket mine consists of more than 2,000 m of underground workings on four main and several intermediate levels. The mine is in quartzitic and calcareous units of the Yellowjacket Formation. The lode is along a wide (100–150 m) zone of fractured rock about 400 m in length that trends N. 70° E. and dips steeply to the northwest. Innumerable northeast- and northwest-striking veins and stringers separated by altered rock are present in the fractured zone. The ore was erratically distributed in the zone with individual ore shoots being 100 m long by 10–15 m wide and 40–50 m deep (Ross, 1934). The ore was extensively oxidized, was free-milling, and originally contained minor amounts of chalcopyrite and pyrite. The average gold content was 0.387 oz Au/ton. Base metals were more common in deeper levels of the mine.

According to Ross (1934), structural relationships of the veins may indicate the existence of undiscovered gold-bearing base-metal ores at depth. The greatest potential for the district, however, probably lies in the altered stockworks and fracture zones that may contain large tonnages of low-grade gold ore amenable to heap leaching. Some exploration of these possibilities was being conducted in the district in 1984.

## Northeast Part

The northeast part of the trans-Challis fault system in Idaho has been heavily mineralized. There are four main types of deposits: (1) stratiform or mobilized stratiform copper-cobalt deposits that are Precambrian in age, (2) thorium and rare-earth deposits that are possibly Precambrian, (3) molybdenum-copper porphyry and stockwork deposits of Tertiary age, and (4) epithermal gold-silver deposits that are Tertiary and are directly related to the trans-Challis fault system. The gold-silver deposits are in the Mackinaw (Leesburg), Mineral Hill, Indian Creek, and the Dahlonega (Gibbonsville) districts. A brief description is also given of some molybdenum-copper deposits.

Production figures for the districts are incomplete; what is known is shown in table B3.

The gold lode deposits have several characteristics in common. All the mines are in vein deposits that have a simple mineralogy. The gangue mineral is quartz, and the economic minerals are free gold and auriferous pyrite. Pyrite is the common sulfide, and most mines

**Table B3.** Production from the Mackinaw (Leesburg), Indian Creek, and Dahlonega (Gibbonsville) districts, Idaho

[Data from U.S. Bureau of Mines (1924–31; 1932–83). Leaders (– –), no production or no data available. No recorded production after 1955. Lode no. and placer no. indicate number of such properties active in specified year]

| | Lode (no.) | Placer (no.) | Gold (dollar value) | Gold (oz) | Silver (oz) | Copper (lb) | Lead (lb) | Lode (no.) | Placer (no.) | Gold (oz) | Silver (oz) | Copper (lb) | Lode (no.) | Placer (no.) | Gold (dollar value) | Gold (oz) | Silver (oz) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dahlonega (Gibbonsville) district | | | | | | | Indian Creek district | | | | | Mackinaw (Leesburg) district | | | | |
| 1910 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3,966 | -- | 29 |
| 1911 | -- | -- | 11,868 | -- | 108 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1912 | -- | -- | 9,628 | -- | 421 | 1,340 | 12,044 | -- | -- | -- | -- | -- | -- | -- | 857 | -- | -- |
| 1913 | -- | -- | 11,796 | -- | 97 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2,132 | -- | 12 |
| 1914 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2,765 | -- | 27 |
| 1915 | -- | -- | 4,863 | -- | 36 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2,384 | -- | 15 |
| 1916 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1917 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2,192 | -- | 8 |
| 1918 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2,448 | -- | 15 |
| 1919 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,893 | -- | 17 |
| 1920 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1921 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1922 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1923 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3,530 | -- | 13 |
| 1924 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3,317 | -- | 20 |
| 1925 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2,725 | -- | 10 |
| 1926 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,817 | -- | 7 |
| 1927 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1928 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2,247 | -- | 8 |
| 1929 | -- | -- | -- | -- | | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,944 | -- | 7 |
| 1930 | -- | -- | -- | -- | | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,972 | -- | -- |
| 1931 | -- | -- | 410 | -- | | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1932 | 4 | 8 | -- | 1,028 | 369 | 3,095 | 267 | 1 | 1 | 830 | 7 | -- | 2 | 13 | -- | 4,083 | 14 |
| 1933 | 9 | 4 | -- | 551 | 640 | 4,875 | 6,351 | 2 | 1 | 29 | -- | -- | 1 | 12 | -- | 334 | 20 |
| 1934 | 10 | 9 | -- | 492 | 450 | 3,500 | 4,162 | 2 | -- | 48 | 34 | -- | 4 | 73 | -- | 651 | 2,025 |
| 1935 | 13 | 4 | -- | 185 | 160 | 795 | -- | 2 | -- | 238 | 34 | 50 | 2 | 22 | -- | 310 | 1,550 |
| 1936 | 5 | 4 | -- | 1,264 | 608 | 2,663 | -- | 1 | -- | 851 | 816 | 6,935 | 1 | 17 | -- | 262 | 12 |
| 1937 | 16 | 13 | -- | 1,239 | 464 | 1,785 | 610 | 2 | -- | 35 | 13 | 124 | 1 | 22 | -- | 200 | 13 |
| 1938 | 9 | 11 | -- | 1,365 | 492 | 408 | 870 | 1 | -- | 60 | 34 | 194 | 3 | 23 | -- | 295 | 280 |
| 1939 | 8 | 8 | -- | 715 | 96 | 346 | 234 | 2 | -- | 32 | 9 | -- | 3 | 17 | -- | 305 | 240 |
| 1940 | 6 | 14 | -- | 959 | 367 | 1,133 | 1,200 | 1 | -- | 221 | 14 | 248 | 3 | 18 | -- | 1,240 | 204 |
| 1941 | 9 | 13 | -- | 3,004 | 311 | 550 | 1,600 | 1 | -- | 412 | 38 | 1,500 | 1 | 16 | -- | 1,221 | 128 |
| 1942 | 2 | 9 | -- | 4,440 | 343 | -- | -- | 1 | -- | 6 | -- | -- | 1 | 9 | -- | 73 | 14 |
| 1943 | -- | 1 | -- | 3 | -- | -- | -- | -- | -- | -- | -- | -- | 1 | -- | -- | 1 | 17 |
| 1944 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2 | -- | 10 | -- |
| 1945 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1 | -- | -- | 2 | 59 |
| 1946 | 1 | 3 | -- | 1,338 | 120 | -- | -- | -- | -- | -- | -- | -- | -- | 4 | -- | 39 | 5 |
| 1947 | -- | 3 | -- | 3,441 | 232 | -- | -- | -- | -- | -- | -- | -- | -- | 4 | -- | 13 | -- |
| 1948 | -- | 1 | -- | 104 | 10 | -- | -- | -- | -- | -- | -- | -- | -- | 4 | -- | 14 | -- |
| 1949 | 1 | 1 | -- | 43 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3 | -- | 9 | -- |
| 1950 | -- | 2 | -- | 8 | -- | -- | -- | -- | -- | -- | -- | -- | 1 | 3 | -- | 14 | -- |
| 1951 | -- | 1 | -- | 9 | -- | -- | -- | -- | -- | -- | -- | -- | 1 | -- | -- | 1 | 11 |
| 1952 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2 | -- | -- | -- | 24 |
| 1953 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1954 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1 | -- | 1 | -- |
| 1955 | 1 | -- | -- | 2 | 8 | 300 | -- | -- | -- | -- | -- | -- | -- | 1 | -- | 7 | 1 |

contain sparse sphalerite, galena, and chalcopyrite. Many of the veins are in northeast-trending shears or fissures that are believed to be part of the trans-Challis fault system. Most of the gold production has been from placers, and the largest lode producer, the Gold Hill mine in the Mackinaw (Leesburg) district, accounts for only a little more than 43,000 oz. None of the lode deposits extend to any great depth.

## Mackinaw (Leesburg) District

The Mackinaw (Leesburg) district, approximately 20 km northwest of Salmon, Idaho, is the oldest mining district in Lemhi County.

### History and Production

Placer gold was discovered near Leesburg (fig. B11) on July 6, 1866, and by August a full-fledged gold rush was underway. By 1867, 130 houses had been built or were under construction, and the new settlement of Leesburg had a population of about 2,000. The town would serve as the jumping-off point for exploration in rugged central Idaho in the coming years. The initial gold rush was over by 1895.

All mining work in the district was placer until 1870. The first lode claim, the Shoo Fly (fig. B11), was located in 1870. In 1880 the Gold Flint was staked, and in 1892 the Italian mine claims were located. Large placers have been worked near Leesburg since the initial discovery in the district. The use of sluice boxes and shakers to mine placers in the late 1800's gave way to hydraulicking in the 1920's and to dredges in the 1930's and 40's. Major production in 1940–41 came from a dry-land dredge, which recovered more than 1,000 oz of gold and 95 oz of silver each year. The jump in gold production shown in table B3 was due to this operation.

Interest in placers has been continuous. In 1981, the Napias Mining Co. began a large placer operation at Leesburg using power shovels and a washing plant. The operation was still active in 1984.

The major lode producer in the district has been the Italian mine, so named because three Italians discovered the property. These men operated the mine until 1902 when it was purchased for $20,000 by the Van Horn Co. of Fremont, Nebr. In 1903, the mine produced $60,000 in bullion. The mine was sold in 1908 to the Leesburg Mining Co., which installed a hoist, started shaft sinking, and discovered gold ore in the shaft. A 30-stamp mill was built in 1910, and a 700-horsepower hydroelectric power plant was installed 11 km west of the mine. The new facilities apparently did little to increase production. The mine operated for 3 months in 1921, had minor production in 1922, and has been inactive ever since. Total production from 1902 through 1935 was 722 oz of gold and 194 oz of silver (U.S. Bureau of Mines, unpub. data).

The Haidee mine is 2.4 km north of the Italian mine. In 1903, a New York firm started driving a 900 m adit on the property. Ore was discovered, but the adit never reached the target vein owing to caving problems, and the project was abandoned. The Gold Flint mine, about 2.4 km north of Leesburg (fig. B11) had about 300 m of drifts along a northeast-striking mineralized fault, according to Umpleby (1913b), but it has been inactive since 1913. The Gold Dust mine had a 10-stamp mill that operated for a total of 90 days (Umpleby, 1913b). Further work was done in 1921, but there was no production. The Gold Ridge mine on the same mineralized fault as the Gold Flint and Gold Dust mines (Umpleby, 1913b) was developed by 300 m of workings; a 10-stamp mill and a 50-ton cyanide plant, built in 1907, operated intermittently for 2 years. Production in 1907 was 9 oz of gold and 10 oz of silver from 75 tons of ore. The mine closed in 1907 and has been inactive since. The Shoo Fly lode produced about $75,000 in gold within several years of discovery, mostly from boulders of vein material that were mined below the outcrop (Umpleby, 1913b). Mine production since then has been sporadic. The property was not developed further until 1932. In 1934, 775 tons of ore were treated by amalgamation, and some production also was recorded in 1935. The mine accounted for all lode production for the Leesburg district in 1936 and 1938. Production from the Shoo Fly mine, from 1932 through 1941, was 666 oz of gold and 19 oz of silver from 1,792 tons of ore. Operations at the mine ceased in 1941.

Umpleby (1913b) noted that the Mackinaw (Leesburg) district had produced about $5 million in gold and silver from placers and $250,000 in lodes by 1913. Two-thirds of the recorded lode production came from the Italian mine and the rest from the Shoo Fly mine. Metal production for the Mackinaw (Leesburg) district, from 1910 to 1955, is shown in table B3.

#### Geologic Setting

The geology of the Mackinaw (Leesburg) district has been described by Umpleby (1913b), Shockey (1957), Bennett (1977), Lopez (1981), Hillisland (1981), and Jordan (1984). Major rock units include the Yellowjacket Formation, the Hoodoo Quartzite, and several varieties of augen gneiss and related rocks that are all Precambrian in age. Tertiary dikes exposed north of Leesburg are probably related to a buried Tertiary plutonic complex that hosts, in part, the Bobcat Gulch porphyry molybdenum-copper deposit (fig. B11). However, Evans and Zartman (1981b) have dated zircons in other igneous rocks in the district as Ordovician (493 Ma), suggesting that the plutonic history of the area is complex. Cretaceous rocks of the Idaho batholith probably also are present but are not as prevalent as noted in the early literature. Miocene lake-bed deposits composed of volcaniclastic sediments and patches of Challis Volcanics are exposed north of Leesburg and southwest of North Fork (fig. B11).

Perhaps the most important structural element in the district is the Panther Creek fault (Bunning and Burnet, 1981), a major structure in the trans-Challis fault system that probably has been active since the Precambrian. The Gold Dust, Gold Reef, and Gold Flint mines are on a parallel structure very close to this fault.

#### Characteristics of the Deposits

Umpleby (1913b) noted five types of veins in the Leesburg district. Quartz veins accompanied by quartz stockworks in granite are the first type. Characteristic of this type is the Italian mine and the nearby Haidee mine. The Italian mine is in a fracture zone that extends more than 1,600 m in a north-south direction and dips 45° W. A second type of deposit is replacement veins along fault planes, characterized by the Gold Dust, Gold Reef, and Gold Flint mines. In these mines, Precambrian metasedimentary rocks are faulted against augen gneiss. All three mines are in the same structural zone which, as noted, is close to and parallels the Panther Creek fault (fig. B11). Umpleby (1913b) noted that these three mines were higher in silver content than other lodes in the district and were probably the source of the placer gold near Leesburg, as that gold contained more silver than other placers in the district. Lenses in schist and granite, a third type of mineralized rock, are believed to be another source of the placer gold. The Shoo Fly mine exploited a lode deposit of this type. A vein in contact with a monzonite dike in the Italian mine is a fourth type that was thought by Umpleby (1913b) to postdate the stockwork mineralization. The last type of vein is replacements along shear zones, as found in the western part of the district.

Quartz is the primary gangue mineral of the lodes, with some calcite stringers; auriferous pyrite and free gold are the economic minerals; and there is usually sparse galena and sphalerite. The monzonite-related vein in the Italian mine is anomalous in that it contains considerable chalcopyrite and sphalerite.

## Mineral Hill District

The Mineral Hill mining district is approximately 34 km west of North Fork, near the former town of Shoup. The district contains three gold mines that have been significant gold producers: the Kentuck (Gold Hill), Grunter, and Clipper Bullion, as well as numerous prospects.

### History and Production

The following history and production data are, for the most part, modified and paraphrased from a study by E.T. Tuchek, A.B. McMahan, and L.Y. Marks (unpub. report for the U.S. Bureau of Mines, 1973). The Kentuck mine (later known as Gold Hill mine) was opened in 1882 and the Grunter mine in 1891. The first production from the Kentuck mine was in 1882. For 2 years ore was processed using a single-stamp mill, two arrastre beds, and direct amalgamation. In 1884, a 10-stamp mill was installed. Production of gold reached a value of $7,200 a month in 1889. The stamp and amalgamation processes were used to treat about 46,000 tons of ore, with a gold recovery rate of 40 percent, until 1893 when the mine closed. Production was only minor until 1931, when the mine was sold and subsequently incorporated as Gold Hill Mines. A 100-ton/day flotation plant was erected in 1935 and operated for several years. The property has been idle since 1949.

The Grunter mine was in production shortly after discovery in 1882. Bell (1904, p. 104) gave the following discussion of one of the early mining ventures on the property:

> The Grunter mine, situated a mile east of the Kentuck on the same vein, is a fine example of one of the most flattering gold enterprises in the state that was butchered by a would-be mining capitalist who, through blundering misconception of the enterprise he was undertaking, started in to put up a first-class ten-stamp concentrating mill for a half interest in the property and wound up by furnishing a five-stamp mill with a hog-trough mortar and an overshot wheel that was just about as effective as a good-sized coffee mill and never gave the property half a chance to show its merits.

Ore was processed in a stamp mill using direct amalgamation until 1935, when the mill was destroyed by fire. In 1938, the property was purchased by Gold Producers, Inc., and a 50-ton/day mill was moved to the mine from the Twin Brothers mine near Gibbonsville. The following year, a 100-ton/day flotation plant was erected. Operations at the mine terminated in 1948.

Underground workings in the two mines consist of 36 adits with crosscuts and stopes, one glory hole, one underground shaft, and numerous prospect pits and trenches. More than 3,000 m of workings are reported in the area. The vein in the Kentuck was worked downdip for about 200 m.

The Gold Hill mine, consisting of 10 patented and 41 unpatented claims, and the Grunter mine, consisting of 5 unpatented claims, were acquired by Nevcal Resources, Ltd., in 1984.

According to U.S. Bureau of Mines unpublished data, production from the two mines is:

| Period | Crude ore (tons) | Gold (oz) | Silver (oz) | Copper (lb) | Lead (lb) |
|---|---|---|---|---|---|
| 1882–1900 | 50,000 | 25,000 | ---[1] | --- | --- |
| 1901–1913 | 67 | 87 | 15 | --- | --- |
| 1932–1949 | 150,281 | 18,127 | 13,614 | 4,712 | 95,418 |

[1]Leaders (---), no production, or no data available.

The Clipper Bullion mine is 1.6 km southeast of the Grunter mine (fig. B11). Ten mining claims were located in 1887, and gold was mined through 1932. Silver was recovered from 1902 through 1932, the last year of operation. Total production, according to Bureau of Mines records and estimates from Umpleby (1913b), was 3,893 oz of gold, 209 oz of silver, and 279 lbs of lead. Mine workings consist of four adits and numerous prospect pits and trenches. According to Umpleby (1913b) there were 820 m of mine workings, but only about 200 m of workings were open in 1972.

Another property with minor production was the Monolith mine, which in 1947 and 1948 produced 6,247 tons of ore that yielded 1,659 oz of gold and 657 oz of silver. Only 1 ton of high-grade ore was mined in 1948 before the mine closed.

The Big Lead mine (fig. B11) produced 144 oz of gold and 8 oz of silver from 322 tons of ore in the period 1904–1923. The mine is developed by about 460 m of adits.

### Geologic Setting

The country rock that hosts producing mines in the Mineral Hill district is augen gneiss that underlies much of the area around Shoup. The augen gneiss intrudes the Yellowjacket Formation of Early and Middle Proterozoic age and amphibolite that itself also intrudes the Yellowjacket elsewhere in the area. Younger granite of the Idaho batholith and Tertiary porphyry dikes ranging in composition from andesite to rhyolite cut the gneiss. Umpleby (1913b) noted that in the Kentuck mine, a granite porphyry dike crosscuts the augen gneiss but is in turn cut by veins. The producing mines are all in shear zones that trend N. 10°–70° E. and dip 40°–90° SE. These shear zones are believed to be part of the trans-Challis fault system.

#### Characteristics of the Ore Deposits

The Grunter and Kentuck (Gold Hill) mines are in a large northeast-trending shear zone that is exposed for 900 m along strike and 300 m down dip in the mine workings. Three primary shears contain major veins in the zone. Numerous fractures and minor shears cross the three major shears. Three more major shears contain veins called the Tramway, Hennessey, and Clipper Bullion in the Clipper Bullion mine. The Tramway strikes N. 70° E., dips 80° S., and averages 1 m in width; the Hennessey strikes N. 20° E., dips 85° E., and is 0.5 m wide; and the Clipper Bullion (the most productive) strikes N. 42° E., dips 65°–85° SE., and is about 1 m wide. The main vein in the Big Lead mine also strikes N. 65° E. and dips 80° S.; it ranges from a few centimeters to about 1 m in width.

The mineralogy of the veins in the mines is simple. Quartz is the dominant gangue mineral, and free gold, auriferous pyrite, and pyrite are the minerals of economic interest. Other minerals present in minor amounts at the Grunter and Gold Hill (Kentuck) mines include sparse galena, sphalerite, and arsenopyrite (Umpleby, 1913b). Tuchek and others (1973) reported minor tungsten minerals in one shear zone. The vein at the Clipper Bullion contains some barite in the gangue, and magnetite occurs in the Big Lead mine. Alteration is similar in all of the mines; the augen gneiss is silicified for several meters away from the veins, and pyrite is disseminated in the wall rock. Rocks along the shear zones are highly altered and iron stained. Oxidation has been relatively minor, and its effect extends to a depth of about 10 m in the glory hole of the mine.

### Indian Creek District

The Indian Creek district is approximately 16 km west of North Fork and 11 km east of Shoup (fig. B11). The topography is rugged, with elevations ranging from 1,067 m to more than 2,134 m.

Two veins—the Ulysses and the Kittie Burton—were mined. These deposits are considered to be epithermal veins associated with the trans-Challis fault system, but the dip of the veins is flat whereas other veins in the zone generally dip steeply.

#### History and Production

Umpleby (1913b) noted that the first claims in the district were located in 1895, but that little further work took place until the Kittie Burton Gold Mining Co. acquired the Kittie Burton and Ulysses properties in December 1901. The late development of the area was a result of difficult access and transportation to the mine site. Wells (1983, p. 78) described some of the early history:

> In spite of such obstacles [transportation], a 15-stamp mill which commenced production in 1902 was enlarged to 30 stamps the next year. This operation processed enough low-grade ($10) ore to yield a monthly profit of 3 percent on a large capital investment through 1904. That September, a fire destroyed the plant and set Ulysses back seriously. At the time of the fire, Ulysses had Idaho's largest active gold mine.

After the 1904 fire, an improved 15-stamp mill was built. By 1907, free-milling ore was mined out, and production slowed as primary sulfide ore was reached. Lessees operated the mine in 1908, and shipments resumed in 1909 when a concentrator was added to the mill. A 900-m Leschen aerial tram connected the Kittie Burton mine to the mill, and another tram delivered ore from the Ulysses. In 1910 the mine was the largest gold producer in Lemhi County. It held the record again in 1914, but production declined drastically in 1915, and the property was idled in 1917. The Buchanan Mining and Leasing Co. repaired the mill and tramline in 1919, went into production in 1920, and produced considerable gold and silver in 1921 and 1922. Minor production, tailings processing, and cleanup carried the mine through 1928 when it closed again. In 1932 the Indian Creek Leasing Company reopened the mine, built a small tramline, and refurbished the mill. The company operated until 1937 when the operation shut down. The American-Idaho Gold Corp. operated the property in 1940, treating 900 tons of ore in a 50-ton flotation mill. All operations ceased in 1943, and there has not been any recorded activity since.

The Sage Creek Lumber Co. operated the Sage Creek mine (fig. B11) in 1950, and produced 75 oz gold and 9 oz silver. The Sage Creek veins are similar to the Kittie Burton and Ulysses veins according to Umpleby (1913b).

Production from the district is shown in table B3. Umpleby (1913b) noted that early production was valued at a little less than $600,000.

#### Geologic Setting

Country rock in the area is metamorphosed Early and Middle Proterozoic Yellowjacket Formation intruded by augen gneiss and amphibolite, all Precambrian in age. Umpleby (1913b) described granite porphyry dikes that intrude the older units.

The Ulysses vein is a tabular body, varying in width to as much as 3.5 m, striking east-west, and dipping 10°–25° S. Because of the flat attitude of the vein, it could be mined by stripping the overburden. The vein does not extend more than 46 m deep. The Kittie Burton vein strikes N. 20°–30° W. and dips 40° SW. in the upper 30 m, but it is almost flat below this depth. It has a maximum thickness of 30 m in the flat part of the vein that was called the "Big Stope" (Umpleby, 1913b).

The mineralogy of both veins is similar. Quartz is the primary gangue in silicified wall rock, and economic minerals include free gold and auriferous pyrite. Some chalcopyrite and pyrrhotite are also present in the ore.

## Dahlonega (Gibbonsville) District

The Dahlonega mining district is near Gibbonsville. Mines in the district produced gold from placers and lodes. Major lode production came from the American Development, Mining, and Reduction (ADM&R) Co. mines near Gibbonsville. The Twin Brothers, Clara Morris, and Big Four mines also have been productive.

#### History and Production

The early history of the district was described by Umpleby (1913b, p. 128) as follows:

> Placers were discovered on Anderson Creek in 1877, and although not very productive, their presence led to the location of gold-bearing veins in September of that year. During the fall, one arrastre was built, and the next year two more added. By this means of treatment $20 to $30 per ton was saved. Early in 1881 most of the producing mines were sold to an English company, which later went into liquidation and sold the properties to Adelbert Ames, of New York who operated them for a number of years. After changing hands several times, the American Development, Mining, and Reduction Company purchased the principal group from the Northfork Reduction Company and in 1895 erected a 30-stamp mill with accessory cyanide and chlorination plants. This company operated until March 20, 1898, when it also became insolvent, the receiver and others operating the property intermittently until July 1906, when the American Development, Mining, and Reduction Co. resumed control.

The closure in 1898 was due to a change in tenor and grade of the ore. The oxidized ore had been mined out, and gold was in sulfides at depth. Lincoln (1912, p. 49) observed, "A series of tests that I made showed that there is no free gold in the deeper ores and that in order to obtain an extraction of 90 percent by cyanidation, it will be necessary to slime them." The ADM&R operation suffered a setback in the fall of 1907 when the principal reduction plant burned.

A 20-stamp mill and 20-ton cyanidation plant were built in 1908 by the ADM&R Co. to replace the older mill that had burned. Production from these mines from 1901 to 1917 was 4,481 oz of gold and 755 oz of silver (U.S. Bureau of Mines, unpub. data).

The district saw little activity until 1930 when Rescue Gold Mines reopened the ADM&R mines. In 1933 tailings were shipped by a lessee from these mines and from the Twin Brothers mine. Smelting ore was shipped from the Lamoreaux, Clara Morris, and Golden Reward mines, and ore was treated from the Big Four and Golden Reward mines by amalgamation and concentration. In 1934, the largest producer was the lease operation at Rescue Gold Mine (ADM&R), although Gibbonsville Premier Gold Mines, Ltd., processed 50 tons of gold ore from the Big Four mine in a new 10-stamp mill. A 50-ton/day flotation-concentration plant was built by Gold Producers, Inc., in 1935 at the Twin Brothers mine, to process ore from the Twin Brothers mine and to custom mill for other mines in the district. Premier was active at Gibbonsville, and the Clara Morris mine was an important producer in 1935 and 1936.

The Golden Reward and Twin Brothers mines were operated in 1937. The 50-ton/day mill at the Twin Brothers mine was moved to the Grunter mine near Shoup the same year. From 1902 to 1938, the Twin Brothers mine yielded 1,449 oz of gold and 1,052 oz of silver (U.S. Bureau of Mines, unpub. data). The loss of the Twin Brothers mill slowed lode production from Gibbonsville mines considerably. Gibbonsville Premier, owner of the Twin Brothers and Big Four mines, operated with small crews until 1942 when the mines were shut down. This marked the end of precious-metal lode mining in the district, although the area was prospected heavily for uranium in the middle 1950's.

Placer mining has continued on and off throughout the productive history of the district. In 1937, placer gold production was increased substantially by North Fork Placers. Placer deposits in the district, which accounted for most of the district's production, yielded 520 oz of gold in 1939. A dramatic production increase, from 959 oz of gold in 1940 to 3,004 oz in 1941 (table B3), was due to a bucket line dredge and two floating dredges. In 1942 a dredging operation by Smith Brothers and Courtis, Inc., recovered 2,466 oz of gold and 203 oz of silver, and the Idaho-Warren Dredging Company recovered 1,900 oz of gold and 123 oz of silver. All lode and placer mines were shut down in 1942 by War Production Board Order L–208. Placer mining resumed in 1946, but ceased again in 1948.

### Geologic Setting

Mines in the Dahlonega district are hosted by the Yellowjacket Formation, which may be the equivalent of the Precambrian Prichard Formation of the Belt Supergroup (Ruppel, 1975). These rocks are intruded by augen gneiss near Shoup; zircons from the gneiss were dated by Evans and Zartman (1981a) at 1,370 Ma. A detailed description of the Yellowjacket Formation in this area was given by Lopez (1981).

A large north-trending dike in the vicinity of Gibbonsville was described by Lincoln (1912) and Umpleby (1913b). It appears to be a Tertiary diorite, probably similar to Tertiary diorite that is common in the Challis quadrangle.

The trans-Challis fault system crosses the area, as do northwest-trending Basin-Range structures of eastern Idaho. As shown on the Dillon $1° \times 2°$ geologic map (Ruppel and others, 1983), closely spaced north-south Tertiary faults also transect the area (Ruppel, 1981). According to Bacon (1905) and Umpleby (1913b), these faults offset veins in the mines. In spite of the complex faulting, the veins in the district trend east-west and contain a simple mineralogy of quartz, auriferous pyrite, pyrite, and free gold. The mineralogy is typical of epithermal veins associated with the trans-Challis fault system.

### Characteristics of the Deposits

The best description of veins at the ADM&R mines was given by Umpleby (1913b, p. 132):

> Six or seven veins have been encountered in the mine [ADM&R], all of them striking east and west, and all except the Eckhart dipping 50–85° N. These veins are thin, tabular bodies and present a marked variation in the thickness from place to place, both along the strike and dip. The larger ones average perhaps 12 inches in width. The better ore occurs in shoots, which pitch east at about the angle of the inclosing rock. As a rule, the ores are higher grade where the inclosing rock is black slate, and comparatively lean where it is quartzite or diorite.
>
> The outcrops of the veins usually have little or no topographic expression. Heavy iron and some manganese stains are everywhere present in them, and in places a short distance below the surface, the vein material is in an earthy mass of manganiferous hematite. The upper 10 to 50 feet is much poorer than the next 100 feet or so, and at 150 to 200 feet primary ore is reached.
>
> The primary ore consists of pyrite, with a few crystals of chalcopyrite, in a silica gangue rarely including a little calcite. The pyrite appears as cubes, as fine-grained disseminations, and as patches. In its broader distribution, the ore occurs in shoots which vary in length from 25 to 300 feet, and within the shoots pyrite has a rather even general distribution, although in detail such as is seen in the hand specimen, a bunchy arrangement is pronounced.

Umpleby (1913b) also noted that oxidation in a few places extends to depths below 50 m but is less in many other places.

### Molybdenum-copper Deposits

The northeast end of the trans-Challis fault system in Idaho contains several molybdenum or molybdenum-copper occurrences that are probably related to the fault system and associated Tertiary igneous intrusive rock. Most of the mineral deposits were discovered within the period 1965–1985.

Molybdenum is mentioned as a resource in Lemhi County, Idaho, in several State Mine Inspector reports, dating to the early 1920's, but the first mention of molybdenum in the part of the county under discussion is in an unpublished report of 1931 by the Owl Mining Company to the State Mine Inspector. Among several mining claims listed as being located west of Shoup (fig. B11) was one called the Molybdenum lode. Little is known about these claims. They are probably related to the plutonic suite of Painted Rocks of Tertiary age mapped north of Shoup (Lund and others, 1983).

The best known molybdenum-copper deposit is the Bobcat Gulch porphyry system (fig. B11), which is about 30 km north of Salmon and was explored by Cominco American, Inc. Bunning and Burnet (1981) described the deposit, noting that mineralization was related to two intrusive centers in which the sequence of intrusion was quartz diorite–granodiorite–quartz latite. The quartz latite is the most heavily mineralized, although the granodiorite also is mineralized and altered locally. Molybdenite but no chalcopyrite is present in quartz veinlets cutting rhyolite porphyry dikes, and molybdenite-pyrite but no chalcopyrite is present in the quartz diorite porphyry. Molybdenite and chalcopyrite are present in quartz latite and granodiorite porphyry, which suggests that the minerals have been introduced during separate mineralizing events. One of the latite dikes was dated at 48.5 Ma (whole rock $^{40}Ar/^{39}Ar$), and biotite from the dike was dated at 49.1 Ma (K-Ar method) (Bunning and Burnet, 1981). Clusters of the quartz latite dikes are exposed at the deposit, and quartz veins in these dikes contain molybdenum. The dikes and plutons trend northwest, although the deposit is on line with the Panther Creek fault. Bunning and Burnet (1981) noted that northwest structures in the area probably predate Eocene intrusion.

Bennett (1977) reported anomalous molybdenum in soil and stream-sediment samples from a locality northwest of Leesburg (fig. B11). In 1979, the Anaconda

Copper Co. followed up on this study (Hillisland, 1981) and examined (without locating molybdenum ore) a 1,672,000 $m^2$ part of the area where soil samples contain concentrations of 10 ppm or greater Mo. Numerous quartz veins but no igneous rocks crop out in the area. More work will be necessary to determine the source of the molybdenum anomaly.

Molybdenite and ferrimolybdite occur in a deposit of quartz veinlets that cut augen gneiss in the Spring Creek area, north of Shoup (fig. B11) and near the Idaho-Montana border. According to King (1964), samples of the mineralized material contained 0.12 to 1.27 percent Mo. The deposit was drilled by Brenda Mining Company during the period 1978–1980 and two adits were driven, but no further work is known to have been done at the property.

## DISCUSSION

The trans-Challis fault system consists of northeast-trending subparallel, high-angle faults, aligned grabens, and roughly aligned intrusive rocks of Tertiary age. It extends at least 270 km across central Idaho and appears to be a broad zone of crustal extension within which faulting has been active since Precambrian time. Evidence gleaned from a literature review and from our field work indicates that most, if not all, of the gold-silver deposits within the system or adjacent to it are genetically related to the faults and to various intrusive rocks of Tertiary age, the emplacement of which has been guided by the faults. Throughout the faulted area, mineralized veins extend along the northeast-trending faults, although locally veins strike in other directions, following fractures established by fault movement within the system. Many veins follow along the walls of dikes, particularly rhyolite dikes, but some veins cut the dikes and clearly are younger. Other dikes cut the veins, which suggests a close vein-dike relationship. Potassium-argon ages of biotite and hornblende from Tertiary plutonic rocks along the fault system range from about 45 to 48 Ma. Younger dikes cut the plutonic rocks, and mineralized veins in the dikes therefore are known to be even younger. To date, we have been unable to satisfactorily establish the age of gold-silver mineralization. The fact that it was of Tertiary age, however, is proven by field relationships and documented by available radiometric ages. Zircon from hydrothermally altered intrusive rhyolite at the Golden Sunbeam mine yielded a fission-track age of about 46 Ma, and sericite from the General Custer vein yielded K-Ar ages of about 44–48 Ma. A fission-track age of zircon from a rhyolite dike at the Little Falls molybdenum deposit is about 29 Ma. Veinlets of molybdenite cut a rhyolite dike at the Little Falls deposit and gold-silver veins at the Golden Sunbeam mine cut altered rhyolite. Sericite from the General Custer vein could be the same age as the vein, but if it originated from the andesitic host rock it could be older.

Hydrothermal alteration of the wall rock adjacent to veins is common along the trans-Challis fault system. Moderately argillized and sericitized rock extends to several meters away from vein walls in Boise Basin, but intensely propylitized zones range from hundreds to thousands of meters in length and width in the Yankee Fork district. Silicification and argillization were more intense near faults and mineralized veins within the propylitized zones than elsewhere. Tertiary plutonic rocks and hypabyssal rocks both are altered near mineralized deposits. Tertiary hydrothermal alteration was extensive in the central part of Idaho and appears to have been directly related to Tertiary plutonism. Criss and Taylor (1983) called attention to widespread hydrothermal alteration around Tertiary plutonic bodies, and field evidence suggests that even more intensive alteration occurred in shattered and permeable rocks along fault zones. The widespread alteration that took place where veins are absent in the Yankee Fork district, and the fact that gold-silver veins in the Boise Basin tend to pinch out in intensely altered and impermeable rocks, suggest that alteration preceded or was contemporaneous with development of ore shoots in veins. Extensive fracturing along the trans-Challis fault system, however, provided access for hydrothermal solutions associated with Tertiary plutonism, which carried mineral components that formed the mineral deposits.

Gold-silver veins along the trans-Challis fault system are epithermal in type, as indicated by the mineralogy of the deposits. The principal ore mineral in most of the gold deposits is auriferous pyrite or native gold, whereas complex suites of silver sulfides with accompanying minor amounts of base metals are more common in others. Quartz is the common gangue mineral, mostly cryptocrystalline to fine grained and banded with fine-grained sulfides. Drusy and comb-textured quartz also is common. The youngest quartz in brecciated vein-quartz sequences is more abundant than older quartz and tends to be more auriferous. Other gangue minerals in the veins, including adularia, also typify epithermal deposits. The ore shoots appear to have been richer near the surface and did not extend to great depths. Most ore shoots have been mined within 200 m of the surface. The presence of extensive placer deposits downstream from known lode deposits indicates that large portions of the epithermal ore shoots have been removed by erosion. Some areas, however, appear to have a good potential for large-tonnage, low-grade gold-silver deposits.

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## APPENDIX—1989 UPDATE

Terrane of the trans-Challis fault system, from the Boise Basin to Gibbonsville, underwent intensive mineral exploration in 1989, and in immediately prior years.

In the northeast part, Meridian Gold Co. and Canyon Resources announced, in 1988, the discovery of the Beartrack deposit northeast of Leesburg. The deposit is in the area of the Gold Dust, Gold Flint, and Gold Ridge mines (fig. B11), and is the largest gold discovery ever made in Idaho. It is reported to contain 2.6 million oz of gold. Plans are to mine the deposit by open-pit methods and to process the ore by the heap-leach technique. In the vicinity of the nearby Haidee mine, major exploration by B.P. Minerals and American Gold Resources was underway in 1989. Tenneco Minerals drilled the Ulysses and Kittie Burton mines in 1986 and further exploration at the mines was planned by Noranda Co. for 1989. About 6,000 tons of ore was mined from the Yellowjacket mine in 1988 and intensive exploration for bulk-minable precious metal ore was planned for the mine in 1989. Renewed exploratory interest in the northeast part of the trans-Challis terrane was reflected by the 5,358 mining claims staked in Lemhi County in 1988.

In the central part, gold mining was resumed at the Valley View mine (fig B11) in 1986. At the Golden Sunbeam mine, Geodome Resources Ltd. was investigating, in 1989, a deposit reported to contain 3.3 million tons of near-surface material that averaged 0.077 oz Au/ton.

# Geologic Setting and Potential Exploration Guides for Gold Deposits, Black Hills, South Dakota

*By* Jack A. Redden[1] *and* Gregory McN. French[2]

## Abstract

The core of the Black Hills is underlain by Early Proterozoic metasedimentary rocks deposited unconformably on Archean basement. Most of the core is dominated by deep-water marine turbidite deposits and minor tholeiitic volcanic rocks (Early Proterozoic, ≈2.0–1.8 Ga), although shallow-water marine shelf quartzite is abundant along the eastern margin. In contrast, the Nemo area in the northeastern part of the core differs from the remainder of the Black Hills because it is characterized by mostly marine fanglomerate, and minor quartzite, arkose, carbonate rocks, and fluvial deposits of Early Proterozoic age (≈2.4–2.1 Ga) which were deposited in a long-lived rift basin. Late Archean (>2.5 Ga) and Early Proterozoic (≈2.4–2.2 Ga) iron-formations in the Nemo area are typically oxide facies, but Early Proterozoic (≈2.0–1.8 Ga) gold-bearing iron-formation units are predominantly carbonate-silicate facies and may be associated with volcaniclastic rocks or tuffaceous metasedimentary rocks.

Early Proterozoic metasedimentary rocks in the central Black Hills were folded ($F_1$) along east-northeast axes and strongly refolded ($F_2$) along north-northwest axes and regionally metamorphosed. The 1.7 Ga Harney Peak Granite and associated pegmatite bodies in the southern Black Hills were emplaced in a major dome which modified earlier structures. Phanerozoic rocks which covered the area were uplifted, along with the basement, to form the present Black Hills during Laramide time.

Gold deposits in Proterozoic rocks include (1) stratabound syngenetic Homestake-type; (2) gold-quartz veins; (3) fault-controlled deposits; and (4) fossil placers. Of these, the Homestake-type is by far the most productive, and is believed to have formed during the deposition of carbonate-silicate-sulfide-facies iron-formation by hot springs in small, shallow, probably fault-bounded basins. The deposits have been modified subsequently to a minor degree by deformation and regional metamorphism.

Phanerozoic gold deposit types include (1) replacement deposits in lower Paleozoic rocks, (2) disseminated and vein deposits in Tertiary igneous rocks in the northern Black Hills, and (3) placer deposits in Cambrian, Tertiary, and Holocene strata.

Of all the various types of deposits, the Homestake-type, the Tertiary replacement deposits in Paleozoic rocks, and the vein and disseminated deposits in Tertiary igneous rocks have much gold resource potential. Lenses and units of iron-formation similar to that at the Homestake mine are abundant in the Rochford and Keystone districts where small gold deposits were mined in the past. Iron-formation units in the Rochford district are apparently younger (1.88 vs. ≈2.0 Ga) than the Homestake Formation, however. Absolute ages of iron-formation units in the Keystone district are unknown, but most gold deposits are unlike the Homestake-type: in the Keystone district they are localized in fault-controlled breccia that cuts iron-formation and other rock types. Gold may have been remobilized, at least in part, from iron-formation.

Replacement deposits in Phanerozoic rocks are limited to areas of Tertiary igneous rocks in the Lead-Deadwood dome and are largely in the basal part of the Cambrian Deadwood Formation. Structure contours on the Proterozoic unconformity indicate that the Lead-Deadwood dome was formed by emplacement of Tertiary sills and dikes in the basement and in Paleozoic strata; minor structural highs represent paleotopographic hills underlain by Proterozoic quartzite, predominantly the Ellison Formation. Isopachs on the lower sandstone-conglomerate part of the Deadwood suggest a strong control of thickness by paleotopography; gold deposits are concentrated in areas where the basal Deadwood is anomalously thin. A combination of lithologic and alteration changes, along with fracturing related to both paleotopographic highs and emplacement of Tertiary rocks, is believed to have been important in localizing the gold deposits.

The basal part of the Deadwood Formation is derived largely from the locally underlying Proterozoic rocks; heavy-mineral suites suggest only minor transport of detrital grains from west to east. The Deadwood is therefore a good geochemical indicator of the underlying rocks and should be

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a significant indicator of underlying or nearby gold deposits in Proterozoic rocks.

Disseminated gold deposits in Tertiary igneous rocks are localized in breccias and fractured stockworks. Alteration mineral assemblages, including argillic, sericitic, and potassic types, locally may be accompanied by quartz, fluorite, and barite. Pyrite is the most common sulfide but sparse amounts of arsenopyrite, pyrrhotite, and magnetite are locally present. Limited salinity and temperature data on fluid inclusions plus isotope data suggest that dominantly magmatic fluids were involved in the disseminated mineralizations, although the source of the metals and relationship of the fluids to specific igneous rock types are not known. Areas of extended igneous activity seem to have been favored for mineralization, but such areas require detailed mapping and exploration to outline mineralized deposits.

## INTRODUCTION

The Black Hills area has produced gold for more than 100 years, much of it being derived from the world-class Homestake gold deposit, which is in Proterozoic rocks exposed in the small Lead-Deadwood dome at the northern end of the core of the Black Hills uplift (fig. B13). Smaller gold deposits in Paleozoic rocks and in Tertiary intrusive rocks also occur throughout the Lead-Deadwood dome. Outside this dome area, small lode deposits in Proterozoic rocks of the main uplift have had sparse production. Gold has also been produced from placer deposits in basal Cambrian rocks, in Tertiary gravel deposits, and in Quaternary gravels, as well as from the lode deposits. The richest placers, however, also were in the Lead-Deadwood area and derived their gold from both lode and older placers. The Lead-Deadwood area is clearly the major focus for gold production and exploration in the Black Hills.

This overview of the geologic setting of the different gold-deposit types in the northern Black Hills presents new data on relationships between the Phanerozoic gold deposits and depositional environments of Phanerozoic host rocks. We also interpret some Proterozoic structural features, correlations of lithologic units, and depositional environments, such that the new data and interpretations may be of use in exploration for new deposits. Work in progress by S.W. Caddey and others and a paper by Norton (1989) describe the geology of the Homestake deposit and Tertiary mineralization in the Bald Mountain area, respectively, and provide more details of gold mineralization in these major deposits.

Gold was discovered along French Creek in the southern Black Hills in 1874 by members of General George A. Custer's expedition. Much richer gold placers were discovered in the Lead area in 1875, and the first lode claims were located shortly thereafter on what ultimately became part of the Homestake deposit. By 1877, gold deposits in the basal Cambrian strata near Tertiary intrusive rocks were recognized in the Lead-Deadwood area. These deposits, Tertiary in age, included not only gold but also silver, lead, zinc, and tungsten, although the value of these latter metals was insignificant relative to that of gold. In the late 1880's dozens of mines were in operation in the Lead-Deadwood area.

Production of gold from the Homestake deposit to 1988 totals more than 36 million troy oz, which far surpasses that from the other Black Hills deposits. The deposits of Tertiary age (as summarized by Norton, 1974) produced approximately 2.7 million oz excluding placer gold. Production from other deposits in the main Black Hills uplift is about 200,000 oz. Another 150,000 oz of gold was produced from unidentified sources (Norton, 1974).

## PRECAMBRIAN ROCKS

The Black Hills consist of two areas of largely granitic rocks surrounded by a terrane of metamorphic rocks, all of Precambrian age. The metamorphic terrane is dominated by metamorphosed equivalents of Early Proterozoic deep-water turbidite deposits, but it includes also significant amounts of metamorphosed shale, black shale, shelf quartzite, and greenstone, and lesser amounts of other rock types. The oldest Early Proterozoic rocks, near Nemo, were deposited in a shallow marine rift environment and are dominated by coarse clastic sediments that also include some fluvial deposits. Small metamorphosed intrusive bodies of gabbro of several ages are relatively widespread. In the southern Black Hills the Harney Peak Granite and associated pegmatite deposits ($\approx$1.7 Ga) represent the youngest known Precambrian rocks. In the following sections, sedimentary protoliths will be used in the description of the metamorphic rock units wherever these protoliths are clearly recognizable.

### Archean Rocks

Late Archean rocks (unit Wos; fig. B13) intruded by $\approx$2.5 Ga granite (unit Wgr) (Ratté, 1986) are present in the center of a small dome at Bear Mountain along the west side of the Precambrian core and in the Little Elk Creek area (Zartman and Stern, 1967) north of Nemo (fig. B13). At Bear Mountain the country rock consists of quartzose biotite-feldspar schist probably derived from graywackes, whereas at Little Elk Creek it consists of schist and feldspathic gneiss derived from marine arkose, quartzite, and conglomerate. Adjacent thin taconite lenses at Little Elk Creek are also probably Late Archean. Schist in the isolated Tinton area (fig. B13) does not resemble most of the Proterozoic rocks in the central Black Hills and is shown as Late Archean(?) although it may be Early Proterozoic.

## Proterozoic Rocks

The oldest Early Proterozoic metasedimentary rocks (unit Xcq) in the Black Hills are in the Nemo area and have been described by Redden (1981). The low-metamorphic-grade protoliths consist largely of marine fanglomerate, quartzite, and an overlying oxide-facies banded iron-formation. A tongue of pyritiferous fluvial conglomerate, grit, and quartzite within the unit contains anomalous concentrations of uranium and small amounts of placer gold. The fanglomerate and associated rocks contain clasts of older, presumably Archean oxide-facies taconite. These coarse clastic sedimentary rocks almost certainly were deposited in a rift environment. A gabbroic, gravity-differentiated layered sill (unit Xlg) that intrudes unit Xcq is 2.17±0.1 Ga (U-Th-Pb zircon date, Z.E. Peterman, written commun., 1986). Thus unit Xcq was deposited between 2.5 and 2.17 Ga, the age interval of the Little Elk Granite. Because the fanglomerate contains clasts of taconite that have been refolded prior to formation of the clasts, and clasts of other rocks similar to those exposed in the Little Elk Creek area, it is inferred to have been deposited unconformably on the Archean units Wes and Wgr (table B4).

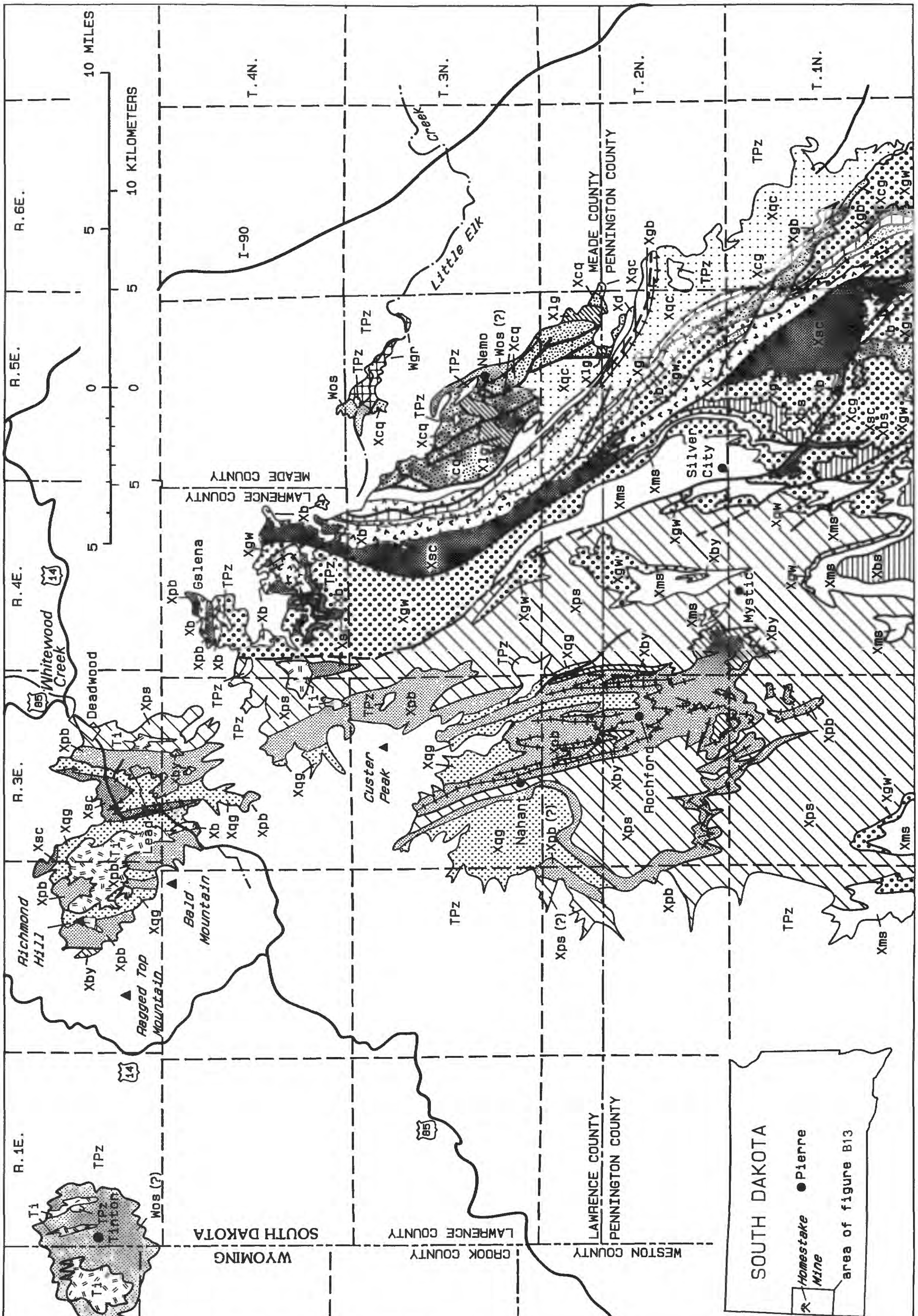
These oldest Early Proterozoic rocks were folded and faulted, and an angular unconformity developed above listric fault blocks which were then covered by marine fanglomerate, quartzite, and arkose of the Estes Formation (unit Xqc) in the Nemo area. Younger shallow-water carbonate deposits (unit Xd) containing clastic terrigenous debris overlie the Estes Formation and are in turn apparently conformably overlain by amygdule-bearing pillow basalt (unit Xb) about 6 km northwest of Nemo. The Nemo section, including units Xcq, Xlg, Xqc, Xd, and Xb, constitutes a typical shallow-water rift-related sequence.

An inferred fault separates the rocks of the Nemo section from those of the central Black Hills basin. The fault is bordered on the west by an unnamed magnetite-rich carbonate-silicate facies iron-formation that is believed to be the lateral equivalent of the oxide-facies Benchmark Iron-formation (included in unit Xcq) in the Nemo area. The Benchmark Iron-formation is the youngest unit exposed below the angular unconformity at the base of the Estes Formation. The unnamed iron-formation is unconformably overlapped by shallow-water shelf quartzite, arkose, silty shale, and local conglomerate which Bayley (1972a, 1972b) named the Buck Mountain Quartzite. The Buck Mountain Quartzite (Xqc) is therefore considered to be equivalent to the Estes Formation, and it is believed to underlie a large, but poorly known area of high-grade metamorphic rocks in the southeastern Black Hills that consists largely of quartzite and sillimanite schists. A gabbroic sill which intrudes unit Xd has been dated at ≈1.97 Ga (Z.E. Peterman, written commun., 1986). If the inferred correlations are correct, this age would represent the minimum age of the Xqc unit shown on figure B13.

At Bear Mountain the unit that is probably equivalent to these Estes-age metasedimentary rocks consists largely of quartzite and arkose (unit Xqc) which unconformably overlie the Archean rocks and fine upwards into a thin carbonate and shale section (unit Xd). These rocks are metamorphosed to various types of schists and marbles.

The shallow-water shelf quartzite (unit Xqc) is overlain by deeper water deposits of the basin in which the Black Hills Proterozoic rocks were deposited. Amygdule-free tholeiitic basalt (unit Xb) forms north-northwest-trending, narrow greenstone fold- and fault-bounded belts along the eastern part of the central Black Hills. Individual flows interfinger with black shale (unit Xsc) to the west, suggesting that the main center of basaltic volcanism was to the northeast. The basalt belts are characterized by interflow units of pyritic graphitic shale and local lenses of massive chert and carbonate-silicate-facies iron-formation. No age determinations have been possible on the basalt, but it is younger than unit Xqc.

In the southwestern and east-central parts of the central Black Hills basin, the sedimentary section is dominated by deep-water turbidite deposits (unit Xgw) characterized by proximal and medial graywacke fans. Proximal graywacke fan deposits are metamorphosed to quartzose schists, whereas more distal deposits contain various metamorphic minerals such as garnet, staurolite, or sillimanite depending on metamorphic grade. Although the detailed delineation and correlation of these fans are not everywhere clear, at least three separate units of graywacke are separated by shale (unit Xbs) and a heterogeneous unit consisting of conglomerate, debris flows, quartzite, shale, basalt, gabbroic sills, and lenses of massive chert and carbonate-silicate-facies iron-formation (unit Xcg). The shale is dominantly garnet phyllite or schist whereas the heterogeneous unit consists of a variety of metamorphic rocks, including recrystallized chert and cummingtonite-grunerite rock derived from the carbonate-silicate-facies iron-formation (larger units shown as Xif). Some of the conglomerate in unit Xcg is in part derived from the shelf quartzite (unit Xqc) to the east. In the Keystone area and west of Rockerville, unit Xcg is associated with tholeiitic pillow basalt (unit Xby), and basaltic fragments occur within debris flows. Thus, a volcanic center was located in the area west of or near Rockerville. Characteristic lithologies of unit Xcg ultimately pinch out in a general westerly direction where the heterogeneous unit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T.1N.
I-90
Little Elk
Creek
Whitewood Creek
Deadwood
Lead
Galena
Nemo
Silver City
Mystic
Rochford
Nahant
Tinton
Richmond Hill
Ragged Top Mountain
Bald Mountain
Custer Peak
MEADE COUNTY
LAWRENCE COUNTY
PENNINGTON COUNTY
CROOK COUNTY
WESTON COUNTY
SOUTH DAKOTA
WYOMING
Homestake Mine
Pierre
area of figure B13

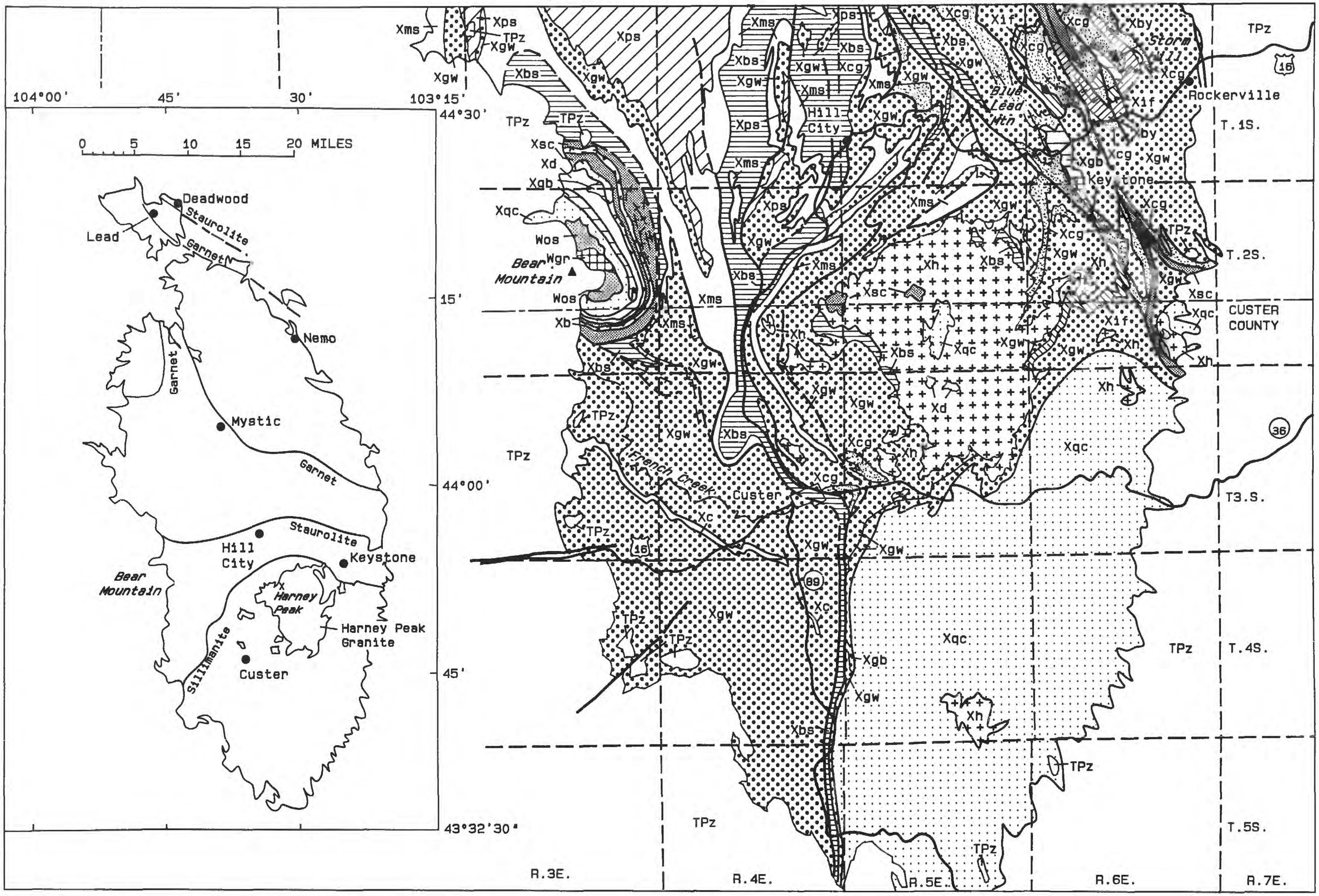



**Figure B13.** Generalized geology of Precambrian rocks in the Black Hills, South Dakota. Explanation on following page.

## DESCRIPTION OF MAP UNITS, FIGURE B13
(For correlation of map units see table B4)

**Ti** Tertiary igneous rocks--Shown only intruding Precambrian rocks

**TPz** Phanerozoic rocks

### EARLY PROTEROZOIC ROCKS

**Xh** Harney Peak Granite--Coarse-grained to pegmatitic muscovite granite and pegmatite

**Xps** Phyllite and slate; mica schist in Lead area--Includes the Grizzly Formation (Dodge, 1942), Swede Gulch Formation (Bayley, 1972c), part of the Oreville Formation (Ratte and Wayland, 1969), and a large area of rocks in the core of the Black Hills

**Xc** Biotite schist, calc-silicate gneiss, and amphibolite--Includes Crow Formation (Redden, 1963) southwest of Custer

**Xgb** Metagabbro; sills and dikes of amphibolite or greenstone--At least two seperate ages ( 1,944 Ma and 1,883 Ma) known

**Xpb** Phyllite and biotite schist--Contains minor chert and amphibole-bearing rocks; locally intruded by thin sills of metagabbro. Includes Poverty Gulch Slate, Nahant Schist, and Irish Gulch Slate in the Rochford area (Bayley, 1972c) and Northwestern and Flag Rock Formations in Lead area (Hosted and Wright, 1923)

**Xms** Muscovite schist and phyllite--Includes part of the Oreville Formation; equivalent to Xpb unit in Rochford and Lead areas

**Xqg** Quartzite, metagraywacke, and siliceous schist--Includes Ellison Formation in the Lead area (Hosted and Wright, 1923), Moonshine Gulch Quartzite north of Rochford (Bayley, 1972c), and siliceous graywacke west of Rochford. Possibly equivalent to part of Xgw and Xcg units in central Black Hills

**Xbs** Biotite schist or phyllite--Thin-bedded and commonly garnet-rich schist; largely parts of the Oreville Formation (Ratte and Wayland, 1969, Ratte, 1986), but includes units east of the Grand Junction fault in the Berne quadrangle (Redden, 1968)

**Xcg** Conglomeratic biotite schist and phyllite--Also siliceous biotite phyllite, garnetiferous schist, quartzite, and carbonate-silicate-facies iron-formation

**Xby** Metabasalt near Rockerville--Includes metabasalt in Rochford, Lead, and Rockerville areas. Believed to be younger than Xb unit but locally may be equivalent in age

**Xgw** Metagraywacke; siliceous mica schist and impure quartzite at repeated stratigraphic intervals--Includes part of Roubaix Formation (Bayley, 1972b), Mayo and Bugtown Formations (Redden, 1968), and members of the Oreville Formation as well as unnamed units in the central Black Hills

**Xb** Metabasalt; amphibolite, greenstone, and actinolite schist--Included are Hay Creek Greenstone (Bayley, 1972c) and part of the Vanderlehr Formation (Redden, 1968)

**Xif** Iron-formation--Iron-formation, ferruginous chert, and minor mica schist; included are Homestake Formation (Hosted and Wright, 1923), Rochford Formation and Montana Mine Formation (Bayley, 1972c), and iron-formation in the Keystone area and in minor areas throughout the Proterozoic core of the Black Hills

**Xsc** Siliceous biotite phyllite, calcareous biotite phyllite, and schist--Includes the Poorman Formation (Hosted and Wright, 1923) and the Reausaw Slate (Bayley, 1972b), which intertongues with metabasalt (Xb)

**Xd** Dolomitic marble and schist; marble, phyllite, and calcareous phyllite--Includes the Roberts Draw Formation in the Nemo area (Redden, 1981) and part of the Vanderlehr Formation at Bear Mountain

**Xqc** Metaquartzite and metaconglomerate; conglomeratic, siliceous schist, feldspathic schist, and minor marble--In the Nemo area, map unit includes taconite conglomerate and is equivalent to the Estes Formation (Redden, 1981); in the eastern and southeastern part of the Black Hills, includes the Buck Mountain Quartzite (Redden, 1981) and Gingrass Draw Slate (Bayley, 1972b) and the extensive quartzite southeast of the Harney Peak Granite; in the Bear Mountain area, includes lower part of the Vanderlehr Formation (Redden, 1968; Ratte, 1986)

UNCONFORMITY

**Xlg** Layered metagabbro--Gravity-differentiated Blue Draw Metagrabbro sill (Redden, 1981)

**Xcq** Metaconglomerate and quartzite; conglomerate and feldspathic schist, biotite schist, taconite, and phyllite--Includes the Boxelder Creek Formation and Benchmark Iron-formation (Redden, 1981)

UNCONFORMITY

### LATE ARCHEAN ROCKS

**Wgr** Granite and gneissic granite--Includes the Little Elk Granite and granite of Bear Mountain

**Wos** Older metasedimentary rocks; dominantly quartz-feldspar-biotite schist--Includes Nemo Iron-Formation (Redden, 1981); schist in Tinton area is Archean (?)

Contact--Dashed where approximately located

Fault--Dashed where approximately located

Garnet Metamorphic isograd (shown in inset) gradually changes to graywacke and loses its identity as a mappable unit. The uppermost turbidite deposits of unit Xgw also pinch out to the west more or less at the longitude of Mystic, thus indicating that the deep part of the basin lay to the east.

A distinctive laminated, mica-rich, typically magnetite- and ilmenite-bearing phyllite-schist (unit Xms), believed to be derived from reworked and altered tuff, is widespread in the west-central part of the uplift. To the east it is overlain by the uppermost turbidite tongue of unit Xgw, but farther east and also to the north it is diluted by turbidite deposits and loses its distinctive characteristics. Similarly, in the Rochford district the tuff unit probably is generally equivalent to a sequence of heterogeneous rocks characterized locally by tholeiitic pillow basalt, volcaniclastic rocks, biotite-rich impure tuffaceous rocks, and carbonate-silicate-facies iron-formation (unit Xpb). Bayley (1972c) divided these rocks in the Rochford district into five separate formations (table B4). He included four of these formations (including two carbonate-silicate-facies iron-formations) in the Flag Rock Group, which he believed was equivalent to the Flag Rock Formation at Lead (Hosted and Wright, 1923; Noble and Harder, 1948). Although additional mapping suggests that these subdivisions may not all be tenable, the general rock types are shown extending toward the Lead area from Rochford in figure B13. In the immediate Rochford area these rocks contain minor coarse angular volcaniclastic material indicative of a localized volcanic center. Alkalic ash-fall tuff that is interbedded with carbonate facies iron-formation at the Montana mine 4 km north-northwest of Rochford is dated at 1.88±0.03 Ga (U-Th-Pb zircon date, Z.E. Peterman, written commun., 1985). The uppermost part of the turbidite section in the central Black Hills is believed to be of this general age.

Below these volcanic-related rocks of the Rochford area is a unit of shallow-water quartzite which Bayley (1972a, 1972c) considered to be equivalent to the Ellison Formation in the Lead area. Weissenborn (1987), however, indicated that this quartzite is also probably equivalent to quartzose graywacke northwest of Rochford that Bayley considered to be part of the younger Swede Gulch Formation. Lateral facies changes in the quartzite in the Rochford area indicate that depositional conditions changed from deeper water west of Rochford to shallower water to the east and in the Lead area. Tuffaceous sedimentary rock within the Ellison Formation is 1.97±0.01 Ga (U-Th-Pb zircon date, Z.E. Peterman, written commun., 1986); therefore the most likely age of the lower part of the turbidite section in the southeastern central Black Hills is ≈2.0 Ga. The two available ages in the Rochford and Lead areas (1.88 and 1.97 Ga) suggest that either an unconformity or a tectonic break must exist within the turbidite section. Although this break has not been identified for certain, the most likely location for an unconformity is below the heterogeneous unit Xcg in the central Black Hills. Volcanic rocks within the heterogeneous debris flow unit (unit Xcg) near Storm Hill west of Rockerville would therefore be approximately equivalent in age to the younger tuff in the Rochford area.

The youngest Precambrian metasedimentary unit consists of a thick, monotonous sequence of graphitic slate and phyllite (unit Xps) derived from shale that underlies much of the northwestern part of the central Black Hills in the area west and north of Mystic. The unit has several different formation names depending on the geographic area studied (Bayley, 1972b, 1972c; Hosted and Wright, 1923).

Small metagabbro bodies (Xgb) intrude all of the Proterozoic rock units except unit Xps. Most of the bodies consist of either greenstone or amphibolite and are too small to show in figure B13. The metagabbro bodies are probably the same ages as associated volcanic rocks and therefore range in age from about 1.87 to 1.97 Ga.

The Harney Peak Granite in the southern Black Hills is the youngest Proterozoic rock and is approximately 1.7 Ga (Rb-Sr whole rock date, Riley, 1970; U-Th-Pb monazite and zircon dates, Z.E. Peterman, written commun., 1986). Thousands of small pegmatite and granitic bodies in the country rock surround the main granitic area shown in figure B13. The granite has been petrographically and chemically described most recently by Redden and others (1982).

## Structure and Metamorphism

The structure of the Proterozoic rocks is extremely complex and not everywhere fully understood. Major structures of representative areas are described in the following section, but no attempt is made to synthesize all structural events.

In the Nemo area Redden (1981) noted that folding preceded listric faulting and the deposition of the Estes-type rocks (unit Xqc) unconformably above the oldest Early Proterozoic rocks (unit Xcq). The unconformity between units Xqc and Xcq trends easterly and dips relatively steeply to the north-northwest. Both units Xqc and Xcq are overturned to the southeast. Folds in unit Xcq plunge about 70° to the north-northwest and are essentially coaxial with younger folds which affect all rock units. These younger folds have a well-developed axial plane foliation that trends about N. 30° W. and is nearly vertical. Conglomerate clasts are flattened and rotated into this foliation plane; their longest axes plunge steeply northwest.

Major faults in the Nemo area include north-northwest-trending listric faults that developed

**Table B4.** Tentative correlation of Precambrian rock unit protoliths in various parts of the Black Hills

[Abbreviations used: ; FM, formation; QTZ, quartzite; BIF, banded iron-formation; MBR, member; lithologic symbols from figure B13]

| Bear Mountain (formation names from Ratte, 1986, and Redden, 1968) | Rochford (formation names from Bayley, 1972c) | Lead (formation names from Hosted and Wright, 1923) | Central Black Hills (formation names from Redden, 1963; Ratte and Wayland, 1969; Bayley, 1972b) | Nemo (formation names as redefined by Redden, 1981) |
|---|---|---|---|---|
| | | | HARNEY PEAK GRANITE (Xh) 1.715±3 Ma | |
| Shale (Xps) part of OREVILLE FM | SWEDE GULCH FM (Xps) shale<br>Gabbroic sills (Xgb) | GRIZZLY FM (Xps) shale | Shale (Xps)<br>Gabbroic sills (Xgb) | |
| Graywacke (Xgw) MAYO FM SW of Custer. Not present E of Bear Mt. | | | | |
| CROW FM (Xc) tuffaceous rocks | | | | |
| Graywacke (Xgw) BUGTOWN FM and ZIMMER RIDGE MBR, OREVILLE FM | | | Graywacke (Xgw) BUGTOWN FM and part of OREVILLE FM | |
| | POVERTY GULCH SLATE (Xpb) shale and chert ROCHFORD FM (Xif) carbonate-silicate BIF | | | |
| Altered tuffs (Xms) Part of OREVILLE FM | NAHANT SCHIST and RAPID CREEK GREENSTONE (Xby) basalt and black shale<br>MONTANA MINE FM (Xif) carbonate-silicate BIF 1,884 ±29 Ma<br>IRISH GULCH FM (Xpb) shale and tuff | FLAG ROCK FM (Xpb, Xby) shale, basalt, chert | Altered tuffs (Xms) Part of OREVILLE FM<br>Gabbroic sills (Xgb) 1,883 Ma | |
| Black shale and distal graywacke (Xbs) Part of OREVILLE FM | | | Graywacke (Xgw) Part of OREVILLE FM<br>Black shale and distal graywacke (Xbs) Part of OREVILLE FM<br>Graywacke (Xgw) Part of OREVILLE FM | Gabbroic sills at Bogus Jim Creek (Xgb) 1,944±15 Ma |
| | MOONSHINE GULCH QUARTZITE (Xqg) sandstone changing to graywacke toward southwest | NORTHWESTERN FM (Xpb) shale<br>ELLISON FM (Xqg) sandstone and siltstone shelf facies 1,974±8 Ma | Debris flow conglomerate to east; sandstone, carbonate-silicate BIF and basalt near Rockerville (Xcg, Xby) | |

**Table B4.** Tentative correlation of Precambrian rock unit protoliths in various parts of the Black Hills—Continued

| Bear Mountain (formation names from Ratte, 1986, and Redden, 1968) | Rochford (formation names from Bayley, 1972c) | Lead (formation names from Hosted and Wright, 1923) | Central Black Hills (formation names from Redden, 1963; Ratte and Wayland, 1969; Bayley, 1972b) | Nemo (formation names as redefined by Redden, 1981) |
|---|---|---|---|---|
| UNCONFORMITY OR FAULT | | HOMESTAKE FM (Xif) carbonate-silicate BIF | | |
| | CONCEALED | POORMAN FM (Xsc) black shale and possible basalt | LOCAL UNCONFORMITY | |
| ---FAULT--- | | CONCEALED | Graywacke (unnamed) (Xgw) | ---FAULT--- |
| UPPER PART, VANDERLEHR FM Basaltic volcaniclastic rocks (Xb), black shale with carbonate-silicate BIF (Xsc) | | | HAY CREEK GREENSTONE (Xb) pillowed basalt and lenses of carbonate-silicate BIF<br>REAUSAW SLATE (Xsc) black shale | Amygdular pillow basalt (Xb) |
| LOWER PART, VANDERLEHR FM Dolomite and shale (Xd) | | | | ROBERTS DRAW FM (Xd) dolomite and siltstone |
| LOWER PART, VANDERLEHR FM Sandstone, arkose, conglomerate (Xqc) | | | BUCK MOUNTAIN QTZ and GINGRASS DRAW SLATE (Xqc) sandstone and siltstone shelf facies | ESTES FORMATION (Xqc) fanglomerate, BIF conglomeratic sandstone, arkose and dolomite |
| ---UNCONFORMITY--- | | | ---UNCONFORMITY--- | ---UNCONFORMITY--- |
| | | | | BLUE DRAW METAGABBRO Gabbroic sills (Xlg) 2,170±110 Ma |
| | | | Carbonate-silicate BIF (Xif) | BENCHMARK IRON-FM (Xcq) oxide-facies BIF |
| | | | ---FAULT--- | BOXELDER CREEK FM (Xcq) BIF conglomerate, fanglomerate, quartzite, lithic arenite |
| | | | | ---UNCONFORMITY--- |
| Granite, pegmatite (Wgr) ca 2,500 Ma Siltstone and graywacke (Wos) | | | | LITTLE ELK GRANITE (Wgr) 2,549±11 Ma Arkose, conglomerate, quartzite, oxide BIF (NEMO IRON-FM) (Wos) |

contemporaneously with the deposition of the Estes-type rocks (unit Xqc). These faults developed sequentially from west to east (Redden, 1981). The largest known fault has a displacement of approximately 10 km, and its dip is inferred to flatten parallel to bedding at depth. Right-lateral shear which may have been contemporaneous with the younger folding produced offsets subparallel to the dominant foliation and reactivated segments of the older listric faults.

In the central Black Hills and especially in the area south of Mystic, stratigraphic repetition and graded bedding in the turbidite deposits indicate that early folds had northeast trends (fig. B14). Bedding attitudes strike predominantly northeast or northwest and dip vertically or steeply south. Outcrop patterns indicate that the early folds have been strongly refolded along north-northwest trends, with the result that the plunges of the early folds reverse abruptly over the axes of later folds. The dominance of south-plunging minor folds over wide areas indicates that early folds were isoclinally overturned to the north. In addition a third set of younger, right-lateral isoclinal folds (not shown on fig. B14) trends more northwesterly than the second set and probably was formed by a right-lateral shear couple. A similar structural pattern is evident in the Rochford area where an anchor-shaped map pattern (fig. B13) suggests that early east-trending folds were refolded along north-northwest axes. Small closed, "eyed" folds are evident on the south end of the Rochford structure (Bayley, 1972c; McMillan, 1977). Continuation of the Rochford structure to the north below Paleozoic rocks and into the Lead-Deadwood dome would suggest that the major south-plunging folds in the Homestake mine (Noble and others, 1949) are actually secondary to the original fold pattern.

Along the eastern side of the central Black Hills from south of Nemo to near Rockerville, early folds, if they existed, appear to have been completely warped into north-northwesterly trends. However, in the Keystone area ample evidence exists of the warping of earlier east(?)-trending folds along northwesterly trends. For example, unit Xcg is a doubly plunging anticline refolded into a southeast-plunging synform in an arcuate exposure extending 1–3 km west-northwest of Keystone (fig. B13).

In the southern Black Hills, these two major earlier fold trends are modified by a domal structure around the Harney Peak Granite. Adjacent to the granite on the north half of the dome, folds plunge gently to the north or northeast, but on the south side of the dome virtually all folds plunge to the south or southwest. Small, nappe-like folds having northeast trends are common on the northwest side of the dome in the Hill City area (Ratté and Wayland, 1969; fig. B13). These may be early folds, or later folds reoriented by emplacement of the granite. A smaller dome at Bear Mountain is believed to have been superposed on earlier structures and to be cored by an unexposed granite contemporaneous with the Harney Peak Granite.

Faults in the central Black Hills trend dominantly north-northwest, although earlier faults having original northeast trends have been recognized locally (figs. B13, B14). The earlier faults are subparallel to stratigraphic contacts, are folded, and probably originated as thrust faults during the earliest folding. The Grand Junction fault (Redden, 1968), which passes through Custer, dips generally to the west and has an unknown amount of displacement. The fault was deformed by the emplacement of the Harney Peak Granite and therefore is older than the granite, but breccias and local quartz veins suggest that movement along the fault probably followed closely in time with the regional metamorphism. Deflection of the fault around the Bear Mountain area supports the belief that the Bear Mountain dome is cored at depth by granite of age similar to that of the Harney Peak Granite. North of Harney Peak the largest faults are a left-lateral fault that passes through Keystone and a right-lateral fault that passes through Silver City. The apparent horizontal displacement along the fault at Silver City is several kilometers, but the fault probably also has a considerable vertical component of movement. Other faults shown in figure B13 are largely northwest trending and apparently have right-lateral displacement, or they follow contacts, making their relative displacements difficult to assess.

The Precambrian rocks have been metamorphosed to various degrees, as shown by the isograds in figure B13 (inset map). The distribution of the garnet isograd in the pelitic rocks indicates a low-grade metamorphic trough trending northwesterly across the north-central Black Hills. The garnet isograd along the northeast part of this trough passes through the Homestake mine. Staurolite at Deadwood and Galena, and the presence of inclusions of pegmatite in Tertiary laccoliths northeast of Deadwood, suggest a Harney Peak-like granite beneath the Paleozoic rocks to account for the increased metamorphic grade to the northeast. The garnet isograd also deflects around the Rochford area, where it appears to follow the superposed north-northwesterly structural trend.

Near the Harney Peak Granite the isograds are compressed and the low-sillimanite isograd coincides more or less with the north contact of the granite. Small areas of high-sillimanite grade rocks (second sillimanite isograd, not shown on fig. B13) are known adjacent to the south side of the granite north of Custer and in unit Xq or Xcq to the southeast. Near the granite, lower-pressure minerals andalusite and cordierite in aluminous schist coexist with staurolite-bearing assemblages, indicating

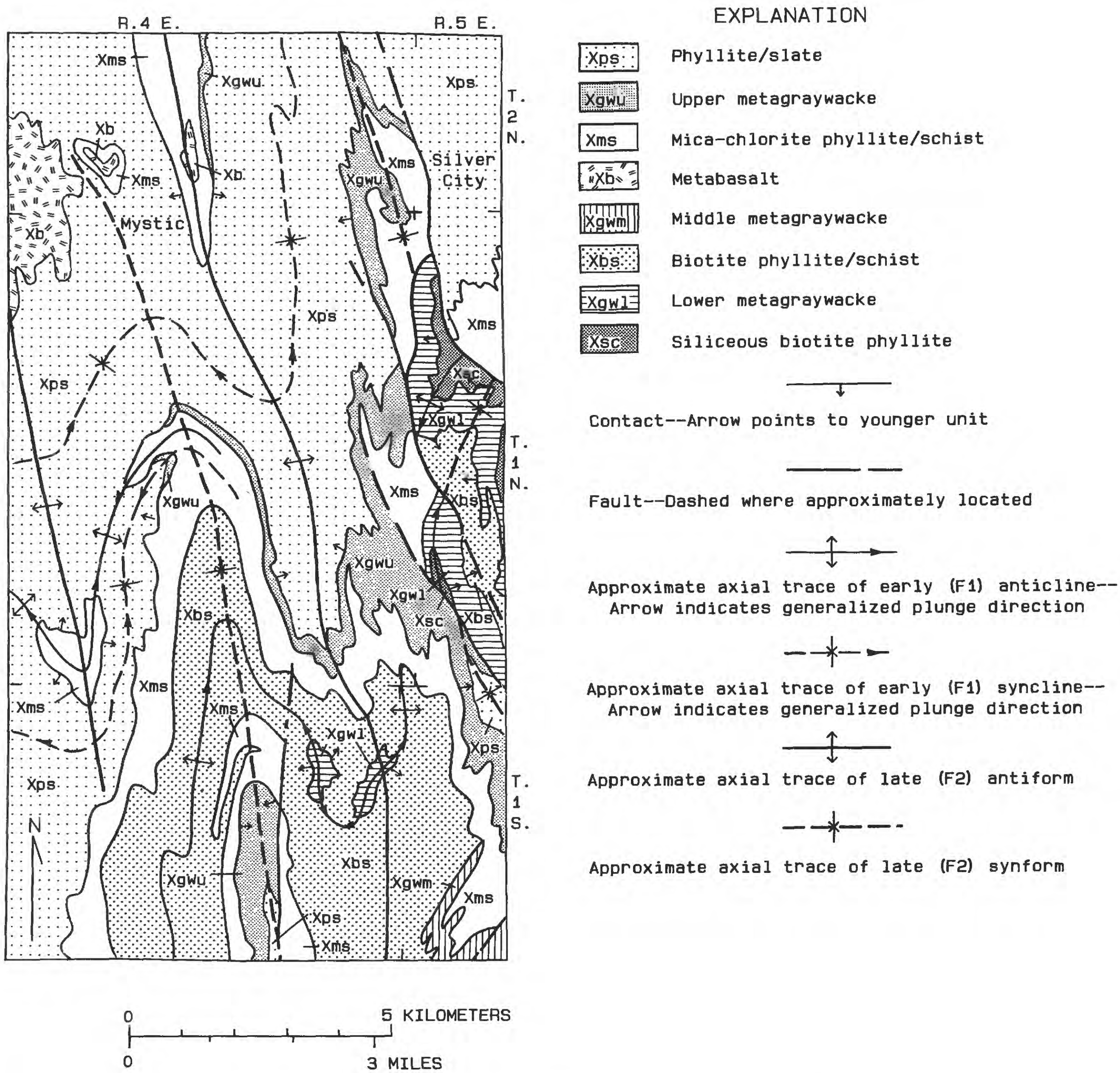



**Figure B14.** Generalized geology of Early Proterozoic rocks in part of the central Black Hills showing early and late fold axes.

pressures of about 3.5 kb at the time of crystallization of the granite (Redden and others, 1982). These and other relationships indicate the superposition of thermal metamorphism associated with the granite upon the earlier regional metamorphism.

In summary, the structural patterns of the central Black Hills indicate that early east-northeast-trending folds ($F_1$) were overprinted by widespread north-northwest-trending folds ($F_2$). $F_2$ folding was accompanied by a general low-grade metamorphism which increased in intensity to the south and developed axial-plane foliation. $F_1$ and $F_2$ folding affected the Nemo area rocks where the oldest Early Proterozoic rocks (unit Xcq) were deformed prior to $F_1$ folding in the central Black Hills. Most of the north-northwest-trending faults in the central Black Hills may have developed during the late stages of $F_2$ folding, but earlier thrust faulting was presumably associated with $F_1$ structures. Emplacement of the Harney Peak Granite caused major and minor domes which modified $F_1$ and $F_2$ structures, and produced a large relatively low-pressure metamorphic aureole in the southern Black Hills. Numerous other post-$F_2$ structural features in local areas will not be discussed in this brief summary.

# PHANEROZOIC ROCKS

## Paleozoic and Mesozoic Rocks

Paleozoic rocks are not subdivided in figure B13, and only those containing gold deposits are discussed here. The oldest Paleozoic rock unit is the Upper Cambrian Deadwood Formation, which unconformably overlies the Precambrian metamorphic rocks. The Deadwood in the northern Black Hills ranges in thickness from about 115 m near Galena (Shapiro and Gries, 1970) to about 150 m west of Lead; it is generally divided informally into lower, middle, and upper parts. The lower part consists dominantly of sandstone, which locally overlies lenses of basal conglomerate. The sandstone is as much as 35 m thick; the conglomerate rarely exceeds 12 m in thickness. Carbonate rocks are present locally in the upper part of the sandstone. The middle part of the Deadwood, about 50 m thick, consists largely of shale and fossiliferous glauconitic limestone pebble conglomerate. The upper part consists of flaggy sandstone, siltstone, pebble conglomerate, and massive red sandstone. The red sandstone is most abundant at the upper contact and contains tubular structures which may be the borings of a large worm. The regional variations of the Deadwood have been described in considerable detail by Kulik (1965), who attributed the various lithologic differences to repeated transgressions and regressions of the Cambrian sea. One of the important features, discussed in more detail in a later section on the gold deposits, is that the lower part of the Deadwood was deposited over a surface of considerable relief which markedly influenced the lithology of the lowermost units.

The only other Paleozoic unit containing gold deposits is the Mississippian Pahasapa Limestone. Gold deposits are sparse in this thick-bedded unit, which is about 170 m thick. The upper part of the Pahasapa is locally cavernous because of a karst surface that developed prior to deposition of overlying Pennsylvanian rocks. Three relatively thin lower Paleozoic formations aggregating about 50 m in thickness separate the Pahasapa from the Deadwood. These include the Ordovician Winnipeg and Whitewood Formations and the Englewood Formation of Devonian and Mississippian age. Above the Pahasapa Limestone is a nearly continuous Paleozoic and Mesozoic section that lacks known gold deposits.

## Cenozoic Rocks

### Tertiary Igneous Rocks

Tertiary igneous rocks intrude the Paleozoic and Precambrian rocks in a relatively narrow belt which crosses the northern Black Hills in a west-northwesterly direction (Redden, 1975; Lisenbee, 1981). These intrusive rocks are especially abundant in the Lead-Deadwood dome, where they are genetically related to Tertiary gold deposits (Norton, 1989), but they are scattered throughout a west-northwest-trending belt across the entire Black Hills (Lisenbee, 1981).

The intrusive rocks are largely porphyritic, and they consist of phonolite, monzonite, quartz monzonite, latite, and trachytic rhyolite of a subvolcanic-volcanic association. Rocks that tend to be undersaturated are concentrated in the northwest part of the main belt of intrusives, whereas oversaturated rocks are most common in the southeast part. In the Bear Lodge Mountains in Wyoming, the igneous rocks are predominantly alkalic, include carbonatite, and are host to large reserves of rare-earth elements (Staatz, 1983). Radiometric ages of all the different intrusive rocks range from approximately 40 to 60 Ma (summarized in Shapiro, 1971; also see Redden and others, 1983).

### White River Group

Small deposits of Oligocene gravel are relatively widespread over the central Black Hills uplift and they document the Laramide uplift and subsequent early Cenozoic erosion of the Black Hills (Darton and Paige, 1925). The deposits are largely locally derived gravel, but their persistence as remnants at elevations in valleys not far above the present drainage floor indicates that much of the Black Hills was eroded before the Oligocene to a relief not much different from that at present. For example, Darton and Paige (1925) recognized remnants of White River deposits along Whitewood Creek within the town of Lead. The White River deposits, not shown on figure B13, are nonetheless of some importance because they contain placer gold derived from older deposits; moreover, they were themselves reworked locally to form the gold-bearing Quaternary gravel which led to the discovery of the lode deposits of the Black Hills.

# TYPES OF GOLD DEPOSITS

The main types of gold deposits in the Black Hills have been recognized for a long time, but recent work on the Precambrian and Phanerozoic rocks permits better understanding of the age, setting, and formation of the deposits. Both Proterozoic and Phanerozoic deposits are recognized; these in turn are subdivided into various genetic types. Proterozoic deposits consist of (1) Homestake-type stratabound deposits, somewhat remobilized syngenetic gold associated with carbonate-silicate-sulfide-facies iron-formation; (2) gold-quartz veins such as worked by the Holy Terror mine at Keystone; (3) fault-controlled deposits such as that of the Bullion mine at Keystone; and (4) fossil placers. Phanerozoic deposits consist of (1) replacement deposits in lower Paleozoic rocks and disseminated and vein deposits in Tertiary igneous rocks such as those at Richmond Hill west of Lead and the Gilt Edge mine at Galena; and (2) placer deposits in Cambrian, Oligocene, and Quaternary rocks. Two or possibly more factors were involved in the formation of some of the deposits.

## Proterozoic Deposits

### Homestake-type

Work is in progress on the world-class Homestake deposit (S.W. Caddey and others, written commun., 1988); only salient features are mentioned here. Deposits smaller than Homestake, but of apparently similar character, are widespread in the Black Hills and are described in a general way.

The major characteristic of the Homestake deposit is its stratabound nature within a carbonate-silicate-sulfide-facies banded iron-formation (Homestake Formation). Quartz veins within the iron-formation are abundant but essentially lack gold. Gold may be enriched in the wall rock along the veins. Sulfide mineralogy of the gold-bearing rocks typically consists of pyrrhotite, pyrite, and arsenopyrite. Free gold is observable only in the richest ore. Chlorite is the most abundant alteration mineral and tends to be associated with richer ore. The host rock consists of either recrystallized chert beds and sideroplesite-rich schist below the garnet isograd or chert and cummingtonite-garnet-biotite-rich rock above the garnet isograd. Chert beds are commonly only a few centimeters thick and both lensoid and ribbonlike.

Within the Homestake deposit, the major structures are north-northwest-striking, southeast-plunging, overturned isoclinal folds. These extremely tight folds are modified by later cross folds, resulting in an exceedingly complex structure. Individual ore bodies are elongate, highly irregular podlike masses localized in apparently tectonically thickened parts of the Homestake Formation. The ore bodies also generally plunge to the southeast through distances exceeding several thousand meters, but they do not coincide with the major fold noses.

Noble (1950) discounted the idea of Precambrian-age mineralization because of the existence of Tertiary gold-bearing veins within the mine, and because he believed that forces related to the intrusion of Tertiary magmas caused some of the cross folding in the mine, and the cross folding, in turn, was thought to have localized the ore. Lead-isotope data obtained by Rye and others (1974) on galena from the mine suggested a ≈2.5 Ga source age for lead in the Homestake Formation if a 1.6 Ga age for its metamorphism is assumed. The 1.97 Ga U-Th-Pb zircon age of metasedimentary rock cited on p. B51 was obtained on a tuffaceous sample from the Ellison Formation but only a few meters from the Homestake Formation. Hence this seems to be a more likely age for the host rock and the age of the gold mineralization. Also more recent Pb isotope models would make the 2.5 Ga date closer to 2.0 Ga (E.H. DeWitt, written commun., 1987), and therefore the age of mineralization almost certainly was Proterozoic. A Proterozoic age also is consistent with that of other gold deposits in rocks of Proterozoic age in the central Black Hills in areas which show no evidence of possible Tertiary mineralization.

Stable isotope investigations by Rye and Shelton (1983) revealed distinct differences in the sulfur, carbon, and oxygen isotope ratios in the formations overlying and underlying the Homestake Formation. They also showed that all the economically recoverable gold within a mineralized horizon is in rock with a $\delta^{34}S$ range of +4.0 to +9.0 permil and that $^{13}C$ and $^{18}O$ are depleted in the gold-rich areas. Their evidence indicates that sulfide minerals were produced in a system dominated by low-temperature bacteriogenic processes and that the mineralization took place in a submarine hot spring system that vented along fracture systems.

Sulfur, carbon, and probably gold have been remobilized to some extent in the mine by regional metamorphism and formation of quartz veins (Rye and Rye, 1974; Wolfgram, 1977); Norton (1974) suggested that the coincidence of the garnet isograd with the Homestake mine may have been important in remobilization of the gold into ore bodies. This remobilization has not been documented, however, and migration distance of gold seems to have been limited to a few meters.

The model of submarine hot spring deposition in a localized tectonic basin agrees with data elsewhere in the Black Hills that show a generally consistent association of tuffaceous sediment (reflecting volcanism) interbedded with carbonate-silicate-facies banded iron-formation. Thin-sections of iron-formation from the Rochford area (iron-formation similar to that of the Homestake mine) show graphite-rich layers in an anastomosing orientation subparallel to bedding: these layers in this orientation may reflect biologic activity associated with hot springs. Elsewhere in the Black Hills massive chert lenses commonly are associated with carbonate-silicate-facies iron-formation and basaltic flows, but such are not known within the Homestake Formation. Massive chert lenses locally present in the turbidite units are believed to represent somewhat lower temperature thermal spring deposits that formed during compaction dewatering of the turbidite section. The thin carbonate-silicate-facies iron-formation units commonly associated with massive chert in the turbidite section ordinarily have a low sulfide mineral content and are essentially barren of gold.

Iron-formation very similar to the Homestake Formation is relatively abundant in the Rochford and Keystone areas where a number of small mines, including the Standby, Montana, King of the West, Bullion, and Keystone, have been developed in iron-formation. Carbonate-silicate facies predominates in these areas; amounts of sulfide-facies iron-formation are relatively small. The low sulfur content (paucity of sulfide minerals) may be a factor in explaining why no major mines have been discovered in these areas.

Studies of the gold content of Homestake-type iron-formation in the Blue Lead Mountain area north of the Keystone gold belt (Raymond, 1981; Raymond and others, 1975) and in areas to the north near Nemo (Fantone, 1983) confirm that gold is considerably enriched within the iron-formation and chert-rich rocks relative to other rock types. Fantone (1983) showed that the enrichments are considerably less than those noted in similar rocks in Australia and South Africa but comparable to those in greenstone belts in Canada. He also noted that the best minor element correlation with gold was arsenic, but even that correlation was not strong.

### Gold-Quartz Veins

The gold-quartz vein type is essentially limited to the southern Black Hills, where all known deposits are small. The Holy Terror mine at Keystone opened one of the richest veins, which has been described (Connolly, 1929; Allsman, 1940) as a massive white quartz vein with minor arsenopyrite and pyrite and abundant free gold. In some specimens, muscovite is common along the contact with wall rock. The vein was less than a meter thick at the surface but thickened to several meters at depth where the grade reportedly was considerably lower than near the surface. Other gold-quartz veins relatively near the Harney Peak Granite, such as that of the St. Elmo mine, are generally no longer accessible but are described as having relatively coarse-grained quartz and virtually no or only very small amounts of pyrite and arsenopyrite. Several quartz veins in the area west of Custer are reported to contain gold-bearing tetradymite (Allsman, 1940), but this telluride mineral has never been confirmed (W.R. Roberts, South Dakota School of Mines and Technology, written commun., 1986). Other small mines on gold-quartz veins in the southern Black Hills located farther away from the granite in areas of lower metamorphic grade are also generally not accessible, but ore samples indicate that the veins typically contain gray quartz and minor sulfide minerals. Graphite is relatively common, although not abundant, and some of the veins are bounded by tourmaline-rich wall rock. Some descriptions indicate that the adjacent schist wall rock was brecciated and gold mineralized. Virtually all the gold-quartz veins are within metamorphosed graywacke, except for a few small mines and prospects southwest of Custer in small quartz veins cutting metagabbro bodies. Northwest of Hill City, exploration workings in veins are all confined to a thin unit of graywacke which lies structurally below the unit of micaceous phyllite (unit Xms, fig. B13) and above slightly pyritiferous graphitic slate and phyllite (unit Xps). These adjacent slates and phyllite rocks have no known mines, although they underlie large areas of the central Black Hills.

That gold-quartz veins are concentrated in graywacke wall rocks in preference to other rocks suggests that the more competent graywacke was favorable for migration of the gold-bearing solutions either because of fracturing or because of original permeability. Local faulting or hydrofracturing may have been instrumental in localizing the veins, as many descriptions cite evidence of movement and minor brecciation. The source of the mineralizing fluids is not known; the fluids could have been of metamorphic origin. Some veins in the southern Black Hills are cut by granites or pegmatites, indicating an age older than that of the granite but possibly contemporaneous with or younger than the early regional metamorphism.

### Fault-controlled Deposits

Fault-controlled epigenetic gold deposits differ from the gold-quartz vein type in that they have diverse wall rocks, occur in rocks of diverse metamorphic grade, and are localized along known faults and breccia zones; however, the two types of deposits may have formed in a somewhat similar manner. The largest deposits of the fault-controlled type include the Keystone and Bullion mines in the Keystone district and other smaller, neighboring deposits localized along a major fault and subsidiary breccia zones (Connolly, 1925, 1929; Allsman, 1940). Recent detailed mineralogic and geologic studies of these deposits are not available, but examination of the available exposures indicates that gold is concentrated in breccia zones which have had repeated movement. Complexly folded chert-cummingtonite iron-formation generally borders or is cut by the mineralized zones, although the enclosing rock may be metagabbro or metabasalt and schist. All the rocks are crossed by the breccia zones which are impregnated with graphite, sericite, and chlorite, and cut by small quartz-carbonate veins. Pyrite and arsenopyrite are concentrated in the breccia and gouge. Although gold generally is in mineralized breccia and gouge, Connolly (1929) indicated that most of the gold in the Columbia mine came from a gray quartz vein which developed prior to the gouge. In most of the deposits pyrrhotite and minor arsenopyrite as well as minor amounts of gold are also concentrated in the iron-formation away from the breccia zones; pyrrhotite appears to be lacking within the breccia. Therefore sulfur appears to have been introduced along with the quartz-carbonate veins in the breccia zones. Because the most productive mines all have iron-formation closely associated with the breccia zones, gold may have been remobilized from the iron-formation and concentrated in the breccia.

At small gold mines localized along faults, northwest of Hill City and west of Custer, iron-formation is not exposed along the faults; instead, the wall rocks are metagraywacke or metamorphosed shale. Therefore, iron-formation may not be a requirement for the concentration of gold. On the other hand, all the fault-related deposits lacking iron-formation in the immediate vicinity are very small; this fact suggests the importance of associated iron-formation rock for the formation of larger deposits.

Most of the faults, and thus the age of gold mineralization, postdate regional metamorphism. The Grand Junction mine west of Custer is along a major fault, but the fault appears to have been deformed by domes associated with the Harney Peak Granite (Redden, 1968) and as such might seem to be an exception. However, local exposures of the fault have minor breccia zones, suggestive of repeated movement. The north-northwest-trending fault passing through Silver City (fig. B13) apparently localized deposits that contain gold and silver-sulfosalt minerals (Larson, 1971). Because these deposits are in an area of low metamorphic grade, the fault-controlled mineralization may have caused a broad regional zonation of antimony and silver at lower metamorphic grades; deposition of gold took place only at higher metamorphic grades.

Kulp and others (1956), in contrast, obtained a much younger (400 Ma) model lead date for galena from the Spokane lead-zinc mine southeast of Keystone. They commented that the age indicated Tertiary mineralization. The lead-zinc vein follows a fault zone which cuts granite/pegmatite, and the age of the galena clearly indicates that the mineralization was not Precambrian but probably Laramide. Obviously, additional isotope work is needed on the fault-related deposits to better establish the ages and depositional conditions.

### Placer Deposits

Proterozoic placer gold is limited to the Nemo area, where it is present in individual beds of pyritic, uraniferous, fluvial conglomerate (Redden, 1980, 1981; Kim, 1979) of unit Xcq. The conglomerate is interbedded with coarse-grained quartzite and grit, and generally individual beds are only a few meters thick. The total thickness of conglomerate may be several tens of meters within a total section of 50–150 m. Individual conglomerate beds intertongue laterally with the associated quartzite in a fashion typical of a braided stream environment.

Although the rocks are metamorphosed, detrital gold particles have been identified, along with detrital chromite, zircon, and numerous other heavy minerals. Much of the pyrite is euhedral, and original titaniferous minerals have altered to sieve aggregates of euhedral rutile, quartz, and pyrite thereby indicating the introduction of sulfur. Gold is generally concentrated in zones of increased radioactivity which correspond to either the base or the upper part of an individual conglomerate bed. The gold content is subeconomic, and short channel samples, up to a meter in length, contain a maximum of only 2 to 3 ppm Au. Most samples contain less than 1 ppm Au. The only known former mine in the conglomerate is the Lucky Strike, located about 6 km northwest of Nemo, which reportedly had an 80-m-deep shaft and several drifts. Although a mill was built on the property, no production records are available.

## Phanerozoic Deposits

### Replacement Deposits in Lower Paleozoic Rocks

These deposits are restricted to the area of Tertiary igneous activity in the northern Black Hills. They are especially concentrated in the area around the Lead-Deadwood dome, and dozens of mines were developed in them around the turn of the century. Norton (1989) has described the history, production, and geology of the major producing area of the Bald Mountain district and the dominant features of the replacement deposits in the lower Paleozoic rocks. Hence only salient features of this type of deposit are repeated here. Because the replacement deposits are transitional to the disseminated and vein deposits in Tertiary igneous rocks, the origin of the deposits is discussed later with that of the disseminated and vein deposits.

The replacement deposits produced principally gold, but some mines also produced silver, lead, zinc, and tungsten. Emmons (1926) and Connolly (1927) recognized that gold and associated metals are distributed in a classical zonal pattern with the tungsten ore centered near the Homestake mine at Lead and the silver-lead ore concentrated on the periphery of the mineralized region. The deposits are largely in the basal part of the Deadwood Formation and are lateral replacements of dolomite or dolomitic quartzite beds extending outward from nearly vertical fractures that cut the basal sandstone (commonly silicified to a quartzite) or basal conglomerate. Localized breccia along the fractures also contained some ore in open-space filling, but this ore was minor. Because lateral replacement from the fractures was limited, density of fractures was important in localizing the largest deposits that could be mined. In some parts of the area, fractures extended upward from the basal Deadwood, and similar carbonate rock below the uppermost sandstone-quartzite part of the Deadwood was mineralized. Rarely an intermediate zone near the middle of the formation was mineralized. In the extreme northwest part of the region near Ragged Top Mountain, mineralization extended upward into the Pahasapa Limestone.

### Disseminated and Vein Deposits in Tertiary Igneous Rocks

Disseminated and vein deposits in Tertiary igneous rocks include those in intrusive bodies that cut the Proterozoic rocks exposed in and adjacent to the Lead-Deadwood dome, and also those in intrusives in the lower Paleozoic rocks of the northern Black Hills. Typical examples of such deposits are the Richmond Hill deposit located in the northwestern part of the Lead-Deadwood dome and the Gilt Edge deposit located about 3 km west of Galena. Considerable drilling has been done on these deposits in recent years, so that the geologic relationships are becoming much better known (Duex and others, 1987; MacLeod, 1986). Mineralization at the Richmond Hill deposit was localized in a Tertiary breccia pipe and adjacent fractured Tertiary igneous rocks and Proterozoic metamorphic rocks. The deposit is largely oxidized, but Duex and others (1987) noted that gold mineralization was richest in areas of most intense argillic alteration. Pyrite and marcasite are the dominant sulfides in unoxidized ore. Quartz-barite and quartz-kaolinite veinlets are locally present.

At the Gilt Edge deposit MacLeod (1986) recognized that argillic, sericitic, and potassic alteration took place in brecciated trachyte porphyry, which hosts a gold deposit that is characterized, at least in part, by small quartz-pyrite veins.

Although the Golden Reward property in the Bald Mountain area described by Norton (1989) is dominantly a sedimentary rock-hosted replacement deposit, recent extensive exploration (Emanüel and Walsh, 1987) indicates that much of the low-grade gold mineralization occurred in igneous breccia bodies and smaller vein stockworks in Tertiary igneous bodies which pervasively intrude the Deadwood Formation. Low-grade mineralization also was not limited to the basal Deadwood but extended throughout the lower half of the formation. Emanüel and Walsh (1987) also recognized an early stage of silicification accompanied by gold-silver mineralization and arsenic-bearing sulfides, which was followed by another mineralization stage characterized by gold-silver-bearing pyrite. In addition, argillic and propylitic alteration types and local fluoritized rock were recognized. Barite, pyrrhotite, and magnetite are sparsely present and tellurium minerals have been noted. Silver: gold ratios of the low-grade ore average about 4:1 in contrast to somewhat lower ratios for the high-grade ore previously produced.

Norton (1989) suggested that Tertiary igneous rocks have served as a heat source to generate hydrothermal fluids which obtained their metals and gangue constituents from the underlying rocks. Thus he envisaged gold coming from a Proterozoic source, possibly the ore in the Homestake Formation or other auriferous iron-formation, which is believed to underlie the Golden Reward property (Emanüel and Walsh, 1987). Deposits were therefore related to hydrothermal convection cells tied to the Tertiary igneous rocks. His model is reasonably consistent with the isotope data of Rye and others (1974) and is the favored model of Emanüel and Walsh (1987).

Recent work by Paterson and Uzunlar (1987) on fluid inclusions in quartz and fluorite from eight different Tertiary deposits in the northern Black Hills indicates that some inclusions have high salinities (20 to 60 wt. percent equivalent NaCl) and filling temperatures in the range of 150–450 °C. Paterson and Uzunlar (1987) also determined $\delta^{18}O$ values for quartz and biotite from Tertiary veins and also for some of the Tertiary igneous rocks associated with the gold deposits. These data, combined with previous $\delta D$ values of Rye and Rye (1974), suggest that the ore-forming fluids were dominated by magmatic water, although Paterson and Uzunlar (1987) noted that the isotopic compositions possibly could result from the interactions of small amounts of meteoric water and larger volumes of Tertiary igneous rock or from the mixing of magmatic and meteoric water. Because Paterson and Uzunlar were also able to sample Tertiary-age veins within Proterozoic rocks at depths as great as 7,200 feet in the Homestake mine, it seems that their evidence for magmatic water is strong. Their fluid-inclusion work positively correlates the higher salinities and temperatures with greater inferred depths of deposition of the different sampled deposits; and only the shallower deposits, in contrast, are characterized by lower salinities and temperatures, suggesting possible involvement of meteoric water.

Tertiary igneous rocks are obviously required to form both the replacement deposits in sedimentary rocks and the disseminated and vein deposits in Tertiary igneous rocks. If the precious metals came directly from the igneous rocks, relating the mineralization to a particular rock type or types would be extremely important. At present such information is not available, although Emanüel and Walsh (1987) suggested that at the Golden Reward an aegerine-nepheline-bearing trachy-syenite is genetically related to the hydrothermal solutions. If on the other hand hydrothermal solutions from the igneous rocks or from heated meteoric waters scavenged the metals from the country rocks, target areas for new deposits would include all areas of Tertiary igneous bodies.

If the characteristics of the different Tertiary deposits are considered, it is apparent that ground preparation was especially important for the formation of disseminated and vein deposits in Tertiary igneous rocks. Favorably prepared ground includes intrusion breccias, brecciated or fractured intrusion margins, faults, and shear zones. Formation of replacement deposits in the lower Paleozoic rocks also has relied on faults, fractures, aquitards, and the existence of favorable carbonate rocks for replacement. Knowledge of the abundance and nature of fractures in the lower Paleozoic rocks and of the depositional environment of the basal Deadwood Formation is therefore important for the discovery of new deposits.

### Placer Deposits

Placer deposits in the basal conglomerate of the Deadwood in the vicinity of the Homestake mine were described in considerable detail by Devereux (1882) and Irving and Emmons (1904), who examined the deposits while they were being mined. Irving and Emmons (1904) recognized that a paleohill above the outcrop of the Homestake discovery controlled the distribution of gold-bearing conglomerate in the Deadwood, and they recognized that the conglomerate pinched out against the hill. Because Tertiary replacement deposits involving silicification, pyritization, and the introduction of additional gold were superimposed upon the placer deposits, the placer origin of the gold in the conglomerate was not always evident. In fact, Noble (1950) believed most of the gold was of Tertiary age, but his view was undoubtedly influenced by the belief that the Homestake ores were emplaced during the Tertiary. Arguments for and against the placer origin have been noted by Norton (1974), and more recent work by French (1985) and examinations by Homestake personnel (Gordon Nelson, oral commun., 1986) document that the placer gold developed in response to preexisting drainages and the advance of the Cambrian sea. Inadequate exposures of remnants of the basal Deadwood exist to document in detail the ancient topography of the outcrop of the Homestake deposit and the adjacent Ellison Formation. However, the available present outcrops suggest, as indicated by Irving (Irving and Emmons, 1904), that a topographic high which shed placer gold into conglomerate of the basal Deadwood was developed over resistant outcrops of the chert-rich Homestake Formation and quartz-rich Ellison Formation. Irving did not believe the conglomerate in the basal Deadwood was fluvial, or if it had been, it certainly was reworked by the advancing Cambrian sea.

Other placer deposits in the Deadwood Formation in the Rockerville area have been mined, and similar deposits were partly reworked and provided gold for gravels in nearby Quaternary deposits. Detrital gold has been recognized in sandstone of the basal Deadwood in the Nemo area; this gold presumably was derived from fluvial placers in the Proterozoic rocks, especially unit Xcq (fig. B13). Tuysuz (1986) also noted placer gold in heavy-mineral concentrates from basal conglomerate of the Deadwood in several samples obtained north of lat 44° N.

Tertiary placers were mined on a small scale south of Rockerville near the settlement of Hayward and also in the Lead-Deadwood area. The Tertiary Hayward placer gold deposits lie very close to the Oligocene and Miocene erosion surface, and their source is likely placer gold in the Deadwood as well as in the Proterozoic rocks to the west. Tertiary placers are also known southwest of Custer (Redden, 1963).

Holocene placers are relatively widespread through the drainages of the Black Hills. The Lead-Deadwood area placers were by far the richest, producing about 200,000 oz of gold (Norton, 1974). Placers were also relatively rich in the Tinton area west of Lead. Over most of the central Black Hills, Holocene placers are relatively low grade; they thus suggest lack of a major exposed lode deposit.

## POTENTIAL DEPOSITS AND EXPLORATION GUIDES

The existence of the Homestake mine in the northern Black Hills, which has produced approximately 36 million oz of gold from about 130 million tons of ore, is an obvious incentive to seek a similar deposit. In addition, the size and grade of some of the Tertiary deposits (see Norton, 1989) are worthy targets under present high gold prices. Because of the extensive prospecting in the past and the continued exploration by mining companies, any rich gold deposit to be found will probably be a concealed one, as Norton (1974) concluded. Hence costly exploration for concealed targets that might or might not be extensions of existing deposits will be benefited by a knowledge of the genetic factors that formed the deposits, and by additional geologic information on the setting of the known deposits.

Norton (1974) outlined possible approaches and favorable areas in the search for new gold deposits in the

Black Hills. Here, we discuss new geologic data that bear on gold mineralization and that may prove useful in exploration. Because the Phanerozoic placer deposits now known are small, they will not be discussed except as an indicator of a possible Proterozoic deposit.

## Homestake-type Deposits

The present commonly favored model of the formation of the Homestake deposit incorporates submarine hot springs, probably a localized basin bounded by syndepositional faults, and volcanic-related tuffaceous rocks. These attributes of the model rule out most of the Proterozoic rocks in the Black Hills and restrict the search either to areas of carbonate-silicate-facies iron-formation or relatively quiet-water depositional environments such as shale basins associated with volcanic activity. Iron-formation is rather widely distributed as shown in figure B13. We believe, however, that the richest concentrations of gold are associated only with iron-formation that has significant concentrations of sulfide minerals, and therefore most of the carbonate-silicate iron-formation horizons are probably not particularly favorable. Another possible guide (as suggested by Norton, 1974) is the garnet isograd, inasmuch as mobilization of gold may have been influenced by the release of volatile components ($H_2O$, $CO_2$) from metamorphic reactions at or near the garnet isograd. If the obviously fault controlled deposits in the Keystone area are excluded, it is true that the known deposits in iron-formation are approximately on the garnet isograd. Recent research involving metamorphosed interbedded impure carbonate rocks, shales, and pure carbonate rocks (Ferry, 1987; Nabelek and others, 1984) suggests that highly channelized fluid flow results from metamorphic reactions (especially decarbonation reactions). Thus, the impure sideroplesite-bearing (at low metamorphic grade) Homestake Formation might act as a major conduit for fluid movement which can concentrate gold into an ore body. If so, the general intersection of the garnet isograd and iron-formation units indicates favorable areas. At present, however, no proof exists that such migrations of gold at the garnet isograd are possible.

In the Homestake mine area, the continuity of the Homestake Formation is relatively well known and the unit is obviously a target examined and sampled by many geologists. Past mining and exploration have been based partly on the concept that major folds in the mine area represent the major structures of the region. As indicated in an earlier section, the regional structural interpretation favored here suggests that major folds in the mine are most likely $F_2$ folds superposed on nearly east trending $F_1$ folds. If this interpretation is correct, the Homestake Formation may be repeated to the north below Paleozoic rocks on the overturned limb of a larger anticline. Also, this model suggests that the plunge of the superposed $F_2$ folds should decrease at depth in the mine as it crosses the east-trending axis of an $F_1$ syncline to the south. A model of the mine workings prepared by Homestake geologists suggests some flattening of plunge in the deepest mine workings, but the data are not conclusive. Also, no intermediate-scale folds having easterly trends have been recognized within the extensive mine workings, although Roland Reed (University of Idaho, oral commun., 1984) has recognized early small-scale, east-trending structures within the mine which he believed might be $F_1$ structures. Although early large east-trending structures exist farther to the south in the Hill City area (fig. B14) and in the Rochford area (fig. B13), one cannot unequivocally assume that they are present in the Lead area. Therefore exploration for a continuation of the Homestake Formation based entirely on the assumption of such $F_1$ folds would be risky unless additional confirming evidence becomes available. Furthermore, there would be no assurance that conditions for gold deposition would necessarily be the same as those that obtained at the Homestake deposit.

In the remainder of the Black Hills, the potential for Homestake-type deposits would appear to be limited to areas such as the Keystone or Rochford districts where considerable sulfide minerals are present in the iron-formation. In the Keystone district, late mobilization of gold into breccia along faults apparently played a significant role in formation of ore. The district has been relatively well explored by earlier mine workings, and although the area has moderate reserves (Allsman, 1940), there are no indications that a major deposit is concealed in the immediate Keystone area. Thick iron-formations north of Keystone (Norton, 1976) contain relatively low gold concentrations (Raymond and others, 1975).

Pillow lavas, coarse volcanic debris, and units of massive chert extensively interbedded with iron-formation (Norton, 1976) indicate that a volcanic center existed a few kilometers west of Rockerville in an area around Storm Hill. Younger metagabbro dikes intrude the section, and in combination with colluvium from massive chert and quartzite, they tend to conceal most of the iron-formation. No mines are known in the area, although numerous prospect pits exist. To our knowledge no exploratory drilling has taken place near this volcanic center. The nearby placer deposits at Rockerville produced at least 20,000 oz of gold, presumably largely from basal Deadwood placers, but Norton (1974) did not consider the Storm Hill area as a likely source of the gold, probably because the area lacks mines. Recent work on the heavy minerals in the basal Deadwood by Tuysuz (1986), and mapping of the basal Cambrian unconformity in many areas by Redden, show that although local relief on the unconformity is as much as 60 m, the lithology and heavy-mineral content of the basal Deadwood are strongly controlled by the immediately underlying Proterozoic rocks. Where the basal Deadwood contains heavy minerals which are not representative of the underlying rocks, the suite is characteristic of the Proterozoic rocks a few kilometers to the west. In other words, beach transport in general occurred from west to east. Hence, we believe that gold in the placer deposits at Rockerville was most likely derived from the Storm Hill area to the west. The quantity of placer gold recovered would not indicate a major exposed ore body, but it could well indicate partially exposed or large low-grade deposits.

The Rochford area with its extensive exposures of iron-formation (Bayley, 1972c), some containing productive gold mines, is an obvious favorable area because of the presence of iron-formation similar to that at the Homestake mine. Furthermore, the area had a similar structural and metamorphic history and was a center of volcanic activity. In addition, arsenopyrite and pyrrhotite from four mines in iron-formations from the Rochford area have $\delta^{34}S$ values similar to those in the Homestake Formation (Ryę and Rye, 1974, p. 300–301). One unfavorable criterion is that none of the Rochford iron-formations are, according to Bayley's (1972c) stratigraphy, time equivalent to the Homestake Formation. The stratigraphic sequence of Bayley that indicates a lack of correlation is corroborated by the 1.97±0.01 Ga U-Th-Pb zircon age of the Ellison Formation (and by inference the underlying Homestake Formation) versus the 1.88±0.03 Ga U-Th-Pb zircon age of iron-formation (Montana Mine Formation) at the Montana mine in the Rochford area.

Although the evidence is strong for assuming that the iron-formations described by Bayley (1972c) are younger than the Homestake Formation, the assumption is uncertain because (1) the structure is extremely complex, (2) there are relatively rapid facies changes in the Rochford area (Cleath, 1986; Weissenborn, 1987), (3) outcrop is extremely sparse north of Rochford near the Paleozoic unconformity and hence geologic interpretations tenuous, and (4) reliable relict structures that can be used to indicate stratigraphic sequence are generally lacking. Hence the lithologic correlations and locally the extensions of certain units shown in figure B13 may be in error. If thrust faulting accompanied the early $F_1$ deformation, as seems likely, it is possible that some apparently conformable contacts are faults which repeat or juxtapose units and have been refolded by the $F_2$ deformation. Thus, we suggest that the correlations indicated by Bayley (1972a,c), which are approximately accepted in this report, should not be considered as irrefutable.

Regardless of the precise correlations of the iron-formation units in the Rochford area, we emphasize that they, like the Homestake Formation, are closely associated with tuffaceous volcanic material and probably formed by hot spring discharge onto the sea floor. The Rochford area iron-formation units also commonly are sulfide bearing and have produced gold. Thus, they clearly have the potential to host a significant gold deposit.

Iron-formation in the Rochford area mapped by Bayley (1972c) locally has been remapped in more detail, and its distribution interpreted differently from Bayley's map (Atkinson, 1976; McMillan, 1977; Cleath, 1986; Weissenborn, 1987). Only the more continuous of the iron-formation units are shown in figure B13, where they are included within unit Xpb. Recent mapping by Weissenborn (1987) along the west side of the Rochford district in the Nahant area and additional reconnaissance work to the west by Redden indicate that the Xpb unit is distributed as shown in figure B13. Although not shown in figure B13, one and possibly two thin units of low-metamorphic-grade carbonate-silicate-facies iron-formation are present within the Xpb unit which rims the Xqg unit west of Nahant. The low-metamorphic-grade iron-formation units may very well be the lateral equivalents of either the Rochford or Montana Mine Formations of Bayley (1972c). These low-metamorphic-grade iron-formation units are poorly exposed, especially near the Paleozoic rocks. The area merits more detailed investigation and prospecting.

The presence of carbonate-silicate-facies iron-formation in the Rochford area (as in other areas) should not be construed as evidence for a concealed gold deposit. In all known areas where ore-grade material has been developed, sulfide-rich rocks accompany the anomalous gold concentrations. Therefore, special efforts should be made to identify sulfide-rich facies and also to examine what appear to be thick depositional parts of iron-formation (rather than structurally thickened sections). Such depositionally thick sections are likely in local fault-controlled basins and should be especially favorable areas for thermal spring deposition. Geochemical indicators of such basins and the particular spring systems which are most favorable for gold deposition would have to be determined in existing mines such as Homestake. Possibly these data are already collected but for obvious proprietary reasons are not published.

In the northeastern part of the Black Hills Precambrian rocks, an unnamed carbonate-silicate iron-formation separates unit Xqc from a fault to the east; the unnamed unit can be traced for approximately 25 km before it disappears below the Paleozoic rocks. This iron-formation is here tentatively correlated with the oldest Early Proterozoic rocks of unit Xcq in the Nemo area (table B4). Bayley (1972a, 1972b) considered this subunit, which he included in the lower part of the Buck Mountain Quartzite, to be equivalent to the Homestake Formation. He based this correlation on the equivalency of the Buck Mountain Quartzite and the Ellison Formation. The correlation which we favor, shown in table B4, indicates that the Buck Mountain Quartzite is older than the Ellison Formation and therefore the iron-formation is probably not equivalent to the Homestake Formation. The iron-formation also has considerable magnetite and stilpnomelane and is locally transitional to the oxide facies. In the relatively few exposures of the iron-formation, the sulfide mineral content is low or lacking completely. Thus, this iron-formation does not appear to have been favorable for gold mineralization. Because most of the unit is concealed by colluvium from adjacent quartzite, however, the possible presence of sulfide-rich lenses cannot be ruled out.

Lenses of carbonate-silicate-facies iron-formation are relatively abundant as interflow units in the greenstone (unit Xb, fig. B13) overlying the Buck Mountain Quartzite to the west as shown by Bayley (1972b). Although these lenses of iron-formation have been prospected extensively, no gold deposits, even small ones, have been located. The gold content of the iron-formation is anomalously high compared to other rock types (Fantone, 1983) but apparently conditions were not favorable for economic concentrations of gold. The present evidence does not indicate that an environment of iron-formation within basalt is favorable for a Homestake-type deposit in the Black Hills.

## Gold-Quartz Veins

As a group, the gold-quartz veins do not appear to be favorable for discovery of a major deposit. Intense surface exploration during the early days of mining in the Black Hills has virtually eliminated the possibility that any deposits as rich as the Holy Terror mine or possibly the Clover Leaf mine are exposed at the surface. If formation of the deposits were connected to regional metamorphism, as some evidence indicates, areas of low metamorphic grade (fig. B13) apparently are unfavorable for these deposits. Also, graywacke and possibly metagabbro (amphibolite) wall rocks are more favorable than any of the shaly rocks. Because fracturing appears to have been an important ore control, possibly some areas above the garnet isograd in crossfolded and fractured competent strata might contain enough small veins to define a large-tonnage, low-grade deposit.

## Fault-Controlled Deposits

Exploration potential for this type of deposit is obviously enhanced where faults cut favorable country rocks, namely iron-formation. Most of the small deposits recognized to the present (1988) are near relatively large faults; seemingly this was a criterion for their formation. However, relatively little is known about the origin of these deposits; some of them may not be Proterozoic in age (DeWitt and others, 1986, p. 76; Norton, 1974, p. 13). Additional work is needed in order to develop criteria that might facilitate discovery of new deposits. If known deposits are representative of this class, however, significant new deposits will be minimal.

## Placer Deposits in Proterozoic Rocks

Although the fossil deposits of the Nemo area have a number of similarities to the Witwatersrand, South Africa, and Jacobina, Brazil deposits, the low gold content, complex structure, and relative thinness of the auriferous conglomerate are believed to be unfavorable for the discovery of a minable deposit. The fluvial conglomerate of unit Xcq is concealed to the east by Paleozoic rocks, and exploration based on the possibility that richer gold deposits might exist in extensions of the unit beneath the cover would be extremely expensive. Furthermore, because the conglomerate was deposited in a braided stream environment, the gravel is unlikely to have extensive lateral continuity nor should gold grade necessarily increase to the east based on present knowledge.

## Replacement Deposits in Lower Paleozoic Rocks

Evaluation of the potential for replacement deposits in the lower Paleozoic section would be enhanced if the following were known: (1) source(s) of the mineralizing fluids and metals; (2) local depositional environment of the basal Deadwood Formation; and (3) reasons for the development of fractures or other ground preparation structures which could serve as channelways or depositional loci for the hydrothermal solutions. In our earlier description of the Tertiary gold deposits, relatively strong evidence was cited that the mineralizing fluids were probably magmatically derived, although the possible involvement of heated meteoric water in the stratigraphically higher deposits cannot be entirely ruled out. Clearly, gold is associated with Tertiary igneous centers, but whether or not one particular type of igneous rock developed the magmatic fluids that carried gold is not certain. The source of the precious and other metals is less clear inasmuch as they could have been magmatically derived with the fluid, or they could have been obtained by reaction of magmatic fluids with wall rocks. Isotope data of Rye and others

(1974) suggest that lead in galena from Tertiary veinlets in Proterozoic rocks could have been derived from the wall rocks. Their isotope data for Tertiary veins in Paleozoic rocks also are compatible with the idea that some of the lead in galena was derived from the enclosing wall rocks. For the precious metals, the only evidence relative to source is Devereux's (1882) statements that placer gold in the Deadwood Formation was locally removed or exhibited solution pitting adjacent to Tertiary intrusive bodies. However, within the Homestake mine no evidence supports any depletion of gold where Proterozoic ore bodies are cut by Tertiary igneous rocks (Gordon Nelson, Mine geologist, Homestake Mining Company, oral commun., 1985). Because the Tertiary gold deposits contain a diverse assemblage of elements (for example, tungsten, molybdenum, gold, silver, lead, zinc, and fluorine), we believe that the precious metals, like the hot fluids, were derived from the Tertiary magmas.

Replacement deposits could have formed in the lower part of the Deadwood Formation only where metal-bearing fluids were available, where suitable rock types were available for replacement, and where local or regional structures were present to help prepare the ground or produce gradients for fluid movement. Ground preparation is exemplified in the Bald Mountain area, where two moderate-sized faults produced a grabenlike structure which was then extensively intruded by igneous sills and dikes. Deposition of the basal Deadwood was clearly controlled by existing topography during Late Cambrian time.

Detailed structure contour maps of the basal Deadwood unconformity and isopach maps of the basal sandstone-conglomerate unit of the Deadwood for the entire Lead-Deadwood dome (figs. B15, B16) and on a larger scale for the Bald Mountain area (fig. B17) have been constructed by French (1985) from drill hole data, mine shaft maps, and surface exposures. A striking feature of figures B16 and B17 is a major thinning of the basal Deadwood in the general area of Bald Mountain. This anomalously thin basal part of the Deadwood overlies resistant quartzites of the Ellison Formation. In the Nemo area and along the eastern side of the Black Hills, Redden (1987) and Daly (1981) documented that buried hills as much as 65 m in relief are preserved above quartzite units in the Proterozoic rocks, whereas paleotopographic lows or surfaces of little relief are generally underlain by phyllite. A clearly defined hill, or thinning of the basal Deadwood above the Ellison Formation, in the vicinity of the Homestake mine, is not apparent in figure B15 due in part to the scale. Irving (Irving and Emmons, 1904, p. 100), however, cited the absence of the basal conglomerate above the Homestake deposit outcrop as clear indication that a paleohigh existed above the ore body and associated Ellison quartzites. Figure B15 also shows a small topographic low above the incompetent rocks of the Poorman Formation north of Lead.

Because the structure contours on the base of the Deadwood Formation may be elevated due to Tertiary intrusive bodies in the underlying Proterozoic rocks (as is true for the major structure of the Lead-Deadwood dome), the structure contours can be used only in conjunction with isopach maps of the basal Deadwood. For example, figure B15 reveals a small structural high about 3 km west of Galena. The high is due to the igneous distension of the basement rocks and emplacement of igneous rocks below the Deadwood. There is no corresponding thinning of the basal Deadwood above the high (fig. B16).

The isopach map of the basal sandstone of the Deadwood for the entire dome (fig. B16) indicates in a general way that thin parts of the basal Deadwood tend to overlie paleotopographic highs developed on quartzite units, especially the Ellison Formation. This relationship is best shown in the Bald Mountain area where detailed control is available (fig. B17). Clearly the thickness of the basal Deadwood is related to paleotopographic highs underlain by quartzite, much like the pinchouts of sandy units above granite knobs in southeast Missouri (Ohle and Brown, 1954). Although precise control is lacking owing to recent erosion that has removed the basal contact, the structure contours and isopachs apparently indicate not only the large-scale northwest-trending Lead-Deadwood dome, but also the north-trending smaller high centered over the Golden Reward mines. The Golden Reward mines are all located near the apex of the dome. To the west in the area of the Tornado shaft (fig. B17), the ore shoots are along a subsidiary structural high. As a generalization, based on the distribution of underground workings, ore shoots are absent in basins where the basal Deadwood is thick. Several possible factors could have caused this distribution. Areas immediately adjacent to highs are likely to have experienced more fracturing and hence are better channelways. Also, local up-dip movement of solutions may have been increased near paleotopographic highs. Thicker sandstone (quartzite) sections in the basins are likely to have experienced less fracturing than those adjacent to highs. Two other important factors are the dolomitic character of the lower quartzite unit and local thinness or possible absence of the quartzite unit above topographic highs. Proterozoic rocks may be directly overlain by dolomitic rocks. Thus, rocks favorable for replacement by the ore-bearing solutions were controlled by paleotopography. The increased dolomite content of the carbonate could have resulted during sedimentation, but as pointed out by Norton (1989), it may have resulted instead

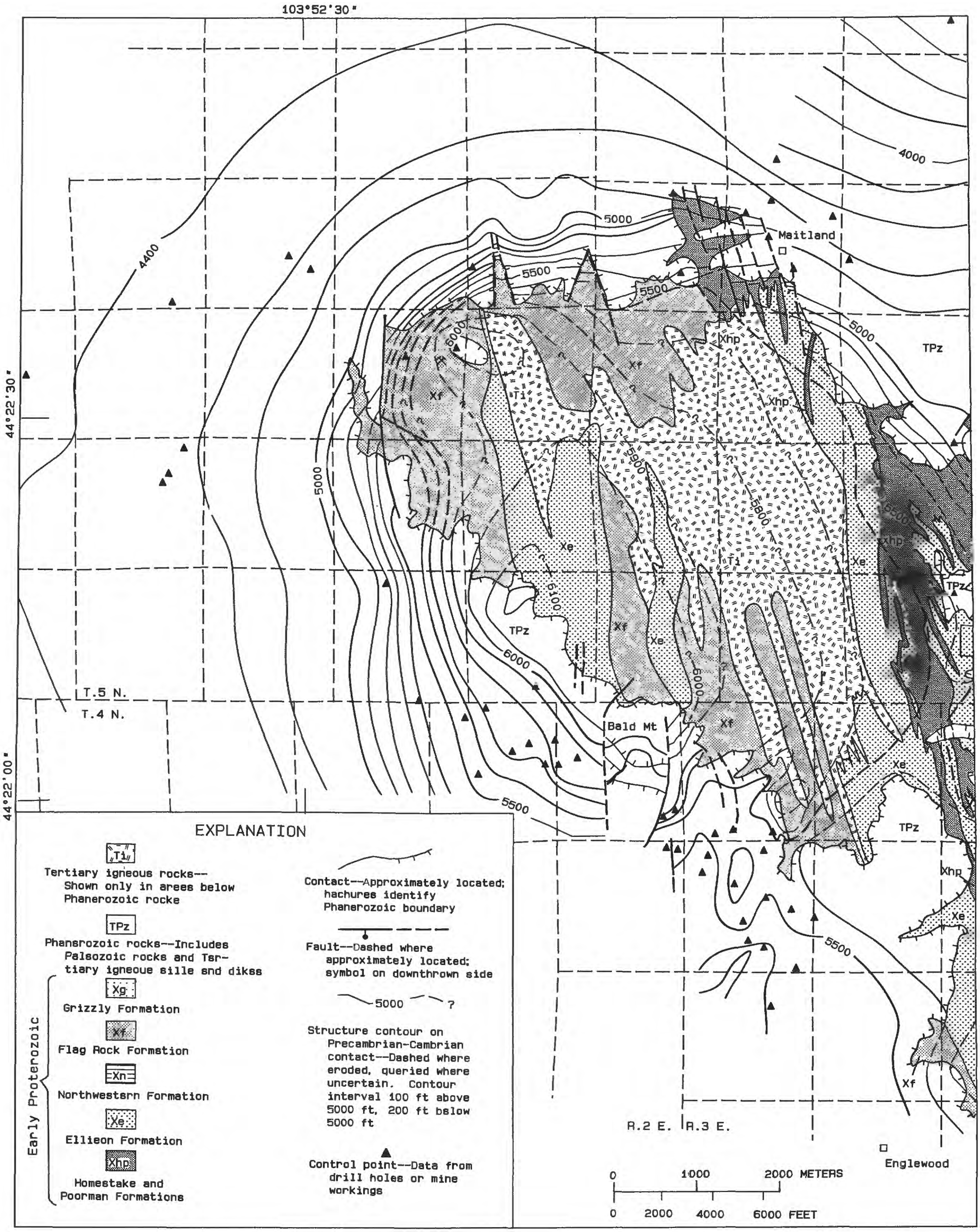
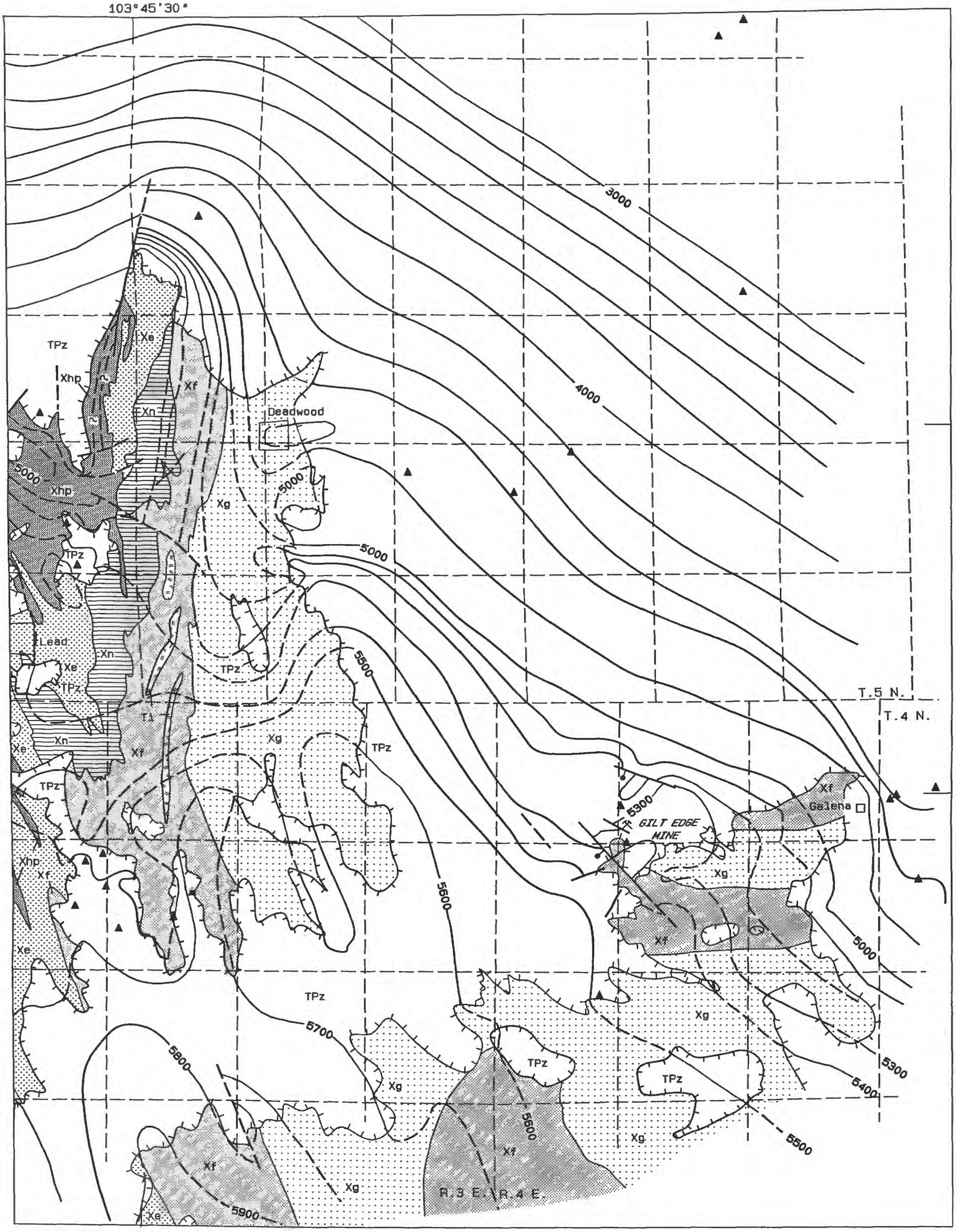



**Figure B15.** Structure contour map of the Precambrian-Cambrian contact, Lead-Deadwood dome, Black Hills. Map from area from MacLeod (1986).




French (1985); Precambrian geology from Noble and Harder (1948) and Bayley (1972a). Structure contours in the Gilt Edge

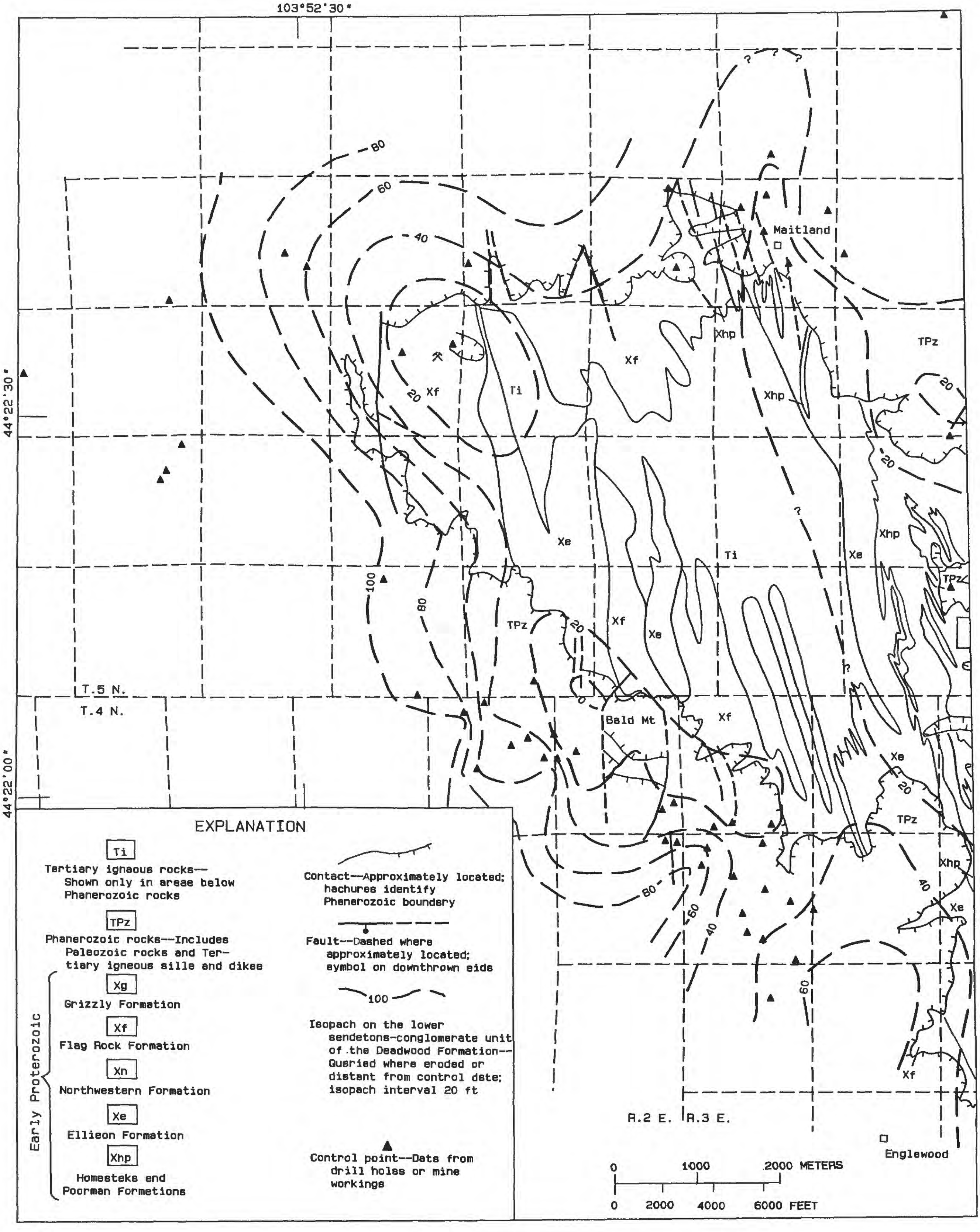
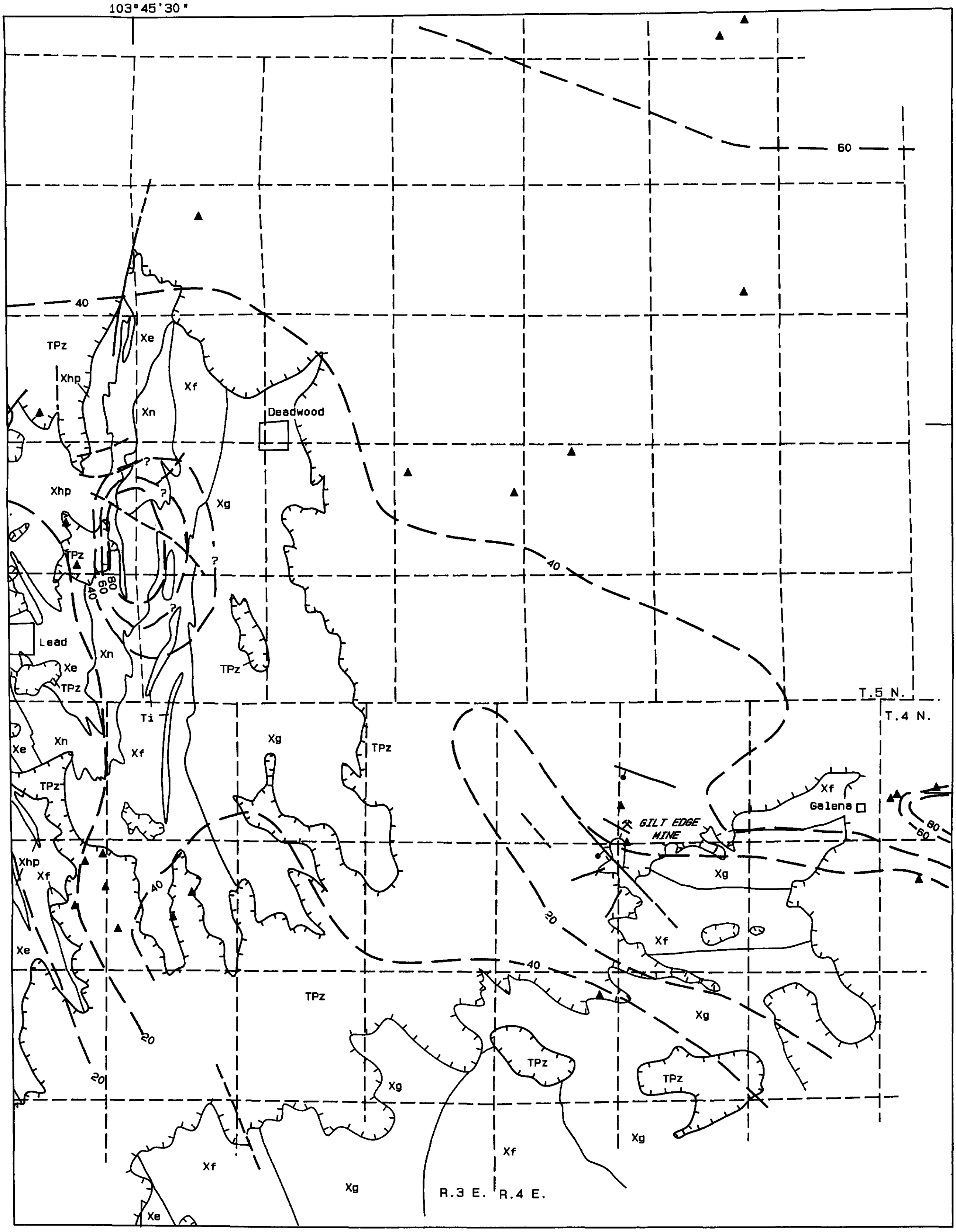



**Figure B16.** Isopach map of the lower sandstone-conglomerate unit of the Deadwood Formation, Lead-Deadwood dome,




Black Hills. Map from French (1985); Precambrian geology from Noble and Harder (1948) and from Bayley (1972a).

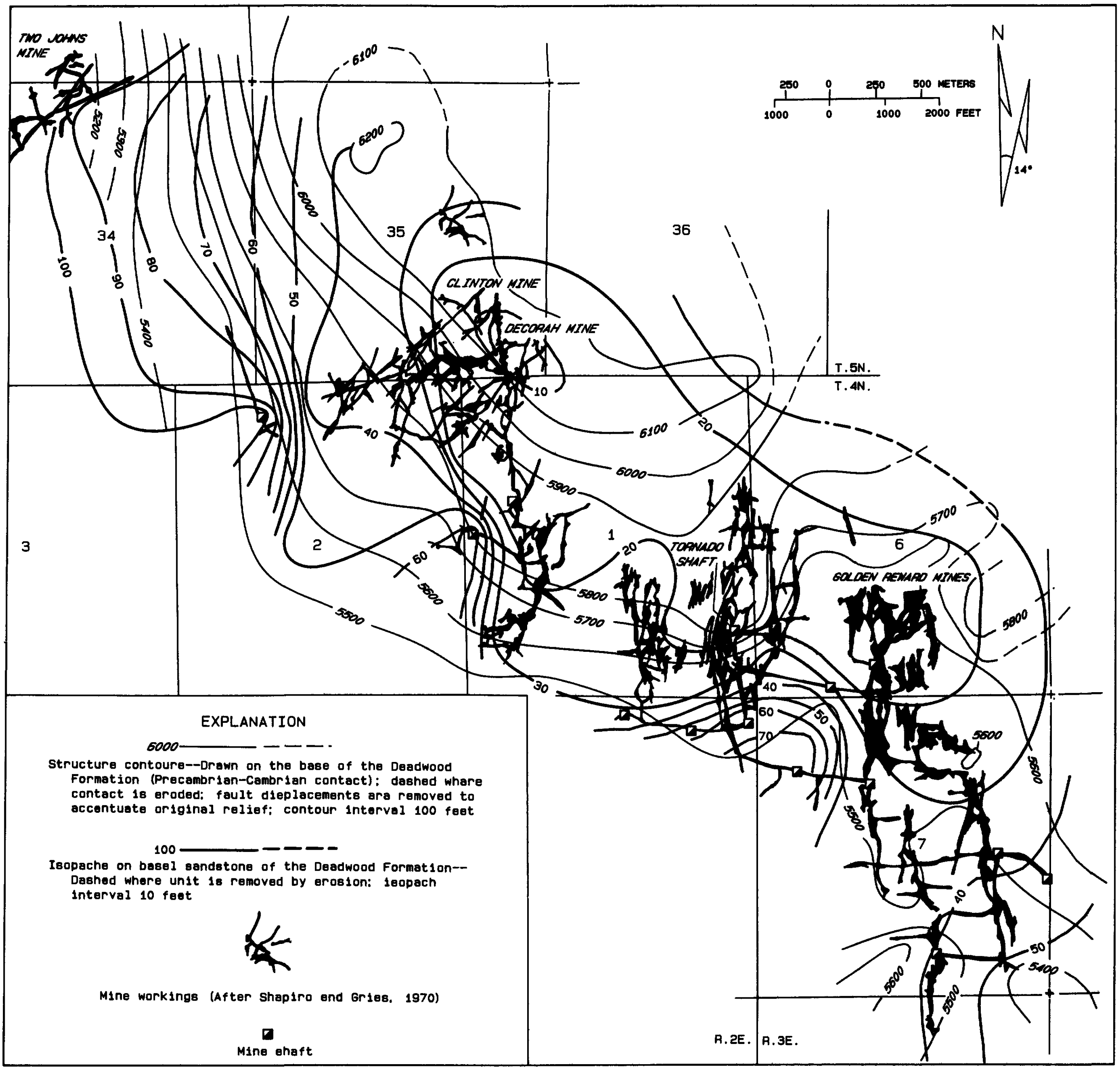



**Figure B17.** Structure contour and isopach map, lower Deadwood Formation, Bald Mountain area, Black Hills.

from alteration during solution movement. Small local structures that created structural highs in the sedimentary rocks are believed to have been important in ore localization, and the emplacement of Tertiary sills at the Cambrian unconformity probably localized fractures.

We suggest, based on the previous descriptions and conclusions, that a thorough knowledge of the topography of the Cambrian-Proterozoic surface is of considerable importance in exploration for new replacement deposits in the lower Paleozoic rocks and especially in the lower Deadwood. Our work elsewhere in the Black Hills to the present (1988) indicates that the basal Deadwood sandstone generally is thicker than average *only* immediately adjacent to areas where the underlying basement rocks consist of quartzite. The basal Deadwood is thin or absent above paleotopographic highs developed locally on the quartzite. The basal Deadwood in areas on or adjacent to ancient topographic highs seems to have been especially favorable for gold deposition, but mineralizing solutions would have been available only close to Tertiary intrusions. In areas that contain no quartzite in the Proterozoic, the basal Deadwood sandstone generally is thin and its grains are poorly rounded. On the other hand, basal sandstone derived from quartzite is thicker and the grains are well rounded. The thick accumulations of well-rounded quartz grains resulted from the partial disintegration of quartzite as a consequence of tropical weathering preceding advance of the Cambrian sea (Redden, 1987).

Where quartzite in the Proterozoic extends in the subsurface away from the Lead-Deadwood dome, there may be increased potential for replacement deposits. Increased potential would also seem possible in Paleozoic rocks above the probable subsurface extension of quartzite south of the Bald Mountain area toward Rochford. Some Tertiary sills intrude and dome Paleozoic rocks as far south as Custer Peak (fig. B13), but the basement rocks do not appear to be greatly uplifted or distended. The approximate axis of the main Black Hills dome extends south-southeast of Bald Mountain toward Rochford, although structure contours on the base of the Deadwood are not accurate enough to show details. Thus, one cannot rule out the possibility that Tertiary igneous rocks, whose presence could be indicated by detailed structure contours, may occur as far south as the north end of the Rochford district.

The Proterozoic quartzite in the Ellison Formation, although unrelated intrinsically to the Tertiary replacement deposits in the lower Deadwood, directly overlies the Homestake Formation. Thus recognition of paleohighs as a result of examination of the lower Deadwood lithologies also may indicate possible extensions of the Homestake Formation in the subsurface. Further, the distribution of detrital gold in the basal Deadwood is an obvious geochemical guide to possible gold deposits in Proterozoic rocks, no matter what their origin.

## Disseminated and Vein Deposits in Tertiary Igneous Rocks

The characteristics of these deposits, as discussed earlier, indicate a continuum between them and the replacement deposits in the lower Paleozoic rocks. The disseminated and vein deposits in Tertiary igneous rocks are discussed separately here because the recent discovery of several such low-grade deposits, suitable for development by open-cut/heap-leach methods, indicates considerable gold reserve potential. Although data are not yet available to indicate whether or not certain Tertiary igneous rocks are more favorable than others, as previously indicated, some generalizations can be made. Earlier lack of success in discovering minable replacement deposits associated with laccolithic intrusions in Paleozoic rocks on the periphery of the Black Hills suggests that such intrusive bodies are unfavorable as guides to gold deposits. On the other hand, in a general way areas characterized by considerable intrusion of the basement rocks or by multiple intrusions in the lower Paleozoic section probably are favorable. The structure contours on figure B15 show greatest closure approximately above the largest mass of Tertiary igneous rocks in the Black Hills, known locally as the Cutting stock. Evidently the Tertiary intrusions were principally responsible for formation of the dome, as documented by Noble and others (1949). Noble (1952) presented firm evidence in the three-dimensional exposures of the Homestake mine that emplacement of the igneous rocks produced distension of enclosing Proterozoic rocks and overlying Phanerozoic rocks approximately equivalent to the quantity of magma emplaced. If the entire Lead-Deadwood dome resulted from this emplacement, approximately 10 $km^3$ of igneous rock is required to be emplaced within the Precambrian rocks (fig. B15). A considerable volume of igneous rock was emplaced also in the lower Paleozoic section, but the igneous rock has been largely removed by erosion above the central part of the dome. The quantity of igneous rock intruded in the Paleozoic section is not known, but based on the extent of sills and dikes in areas such as the Golden Reward, an estimate of at least 20–30 percent of the volume present in the basement dome seems reasonable. The quite extensive introduction of magma in the basement rocks readily could provide either fluids and precious metals derived from crystallization of the magma under low-pressure conditions, or adequate heat for thermal leaching by meteoric ground-water fluids of metals from wall rocks or igneous rocks.

Ground preparation that resulted from emplacement of breccia pipes or dikes, and fracturing adjacent to igneous intrusions or along later faults, probably were prerequisites for mineralization (Emanüel and Walsh, 1987). Some igneous sills may have acted as aquacludes and may have trapped fluids, which were then able to precipitate low-grade gold in underlying sedimentary or igneous rocks. Faulting, fracturing, and jointing, on both a regional scale and a local scale, also were important as ground preparation for both lode and sediment-hosted mineralization. Small-scale faulting commonly was associated with emplacement of sills and dikes, and earlier igneous bodies emplaced at higher stratigraphic levels as well as the enclosing sedimentary rocks were displaced by sill and dike intrusion. At present there are no specific guides to predict faults or fracture patterns. A roughly radial fracture pattern might be expected around the slightly elongated (N. 30° W.) Lead-Deadwood dome (fig. B15). Slaughter (1968) suggested that a regional poorly developed radial fracture pattern in fact existed, but later work by Shapiro and Gries (1970) and by Rueb (1984) did not substantiate such a pattern. The lack of clear-cut fracture patterns around the Tertiary Lead-Deadwood dome probably is related to preexisting divergent fracture patterns that resulted from the Laramide uplift of the Black Hills. Most of the mapped faults and many lenticular igneous bodies trend subparallel to the dominant N. 30° W. schistosity of the Proterozoic rocks. The available data on existing deposits suggest that diverse local features of igneous emplacement and fracturing were more important controls on ore deposition than were the regional fractures. Probably areas of continued igneous intrusion and accompanying fracturing and faulting are most likely to contain disseminated gold deposits which have commercial potential. Because of the complexity of the relationships, detailed maps, though generally not available, are a clear necessity to indicate favorable targets. We cannot overemphasize the need for detailed mapping that not only shows the distribution of intrusive rocks but also recognizes the different petrologic and alteration characteristics of the rocks.

## CONCLUSIONS

Proterozoic strata of the Black Hills record a relatively detailed history of development of an apparently small intracontinental basin, although not all stratigraphic relationships have been completely resolved. The basin had a complicated history that began with rifting in Early Proterozoic time (≈2.4–2.1 Ga) and progressed through marine deep-water turbidite deposition and accompanying volcanism later in the Early Proterozoic (≈2.0–1.8 Ga). Most of the volcanic rocks are tholeiitic basalts; only a minor amount of relatively young (≈1.9 Ga) alkalic tuff is known. The strong association of gold and carbonate-silicate-facies iron-formation in the Black Hills is well known. We note that this facies is commonly associated with tuffaceous or volcaniclastic rocks, and on the basis of the gold association with the Homestake Formation, we suggest that gold was probably deposited by submarine hot springs. Submarine hot springs were also responsible for local lenticular deposits of chert and iron-formation, apparently less enriched in gold, in the turbidite section.

The potential for the discovery of significant gold deposits is limited largely to Homestake-type stratiform deposits, or to deposits associated with Tertiary igneous rocks. Correlation and extension of the Homestake Formation outside of the Lead-Deadwood dome have not yet been possible. Available age data and stratigraphic sequences suggest that at least some of the iron-formation units in the Rochford areas are considerably younger than the Homestake Formation. Recent work indicates that rapid lateral facies changes occur in the Rochford district; these must be fully understood in order to assess the potential for Homestake-type deposits. Because the Rochford district is near an Early Proterozoic volcanic center, and because the Early Proterozoic depositional environment deepened from Lead toward Rochford and to the area west of Rochford, stratiform deposits that may have formed could be of a nature somewhat different from that of the Homestake deposit.

An apparent continuum exists between the Tertiary replacement deposits in lower Paleozoic rocks and the disseminated and vein deposits in the Tertiary igneous rocks. Areas of intensive Tertiary igneous activity characterized by brecciation, fracturing, and faulting are favorable for low-grade gold deposits, both in the igneous rocks and in adjacent sedimentary rocks. Knowledge of paleotopography of the basal Deadwood unconformity may be important in recognizing areas of favorable rock types, or areas of porosity features favorable for mineralization, because the character of the basal Cambrian rocks is directly related to the paleotopography. Paleotopography is also related to the underlying Proterozoic rocks, and it can be used as a general guide to basement rock types.

Additional work is needed to establish whether or not gold is genetically related to specific Tertiary igneous rock types, and to establish the ultimate source of the gold. Hence, detailed geologic mapping and exploratory drilling in the Tertiary igneous rocks are critical for the discovery of new deposits.

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