UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PRELIMINARY ASSESSMENT OF THE MINERAL RESOURCES OF THE CEDAR CITY 1° X 2° QUADRANGLE, UTAH

By

Robert G. Eppinger[1], Gary R. Winkler[2], Theresa M. Cookro[3], Michael A. Shubat[4], H. Richard Blank[5], James K. Crowley[6], Robert P. Kucks[5], and Janet L. Jones[1]

Open-File Report 90-34

Prepared in cooperation with Michael A. Shubat, Utah Geological and Mineral Survey, Salt Lake City, Utah.

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

[1]U.S. Geological Survey, DFC, Box 25046, MS 973, Denver, CO 80225
[2]U.S. Geological Survey, DFC, Box 25046, MS 905, Denver, CO 80225
[3]U.S. Geological Survey, DFC, Box 25046, MS 937, Denver, CO 80225
[4]Utah Geological and Mineral Survey, Salt Lake City, UT
[5]U.S. Geological Survey, Denver West 2, MS 964, 1527 Cole Blvd., Golden, CO 80401
[6]U.S. Geological Survey, National Center, MS 927, Reston, VA

1990

EXECUTIVE SUMMARY

The Cedar City 1° X 2° quadrangle in southwestern Utah contains abundant mineral resources and the probability of new mineral discoveries is high, particularly for precious metals in the western half of the quadrangle. Currently, several mining companies are exploring for precious metals in the quadrangle, and a new bulk-minable gold mine has recently opened. The quadrangle contains the famous Iron Springs (Fe) and the unusual Silver Reef (Ag) districts, and has until recently produced primary gallium and germanium (used in high-technology optics and electronics) from the Apex mine in the Tutsagubet district. Deposits of uranium, coal, and oil and gas are numerous, and intermittent hydrocarbon exploration continues. The quadrangle contains two known geothermal resource areas, as well as deposits of sand and gravel, volcanic ash and cinders, dimension and decorative stone, kaolin, bentonite, and gypsum.

Dramatic physiographic and geologic contrasts in the quadrangle reflect the first-order crustal boundary between the Colorado Plateau and the Basin and Range provinces, which diagonally traverses the middle of the quadrangle. This boundary exerted fundamental control on types and locations of mineral and energy deposits formed. The geologic record indicates four main evolutionary stages that controlled metal deposition. First, regional uplift east of the quadrangle beginning about 250 million years ago resulted in westward regression of the sea and deposition of fluvial to saline sediments of Mesozoic age across broad coastal plains. During extended periods of subaerial exposure, deeply circulating meteoric water interacted with and leached metals from pre-Mesozoic marine shale and basement rocks. Second, eastward-directed thrusting and folding of the Sevier orogeny beginning about 110 million years ago juxtaposed pre-Mesozoic rocks above the Mesozoic sequence. Third, regional volcanism between about 34 and 20 million years ago erupted calc-alkaline volcanic rocks and emplaced related porphyritic plutons. Finally, regional extension disrupted the western part of the quadrangle beginning about 15 million years ago and a bimodal mafic-silicic assemblage of volcanic and intrusive rocks was emplaced at about the same time. The volcanic and intrusive events provided heat sources and structural channel ways that controlled ensuing hydrothermal activity which precipitated epithermal base- and precious-metal vein and disseminated deposits, and possible porphyry deposits at depth.

This study of the Cedar City quadrangle was conducted as a multi-disciplinary effort by USGS and Utah Geological and Mineral Survey personnel. The study identified areas with known and potential resources of epithermal base- and precious-metal, Mo porphyry, solution-collapse breccia pipe, sediment-hosted Cu-Ag-U, placer, and iron skarn deposits. In addition, some drawbacks and limitations to the existing geologic, geophysical, geochemical, and mineral resource data were identified. Clearly this preliminary assessment merely sets the stage for further studies. Existing data should be used more fully and new data are needed for future investigations. Many topical research studies within the quadrangle also would improve our understanding of the regional geologic framework and mineralizing processes and build upon recently completed and on-going resource assessments in the adjacent Richfield and Delta quadrangles in Utah.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

Section 2 INTRODUCTION

Interdisciplinary geologic, geophysical, geochemical, and mineral occurrence data were assembled to make a preliminary mineral resource assessment of the Cedar City 1° X 2° quadrangle. This study was done as part of the National Mineral Resource Assessment Program (NAMRAP) to aid in planning and selection of quadrangles within the conterminous United States for future mineral resource study. This "pre-assessment" study was a cooperative effort by the USGS and Utah Geological and Mineral Survey. The interaction between the two agencies brought to light current information on geologic activities within the quadrangle which otherwise might have been overlooked. Most figures in this report are reduced from 1:250,000-scale plates. The plates are available from the authors for reproduction by the user.

Geologic studies in southwestern Utah began in the mid-1800's in conjunction with engineering and military surveys of the western territories. Prospectors and miners pushing east from the California Mother Lode and west from the Colorado Front Range followed soon thereafter. Exploration within the Cedar City 1° X 2° quadrangle eventually led to discovery of the Iron Springs district, now the largest iron producer in the western U.S. The quadrangle also hosts two unusual deposits: sandstone-hosted silver chloride deposits at Silver Reef and gallium-germanium deposits at the Apex mine. Exploration for gold now underway has resulted in discovery and development of bulk-minable gold deposits in the western part of the quadrangle.

The Cedar City quadrangle covers an area of about 7,500 square miles in the southwestern quarter of Utah (fig. 1). The quadrangle includes two major physiographic provinces, the High Plateaus region of the Colorado Plateau in the eastern half of the sheet, and the eastern Basin and Range province in the western half of the sheet. The Escalante Desert forms a large physiographic feature in the northwestern quadrant. Elevations range from less than 2,400 ft near the southwestern corner to over 11,000 ft northeast of Cedar Breaks National Monument. Major towns within the quadrangle include Cedar City, St. George, Panguitch, and Kanab. Several federal and state highways traverse the region and numerous secondary roads lead from these.

The majority of the land within the Cedar City quadrangle is in the public domain. Approximately 40 percent of the lands are under U.S. Bureau of Land Management jurisdiction, 30 percent are National Forest, and about 15 percent are privately held. The remaining lands are national parks and national monuments, or are held by the State of Utah. National parks and monuments, state parks, wilderness areas and BLM wilderness study areas are shown on figure 2.

It is stressed that this preliminary mineral resource assessment was conducted within about 6 months in 1988/1989, and is based solely on existing data. No fieldwork was involved. This report--prepared as a planning document for future NAMRAP quadrangle selection--identifies areas of known and potential resources for a variety of metal deposits, as well as the limitations of the existing geologic, geophysical, geochemical, and mineral resource data. Recommendations for future mineral resource studies are included.

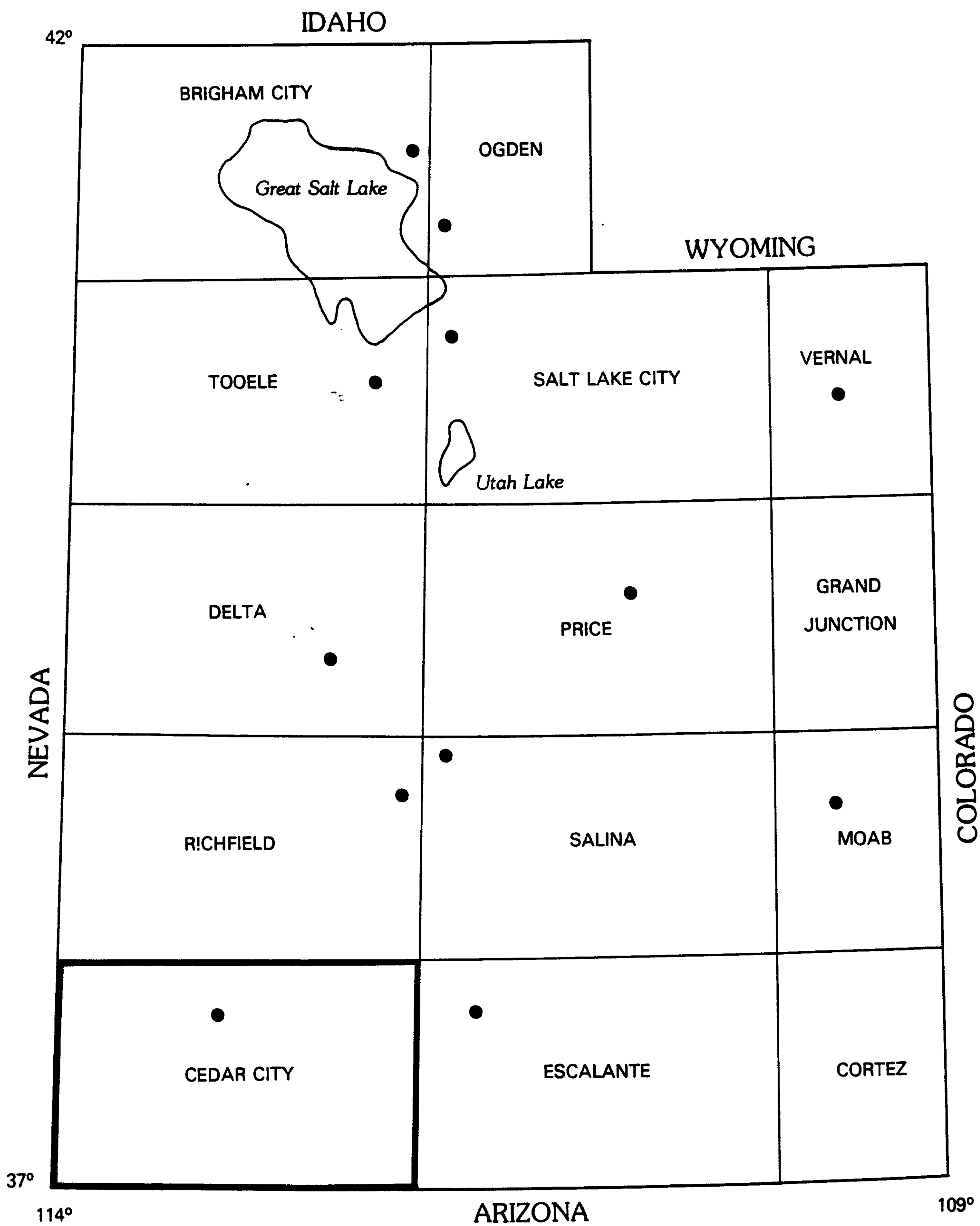


Figure 1.--Location map for the Cedar City 1° x 2° quadrangle, Utah.

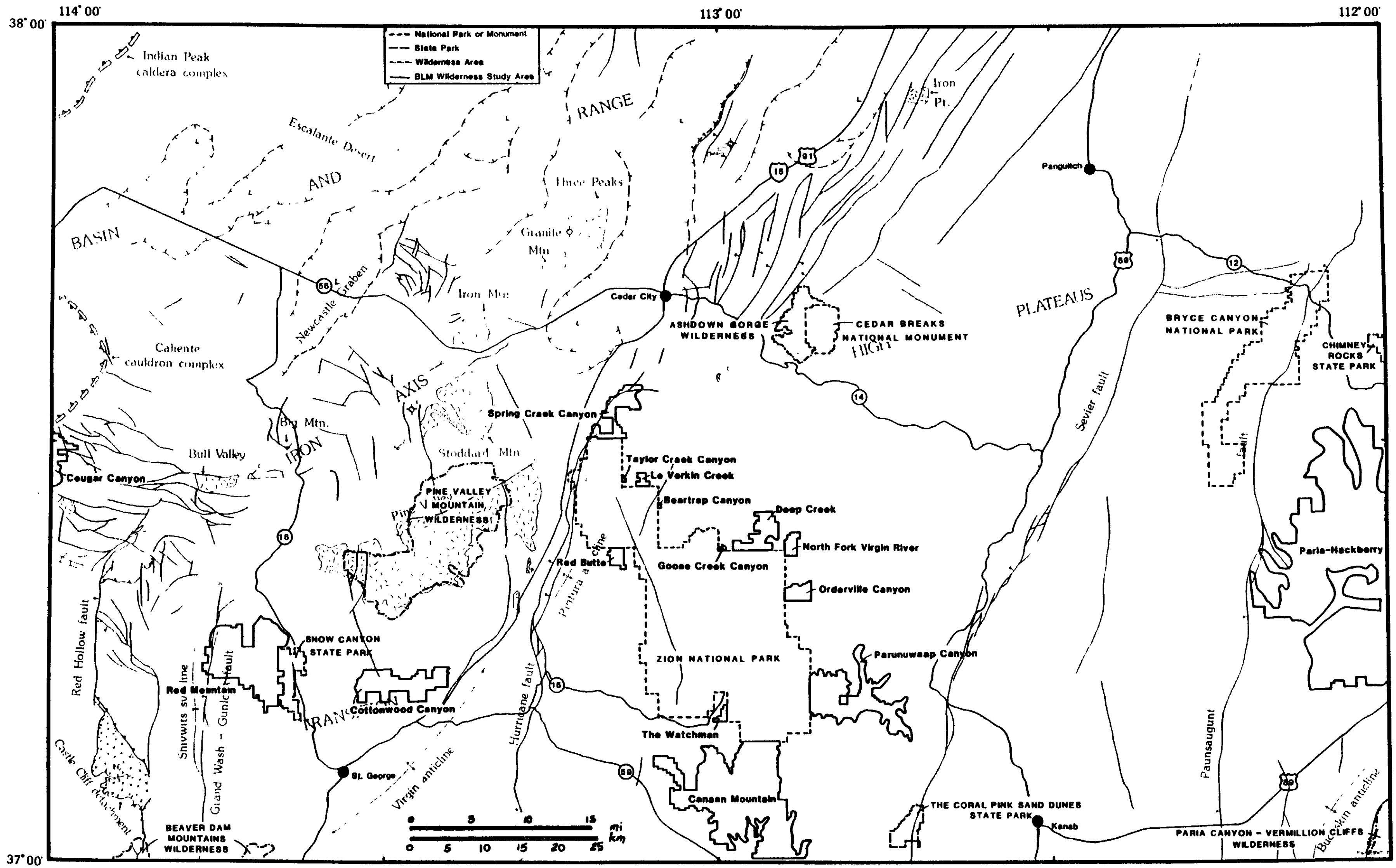


Figure 2. Map showing approximate boundaries of BLM wilderness study areas, national parks and monuments, state parks, and wilderness areas in the Cedar City 1° X 2° quadrangle, Utah. Base map is from figure 3.

Section 3 GEOLOGIC SETTING, by G.R. Winkler and M.A. Shubat

INTRODUCTION

The area of the Cedar City quadrangle spans dramatic physiographic and geologic contrasts between the Basin and Range and Colorado Plateau provinces. The boundary between the two provinces passes diagonally from northeast to southwest roughly through the middle of the quadrangle (figure 3). Except in the basins, bedrock generally is well-exposed and the area attracted the attention of earth scientists as early as the 1860's. Studies over the past 130 years have defined the general framework of the contrasting eastern and western parts of the quadrangle, and have noted the different types and locations of mineral and energy deposits formed in the two parts.

STRUCTURE

In the Cedar City quadrangle, the boundary between the High Plateaus section of the Colorado Plateau and the Basin and Range province follows an important structural hingeline active since early Paleozoic or even Proterozoic time. It is characterized by a westward change from cratonic to miogeoclinal sedimentary facies in Paleozoic and early Mesozoic rocks (Figure 4, Plate 1). In the Cedar City area, it also corresponds closely to the easternmost extent of eastward-directed thrusting and related folding of the late Mesozoic Sevier orogeny (Armstrong, 1968; Burchfiel and Hickcox, 1972). The Square Top Mountain thrust (Hintze, 1986), which, in the Goldstrike area, places miogeoclinal Paleozoic marine rocks above Mesozoic terrestrial and marginal marine rocks, may mark one foreland thrust. Another Sevier-age thrust, the Iron Springs fault, extends in the subsurface from the Bull Valley Mountains through the Iron Springs district to the Red Hills and shows about 3.5 mi of eastward displacement (Van Kooten, 1988). Other thrust faults have been penetrated in Hunt Oil's Table Butte and ARCO's Three Peaks hydrocarbon exploration wells northeast of the Iron Springs district (Shubat and McIntosh, 1988; Van Kooten, 1988). Related folds may include the Shivwits syncline and the Virgin anticline. Thrusts that displace rocks as young as the lower part of the Paleogene Claron Formation are known in the High Plateaus from oil company seismic data, and are well exposed just north of Bryce Canyon National Park (Lundin, 1987). Thus, at least locally, compressional deformation extended into the Early Tertiary (Rowley and others, 1979).

Structural differences between the eastern Basin and Range and the western High Plateaus provinces are well-documented from about 26 Ma, by ash-flow tuffs which are widespread throughout the Basin and Range province, but terminate near the present western edge of the High Plateaus against presumed paleoscarps created at the ancestral boundary (Rowley, Anderson, and others, 1978). The distribution patterns of the early Tertiary tuffs, however, indicate a probable west-northwest orientation to paleoscarps in the Markagunt Plateau, a trend that is not parallel to the present boundary between the Basin and Range and High Plateaus provinces (Anderson, 1988). In the Early Miocene, east-northeast trending plutons were intruded along a remarkably linear trend, termed the "iron axis" (Mackin, 1960; Tobey, 1976). This trend apparently followed a Sevier-age decollement (Rowley and Barker, 1978). In the eastern Basin and Range province, Best (1988) shows east-west isopach trends of 30-20 Ma ash-flow tuffs, implying an east-west grain to the paleotopography, and Eaton and others (1978) describe a

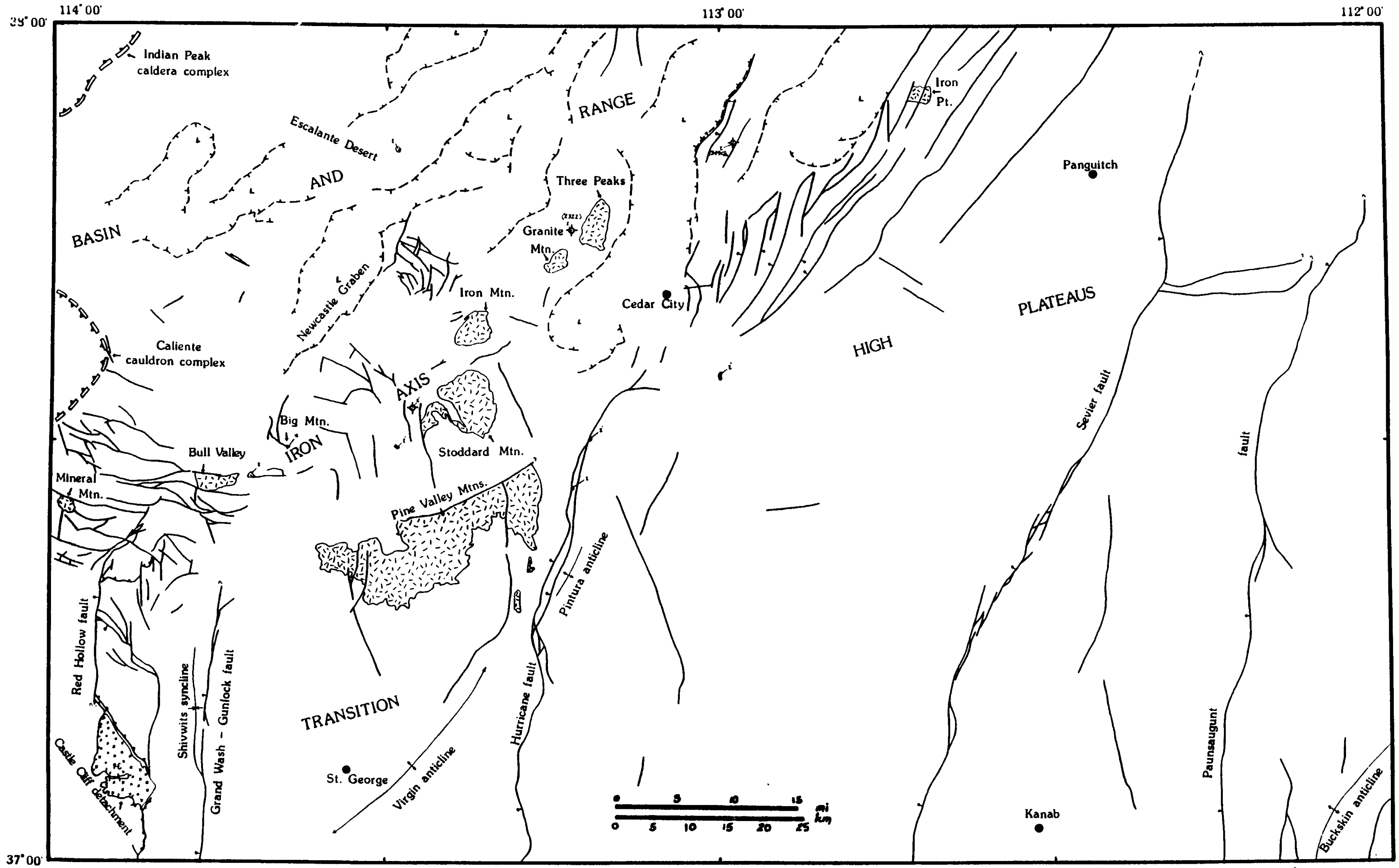


Figure 3.--Map showing structural elements of the Cedar City 1° X 2° quadrangle, Utah.

EXPLANATION

 Contact

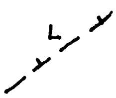
 Anticline, showing dip of limbs and direction of plunge

 Syncline, showing dip of limbs

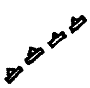
 Steep fault, ball on downthrown side, dashed where uncertain

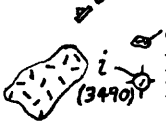
 Thrust fault, teeth on upper plate

 Low-angle normal (detachment) fault, barbs on lower plate

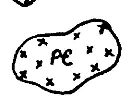


Density-contrast boundary beneath Quaternary cover, dashes mark steepest gravity gradient, barbs point toward gravity low, L = center of low

 Inferred outer limit of caldera or cauldron complex, teeth point toward center of complex



Miocene prophyritic intrusive rocks, *i* = small occurrence in outcrop or in well (depth to intrusion shown, if known)



Precambrian crystalline rocks of Beaver Dam Mountains

Figure 3.--(continued)

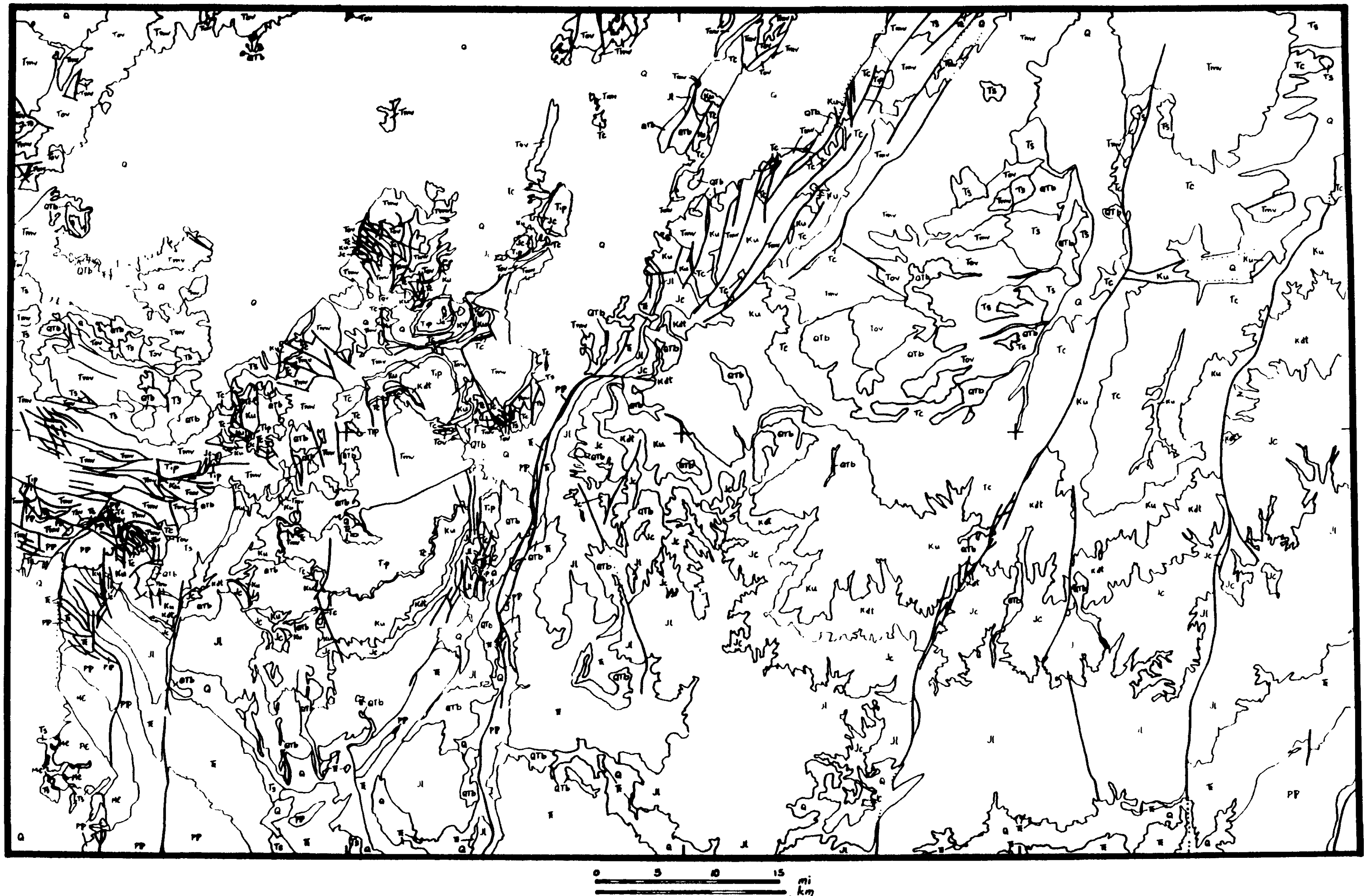


Figure 4.--Geologic map of the Cedar City 1° X 2° quadrangle, Utah, simplified from plate 1.

DESCRIPTION OF MAP UNITS

UNCONSOLIDATED DEPOSITS

Q **Unconsolidated deposits, undivided (Quaternary)**—Miscellaneous surficial deposits, including younger and older alluvium and colluvium, landslides, dunes, and dry or marshy lacustrine sediments

Ts **Quaternary and Neogene deposits (Pleistocene?, Pliocene, and Miocene)**—Miscellaneous poorly consolidated deposits of late Tertiary or younger age; comprised of poorly sorted gravelly deposits of uncertain age, generally deposited on erosional surfaces above present gradients; and variegated, coarse- to fine-grained clastic fluvial rocks, locally with intercalated airfall tuffs, lacustrine rocks, or evaporites, generally deposited in structurally-controlled valleys. Includes Sevier River Formation (Pliocene and Miocene) and Muddy Creek Formation (Miocene)

SEDIMENTARY ROCKS

Tc **Claron Formation (Paleogene)**—Light tan, pink, and rusty red lacustrine, fluvial,and alluvial limestone, calcareous sandstone, conglomerate, and shale; primary features mostly obscured by pedogenic processes; upper part of formation locally is interbedded with, but more commonly overlain by, 32-29 Ma ash-flow tuff; lower Tertiary strata are widespread in the High Plateaus and Basin and Range provinces

Ku **Cretaceous rocks, undivided (Upper Cretaceous)**—Diverse sedimentery rocks, including, on the High Plateaus, fluvial to shallow marine sandstone, shale, mudstone, and pelletal limestone, with local thin to thick beds of bituminous coal (Straight Cliffs Formation, Wahweap Sandstone, and Kaiparowits Formation); in the Basin and Range province, thin-to thick-bedded fluvial sandstone, with subordinate shale, conglomerate, limestone, and coal, and minor bentonitic layers and talus or fanglomerate (Iron Springs Formation); and, in the Bull Valley Mountains, fanglomerate, conglomerate, and sandstone conformabla overlying the Iron Springs Formation and unconformably underlying the Claron Formation (Grapevine Wash Formation)

Kdt **Tropic and Dakota Formations, undivided (Upper Cretaceous)**—An upper sequence of dark gray marine shale with thin sandstone and siltstone beds near top and base, and bentonite beds and nodular limestone in lower part (Tropic Formation), and a lower sequence of westward-thickening fluvial and littoral sandstone interbedded with mudstone, carbonaceous shale, coal, and local basal pebble conglomerate (Dakota Formation)

Jc **Carmel Formation, (Upper? and Middle Jurassic)**—Consists of upper gypsum-bearing sequence of gray-, green-, and red-weathering marine and marginal marine sandstone, siltstone, mudstone, and minor limestone (in High Plateaus, includes Winsor Member, gypsiferous member, and banded member; in Basin and Range province, includes the upper part of the Judd Hollow and Crystal Creek Members); and lower sequence of predominantly silty, dense, oolitic limestone with thin-bedded mudstone, siltstone, and sandstone (includes Homestake Limestone Member in the Iron Springs district)

Jl **Jurassic rocks, undivided (Middle? and Lower Jurassic)**—Thickly crossbedded eolian sandstone with local thin lenses of limy mudstone in upper part (Temple Cap Formation and Navajo Sandstone); crossbedded and planar-bedded fluvial and lacustrine sandstone, siltstone, and shale in middle part (Kayenta Formation); and fluvial crossbedded reddish-brown sandstone, mudstone, siltstone, and claystone in lower part (includes upper Springdale Sandstone, medial Whitmore Canyon, and lower Dinosaur Canyon Members of Moenave Formation)

TR **Triassic terrestrial and marine rocks, undivided (Triassic)**—Includes the Chinle Formation, which is characterized by rapid lateral facies changes and by varicolored fluvial and lacustrine rocks, generally sandy near top, limy, muddy and bentonitic in middle, and sandy and conglomeratic (Shinarump Member) near base; and the Moenkopi Formation, consisting of marginal marine and marine reddish-brown siltstone, mudstone, and calcareous sandstone, with limestone and evaporite tongues that thicken westward (includes six members, an upper red and Shnabkaib Member, a medial red and Virgin Limestone Member, and a lower red and Timpoweap Member)

PP **Upper Paleozoic rocks, undivided (Lower Permian and Pennsylvanian)**—Lower Permian rocks include Kaibab Limestone, Toroweap Formation, and Hermit Shale, consisting of fossiliferous, cherty, dolomitic marine limestone, and calcareous or gypsiferous shale, siltstone, and sandstone; Queantoweap or Coconino sandstone, consisting of light-colored, crossbedded eolian sandstone, with minor continental redbeds; and Pakoon Formation, consisting of cherty dolomitic limestone. Pennsylvanian rocks are comprised of the Callville Limestone, thin-bedded cherty limestone with minor lenticular sandstone and shale

MC **Lower Paleozoic rocks, undivided (Lower Mississippian, Devonian, and Cambrian)**—A thick marine sequence in the Beaver Dam Mountains, including fossiliferous gray limestone with brown to red bedded chert (Redwall Limestone); banded cherty dolomite and minor limestone (Muddy Peak Dolomite, Nopah Dolomite, and Bonanza King Formation); fissile micaceous shale (Bright Angle Shale); and massive very hard quartzite, pebble conglomerate, and minor arkose (Tapeats Quartzite)

VOLCANIC ROCKS

QTb **Basalt (Quaternary to Miocene)**—Alkali-olivine basalt flows, cones,and domes younger than about 2 Ma are widespread in southwestern Uteh; as mapped, includes basalt as old as Miocene in the Modena area

Tmv **Bimodal volcanic rocks, undivided (Miocene)**—Diverse bimodal mafic-silicic igneous rocks. In the Basin and Range province, includes (1) local extensively altered rhyolite, trachyte, and dacite domes and coalescing flows of late Miocene age; (2) near-vent flows, volcaniclastic aprons, and thick local accumulations of ash-flow tuffs of early Miocene age (Rencher Formation, Racer Canyon tuff, Volcanics of Pine Valley, Cove Mountain Formation, Ox Valley Tuff, Blawn Formation, and Steamboat Mountain Formation); and (3) westward-thickening silicic ash-flow tuff sheets of regional extent erupted from probable sources near Caliente, Nevada, in the early Miocene (Harmony Hills Tuff, Condor Canyon Formation, and Leach Canyon Formation of Quichapa Group). On the High Plateaus, includes (1) tectonic slide megabreccia of uncertain age containing blocks derived from Needles Range, Isom, Quichapa, and Mount Dutton volcanic units, and diverse nonvolcanic blocks derived from underlying units; (2) flows and volcaniclastic rocks derived from central-vent volcanoes (Mount Dutton Formation and Bullion Canyon Volcanics); and (3) ash-flow tuff of the Quichapa Group

Tov **Calc-alkaline volcanic rocks, undivided (Early Miocene and Oligocene)**—Diverse calc-alkaline igneous rocks ranging in age from about 31 to 25 Ma, comprised of unnamed deposits from stratovolcanoes on the High Plateaus, and voluminous regional calc-alkaline ash-flow tuff sheets of the Needles Range Group and Isom Formation in the Basin and Range province

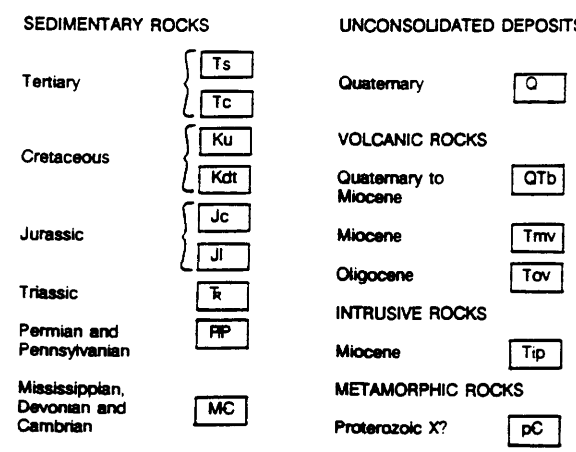
INTRUSIVE ROCKS

Tip **Porphyritic quartz monzonite plutons (Miocene)**—Shallowly-intruded plutons of porphyritic quartz monzonite that are concordant with overlying and underlying stratified rocks; plutons post-date the 21 Ma Harmony Hills Tuff and pre-date the 19 Ma Racer Canyon Tuff; small plutons occur east of the Hurricane fault; west of the fault, they underlie much of the Pine Valley Mounteins and the entire Iron Springs mining district and may extend westward as an intrusive arch beneath the Bull Valley Mountains

METAMORPHIC ROCKS

p€ **Crystalline rocks, undivided (Proterozoic X?)**—Consist chiefly of dark gray diorite gneiss, amphibolite, and sillimanite-bearing schist similar to Vishnu Schist of the Grand Canyon; intricately intruded by pink granitic pegmatite and white graphic granite dikes; exposed only on the west side of the Beaver Dam Mountains; age of intrusive rocks uncertain, but they correlate with rocks in the Grand Canyon that have been dated radiometrically at about 1650 Ma

CORRELATION OF MAP UNITS



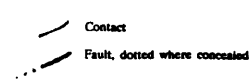


Figure 4.--(continued).

north-south regional topographic gradient across the entire Basin and Range province at the approximate latitude of Cedar City. The gradient separates distinct subprovinces of the Basin and Range province, a northern sector of higher elevation and widely distributed but lesser-magnitude extension, and a southern sector of lower elevation and greater extension (Wernicke and others, 1988).

Extension in the eastern Basin and Range province occurred principally during the last 15 Ma. Relative importance of low-angle normal, high-angle normal, and strike-slip faults in regional extension is the focus of many current studies; each type of fault occurs in the Cedar City quadrangle.

Two types of low-angle normal faults occur in the transition between the High Plateaus and Basin and Range provinces: minor gravity-slide blocks and major detachment faults. Slide blocks as long as 2.5 mi have moved eastward up to 1.2 mi from flanks of domes lifted by rapidly-emplaced shallow intrusions in the Iron Springs district (Mackin, 1960; Blank and Mackin, 1967). Rocks as young as 21 Ma are involved in the movement (Rowley and others, 1979). Similar structures are present in the Pine Valley (Cook, 1957) and Bull Valley (Blank, 1959) Mountains. Wernicke and Axen (1988) describe a middle to late Miocene detachment fault in the Beaver Dam Mountains, where an extensional allochthon broke away from the margin of the Colorado Plateau and slid tens of miles west-southwest off an uplifted basement high. North of the Cedar City quadrangle, formation of the Sevier Desert detachment may be comparable; as interpreted from COCORP deep-seismic data by Allmendinger and others (1983), the detachment plane dips shallowly westward to reach a depth of at least 6 mi.

The main phases of steep basin-range faulting in southwestern Utah seem to be younger than 10 Ma, based on offsets of young volcanic rocks (Rowley and others, 1979; Rowley and others, 1981). Steep faults are abundant in the Basin and Range province; locally, range fronts are 3,000 ft or more in height. To produce the deep grabens evident on gravity records, relative movement on faults must have been at least several times this amount. In the High Plateaus, steep faults are less abundant and displacement on individual faults decreases eastward. Some offset occurred as recently as Pliocene or Pleistocene, inasmuch as the Sevier River Formation near Panguitch shows low but significant dips adjacent to the Sevier fault (E.G. Sable, written commun., 1988). Tectonic disruption of the uplifted edge of the Colorado Plateau continued episodically throughout the Neogene, and Quaternary offset is manifested by various strands of the Hurricane fault system (Anderson, 1978).

Steep faults in the Basin and Range and High Plateaus provinces generally follow north-northeast and north-northwest trends, creating parallel, en-echelon, rhombic, and zig-zag patterns. The faults occur in zones, many of which appear to localize igneous activity and mineral deposits. The complex mosaic of faults, indeed, may reflect instability induced by long-term crustal residence and repeated extrusion of subjacent magma, as well as regional crustal extension (T.A. Steven, oral commun., 1988). As Anderson (1984) emphasized, strike-slip displacement may combine with normal faulting to produce extension. In the western Bull Valley Mountains, the arcuate and branching network of faults has created generally east-west trending grabens, horsts, and tilted blocks. Strike-slip displacement has been inferred on many of these faults, and a sequential development determined locally by Adair (1986) implies regional wrench faulting in response to basin-range extension. These broad zones of strike-slip translation may separate subprovinces in the Basin and Range that are characterized by differing amounts or directions of extension (Shubat and Siders, 1986).

Faults with Holocene offset occur locally (Anderson, 1978); the intermountain seismic belt of Smith and Sbar (1974) approximately follows the boundary between the Basin and Range and Colorado Plateaus provinces, and is intersected by the southern Nevada seismic belt near Cedar City.

The Pioche-Marysvale and Delamar-Iron Springs igneous belts extend east-northeast across southern Utah. These belts contain all of the large calderas, most of the exposed plutons, and many volcanic centers, hot springs, and areas of altered rocks in southwestern Utah. The coincidence of mineral deposits with these belts has been noted at least since the time of Butler and others (1920), and has been described in more detail in numerous subsequent papers (e.g., Shawe and Stewart, 1976; Stewart and others, 1977). The roughly east-west magmatic belts are Oligocene to middle Miocene in age and may be controlled by deep structures, but most surface structures are oblique to the trend. More likely, the belts reflect the recurrent development of magma chambers that were tapped periodically to supply the voluminous ash-flow tuffs and other volcanic rocks of southwestern Utah (T.A. Steven, oral commun., 1988). The belts extend beyond the boundary of the Basin and Range province into the High Plateaus. Their anomalous orientation with respect to regional tectonic patterns has not been explained satisfactorily. Subsequent bimodal mafic-silicic igneous activity tended to follow these earlier belts and was associated with specific mineral deposits, but late Miocene and younger features seem to cut across earlier trends.

GEOLOGIC HISTORY

Phanerozoic stratified rocks in the Cedar City quadrangle have an aggregate thickness in excess of 32,000 ft; more than 13,000 ft of Paleozoic strata, 12,000 ft of Mesozoic strata, and 7,000 ft of Cenozoic strata are exposed. In the Beaver Dam Mountains, the sequence rests unconformably upon Precambrian schist, gneiss, and granite pegmatite, similar to the Vishnu Schist and Zoroaster Granite of the Grand Canyon region (Hintze, 1986).

Paleozoic rocks include a thin transgressive marine lower sequence of Cambrian shelf sandstone and shale; a thick marine medial sequence of Cambrian and Devonian through lower Permian limestone, dolomite, and carbonaceous shale; and an thick upper sequence of eolian sandstone and fluvial redbeds overlain by marine to marginal marine limestone, gypsiferous siltstone, and calcareous sandstone. Several Paleozoic carbonate units contain caverns, sinkholes, or other dissolution features. Many vertically-oriented cylindrical pipes were filled with collapse-breccia from overlying units as solution enlarged them through time. In the Marble Platform region north of the Grand Canyon, about 5 percent of these pipes contain mineral deposits enriched in base metals, silver, and uranium (Wenrich and others, 1988). The pipes have bases in the Mississippian Redwall Limestone, which was exposed for 20 million years following its deposition. Overlying units affected by collapse include rocks at least as young as Triassic. Another 20 million-year hiatus separated deposition of the uppermost Paleozoic Kaibab Limestone and the overlying Mesozoic sequence. During this hiatus, an erosion surface with at least 650 ft of relief and extensive karst was developed upon the Kaibab.

Mesozoic rocks include thick Triassic, Jurassic, and Cretaceous sequences formed mostly in rivers, lakes, dunes, and sabkhas, but also during intermittent marine incursions in all three systems. Marine transgressions were from the west in the Triassic and Jurassic but were from the east in the Cretaceous. The Triassic sequence includes thick marginal marine to fluvial and lacustrine strata that are characterized by marked lateral facies changes from dolomitic mudstone and limestone to carbonaceous conglomerate and sandstone, volcanic claystone, gypsiferous siltstone and bedded gypsum. The evaporite beds form tongues that thicken westward. The Jurassic sequence includes a thick lower interval of fluvial, lacustrine, and eolian sandstone, siltstone, and shale, and a thick upper interval of marine and marginal marine limestone, and gypsum, gypsum-bearing siltstone, mudstone, and sandstone. After a hiatus in sedimentation of about 45 million years, Cretaceous strata of Albian age were deposited above a regional unconformity. These strata resulted from synorogenic sedimentation related to the onset of Sevier thin-skinned thrusting and synorogenic sedimentation (Lawton, 1987). In the eastern part of the quadrangle, the Cretaceous sequence indicates repeated marine incursions from east to west: coal-bearing (and locally uranium-bearing) fluvial and littoral conglomerate and sandstone units at the base are succeeded upward by marine shale, siltstone, and sandstone, and by fluvial to shallow marine coal-bearing sandstone, shale, and minor pelletal limestone. In the western part of the quadrangle, the Cretaceous sequence is entirely nonmarine and thickens markedly toward the thrust belt where it includes several disconformities (Gustason, 1987), as would be expected in an active foreland basin sequence. In the Iron Springs area, the Cretaceous strata include local talus or fanglomerate deposits (Mackin, 1947).

By Cenozoic time, continuing regional deformation and uplift of the Sevier orogeny had created highlands in the area near the western edge of the Cedar City quadrangle, which was the source of detritus shed into adjacent nonmarine basins to the east, where deposition may have been continuous from latest Cretaceous into the early Tertiary (Wiley, 1963). The basal part of the Tertiary section locally was involved in deformation related to eastward-advancing thrust sheets. In the High Plateaus, apparently in most places there was a hiatus between Cretaceous and Tertiary deposition (Rowley and others, 1979), although Bowers (1972) defined intervening stratigraphy in the area of the Table Cliffs Plateau. The lower Tertiary sedimentary sequence consists of fluvial and lacustrine limestone, calcareous sandstone, conglomerate, and shale deposited in a broad, flat basin that extended across most of the Cedar City quadrangle.

In early Oligocene time (about 34 Ma), conditions changed dramatically as calc-alkaline volcanism formed scattered clusters of stratovolcanoes and calderas, and intervening lowlands were covered by widespread sheets of ash-flow tuff (Rowley and others, 1975; Best, 1986a). The Indian Peak caldera complex was active from about 33 to 26 Ma and had at least seven eruptive cycles, which expelled more than 10,000 cubic kilometers of rhyolite, dacite, and andesite ash-flow tuff (Best, 1986a). Nested calderas extend from near Pioche, Nevada, into the Cedar City quadrangle at least as far as Modena, and gravity and magnetic data indicate that they probably continue beneath the northwestern part of the Escalante Desert. In the High Plateaus province, intermediate-composition stratovolcanoes formed in the Marysvale area north of the quadrangle, and related lahars and ash-flow tuffs spread southward as far as the Panguitch area (Anderson and Rowley, 1975; Steven and others, 1979). During Miocene time in the High Plateaus province, complexly interfingering flows, flow breccia, and volcaniclastic detritus derived from the Marysvale area were interlayered with regional ash-flow tuff units from the Basin and Range province to the west. In the western Markagunt Plateau, these units are mixed in slide megabreccias (Sable and Anderson, 1985).

The ash-flow tuff province of southwestern Utah extends over most of the northwestern part of the Cedar City quadrangle. From about 26 to 19 Ma, the area was a broad plain across which spread thin regional ash-flow tuff sheets derived from sources in the Basin and Range province, including the Caliente cauldron complex just west of the Cedar City quadrangle. The ash-flow tuffs pinch out against andesitic stratovolcanoes, which rose above the plain locally along the Pioche-Marysvale and Delamar-Iron Springs igneous belts. The stratovolcanoes shed andesitic debris that is intercalated in places with ash-flow tuff sheets.

At about 20 Ma, laccoliths of porphyritic quartz monzonite intruded Mesozoic and Cenozoic sedimentary strata in the Iron Springs district (Mackin, 1960, 1968; Rowley and Barker, 1978), and were the source of major replacement iron ore bodies in limestone of the Carmel Formation. To the southwest, Blank (1959) showed that the similar Bull Valley pluton occupies the core of an eruptive complex; it also has been explored for iron (Tobey, 1976). The Mineral Mountain pluton, near the west edge of the map, may be part of the same volcanic and plutonic belt (Cook, 1960).

Throughout later Cenozoic time, episodic volcanism produced bimodal assemblages of basalt lava flows and high-silica alkali rhyolite lava flows, domes, and epiclastic rocks, which were erupted from numerous local centers. Their total volume, however, is much less than that of the older calc-alkaline volcanic rocks. The basalt flows are widespread but generally of small volume. Although the rhyolitic rocks are restricted and of small volume in the Cedar City quadrangle, in the Pioche-Marysvale igneous belt to the north, they form major composite accumulations. Many of the rhyolite centers include dike swarms and shallow porphyritic intrusions (Keith, 1980; Keith and others, 1986; Best and others, 1987). Hydrothermal activity accompanied episodes of silicic magmatism in both the Basin and Range (Steven and Morris, 1984, 1987; Best and others, 1987) and the High Plateaus (Steven and others, 1979) provinces. Circulation of hydrothermal fluids was focused along zones of concurrent faulting. Altered volcanic and adjacent nonvolcanic rocks are extensive in the Antelope Range (Shubat and McIntosh, 1988), the western Bull Valley Mountains (Limbach and Pansze, 1987), the Escalante district (Siders and Shubat (1986), and north of the Escalante Desert (Best and others, 1987), where they are coextensive with altered rocks in the southwest part of the Richfield quadrangle (Steven and Morris, 1984, 1987). Productive silver veins in the Escalante and Antelope Range districts were formed at about the same time nearby volcanic domes, fissures, and breccias were erupted (Siders and Shubat, 1986).

Basin-range faulting produced numerous local basins in which volcaniclastic and sedimentary rocks were deposited in the Neogene. In the High Plateaus province, structural basins are less deep than in the Basin and Range province and drainage is fairly well-integrated: the deepest fill (in the area of the Sevier fault) is on the order of 1,150 ft (Rowley and others, 1979). In the Basin and Range province, many basins are several thousand ft or more deep, and drainage is not well-integrated; some grabens may have had only interior drainage throughout their histories and may have accumulated very thick sequences of basin fill, including evaporites, as they have to the north in the Sevier Desert (Lindsey and others, 1981). A prominent gravity low west of the Antelope Range, for example, has been interpreted by Pe and Cook (1980) as the Newcastle graben that may contain 9,800 ft or more of basin-fill.

STATUS OF GEOLOGIC MAPPING

Figures 5 through 9 show the current status of geologic mapping in the Cedar City 1° X 2° quadrangle. Areas encompassed by individual maps are outlined on the figures and are labeled with the name of the authors and year of publication. Geologic maps have been separated as follows:

Figure 5 - Maps published by the USGS, excluding 1:24,000-scale maps;
Figure 6 - Maps published by the USGS, 1:24,000-scale;
Figure 7 - Maps published by the Utah Geological and Mineral Survey (UGMS) (all scales);
Figure 8 - Maps in theses (all scales);
Figure 9 - Maps from other sources (journal articles, guidebooks, etc.).

In total, the figures show locations of 114 geologic maps. Sources of information for this compilation include the USGS index to geologic maps in Utah (McIntosh and Eister, 1979), an unpublished index to geologic maps compiled by Russell Knight of the UGMS, an index to geologic thesis maps in Utah (Knight, 1985), and a review of current literature.

CURRENT ACTIVITIES

U.S. Geological Survey (USGS)

A major project of the National Geologic Mapping Program in the Office of Regional Geology is underway in the region of structural transition from the Basin and Range province to the Colorado Plateau province (BARCO) in southeastern Nevada, southwestern Utah, and northwestern Arizona. The 5-year project is coordinated by R.B. Scott, and encompasses eight 1:100,000-scale quadrangles, including all four quarters of the Cedar City 1:250,000-scale quadrangle. The objectives of the project include mapping and compiling the geologic framework with emphasis on the late Mesozoic and Cenozoic tectonic and magmatic evolution of the region. Many USGS scientists, including specialists in sedimentary and volcanic stratigraphy, petrology, structural geology and neotectonics, Quaternary geology and geomorphology, geochronology, geophysics, and paleomagnetics are participating in the project, and are cooperating with academic and state survey colleagues. Although the ultimate compilation scale for geologic maps is 1:100,000, much new geologic mapping at a scale of 1:24,000 or 1:50,000 will be completed during the duration of the project. The timetable and USGS personnel who currently are responsible for compilation of individual 1:100,000 quadrangles within the Cedar City 1:250,000 quadrangle are:

Kanab (1989): E.G. Sable, R.W. Hereford
Panguitch (1990): E.G. Sable, R.W. Hereford
Saint George (1992): E.G. Sable, R.E. Anderson, and H.R. Blank, Jr.
Cedar City (1992): H.R. Blank, Jr., and P.D. Rowley

Utah Geological and Mineral Survey (UGMS)

In southwestern Utah, the UGMS has active programs to prepare geologic maps of mining districts, to inventory metal, energy, and industrial mineral resources, and to develop and update computerized resource data bases. Recently completed geologic maps include a tier of quadrangle maps extending from the Antelope Range district through the Escalante district to the Nevada border (Siders, 1985a,b, 1986; Shubat and Siders, 1988). A summary report has recently been completed on the geology and mineral potential of the Antelope Range district (Shubat and McIntosh, 1988). A compilation of the geology and mineral resources of Kane County is soon to be released (Doelling, in

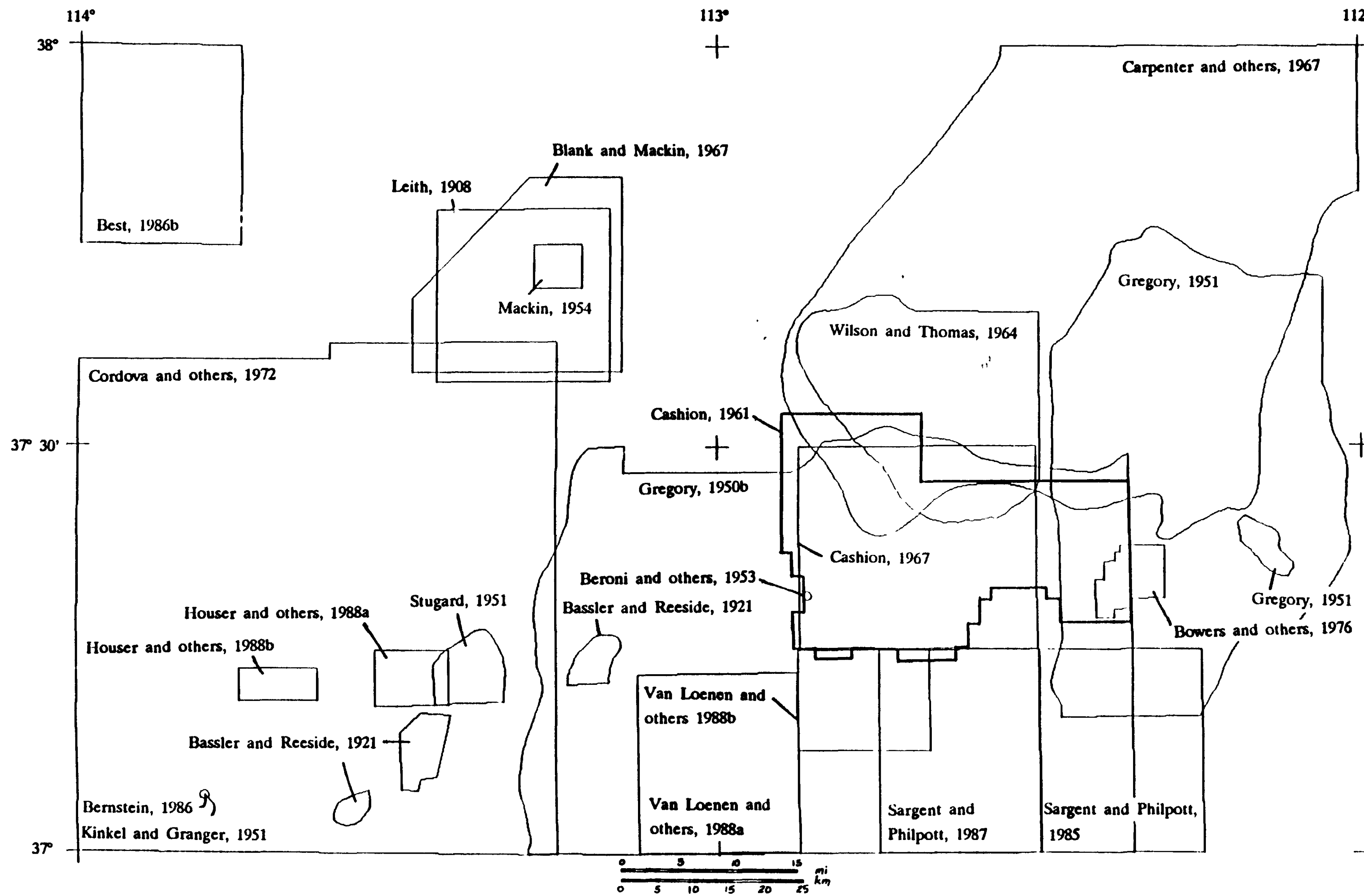


Figure 5.--Index to geologic maps published by the U.S. Geological Survey (exclusive of 1:24,000 scale maps) in the Cedar City 1° X 2° quadrangle, Utah.

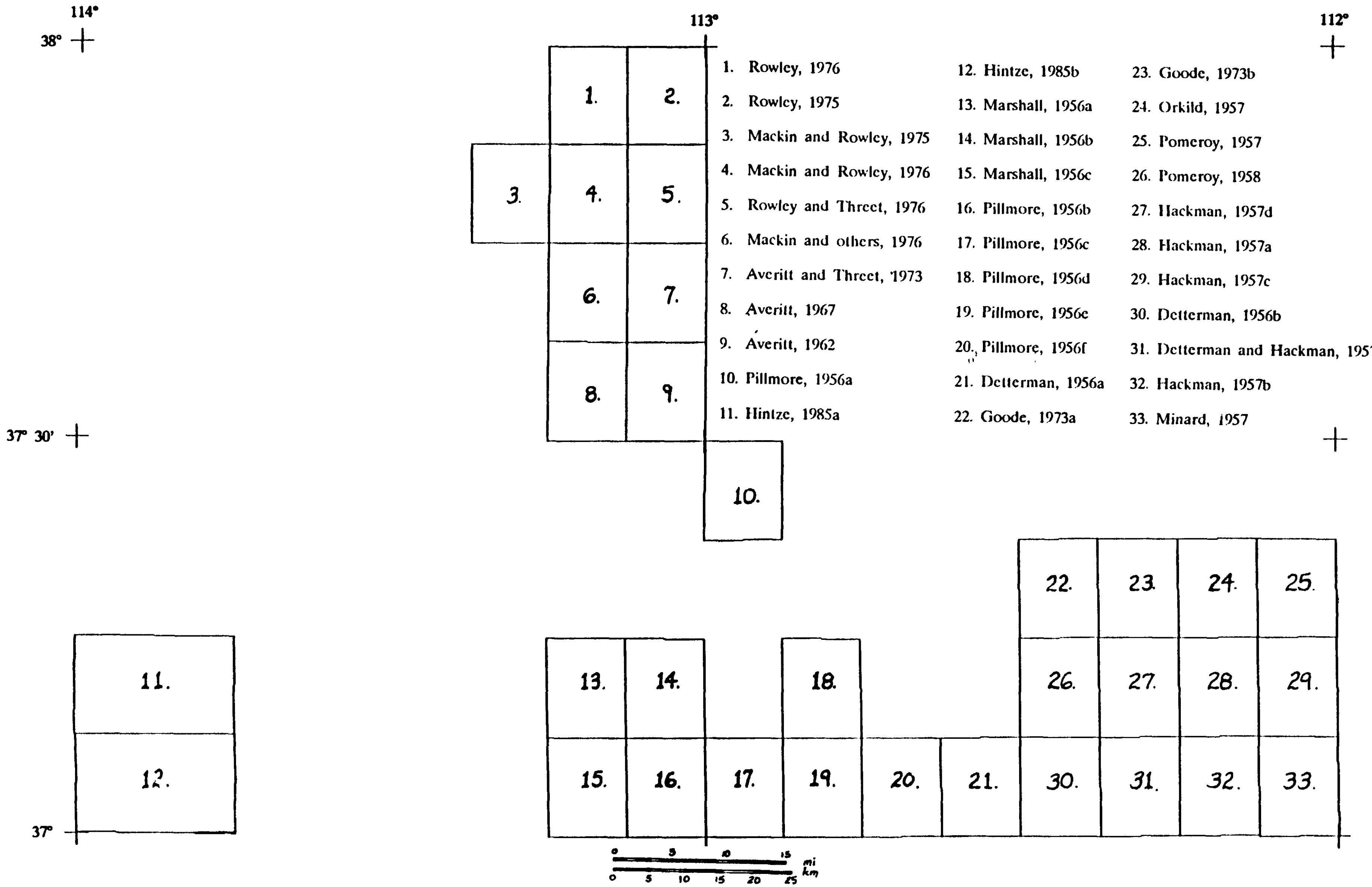


Figure 6.--Index to 1:24,000 scale geologic maps published by the U.S. Geological Survey in the Cedar City 1° X 2° quadrangle, Utah.

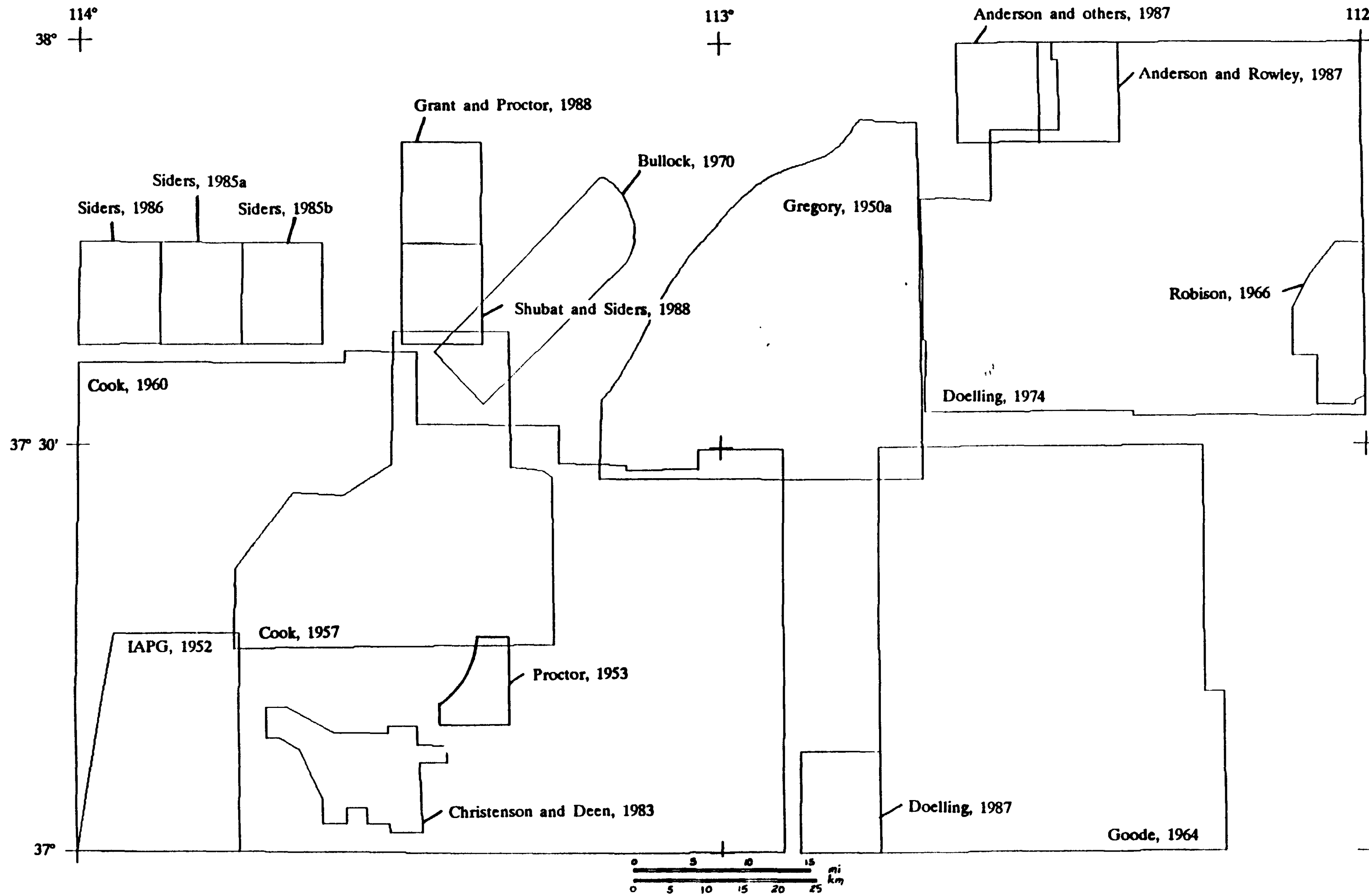


Figure 7.--Index to geologic maps published by the Utah Geological and Mineral Survey in the Cedar City 1° X 2° quadrangle, Utah.

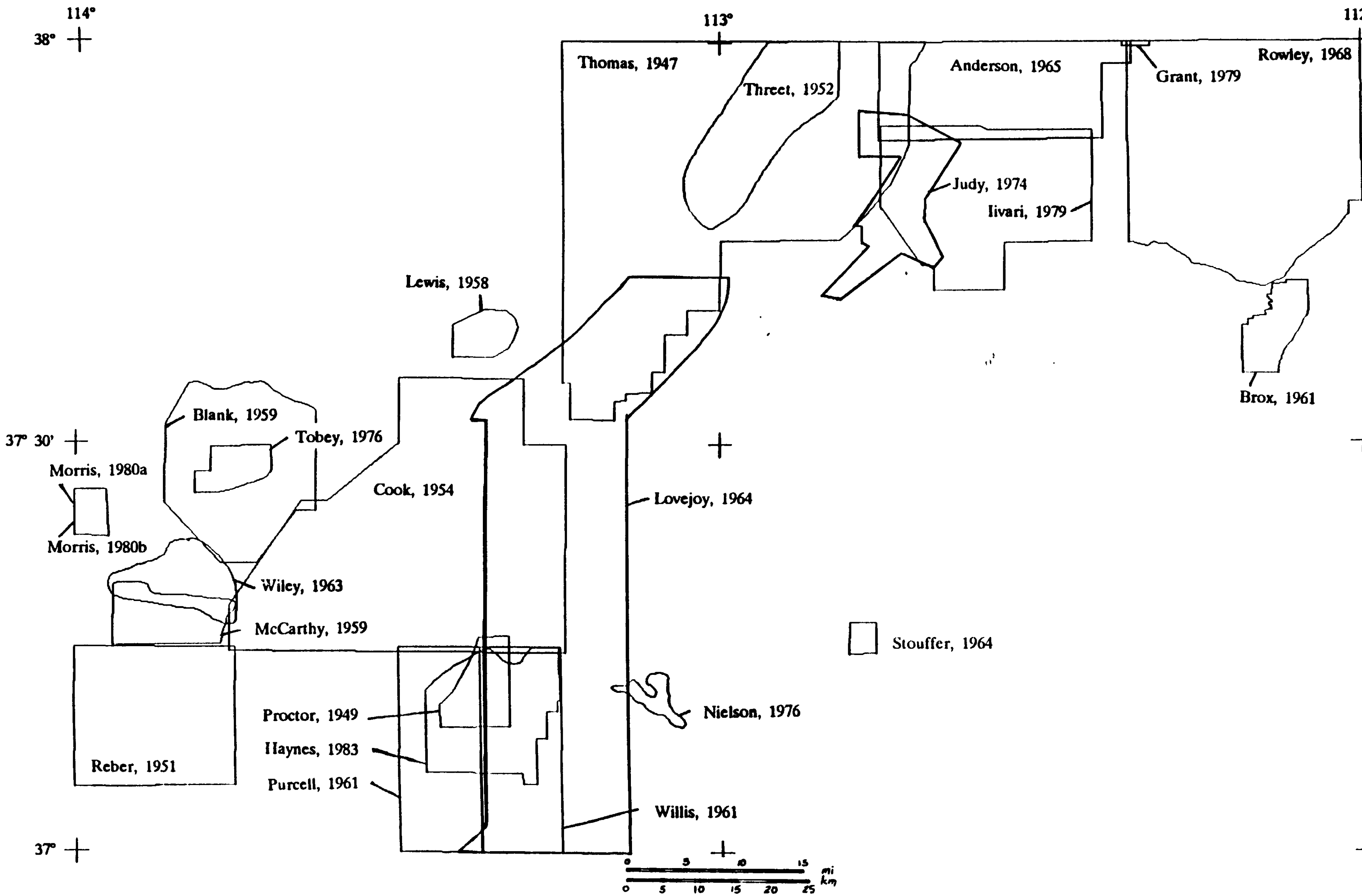


Figure 8.--Index to geologic thesis maps in the Cedar City 1° X 2° quadrangle, Utah.

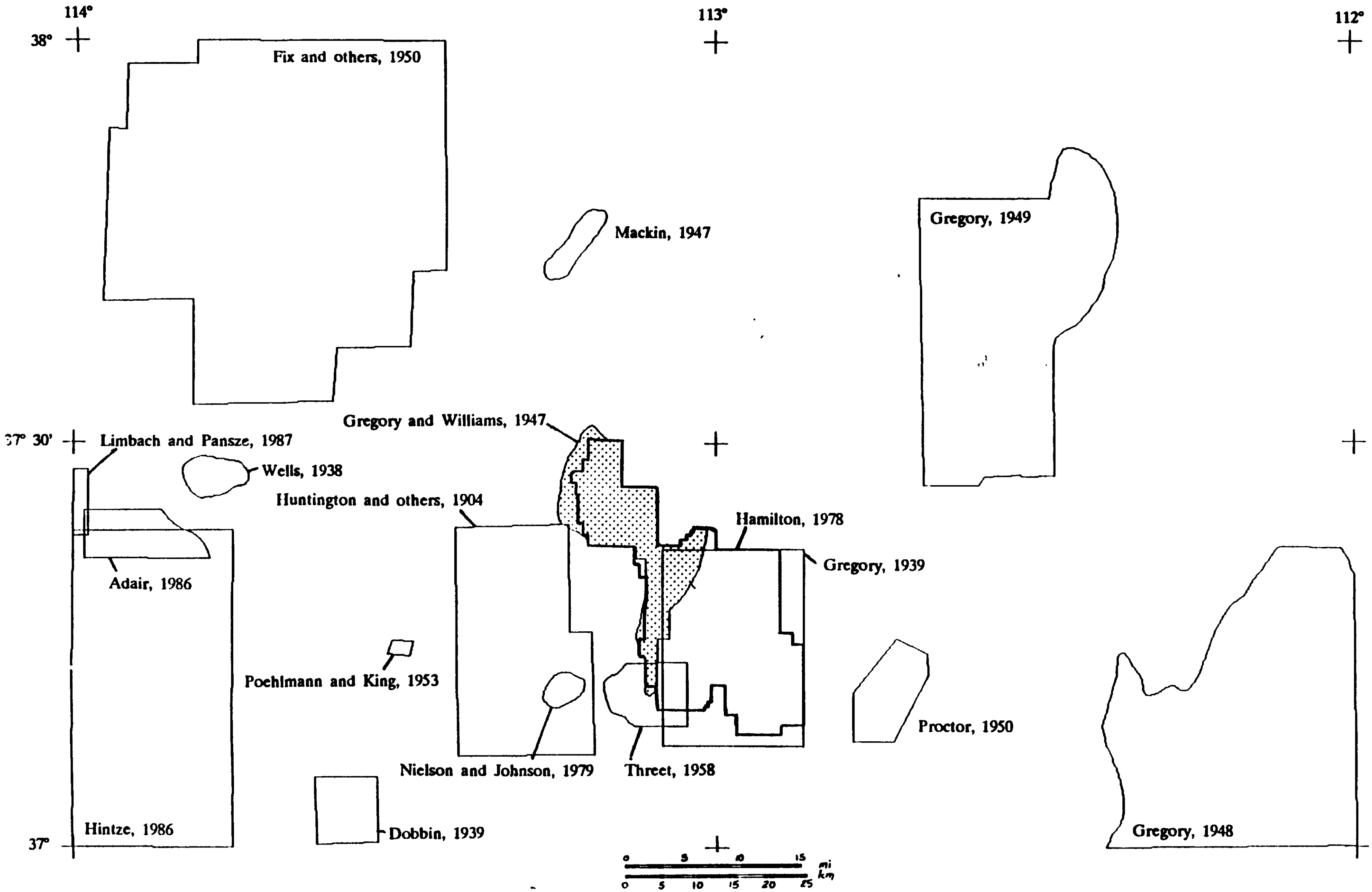


Figure 9.--Index to geologic maps from other sources in the Cedar City 1° X 2° quadrangle, Utah.

press). The UGMS has published a study on the geothermal potential of the St. George area (Budding and Sommer, 1986), and is currently studying the geothermal potential of the Newcastle Known Geothermal Resource Area under joint UGMS-Department of Energy funding.

Universities

Brigham Young University (BYU): For many years, BYU summer field camps under the general direction of Lehi F. Hintze, Myron G. Best, J. Keith Rigby, and others have been located in southwestern Utah. Much of the current understanding of the regional stratigraphy and structure, particularly in the Paleozoic sequences, has been developed by Hintze and his students, who continue with active field studies in the area. Recent publications by Hintze and associates include numerous geologic maps in the Beaver Dam Mountains and Gunlock-Motoqua areas in the southwestern part of the Cedar City quadrangle. Best and his students have defined much of the Tertiary volcanic stratigraphy of the Basin and Range province, and continue with active programs, having published several recent geologic maps in the northwest part of the Cedar City quadrangle and contiguous parts of the Richfield quadrangle to the north. Recent work by Rigby and his students has focused on uppermost Paleozoic and Mesozoic sequences in the region, and on late Cenozoic basaltic volcanism.

University of Utah: Erich U. Petersen and students are studying the geologic setting of the Apex gallium-germanium mine in the Beaver Dam Mountains, and are carrying out detailed investigations of the mineralogy and paragenesis of the deposit.

Kent State University: In the southwestern High Plateaus, John J. Anderson has been studying the Tertiary stratigraphy, particularly of the volcanic rocks, for more than 20 years. Anderson currently is completing geologic maps of several 7.5' quadrangles east of Parowan. One of his students currently is studying stratigraphy and sedimentology of the early Tertiary Claron Formation in the area.

Harvard University: Brian Wernicke and Gary Axen (also of Northern Arizona University) are collaborating with John M. Bartley (Univ. of Utah) in studies of regional structural patterns in the Basin and Range province, particularly tectonic styles of extensional and detachment faulting. Their work along the eastern margin of the province includes structural studies in the Beaver Dam Mountains.

University of Nevada-Reno: James E. Trexler and his students are studying facies relations between late Mesozoic and early Tertiary strata in the High Plateaus. Their initial work is northeast of the Cedar City quadrangle in the North Horn and Flagstaff Formations, but will bear on problems in distinguishing Claron from subjacent units within the quadrangle. In addition, Trexler is continuing his work on broad facies distributions within Mesozoic sequences of the Colorado Plateau.

New Mexico State University: Timothy F. Lawton and his students are studying Cretaceous synorogenic clastic deposits in the foreland of the Sevier orogenic belt throughout the Rocky Mountains. Most of their work has been in central Utah north of the Cedar City quadrangle, but it provides information on rocks correlative with Upper Cretaceous units in the Cedar City quadrangle.

Industry

BP Minerals: Personnel are conducting exploration in Antelope Range for precious metals.

Geneva Steel: Leasers are producing 400,000 tons/year from mines at Desert Mound (Iron Springs district) for steel production at the Geneva Works, Orem, Utah.

Hecla Mining Company: The Escalante silver mine was closed on Dec. 31, 1988. The mill will remain active by milling ore stockpiles until 1990.

Homestake Mining Company: Personnel conducted an extensive exploration program for precious metals in Antelope, Goldstrike, Mineral Mountain, Modena, Gold Springs, and Stateline districts in the 1980s; apparently the company has no current activity in the Cedar City quadrangle.

Musto Explorations, Ltd. (St. George Mining Corp.): This former operator of the Apex Ga-Ge mine and mill in Beaver Dam Mountains is now under Chapter 11 bankruptcy proceedings and is looking for a purchaser.

Tenneco Minerals: The company is developing the recently discovered Goldstrike mine, where gold mined from open pits is scheduled for production by heap leach methods in 1989.

RECOMMENDATIONS FOR ADDITIONAL GEOLOGIC STUDIES

Although geologic studies have been conducted in the Cedar City region for more than 100 years, much remains to be learned about the physical, chemical, and biological controls for the numerous types of mineral and energy resources that occur widely in the region. The following paragraphs briefly describe nine topics that are focused on the structural, stratigraphic, and petrologic features of known host rocks or of sequences with favorable characteristics. Such topical investigations can be expected to provide exploration criteria for delineating additional as yet undiscovered mineral resources. Additional background data about specific mineral deposits or mining districts mentioned in these recommendations will be found in the ensuing sections of this report.

The Precambrian complex of the Beaver Dam Mountains

Precambrian crystalline rocks are well exposed on the west side of the Beaver Dam Mountains, but have been studied only in reconnaissance. The rocks consist of strongly foliated schist intricately intruded by pegmatitic granite dikes, and have been correlated with rocks exposed in the inner gorges of the Colorado River in Arizona. The granitic rocks have not been dated, nor is the age of metamorphism of the enclosing rocks known. At least three types of mineral deposits are found in comparable Precambrian complexes elsewhere in the region, but their potential occurrence has not been evaluated in the Beaver Dam Mountains. First, the pegmatites have not been explored systematically for possible gemstone deposits, nor has their trace element chemistry been analyzed carefully for the presence of beryllium, lithium, tin, or other elements known to occur in specialized pegmatites. The presence of tin- or tungsten-bearing skarns, greisens, or stockwork vein systems associated with the intrusive contacts likewise has not been evaluated. Second, only brief descriptions of the schists have been published, and protoliths have not been inferred. Mafic metamorphic rocks in the Bunkerville district in the Virgin Mountains to the south, which are probable correlatives, are known to be rich in palladium and platinum, but whether high concentrations of these metals extend northward is not known. Third, the Precambrian complex is the footwall beneath a major low-angle detachment surface, and needs to be thoroughly scrutinized for gold and base metal-bearing fractures and veins that might have been produced during or after the episode of low-angle faulting. Such surfaces have served as pathways for base- and precious-metal mineralization elsewhere in the Basin and Range province.

The Paleozoic sequence in the Goldstrike-Mineral Mountain area

Although Paleozoic stratigraphy has been studied thoroughly in the Beaver Dam Mountains, relations are less well known to the north in the Goldstrike district. Additional work on at least four aspects of the Paleozoic sequences will have important bearing on evaluating potential mineral resources. First, the Mississippian sequence in the Goldstrike area needs to be mapped carefully, and this detailed mapping needs to be extended westward beyond Mineral Mountain. Apparently, the Chainman Shale and the Scotty Peak Quartzite are present, although they do not occur in the Beaver Dam Mountains. The extent of the dark, carbonaceous Chainman Shale, particularly, is critical, as the unit provides a source for both organic carbon and metals. The Scotty Wash Quartzite locally contains small amounts of gold. Second, much of the Paleozoic sequence consists of carbonate rocks, some of which are altered to jasperoid that locally bears gold. Are these jasperoids confined to particular stratigraphic levels, such as sandy beds in the Permian Pakoon Dolomite? Or are several levels within the Paleozoic sequence susceptible to silicification? Third, the stratigraphic settings for mineralized solution-collapse breccias in the Paleozoic carbonate sequences need to be examined carefully. Past exploration for such deposits generally has focused on their structural control. Solution breccias have been mined, at several stratigraphic levels, for uranium and base metals in the Grand Canyon region, and for gallium and germanium at the Apex Mine west of St. George. Fourth, contacts between favorable Paleozoic carbonate rocks and Cenozoic igneous rocks, particularly shallow intrusions, need to be mapped in greater detail, and altered rocks potentially associated with concealed plutons need to be distinguished carefully. Highly productive silver-rich base metal replacement deposits and affiliated vein systems in nearby districts are localized along such contacts.

Nature and extent of the Claron Formation in the Basin and Range province

In the Goldstrike district, the Tertiary fluvial and lacustrine Claron Formation contains disseminated gold. However, only broad geologic and structural features of the district have been described. Ore-grade gold apparently is limited to basal units in the Claron Formation, which rest unconformably upon diverse underlying units. Are these gold occurrences related to the unconformity, and hence widespread? Are the gold occurrences confined to areas where the subjacent rocks are Paleozoic carbonate rocks that contain gold-bearing veins? There is virtually no contemporary data on gold-bearing veins. Does the gold occur only in silicified zones, which locally follow the contact? So little has been published on the chemistry and mineralogy of widespread altered rocks of the Claron Formation that their potential significance with respect to mineralization cannot be evaluated. Does gold occur near contacts between young andesitic plugs and calcareous facies within the Claron Formation? The NURE geochemistry indicates broad chemical differences in the Claron Formation, which locally is magnesium-rich. This pattern could be interpreted as dolomitization related to hydrothermal activity. At the present level of knowledge, any of these alternatives is plausible, but each prompts very different exploration strategies.

Stratigraphy and chronology of Tertiary igneous rocks in the Basin and Range province

The volcanic and shallow intrusive rocks in the west-central part of the Cedar City quadrangle are known in lesser detail than igneous rocks elsewhere in southwest Utah. However, the emplacement of the igneous rocks greatly influenced the locations and tenor of many epithermal precious-metal mineral deposits. In the area of the Escalante Desert, further study of the local volcanic units that host the Escalante silver mine is needed in order to test correlations with regional units. Rhyolite flows and coalescing domes seem to be more widespread in the area of the Escalante Desert, and were extruded from east-trending fissures. How are they related to the silicic breccias that in several areas are mineralized? Did the rhyolite domes act as heat sources for mineralizing events? Do the rhyolites mark one rim of a caldera system? Where are the sources for the tuffs in the Bull Valley Mountains?

Age and petrochemistry of intrusions

Many monzonite to quartz monzonite intrusions occur in the Cedar City quadrangle, several of which are intimately associated with large resources of iron. The ore-related intrusions occur along a linear trend, the "Iron Axis," whereas unmineralized (but otherwise analogous) intrusions occur off the axis. Are there differences in age and composition between ore-related and barren intrusions? High-precision $^{40}Ar/^{39}Ar$ dating combined with modeling of fractional crystallization/partial melting might resolve subtle differences between these intrusions. It also is possible that no significant petrogenetic differences exist between the intrusions and that formation of iron skarns is related strictly to the mechanical circumstances of intrusion.

Relations between intrusion, extrusion, and faulting

In the western Cedar City quadrangle, a complex history of compressional and extensional deformation created upper crustal structures that helped to control locations of Tertiary igneous activity and associated mineral deposits. Structural styles created by both the Sevier orogeny and basin-range deformation need additional detailed investigation. For example, the relation of the Mineral Mountain intrusion to a faulted anticline of Sevier age in the surrounding Paleozoic rocks has not been established and the geology needs to be mapped carefully. In the Iron Springs district to the east, structural control was critical in localizing iron-bearing plutons that apparently have comparable petrology and age to the Mineral Mountain intrusion. The amount of displacement on Sevier thrusts that involve the Paleozoic sequence (such as the Goldstrike thrust) also is an important topic for further work, and will require regional sedimentary facies analysis of Paleozoic sequences, as well as structural analysis. The chronology of basin-range high-angle faulting and relations with silicic volcanism seem to be particularly important topics for additional investigation. In the Antelope Range, for example, the coincidence of faults and shallow silicic intrusions with the richest silver-bearing veins is striking, and the same controls may be important for the silver veins of the Escalante district. Detailed geologic mapping and dating of igneous rocks and mineralized veins by $^{40}Ar/^{39}Ar$, will elucidate the chronology of events in districts, yielding a better understanding of deposit genesis.

Relation of gold-bearing veins in Gold Springs and Stateline districts to the Indian Peak caldera complex

Two formerly-productive mining districts, Gold Springs and Stateline, are located near the western boundary of the Cedar City quadrangle. They occur within an area that has been mapped only in reconnaissance, but which straddles the proposed margin of the Indian Peak caldera complex. Preliminary work in the districts indicates that the gold-bearing veins are hosted by Oligocene andesitic rocks, and that the veins and their controlling structures are overlain unconformably by ash-flow tuff sheets. If these age relations can be verified, the identity of the overlying tuffs ascertained, and adularia from the veins dated, it may be possible to document a pre-Miocene, gold-rich mineralizing event with significant potential in the northwest part of the Cedar City quadrangle. Mapping of the districts also may show a genetic link with the Indian Peak caldera complex.

Detailed study of the Escalante district

Several productive epithermal districts in the Cedar City quadrangle have received surprisingly little detailed study of their trace and rare-earth element geochemistry, isotopic signatures, temperatures of formation, and chronology of mineralizing events. For example, in the Escalante district, which is one of the larger silver producers in the western United States, the mineralogy of the bonanza veins and host rocks has not been described thoroughly, and there have been no geochemical studies published on the contrasts between mineralized and barren veins. The latter crop out widely near the productive veins. Much more information is needed on the temperatures, salinities, and isotopic compositions of ore and gangue minerals before paragenetic relations can be established and before the veins can be linked to specific igneous or tectonic events.

Patterns and displacement histories of faults in the Basin and Range province

Most precious-metal deposits in the eastern Basin and Range province are located along high-angle faults of Oligocene and younger age. Many deposits are found at intersections of separate fault systems. They apparently formed where shallow structures provided access to deeply-circulating heated water. The study of fault patterns and their relation to precious- and base-metal mineral occurrences that is underway to the north in the Richfield quadrangle should be extended into the Cedar City quadrangle. For example, in the Bull Valley Mountains, geologic mapping to date has indicated a complex network of NE- and NW-trending high-angle faults and widespread hydrothermally altered rocks. The timing, sense, and amount of offset along the disparate traces, and their relation to altered rocks, however, are not known adequately yet. From an exploration standpoint, information on displacement histories of faults that cut or controlled known mineral deposits is especially important. It may become possible to project with confidence the trends of favorable systems onto pediment surfaces beneath cover.

Basin-range faults also are numerous in the westernmost Markagunt Plateau and the Red Hills, where they are not known to be mineralized. Detailed structural analysis of these faults is needed, both because of their bearing on Cenozoic development of the Hurricane fault system and their role in the structural differentiation between the High Plateaus and the eastern Basin and Range provinces.

Section 4 GEOPHYSICAL STUDIES, by H.R. Blank and J.K. Crowley

INTRODUCTION

Existing geophysical data for the Cedar City 1° X 2° quadrangle consist of regional aeromagnetic, aeroradiometric, and gravity surveys, remote sensing imagery (LANDSAT MSS and TM data), and seismic reflection profiles. The LANDSAT TM and seismic reflection data are available from the private sector. Each of these data sets can provide certain unique constraints and insights for geologic framework synthesis and mineral resource assessment.

AEROMAGNETICS

Data

Because of the presence of extensive deposits of magnetic iron ore in the Iron Springs and Bull Valley districts, magnetometer surveys have long been employed in the region as a direct aid to exploration. The earliest surveys were carried out on the ground by the U.S. Bureau of Mines (Cook, 1950a) and by private investigators. Subsequently an aeromagnetic survey of the Iron Springs district was made by the USGS with the objective of delineating the subsurface extent of quartz monzonite porphyry intrusions associated with the ore (Blank and Mackin, 1967), and U.S. Steel Corporation (now USX) flew a detailed survey of the entire "iron axis" of southwest Utah. The U.S. Steel data have been purchased and digitized by the USGS, and are currently being interpreted as a component of the "BARCO" project of the National Geologic Mapping Program. Remaining portions of the Cedar City 1° X 2° quadrangle are included in regional surveys of the Basin and Range (USGS, 1972) and Colorado Plateau (Shuey and others, 1973) provinces. The results of both these regional surveys have been published as part of a residual total intensity aeromagnetic map of Utah at scale 1:1,000,000 (Zietz and others, 1976). Flight elevations were 9,000 ft for the Basin and Range province and 12,000 ft for the Colorado Plateau. The traverse spacing, 2 miles, is considerably wider than the optimum for studies at 1:250,000-scale or larger. The two surveys overlap in part along the Hurricane Fault zone. The overlap is incomplete, and the traverse headings are north-south, so that in general the traverses tend to parallel rather than cut across structural trends. This leads to uncertainties in interpreting the aeromagnetic data at the critical province boundary. The problem is somewhat mitigated by an aeromagnetic and spectral aeroradiometric survey flown for the National Uranium Resource Evaluation Program (NURE). This survey collected data of both kinds simultaneously along east-west traverses spaced 3 miles apart at a nominal 400 ft above terrain (Geodata International, 1980).

Qualitative interpretation of the aeromagnetic and gravity fields over parts of the Cedar City 1° X 2° quadrangle are given in USGS reports on BLM wilderness study areas (WSA) by Van Loenen and others (1988 a, b; 1989 a, b), Houser and others (1988 a, b) and Conrad and others (in preparation). An index of USGS reports on BLM WSA's is given on figure 10. Also shown on figure 10 are locations of the US Steel-Iron Axis and USGS-Iron Springs aeromagnetic surveys and gravity surveys by the University of Utah group.

Figure 11 presents a composited residual total-intensity aeromagnetic anomaly map of the Cedar City quadrangle. NURE data was used in only a small area, which fills a narrow gap between surveys done by the USGS and Univ. of Utah. All data are at the original flight altitudes (9,000 ft, 12,000 ft, 400

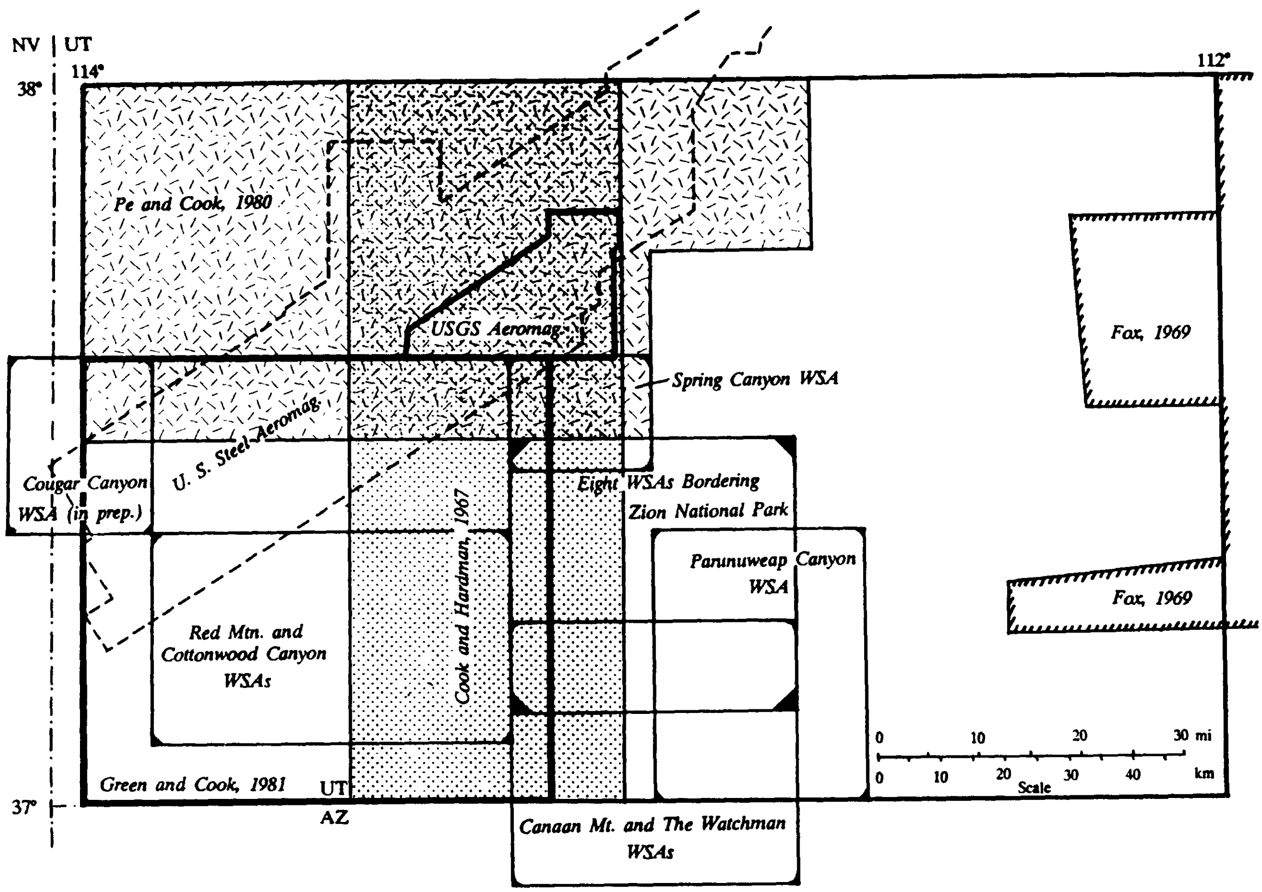


Figure 10.--Index map showing location of aeromagnetic and gravity studies, Cedar City 1° X 2° quadrangle, Utah. Basin-Range and Colorado Plateau aeromagnetic surveys by USGS (1972) and University of Utah (Shuey and others, 1973) are omitted. NURE aeromagnetic and aeroradiometric surveys cover the entire quadrangle at broad spacing (Geodata International, 1980).

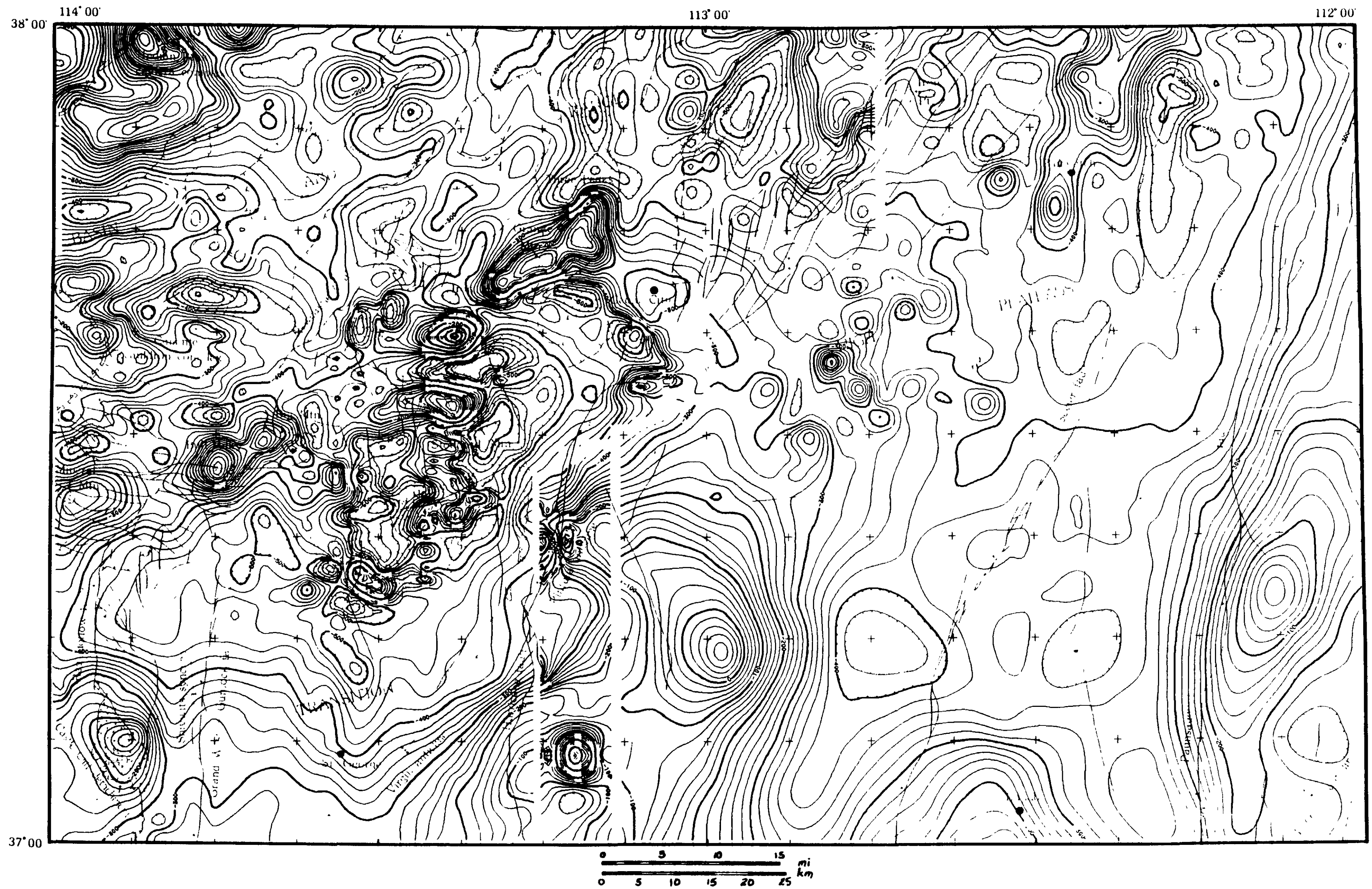


Figure 11.--Residual total-intensity aeromagnetic map of Cedar City 1° X 2° quadrangle, Utah. Contour interval 20 nT. Sources of data: West-U.S. Geological Survey (1972), N-S traverse headings, 9000 ft bar. elevation, 2 mile traverse spacing; Central-Geodata International (1980), E-W traverse headings, 400 ft. terrain clearance (drape), 3 mile traverse spacing; East-R.T. Shuey (Univ. of Utah, written communication, 1986), N-S traverse headings, 12,000 bar. elevation, 2 mile traverse spacing.

ft-drape). The contour interval is 20 nanoteslas and the International Geomagnetic Reference Field has been removed.

Interpretation

By combining the published 1:1,000,000-scale total-intensity aeromagnetic maps of Utah (Zietz and others, 1976), Nevada (Zietz and others, 1978), and Arizona (Sauck and Sumner, 1970), the Cedar City 1° X 2° quadrangle can be placed in a regional aeromagnetic setting (figure 12). Several first-order aeromagnetic anomaly features are apparent:

(1) The northwest part of the quadrangle is transected by an east- to east-northeast-trending system of aeromagnetic anomalies associated with the Pioche-Marysvale mineral belt (Shawe and Stewart, 1976; Stewart and others, 1977; Rowley and others, 1978). This belt is a locus of Cenozoic igneous and hydrothermal activity and mineralization. Its aeromagnetic signature consists of numerous intense, relatively short-wavelength and predominantly positive anomalies superimposed on the regional high whose outline is sketched in the figure. In some cases the short-wavelength anomalies are clearly produced by Tertiary granitic stocks, or by thick piles of Tertiary volcanic rocks. North of the quadrangle, in the Mineral Mountains, these anomalies may be due in part to Proterozoic crystalline basement rocks, and at the extreme west end of the mineral belt, near the south end of Cave Valley, Nevada, they are associated with a Mesozoic pluton. Because of the predominantly Tertiary age of magmatism in the belt and the fact that it is generally a region of low, rather than high, Bouguer gravity anomaly levels, the long-wavelength component of the anomaly system is believed due mainly to deep-seated Tertiary plutons rather than to Mesozoic plutons or to the much denser Precambrian crystalline basement. Many of the most prominent local anomalies of the belt probably represent concealed Tertiary intrusions, and hence, potential exploration targets as loci of hydrothermally altered rocks and epithermal mineral deposits.

(2) The "iron axis" of southwestern Utah is revealed as a set of discrete positive anomalies trending more or less northeast, approximately parallel to the southeastern margin of the Pioche-Marysvale belt. These anomalies represent the disposition of Tertiary quartz monzonite intrusions, with relatively minor contributions from associated iron deposits.

(3) Broad anomaly highs occur over the Beaver Dam Mountains, where Precambrian rocks are exposed, and over parts of the Colorado Plateau, where Precambrian basement lies at a depth of 1-3 mi beneath the surface. Since there are no known or suspected sources of detectable long-wavelength anomalies within the Phanerozoic sedimentary section, these anomalies must arise either from intrabasement inhomogeneities or from local structural or topographic relief on the basement surface.

Figure 13 is an interpretive sketch map of principal anomalies from the residual aeromagnetic map on figure 11. On figure 13 we identify anomalies spatially associated with the Indian Peak and Caliente caldera complexes of the Pioche-Marysvale mineral belt; anomalies associated with quartz monzonite intrusions of "iron axis" affinity, including the Mineral Mountain and Pine Valley bodies; anomalies of unknown origin but probably produced by buried monzonitic intrusions beneath Sevier Valley, Parowan Valley, and the west flank of the Red Hills along the northern margin of the map area; and north-

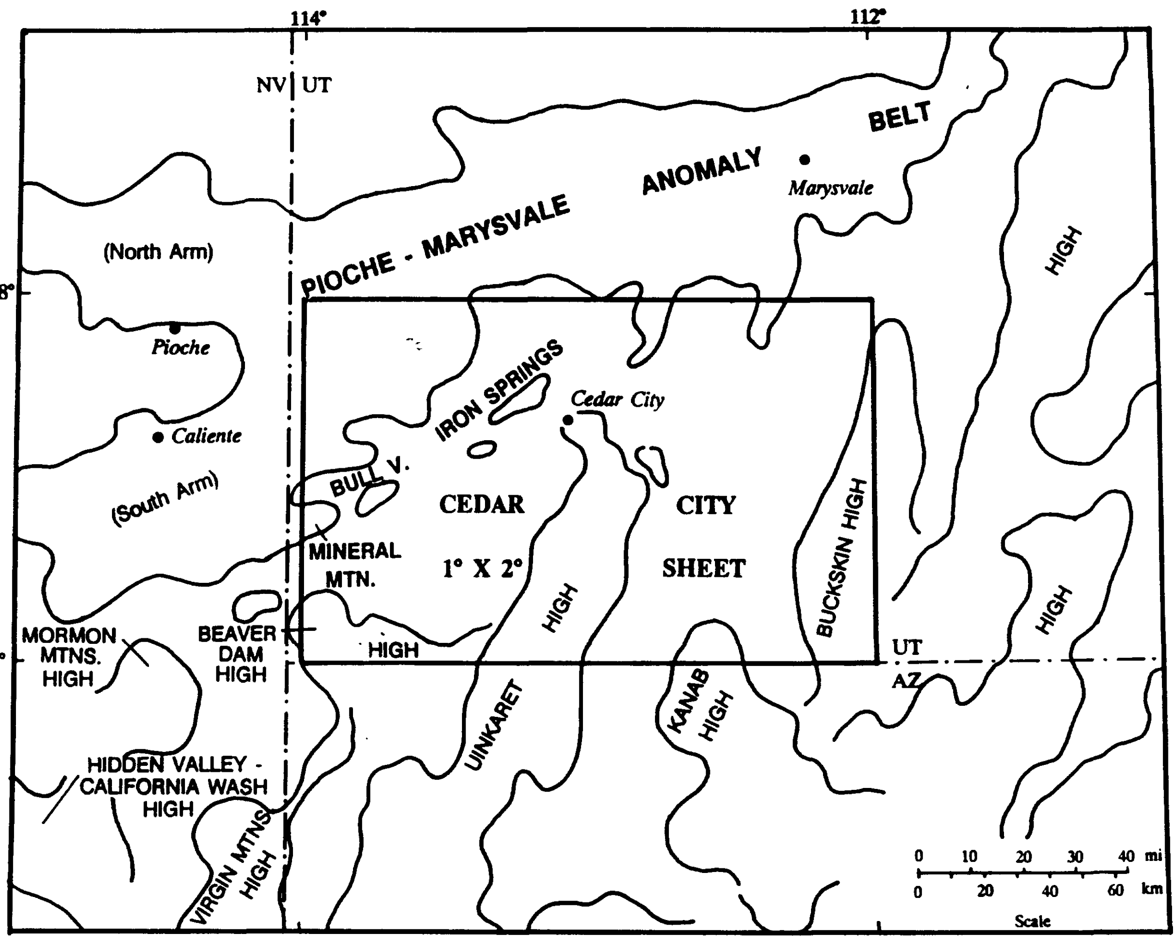


Figure 12.--Sketch map of regional aeromagnetic anomaly highs in vicinity of Cedar City 1° X 2° quadrangle, Utah. For sources of data, see text. Note relation of quadrangle to Pioche-Marysvale belt of magnetic anomalies, magmatism, and mineral deposits.

to northeast-trending anomalies presumably deriving from Precambrian crystalline basement sources in the Beaver Dam Mountains and beneath the Colorado Plateau. Also noted are short-wavelength anomalies produced by basaltic vent and flow rocks on the Markagunt Plateau southeast of Cedar City. Some monzonite bodies, such as the Iron Point and Pine Valley intrusions, have little or no aeromagnetic expression, possibly because of a relatively limited depth extent or severe deuteric alteration of their iron minerals.

Two regions of "magnetic basement" as expressed by long-wavelength components of the anomaly field are distinguished on figure 13. In the north and northwest, this basement is inferred to be mainly intrusive rock of Tertiary age, with the reservations given above. In the southern part of the quadrangle, the basement is believed to be mainly or entirely Precambrian crystalline rock. The lines of demarcation are drawn schematically and are not intended to represent actual source boundaries.

A relatively low-amplitude, southeast-trending anomaly ridge connects the two regions of contrasting magnetic basement in the vicinity of Cedar City. The source of this ridge could be either Tertiary quartz monzonite or rocks of the Precambrian crystalline complex. The former interpretation is favored, because (1) the anomaly seems to be an extension of the Three Peaks-Granite Mountain monzonite anomaly of the Iron Springs district, and (2) it projects into the axial zone of a weakly developed antiform that involves Paleozoic-Mesozoic rocks of the Hurricane front, so that emplacement of the anomaly source could have produced the observed deformation. The ridge is also a weak gravity high.

Long-wavelength anomalies identified with Precambrian basement on figure 13 are, from west to east, the "Beaver Dam high", an unnamed and weakly developed high, the "Uinkaret high", the "Kanab high", and the "Buckskin high." Each of these anomalies has an associated positive gravity anomaly and is flanked on its west side by a major regional high-angle normal fault--the Beaver Dam-Virgin Mountains breakaway fault (not shown) and the Grand Wash-Gunlock, the Hurricane, the Sevier, and the Paunsaugunt faults, respectively. Density discontinuities implied by the gravity anomalies (which reflect the mass excess of Paleozoic carbonate and Precambrian crystalline rock) and mapped traces of the regional normal faults coincide with apparent magnetic discontinuities in places but not everywhere. Moreover, the local configuration of some aeromagnetic anomalies suggests a "point" source such as a plug or dome. In view of these relationships, and the fact that only in the Beaver Dam Mountains are source rocks exposed, four conceivable factors should be considered in attempting to explain the aeromagnetic anomalies: (1) relative uplift of basement rock along the north-south-trending regional faults, (2) doming of the basement surface (as in the case of the Beaver Dam high), (3) intrabasement magnetization contrasts, and (4) post-Paleozoic emplacement of magnetic intrusive rock into the Precambrian basement complex, possibly in conjunction with doming. The contributions of each factor may vary from negligible to dominant, depending on the anomaly. To the extent that factors (2) and (4) are involved, an anomaly should be regarded as a possible locus of a hydrothermal system, and therefore, potentially prospective. Quantitative modeling of the potential-field data in conjunction with detailed geologic mapping and geochemical work might point to the most plausible among the various interpretive scenarios.

The Virgin Anticline, a major fold with a strong gravity expression, apparently lacks magnetic expression. If basement rocks are involved in the fold, they are either too deep or too weakly magnetized for the structure to

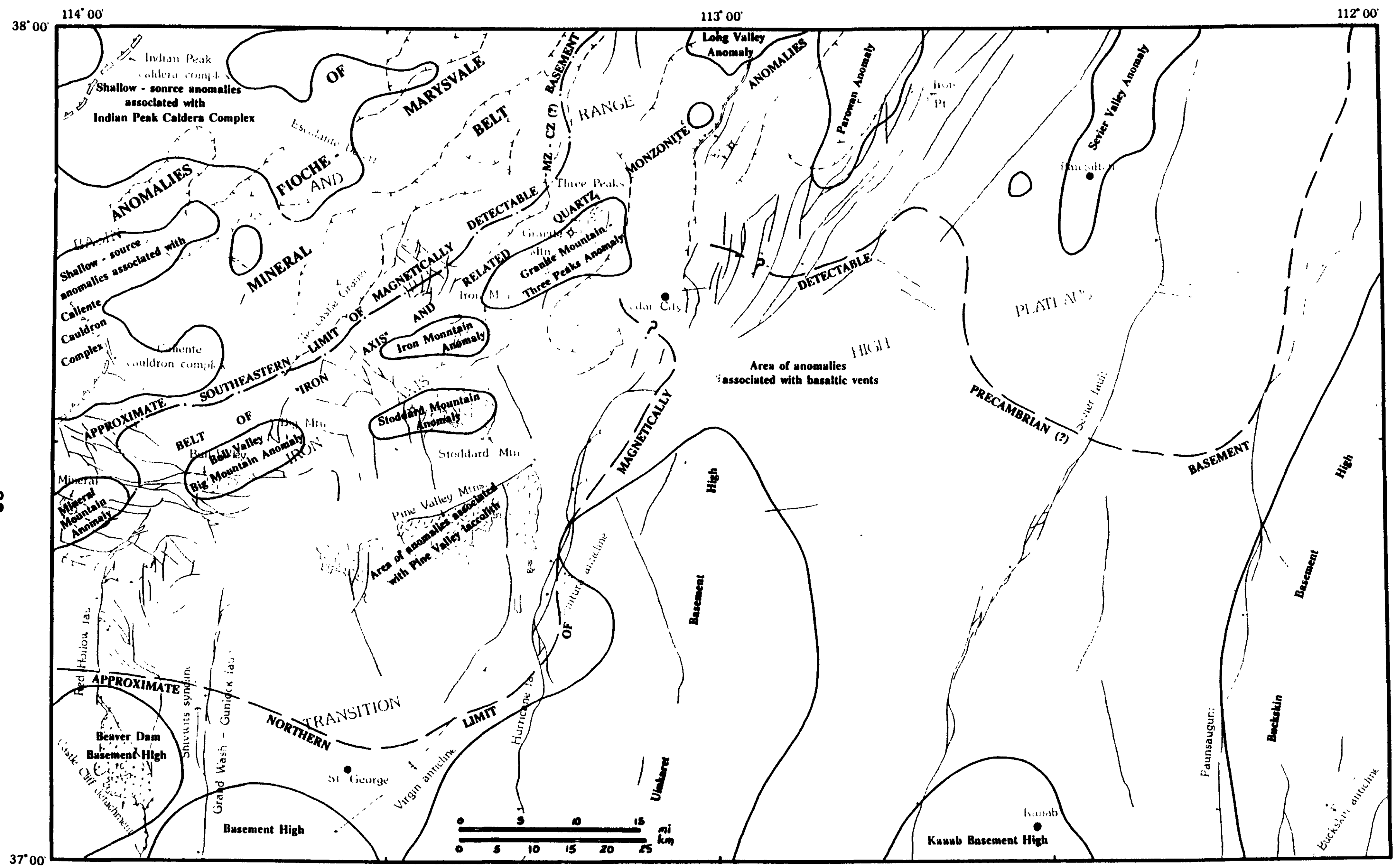


Figure 13.--Interpretive sketch map of principal anomalies, aeromagnetic map of Cedar City 1° X 2° quadrangle, Utah.

have been detected. Alternatively, the fold may be allochthonous on a low-angle basement decollement structure.

GRAVITY

Data

Regional gravity coverage of the Cedar City 1° X 2° quadrangle consists of about 2,600 stations, or about one station per 3 mi^2, but the station distribution is far from even. Coverage varies from 0 to about 50 stations per 7½' quad. Coverage of the western part of the quadrangle in the Basin and Range province is mostly adequate; coverage of the eastern one-third of the quadrangle, on the Colorado Plateau, is seriously deficient. The main sources of data are surveys by K.L. Cook and his students at the University of Utah (Cook and Hardman, 1967; Pe and Cook, 1980; Green and Cook, 1981; Montgomery, 1973; Fox, 1968; Gray, 1966; and Zimbeck, 1965), and BLM WSA studies of the USGS (see figure 10). Principal facts from these sources are on file at the Univ. of Utah and the USGS and may also be obtained through the National Geophysical Data Center, NOAA, Code E/GC, 325 Broadway, Boulder, CO 80303. Additional data have been obtained in the Beaver Dam Mountains and northern Mesquite Basin areas by students at Brigham Young University (Baer, 1986).

All available data have been reduced to Bouguer anomaly values and are computer-terrain-corrected out to a radius of 100 mi at a standard density of 2.67 g/cm^3. The result of these operations is the complete Bouguer anomaly (CBA) map of figure 14, contoured at 2 mGals. Station locations on this map are shown by hollow circles. The map extensively refines the gravity field shown on the simple Bouguer anomaly map of Utah published in 1975 (Cook and others), although the main anomaly features remain unchanged. A revised complete Bouguer anomaly map of Utah is currently in preparation (V. Bankey and K.L. Cook, Univ. of Utah, oral communication, 1988), and an up-to-date CBA map of the Cedar City 1° X 2° quadrangle and adjacent areas is scheduled for release in 1989 as a USGS Open-File product of "BARCO".

It is important to recognize that the reduction density used for figure 14 is high compared with the density of rocks comprising most of the topography of the Colorado Plateau section, which results in an inverse correlation of Bouguer anomaly values and topographic elevation. Some local anomalies are thus attributable to density deficiencies in the topography. For example, Bouguer anomaly levels on the plateau rims flanking Zion Canyon are negative relative to those on the Canyon floor, since the plateau rocks were assumed to have an unrealistically high density for the Bouguer reduction. A similar inverse correlation occurs on a regional scale but for a different reason: the High Plateaus of southwest Utah (and the Colorado Plateau in general) must be underlain by some form of mass deficiency to compensate for the excess topographic load. The regional mass deficiency is not taken into account with a standard Bouguer reduction. To suppress this effect the data were also further reduced to isostatic residual anomalies based on an Airy-Heiskanen model at 2.67 g/cm^3 crustal density and a crust-mantle density difference of 0.4 g/cm^3, T = 35 km. The isostatic residual field is shown on figure 15 at a contour interval of 4 mGals.

Interpretation

Comparison of figures 14 and 15 reveals that the total anomaly relief of the region has been reduced by about half through use of a standard isostatic

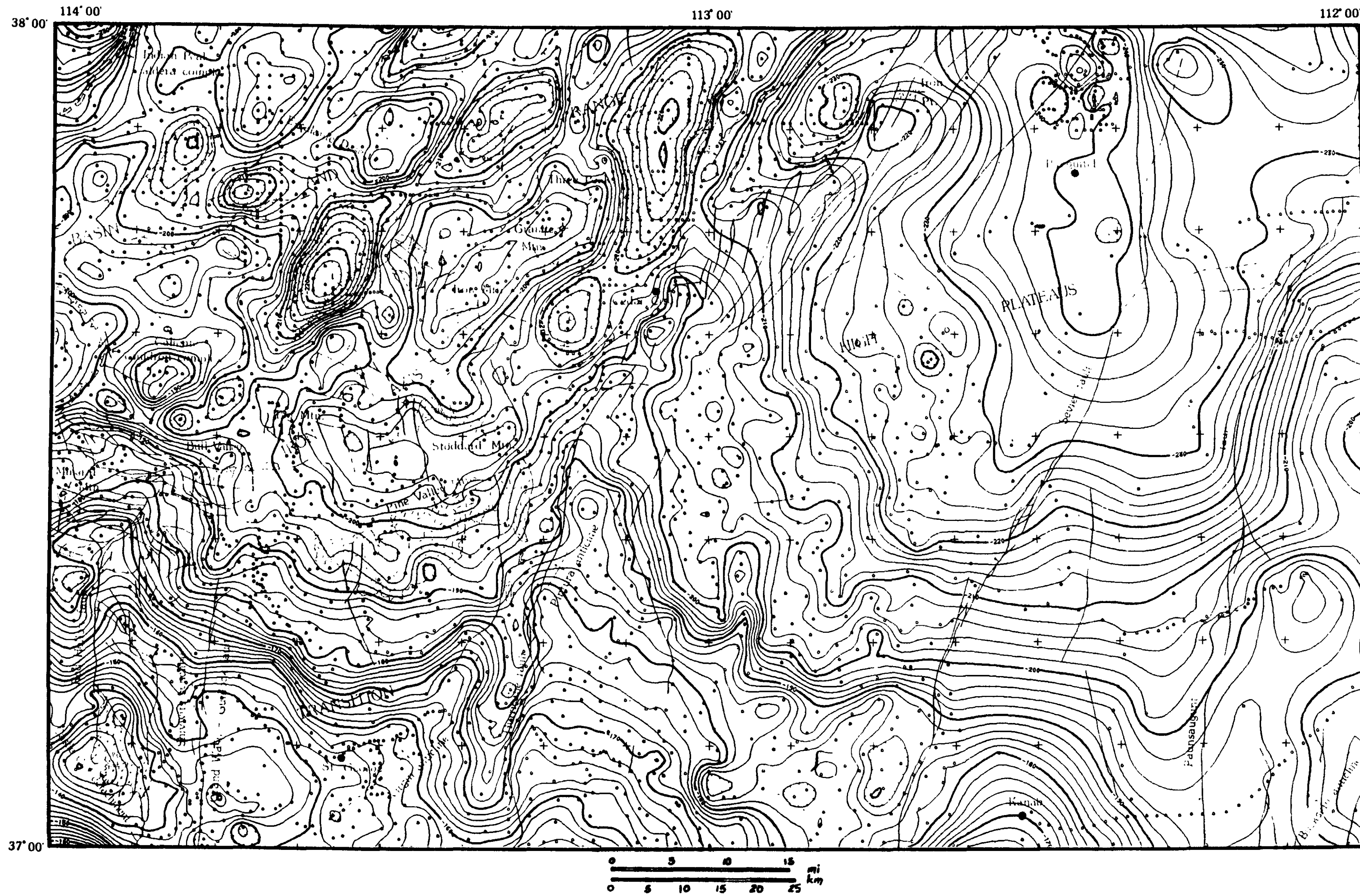


Figure 14.--Complete Bouguer gravity anomaly map of Cedar City 1° X 2° quadrangle, Utah. Contour interval 2 mgals. Reduction density 2.67 g/cm^3. Gravity stations located at open circles. Terrain-corrected to 100 mi (167 km) from stations. For sources of data, see text.

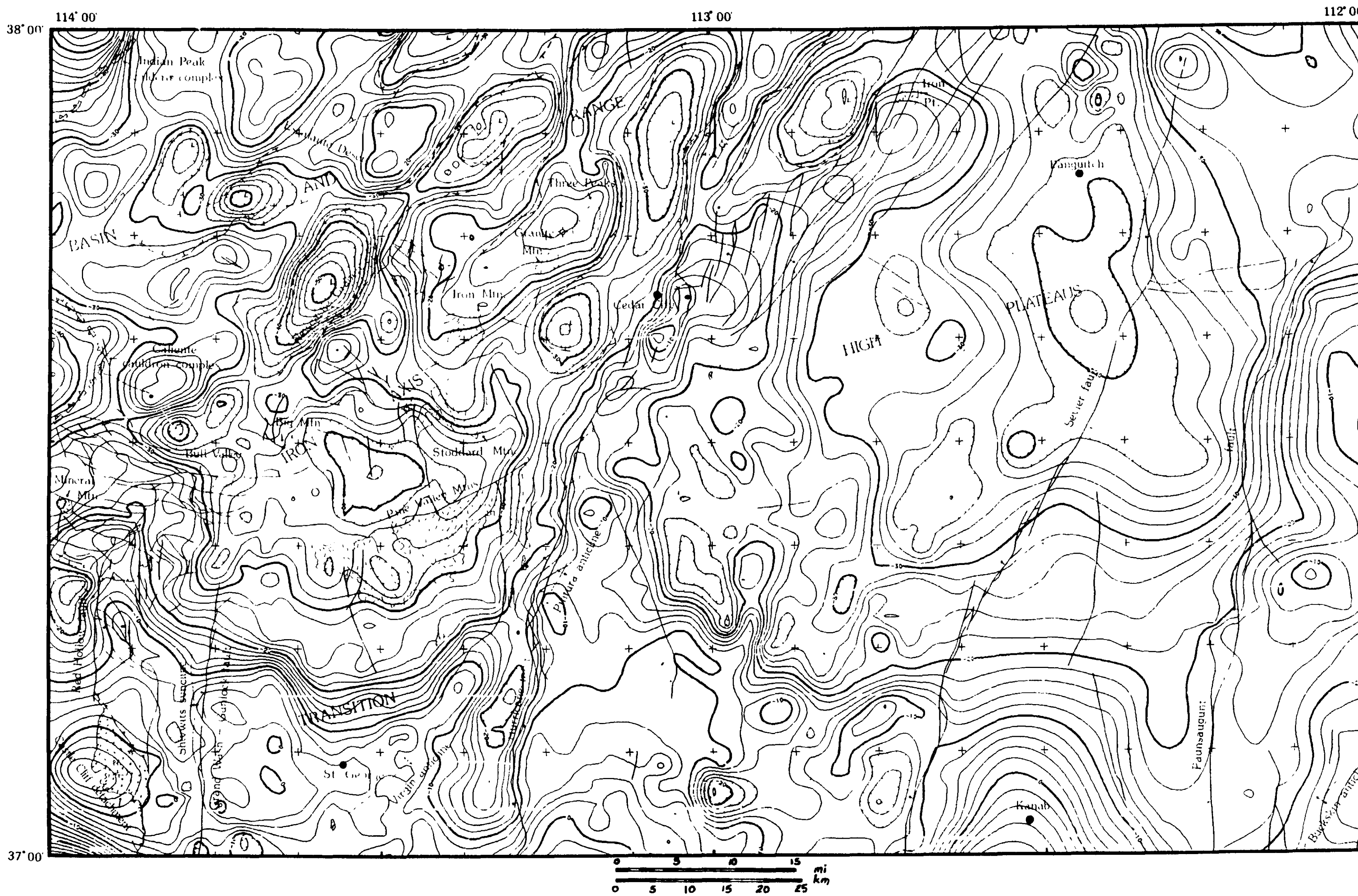


Figure 15.--Residual isostatic gravity anomaly map of Cedar City 1° X 2° quadrangle, Utah. Contour interval 2 mgals. Airy-Heiskanen model, at crustal density 2.67 g/cm^3, crustal-mantle density difference 0.4 g/cm^3, T=35 km. For sources of data, see text.

model, but that almost all values are still negative, i.e., the standard model is inadequate. On both maps the mean anomaly levels are much lower in the north than in the south, where they approach zero. The east-west belt of steep gradient that produces this contrast extends all the way from the Sierra Nevada in eastern California to well within the Colorado Plateau in south-central Utah. It coincides with a sharp northerly increase in regional average elevation and, at least in the Basin and Range province, with a marked northerly increase in volume of silicic magmatism as expressed by exposed Cenozoic volcanic products. An analysis of the southern Nevada sector of this gravity gradient led Eaton and others (1978) to conclude that it marks a fundamental change in composition of the middle to upper crust from less silicic (denser) to more silicic (lighter), as a consequence of regional magmatism. In the Cedar City quadrangle, Precambrian basement depths are apparently greater on the north side of the gravity gradient both in the Basin and Range and Colorado Plateau provinces, but for the latter a relationship with volume of silicic magmatism has yet to be established.

Figure 16 is intended for use in conjunction with figure 15, and is a map of horizontal gradient maxima computed from the grid of complete Bouguer anomaly values mapped on figure 14. This map therefore lacks directional bias. Each circle represents a "significant" gradient maximum at a particular grid point, with the size of the circle proportional to the intensity of that gradient. The vector orientation of the gradient can be roughly determined from the map on figure 15.

A remarkably strong and continuous northeast-trending set of horst-graben or fold structures is evidently concealed beneath the Escalante Desert in the northwest quadrant of the quadrangle. The deepest depression (at 16 mGals anomaly amplitude) associated with these structures is probably the Newcastle Basin, a Known Geothermal Resource Area (KGRA). Other prominent depressions are labeled the "Lund", "Avon", "Cedar", and "Parowan" basins. The Cedar basin is separated into northern and southern portions by a weak gravity ridge corresponding to the weak southeast-trending magnetic anomaly ridge near Cedar City. Exposures of quartz monzonite intrusions of the iron axis suite are found on the southeast flank of gravity highs, which is generally the steeper side of the anomaly sources and in the vergence direction of Sevier orogeny fold-axes. The Virgin Anticline, possibly the farthest southeast of the presumed Sevier structures, produces a strong northeast-striking anomaly ridge near St. George. Some northeasterly anomaly trends may reflect faults with a significant component of strike-slip movement.

Gravity lows near the northwest and west-central margins of the quadrangle are believed bounded by arcs of two caldera ring-fracture systems - the Indian Peak caldera complex and the Caliente cauldron complex, respectively. Figure 17 shows the location of these two systems as interpreted from regional gravity data (Blank, 1987). The Indian Peak complex is represented by a gravity depression in the shape of a 30 x 50 mi ellipse with major axis oriented northwest-southeast. The depression roughly coincides with the overall outline of a set of nested late Oligocene calderas mapped by Best and others (in press). It may be significant that the major Pb-Ag mining camps of Pioche, Bristol, and Atlanta are located just outside the inferred principal ring-fracture zone, and that age of mineralization is thought by some to be as young as mid-Tertiary (D. Shawe, oral communication, 1986). The configuration of the Miocene Caliente complex is less well known. The ring-fracture system indicated by Ekren and others (1977) will probably be modified as the result of detailed mapping currently in progress by P.D. Rowley, R.E. Anderson, R.B. Scott of the USGS, and others. A paleo-

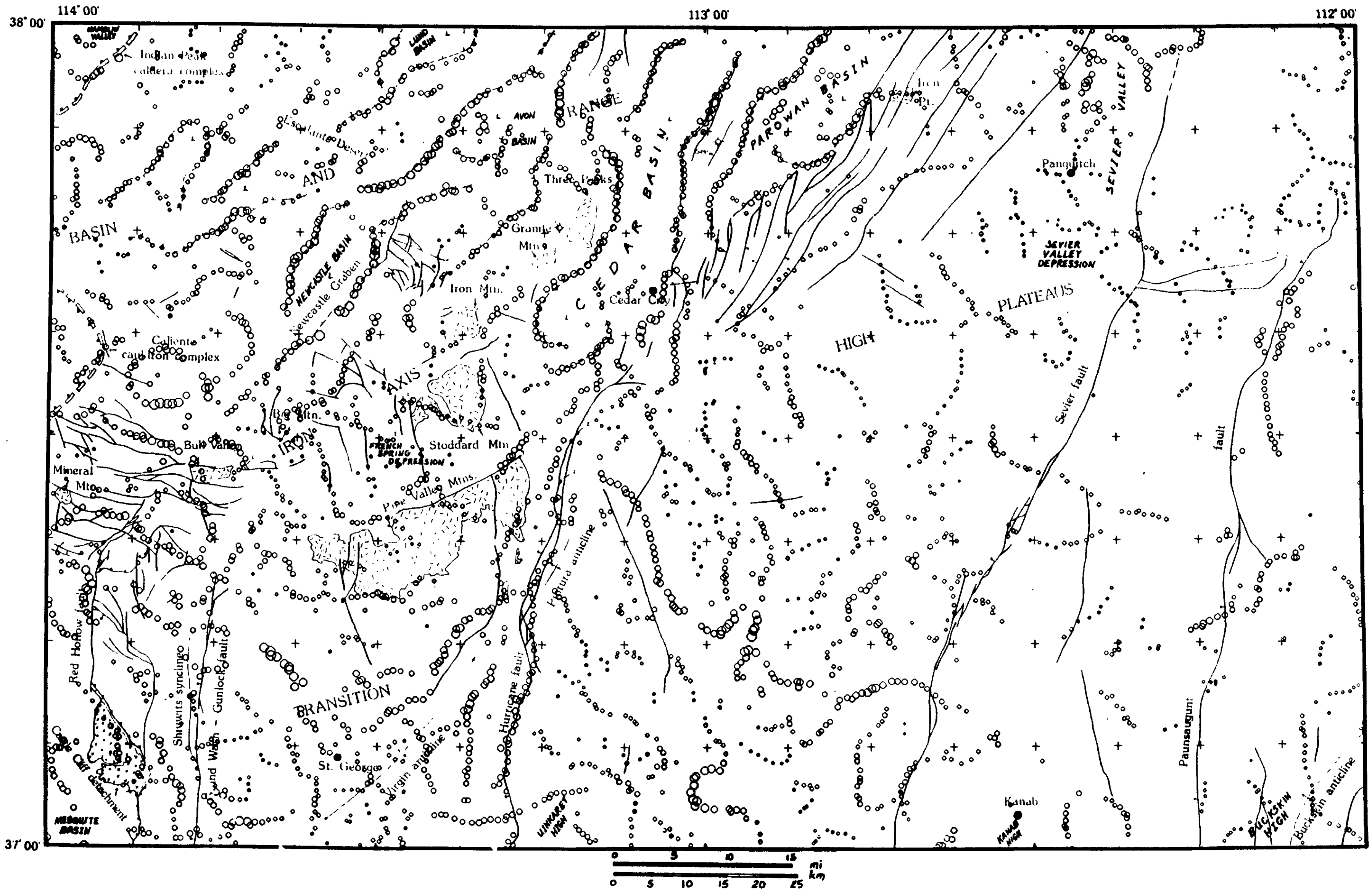


Figure 16.--Significant maxima, horizontal gradient of complete Bouguer gravity anomaly field, Cedar City 1° X 2° quadrangle, Utah. Size of symbol proportional to magnitude of gradient at maximum. Grid interval 1 km. For sources of data, see figure 15 and text.

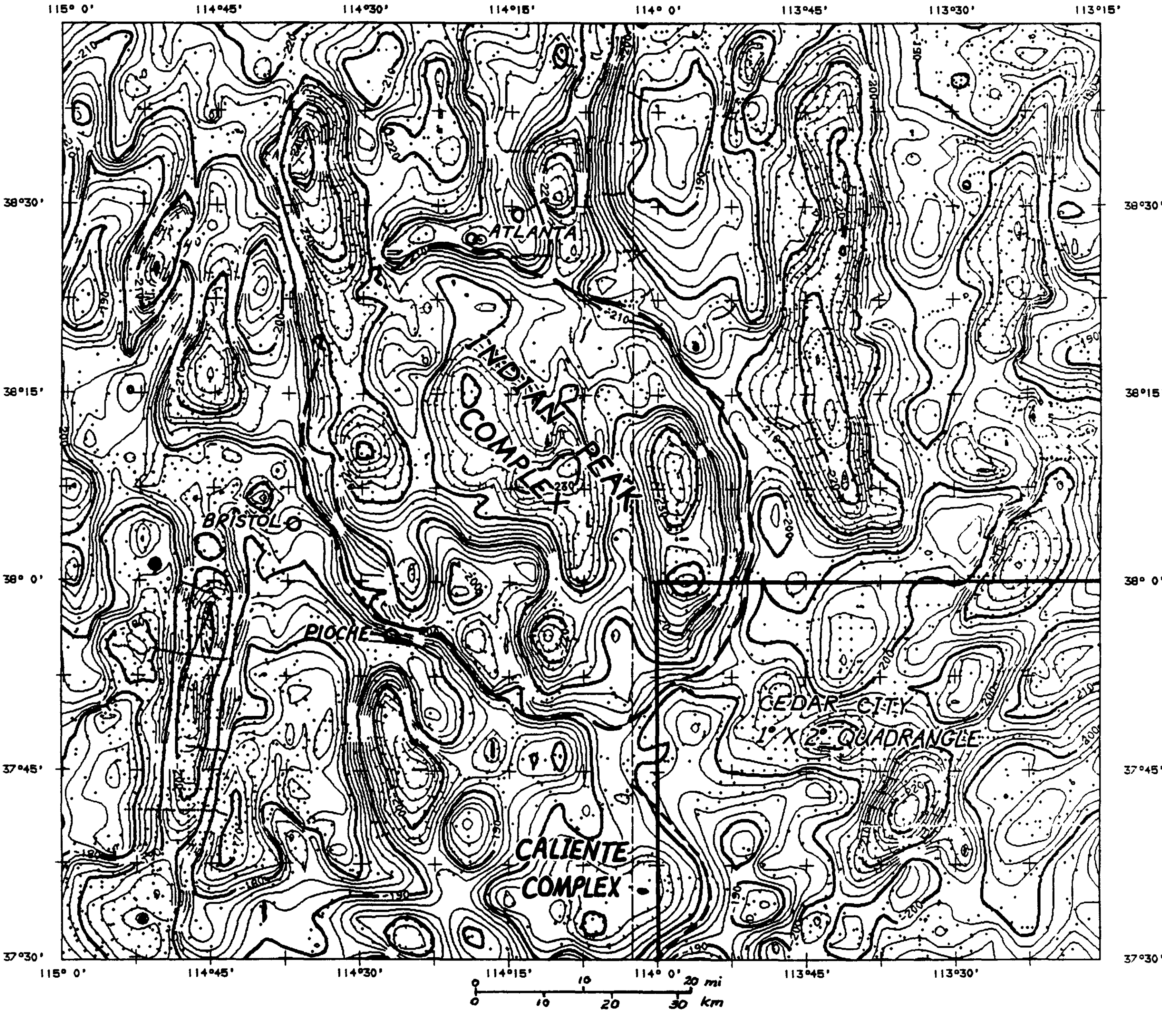


Figure 17.--Complete Bouguer gravity map of a portion of western Utah and eastern Nevada, showing relation of Cedar City 1° X 2° quadrangle to Indian Peak and Caliente caldera complexes as inferred from gravity field. Contour interval 4 mGals. Reduction density 2.67 g/cm^3.

topographic rim of the caldera system has been mapped in the Mt. Escalante 7½' quadrangle of Utah (Siders, 1986). Much of the complex is a locus of intensely hydrothermally altered rocks and possibly epithermal mineral deposits (Conrad and others, in preparation).

One of the deepest (6-9 mi) tectonic depressions in North America is associated with predominantly westward extension of terrain flanking the Beaver Dam and northern Virgin Mountains. The Beaver Dam breakaway structure produces a steep gravity gradient flanked by an 80-mGal gravity low just off the southwest corner of the map (Blank, 1988). A much less severe gradient marks the western margin of the Beaver Dam block in the Cedar City quadrangle.

The broad, deep gravity low in the vicinity of the Pine Valley Mountains, approximately centered near French Spring between Pine Valley and Stoddard Mountain, coincides with a similarly broad aeromagnetic low, and seems to represent structural depression of the Precambrian basement. Development of the depression may in some way be related to Miocene Pine Valley magmatism. A possibly analogous set of anomalies is present in the Colorado Plateau province in the vicinity of Sevier Valley, although there the gravity low is less well defined due to sparse data coverage, and the granitic rocks are not exposed.

The Hurricane, Sevier, and Paunsaugunt faults all bound the west side of gravity highs for at least part of their traces. The anomalies are due mainly to block-faulted dense basement rock and shelf carbonates. The gravity features correspond to aeromagnetic highs discussed earlier, and are similarly labeled Uinkaret, Kanab, and Buckskin highs, respectively.

AERORADIOMETRICS

Data

Spectral aeroradiometric data obtained for the Cedar City 1° X 2° quadrangle by the NURE program provide a synoptic overview of surface concentrations of U, K, and Th. However, due to the wide traverse spacing (nominally 3 miles) and highly variable terrain clearance (nominally 400 ft, but often well above significant detection thresholds) of the NURE flights in this region the results must be interpreted with caution. Digital tapes of reduced data have been provided by J.A. Pitkin and J.S. Duval of the USGS. We have combined maps of concentrations of each of the three radioelements to produce a single map showing the most highly anomalous zones for percent K and ppm equivalent U (eU) for both uranium and thorium (figure 18).

Interpretation

Examination of figure 18 in relation to regional geology of the Cedar City 1° X 2° quadrangle leads to the following observations:

(1) Virtually all the northwest quarter of the quadrangle is anomalously high in U, K, and Th. This area is less extensive than the region inferred from the magnetics (figure 11) to be underlain by Mesozoic-Cenozoic basement but does include the area of most intense aeromagnetic anomalies as well as the northwest side of the Escalante Desert--the side that receives drainage from the calc-alkaline Caliente and Indian Peak eruptive-tectonic complexes. The highest concentrations of U (>8 ppm) and Th (>30 ppm eU) found anywhere in the quadrangle occur in the Paradise Mountains due east of the State Line gold district; the anomaly maxima are surmised to occur off the map and over the mining camps. A basalt field south of Modena and localized areas southeast of

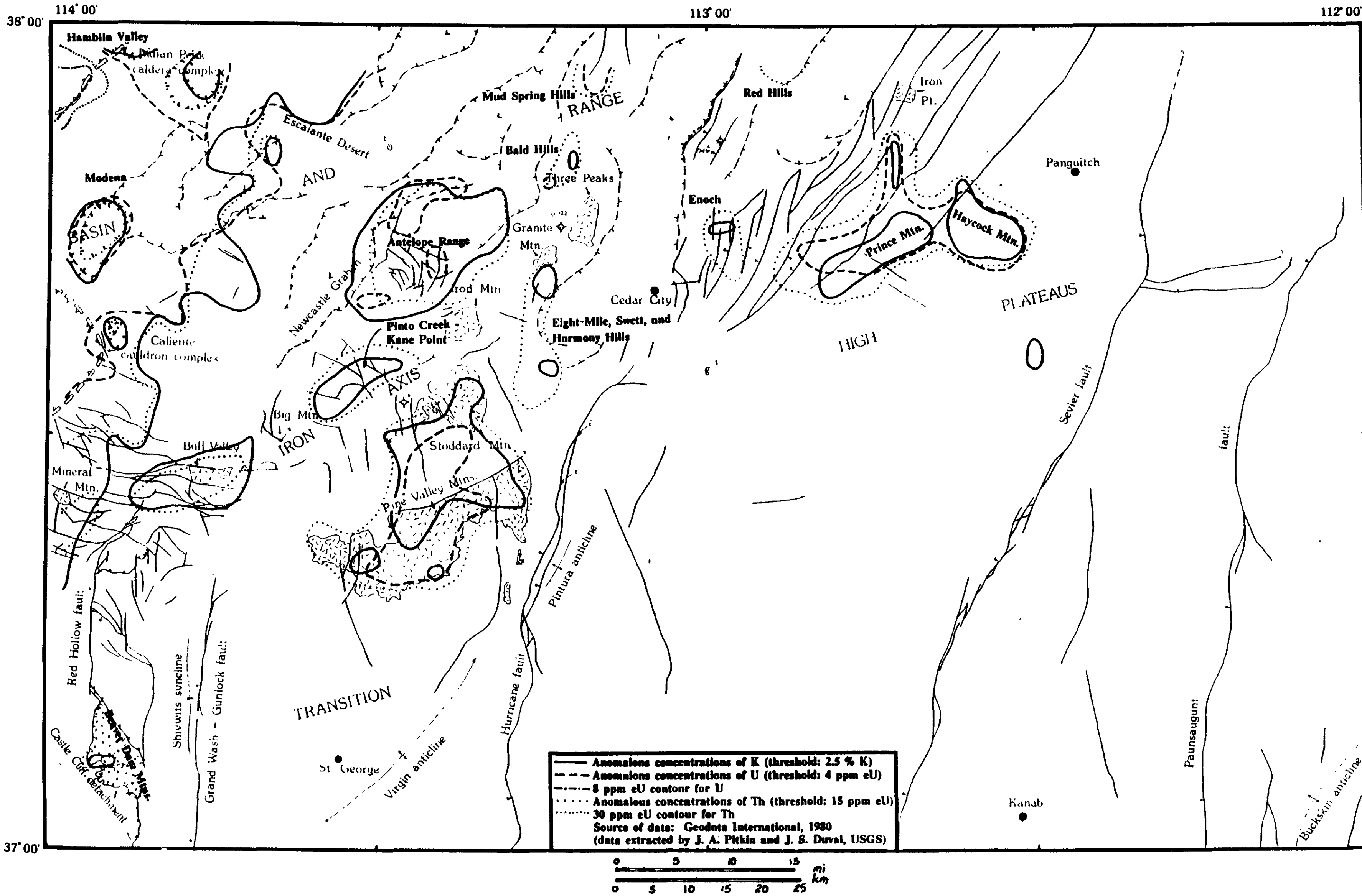


Figure 18.--Anomalous concentrations of K, U, and Th, Cedar City 1° X 2° quadrangle, Utah.

Hamblin Valley show lower concentrations of all three radioelements than the average in this region.

(2) A small area anomalously high in K and Th occurs on the west flank of the Beaver Dam Mountains, with maxima centered in the vicinity of Welcome Spring. The same area also has somewhat higher concentrations of U than average, and roughly corresponds to outcrop areas of Precambrian granitic rocks and to exposures of the sole of a detachment fault.

(3) Large tracts of Mineral Mountain, the Bull Valley Mountains, the Pine Valley Mountains-Mt. Stoddard area, the Pinto Creek-Kane Point area, and the Eight-Mile Hills/Swett Hills/Harmony Hills area show anomalously high concentrations of potassium and thorium, and to a lesser extent, uranium. For the most part these concentrations seem to be associated with exposures of potassium-rich quartz monzonite intrusive rock and equivalent quartz latites, including Harmony Hills Tuff of the Quichapa Group. However, the petrographically similar intrusions of the Iron Springs district show no comparable enrichment of radioelements.

(4) The Antelope Range is a locus of anomalously high concentrations of all three nucleides, and include the highest levels of K (>5.5%) found anywhere in the quadrangle. The Antelope Range also shows abundant evidence of hydrothermal activity and mineralization.

(5) Sharply localized concentrations of radioelements in the Bald Hills, Mud Spring Hills, and Red Hills north of Little Salt Lake are associated with outcrop areas of Isom Formation.

(6) An area of the Hurricane fault southeast of Enoch shows anomalously high levels of K and Th and minor enrichment of U. This area is located at the western extreme of an extensive, roughly east-west-trending zone of anomalous values which reach maxima over Haycock Mountain and Prince Mountain, in the vicinity of Panguitch Lake (southwest of the town of Panguitch). The source of the high concentrations is unknown, but they appear to be associated with mapped "undifferentiated volcanic rocks", and at least locally, with exposures of the Isom Formation.

REMOTE SENSING

Digital analysis of LANDSAT Multispectral Scanner (MSS) data has been used for more than a decade to map hydrothermally altered rocks (Rowan and others, 1974). The technique is based on the detection of intense Fe^{3+} absorption caused by ferric-oxide minerals in gossans and some other hydrothermally-altered rocks. Selected ratios of the MSS channels are combined to form color ratio composite (CRC) images in which areas with anomalously high concentrations of ferric-oxide minerals, collectively termed limonite, are displayed in a specified color. However, extensive field evaluation is needed to distinguish limonitic hydrothermally-altered rocks from limonitic weathering of unaltered rocks. Also, hydrothermally-altered rocks that lack ferric oxide minerals cannot be detected by this method.

LANDSAT Thematic Mapper (TM) images are more versatile than MSS images for mapping hydrothermally-altered rocks, because TM images have greater spatial resolution, and offer additional spectral coverage of the near-infrared (NIR) wavelength range. Besides limonite, many hydrothermally-altered rocks contain other NIR-absorbing minerals, including alunite, pyrophyllite, carbonates, clays, and micas, all of which can be detected using digitally enhanced TM or TM-equivalent images (Podwysocki and others, 1983). Some of these minerals are also common in unaltered rocks, and positive identification of hydrothermally altered rocks still requires field checking.

Digital Image Processing

An available LANDSAT 4 TM scene for the Cedar City area was examined in early stages of this study. Unfortunately, the data were not suitable for constructing CRC images due to extensive snow cover at the time the data were collected. Lacking other TM data, a LANDSAT MSS scene covering about 85 percent of the Cedar City quadrangle was computer-processed for this assessment. This scene, obtained on June 28, 1974, was nearly cloud-free and of high overall quality. A CRC image was generated using MSS band ratios 4/5, 6/7, and 5/6, displayed as red, green, and blue, respectively. In this CRC combination well-exposed limonitic rocks appeared blue-green. The image was used to make a map of limonitic rocks for use with other Cedar City datasets (figure 19).

Examination of the CRC image, the limonite map, the geologic map, and a map of mines and prospects for the Cedar City quadrangle leads to several conclusions:

(1) Nearly all of the well-exposed limonitic rocks in the study area are iron-stained sedimentary units that lack mines and prospects. However, a large cluster of silver mines and prospects are found along the contact between the limonitic Kayenta and Moenkopi Formations near the town of Leeds, Utah. The significance of this association of mines with limonitic sedimentary rocks is not known and merits further study.

(2) Vegetation cover in the higher elevations generally obscures rock units that appear limonitic at lower elevations. In places, the limonitic units are visible through breaks in the vegetation, indicating that the vegetation cover is not total, but instead represents a mixed-pixel situation (i.e., vegetation plus limonite). Under these conditions, the increased spatial resolution afforded by TM data (30 meters versus 79 meters for MSS) could permit useful mapping of altered rocks in many areas with moderate vegetation cover.

(3) Only a few small areas of limonite are discernible in the Tertiary volcanic and intrusive rocks. One such area is associated with the a gold-silver prospect located in the northwest part of the study area. Again, TM data could help to better define other small areas of altered rocks, if any are present, and would permit other hydrothermal alteration minerals besides iron-oxides to be detected.

(4) Known iron mines and prospects located between Iron Mountain and Three Peaks are clearly delineated as light blue areas on the CRC image. No "new" iron anomalies are indicated by the MSS data.

SEISMIC REFLECTION

Exploration interest by the petroleum industry in the hydrocarbon potential of the overthrust belt of the Basin and Range province and certain adjacent portions of the Colorado Plateau has generated abundant seismic

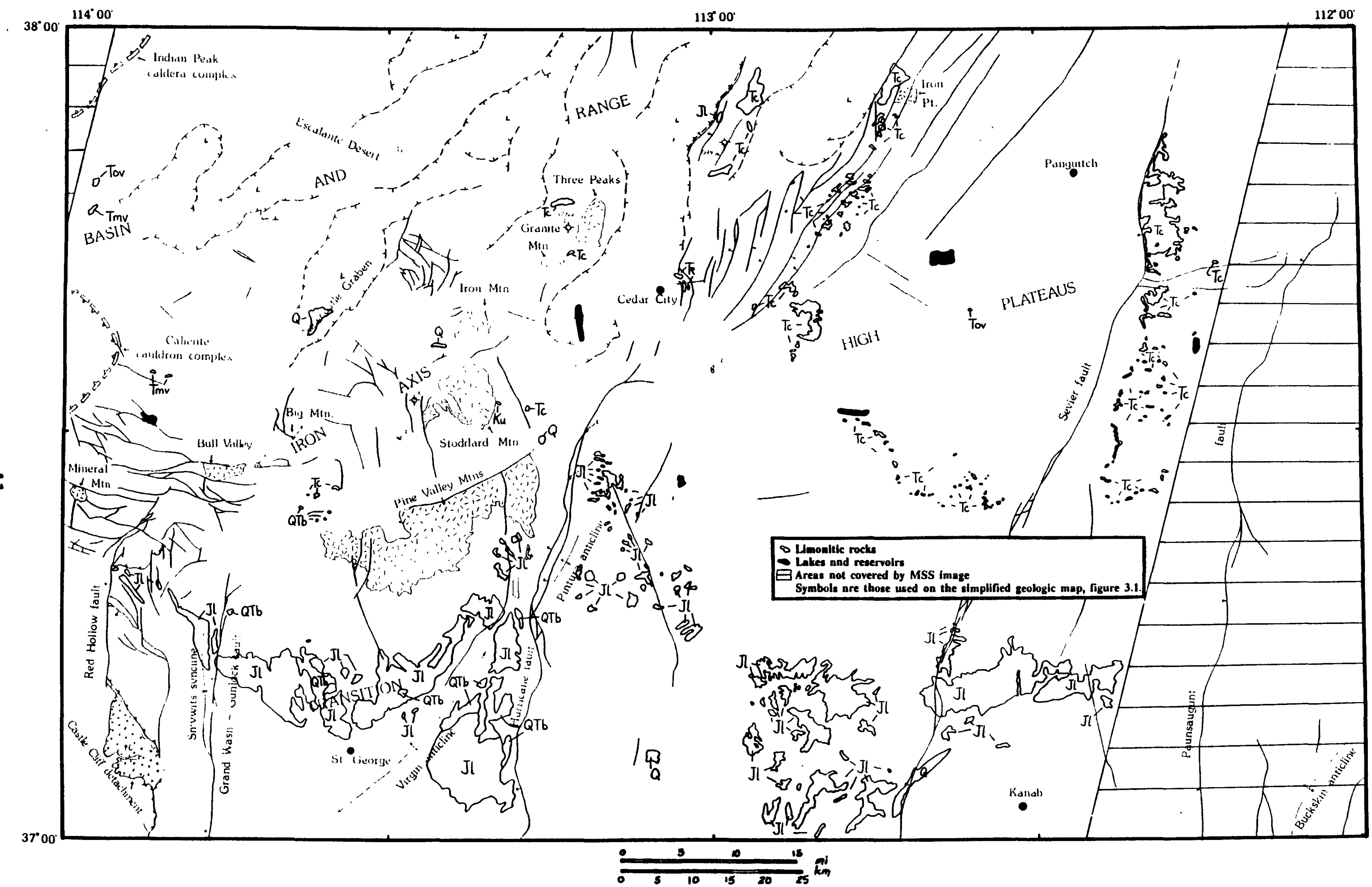


Figure 19.--Map of limonitic rocks, Cedar City 1° X 2° quadrangle, Utah, derived from LANDSAT MSS scene converted to color ratio composite image.

reflection data for the Cedar City 1° X 2° quadrangle in recent years. Most or all of the data seems to be the product of speculative surveys and is available from various brokers at prices ranging from about $800 to $1,400 per line-mile. We have examined many of the sections and found the data quality to run the gamut from truly excellent to virtually unusable.

Figure 20 shows coverage available through a single broker (NORPAC). It is unlikely that much more data exist beyond what is indicated. At least two lines that cross the Hurricane fault probably could be used to study the geometry of the fault plane at depth. This would be helpful in assessing the role of the Hurricane and similar faults in regional extension, and could bear on the question of where and why such fault zones are mineralized. Other lines might prove useful in addressing specific local structural problems elsewhere on the quadrangle.

Reflection profiles across monzonite intrusions of the Iron Springs district have recently been analyzed by Van Kooten (1988). Seismic exploration followed the discovery of surface hydrocarbon anomalies in the vicinity, which suggested the possibility that thermal maturation of source rocks may have been enhanced in the vicinity of the intrusions. The results clearly show that intrusive rock is floored at a depth of several thousand feet below the surface, confirming an aeromagnetic interpretation earlier made by Blank and Mackin (1967).

SUMMARY AND RECOMMENDATIONS

Geophysical data available for this preliminary assessment of the Cedar City 1° X 2° quadrangle have proved to be a useful adjunct for investigating the regional geologic framework and identifying regional environments favorable for hosting mineral deposits. However, geophysical methods should be much more extensively exploited in a full-scale mineral resource assessment. Among the principal objectives of a more detailed geophysical program are: delineation of structural controls on mineral deposit distributions, delineation of buried or poorly exposed intrusive bodies that might have served as heat engines for circulation of hydrothermal fluids, and identification and characterization of zones of shallow hydrothermally altered rocks. For these tasks the data on hand should be augmented and in some cases supplemented with new data from untapped sources. In the following paragraphs we summarize the role of each broad class of data thus far employed, point out what additional data or data processing are required, and recommend a number of specific topics for geophysical investigation.

The principal sources of long-wavelength aeromagnetic anomalies in the Cedar City quadrangle are Precambrian crystalline rocks and Cenozoic (and possibly Mesozoic) intrusions; the sources of shorter wavelength anomalies are Cenozoic volcanic rocks, iron deposits, and near-surface magnetization contrasts within intrusive bodies or Precambrian metamorphic terrane. Magnetic properties of known anomaly source rocks in the quadrangle are highly variable. As examples, the iron deposits range from essentially non-magnetic (siliceous hematite) to very strongly magnetic (magnetite veins); the concealed vitrophyre of a rhyolite ash-flow tuff of the Quichapa Group has such strong remnant magnetization at one locality that it was drilled by an iron-exploration company, whereas the vapor-phase zone of that same tuff is magnetically "transparent"; the magnetization of hypabyssal monzonite in the Iron Springs district critically depends upon structural position within intrusive bodies. Sharp local variations in the magnetic properties of Precambrian crystalline basement rocks may also occur (they do in the Beaver Dam Mountains). Evidently the existing aeromagnetic coverage is inadequate

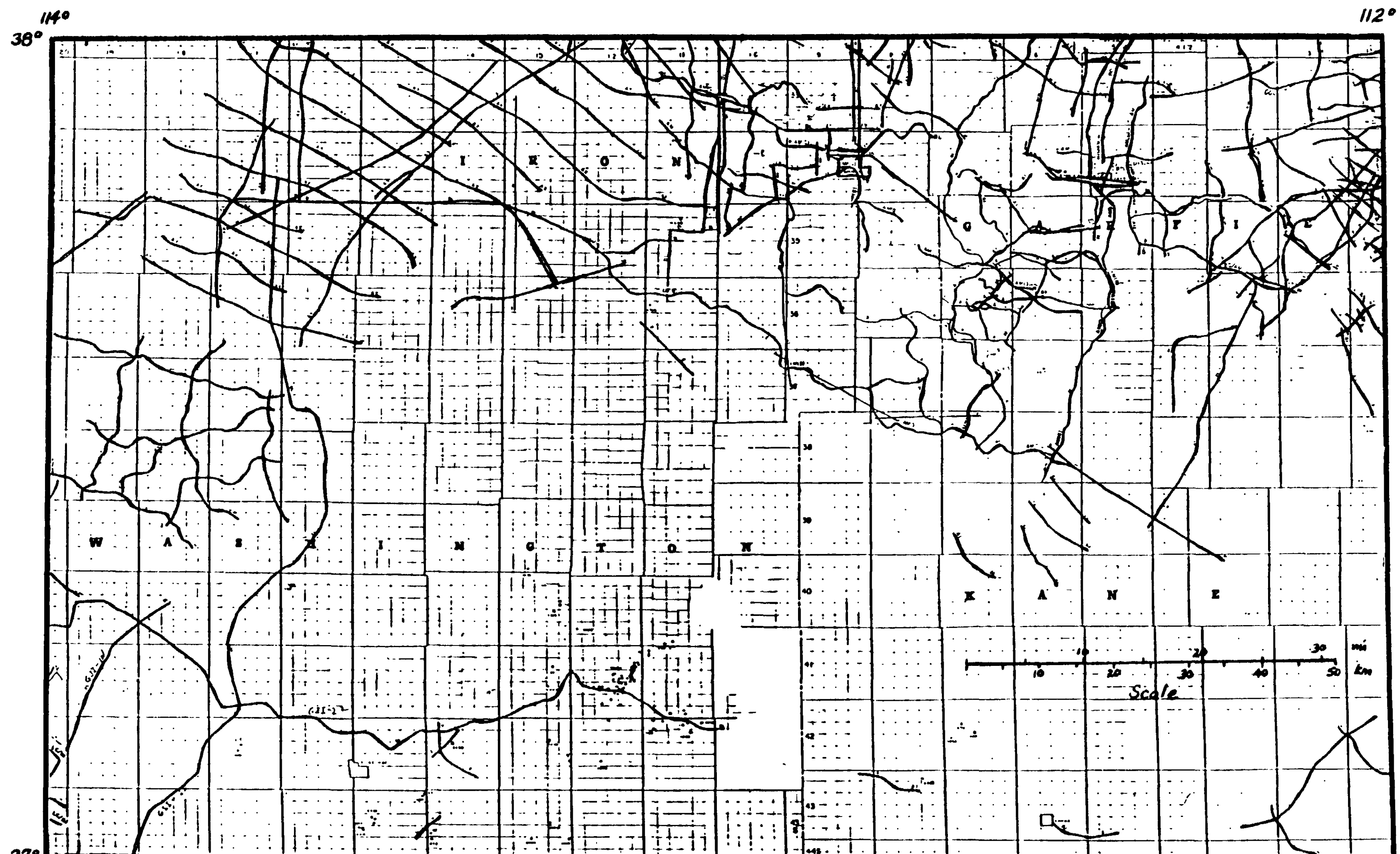


Figure 20.--Index map of seismic reflection profiles available for Cedar City 1° X 2° quadrangle, Utah, through a commercial broker, October 1988.

for resolution of such variations and associated structures. We recommend tightening of the coverage to half-mile traverse spacing in the Basin and Range province and 1-mile spacing on the Colorado Plateau, where the targets are deeper. The enhanced aeromagnetic data set should be then subjected to routine processing as a prelude to special topical studies and quantitative interpretation by modeling techniques. This processing should include production of reduction-to-the-pole, pseudogravity, horizontal and vertical gradient, wavelength-filtered, and anomaly-trend maps of the entire quadrangle.

The principal sources of positive gravity anomalies in the quadrangle are uplifts involving high-density Precambrian metamorphic basement rocks and/or thick carbonate successions of Paleozoic age. Granitic stocks, whether Tertiary or Precambrian, are of intermediate density and produce relatively positive or negative Bouguer anomalies depending upon the density of their host. Stratified volcanic rocks include a high proportion of pyroclastic products and are generally less dense in bulk than the intrusions. The strongest negative gravity anomalies are produced by thick accumulations of clastic sedimentary rocks, especially those in upper Cenozoic basins. Thus the gravity method reveals details of basin-range structure, including the configuration of buried uplifts, and distinguishes between pediment and fill. On the Colorado Plateau, it has the potential to provide important constraints on interpretations of structural relief on the Precambrian basement, but coverage needs to be considerably improved. The contrast in anomaly resolution between areas of adequate coverage and those where data are sparse or lacking is strikingly illustrated by reference to figure 14. We recommend the addition of about 600 new gravity stations to the existing set, 500 of which should be on the Colorado Plateau. Routine preliminary processing of the enhanced gravity data set should employ variable Bouguer reduction densities (e.g., 2.4 g/cm^3 on the Colorado Plateau versus 2.67 g/cm^3 for the Basin and Range province), alternative isostatic reduction models, and routines for calculation of horizontal gradients.

At present not much is known about the sources of aeroradiometric anomalies detected by the NURE surveys, which are essentially of broad reconnaissance scope. In map form the results offer only a gross representation of regional variation in the surface distribution of the radioelements U, K, and Th. Ground follow-up is required in order to determine specific locations of high radioelement concentrations and whether they are related to altered rocks or primary lithologies. As preliminary steps, the data should first be transformed into element-ratio maps; a map of excessive terrain clearance should be prepared as a guide to identification of areas not yet reconnoitered (NURE flights passed directly over at least two mapped uranium workings on the Colorado Plateau without recording an anomaly, probably because of the height of the detector); and individual profiles should be examined for formational signatures that may yield clues to presence of hydrothermally altered rocks.

Preliminary interpretation of existing LANDSAT MSS and TM imagery for the Cedar City quadrangle has yielded uneven results, mainly due to extensive areas of vegetation cover and limonitic unaltered sedimentary rocks (MSS scenes) and snow cover (TM scene). We recommend purchase and analysis of new, snow-free TM scenes prior to conducting ground follow-up field studies. Also, acquisition of Side-looking Radar (SLAR) and Airborne Imaging Spectrometer (AIS) data is recommended for mapping zones of silicification and linear tectonic features, respectively. SLAR coverage of the Cedar City quadrangle is scheduled to be acquired by the USGS radar program in FY 1989. Progress in the development of the airborne imaging spectrometer remote sensing technique should be closely monitored for its potential application to the characterization of hydrothermally altered zones, particularly those areas where hydroxyl-bearing and carbonate minerals may be present.

No seismic reflection data were studied for this preliminary assessment but several key profiles that were briefly inspected at the vendor's offices provide an indication of their potential utility. The best use of the data is most likely in conjunction with aeromagnetic and gravity profiles, to establish fault geometry and measure basement offsets, and constrain interpretations of the form of hypabyssal intrusions. Locally it may be possible to use the coherence of energy reflected from a given zone as a measure of its internal deformation. We recommend acquisition of critical profile segments from industry at an appropriate stage in the regional study when problems to be addressed by seismic data are sharply focused and clearly identified. Some data will require further processing to improve the signal-to-noise-ratio.

The following topical investigations mostly involve more than one geophysical method and presume an expanded data base; all envision parallel geological and geochemical studies.

(1) Structural fabric studies. The aeromagnetic and gravity anomaly fields and TM imagery should be subjected to linear-trend analysis to determine regionally dominant fault and fold orientations as possible structural controls for ore deposition. In addition the regional fault pattern may indicate foci of uplift resulting from intrusion (e.g., see Steven, 1989).

(2) Studies of the Hurricane and related normal faults. The magnetic and gravity expressions of these faults should be modeled to determine dip, offset, and possible listric curvature; the results could be checked against seismic reflection interpretations.

(3) Studies of buried intrusions of the Pioche-Marysvale belt, the iron axis, and the Sevier Valley area. Forward and inverse modeling of magnetic and gravity fields to investigate depth extent should be combined with radiometric and TM data for surface extent in pediment-covered areas to produce 3-dimensional models of known and suspected intrusive bodies. In some areas seismic reflection profiles and deep drilling data are available for control.

(4) Studies of basin-range structure beneath the Escalante Desert. Modeling of aeromagnetic and gravity fields should be combined with lineament analysis from TM data and with seismic reflection data, to locate faults, estimate depth of basin fill, and help discriminate between local intrusion-related and more regional extensional structures.

(5) Studies of basement structure beneath the Colorado Plateau. Model studies and depth-to-source estimates using potential-field data and available seismic control should be carried out to help resolve basement surface relief and identify intrabasement contrasts.

(6) Studies of ring fractures that extend into the Cedar City quadrangle from the Indian Peak caldera and Caliente cauldron complexes. Potential-field data, supplemented by TM imagery, are the principal source of information for this study. (The ring-fracture zones might also be investigated with electrical methods if there are other indications that they are favorable targets).

(7) Studies of hydrothermal alteration. TM, AIS, and aeroradiometric data should all be applied to delineation and characterization of hydrothermally altered areas, along with ground follow-up. At half-mile spacing the aeromagnetic profile data may also prove useful.

(8) Studies of magnetic properties of zoned quartz monzonites and their extrusive equivalents. Much geologic information is already available regarding petrologic and mineralogic variations of consanguineous quartz monzonite/quartz latite bodies emplaced beneath several miles of cover, in vent environments, and on the surface as thick ash-flows and flow-breccias. It would be extremely useful to relate these variations to variations in magnetic properties of the rocks, since the results could be extrapolated to interpretation of aeromagnetic signatures of completely concealed sources.

Section 5 GEOCHEMICAL STUDIES, by R.G. Eppinger

INTRODUCTION

Abundant geochemical data exist for the Cedar City 1° X 2° quadrangle, but they were collected by personnel under various programs using assorted types of samples, and were analyzed by different methods. As a consequence, no single data base can be compiled to unify the efforts of the individual groups; it is necessary to treat each database separately. The largest database is derived from the National Uranium Resource Evaluation (NURE) program, conducted in the Cedar City quadrangle approximately from 1979 through 1984. A more recent body of data comes from recently completed and on-going studies related to the USGS BLM Wilderness Study Area (WSA) program (stored in the USGS RASS data storage system). A third data set (hereafter called PLUTO) represents sample analyses stored in the USGS Branch of Geochemistry PLUTO data storage system, and consists of analytical results from a hodgepodge of samples of various media, collected over some 20 years by numerous USGS personnel with diverse goals, and analyzed by various methods in USGS laboratories.

ADEQUACY OF DATA

Although numerous geochemical surveys have been conducted within the Cedar City quadrangle, the resulting data are not adequate for rigorous mineral resource assessment. Each data set is hampered by one or more of the following shortcomings: insufficient sampling density, incomplete areal coverage, inappropriate sample type and/or analysis, and unknown data quality.

The NURE geochemical data set is the most extensive and has the most uniform coverage, and therefore is best suited for this preliminary assessment. However, the NURE program was designed specifically for uranium resource evaluation. Thus, in applying NURE data to more broad-scale mineral resource evaluation several weaknesses are apparent: the overall NURE sampling density is much less than one sample per square mile; large areas of the quadrangle were not sampled, resulting in large gaps where no information exists; and although more than 37 elements were analyzed for in the NURE program, many ore- and ore-related elements important for mineral resource assessment were not determined. Critical elements not sought in NURE stream sediment and soil samples from the Cedar City quadrangle include As, Au, Bi, Cd, Ga, Ge, Hg, Sb, Se, Sn, and W. Surprisingly, U was determined in only about 10 percent of the soil samples, and in less than 0.5 percent of the stream sediment samples. The relatively high determination limit for Ag (2 ppm) limits the usefulness of this element. No analytical or sample site duplicates are included in the NURE data set, inhibiting assessment of data quality. Finally, the NURE program did not include collection of heavy mineral concentrates, which provide important information on mineralogy and provide chemical data with greater contrast.

The USGS BLM WSA surveys generally used adequate sampling density for stream sediment surveys (about one sample per square mile), and generally included analyses for a suite of elements more relevant to mineral resource evaluation than the NURE studies. However, the WSAs represent very small areas within the Cedar City quadrangle. Further, data for the individual USGS BLM WSAs cannot be grouped together as a single database because of incompatible sample types and different analytical methods used. For example, heavy mineral concentrates collected in WSAs within the quadrangle include raw panned concentrates (no further lab preparation), and heavy-mineral concentrates (prepared using heavy liquid and magnetic separations) sieved to -16 mesh, -18 mesh, and -35 mesh; resulting in at least four different sub-samples. Analytical and sample site duplicates are lacking for the WSA studies, so that it is difficult to assess data quality.

Data for the Cedar City quadrangle from the PLUTO data base consist of 286 analyses done by the U.S. Geological Survey on samples submitted over two decades by numerous USGS workers, and represent diverse sample types--rocks, stream sediments, soils, vegetation, water, and coal--collected from throughout the quadrangle. Sample representativity and reasons for sample collection are largely unknown, and commonly the type of analysis (i.e., partial or total, etc.) was not recorded. A rigorous geochemical evaluation of the PLUTO data set thus cannot be made. Some rock analyses, however, have been used elsewhere in this evaluation as they pertain to known mineral occurrences.

USGS BLM WILDERNESS STUDIES

Sixteen BLM Wilderness Study Areas, for which geochemical data is or soon will be available, lie partly or wholly within the Cedar City quadrangle. As shown on figure 2, the combined areas for the WSAs comprise only a small percentage of the Cedar City quadrangle. Thirteen of the WSAs lie in dominantly Mesozoic sedimentary rocks of the Colorado Plateau, and 12 of these are adjacent to Zion National Park. Three WSAs lie in crystalline and sedimentary rocks of the Basin and Range province in the western part of the quadrangle. For this preliminary assessment, pertinent data for WSAs have been extracted from published mineral resource potential reports and verbally from personnel involved in the studies. Future detailed work which may encompass areas including the WSAs may be able to use the data to greater advantage.

Samples collected in the WSA surveys include a variety of sub-types of stream sediments and heavy mineral concentrates from stream sediments; and, in lesser abundance, rocks. Analytical methods used include semiquantitative emission spectrography, quantitative ICP atomic emission spectrography, neutron activation, and atomic absorption methods. A summary of WSA data, including study area size, numbers and types of samples collected, any geochemical anomalies discovered, and publications, is given in table 1. In general, very few geochemical anomalies were found; the majority of the WSAs are underlain by thick sequences of unmineralized Mesozoic sedimentary rocks. A few samples containing anomalous elements were collected from the Canaan Mountain, Red Butte, Red Mountain, and Spring Creek Canyon WSAs (table 1). These data are used here as accessory information in interpreting the NURE data.

NURE STUDIES

Reconnaissance hydrogeochemical and stream-sediment sampling comprised one element of the NURE program to evaluate uranium resources. The data were expected to help outline geochemical provinces and suggest favorable areas for more detailed studies, rather than to identify individual ore bodies or deposits (Averett, 1984). Abundant NURE geochemical data exist for the Cedar City quadrangle, but are of mixed utility--some data sets are readily useful, while others will require much re-organization, manipulation, and in some cases tedious detective work to discern what was sampled, how it was sampled, and how it was analyzed.

Available NURE Data

Cook and Fay (1982) and Grimes (1984) report that 1,772 stream sediment, 383 groundwater, and 97 surface water samples were collected in the Cedar City quadrangle. However, the USGS Branch of Geochemistry NURE database for the quadrangle reveals that the NURE database is much more extensive and that many samples collected were not analyzed (table 2).

Analytical Methods

An outline of NURE sampling and analytical methods is provided in appendix 1. Samples were collected under the direction of Savannah River Laboratories personnel and analyzed at both the Savannah River Lab and the Oak Ridge Gaseous Diffusion Plant. Stream sediment and soil samples were dissolved using a nitric/hydrofluoric acid digestion and analyzed using inductively coupled plasma atomic emission spectrography (ICP-AES) and neutron activation. Water samples were filtered at 0.8 microns and split in the lab for analysis. One split was analyzed using an ion exchange resin procedure and neutron activation; the second split was analyzed directly by ICP-AES and flameless atomic absorption. Elements analyzed for in the various sample media are shown on figure 21.

Talus and Hot Springs Sinter Samples

Two talus and four hot springs sinter samples were collected; one talus and two hot springs sinter samples were analyzed. No information is provided on the nature of the samples (i.e., rock type, fresh or altered, grab or composite, etc.) or on how the samples were analyzed. A scan of the data for both sample media did not reveal any unusual element concentrations. For these reasons, data for the talus and hot springs sinter samples are not used this preliminary assessment.

Stream Sediment Samples

Minus-100-Mesh Stream Sediments

The minus-100-mesh stream sediments fraction commonly was collected throughout the NURE program. About 181 minus-100-mesh stream sediments were collected in the Cedar City quadrangle and 90 of these were analyzed. Those not analyzed are presumed to be splits from the original samples, as they have the same geographic coordinates and field numbers (except for an additional "S" suffix) as the analyzed samples. Basic statistics and lower limits of analytical determination are provided in appendix 2. The means presented in appendix 2 are calculated for valid observations only. Elements with qualified values of "L" (=less than lower determination limit) have true means that are below the calculated means. This is most critical for elements with an abundance of "L"s reported, such as Ag, B, Co, Hf, Mo, and Pb. This same limitation applies to all tables of basic statistics shown in this report. The relatively small size of the data set (about 90 samples analyzed) limits its usefulness in assessing an area as large as the Cedar City quadrangle. Samples are widely separated throughout the quadrangle and difficult-to-interpret single-site anomalies are common. Thus, this data set was not used in this study.

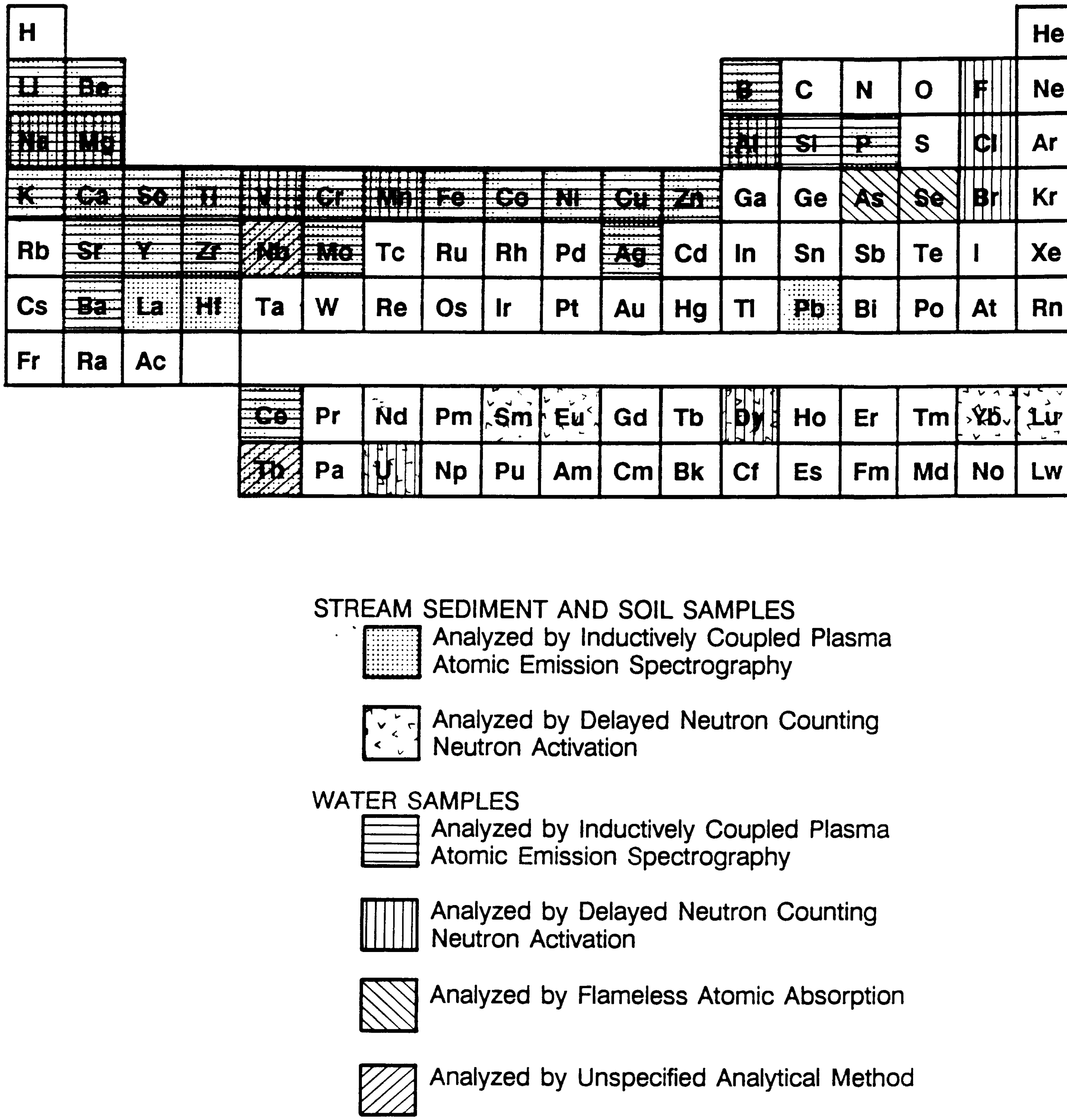


Figure 21.--Periodic chart showing elements analyzed for on NURE stream sediment, soil, and water samples collected in the Cedar City quadrangle.

Minus-16-Mesh to Plus-100-Mesh Stream Sediments

Cook and Fay (1982) report that coarse stream sediment fractions were collected in arid areas of the western U.S. in order to minimize eolian contamination. This rationale was apparently followed for the Cedar City quadrangle.

The minus-16-mesh to plus-100-mesh fraction of stream sediments (hereafter called coarse stream sediments) provides a much larger data base (1,693 samples collected, 836 samples analyzed) than is available for the fine fraction. Most of the samples not analyzed have the same geographic coordinates and field numbers (except for an additional "S" suffix) as the analyzed samples, and are presumed to be splits from the original samples. This data set was selected for use in this preliminary assessment because of its large size and relatively uniform coverage across the quadrangle. However, several large areas in the north and south-central parts of the quadrangle were not sampled, and it appears that sampling density is closely related to accessibility by roads; roadless areas were not sampled. Coarse stream sediment sample sites are shown on figure 22.

Basic statistics and lower limits of analytical determination for 836 coarse stream-sediment samples are provided in table 3. The distributions of Ag, Hf, and Mo are severely truncated at the limit of sensitivity, resulting in numerous "less thans" (L) for these elements. For these elements, little more can be done than to look for enriched areas. Analyses for Dy, Eu, Lu, Sm, U, and Yb are reported for only two samples, limiting usefulness of these elements. For remaining elements, ranges of values are an order of magnitude or more, larger than expected from sampling and analytical variation alone, which likely indicate variable chemical characteristics in the stream sediments. There are sufficient valid observations with relatively large concentration ranges to look for inter-element associations (see Results section).

Soil Samples

About 1,394 minus-100-mesh soil samples are listed for the Cedar City NURE program, and 721 of these were analyzed. As with the stream sediments, most of the samples not analyzed have the same geographic coordinates as the analyzed samples, and are presumed to be splits from the original samples. Although soil sample coverage is not quite as uniform as for the coarse stream sediments, many of the soil samples were collected in areas where coarse stream samples are lacking. Thus, the soil and coarse stream-sediment samples used together provide fairly uniform coverage of the quadrangle for all but large (>200 mi^2) unsampled areas in the north-central part of the quadrangle. Figure 22 shows sample sites for both soils and coarse stream sediments.

No information was found concerning the soil media sampled (i.e., sampling by specific soil horizon?, by constant depth?, organic-rich?) or how the samples were analyzed (i.e., method used?, partial or total digestion?). As most of the Cedar City quadrangle has a semiarid climate, it is possible that some the samples contain an eolian component. Thus, the soil data must be used cautiously. It is assumed here that soils were prepared and analyzed using methods employed for stream sediments.

Cook and Fay (1982), in a report on NURE reconnaissance work throughout the western U.S., state that in arid areas with poorly developed drainage, soil samples were collected rather than stream sediments. The majority of soil samples collected within the Cedar City quadrangle plot along

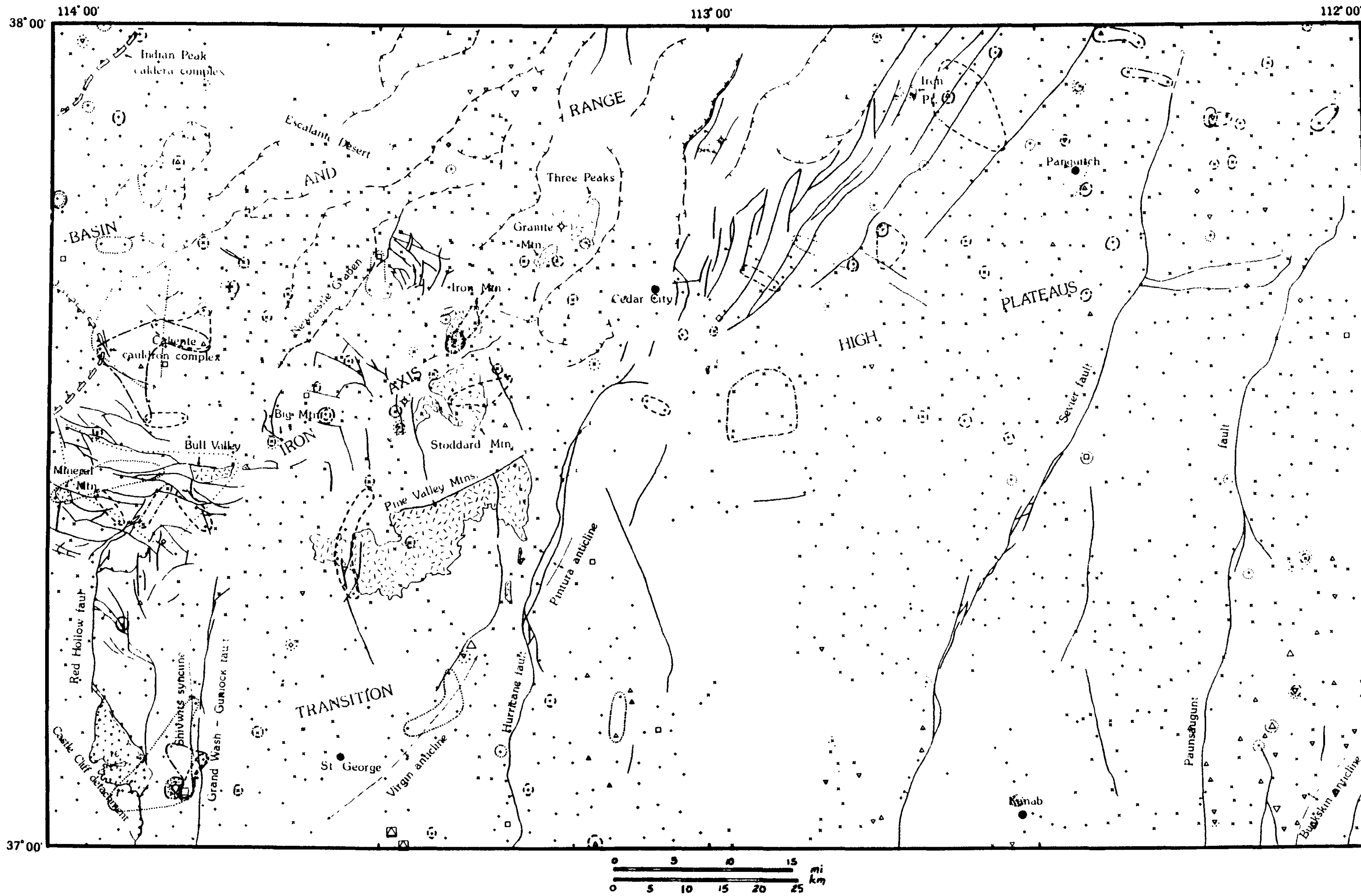
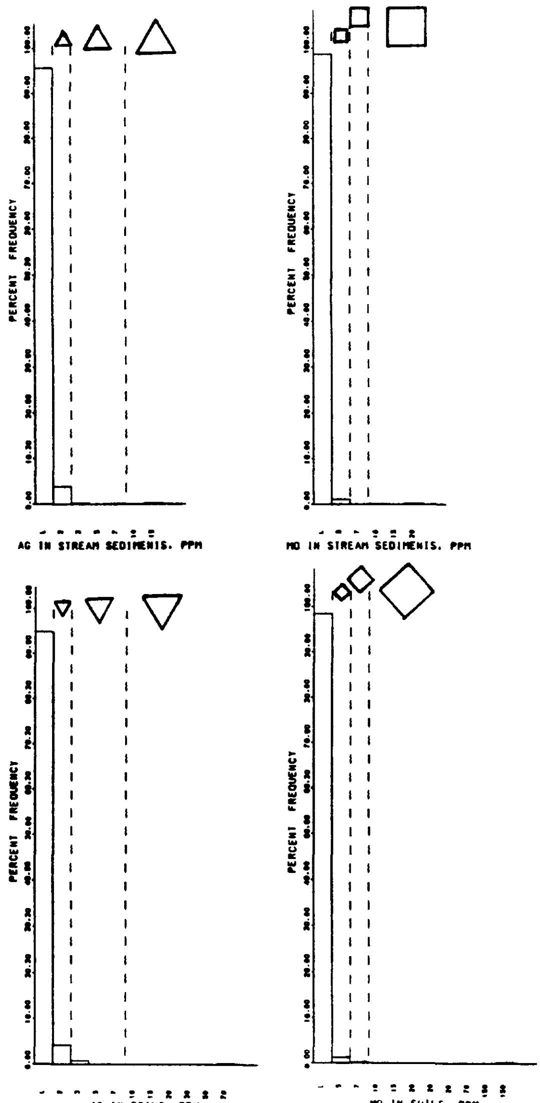
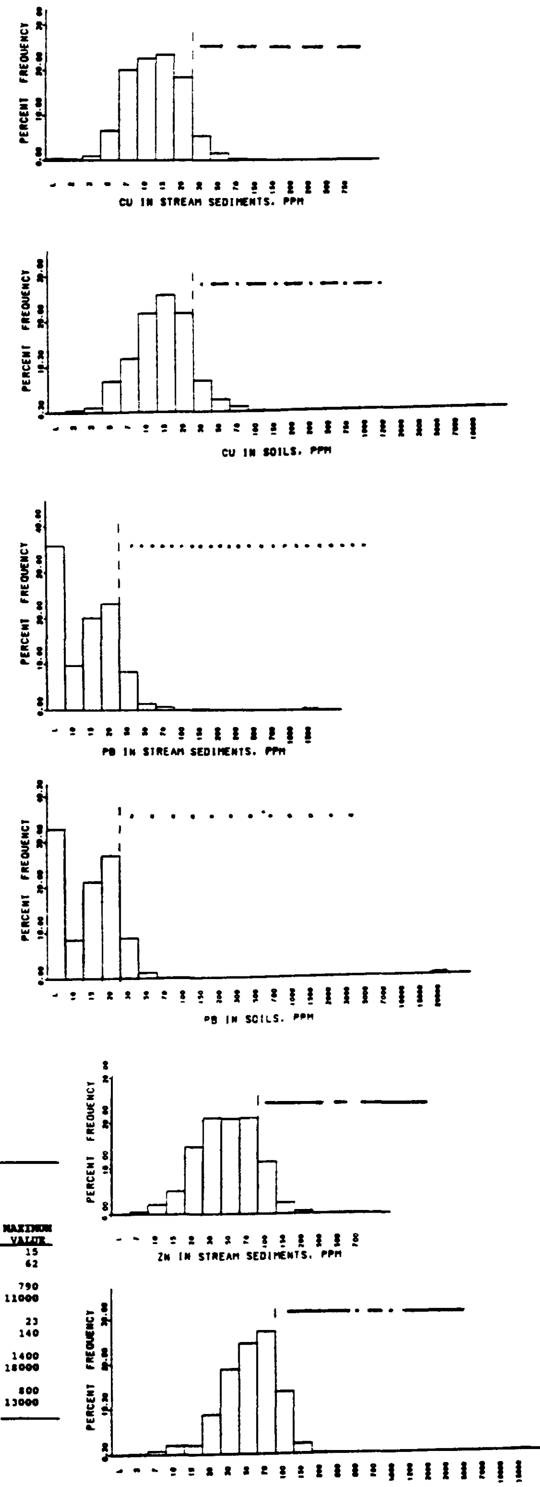


Figure 22.--Anomalous silver, copper, lead, molybdenum, and zinc in NURE stream sediments and soils, Cedar City 1° X 2° quadrangle, Utah. Symbol explanations and additional information are provided on following page.





Statistical information for silver, copper, molybdenum, lead, and zinc
in NURE stream sediments (minus 16 mesh to plus 100 mesh)
and soils (minus 100 mesh). All values are in parts per million.

MAP SYMBOL	ELEMENT	SAMPLE MEDIA	# OBSERVATIONS	THRESHOLD	# DETECTIONS ABOVE THRESHOLD	PERCENTILES 50th	94th	97.5th	MINIMUM VALUE	MAXIMUM VALUE
△	Ag	str. sed.	834	2	37	L2	L2	2	L2	15
▽	Ag	soil	646	2	33	L2	L2	2	L2	62
— — — —	Cu	str. sed.	834	30	46	12	29	37	L2	790
—·—·—	Cu	soil	646	30	48	14	32	44	2	11000
□	Mo	str. sed.	834	4	12	L4	L4	L4	L4	23
◇	Mo	soil	646	4	10	L4	L4	L4	L4	140
···········	Pb	str. sed.	834.	30	63	14	31	39	L10	1400
· · · · · · ·	Pb	soil	646	30	39	15	0	35	L10	18000
—— – ——	Zn	str. sed.	834	125	24	43	104	128	6	800
——·—·——	Sn	soil	646	125	15	52	105	120	5	13000

\+ NURE STREAM SEDIMENT SAMPLE SITE (plus-100 mesh to minus-16 mesh)

x NURE SOIL SAMPLE SITE (minus-100 mesh)

Figure 22.--(continued).

drainages; it is possible that many, if not most soil samples are in fact stream sediments. This is supported by the similar means and standard deviations for stream sediments and soils (tables 3 and 4, respectively). Nevertheless, because of uncertainty as to the true nature of the soils, the two sample media are treated separately throughout this study.

Basic statistics for 37 elements analyzed in 721 soil samples are provided in table 4. As was found with the coarse stream sediments, the distributions of Ag, Hf, and Mo are severely truncated at the limit of sensitivity, resulting in an abundance of "less thans" for these elements. These elements are best utilized by simply looking for enriched areas. Analyses for Dy, Eu, Lu, Sm, U, and Yb are only marginally useful because (1) only 75 soil samples were analyzed for these elements, (2) all the elements have very narrow concentration ranges, and (3) all 75 samples were collected in one small area in the west-central part of the quadrangle. The range of values for most of the remaining elements is an order of magnitude or more, a range in excess of that expected from sampling and analytical variation. The broad ranges likely are due to variable chemical characteristics in the soils. There are sufficient valid observations with relatively large concentration ranges to assess the data for inter-element associations (see Results section).

Water Samples

Nearly 500 water samples (stream, spring, and well) were collected in the Cedar City quadrangle during the NURE program. Information is lacking concerning exactly what was sampled, how the samples were prepared, and how they were analyzed. Thus, water data are use cautiously here.

Stream waters (97 samples) were commonly collected along roads or near areas of human activity, where potential for contamination is considered to be high. Therefore, stream waters are avoided in this study. However, basic statistics for the stream waters are provided for reference in appendix 3.

Means and standard deviations for analyses of water samples from wells (141) and springs (244) were examined and found to be similar. Minimum values were also very similar in both sample media and maximum values were generally within an order of magnitude of one another. For these reasons, and because of the similar nature of the sample media, the well and spring water data were merged together into a single data set of 385 "groundwater" samples. Sample localities for groundwater samples are shown on figure 23.

Basic statistics and lower analytical determination limits for 385 groundwater samples are provided in table 5. Variations of several orders of magnitude are common for many elements, while others vary only slightly. Severely truncated distributions are found for Be, Ce, Cr, and Th.

RESULTS--NURE DATA

Coarse Stream Sediments and Soils

Single Elements

Considerable variation is exhibited for Cu, Pb, and Zn in coarse stream sediments and in soils (tables 3 and 4). These elements are of special interest in this study, as they are common to many of the metallic mineral deposits found in the Cedar City quadrangle. Anomaly thresholds for Cu, Pb, and Zn were determined subjectively by inspection of histograms. Only a few

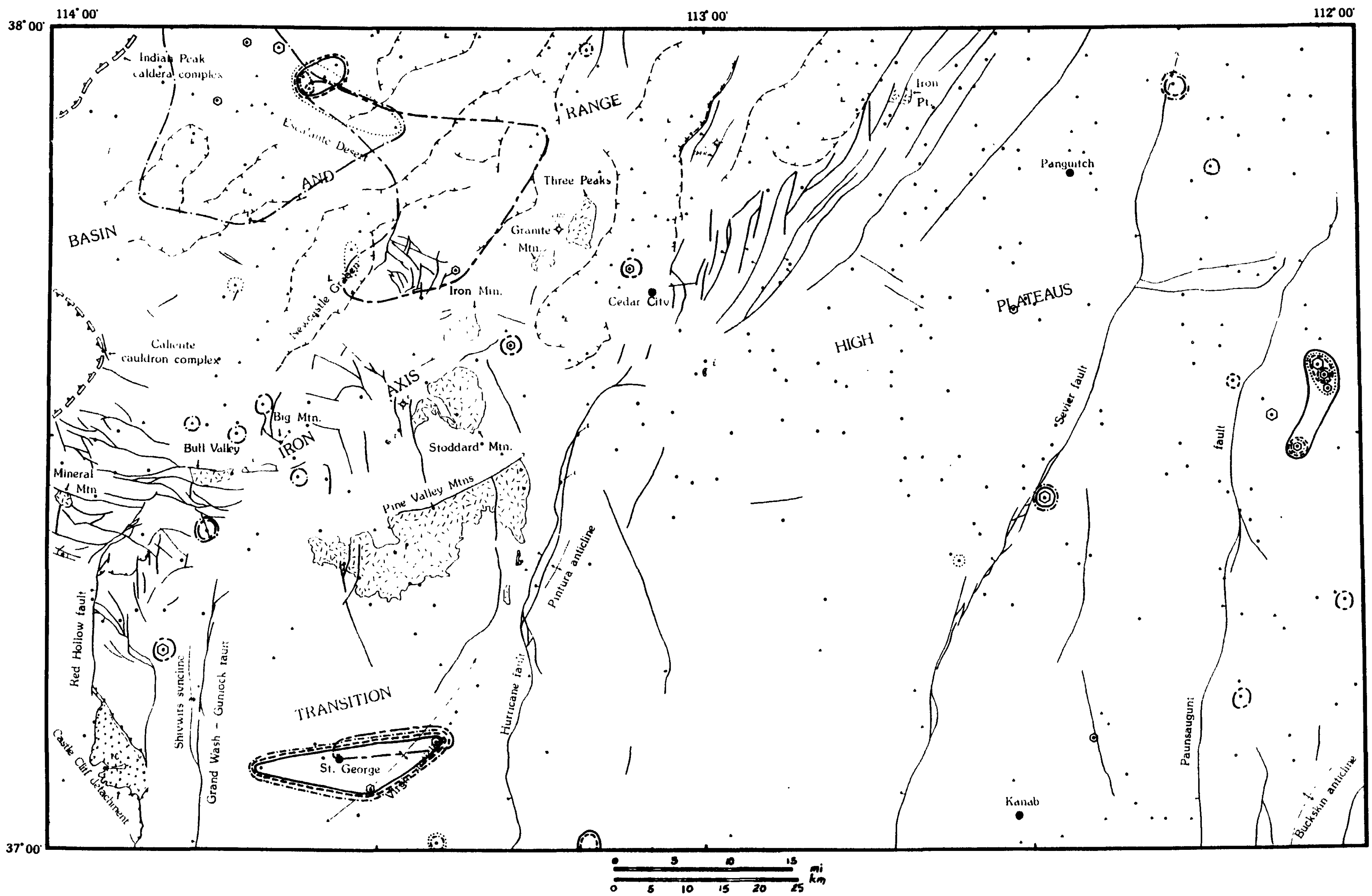
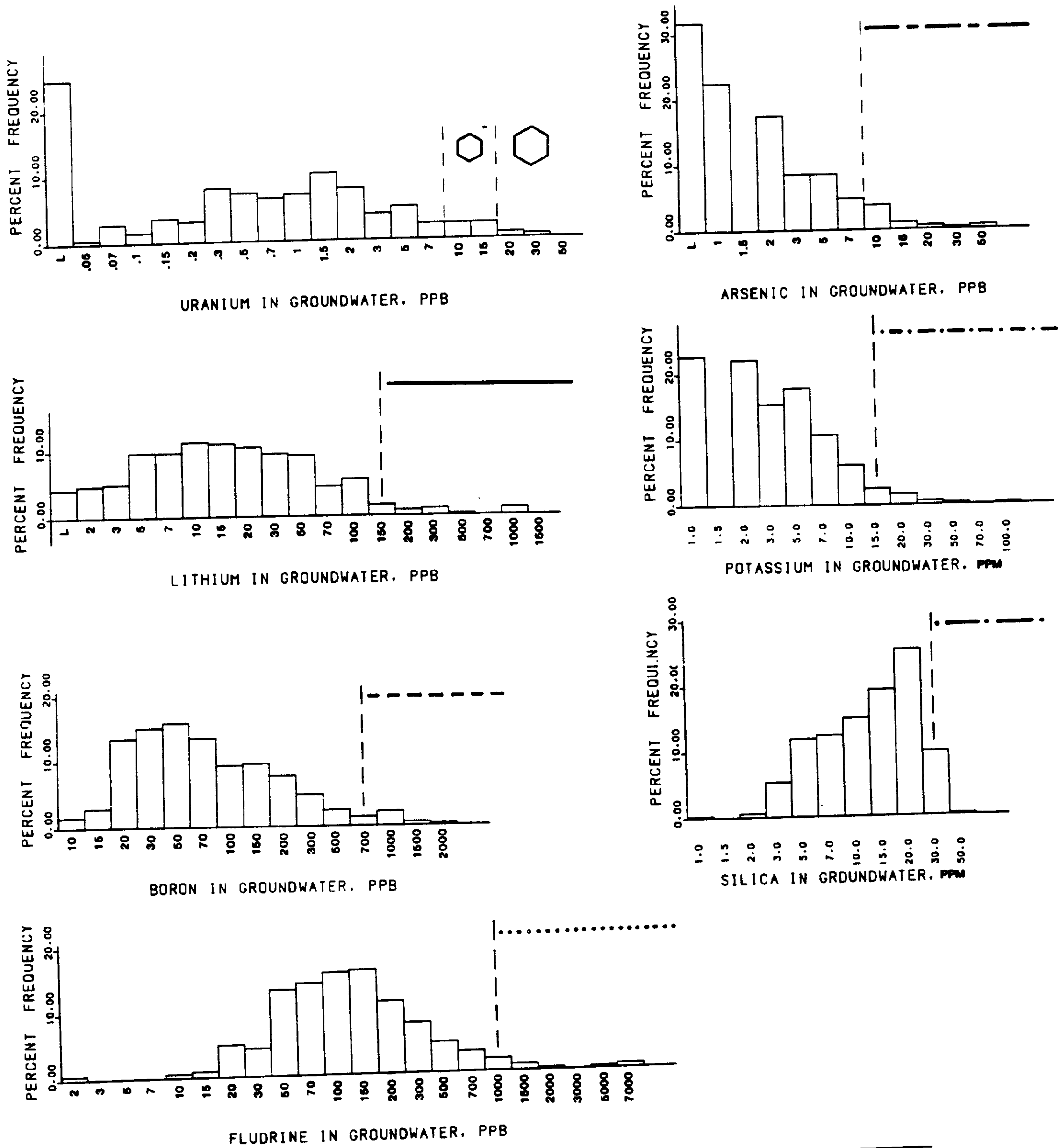


Figure 23.--Anomalous arsenic, boron, fluorine, lithium, potassium, silica, and uranium in NURE groundwater samples, Cedar City 1° X 2° quadrangle, Utah. Symbol explanations and additional information are provided on following page.



Statistical information for uranium, lithium, boron, fluorine, arsenic, potassium, and silica in NURE groundwater samples. All values are in parts per billion.

MAP SYMBOL	ELEMENT	# OBSERVATIONS	THRESHOLD	# DETECTIONS ABOVE THRESHOLD	PERCENTILES 50th	94th	97.5th	MINIMUM VALUE	MAXIMUM VALUE
⬡	U	3a5	10	17	.51	7	14	L(.04)	35
————	Li	379	150	15	14	100	250	L(2.0)	1200
— — — —	B	379	700	13	59	440	870	10	2100
··········	F	385	1000	12	110	580	1100	2.0	6000
—— — ——	As	37a	10	1a	1	9	12	L(1.0)	45
—·—·—·—	K	379	15000	13	3000	12000	19000	1000	97000
——·——·	Si	379	30000	20	14000	29000	32000	1000	49000

▲ NURE WELL WATER SAMPLE SITE

● NURE SPRING WATER SAMPLE SITE

Figure 23.--(continued).

Mg and Mo values were detected in the coarse stream sediments and soils. With detection limits of 2 ppm and 4 ppm, respectively, any Ag or Mo detected is considered anomalous in this study. Figure 22 shows occurrences of anomalous base metals, Ag, and Mo; and histograms, threshold values, and statistical information for these elements in coarse stream sediments and soils. For base metal anomalies on figure 22, at least 80 percent of the samples within outlined areas have values above the subjective threshold.

Numerous base-metal anomalies are indicated on figure 22. The largest clusters of samples containing anomalous Cu+Pb+Zn are found in the western part of the quadrangle in crystalline rocks of the Basin and Range province. Other large clusters containing anomalous Zn and, to a lesser degree, Cu are found in Tertiary volcanic rocks near the northeastern quarter of the quadrangle. Numerous smaller base metal anomalies, particularly Cu and Pb, occur throughout the quadrangle.

Anomalous amounts of Ag also are found throughout the quadrangle (figure 22). The largest cluster of samples containing anomalous Ag is found in Permian, Triassic, and Jurassic sedimentary rocks in the southeastern part of the quadrangle. Here, 27 soil and coarse stream sediment samples contain low-level Ag anomalies from 2 to 10 ppm, and isolated Pb, Cu, and Mo anomalies are found within the anomalous Ag cluster. Two smaller clusters containing low-level anomalous Ag are found along the southern edge of the quadrangle. A fourth cluster containing low-level anomalous Ag in soils occurs in the Escalante Desert in the north-central part of the quadrangle. The highest Ag values are found in samples from mining districts in the southern Beaver Dam Mountains and at Silver Reef, both in the southwestern quarter of the quadrangle. Two adjacent stream-sediment samples containing high Ag and high Mo occur in Triassic sedimentary rocks about 8 miles southeast of St. George, along the southern boundary of the quadrangle.

Single site anomalies for Mo are scattered across the quadrangle and are difficult to assess (figure 22). Adjacent samples containing anomalous Mo are found in only two areas: two samples in the Tutsagubet mining district, also containing base metal and Ag anomalies, and the two Ag-rich samples southeast of St. George described above.

Factor Analysis

A multi-element data set of this size generally contains redundant information. This redundancy results from the similar behavior of certain groups of elements in the natural environment. Common behavior of a group of elements within a data set may be due to influences by, among other things, rock type or mineral deposits. Correlation and factor analysis are statistical tools which look for and quantify these interrelationships.

The matrix of correlation coefficients provides a first-pass at identifying mutually correlated elements. Correlation matrices for coarse stream sediments and soils are provided in tables 6 and 7, respectively. A cursory scan of these matrices reveals several high correlations between elements. Extremely high correlations for the base metals (i.e., 1.0) in soils are due to strong influence by one sample in the Tutsagubet mining district, which contains greater than 4 percent combined Pb+Cu+Zn. However, correlations after removing this sample from the data set are still significant (around 0.8).

Factor analysis provides a method of analyzing the correlation matrix, indicating groups of mutually correlated elements, and quantifying the relative intensities (loadings) of these groups. Spatial distributions of the interrelated elements can then be plotted as factor scores. R-mode factor analysis was performed separately on the coarse stream sediment and the soil data sets. Qualified values ("L"s) were first replaced as indicated in tables 6 and 7. For both sample media, six-factor varimax models were selected as most suitable for simplifying the data into meaningful element associations.

Common factors are found in the coarse stream sediments and soils (table 8). In order to assess the spatial distribution and possible geologic controls for the associations, factor scores were calculated and plotted on maps. Most of the factors appear to be lithologically controlled, although a fair amount of analytical noise may be present. The distributions of scores for factors related to lithologies are not shown here, except for those factors which may aid in identifying areas containing potential mineral deposits.

The Pb-Cu factor (Table 8) identifies areas of known mineral deposits. This factor strongly delineates the Tutsagubet mining district. The factor is heavily influenced by Pb; influence on the factor is due largely to a few samples from the Tutsagubet mining district which contain extremely high values for Pb, Cu, and Zn. Because the Pb-Cu factor essentially identifies Pb anomalies shown on Figure 22, the Pb-Cu factor is not shown here.

Groundwater

Single element plots for the groundwater data were made for the following 12 elements: Ag, As, B, Cu, F, K, Li, Mo, Si, V, U, and Zn. Scattered random single-element, single-site anomalies for five of these elements (Ag, Cu, Mo, V, and Zn) occur across the quadrangle, apparently unrelated spatially or geologically. Interference problems are suspected for these elements and they are not discussed further. Anomalous values for the remaining seven elements (As, B, F, K, Li, Si, and U) occur at a few single sites, but also as interpretable clusters of samples. Figure 23 shows groundwater sample sites, histograms, and outlined anomalous areas for As, B, F, K, Li, Si, and U.

Three clusters of samples containing multi-element anomalies are shown on figure 23. The largest cluster includes samples from a large area in the Escalante Desert. The highest values for B, F, Li, and K are found in five wells near Zane in the Escalante Desert. Anomalous Si is found in numerous wells in the Escalante Desert and high U occurs at a few sites. Several wells and springs in the Antelope Range and adjacent Escalante Desert contain anomalous As. The second cluster of anomalous groundwater samples (5 sites) is located in the vicinity of St. George, where anomalous As, B, Li, K, and U are found. The third cluster of anomalous groundwater samples is located east of Bryce Canyon National Park, where five springs contain anomalous values in one or more of the following elements: B, Li, F, K, and U.

INTERPRETATION--NURE DATA

Single Elements

Figure 22 shows numerous base metal anomalies. Many of these are single-site anomalies and are not interpreted here. The large group of samples in the northeast part of the quadrangle is anomalous in Zn and to a lesser degree in Cu and Pb; these anomalies may be due either to local mafic volcanic rocks in the area or to analytical noise (see discussion of factor 1, Appendix 4).

Several other groups of samples with anomalous base metals, Ag, and/or Mo reflect mining districts or areas which possibly contain mineral deposits.

Geochemical signatures for these districts and anomalous areas are described in the Summary of Geochemical Anomalies section.

Factor Analysis

This section describes NURE stream sediment and soil factors which may be related to mineral deposits. Factors likely related to lithology or analytical noise are discussed in Appendix 4.

A factor dominated by Th-Nb-Be-Ce-La-Y occurs in both sample media (factor 4 in stream sediments; factor 5 in soils; table 8). Most samples with high scores (figure 24) are located in a large cluster in the northwestern part of the quadrangle, where Miocene high-silica rhyolite domes crop out locally (Antelope and White Rock Mountains). North of this area in the southern parts of the White Rock Mountains, Needle Range, and Wah Wah Mountains, are Miocene topaz rhyolite flows and domes which are enriched in F, Na, K and incompatible lithophile elements (Rb, U, Th, Ta, Nb, Y, Be, Li, and Cs) (Christiansen and others, 1986). The Th-Nb-Be-Ce-La-Y factor in samples from the northwestern part of the quadrangle may reflect a more widespread presence of lithophile element-enriched rhyolites than previously recognized.

Rhyolites of this character are intimately related to economic deposits of Be, U, F, Li, and Sn, and may be surface manifestations of rhyolitic stocks associated with Climax-type Mo deposits (Christiansen and others, 1986). Rhyolite flow domes are also spatially associated with epithermal precious metal deposits in the region (Shubat and McIntosh, 1988). Thus, the Th-Nb-Be-Ce-La-Y factor delineates an area which may host a variety of deposit types.

A B-Li-K factor occurs in soils and coarse stream sediments. This suite of elements is common for salt deposits and may indicate areas of potential evaporite accumulation. However, sodium would be expected to occur in this factor if it reflects salt deposits. For soils, the lack of correlation between Na and the B-Li-K factor (factor 6), and the strong correlation between Na and factor 1, may indirectly support the conclusion that factor 1 represents systematic noise. For stream sediments, Na correlated strongly with factor 2, the feldspar factor (K-Ba-Na-Al).

A plot of high scores for the B-Li-K factor indicates four general groups of samples (figure 25). A large cluster with high scores, particularly for soils, is found in Quaternary gravels in the Escalante Desert. This factor may reflect recent evaporite accumulation or thermal water leaking into groundwater within the basin. The latter alternative is discussed more in the groundwater interpretation. A second large cluster of samples with high B-Li-K scores occurs along the southern edge of the quadrangle in Triassic Moenkopi Formation or in Quaternary alluvium draining Moenkopi Formation. The Moenkopi Formation contains evaporite tongues which are the likely the sources for the cluster. A third smaller group of stream sediment samples with high B-Li-K scores in the east-central part of the quadrangle may indicate evaporitic facies of the Claron Formation. A fourth small group of stream sediments with high B-Li-K scores generally drains areas containing undifferentiated Cretaceous Dakota and Tropic Formations and may indicate local evaporitic facies.

Groundwater

Groundwater samples from a group of wells in Quaternary gravels in the Escalante Desert are anomalous in B, Li, K, F, Si, and As (figure 23). The group is located in the same general area as soils and stream sediments with

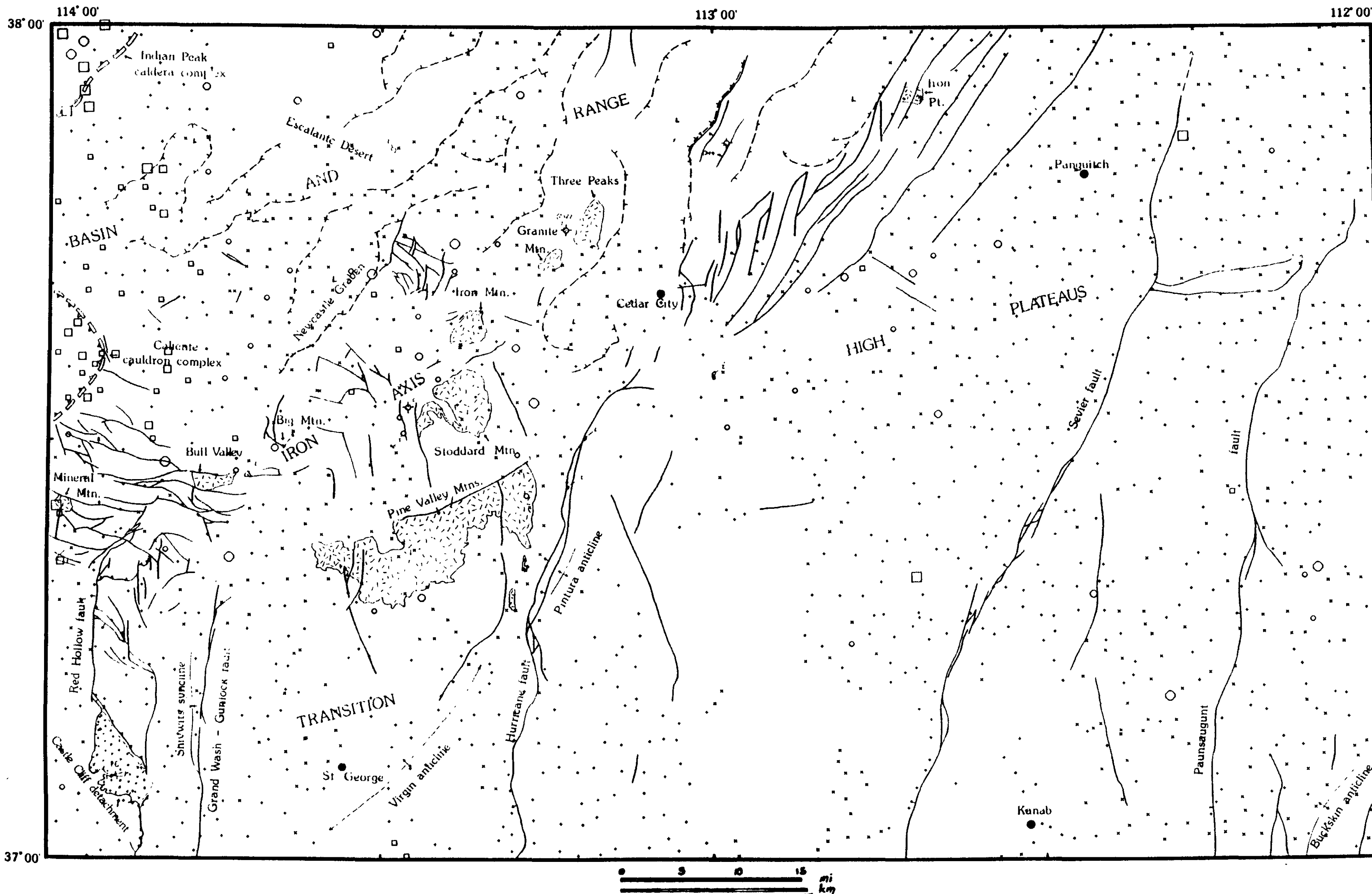
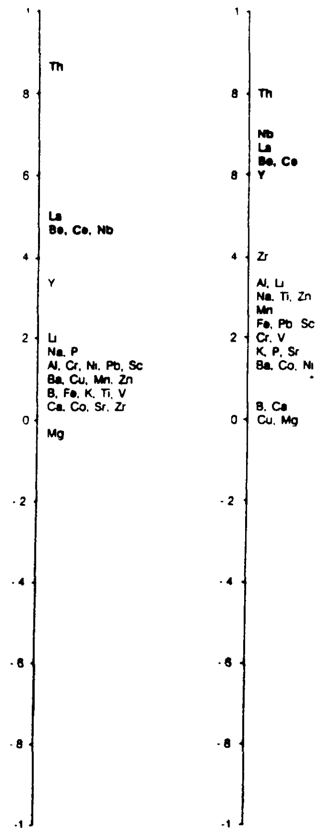
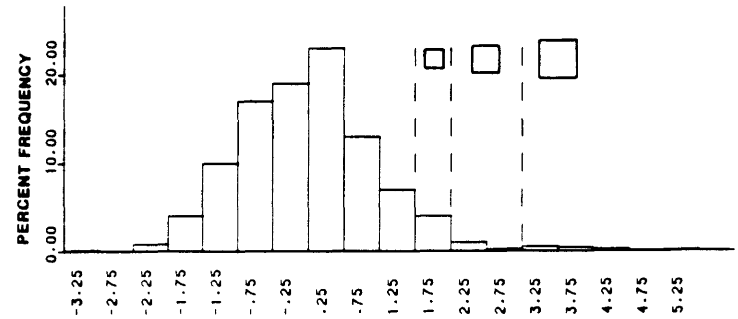


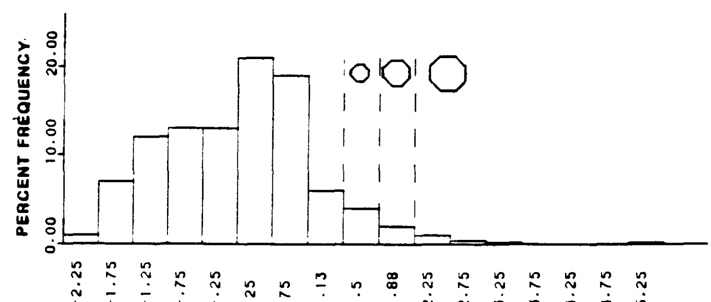
Figure 24.--Factor score plot for the Th-Nb-Be-Ce-La-Y factor in soils and coarse stream sediments, Cedar City 1° X 2° quadrangle, Utah. Symbol explanations and additional information are provided on following page.



Soils, Factor 5 Stream Sediments, Factor 4



Th-Nb-Be-Ce-La-Y FACTOR, STREAM SEDIMENTS



Th-Nb-Be-Ce-La-Y FACTOR, SOILS

The factor scores shown in these histograms have a mean of 0 and a standard deviation of 1. Therefore, the factor score for a given sample is a measure of the deviation of that sample from a sample of mean composition, measured in units of standard deviation.

Factor composition, as indicated by the relative correlation of elements to the factor. Elements with positive correlations above .4 strongly influence the the factor. Data is based on a 6-factor, R-mode, varimax factor analysis.

+ NURE Stream Sediment Sample Site (plus-100 mesh to minus-16 mesh)

x NURE Soil Sample Site (minus-100 mesh)

Figure 24.--(continued).

anomalous scores for the B-Li-K factor (figure 25). While the B-Li-K factor alone may suggest a salt deposit origin, the additional elements anomalous in groundwater (F, Si, and As) suggest that a geothermal origin is also possible. A low-temperature geothermal source for anomalies in wells in the Escalante Desert near Zane was also suggested by Klauk and Gourley (1983); they reported anomalous Li and B, anomalous total dissolved solids, and elevated temperatures (68° to 82° F) in the same wells as those sampled during the NURE program. Thermal springs are found elsewhere in the Escalante Desert in the Richfield quadrangle, and hot water was encountered in a well near Newcastle in the Cedar City quadrangle.

The groundwater anomaly in the Escalante Desert likely extends northward into the Richfield quadrangle. Moderately to strongly anomalous fluoride, moderately anomalous As, and scattered U, Cu, Zn, and sulfate anomalies in surface and groundwater are reported along the southern boundary of the Richfield quadrangle between longitudes 113° 30' and 113° 45' (McHugh and others, 1984). Anomalous U found in NURE groundwater samples along the northwestern part the Cedar City quadrangle may be related to enriched U reported in rhyolites to the north, in the southern Wah Wah Mountains (Christiansen and others, 1986).

The Li-B-K-As-U anomaly in groundwater surrounding St. George is difficult to assess. The anomaly occurs in four springs and one well in Quaternary gravels and Triassic Moenkopi Formation and is within a broader anomalous area defined by the B-Li-K factor in soils and coarse stream sediments. No thermal springs or geothermal wells are reported in the area. The anomaly may be related to evaporite tongues within the Moenkopi Formation, to salt accumulation in basin gravels, to unrecognized geothermal activity, and/or to groundwater contamination around St. George.

Five springs east of Bryce Canyon National Park are anomalous in one or more of the following elements: B, Li, F, K, and U. The springs are located in undifferentiated Cretaceous Dakota and Tropic Formations and in Jurassic Carmel Formation. Perhaps the anomalies are due to local evaporite facies within these formations, and/or to unrecognized geothermal activity in the area.

SUMMARY OF GEOCHEMICAL ANOMALIES

Several significant geochemical anomalies derived from various NURE and BLM Wilderness Study Area data sets in the Cedar City quadrangle are summarized here and shown on figure 26. This summary focuses on clusters of anomalous stream sediments, soils, and groundwater samples which may be related to mineral deposits. Numerous single-site, single-element anomalies shown on figures 22, 24, and 25 are not discussed here.

Anomalous base metals, Ag, and Mo, delineate several mining districts in the western part of the quadrangle. Two samples from the Silver Reef mining district (area 1A; commodities: Ag, Cu, V, U) contain moderately anomalous to highly anomalous Ag at sites located on Triassic Moenave Formation. Several samples also contain anomalous Pb. Within the Tutsagubet mining district (area 2; commodities: Pb, Cu, Au, Ga, Ge) several samples are anomalous in Pb and Zn, two samples are anomalous in Cu, and two are strongly anomalous in Ag and Mo. The Goldstrike and Mineral Mountain districts (area 3A; commodities: Au, Ag, Cu, Pb, Zn) contain several samples anomalous in Pb and Cu, and a few samples anomalous in Ag and Mo. The Antelope Range district (area 3B, commodities: Ag, Au, Cu, Pb) has a few samples with anomalous Pb

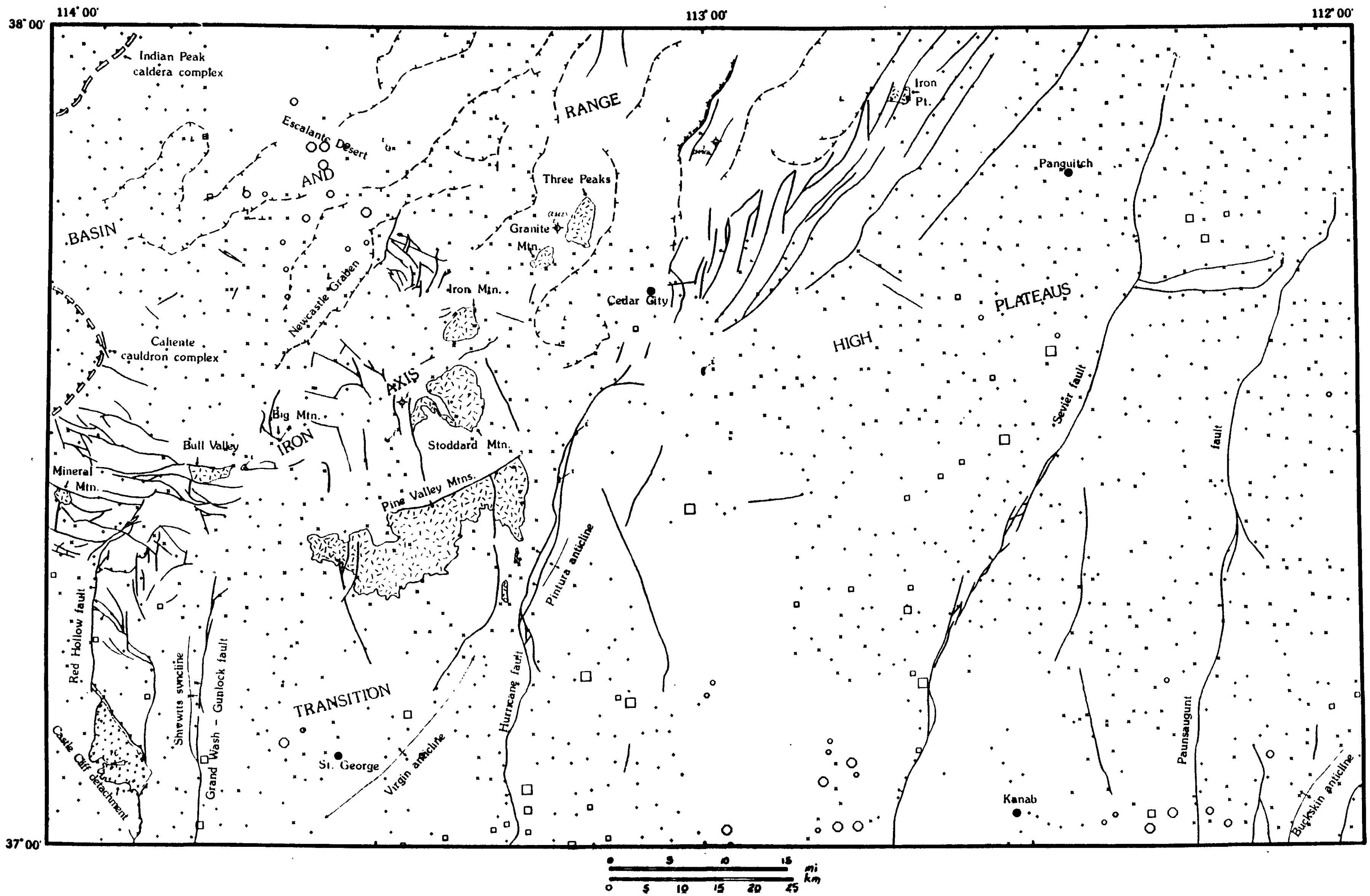
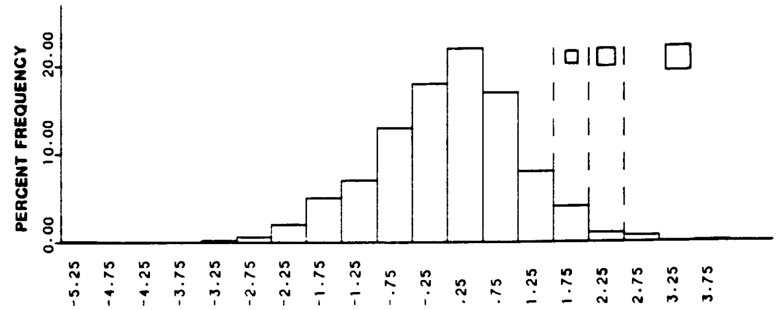
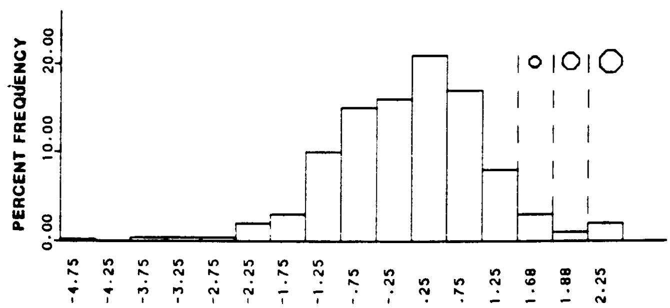


Figure 25.--Factor score plot for the B-Li-K factor in soils and coarse stream sediments, Cedar City 1° X 2° quadrangle, Utah. Symbol explanations and additional information are provided on following page.

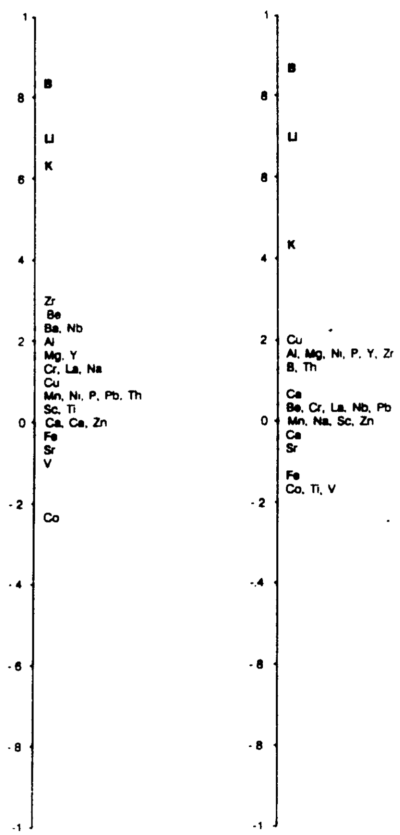


B-LI-K FACTOR, STREAM SEDIMENTS



LI B-LI-K FACTOR, SOILS

The factor scores shown in these histograms have a mean of 0 and a standard deviation of 1. Therefore, the factor score for a given sample is a measure of the deviation of that sample from a sample of mean composition, measured in units of standard deviation.



Soils, Factor 2

Stream Sediments, Factor 6

Factor composition, as indicated by the relative correlation of elements to the factor. Elements with positive correlations above .4 strongly influence the the factor. Data is based on a 6-factor, R-mode, varimax factor analysis.

\+ NURE Stream Sediment Sample Site (plus-100 mesh to minus-16 mesh)

x NURE Soil Sample Site (minus-100 mesh)

Figure 25.--(continued).

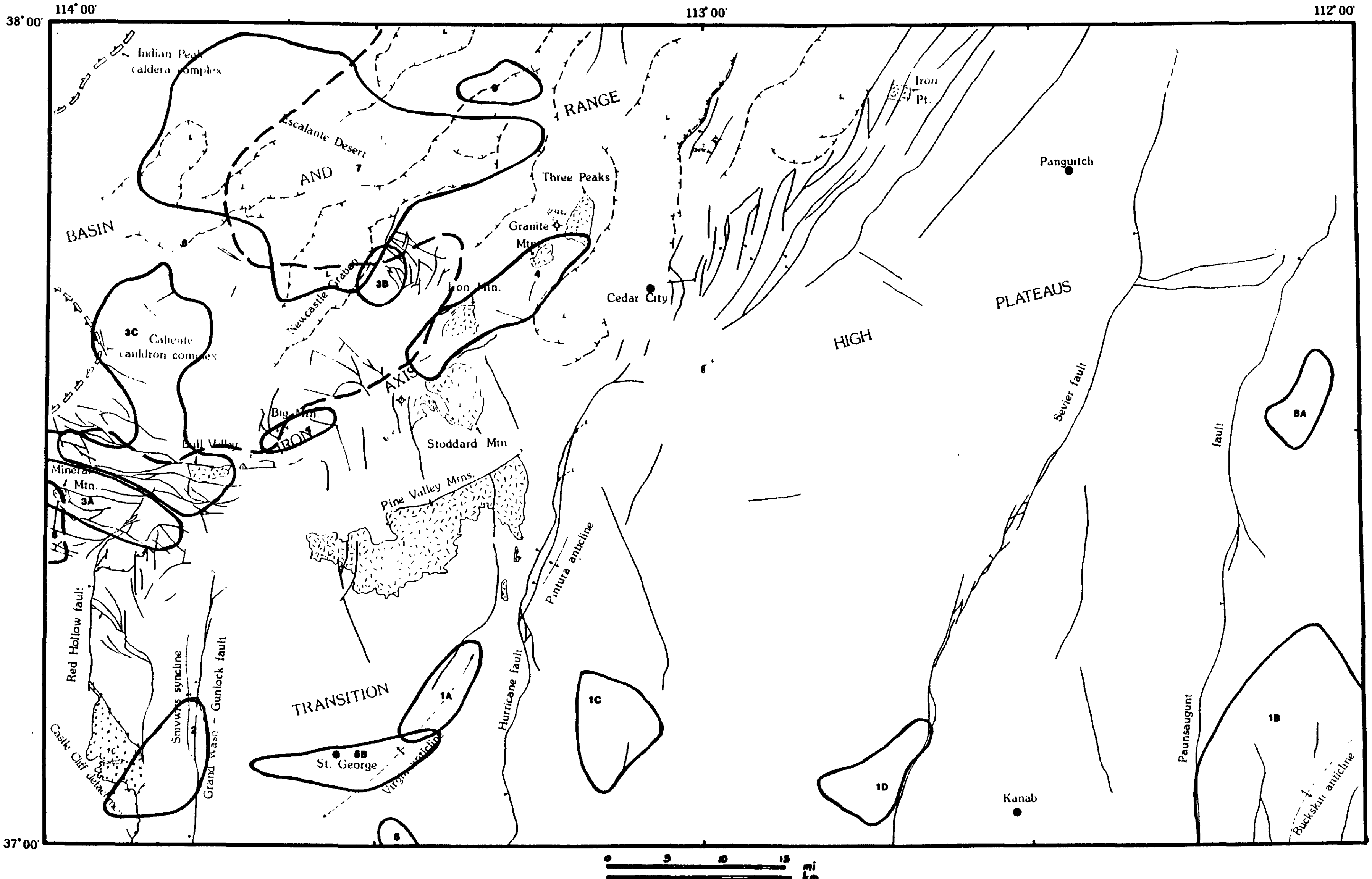


Figure 26.--Summary map of geochemical anomalies possibly related to mineral deposits, Cedar City 1° X 2° quadrangle, Utah. Symbol explanations and additional information are provided on following page.

MAP EXPLANATION

[Information in this table is derived principally from NURE coarse stream sediment, soil, and groundwater data, with accessory information from USGS BLM Wilderness Study Area data. Parentheses indicate minor components. Circled areas on map enclose anomalous samples only; entire mining districts are not necessarily enclosed by the circles.]

AREA ON MAP	LOCATION ON QUADRANGLE	DISTRICT NAME (if applicable)	ANOMALOUS METALS	ADDITIONAL COMMENTS
1A	SW quadrant	Silver Reef	Ag, Pb	mined for Ag; some Cu, V, and U produced
1B	SE corner	Paria	Ag, Pb,	unexplained low-level NURE soil and stream sediment anomaly; coincides in part with the Paria mining district, which has precious and base metal occurrences; shares some geologic and geophysical similarities with Silver Reef; no Ag detected in USGS samples from Paria-Hackberry BLM WSA in northern part of area 1B; real or analytical noise??
1C	S center	none	Ag, Pb, Mo	unexplained low-level NURE stream sediment anomaly; possibly due to high background in Chinle Fm.
1D	S center	none	Ag	unexplained low-level NURE soil/stream sediment anomaly
2	SW corner	Tutsagubet	Cu, Pb, Zn, Ag, Mo	mined for Pb, Cu, Au; Ga, Ge mined at Apex Mine
3A	W edge	Goldstrike/ Mineral Mtn.	Cu, Pb, (Ag, Mo)	mined for Au, Ag, base metals
3B	W central	Antelope Range	Pb, (Mo)	mined for Ag, Cu, Pb
3C	W edge	none	Cu, Pb, Zn, Fe, (Ag, Mo)	unexplained NURE soil/stream sediment anomaly; has geologic similarities with Goldstrike, Mineral Mountain, and Antelope Range districts
4	W central	Iron Springs/ Bull Valley	Fe, Cu, Pb, Zn	numerous scattered single site NURE soil and stream sediment anomalies; mined for Fe
5	S edge of SW quadrant	none	Ag, Mo	2 unexplained adjacent, highly anomalous NURE stream sediments
6	NW part of quad	none	Th-Nb-Be-rare earth factor	strong lithologic factor in NURE soils and stream sediments which apparently identifies area containing high silica topaz rhyolites
7	NW quadrant	none	B-Li-K factor Li, B, K, F, Si, As, U	strong salt factor in NURE soils and stream sediments; single elements listed are anomalous in NURE groundwater; some of the wells have elevated temperatures--68° to 82° F (Klauk and Gourley, 1983); possible low-temperature hot spring activity or recent evaporite accumulation in basin
8A	E edge	none	Li, B, K, F, U	unexplained NURE groundwater anomaly; near Paunsaugunt fault; hot spring activity??
8B	SW quadrant	none	Li, B, K, As	unexplained NURE groundwater anomaly; surrounds St. George--possibly due to contamination
9	NW quadrant	none	Ag	unexplained NURE soil anomaly in Quaternary alluvium; related to adjacent hot spring activity in area 7??

Figure 26.--(continued).

and one sample with high Mo. The Iron Springs and Bull Valley districts (area 4; commodity: Fe) contain scattered samples with anomalous Fe, Cu, Pb, and Zn.

Area 1B is a large area containing 24 NURE soil and stream sediment sites with anomalous low-level Ag, scattered anomalies in Pb, and one sample with anomalous Mo and Cu. The area coincides with the Paria mining district, a vaguely defined district with precious and base metal occurrences. Host rocks in parts of area 1B are similar to those at Silver Reef and several samples with anomalous Ag are located on Triassic Moenave Formation. Silver Reef and area 1B have similar geophysical anomalies which may reflect comparable basement morphologies. However, unlike Silver Reef, several samples with anomalous Ag are located on Triassic Moenkopi Formation and Permian Kaibab Limestone. Other possible sources for the metal anomalies include sediment-hosted Cu deposits or mineralized breccia pipes which, elsewhere in the Colorado Plateau, are locally anomalous in Ag (K.J. Wenrich, U.S. Geological Survey, oral communication, January, 1989). Finally, no Ag was found in samples from the Paria-Hackberry BLM WSA, which overlaps the northern part of area 1B. This is particularly significant, as the analytical detection limit for Paria-Hackberry stream sediment samples (0.5 ppm) is lower than that for NURE samples (2 ppm). Whether the Ag anomaly in area 1B is real or represents analytical noise is unclear from these data.

Area 1C contains several NURE stream sediment samples with low-level Ag anomalies, and a few samples with anomalous Pb and Mo. Bedrock is principally Triassic Moenkopi and Chinle Formations. The Chinle Formation is locally anomalous in these metals and is likely responsible for the anomalies.

Area 1D contains several NURE soil and coarse stream-sediment samples with unexplained low-level Ag anomalies. Bedrock is undivided Triassic and Jurassic sandstones (Temple Cap, Navajo, and Kayenta), which are not known to be metalliferous. The potential for analytical noise cannot be ruled out, although this possibility is minimized by the fact that Ag anomalies occur in two sample media which were analyzed separately.

Numerous NURE stream sediment and soil samples in area 3C are anomalous in base metals and Fe and contain low-level anomalous Ag and Mo. The area is underlain dominantly by Tertiary intermediate and silicic volcanic rocks, and locally by Quaternary basalt. There are no known mineral deposits in the area, although the geochemical signature is similar to that found in the Goldstrike, Mineral Mountain, Antelope Range, and Tutsagubet mining districts. Further, both the Antelope Range district (area 3B and area 3C) are included in the area with anomalous scores for the Th-Nb-Be-rare earth elements factor (area 6). While samples from area 3C are anomalous relative to all samples in the quadrangle, absolute values for the anomalous metals are not highly anomalous (all base metals within the area are less than 200 ppm and Ag and Mo are near the lower analytical determination limit). It is uncertain whether the anomalies are related to high background values in mafic volcanic rocks or mineralization.

Area 5 contains two NURE stream sediment samples which are highly anomalous in both Ag and Mo, with respect to other samples in the quadrangle. The samples are taken from Quaternary gravels derived from Triassic Moenkopi and Chinle Formations. The two samples also have high scores for the Th-Nb-Be-rare earth element factor. No known mineral occurrences are found in the area. Whether the anomalous metals can be attributed to high background values in the Chinle Formation, or are related to mineralization, is not known.

Area 6 in the northwest part of the quadrangle has anomalous scores in the Th-Nb-Be-rare earth element factor in soils and coarse stream sediments. This strong lithologic factor is likely related to Miocene high silica rhyolite flows and domes, which crop out sporadically within the northwestern part of the quadrangle and extensively further north in the White Rock, Needle Range, and Wah Wah Mountains. The factor is significant because rhyolites of this character are intimately related to lithophile mineral deposits (Be, U, F, Li, and Sn), and possibly Climax-type Mo deposits (Christiansen and others, 1986). Further, emplacement of flow domes may provide favorable structures and heat sources for later epithermal deposits.

A large area of Quaternary gravel in the Escalante Desert contains NURE soil and stream sediment samples with anomalous scores for the B-Li-K factor (area 7). NURE groundwater samples within area 7 are also anomalous in Li, B, K, F, Si, U, and As. The high B, Li, and K contents may indicate recent salt accumulations within the basin, except that the associated groundwater anomalies for F, Si, and As, and elevated temperatures in wells near Zane (68° to 82° F; Klauk and Gourley, 1983) support a thermal spring origin for the suite of elements. Alternatively, many of these elements may be derived from high silica rhyolite in alluvium shed from outcrops to the north.

Areas 8A and 8B are unexplained NURE groundwater anomalies containing Li, B, and K (± F, U, and As). No thermal springs or geothermal wells are reported in either area. The anomalies may be lithologic, related to local evaporitic sedimentary facies or, for area 8B, environmental, related to human activities around St. George.

Area 9 is an unexplained cluster of five NURE soil samples containing low-level anomalous Ag. The sites are underlain by Quaternary gravels. It is not known whether the anomaly represents analytical noise or is related to possible geothermal activity in adjacent area 7.

RECOMMENDATIONS

Existing data and samples preclude the need to re-sample the entire quadrangle, although the regional NURE database has significant drawbacks, such as low sample density, mixed sample media, a lack of samples in many areas, and lack of analyses for critical pathfinder elements. Retrieving, reprocessing, and re-analyzing of NURE stream sediments and soils might provide adequate information to permit more focused subsequent fieldwork, but additional sampling will be necessary. Sampling areas lacking NURE coverage, validating existing anomalies, and detailed field studies in mining districts and anomalous areas shown on figure 26 should constitute the major part of expanded geochemical mineral resource studies in the quadrangle. Several specific recommendations are listed below.

(1) Archived NURE stream sediments and soils should be analyzed for Ag, As, Au, Bi, Cd, Ga, Ge, Sb, Se, Sn, U, and W. If enough sample remains F, Hg, Te, and Tl content should be determined. More sensitive analyses for Ag (at least 0.5 ppm), ultra-sensitive analysis for Au (around 1 ppb), and quantitative analysis for the other elements are recommended. Except for Ag, these elements were not analyzed for in NURE stream sediments and soils; the first 12 elements listed are critical for mineral resource assessment.

(2) Many NURE stream sediment (857) and soil (673) samples were collected but were not analyzed (table 1). Many of these samples have the same geographic coordinates and field numbers as the analyzed samples and are likely splits

from the original samples. However, some of the unanalyzed samples plot in areas where data are lacking and could provide valuable information. Duplicate samples could provide additional material for analyses suggested in (1) above.

(3) If the duplicate set of samples described in (2) above have not been pulverized and are large volume samples (unlikely) then heavy-mineral concentrates could be prepared. These concentrates would provide much needed information on mineralogy, as well as chemical data with greater contrast.

(4) Numerous soil and groundwater samples were collected and analyzed during the NURE survey. Although preliminary interpretations of these data have been made here, information on sampling and analytical procedures is lacking. This information should be acquired (probably by contacting personnel involved in the NURE study) to more fully understand what the data represent.

(5) Interpretation of the NURE data has revealed several areas with unexplained geochemical anomalies (figure 26). Samples from these areas should be re-analyzed to ascertain whether the anomalies are real or due to analytical noise. Fieldwork to validate real anomalies will be required.

(6) Several large areas of the quadrangle are either not covered or are inadequately covered by existing geochemical databases. Reconnaissance stream sediment, heavy-mineral concentrate, and rock samples need to be collected at approximately 1,000 sites and analyzed.

(7) All of the known mining districts should be sampled in detail (stream sediments, heavy-mineral concentrates, and rocks) to determine the geochemical signature expected for similar deposits elsewhere within the quadrangle and to explore for unknown extensions of the districts. This important information is insufficient or lacking with the present geochemical database.

(8) NURE groundwater data have been interpreted in this report in a very preliminary fashion. More information can likely be gleaned from the data by hydrogeochemists better acquainted with the specialized techniques available for interpreting water data.

(9) Non-traditional geochemical approaches, such as biogeochemical, soil gas, and partial leachate pebble coating analyses, should be considered in large areas of the western half of the quadrangle that are concealed by Quaternary alluvial and eolian deposits. Integrated studies in the quadrangle combining non-traditional geochemical and geophysical methods may aid in understanding and exploring for concealed deposits.

Section 6 RESOURCES OF THE CEDAR CITY QUADRANGLE,
by T.M. Cookro, M.A. Shubat, and J.L. Jones

INTRODUCTION

The Cedar City quadrangle, with 13 metal mining districts, has abundant mineral resources. Principal commodities are iron, silver, gold, gallium, germanium and base metals. Figure 27 shows metallic mining districts and mines, prospects, and occurrences cataloged in the U.S. Geological Survey Mineral Resource Data System (MRDS) file. The Iron Springs and Pinto districts produced the greatest amount of iron ore west of Minnesota and currently supply about 550,000 tons of ore per year to the Geneva steel plant in Orem, Utah. The recently closed Escalante Mine, in the Escalante district, was one of the largest silver mines in the western U.S. Gold has been produced as a by-product at various base metal and silver mines and a new bulk minable gold deposit is nearly in production in the Goldstrike district. Until recently, the Apex mine, in the Tutsagubet district, produced gallium (used for integrated circuits) and germanium (used in infrared optics and fiber optics) from a collapse breccia-pipe. The pipe originally was mined for highly oxidized ores of copper, lead and silver with minor gold and zinc. In the Silver Reef district, silver was produced from a roll front environment similar to the uranium roll front environment. Exploration programs are in progress in the Goldstrike, Tutsagubet, and Antelope Range districts.

A variety of industrial mineral resources are known within the quadrangle, including sand and gravel, volcanic rock products, bentonite clay (produced for the Glen Canyon Dam project), kaolin, petrified wood, agate, dimensional sandstone, limestone, gypsum and marble. Figure 28 shows industrial mineral mines, prospects, and occurrences catalogued in the MRDS data base. Groundwater resources are plentiful, although the topic is not discussed in this report.

Oil and coal resources are also abundant within the Cedar City quadrangle. The Virgin oil field has produced 25M barrels; it is Utah's oldest oil field and is the largest field in southwestern Utah. Three coal fields, the Kolob, Harmony, and Alton, and part of a fourth, the Kaiparowits Plateau coal field, lie within the quadrangle and contain approximately 6 billion tons of reserves. The Kolob coal field originally produced coal for local use (in the late 1940's) but now supplies coal to the California Pacific Utilities Company. Geothermal resources in the Cedar City quadrangle include low- and moderate-temperature systems, one of which supports commercial greenhouse operations at Newcastle. Energy resources within the quadrangle are shown on figure 29.

During the course of this preliminary assessment, the MRDS data base for the quadrangle was updated using the mineral occurrence files at the Utah Geological and Mineral Survey, which contain the most current information available for the state. This update consisted of adding 87 new records, upgrading existing records to account for recent discoveries, and deleting 87 records that lacked location data and commodity information. The revised file contains 345 records, 209 of which refer to metallic deposits and 136 to non-metallic records. Sand and gravel deposits were excluded because of the large number and wide distribution of these deposits in the Cedar City quadrangle. Site locations in figures 27-29 reflect the additions to the MRDS data base. Site numbers and additional information contained in the Cedar City MRDS data base can be obtained through Don Huber, Branch of Resource Analysis, U.S. Geological Survey, Menlo Park, Calif.

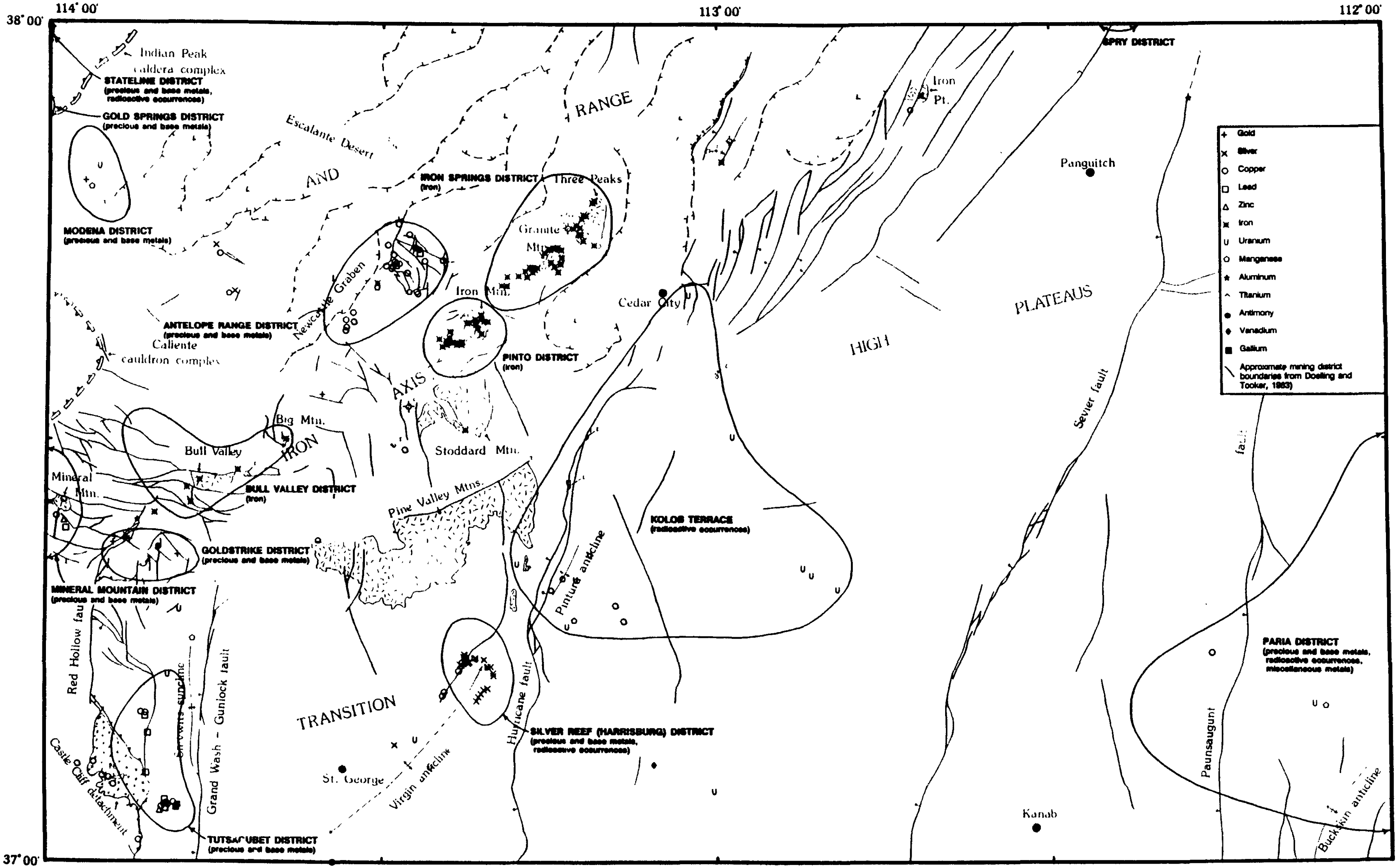


Figure 27.--Metallic and uranium ore deposits and occurrences in the Cedar City 1° X 2° quadrangle, Utah.

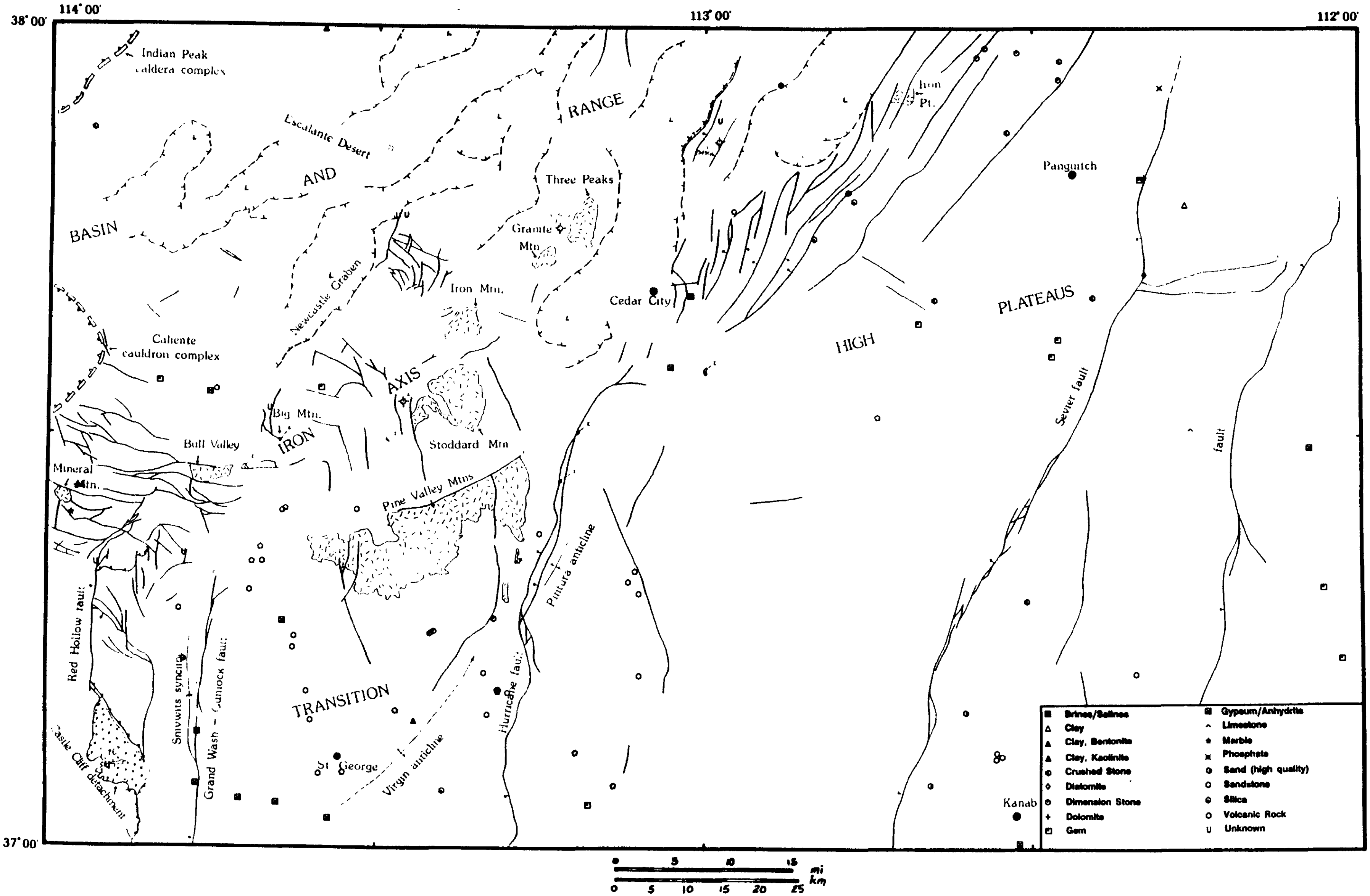


Figure 28.--Industrial minerals, gemstones, and dimension stone in the Cedar City 1° X 2° quadrangle, Utah.

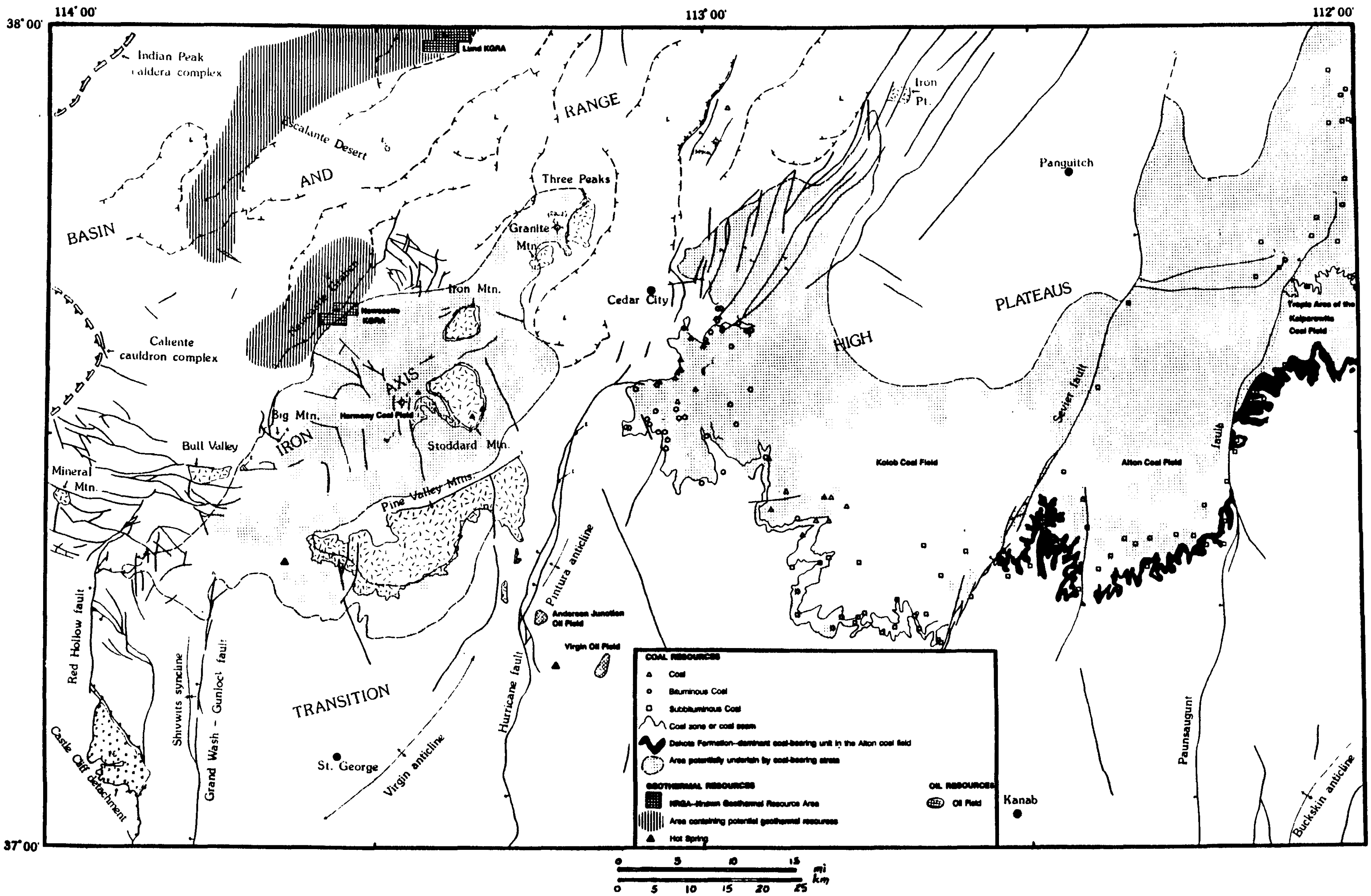


Figure 29.--Coal, oil, gas, and geothermal resources in the Cedar City 1° X 2° quadrangle, Utah.

Table 9 summarizes where known and potential resources are found within the stratigraphic section. Table 10 is a brief summary of metallic mining districts within and on the borders of the Cedar City quadrangle. Critical factors controlling the location of mineral deposits in the districts were extracted from studies of the major mines. Following table 10, mining districts are discussed in detail and suggestions are given for various topical studies that will greatly improve knowledge of resources within the quadrangle.

METALLIC RESOURCES, BY DISTRICT, WITHIN THE QUADRANGLE
(Refer to figure 27 for district locations)

ANTELOPE RANGE (SILVER BELT) DISTRICT

DESCRIPTION: The Antelope Range district contains base- and precious-metal veins. Prospecting began in the 1870's when it was known as the Silver Belt district. Most of the recent exploration (1950 to present) has been in the Blair area, and in Bullion Canyon where epithermal silver veins are localized around rhyolitic and dacitic volcanic domes. The veins contain maximum values of 9 oz/ton silver and 0.22 oz/ton gold.

REFERENCES: James, 1987; Shubat and McIntosh, 1988; Shubat and Siders, 1988; Siders and Shubat, 1986.

GEOLOGICAL ENVIRONMENT: Epithermal precious metal veins occur along northwest-striking high-angle faults cutting volcanic and sedimentary rocks, adjacent to rhyolite and dacite domes.

Rock Types: Precious metal veins are in Mesozoic and Tertiary sedimentary rocks and Cenozoic volcanic and sedimentary rock. Host rocks include limestone of the Carmel and Claron Formations, clastic sedimentary rocks of the Iron Springs Formation, and a sequence of Tertiary ash-flow tuffs.

Textures/Structure: Neogene extensional faulting produced northwest-striking structures that host mineralized veins. Veins occur as open-space fillings with colloform banding, cockscomb textures, and encrustations. Vein length ranges from 100 to 4,500 ft. Vein width is variable. In places veins grade into stockwork or breccia zones. The average strike of the veins is N. 30° W.

Age Range: Northwest-striking faults which host deposits formed between 21 and 8.4 Ma. Alteration, related to ore deposition, occurred at about 8.5 Ma, and was about contemporaneous with rhyolitic and dacitic volcanism.

REPRESENTATIVE DEPOSITS: occurrences

Mineralogy: Silver-bearing veins are dominantly vuggy-textured quartz (locally rose-colored to amethyst), with some base metals and abundant barite. Silver is present in several hypogene sulfosalt minerals: pearceite, tennantite, stromeyerite, and proustite. Gold-bearing chalcedony-pyrite veins are less abundant than silver-bearing veins. Earlier base-metal veins originally contained galena, chalcopyrite, sphalerite, and pyrite. Most veins are now oxidized and sulfides are sparse; supergene ore minerals include tenorite, cuprite, covellite, digenite, malachite, chrysocolla, brochantite, cerussite and smithsonite. Primary gangue minerals are quartz, calcite, chalcedony, barite, pyrite, and psilomelane.

Alteration: Alteration was of two types: structurally controlled and pervasive. Structurally controlled alteration resulted in silicification, and phyllic and potassic assemblages. Pervasive alteration resulted in argillic, extreme silicic, and kaolinitic assemblages.

Ore Controls: A hydrothermal system developed peripheral to a rhyolite-dacite volcanic center with circulation of fluids occurring along northwest-trending faults. Ore minerals precipitated in response to episodic boiling.

Weathering: oxidation of ore minerals

Geochemical Signature: Ag, Au, Cu, Pb, Mn, Ba, Zn, Mo

MINERAL DEPOSIT MODELS WITHIN THE DISTRICT

Known Deposit Types: Epithermal base and precious metals veins of the quartz-adularia (low sulfur) bonanza-type or the adularia-sericite type. The veins are somewhat similar to those at the Escalante silver mine, and are a silver-rich variant of the Creede-type model.
Potential Deposit Types: Stratigraphically-controlled disseminated precious metal deposits and manto replacement deposits.

BULL VALLEY DISTRICT

DESCRIPTION: The district is located in the Bull Valley Mountains, on the southern edge of the Escalante desert, and in the western part of Washington County, Utah. No production has been recorded for the district, however, it has potential for minable iron ore, and speculative potential for epithermal precious metal vein systems.

REFERENCES: Blank, 1959, Blank and Mackin, 1967; Bullock, 1970; Limbach and Pansze, 1986; Siders and Shubat, 1986; Tobey, 1976.

GEOLOGICAL ENVIRONMENT: Iron deposits occur in magnetite skarn, vein, and replacement deposits related to intrusion of the Bull Valley pluton and in thermal springs spatially associated with the intrusion.
Rock Types: The richest iron deposits are veins in the vent zone of the Rencher Formation, a white to pinkish or red quartz latite tuff and tuff-lava which is co-magmatic with the Bull Valley pluton. An extensive bed of siliceous hematite occurs as pore-filling replacement of a tuffaceous sandstone between two Rencher ash flows. Pre-Rencher volcanics, hypabyssal intrusive bodies of quartz monzonite porphyry, the Iron Springs Formation, the Homestake Limestone Member of the Carmel Formation, and limestone strata within the Claron Formation also host minor iron deposits and prospects within the area.

Textures/Structures: Siliceous hematite deposits are associated with presumed fumarolic vent zones within the Rencher Formation. Iron deposits also occur in brecciated quartz monzonite and on the margins of the pluton, which may indicate that some venting followed intrusive doming, collapse, and explosive release of ash flows; and as precipitates from thermal springs. The intrusions followed zones of structural weakness along Sevier- or Laramide-age faulted anticlines. Iron minerals also occur along faults and fractures in zones of intensely silicified or propylitized rock.

Replacement deposits occur in limestone of the Claron Formation as well as in the Homestake Limestone Member, where these units are intruded by the Bull Valley pluton.

Age Range: Age is about the same as intrusion of the Bull Valley pluton and extrusion of Rencher tuffs; about 22-21 Ma.

REPRESENTATIVE DEPOSITS: The Pilot Deposit contains from 15-20 M tons of ore at 31 percent Fe; Cove Mountain has about 1 M tons of highly siliceous hematite at 45 percent Fe. Milling is a problem throughout the district due to silicification.

Mineralogy: Mineral deposits are of three basic types, listed in order of decreasing depth and increasing distance from Bull Valley intrusion: (1) magnetite skarn replacement, breccia, and vein deposits; (2) hematite veins and breccias; and (3) hematite-silica jaspilite replacement bodies. Hematite and magnetite replace volcanic rocks and limestone.

Alteration: Propylitic alteration is pervasive in volcanic rocks; silicification is more localized. Propylitically altered rocks associated with the iron deposits consist of the following minerals: chlorite, calcite, epidote, minor pyrite, minor clays, and secondary quartz, limonite, jarosite. Chlorite replaces biotite, hornblende, lithic fragments, pumice, some groundmass, and is in veinlets with white quartz. Epidote occurs as radiating crystals replacing plagioclase, and as disseminations in veinlets with gray quartz. In silicified zones the secondary quartz is medium gray, and contains fine-grained pyrite.

Ore Controls: Association with the quartz monzonite pluton is the primary mineralization control. Epithermal fluid migration and fracture systems are secondary controls. Thermal springs are prominent in the region.

Weathering: unknown

Geochemical Signature: Fe, Au, Ag, As, Cu, Mo, and Hg

MINERAL DEPOSIT MODELS WITHIN THE DISTRICT

Known Deposit Types: Iron Skarn (18d of Cox and Singer, 1986)

Potential Deposit Types: Hot Spring Au-Ag (high Ag) (25a of Cox and Singer, 1986)

ESCALANTE DISTRICT

DESCRIPTION: The largest recent primary silver producer in the state of Utah has been the Escalante silver mine, located in Iron County, 45 mi west of Cedar City, in the Escalante Valley. Mining began at the Escalante mine in 1896. Total production is unknown, but in 1934 the mine produced 500 tons of milled concentrates; in 1966, 13,000 tons at 11 oz/ton were produced; and from 1981 to 1985, 300,000 tons were produced at 10-10.5 oz/ton. Hecla Mining Company, the current owner, closed the mine on December 31, 1988. The mill will remain active by milling ore stockpiles until 1990.

REFERENCES: Allen, 1979; Anonymous, 1988; Arentz, 1978; Biehl and Grant, 1987; Burger, 1984; Fitch and Brady, 1982; James, 1987; Petersen and Rasmussen, 1988; Siders, 1985b; Siders and Shubat, 1986.

GEOLOGICAL ENVIRONMENT: Silver-rich epithermal precious metal veins are related to extensional faulting and bimodal volcanism.

Rock Types: Miocene volcaniclastic rocks of Newcastle Reservoir host the silver veins. The rocks consist of interbedded tuffaceous sandstone and tuffaceous conglomerate of mostly latitic composition with beds ranging in thickness from 2 in to 6 ft. Cross-bedding and channel filling are locally present. Fresh rock is light reddish brown to light gray. The rocks strike E-W and dip about 10° S.

Textures/Structure: Silver occurs in quartz veins which contain finely disseminated hematite. The silver-bearing quartz vein at the Escalante mine strikes N. 22° E., and dips 70° W., is 3,500 ft long, and extends to a depth of about 800 ft, with an average width of 19 ft. Crustiform banding and drusy quartz-lined vugs are common in the vein which also shows evidence of repeated brecciation and quartz veining.

Supergene processes have locally enriched the ore. There are three distinct ore zones:

1. The leached zone, above 5,100 ft in elevation, with an average grade of 6-8 oz/ton silver.
2. The secondarily enriched zone, between 5,100 and 4,650 ft, with an average grade of 9-18 oz/ton silver.
3. The primary zone, below 4,650 ft, with an average grade of 3 - 5 oz/ton silver.

Age Range: Mineralization occurred at 11.6 Ma, based on K/Ar dating of vein adularia.

REPRESENTATIVE DEPOSITS: Escalante Silver Mine (Hecla)

Mineralogy: Ore vein mineralogy includes crustiform quartz, adularia, hematite, minor pyrite, fluorite, barite, calcite, native silver, argentite, cerargyrite, willemite, galena and sphalerite, with secondary cerussite, mimetite and copper oxide. Silver is not visible in hand specimen, but occurs as fine grains of native silver and as silver chloride and sulfide. At depth, below the water table, the deposit is richer in lead and zinc, and poorer in silver than the near-surface ores.

Alteration: Hydrothermally altered rocks are silicified and argillized and grade outward into calcite-enriched rock.

Ore Controls: Neogene extensional faulting produced the conduits for mineralizing fluids, and bimodal volcanism provided the heat for a hydrothermal system.

Weathering: unknown

Geochemical Signature: Ag, Pb, Zn, Ba; minor Au, Cu, F

MINERAL DEPOSIT MODELS WITHIN THE DISTRICT:

Known Deposit Types: Creede Epithermal (25b)

GOLD SPRINGS AND STATELINE DISTRICTS

DESCRIPTION: Because lithologies and mineralization processes are similar, the Gold Springs and Stateline mining districts are grouped together in this section. Mining began in the area in 1897 and continued intermittently until 1948, producing a minimum of 22,000 tons of ore containing 0.425 oz/ton gold, 1.84 oz/ton silver, and minor base metals.

REFERENCES: Butler and others, 1920; Perry, 1976; Thomson and Perry, 1975.

GEOLOGICAL ENVIRONMENT: Gold occurs with pyrite in quartz-adularia veins along faults that cut Tertiary volcanic rocks (silver to gold ratio varies).

Rock Types: The volcanic sequence is, from older to younger, andesite flows, ash-flow tuffs, and rhyolite flows. The andesite flows host most of the veins. Intrusive plugs of rhyolite porphyry cut the lower part of the volcanic section.

Textures/Structures: Veins, some in a stockwork pattern, have crustiform banding, with individual bands consisting of either calcite or quartz and adularia. Gold is associated with the quartz and adularia bands. At the Stateline district, veins strike north-south, dip to the west, and are several miles long.

The andesite lava flows, ash-flow tuffs, rhyolite, and intrusive rocks are porphyritic. Local vents feed the andesite and rhyolite flows, but sources for ash-flow tuffs are not known.

Age Range: The volcanic rocks are not dated but are probably late Oligocene through Miocene in age. Veins are mostly restricted to the older andesite flows and are unconformably overlain by felsic volcanic rocks.

Tectonic Setting: Calc-alkalic volcanism, within a broad intra-arc setting, was followed by bimodal volcanism coincident with the onset of crustal extension. Extension produced generally north-, northwest-, and east-northeast-striking high-angle faults.

REPRESENTATIVE DEPOSITS: In the Gold Springs district: Jennie mine, Jumbo mine, Independence mines, and Aetna mine. Largest production in the district, from the Jennie mine, was 16,391 tons containing 0.223 oz/ton gold, 1.3 oz/ton silver, and minor copper and lead. In the Stateline district: Ophir mine (mostly silver), Johnny mine (mostly gold).

Mineralogy: Ore vein minerals include native gold, possibly gold-silver tellurides, and cerargyrite. Gangue minerals are quartz, adularia and calcite. Secondary limonite is common.

Alteration: Silicified rock and argillic and propylitic alteration assemblages are mostly restricted to the older andesite unit.

Ore Controls: High-angle faults cutting andesite flows controlled emplacement of quartz veins. Relationships between mineralized veins and intrusive rocks, vents, or possible caldera margins are unknown.

Weathering: Some pyrite is oxidized to limonite, and secondary enrichment of ore has been proposed.

Geochemical Signature: Au, Ag, Cu, Pb, Fe, Te

MINERAL DEPOSIT MODELS WITHIN THE DISTRICT
Known Deposit Types: epithermal gold veins (quartz-adularia type) (25c), Creede type (25b).

GOLDSTRIKE DISTRICT

DESCRIPTION: The Goldstrike district, located in northwestern Washington County, lies along the west-central margin of the Cedar City quadrangle. Published reserves are 4M short tons of ore containing 0.02 oz/ton gold for a total of 80,000 oz of gold.

REFERENCES: Adair, 1986; Webb, 1988; Willden and Adair, 1986.

GEOLOGICAL ENVIRONMENT: Gold occurs in structurally-controlled epithermal vein and disseminated deposits.

Rock Types: Gold occurs in jasperoid bodies along faults, and disseminated in the basal clastic member of the Eocene to Oligocene Claron Formation. The host rocks are white to yellow sandstone and conglomeratic sandstone that were deposited on an irregular surface. Mineralized rocks are silicified and contain vuggy quartz and chalcedonic accretions. Locally the underlying Mississippian Scotty Wash Quartzite is mineralized.

Textures/Structures: The southeast-verging Goldstrike thrust, and associated asymmetric folds, formed during the Sevier orogeny in late Cretaceous time, and are cut by northwest-striking transcurrent Neogene faults. The complex intersection of these features probably controls locations of gold deposits at Goldstrike. Locally, gold-bearing jasperoid is common where high-angle faults cut Paleozoic carbonate rocks. At the Hamburg mine, gold-bearing veins are located along contacts between altered andesite lava flows and basalt dikes, and within the Callville Limestone.

Age Range: Mineralization is younger than the basal Claron Formation and probably younger than the Leach Canyon tuff which is argillically altered along mineralized faults. Faults that host mineral deposits may be as young as 10-15 Ma, which regionally is the age of the most intense extensional deformation.

REPRESENTATIVE DEPOSITS: Veins occur at the Gunlock-Bonanza claims, Hamburg mine (1,700 tons of ore at 0.28 oz/ton in gold were mined), Bonanza (Covington) mine, Hassayampa mine, and Peace mine (production not published). The Goldstrike disseminated gold deposit is scheduled for production in 1989.

Mineralogy: Gold-bearing veins and disseminations are limonitic and siliceous. Gold also exists as free gold.

Alteration: Paleozoic carbonate rocks have been altered to jasperoid along high-angle faults and along the irregular basal sandstone or conglomeratic sandstone units of the Claron Formation. Associated with mineral deposits are altered rock assemblages reflecting silicification, decarbonization, and some argillization.

Ore Controls: Deposition of gold in the district was controlled by: high angle faulting, high permeability of host rock, presence of hydrothermal fluids, a barrier (of mudstones and red beds) to upward movement of those hydrothermal fluids, and the presence of organic debris.

Weathering: unknown

Geochemical Signature: As, Sb, Hg, Au, Fe

DEPOSIT MODELS WITHIN THE DISTRICT

Known Deposit Types: Carbonate-hosted Au-Ag? (Carlin-type) (26a)

IRON SPRINGS AND PINTO DISTRICTS

DESCRIPTION: Utah ranks fifth in the United States in iron ore production and all of this has come from the Iron Springs and Pinto districts since 1849. The Iron Springs district contains magnetite-hematite deposits adjacent to the Granite Mountain and Three Peaks plutons, and the Pinto district has similar deposits adjacent to the Iron Mountain pluton. The same processes controlled mineralization in both districts. Both districts were mined for in-situ and alluvial deposits. Production was 72M tons from 1923 to 1965. From 1968 to 1970 the total production was 78M tons of iron ore and potential reserves in 1970 were estimated at 300M tons, with an ore thickness averaging 230 ft. In 1988, the districts produced 550,842 tons of ore that were consumed at the Geneva steel plant in Orem, Utah. Production in 1989 is continuing at the same rate.

REFERENCES: Allsman, 1948; Bullock, 1970; Butler, 1920; Cook, 1950b; Cook and Hardman, 1967; Kemp, 1909; Leith, 1910; Leith and Harder, 1908; Lewis, 1958; Mackin, 1947, 1952a, 1952b, 1954, 1955, 1968; Mackin and Ingerson, 1960; Petersen and Rasmussen, 1988; Ratte, 1963; Rowley and Barker, 1978; Shubat and Siders, 1988; Siders and Shubat, 1986; Van Kooten, 1988; Walenga, 1988a; Wells, 1938; Young, 1947.

GEOLOGICAL ENVIRONMENT: Iron deposits are principally in skarn and replacement deposits formed during emplacement and deuteric alteration of quartz monzonite laccoliths.

Rock Types: The district consists of a northeast-trending line of three exposed Miocene quartz monzonite porphyry laccolithic intrusions: the Iron Mountain, Granite Mountain, and Three Peaks plutons. Ore replaced several sequences of limestone that dip away from the intrusions. The intrusive contact is generally concordant with sedimentary bedding and is at the same approximate stratigraphic level throughout the district, within the Temple Cap Siltstone Member of the Carmel Formation.

Lithology of the Intrusions and Ore Genesis: The intrusions were emplaced at very shallow levels, as shown by extensive doming of the flanking units, but they did not vent at the surface. The outer zone of the intrusions consists of gray quartz monzonite porphyry with hornblende, augite, biotite, and plagioclase in a groundmass of intergrown quartz and quartz-potassium-feldspar. The outer zone crumbles readily to grus and biotite and hornblende have been altered to a mosaic of potash feldspar, chlorite, pyroxene (low Fe), and magnetite. Deuteric alteration of the outer zone has been suggested (Mackin, 1960) as the mineralizing process whereby iron was released from ferromagnesian minerals and transported to the margins of the intrusions where it replaced favorable carbonate host rocks. Fluids derived from alteration were probably released from those parts of the laccoliths where renewed intrusion opened tension joints in the semi-solid mush of the outer zone.

Lithology of the Host Limestone: The Homestake Limestone Member of the Carmel Formation is gray to black, massive to thick-bedded, and ranges in thickness from 210 to 270 ft. Contact metamorphism produced an albite-phlogopite-rich rock from local mudstones, an oligoclase-tremolite-bearing rock from sandstone, and a wollastonite-diopside-plagioclase assemblage from limestone beds.

Textures/Structures: Magnetite and hematite ore is in tabular pod-like bodies that replace limestone around the borders of quartz monzonite porphyry laccoliths that were emplaced along the northeast-striking Iron Springs thrust fault. The thrust lies at or near the base of the Carmel Formation. Deposits are adjacent to those parts of the plutons that were arched upward during late magmatic distention. The distention created significant selvage joint zones, which contain minor amounts of iron.

Age Range: The Iron Mountain, Granite Mountain, and Three Peaks plutons are about 20 Ma old based on K-Ar ages and field relations. Field relations indicate that the intrusions post-date the 21 Ma Harmony Hills Tuff and predate the Rencher Formation and Racer Canyon Tuff (19 Ma).

REPRESENTATIVE DEPOSITS: In the Iron Springs district: Pioche-Vermillion ore body at the northeast end of Granite Mountain; Desert Mound at the southwest end of Granite Mountain. In the Pinto district: The Rex, McCahill, and Burke ore bodies

Mineralogy: The ore minerals are magnetite and hematite. Other minerals within the tactite include: apatite, mica, siderite, diopside, garnet, pyrite, chlorite, calcite, barite, amphibole, limonite, amethyst, marcasite, chalcopyrite, bornite, galena, barite, epidote, vesuvianite, scapolite, and tourmaline. The apatite is intergrown with magnetite, tremolite, actinolite, phlogopite, and wollastonite. Local oxidation of copper sulfides produced azurite, malachite, and chrysocolla. Other mineral phases present are chalcedony, magnesite, and gypsum.

Alteration: The dark limestone is bleached, and locally silicified. Contact metamorphism is mostly isochemical although silica, magnesium, and aluminum were locally introduced with iron.

Ore Controls: The iron-rich intrusive, extensional joints, and the presence of the Carmel Formation limestone member are the important ore controls. In addition, deposits are on the eastern edge of the Sevier thrust system. The thrust faults appear to have controlled the morphology of the intrusions, which may have played an important role in concentrating iron within the plutons.

Weathering: local oxidation of copper sulfides

Geochemical Signature: Fe, Si, Mg, Al, P, F, Ba, Cu, Pb

MINERAL DEPOSIT MODELS WITHIN THE DISTRICT

Known Deposit Types: Fe skarn (18d)

MINERAL MOUNTAIN DISTRICT

DESCRIPTION: The Mineral Mountain district, located near the west-central margin of the Cedar City quadrangle, consists of prospects containing iron, copper, and gold, with traces of lead, silver, zinc, molybdenum, and tungsten. The district is centered on the Mineral Mountain stock, which is the westernmost intrusion along the east-northeast-trending "Iron Axis", stretching from Mineral Mountain to the Iron Springs district. Despite intermittent exploration at Mineral Mountain since the 1890's, no production of metals is known from the district. Non-metallic resources in the district include marble (one quarry produced approximately 10 tons) and veins containing halloysite and alunite.

REFERENCES: Bullock, 1970; Crawford and Buranek, 1948; and Morris, 1980a and 1980b.

GEOLOGICAL ENVIRONMENT: Paleozoic carbonate rocks host mineral occurrences that lie along the margins of the granitic Mineral Mountain stock. The stock intruded a south-trending anticline developed in carbonate rocks and overlying Tertiary volcanics. A west-northwest-striking, post-mineralization dextral fault displaced the northern third of the Mineral Mountain stock 4,200 ft to the east.

Rock Types: Paleozoic rocks in the district are the Callville Limestone, which includes limestone and dolomite, and overlying calcareous sandstone of the Queantoweap Sandstone. Although not identified, the Pakoon Dolomite is probably present between the Callville Limestone and Queantoweap Sandstone. The Tertiary volcanic sequence consists of several regional dacitic to rhyolitic ash-flow tuff units separated by andesitic flows, autobreccia, and debris flows. An alkali-feldspar granite porphyry stock (the Mineral Mountain stock) and a small alaskite plug intrude the sedimentary rocks and are cut by kersantite and porphyritic granite dikes.

Textures: Volcanic rocks and most intrusive rocks are porphyritic. Alaskite is equigranular and kersantite is aplitic.

Age Range: Paleozoic rocks are Pennsylvanian to Permian in age. Volcanic rocks range from late Oligocene to middle Miocene in age. The Mineral Mountain stock (alkali-feldspar granite porphyry) intrudes the volcanic rocks and the youngest dated rock that is intruded is the 22 Ma Harmony Hills

Tuff. Thus, the Mineral Mountain stock has a maximum possible age of 22 Ma, which is also the maximum age of other intrusions along the iron axis.

Depositional Environment: Pennsylvanian and Lower Permian limestone and dolomite were deposited in a carbonate shelf environment flanking an Early Permian uplift to the east. Tertiary ash-flow tuffs were deposited on a surface of low relief dotted with local andesitic volcanos.

Tectonic Setting: Intrusion of the Mineral Mountain stock coincides in age with the onset of extensional tectonics in the region (about 21 Ma). The west-northwest-striking dextral fault that cuts the northern part of the Mineral Mountain stock post-dates the intrusion, alteration, and mineralization. This fault was probably produced during the regionally extensive, southwest-directed extensional episode.

REPRESENTATIVE DEPOSITS: Emma Mine. Although not a producer, this is the most developed prospect in the district. The deposit consists of massive, stratiform lenses and stringers of magnetite and copper minerals replacing carbonate rocks within the thermal aureole of the intrusion. A 1903 report indicated that the ore contained 21 ppm gold and 11.5 percent copper. More recent analyses, however, indicate that the ore consists mostly of iron (38.6 percent) and silica (11.8 percent) with minor copper and trace amounts of gold and silver. Other deposits in the district consist of magnetite veinlets that contain minor amounts of tungsten, molybdenum, and silver, which are associated with lamprophyre dikes. Jasperiod bodies that replace the Callville Limestone along the axis of a south-trending anticline south of Mineral Mountain is being prospected for gold.

Mineralogy: Replacement ore and gangue minerals consist of magnetite, chalcopyrite, brucite, and antigorite with minor amounts of quartz, chlorite, spinel, periclase, forsterite, monticellite, augite, garnet, and sphene. Quartz and calcite veins cut the ore. Calcite veins locally contain chrysocolla, azurite, and malachite. Veinlets associated with lamprophyre dikes contain magnetite, limonite, and pyrite.

Textures/Structures: Unknown.

Alteration: A zone of marmorized rocks, between 300 and 3,600 ft wide, surrounds the Mineral Mountain stock and a thin (3 ft) skarn zone locally occurs at the intrusive contact. Adjacent to skarn zones the granite is commonly bleached. Argillized, silicified, propylitized, and pyritized rocks also flank the intrusion. Of these, argillized rocks are most widespread. Silicified rocks occur near the intrusion; propylitized and pyritized rocks are found only locally.

Ore Controls: Dolomitic beds in proximity to the Mineral Mountain stock are favorable for replacement deposits. Pre-intrusion faults and fractures localized fissure veins and veinlets of magnetite. A pre-intrusion anticline may have localized the Mineral Mountain stock.

Weathering: Secondary solutions oxidized chalcopyrite and precipitated chrysocolla, malachite, and azurite along open fractures. Quartz boxwork structures have formed by the removal of carbonate clasts from silicified breccias.

Geochemical Signature: Fe, Cu, Au, Ag, W, Mo. Outlying prospects reported to contain Pb and Zn in addition to the above elements.

MINERAL DEPOSIT MODELS WITHIN DISTRICT:

Known Deposit Types: Fe-skarn, polymetallic replacement (?)

Potential Deposit Types: Sediment-hosted gold, epithermal gold veins.

MODENA DISTRICT

DESCRIPTION: The Modena district consists of a group of four prospects located near the mouth of Modena Draw in the northwestern part of the Cedar City quadrangle. Veins explored by prospectors reportedly contain some gold and silver, however, no production is recorded for the district.

REFERENCES: Best, 1987; Butler and others, 1920.

GEOLOGICAL ENVIRONMENT: Veins occur along north-striking, high-angle faults cutting Miocene volcanic rocks.

Rock Types: Local volcanic sequence, from older to younger, is hornblende andesite lava flows, rhyolitic ash-flow tuff, latite lava flows, and rhyolite lava flows. Rhyolite lava flows are locally underlain by poorly-welded ash-flow and air-fall tuff. No pre-volcanic rocks are exposed.

Textures: All units are porphyritic. Flow units contain minor intercalations of autobreccia.

Age Range: Older intermediate-composition lava flows and ash-flow tuff are 22-24 Ma. Younger rhyolite lava flows are 10-13 Ma. Veins and hydrothermally altered rocks are younger than 10-13 Ma.

Depositional Environment: Lava flows derived from local vents with eruptions separated by periods of subaerial erosion.

Tectonic Setting: Intermediate flows are part of regional calc-alkalic suite. Younger flows are part of bimodal extension-related suite. Local product of extension are north-striking faults that host veins. District lies near the buried southern margin of the Indian Peak caldera complex.

REPRESENTATIVE DEPOSITS: There are no known ore deposits in the Modena district.

Mineralogy: There are no identified ore minerals, but gangue minerals include quartz, carbonate, and manganese minerals. Carbonate minerals are reported to contain more iron and manganese than vein carbonate in the Gold Springs district.

Textures/Structures: Veins show crustiform banding and are as much as 10 ft wide. Stockwork zones are present locally.

Alteration: Silicified, argillized, and propylitized altered rocks are locally present. Altered rocks lie within a north-trending zone about 2.5 mi long by 1 mi wide.

Ore Controls: High-angle faults.

Weathering: Unknown.

Geochemical Signature: Unknown.

MINERAL DEPOSIT MODELS WITHIN DISTRICT:

Known Deposit Types: Epithermal gold and silver veins (?).

PARIA DISTRICT

DESCRIPTION: The Paria district, located in Kane County in the southeastern part of the quadrangle, has a history of gold and uranium prospecting, although there has been no known production. Placer gold and platinum deposits have been reported.

REFERENCES: Butler and others, 1920.

GEOLOGICAL ENVIRONMENT: Gold, platinum, and uranium apparently occur in stream channels.

Rock Types: Occurrences are in Quaternary stream and bar sand deposits and the metals may be derived from Triassic sandstone.

Textures/structures: Gold is very fine grained and local in extent.

Age Range: Quaternary (?)

REPRESENTATIVE DEPOSITS: only occurrences

Mineralogy: Scarce gold and even more scarce platinum are reported; the uranium mineral is not reported.

Ore Controls: weathering cycle

Weathering: unknown

Geochemical Signature: Au, Pt?, U?

MINERAL DEPOSIT MODELS WITHIN THE DISTRICT
Known Deposit Types: unknown - possibly local placer gold

SILVER REEF (HARRISBURG) DISTRICT

DESCRIPTION: The Silver Reef district is located in Washington County, on the southeast side of the Pine Valley Mountains, on the flanks of the Virgin anticline. The Hurricane fault is about 4 mi east of the district. Mining started in the district in 1875, and by 1900 about 7M ounces of silver had been produced. Mines were shallow, with the deepest only 330 ft in depth.

Ore bodies ranged from an average of about 200-300 ft long by 100-150 ft wide, to a maximum of 400 ft long by 200 ft wide, and were as much as 20 ft thick. Silver grade varied widely. Locally the grade was as high as 500 oz/ton, but averaged about 20-25 oz/ton. The average copper grade was around three percent. Ore contained a very minor amount of gold. Recently, a heap leach operation treated tailings from an old district mill. Some uranium and vanadium were produced in the district in the early 1950's. The uranium ore was silver-bearing.

REFERENCES: Cornwall and others, 1967; Heyl, 1978; James, 1987; James and Newman, 1986; Petersen and Rasmussen, 1988; Proctor, 1953; Proctor and Brimhall, 1986, 1987.

GEOLOGICAL ENVIRONMENT: Silver deposits occur in a roll front environment related to anticlinal structures and organic debris.

Rock Types: Silver ore is in the Springdale Sandstone Member of the Jurassic Moenave Formation, a ledge-maker which crops out on the northeast-trending Virgin anticline and two subsidiary folds to the west. Springdale Sandstone, formerly called Silver Reef Sandstone, generally contains anomalous silver. The sandstone is fine-grained and consists mostly of quartz with minor muscovite, clay, feldspar, and accessory minerals. Fluvial textures and features are common, and include channels, point bars, well-developed cross bedding, local areas of fossilized rush and reed remains, rare petrified and carbonized tree parts, and interlayered clay-gall conglomerates.

The highest grade silver ore is near or at the contact of the light gray Leeds sandstone unit and the overlying lavender Tecumseh sandstone unit of the Springdale Sandstone Member. Copper preferentially occurs in lighter gray Leeds sandstone unit, as coatings on and replacements of fossil plant materials. Uranium occurs in thin- to medium-bedded red shale and siltstone of the Dinosaur Canyon Member of the Moenave Formation. The Moenave Formation is underlain by the Chinle Formation, which is a source of uranium in the Four Corners area to the east, and which has slightly anomalous base-metal and silver concentrations throughout the region.

Textures/Structures: The district lies within the Virgin and Leeds anticlines. Ore zones are lens-shaped bodies related to paleo-stream channels containing carbonaceous plant remains. Some ore lies in north-trending shear and fault zones. Silver and some copper are particularly associated with clay galls and plant remains. Ore bodies are located beneath clay beds in highly fractured areas, especially near faults of minor displacement. Sevier-age thrust faults, on the flanks of the Virgin anticline, repeat the ore zone three times.

Age Range: post-Jurassic

REPRESENTATIVE DEPOSITS: White, Buckeye and Butte "reefs"

Mineralogy: This is an uncommon ore-grade occurrence in the U.S. of the silver chloride cerargyrite (horn silver) and silver halides in sandstone. Silver bromides and native silver are also present.

Copper and uranium minerals are malachite, azurite, carnotite, autunite, and torbernite. Argentite occurs below the water table. Roscoelite and montroseite are the vanadium minerals within the deposit. Gangue minerals are biotite, calcite, chlorite, iron oxide, limonite, muscovite, plagioclase, and coarse- and fine-grained quartz.

Alteration: Rocks are moderately silicified, bleached, and oxidized.

Ore Controls: Important factors include paleo-stream channels, clay layers, organic debris, and anticlinal structures. Ore zones in sandstone occur along bedding planes and in paleo-stream channels. Ore is commonly associated with fossil plant debris. Fossil wood and organic debris contain high grade silver. Silver also occurs within some clay zones. Ore minerals are generally concentrated above the water table. Rock permeability was important in localizing silver. Ore grades decline with depth, where bedrock becomes is less permeable and dips of beds flatten.

Weathering: unknown

Geochemical Signature: Ag, Se, Hg (possibly introduced by amalgamation plants), trace Au, locally Cu, V, U, Mo, Zn, Pb, Ni, Co, and As.

MINERAL DEPOSIT MODELS WITHIN THE DISTRICT

Known Deposit Types: Silver-rich version of the uranium roll front and/or sediment-hosted copper models (30b, 30c).

TUTSAGUBET DISTRICT

DESCRIPTION: The Apex (Dixie) mine, located in the Tutsagubet district in the Beaver Dam Mountains, was the first mine in the world to produce gallium and germanium as primary products. The first activity in the district was in 1871, and for most of its history (1884-1962) mining was primarily for copper, silver, gold, and zinc. Production totalled over 7,000 metric tons of copper, 400 metric tons of lead, 180,000 troy oz of silver and minor amounts of gold and zinc. Most copper-rich ore had been removed before gallium and germanium mining at the Apex mine began in 1985. Present reserves for the Apex mine are 180,000 tons of ore averaging 0.042 wt. percent Ga and 0.115 wt. percent Ge, with approximately 1.9 wt. percent Cu, 1.8 wt. percent Zn, and 2 oz/ton silver. The ore grade cutoff is 0.02 wt. percent combined gallium and germanium. Hecla Mining Company recently purchased the Apex property from the bankrupt St. George Mining Company, with the intent of keeping it on line producing gallium and germanium.

REFERENCES: Bernstein, 1986; Dutrizac and others, 1986; Harris and Ryan, 1984; Petersen and Rasmussen, 1988; Petersen and others, 1988; Verbeek and others, 1987; Walenga, 1988b; Wenrich, 1985; Wenrich and others, 1987.

GEOLOGICAL ENVIRONMENT: Mineralized breccia pipe deposits.
Rock Types: Mineral deposits are within the Pennsylvanian Callville Limestone. Stratigraphically below this limestone is the Mississippian Redwall Limestone, and above the Callville Limestone is the Permian Pakoon Limestone. Collapse breccia pipes formed in all of these units and are the primary features hosting mineral deposits.

The Callville Limestone consists of gently westward-dipping, thin-bedded limestone. The limestone contains chert nodules, scattered shale beds, poorly preserved horn corals, and solution cavities ranging in size from vugs to caves.

Textures/Structures: Ore is in highly irregular, branching, near-vertical breccia pipes. The base of the collapse breccia pipes is in the Redwall Limestone, but most of the ore is in the overlying Callville Limestone. The Apex fault, which strikes north-northwest and dips 64-71° W, is prominent at the Apex and Paymaster mines. Breccia pipes are found locally along the fault trace, but depart from the fault at depth.

Age Range: Late Triassic to Early Jurassic; main stage mineralization was dated at 200 Ma (Sr^{87}/Sr^{86} date), a time which corresponds to karstification throughout the region, and the change from basically miogeoclinal marine to terrestrial deposition.

REPRESENTATIVE DEPOSITS: Apex (Dixie) mine, Paymaster mine

Mineralogy: The mineralogy of the ore includes: goethite, limonite, hematite, jarosite, azurite, malachite, conichalcite, and other metal oxides and arsenates. Ore is highly oxidized down to at least 1,400 ft below the surface. The sparse sulfide ore contains pyrite, galena, sphalerite, chalcopyrite, quartz, and traces of barite.

Germanium is concentrated in goethite (0.5 percent, maximum value), hematite (0.7 percent, max. value) and limonite (0.5 percent, max. value). Gallium is concentrated in jarosite (0.7 percent, max. value), limonite (2.0 percent, max. value), beudantite, and primary chalcopyrite.

Vugs, ranging from a few millimeters to several centimeters across, are common in goethite; they contain botryoidal crusts or euhedral crystals of azurite, malachite, conichalcite, rosasite, or brochantite.

Two stages of quartz are present: (1) an early low-temperature quartz phase, which includes illite, alunite, and minor sulfides, and (2) a later high-temperature quartz phase, which includes goyazite, svanbergite, and copper and lead sulfides, overprinted by jarosite and iron oxide minerals.

Alteration: Dolomitized limestones are pervasive in the ore zone. Mineralized zones are silicified.

Ore Controls: Breccia pipes, formed by solution collapse, provided conduits for metal-bearing solution movement and provided an ideal environment for ore deposition.

Weathering: Chemical weathering is extensive, with nearly complete oxidation of the ore body.

Geochemical Signature: Ga, Ge, Cu, Pb, Zn, Ag, Fe, As

MINERAL DEPOSIT MODELS WITHIN THE DISTRICT:
Known Deposit Types: Arizona U breccia pipe deposits (Wenrich, 1985) or Kipushi model (32c).

NOTE: The St. George Mining Company processing plant (constructed in 1984) is designed to extract Ga and Ge with by-product Cu, Zn, and Ag. Gallium, a liquid at normal temperatures, has semiconducting properties. Gallium arsenate is preferred over silicon as an integrated circuit base. Germanium, used in infra-red optics, catalysts, and fiber optics; is a grayish-white, hard but brittle metal.

NON-METALS AND INDUSTRIAL MINERALS

References: Cook, 1960; Doelling, 1983; Gregory, 1951; Harris and Ryan, 1984; Perry, L. I., unpublished data.

The Cedar City quadrangle is rich in non-metal and industrial mineral resources including sand and gravel, bentonite clay, kaolin, gypsum, limestone, marble, dimension stone, volcanic cinder, agate, and petrified wood (figure 28). Bentonite clay occurs the Dakota Formation and the Tropic Shale. The largest bentonite mine was the American Mud and Chemical Company mine, which produced from 80-105 barrels of gel per ton of bentonite. The bentonite was utilized during construction of the Glen Canyon Dam. There are stratabound gypsum/anhydrite beds in the Jurassic Carmel Formation, and in the Middle to lower Triassic Moenkopi Formation. Only minor amounts of gypsum have been produced, generally used for making wall board. Some gypsum beds are located in the Tutsagubet and Paria mining districts. The Pennsylvanian Callville Limestone has potential for building marble. Also present are potential resources of dimension stone, other clays, titanium, zircon, monazite, diatomite, silica, volcanic cinder, guano, agate, and petrified wood. Only small tonnages of these resources have been developed in the quadrangle.

OIL AND GAS RESOURCES AND POTENTIAL

References: Bassler and Reside, 1921; Blakey, 1979; Campbell and Ritzma, 1979; Crawford, 1963; Gregory, 1950a, 1950b; Kerns, 1986; Shubat and Siders, 1988; Utah Geological and Mineral Survey, 1983; Van Kooten, 1988; Whitley, 1978.

Introduction

Southwestern Utah has significant hydrocarbon potential. Several oil fields have been developed and oil seeps are common in the area. The Upper Valley field, which has produced 25M barrels of oil, is the largest field in southwest Utah. It is located in the Escalante quadrangle, just east of the Cedar City quadrangle. The field produced oil from the Permian Kaibab Formation and the Lower Triassic Timpoweap Member of the Moenkopi Formation. The Virgin field in the Cedar City quadrangle is the oldest field in Utah and has been the largest oil producer within the quadrangle (figure 29). Minor production occurred in the Anderson Junction field. Elsewhere in the quadrangle are local oil seeps, and traces of oil have been encountered in drill holes from the Mississippian Redwall Limestone to the lower Mesozoic Timpoweap Member of the Moenkopi Formation. Local soil hydrocarbon anomalies occur in the Iron Springs area.

Virgin Oil Field

The Virgin oil field, first developed in 1907, is located 1.5 mi northeast of Virgin, adjacent to Zion National Park (some production was within the park boundary). The field consists of mostly shallow wells in North Creek valley. Production through 1963 was 195,000 barrels from 30 wells. Oil was derived from the Timpoweap Member of the Triassic Moenkopi Formation with minor production from the Pennsylvanian Callville Limestone.

The field lies in a small synclinal pocket near the axis of a broad, low-relief, anticline that plunges gently north. The oil-bearing zone is 1-8 ft thick in limestone in the uppermost part of the Timpoweap Member, from 475 ft to 750 ft below the surface. Hydrocarbons occur in vugs associated with pisolites and algal structures. Oil from the Virgin field is dark brown and very fluid; in deeper wells it is associated with gas. There is a refinery at Cedar City and in the 1950's oil was marketed locally as gasoline, kerosene, tractor and burner fuel, and road oil.

The Timpoweap Member of the Moenkopi Formation was deposited along the shoreline of the seaway parallel to the present Hurricane Cliffs, with open sea to the east. It formed in restricted lagoonal and tidal flat environments.

Anderson Junction Oil Field

Two wells in the Anderson Junction oil field, located 2.5 mi northeast of Toquerville in Washington County, produced 1,443 barrels of oil between 1968 and 1970. The productive stratigraphic level in the field is in the Pennsylvanian Callville Limestone, with oil shows in the Permian Pakoon Dolomite and Mississippian Redwall Limestone. The producing zone of the Callville Limestone lies at a depth of 4,607 feet below the surface. Sevier-age folds and thrust faults in the area trend north-northeast and both structural and stratigraphic elements are involved in trapping the oil.

Potential for Additional Oil

Favorable characteristics for additional oil accumulations include: (1) presence of source rocks in the western part of the quadrangle; (2) occurrence of structural traps, both with surface expression (such as the Virgin anticline), and, as demonstrated by seismic records, beneath Tertiary volcanic and sedimentary cover or Sevier-age thrust faults; and (3) presence of subtle stratigraphic traps formed by facies changes where upper Paleozoic and lower Mesozoic formations thin or wedge out across the persistent tectonic hingeline between the Basin and Range and High Plateaus provinces. Structural features favoring oil accumulation are prominent west of the Hurricane Cliffs where the Harrisburg, Washington, and Bloomington domes are located; each is an enclosed structural high along the Virgin anticline. However, the productive stratigraphic level in the Virgin field is missing from the Harrisburg and Washington domes; where it is present on the flanks of Bloomington dome, it contains no shows of oil or asphaltic material. The domes have been drilled to the Coconino Sandstone; although very minor shows were present at the Coconino Sandstone-Kaibab Formation contact, no commercial quantities were discovered.

There is potential for oil beneath the laccoliths in the Iron Springs district, particularly below the Three Peaks laccolith. Drilling and seismic data generated by ARCO show the Three Peaks intrusion as a laccolith which overlies a large anticline in Paleozoic and Mesozoic rocks. The anticline, believed to have formed in the early Late Cretaceous through middle Tertiary, has more than 600 ft of structural closure beneath the laccolith, covers about 35 mi^2, and is a favorable trap for hydrocarbons. Heat from the intrusion did not affect Lower Triassic and older rocks. In the anticline the lower Moenkopi, Kaibab and Toroweap Formations contain vugs and traces of hydrocarbons. The rocks are also intensely fractured. Drilling on soil gas targets has produced only traces of hydrocarbons. Hydrocarbons may have escaped through locally highly-fractured rock, but there are a number of possible structural traps beneath the laccoliths.

At least 13 exploratory wells for oil and gas have been drilled in the Basin and Range province in Iron and Washington Counties since 1949, including the Table Butte (Hunt Oil) and Three Peaks (ARCO) wells. Although commercial quantities of oil or gas have not yet been found, traces of hydrocarbons were encountered within the Moenkopi and Kaibab Formations. In the Sevier foreland region, hydrocarbons that were generated may have migrated up dip to the east and up thrust ramps or steep faults to be expelled at the surface. The potential reservoir rocks in the region also may have been flushed of their hydrocarbons by strong regional paleohydrologic flows. Wells drilled recently in the vicinity of the Hurricane fault have flowed voluminous quantities of fresh water from prospective rocks, and such flows may have been regionally pervasive throughout much of Cenozoic time.

Nonetheless, the limited exploration to date has not tested adequately the hydrocarbon potential of the region, particularly in the areas of Tertiary cover. The numerous favorable characteristics create a moderate likelihood that further exploration will discover hydrocarbon resources.

There is a slight possibility that Tertiary lacustrine source rocks are preserved in the Escalante Desert beneath the thick Quichapa and younger volcanic sequence. Nearby basins in the Sevier Desert, the Great Salt Lake, and eastern Nevada contain source rocks and indications of oil in lacustrine sequences. Tertiary fill in the Escalante Desert is thick enough that thermal maturity will have been reached, but there has been no deep exploratory drilling to test the potential. Relatively shallow geothermal wells near Zane and Newcastle did not penetrate beneath the Miocene volcanic sequences.

COAL RESOURCES

References: Aresco and others, 1957, 1959, 1961; Ashley, 1918; Averitt, 1962; Cashion, 1961; Doelling and Graham, 1972; Gregory, 1950a, 1950b, 1951; Lee, 1907; Robison, 1963, 1964, 1966; Utah Geological and Mineral Survey, 1983.

Introduction

In southern Utah, minable coal beds occur only in Cretaceous strata within the Colorado Plateau province. Within the Cedar City quadrangle only the Alton (Kanab) and Kolob fields (figure 29) have been developed. Other coal resources exist in the Harmony field and in the Tropic area of the Kaiparowits Plateau field.

Alton (Kanab) Field

The Alton field, in the western parts of Kane and Garfield counties, is bounded by the Paunsaugunt fault on the east and the Sevier fault on the west. Coal is exposed at the surface in the upper Johnson Valley and thins to the east. Coal beds occur at two different stratigraphic intervals in the Dakota Formation. In the lower interval, which occurs from 30 to 60 ft above the base of the formation, coal beds are thin and lenticular. The thickest known bed is 4 ft 10 in thick. The upper interval, which is about 400 ft above the base of the Dakota, has one continuous bed with an average thickness of 17 ft with 5 to 60 ft of overburden. The coal is borderline between subbituminous A and bituminous C, with moderately high ash contents. There are a number of small mines in the field that produced coal for local domestic fuel needs. Aggregate production in the area (through 1961) has been less than 250,000 short tons. Reserves are estimated at 2.1 billion short tons.

Kolob Field

The Kolob Field, in western Kane and Garfield Counties and the eastern parts of Iron and Washington Counties, is bounded on the east by the Sevier fault and on the west by the Hurricane fault. Coal beds occur over an area of 400 mi^2 in three zones within the upper part of the Tropic Shale and one zone in the lower part of the Straight Cliffs Sandstone. The uppermost zone in the Tropic Shale contains one bed 7 ft thick. The coals vary in quality but average on the border between high volatile C bituminous and subbituminous A; the coal has a high ash and sulfur content with moderate heat value. Reserves are estimated at slightly less than 3,000M short tons.

Coal from the Kolob field was used locally until 1947, when a coal-fired electric-generating plant began operation near Cedar City. The plant owner, California Pacific Utilities Company, is now the main consumer of coal from the field. The Koal Kreek, Tucker, and Webster mines are the largest in the area, and have produced from 6,500 short tons (1947) to 40,000 short tons (1961) annually.

The Tropic Area of the Kaiparowits Plateau Field

Coal resources are near the town of Tropic east of the Paunsaugunt fault on the Colorado Plateau, in an area of about 100 mi^2 in southwestern Garfield County, Utah. Coal occurs in the Dakota, Straight Cliffs, Wahwap and Kaiparowits Formations of Cretaceous age. Minable thicknesses occur only in the lower part of the Straight Cliffs Sandstone, in the Henderson coal zone. The zone is from 10 to 50 ft thick, with multiple lenticular beds of coal having an average thickness of about 12 ft and a maximum thickness of 32 ft. The quality of the coal is near the boundary between subbituminous A and high-volatile bituminous C. Reserves in the Henderson coal zone are estimated at about 950M short tons, with 470M indicated and 480M inferred.

Harmony Field

The Harmony field lies west of the Hurricane fault in Washington and Iron Counties. Coal beds are discontinuous, having been deformed by local Miocene intrusions. The Harmony field, defined by the occurrence of coal-bearing Cretaceous sedimentary rocks, is in the Pine Valley, Bull Valley, and Harmony Mountains. Coal seams are in the Tropic Shale and are up to 20 ft thick, but because they are deformed the beds are interspersed with waste. Coal quality ranges from subbituminous A to high-volatile bituminous C. Near the intrusions, the coal becomes a semi-anthracite. This field has the least potential for economic deposits of coal of all coal fields within the Cedar City quadrangle.

GEOTHERMAL RESOURCES

References: Budding and Sommer, 1986; Clement, 1980; Clement and Chapman, 1981; Klauk and Gourley, 1983; Mabey and Budding, 1987; Rush, 1983; Utah Geological and Mineral Survey, 1983.

Introduction

The U.S. Geological Survey divides geothermal resources into three categories: low-temperature (less than 90° and greater than 10° C above the mean annual air temperature at the surface), moderate-temperature (between 90° and 150° C), and high-temperature resources (greater than 150° C). Low- and moderate-temperature resources are useful in space heating and agribusiness whereas high-temperature resources are typically used for commercial power generation and industrial process applications. Within the Cedar City quadrangle, one moderate- to high-temperature system, the Newcastle KGRA (Known Geothermal Resource Area) is currently being studied and exploited (figure 29). A potential moderate-temperature system has been identified near Zane, in the north-central part of the quadrangle, but remains unexplored. The Thermo KGRA is a moderate- to high-temperature system that lies just north of the quadrangle in the middle of the Escalante Valley. Low-temperature resources are suspected to underlie much of the northwestern margin of the Escalante Valley and parts of the St. George Basin, in the Santa Clara and Virgin River Valleys.

Low-Temperature Resources

Three areas with low-temperature geothermal potential have been identified within the Cedar City quadrangle. These are the Veyo Hot Spring, Pah Tempe (La Verkin) Hot Springs, and Washington Hot Pot areas. The Veyo Hot Spring, located southeast of the town of Veyo along the Santa Clara River, has recorded temperatures of 30°-37° C and yielded calculated geothermometer temperatures of 37°-51° C. The Pah Tempe Hot Springs, located between the towns of Hurricane and La Verkin, has a recorded temperature of 42° C and a calculated reservoir temperature of 80° C. An area of anomalously high well water temperatures extends approximately 4 mi west of the Washington Hot Pot (west of the town of Washington and north of St. George) and samples of well water yielded a calculated reservoir temperature of 67° C.

Klauk and Gourley (1983) investigated the geothermal potential of the Escalante Valley and their low-temperature resource results are summarized on the energy resources map of Utah (Utah Geological and Mineral Survey, 1983). In general, the entire western and northern part of the Escalante Valley, including Newcastle KGRA, Lund, and Zane areas, has potential for the discovery of low-temperature waters.

Moderate- to High-Temperature Resources

Two areas within the Cedar City quadrangle, the Newcastle KGRA and the Zane area, have known or suspected potential for this resource. At Newcastle, three commercial greenhouse operations, a church, and several private residences use thermal waters for space heating. To date, no drawdown or reduced reservoir temperatures have been experienced. Wells in the KGRA yielded a maximum temperature of 130° C and calculated geothermometers indicate a reservoir temperature between 145° and 170° C. Results from a recent temperature gradient survey, conducted by the Utah Geological and Mineral Survey in conjunction with the University of Utah, indicate that the potentially hottest part of the system has yet to be tested by drilling. Available data suggest that the geothermal resource is a result of deeply-circulating meteoric water rising along a major range-bounding fault. The hot water discharges into an aquifer at a depth of 330 to 500 ft and mixes with non-thermal water. This subsurface discharge bypasses surface discharge and indicates that additional blind geothermal systems may exist within the Cedar City quadrangle.

Klauk and Gourley (1983) identified a possible moderate-temperature geothermal resource located approximately 3 mi northwest of Zane, in the north-central part of the Cedar City quadrangle. They identified the resource on the basis of elevated well-water temperatures (20°-28° C), high total dissolved solids, enriched boron and lithium values, and elevated calculated reservoir temperatures (103°-120° C). A variety of geothermal models have been suggested for the Zane area, all of which involve the rise of heated meteoric water along a buried basin-range normal fault bounding a horst (as defined by gravity data).

RECOMMENDATIONS FOR ADDITIONAL MINERAL RESOURCE STUDIES

Metallic and Industrial Minerals

Topical studies of metallic and industrial minerals within the Cedar City quadrangle would contribute needed data to support a more thorough mineral resource assessment. The following are most pertinent.

(1) The Apex Mine: Detailed studies are needed to determine genesis of this uncommon Ga-Ge-base-precious metal deposit, so that other areas containing similar deposits may be identified. The relationship of the breccia pipe at the Apex mine to other breccia pipe deposits in southern Utah and northern Arizona described by Wenrich and others (1985) needs to be established.

(2) The Escalante Mine: One of the larger silver producers in the western United States was the Escalante silver mine in the Cedar City quadrangle. Accurate dating, fluid inclusion work, and a detailed mineralogical study would aid in understanding timing, P-T conditions, and the stages of ore deposition. Finally, minor and trace element geochemistry of the volcanics coupled with regional structural analysis (Ag-bearing veins versus barren veins in the different fault systems) would aid in refining the deposit model and identifying other areas of potential silver deposits. Flooding of the Escalante Silver mine may inhibit future studies as the mine is now closed.

(3) Epithermal silver and gold veins in the Antelope Range: Silver deposits in the Antelope Range need detailed isotopic studies to determine the origin of mineralizing fluids. Also $^{40}Ar/^{39}Ar$ dating of vein minerals and volcanic rocks would refine the chronology of mineralizing events.

(4) Disseminated epithermal gold in the Goldstrike district: Detailed petrology, geochemistry, and structural studies of faulting at the Goldstrike district would help in understanding ore deposition. This is particularly important as Tenneco is about to begin producing from the first bulk-minable gold deposit to be developed in southwest Utah. Stratigraphic studies are needed to correlate ore-hosting members of the Claron Formation with exposures in other districts and to determine the southeastern extent of the Chainman Shale.

(5) Iron skarns: Detailed studies of plutons in the region would help delineate characteristics of Miocene intrusions related to massive iron skarn deposits, and to distinguish barren from productive plutons.

(6a) Silver-rich roll front deposits at Silver Reef: This uncommon system is not well understood. Why is the silver so highly concentrated here and not in other roll front environments? The Jurassic Moenave Formation, which hosts the Silver Reef deposits, also hosts other roll front systems which are not enriched in silver. What mechanism is responsible for this locally unique silver enrichment?

(6b) Silver-rich crust: The Cedar City quadrangle is particularly silver-rich. Regional crustal studies might aid in determining large-scale mechanisms which may be responsible for regional silver enrichment.

(7) Age determinations: Radiometric dating is necessary for all mining districts, to determine relationships between mineralization and tectonic and magmatic evolution. Dating, coupled with whole rock and trace element geochemistry of igneous rocks, is needed to refine our understanding of relationships between east-west trending magmatic belts and mineralization in the quadrangle.

(8) Gold-rich epithermal systems: The Gold Springs and Stateline mining districts contain gold-rich veins hosted by Oligocene andesite flows. A better understanding of the volcanic stratigraphy and age of the mineralizing events in these poorly-studied districts is needed to interpret the relationships between mineralization, andesitic constructional volcanism, extensional deformation, and formation of the Indian Peak caldera complex. Results of such a study would help evaluate gold potential of similar geologic terranes in the Cedar City quadrangle.

(9) Industrial minerals: Favorable geology and a wide variety of industrial mineral deposits and occurrences in the quadrangle suggest that undiscovered resources are likely. However, detailed studies are needed for estimating grade and quantity of potential industrial mineral resource.

Oil and Coal:

Oil and coal could be subjects of several topical studies within the quadrangle. Adequate assessment of these resources would require oil and coal geologists to be on the NAMRAP team.

Geothermal Resources:

Potential for a moderate-temperature geothermal resource exists in the Zane area of the Escalante Desert, along the northern margin of the Cedar City quadrangle. Since the discovery of this potential in 1983, no exploration or development work in the area has been done. A program consisting of studying Quaternary deposits, deep resistivity soundings, shallow thermal gradient monitoring wells, water geochemistry, hydrologic modeling, and detailed gravity profiling would greatly enhance our ability to assess the potential of this resource.

Section 7 PRELIMINARY MINERAL RESOURCE ASSESSMENT OF THE CEDAR CITY 1° X 2° QUADRANGLE, UTAH

The Cedar City 1° X 2° quadrangle contains known resources of Ag, Au, Cu, Fe, Ga, Ge, Mn, Pb, Sb, U, V, Zn, oil, coal, and many industrial minerals and materials. The available geologic, geochemical, and geophysical data reviewed in the preceding sections provide the foundation for a regional assessment for undiscovered resources within the quadrangle. This preliminary assessment uses the geological, geophysical, and geochemical signatures of known mineral deposits and their host rocks to predict areas where additional deposits are likely to occur. The mineral-deposit models used here are variants of those described in Cox and Singer (1986).

Areas favorable for potential mineral resources are shown on figures 30, 31, and 32. On each figure are outlines of tracts of varying resource potential for specific types of mineral deposits, and lists of geological, geochemical, or geophysical criteria for delineating the tracts. Resource potential has been divided into three levels, A, B, and C, which correspond to high, moderate, and low likelihood that undiscovered deposits of the stated type occur in the tracts. An area designated A contains known deposits or obvious extensions of known favorable environments. In a few places, sufficient production or grade information is available that postulated deposits can be ranked as probably major (I), significant (II), or minor (III). An area designated B does not contain identified deposits, but has more than one (in some cases, several) characteristic of terranes that are known to host mineral deposits of the type being considered. An area designated C contains only one favorable geological, geochemical, or geophysical characteristic.

The uneven areal distribution and quality of available information imposes severe constraints on the use of mineral deposit analogues. Generally, insufficient information is available to identify a specific deposit-type to be expected. For example, much of the western part of the Cedar City quadrangle contains areas that are favorable for the occurrence of epithermal precious- or base-metal deposits, but in most places insufficient information on mineralogy, alteration, or geochemistry is available to support speculation on what is likely to exist. Therefore the model of epithermal deposits that we use is a composite: it includes deposits with characteristics of at least four types distinguished in Cox and Singer (1986), and may include aspects of several additional types. On some tracts where sufficient information is available, and the assignment of a specific model seems warranted, it is indicated by a lower case qualifier following the resource potential. (For example, A co indicates high potential for the occurrence of silver-gold vein deposits of the Comstock type.)

MINERAL-DEPOSIT TYPES

(**Model Numbers** in parentheses refer to descriptive models in Cox and Singer, 1986)

Epithermal precious- and base-metal vein systems (figure 30)

Silver-gold and polymetallic vein systems occur in many places in the western half of the Cedar City quadrangle. Examples include: (1) well-described veins of the Escalante mine and the Antelope district, which are silver-rich, and have many characteristics of veins in the Creede district

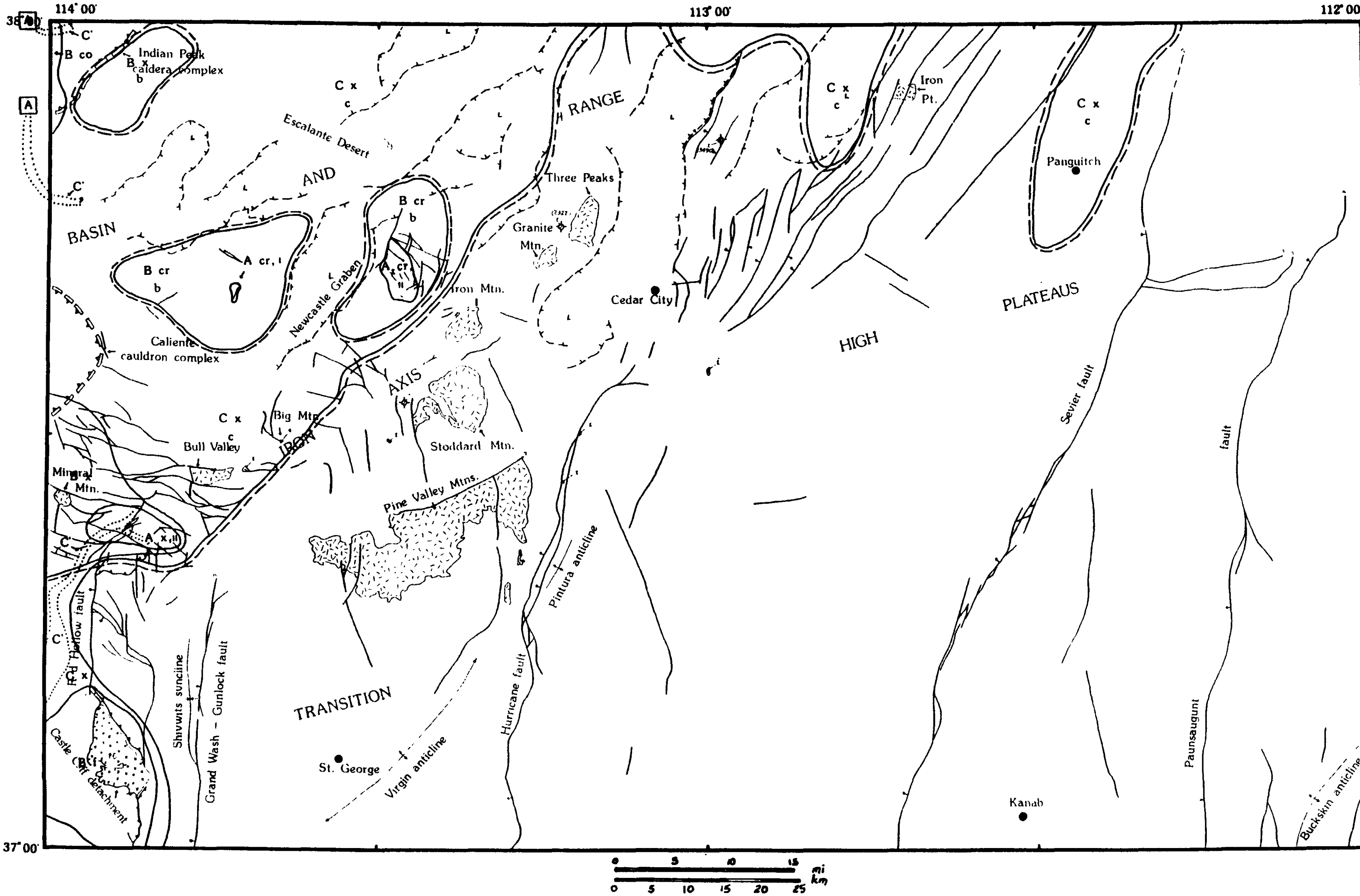


Figure 30.--Areas with potential for epithermal precious and base metal, porphyry Mo/Cu, and placer gold deposits in the Cedar City 1° X 2° quadrangle, Utah. Symbols are explained on following page.

EPITHERMAL PRECIOUS- AND BASE-METAL VEIN SYSTEMS

Resource Potential	Deposit Type (Cox & Singer Model No.)	Additional Information
A = identified deposits; high likelihood of undiscovered deposits	f = characteristics of gold on flat faults (Model 37b)	I = major deposits, large production
B = more than one favorable factor; moderate likelihood of undiscovered deposits	cr = characteristics of Creede epithermal veins (Model 25b)	II-Significant occurrence
C = at least one favorable factor; low likelihood of undiscovered deposits	co = characteristics of Comstock epithermal veins (Model 25c)	III = Occurrence
	x = characteristics ambiguous or unknown	

Speculative Epithermal Deposit Types

There are numerous epithermal deposit models not listed above that cannot be excluded, but for which we have inadequate information to assess their likelihood of occurrence. These speculative deposits, which would be located within the "C" epithermal envelopes, include the following:

Model **22a** = volcanic-hosted Cu-As-Sb;
25a = Hot-springs Au-Ag (high silver);
25c = epithermal Mn
25d = Sado epithermal veins
25e = epithermal quartz-alunite veins
25f = volcanogenic U;
26a = carbonate-hosted Au-Ag (Carlin);
27d = silver Sb deposits;
and **36a** = low-sulfide Au-quartz veins

PORPHYRY MOLYBDENUM-COPPER DEPOSITS

Resource Potential	Deposit Type (Cox & Singer Model No.)	Additional Information
b = more than one favorable factor; moderate likelihood of undiscovered deposits	Climax-type porphyry Mo (Model 16) or porphyry Cu (Model 17)	No "a" envelopes shown; insufficient information
c = at least one favorable factor; low likelihood of undiscovered deposits		

PLACER GOLD DEPOSITS

Resource Potential	Deposit Type (Cox & Singer Model No.)	Additional Information
C' = at least one favorable factor; low likelihood of undiscovered deposits	placer gold (Model 39a)	Only "C'" envelopes shown

Figure 30.--(continued).

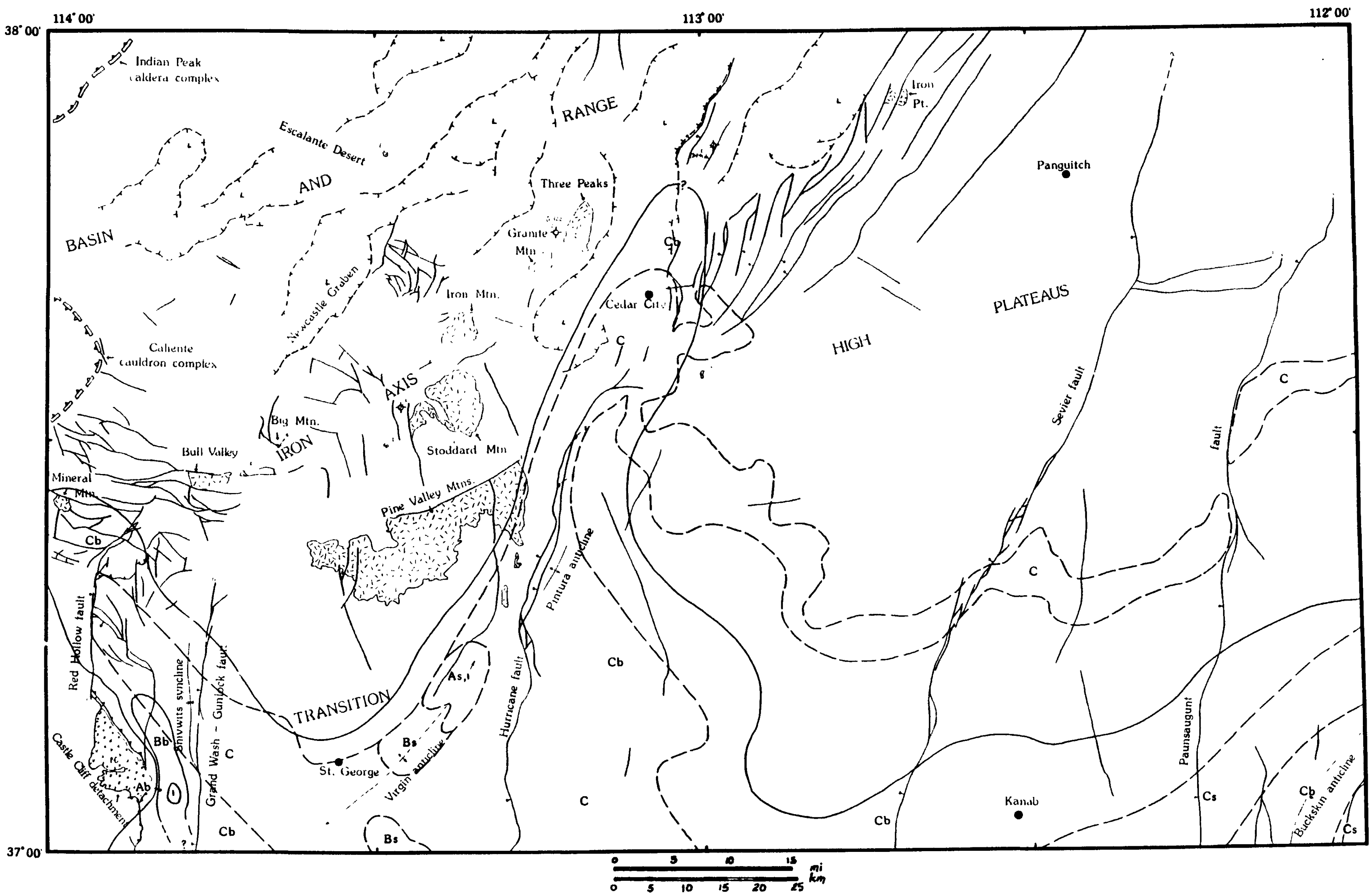


Figure 31.--Areas with potential for solution-collapse breccia pipes, and sandstone-hosted uranium, silver, or copper deposits in the Cedar City 1° X 2° quadrangle, Utah. Symbols are explained on following page.

SOLUTION-COLLAPSE BRECCIA PIPES

Resource Potential	Deposit Type (Cox & Singer Model No.)	Additional Information
Ab =identified deposits; high likelihood of undiscovered deposits	Variant of Kipushi Cu-Pb-Zn **(Model 32c)**	I=major deposits, large production
Bb =more than one favorable factor; moderate likelihood of undiscovered deposits		
Cb =at least one favorable factor; low likelihood of undiscovered deposits		

SANDSTONE-HOSTED SILVER, URANIUM, OR COPPER DEPOSITS

Resource Potential	Deposit Type (Cox & Singer Model No.)	Additional Information
A=identified deposits; high likelihood of undiscovered deposits	Variant of tabular sandstone-hosted uranium deposits **(Model 30c)**	I=major deposits, large production
B=more than one favorable factor; moderate likelihood of undiscovered deposits		suffix **s**= silver-rich
C=at least one favorable factor; low likelihood of undiscovered deposits		no suffix= uranium-rich or both U and Ag

Figure 31.--(continued).

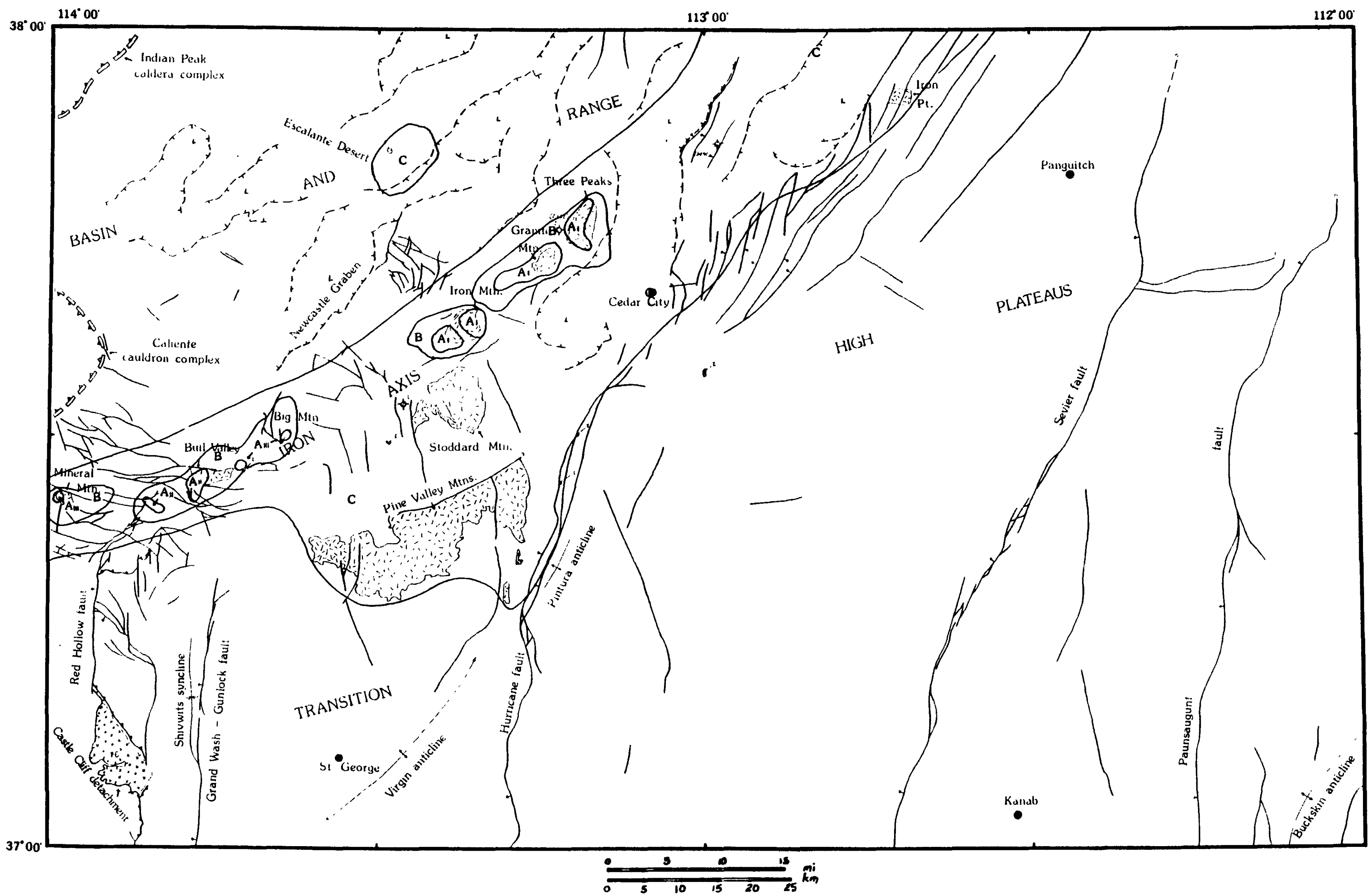


Figure 32.--Areas with potential for iron skarns and related deposits in the Cedar City 1° X 2° quadrangle, Utah. Symbols are explained on following page.

IRON SKARNS AND RELATED DEPOSITS

Resource Potential	Deposit Type (Cox & Singer Model No.)	Additional Information
A=identified deposits; high likelihood of undiscovered deposits	Iron skarns **(Model 18d)**	**I**=major deposits, large production
B=more than one favorable factor; moderate likelihood of undiscovered deposits		**II**=Significant occurrence
C=at least one favorable factor; low likelihood of undiscovered deposits		**III**=Occurrence

Figure 32.--(continued).

in Colorado (**Model 25b**); (2) less-well described veins of the Stateline and Gold Springs districts, which are richer in gold, and are similar to veins in the Comstock district in Nevada (**Model 25c**); and (3) poorly-known vein occurrences in the Tutsagubet district and near Mineral Mountain, which contain a broad suite of metals found in polymetallic veins (**Model 22c**). Included in this composite epithermal model are possible gold occurrences in the Tutsagubet district, where alteration may be related to low-angle faulting along the Castle Cliff detachment (**Model 37b**). Significant gold discoveries made in the Goldstrike district between 1975 and 1985 represent an enigma: although very minor production from the district in the early 1900's was from gold-bearing calcareous veins in Paleozoic host rocks, and jasperoids that locally are gold-bearing are known to be widespread, gold deposits of current interest occur as disseminations in the silicified basal part of a Tertiary calcareous sequence, which lies unconformably upon older host rocks. Although the deposits at Goldstrike have many aspects of Carlin-type carbonate-hosted gold-silver deposits (**Model 26a**), genesis is poorly understood and insufficient information is available to rule out other possible epithermal deposit types.

Favorable factors for the occurrence of epithermal mineral deposits include: (1) networks of faults and fractures, particularly if related to igneous doming or caldera margins; (2) limonitic or argillic alteration and silicification, particularly of calcareous rocks; (3) multiple centers of Oligocene and Miocene calc-alkaline and bimodal volcanism and related shallow intrusion; (4) presence of anomalous values of Cu, Pb, Zn, Ag, or Mo in stream sediments and soils; (5) presence of a Th-Nb-Ce-La-Y association in stream sediments and soils, which may indicate the presence of alkali rhyolite domes and flows; (6) literature reports of occurrences of minerals containing metals such as Hg and Sb, which commonly are associated with epithermal deposits; and (7) gravity data that indicates steep faults in buried extensions of favorable terrane.

Much of the Basin and Range province in the Cedar City quadrangle is promising terrane for the occurrence of undiscovered epithermal deposits. The well-known Pioche-Marysvale and Delamar-Iron Springs Tertiary magmatic trends extend through the province, and parts of the margins of both the Indian Peak and Caliente caldera complexes are present. A mosaic of Miocene and younger high-angle faults is present throughout the region, which provides deep plumbing systems for migration of mineralizing fluids. Apparently, altered areas and former solfataras are widespread, but few descriptions and no geochemical results have been published. Existing geochemical data are insufficient to focus on particular areas as most promising for undiscovered epithermal deposits; acquisition of new data is necessary.

Five epithermal deposit models are pertinent to known occurrences in the quadrangle, and potentially indicate types of deposits that are present as undiscovered resources, particularly within the areas labeled A (figure 30): Creede (**25b**), Comstock (**25c**), polymetallic veins (**22c**), gold on flat faults (**37b**), and Carlin (**26a**). Grade and tonnage figures from known deposits worldwide (in Cox and Singer, 1986) can be used to predict possible grades and tonnages of undiscovered resources.

For the **Creede** deposit-type, expected products are: copper, lead, zinc, silver, and gold. The median values for deposits worldwide are 1.5 grams per tonne gold, 130 grams per tonne silver, 1.7 percent zinc, 2.5 percent lead, and 0.16 percent copper. Median tonnage is more than 1.4 million tonnes of ore.

The **Comstock** type is rich in gold, silver, copper, zinc, and lead, with median worldwide values of 7.5 grams per tonne gold and 110 grams per tonne silver. Data on byproducts is scarce, but apparently the following grades are in the 50th percentile: 0.071 percent copper, 0.025 percent zinc, and 0.11 percent lead. Total median tonnage for deposits worldwide is 0.77 million tonnes of ore per deposit.

The median tonnage for world-wide **polymetallic vein** deposits is 0.0076 million tonnes with median values of 820 grams per tonne silver, 0.13 grams per tonne gold, 9 percent lead, and 2.1 percent zinc. A small number of deposits worldwide contain copper, and of those deposits the median copper grade is 0.89 percent.

Not enough information is available to compile statistics for median grade/tonnage figures for deposits of the **gold on flat faults** type. Median tonnage and grades for deposits of the **Carlin** type are 5.1 million tonnes of ore at 2.5 grams per tonne gold, sometimes with minor silver.

Porphyry Mo/Cu deposits (figure 30)

There are no known deposits of the Climax Mo type (**Model 16**) or porphyry Cu type (**Model 17**) in the Cedar City quadrangle. The nearest porphyry deposit, in the Pine Grove district about 25 miles north of the quadrangle boundary in the Wah Wah Mountains, is a deeply-buried stockwork molybdenum-tungsten deposit in a series of 24 Ma hypabyssal quartz monzonite stocks (Keith and others, 1986). The stocks are believed to be cogenetic with widespread early Miocene rhyolite of the Blawn Formation. Enclosing the intrusion are extensively faulted Proterozoic and Cambrian strata, which host small replacement Zn-Pb-Cu-Ag-Au ore bodies in carbonate rocks. Although comparable rocks are not known to be present anywhere at the surface in the Cedar City quadrangle, they may be present at depth in the northwest part. Potential for other types of porphyry deposits (such as the low fluorine porphyry Mo type, **Model 21b**, or porphyry Cu-Mo type, **Model 21a**) cannot be excluded for the Cedar City quadrangle. Unfortunately, critical information for differentiation is lacking on igneous rock chemistries and textures, on possible multiple stages of intrusion, and on diagnostic alteration features. Thus, the various types of porphyry deposits are lumped together here and in figure 30 under climax Mo type (**Model 16**) and porphyry Cu type (**Model 17**).

Favorable factors for the occurrence of porphyry deposits at depth are: (1) outcropping high-silica rhyolitic flow domes, breccias, and flows, particularly if associated with shallow intrusions; (2) evidence of multiple phases of rhyolitic magmatism; (3) presence of silver-gold-base metal vein systems at surface, particularly if several stages of metal deposition are shown; (4) presence of anomalous values of Ag, Mo, F, Pb, Cu, or Zn in NURE stream sediment, soil, and groundwater samples; (5) presence of a Th-Nb-Be-Ce-La-Y association in NURE stream sediments and soils, which may reflect the presence of high-silica rhyolite domes and flows; and (6) presence of a strong, closed, positive magnetic anomaly that may reflect a buried intrusion.

Favorable tracts for the occurrence of porphyry deposits at depth in the Antelope, Escalante, and Modena districts enclose tracts that are favorable for epithermal deposits. These multistage precious- and base-metal vein systems may comprise the upper levels of deep-seated hydrothermal systems driven by stocks at depth. As was the case in the evaluation of potential for epithermal deposits, the broad envelope of level C potential in the western part of the quadrangle reflects a lack of pertinent data to support more refined modeling.

Although igneous pipes that fed the laccoliths of the Iron Springs district must be present beneath them, it is not likely that the laccoliths conceal broad stocks that might host porphyry deposits. Exploration drilling through the Three Peaks and Iron Mountain bodies did not re-enter igneous rock at depths of more than 10,000 feet, nor was any contact metamorphism apparent that might be attributed to a nearby intrusion.

Median grade and tonnage worldwide for Climax Mo type deposits (**Model 16**) are 200 million tonnes of ore with a grade of 0.19 percent molybdenum. For porphyry Cu deposits (**Model 17**), median tonnage and grade are 140 million tonnes of ore with a grade of 0.54 percent copper.

Placer gold deposits (figure 30)

The placer gold potential of streams that drain gold districts of the Cedar City quadrangle has not been evaluated thoroughly, and there is no evidence of historic placer production. Favorable factors for the occurrence of placer gold (**Model 39a**) are: (1) presence of gold-bearing veins or disseminated deposits in drainage areas; and (2) recurrent uplift with production of multicycle sediments or abandonment of high-level terrace deposits.

Gold Springs Wash and its tributaries drain much of the area of the Gold Springs district. Although the upper reaches of the streams drain southwest, where they reach Prohibition Flat, they curve to the east and enter the Cedar City quadrangle west of Modena. Near the northwest corner of the quadrangle, Johnny Canyon and Mormon Gulch drain eastward from the Stateline district. Because many veins in the two districts contained visible gold, it is plausible that detrital gold eroded from outcropping veins might have migrated downstream and become concentrated sufficiently to form minable placers near the Nevada state line and in southwestern Hamblin Valley.

The East Fork of Beaver Dam Wash and its tributaries drain all of the 15 mi^2 Goldstrike district. The recently discovered ore-grade disseminated gold in bedrock has not been identified visually and can not be concentrated by panning. However, the possibility of placer resources in the drainages should not be discounted, inasmuch as "specimen" gold in veins was described from early work in the district, and mechanical or biological amalgamation of gold might occur during downstream transport. It also is possible that any gold associated with detachment faults on the west side of the Beaver Dam Mountains, when eroded, would have traveled down the steep alluvial fans to be concentrated in former or present terraces of Beaver Dam Wash.

Solution-collapse breccia pipes (figure 31)

South of the Cedar City quadrangle, thousands of solution-collapse breccia pipes (variant of **Model 32c**) occur, but only about 5 percent of them are known to host mineral deposits. Metal contents of deposits are diverse, and generally include enrichment in Ag, Co, Cu, Mo, Ni, Pb, U, V, or Zn. At the Apex and Paymaster mines in the Beaver Dam Mountains, breccia pipes recently have been identified as hosts for mineral deposits. The limonitic ore fills interstices in a breccia derived from solution-collapse of silty and sandy carbonate rocks of the Pennsylvanian Callville Limestone. No other breccia pipes have been identified in the Cedar City quadrangle, but regionally the pipes occur at stratigraphic levels from the Mississippian Redwall Limestone through the lower Jurassic Wingate Sandstone. Ore-grade deposits occur most commonly in rocks of Early Permian age.

Favorable factors for the occurrence of mineralized breccia pipes are: (1) presence of overall upper Paleozoic-lower Mesozoic sequence of the Marble

Platform, particularly the Redwall (or equivalent) Limestone, within which most pipes are rooted; (2) presence of karst surfaces, caverns, or other solution features; (3) anomalous values of Cu, Pb, Zn, Ag, and Mo in analyses of NURE stream sediments and soils; and (4) evidence of organic carbon in host rocks.

The appropriate stratigraphic sequence is exposed widely in the southern and western part of the Cedar City quadrangle. Upper Paleozoic rocks that are possible hosts crop out in the Beaver Dam Mountains, near Goldstrike, along the Hurricane fault, and on Buckskin Mountain, and occur at depths of less than 2,000 feet as far north as Cedar City. Although lower Mesozoic rocks are not known to host breccia pipes in the Cedar City quadrangle, they have not been explored extensively for indications of pipes. Much of the quadrangle south of the White Cliffs and in the vicinity of St. George has low potential for their occurrence. For pipes that contain primary sulfide minerals, favorable factors are (1) noncalcareous interbeds in carbonate sequences, and (2) bleaching of normally red sedimentary rocks. For pipes containing secondary oxides (which include the gallium and germanium), the occurrence of jarosite, limonite, and goethite, particularly in carbonate rocks, is a key factor.

It must be emphasized that existing geochemical and geophysical data lack adequate resolution to identify the typically small surface features related to solution-collapse breccia pipes; favorable lithologies and known deposits in the region are the principal criteria used here.

Sandstone-hosted silver, uranium, or copper deposits (figure 31)

The unusual silver chloride ores of the Silver Reef district yielded more than 7M oz of silver prior to 1900. Their genesis has been a subject of debate for at least 100 years, and remains equivocal. Although they are unusually silver-rich, they have many aspects of tabular sandstone-hosted uranium deposits (**Model 30c**), with an additional requirement for a saline brine to complex the silver. In general, silver concentrations are highest where uranium concentrations are low and copper only moderate (particularly the northwest flank of the anticline). High uranium concentrations are located only on the southeast flank.

Favorable factors for the occurrence of sandstone-hosted tabular deposits are: (1) presence of permeable Mesozoic fluvial deposits, particularly braided channel facies; (2) abundance of detrital carbonaceous material; (3) presence of mud-flat or evaporitic facies in the sequence, which are potential sources of metals and brines; (4) traces of hydrocarbons, indicating possible petroleum migration through a permeable paleoaquifer; (5) presence of anomalous values of Ag, Cu, Mo, and V in geochemical media; and (6) anomalous radioactivity but low magnetic susceptibility near mineral deposits.

Silver is slightly anomalous in most samples of Springdale Sandstone collected within 75 miles of the Silver Reef district (Proctor and Brimhall, 1987). Units within the underlying Moenkopi and Chinle Formations also locally contain anomalous concentrations of many metals, notably Cu, Ag, and Au. Extensive exploration drilling for down-dip and along-strike extensions of the Silver Reef ore bodies has found few high-grade intercepts, and regional evaluation of Triassic and Jurassic fluvial units has not identified significant silver concentrations. However, inasmuch as most favorable geologic factors are present south and west of the Silver Reef district and on both flanks of the Buckskin anticline, and unexplained anomalous silver values are present in the NURE geochemical data, there is a low potential that additional occurrences exist.

Over much of the Colorado Plateau, fluvial sandstone units within the Chinle Formation contain tabular or roll-front uranium deposits. The presence of very permeable host rocks to act as fluid conduits and abundant carbonaceous material to act as reductants are critical factors in controlling uranium precipitation. Only a few local occurrences are known in the Cedar City quadrangle, but favorable conditions are widespread.

In at least three places in the quadrangle, carbonaceous coarse clastic units in the basal part of the Dakota Sandstone contain small uranium occurrences. It is not known whether lignite beds in overlying strata contain significant amounts of uranium. Additional undiscovered occurrences are likely.

Iron skarns and related deposits (figure 32)

The Iron Springs mining district is the largest iron district in the western United States, and produced more than 500,000 tons of iron ore at a grade of about 50 percent Fe in 1988. The district encompasses three aligned Miocene quartz monzonite laccoliths, which trend northeast. Iron was derived from the plutons and deposited as replacement magnetite-hematite bodies (skarns) in the Carmel Formation near intrusive contacts **(Model 18d)** or as veins within the plutons. Locally, alluvial deposits have been formed adjacent to outcropping ore bodies.

Favorable factors for the occurrence of iron deposits are: (1) presence of concordant porphyritic plutons; (2) emplacement at shallow depths within chemically reactive rocks, particularly the Homestake Limestone member of the Carmel Formation; (3) presence of extension joints within plutons near contacts; (4) anomalous Fe, Cu, Pb, and Zn concentrations in geochemical samples; and (5) pronounced positive magnetic anomaly.

The Iron Springs district is part of a regional belt about 60 mi long of similar hypabyssal intrusions, which extends from Mineral Mountain near the west edge of the Cedar City quadrangle to the Iron Point laccolith at the west edge of the Markagunt Plateau (figure 4). Most of the intrusions along this so-called "iron axis" have been prospected for iron, and significant additional reserves have been identified. Resources of iron and phosphorous also are present in volcanic rocks of the Miocene Rencher Formation as magnetite-hematite-apatite veins and breccias, and as hematite-silica replacement bodies, which may mark locations of hot springs or vents. Resources in additional undiscovered iron or polymetallic skarns or related base-metal vein systems are likely at depth adjacent to known occurrences in plutons or vent complexes throughout the "iron axis." Iron skarn deposits worldwide have a median tonnage of 7.2 million tons of ore with a median grade of 50 percent iron.

Section 8 SUMMARY AND RECOMMENDATIONS

The Cedar City 1° X 2° quadrangle is located in southwestern Utah and spans the transitional boundary between the Colorado Plateau and the Basin and Range provinces. The quadrangle contains abundant mineral resources: more than 200 mines, deposits, and occurrences of metallic and industrial minerals have been identified, approximately 150 deposits of coal are known, and nearly 300 deposits of stone, volcanic materials, and sand and gravel indicate important resources for local uses. Production in ferrous, base, and precious metal districts began in the middle and late 19th century; production continues today for iron, precious metals, and rare metals (gallium and germanium).

The most productive districts were Iron Springs (Fe) and Silver Reef (Ag), which are the largest of their types in the western United States. Iron and silver production continue at reduced rates currently (Iron Springs and Escalante districts, respectively); one former base metal district (Tutsagubet district) recently has produced primary gallium and germanium; bulk-minable gold deposits are being developed (Goldstrike district); and exploration for precious metals is being conducted by several companies in the Antelope Range, Goldstrike, and Tutsagubet districts. Deposits of uranium, coal, and oil and gas are numerous. Coal is mined in small operations for power generation, and intermittent exploration for hydrocarbons continues. The quadrangle contains known geothermal resources in the Escalante Desert area and near St. George. The industrial commodities, such as sand and gravel, volcanic ash and cinders, dimension and decorative stone, kaolinite and bentonite, and gypsum, are also widespread.

Most mineral deposits in the Cedar City quadrangle are associated with distinct structural and stratigraphic envirnoments and many of these occur in the transition zone between the Colorado Plateau and the Basin and Range province, a zone which also marks the position of a persistent tectonic hingeline. The geologic history of the region indicates that there were four main evolutionary phases that controlled metal deposition.

(1) During late Triassic and early Jurassic time, regional uplift east of the quadrangle resulted in general westward regression of the sea and in deposition in rivers or sabkhas across broad coastal plains. During protracted periods of subaerial exposure, meteoric water circulated deeply and widely throughout the region, and interacted with marine shale and basement rocks to leach base and rare metals. Numerous solution-collapse breccia pipes are rooted in the Mississippian Redwall Limestone and extend upward through overlying carbonate sequences; these provided both permeable conduits to channel metal-bearing solutions and reactive host rocks to trap metals. Enrichment of metals may have continued episodically through the subsequent three phases; in fact, much of the metal migration may have occurred during Tertiary time. Deep circulation of large volumes of groundwater continues today, as indicated by copious water flows from recent exploration wells. Several Mesozoic sequences contain abundant organic detritus and residual hydrocarbons, which acted as reductants in the precipitation of uranium, vanadium, and copper roll-front deposits; a comparable process may have been responsible for deposition of the unique silver chloride deposits at Silver Reef.

(2) In the late Mesozoic, eastward-directed thrusting and related folding of the Sevier orogeny emplaced allochthons of Paleozoic miogeoclinal rocks above Mesozoic nonmarine and marginal marine rocks. Hydrocarbon generation reached a peak during waning stages of orogeny. In the foreland zone, fault ramps apparently reached the surface and provided zones of structural weakness

along which hydrocarbons may have migrated (and escaped) and that were intruded later by Tertiary plutons.

(3) In the Oligocene and early Miocene, regional calc-alkaline volcanism formed stratovolcanoes and calderas, which were surrounded by widespread sheets of ash-flow tuffs. Gold-bearing vein systems hosted by andesitic rocks in the Gold Springs district may be of this age. Upper crustal structures created at that time perhaps localized deposits that formed later. Near the end of this phase, subvolcanic porphyritic plutons were intruded along the so-called "iron axis," and ferrous and base metal skarn and replacement deposits formed in adjacent calcareous rocks.

(4) Concurrent with the onset of regional extension in mid-Miocene time, magmatism became bimodal and more limited in extent, with generally small eruptions from local centers. Peak activity apparently was between 15 and 10 Ma. Detachment faulting may have created an environment for deposition of precious metals. Hydrothermal activity accompanied each episode of silicic volcanism and was focused along zones of recurrent faulting. The faulted mosaic of "prepared ground" provided pathways for epithermal solutions to follow, and numerous vein and disseminated precious-metal deposits formed. Some of these epithermal deposits may be underlain by porphyry deposits at depth.

Although many geochemical samples from the Cedar City quadrangle have been analyzed the various data sets cannot be merged into a single database. The NURE data, although not ideal, is best suited for this preliminary assessment. Several significant geochemical anomalies found in the NURE data delineate mining districts in the western part of the quadrangle, and identify some as-yet unexplained clusters of anomalous samples elsewhere. Significant geochemical anomalies, summarized below, suggest that follow-up work probably would be advantageous in several areas within the Cedar City quadrangle; the unexplained nature of many of these anomalies illustrates the limited usefulness of the present data and the need for further geochemical studies. Anomalous contents of base metals, silver, and molybdenum delineate to various degrees the Silver Reef, Tutsagubet, Goldstrike, Mineral Mountain, and Antelope Range districts (figure 26, areas 1A, 2, 3A, and 3B, respectively). The Iron Springs and Bull Valley districts are identified by iron and base metal anomalies (area 4).

A large area (1B) in and around the Paria district contains numerous samples with low-level anomalous silver. Host rocks and geophysical features are similar to those at Silver Reef, but it is unclear from the present data whether the anomalous silver values are real or represent analytical noise. Similarly, other small clusters of samples contain low-level anomalous silver (1C, 1D, and 9), which may be real or may be due to analytical noise. Anomalous base metals, iron, silver, and molybdenum are found in area 3C, an area that shares geochemical and geologic features with surrounding mining districts in the region. It is uncertain whether these anomalies are related to mineral occurrences or to high background values in mafic volcanic rocks. Highly anomalous silver and molybdenum in area 5 may be due to locally high background values in the Chinle Formation, or to mineral occurrences (sediment-hosted base or precious metals?). Numerous samples in a large part of the northwestern quarter of the quadrangle (area 6) are anomalous in an associated group of elements (Th-Nb-Be-Ce-La-Y), which may be indicative of high-silica alkali rhyolite flows and domes found sporadically in the region. Rhyolite of this composition may host Climax-type Mo and precious-metal epithermal deposits, and deposits that are enriched in lithophile elements (Be, U, F, Li, and Sn). Samples from Quaternary sediments in area 7 are anomalous in B, Li, K, F, Si, U, and As, a geochemical suite which likely identifies thermal waters in the basin. Two anomalous areas (8A and 8B) have geochemical signatures similar to area 7, although the origin of these anomalies remains unexplained.

Existing geophysical data utilized in this study of the Cedar City quadrangle include regional aeromagnetic, aeroradiometric, and gravity surveys, and remote sensing imagery (LANDSAT MSS data). These data help delineate the principal structural elements and subsurface bulk lithologies, a prime requisite for mineral resource assessment.

Regional aeromagnetic coverage is at 2-mile flight traverse spacings, except for a much more detailed survey of the "iron axis". Relatively long wavelength magnetic anomalies are produced by Precambrian crystalline basement and by Tertiary intrusive bodies, while shorter wavelength anomalies are produced by variation in the magnetic properties of extrusive rocks, iron deposits, and Cenozoic volcanic rocks. Phanerozoic sedimentary rocks have no magnetic expression. Aeromagnetic data are most useful for delineating faults and buried intrusions, although not all such structures are detected. Gravity coverage is adequate for regional-scale investigations over most of the Basin and Range Province and the western part of the Colorado Plateau. Relative anomaly highs are produced by structural uplift of Precambrian crystalline basement and thick carbonate successions. In the Basin and Range Province the anomaly maps delineate concealed northeast-trending valley-and-ridge structural fabric beneath the Escalante Desert, allow an estimate of basin fill thicknesses, and facilitate mapping of bedrock pediments veneered with alluvium. NURE aeroradiometric coverage, flown at 3-mile traverse spacing with highly variable terrain clearance, yields a gross representation of regional variation in the surface distributions of the radioelements U, K, and Th. Almost all rocks in the northwest part of the quadrangle are anomalous for the three elements, likely due to calc-alkaline rocks related to the Caliente and Indian Peak eruptive-tectonic complexes. In addition, several smaller areas in the western half of the quadrangle are rich in radio-elements. Radioactive sources in these areas include Precambrian granitic rocks, Tertiary potassium-rich intrusive and volcanic rocks, and local hydrothermally altered rocks. Available LANDSAT MSS imagery covers most of the Cedar City quadrangle, but is generally inferior because of extensive vegetation cover and limonitic unaltered sedimentary rocks. Only a few small areas of limonite in Tertiary volcanic and intrusive rocks are discernible.

Limitations of This Preliminary Assessment

This preliminary evaluation of available geological, geochemical, and geophysical information on the Cedar City quadrangle and its identified mineral and energy resources indicates a strong likelihood that additional resources remain to be discovered, especially in the Basin and Range province. Most of the elements for oil and gas discovery are present in the foreland area of the Sevier orogeny near the eastern margin of the province. Terranes in the western half of the Cedar City quadrangle are favorable for several types of mineral deposits, particularly for precious metal deposits. However, the structural and petrologic features of potential host rocks and their temporal relations are incompletely known. Therefore, the possibility of precious-metal resources cannot be evaluated accurately without further investigations.

The present geochemical data for the Cedar City quadrangle has several drawbacks. Samples collected in the quadrangle are widely spaced, several large regions have not been sampled, and samples were not analyzed for many critical pathfinder elements for known deposits in the region. Missing elements include As, Au, Be, Bi, Cd, Hg, Sb, Te, Tl, and W for epithermal base and precious metals; Ga and Ge for deposits similar to those at the Apex Mine; and Se, Br, and U for sediment-hosted Cu, Ag, and U deposits known in the region. These deficiencies severely hamper this preliminary assessment; further geochemical studies in the quadrangle are warranted.

Geophysical data used in this preliminary assessment generally support reconnaissance interpretation, but are of limited utility in detailed investigations. Regional aeromagnetic data are based on traverses spaced about 2 miles apart. Optimally, this coverage should be increased to 1/2-mile spacing over the western portion of the quadrangle and 1-mile spacing over the Colorado Plateau to the east. More gravity determinations are necessary in some parts of the quadrangle, most importantly in the Colorado Plateau. Aeroradiometric data require detailed assessment to determine characteristic radioelement signatures and identify areas of hydrothermally altered rock. The remote sensing imagery used in this assessment is rudimentary at best; only LANDSAT MSS imagery has been examined, and this with mixed results. Commercially available remote sensing data not utilized in this study include LANDSAT TM and AIS imagery, whose much higher spatial resolution makes it possible to discriminate between several types of hydrothermally altered rocks. Also not utilized in this study are side-looking radar (SLAR) scenes useful for mapping linear features, and commercially available seismic reflection profiles which could be very useful for detailed studies.

Recommended Topical Studies

Several topics are recommended for continuing investigation in the Cedar City region by USGS, UGMS, academic, and industrial scientists. These topical investigations, listed below, are discussed more fully in the "Recommendations" segments of the geology, geophysics, geochemistry, and mineral resource sections of this report (pages 20, 42, 68, and 94, respectively). Many of these topical investigations could easily be combined into multi-disciplinary studies.

Geologic Topics:

- The Precambrian complex of the Beaver Dam Mountains
- Paleozoic sequences in the Goldstrike-Mineral Mountain area
- The Claron Formation in the Basin and Range province
- Tertiary igneous rocks in the Basin and Range province
- Relations between intrusion, extrusion, and faulting
- Ages and petrochemistry of intrusions
- Patterns and displacement histories of basin-range faults

Geophysical Topics:

- Structural fabric of the Cedar City quadrangle as determined from analysis of geophysical (including remote sensing) linear features
- Buried intrusions of the Pioche-Marysvale belt in the Cedar City quadrangle
- Buried intrusions of the Sevier Valley area--the subsurface extent of "iron axis" and related monzonitic intrusions

- Magnetic properties of quartz monzonite porphyry and its extrusive equivalents in southwest Utah
- Hydrothermally altered rocks and their distribution from remote sensing (LANDSAT TM; AIS; SLAR)
- The nature and significance of magnetic-basement features of the Colorado Plateau
- Geometry of the Hurricane and related normal faults
- Structure concealed beneath the Escalante Desert and other alluvium-covered areas, including range-front faults
- Delineation of caldera ring fractures and their possible relation to mineralization
- Anomalous aeroradiometric signatures and their geologic significance

Geochemical Topics:

- Analysis of archived NURE stream sediment and soil samples for several missing critical elements, to provide new data with lower detection limits
- Validation of anomalous archived NURE samples by re-analysizing, followed by field checking of real anomalies
- Collection of additional stream sediment, heavy mineral concentrate, and rock samples throughout the quadrangle in areas inadequately covered by existing studies
- Detailed sampling of known mining districts using various sample media to determine district extensions and geochemical signatures expected for similar deposits
- Application of non-traditional geochemical approaches (biogeochemistry, soil gases, pebble coatings, etc.) in the large areas of the western half of the quadrangle covered by Quaternary deposits

Mineral Resources/Deposits:

- Detailed genetic studies of the Apex Ga-Ge mine in the Tutsagubet district
- Detailed genetic studies of gold-rich epithermal systems in Gold Springs and Stateline districts
- Detailed genetic studies of silver-rich epithermal systems in the Escalante and Antelope Range Districts
- Detailed genetic studies of bulk disseminated gold deposits in the Goldstrike district
- Detailed study of the silver-rich roll-front system in the Silver Reef district
- Radiometric dating in all mining districts

These studies can be expected to provide specific data to identify commodities, develop exploration criteria, and define areas that are favorable for particular types of deposits. If done in a timely manner, it may by possible to coordinate them with deep crustal studies now underway (BARCO) in the eastern Basin and Range province and with current initiatives to develop technology that will delineate concealed mineral deposits. Combining these studies would provide an important third dimension that often is missing in mineral-resource evaluations, and might even permit interpreting the resource potential of deeply covered areas such as the Escalante Desert.

Mineral-resource investigations of the Cedar City quadrangle will build upon the recently completed resource assessment of the Richfield quadrangle to the north, and gain from investigations in progress in the Delta quadrangle (north of Richfield), thereby continuing to develop a regional framework for understanding the important mineral belts in the Basin and Range province of western Utah. A major additional benefit will be the continued productive cooperative involvement of scientists from the U.S. Geological Survey and the Utah Geological and Mineral Survey.

Section 9 REFERENCES CITED

Adair, D. H., 1986, Structural setting of the Goldstrike district, Washington County, Utah, in Griffen, D.T., and Phillips, W.R., eds., Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 137-148.

Adrian, B.M., Turner, R.L., Malcolm, M.J., Fey, D.L., Vaughn, R.B., Van Loenen, R.E., and Taylor, C.D., 1988, Analytical results and sample locality map of stream-sediment, heavy-mineral-concentrate, and rock samples from the Canaan Mountain (UT-040-143) and the Watchman (UT-040-149 Wilderness Study Areas, Kane and Washington Counties, Utah: U.S. Geological Survey Open-File Report 88-524.

Allen, D.R., 1979, Geology and geochemistry of the Escalante silver veins, Iron County, Utah: Salt Lake City, University of Utah, unpublished M.S. thesis, 71 p.

Allsman, P.T., 1948, Investigations of iron-ore reserves of Iron County, Utah: U. S. Bureau of Mines Report of Investigation 4388.

Allmendinger, R.W., Sharp, J.W., Von Tish, D., Serpa, L., Brown, L., Kaufman, S., Oliver, J., and Smith, R.B., 1983, Cenozoic and Mesozoic structure of the eastern Basin and Range province, Utah, from COCORP seismic-reflection data: Geology, v. 11, p. 532-536.

Anderson, J.J., 1965, Geology of northern Markagunt Plateau, Utah: Austin, University of Texas, Ph.D. dissertation, scale 1:63,360.

Anderson, J.J., 1988, Pre-Basin-Range block faulting along west and northwest trends, southeastern Great Basin and southern High Plateaus [abs.]: Geological Society of America Abstracts with Programs, v. 20, n. 3, p. 139.

Anderson, J.J., and Rowley, P.D., 1975, Cenozoic stratigraphy of the southwestern High Plateaus of Utah, in Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., Cenozoic geology of the High Plateaus of southwestern Utah: Geological Society of America Special Paper 160, p. 1-52.

Anderson, J.J., Iivari, T.A., and Rowley, P.D., 1987, Geologic map of the Little Creek Peak quadrangle, Garfield and Iron Counties, Utah: Utah Geological and Mineral Survey Map 104, scale 1:24,000.

Anderson. J.J., and Rowley, P.D., 1987, Geologic map of the Panguitch NW quadrangle, Iron and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 103, scale 1:24,000.

Anderson, R.E., 1978, Quaternary tectonics along the Intermountain Seismic Belt south of Provo, Utah: Brigham Young University Geology Studies, v. 25, pt. 1, p. 1-10.

Anderson, R.E., 1984, Strike-slip faults associated with extension in and adjacent to the Great Basin [abs.]: Geological Society of America, Abstracts with Programs, v. 16, no. 6, p. 429.

Anonymous, 1988, Hecla's Escalante ore reserves are running out, company says: Pay Dirt (April), no. 103, p. 21A.

Arentz, S.S., 1978, Geology of the Escalante Mine, Iron County, Utah, in Shawe, D.R., and Rowley, P.D., eds., Guidebook to mineral deposits of southwestern Utah: Utah Geological Association Publication 7, p. 59-63.

Aresco, S.J., Haller, C.P., and Abernethy, R.F., 1957, Analyses of tipple and delivered samples of coal (collected during the fiscal year 1956): U.S. Bureau of Mines Report of Investigation 5332, 67 p.

Aresco, S.J., Haller, C.P., and Abernethy, R.F., 1959, Analyses of tipple and delivered samples of coal (collected during the fiscal year 1958): U.S. Bureau of Mines Report of Investigation 5489, 54 p.

Aresco, S.J., Haller, C.P., and Abernethy, R.F., 1961, Analyses of tipple and delivered samples of coal (collected during the fiscal year 1960): U.S. Bureau of Mines Report of Investigations 5792, 44 p.

Armstrong, R.L., 1968, Sevier orogenic belt in Nevada and Utah: Geological Society of America Bulletin, v. 79, p. 429-458.

Ashley, G.H., 1918, Cannel coal in the United States: U. S. Geological Survey Bulletin 659, 127 p.

Averett, W.R., 1984, Guide to data reports of the hydrogeochemical and stream sediment reconnaissance, National Uranium Resource Evaluation Program: U.S. Department of Energy Grand Junction Office Report Number GJBX-5(84).

Averitt, Paul, 1962, Geology and coal resources of the Cedar Mountain quadrangle, Iron County, Utah: U.S. Geological Survey Professional Paper 389, scale 1:24,000.

Averitt, Paul, 1967, Geologic map of the Kanarraville quadrangle, Iron County, Utah: U. S. Geological Survey Geologic Quadrangle Map GQ-696, scale 1:24,000.

Averitt, Paul, and Threet, R.L., 1973, Geologic map of the Cedar City quadrangle, Iron County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1120, scale 1:24,000.

Baer, J.L., 1986, Reconnaissance gravity and magnetic survey of the northern Mesquite basin, Nevada-Utah, p. 109-118, in Griffin, D. T., and Phillips, W. R., (eds.), Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, Salt Lake, 217 p.

Bassler, H., and Reeside, J.B., Jr, 1921, Oil prospects in Washington County, Utah: U.S. Geological Survey Contributions to Economic Geology Bulletin 726, Part II, p. 87-107.

Bernstein, L.R., 1986, Geology and mineralogy of the Apex germanium-gallium mine, Washington County, Utah: U. S. Geological Survey Bulletin 1577, 9 p.

Beroni, E.P., McKeown, F.A., Stugard, Frederick, Jr., and Gott, G.B., 1953, Uranium deposits of the Bulloch group of claims, Kane County, Utah: U.S. Geological Survey Circular 239.

Best, M.G., 1986a, Tertiary geology of the area between Milford, Utah, and Pioche, Nevada, in Griffen, D.T., and Phillips, W.R., eds., Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 77-86.

Best, M.G., 1986b, Preliminary geologic map and sections of the area between Hamblin Valley and Escalante Desert, Iron County, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1774, scale 1:48,000.

Best, M.G., 1987, Geologic map and sections of the area between Hamblin Valley and Escalante Desert, Iron County Utah: U.S. Geological Survey Map I-1774, scale 1:50,000.

Best, M.G., 1988, Easterly trending Oligocene to early Miocene (30-20 Ma) paleotopography and other geologic features, southeastern Great Basin [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 3, p. 143.

Best, M.G., Mehnert, H.M., Keith, J.D., and Naeser, C.W., 1987, Miocene magmatism and tectonism in and near the southern Wah Wah Mountains, southwestern Utah: U.S. Geological Survey Professional Paper 1433-B, p. B31-B46.

Best, M.G., Christiansen, E.H., and Blank, H.R., Jr., in press, Oligocene Needles Range magma system, Utah-Nevada: lavas, voluminous tuffs, and caldera complex: Geological Society of America Bulletin.

Biehl, J.W., and Grant, S.K., 1987, The geology of the Escalante silver district, Iron County, Utah-a possible caldera setting, in Kopp, R.S., and Cohenour, R.E., eds., Cenozoic geology of western Utah, sites for precious metal and hydrocarbon accumulations: Utah Geological Association Publication 16, p. 463-470.

Blakey, R.C., 1979, Oil impregnated carbonate rocks of the Timpoweap Member Moenkopi Formation, Hurricane Cliffs area, Utah and Arizona: Utah Geology, v. 6, no. 1, p. 45-54.

Blank, H.R., Jr., 1959, Geology of the Bull Valley district, Washington County, Utah: Seattle, University of Washington, unpublished Ph.D. dissertation, 177 p.

Blank, H.R., Jr., 1987, The role of regional aeromagnetic and gravity data in mineral resource investigations, southeastern Nevada, p. 5-6, in Sach, J.S., (ed.), U. S. Geological Survey Research on Mineral Resources, 1987 [ext. abs.]: U. S. Geological Circular 995, 82 p.

Blank, H.R., Jr., 1988, Basement structure in the Las Vegas region from potential-field data [abs.]: Geological Society of America, Abstracts with Programs 1988, 84th Annual Meeting, Cordilleran Section, p. 144.

Blank, H.R., Jr., and Mackin, J.H., 1967, Geologic interpretation of an aeromagnetic survey of the Iron Springs district, Utah: U.S. Geological Survey Professional Paper 516-B, 14 p.

Bowers, W.E., 1972, The Canaan Peak, Pine Hollow, and Wasatch Formations in the Table Cliff region, Garfield County, Utah: U.S. Geological Survey Bulletin 1331-B, 39 p.

Bowers, W.E., Aigen, A.A., and Landis, E.R., 1976, Coal resources of the Alton, Utah, EMRIA site: U.S. Geological Survey Open-File Report OFR-76-386.

Brox, G.S., 1961, Geology and erosional development of northern Bryce Canyon National Park: Salt Lake City, University of Utah, M.S. thesis, scale 31,680.

Budding, K.E., and Sommer, S.N., 1986, Low-temperature geothermal assessment of the Santa Clara and Virgin River Valleys, Washington County, Utah: Utah Geological And Mineral Survey Special Study 67, 34 p.

Bullock, J.H., Barton, H.N., Fey, D.L., and Kennedy, K.R., 1988, Analytical results and sample locality maps of stream-sediment and heavy-mineral-concentrate samples from the Deep Creek, La Verkin Creek, North Fork Virgin River, Orderville Canyon, and Parunuweap Canyon Wilderness Study Areas, Kane and Washington Counties, Utah: U.S. Geological Survey Open-File Report 88-581.

Bullock, K.C., 1970, Iron deposits of Utah: Utah Geological and Mineral Survey Bulletin 88, 101 p.

Burchfiel, B.C., and Hickcox, C.W., 1972, Structural development of central Utah, in Baer, J.L., and Callaghan, Eugene, eds., Plateau-Basin and Range transition zone, central Utah: Utah Geological Association Publication 2, p. 55-66.

Burger, J.R., 1984, Ranchers end slices Escalante silver deposit: Engineering and Mining Journal, v. 185, no. 1, p. 48-53.

Bush, A.L., and Lane, M.E., 1982a, Geochemical data and sample locality map of the Vermillion Cliffs-Paria Canyon Instant Study Area and adjacent wilderness study areas, Coconino County, Arizona and Kane County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1475-B, scale 1:62,500.

Bush, A.L., and Lane, M.E., 1982b, Mineral resource potential map of the Vermillion Cliffs-Paria Canyon Instant Study Area, Coconino County, Arizona and Kane County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1475-D, scale 1:62,500.

Butler, B.S., 1920, Iron Springs district, in Ore Deposits of Utah: U.S. Geological Survey Professional Paper 173, p. 568-582.

Butler, B.S., Loughlin, G.F., Heikes, V.C., and others, 1920, The ore deposits of Utah: U. S. Geological Survey Professional Paper 111, 672 p.

Campbell, J.A., and Ritzma, H.R., 1979, Geology and petroleum resources of the major oil-impregnated sandstone deposits of Utah: Utah Geological and Mineral Survey Special Studies 50, 24 p.

Carpenter, C.H., Robinson, G.B., Jr., and Bjorklund, L.J., 1967, Ground-water conditions and geologic reconnaissance of the upper Sevier River basin, Utah: U. S. Geological Survey Water-Supply Paper 1836.

Cashion, W.B., 1961, Geology and fuels resources of the Orderville-Glendale area, Kane County, Utah: U.S. Geological Survey Coal Investigation Map C-49.

Cashion, W.B., 1967, Geologic map of the south flank of the Markagunt Plateau, northwest Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-494, scale 62,500.

Christenson, G.E., and Deen, R.D., 1983, Engineering geology of the St. George area, Washington County, Utah: Utah Geological and Mineral Survey Special Study 58, 32 p.

Christiansen, E.H., Sheridan, M.F., and Burt, D.M., 1986, The geology and geochemistry of Cenozoic topaz rhyolites from the Western United States: Geological Society of America Special Paper 205, 82 p.

Clement, M.D., 1980, Escalante Desert--Heatflow and geothermal assessment of the Oligocene/Miocene volcanic belt in southwestern Utah: Salt Lake City, University of Utah, unpublished M.S. thesis, 118 p.

Clement, M.D., and Chapman, D.S., 1981, Heat flow and geothermal assessment of the Escalante Desert, southwestern Utah, with emphasis on the Newcastle KGRA: U.S. Department of Energy document DOE/ID/12070-28.

Conrad, J.E., and others, in preparation, Mineral resources of the Cougar Canyon Wilderness Study Area, Washington County, Utah: U.S. Geological Survey Bulletin.

Cook, E.F., 1954, Areal geology of the Pine Valley Mountains, Utah: University of Washington, Ph.D. dissertation, (also Utah Geological and Mineral Survey Bulletin 58).

Cook, E.F., 1957, Geology of the Pine Valley Mountains, Utah: Utah Geological and Mineralogical Bulletin 58, 111 p.

Cook, E.F., 1960, Geologic atlas of Utah, Washington County: Utah Geological and Mineral Survey Bulletin 70, 119 p.

Cook, J.R., and Fay, W.M., 1982, Data report: Western United States, hydrogeochemical and stream sediment reconnaissance, National Uranium Resource Evaluation Program: U.S. Department of Energy Grand Junction Office Report Number GJBX-132(82).

Cook, K.L., 1950a, Magnetic surveys in the Iron Springs district, Iron County, Utah: U.S. Bureau of Mines Report of Investigation 4586, 78 p.

Cook, K.L., 1950b, Geology of eastern Iron County, Utah: U.S. Bureau of Mines Report of Investigation 4586, 78p.

Cook, K.L., and Hardman, Elwood, 1967, Regional gravity survey of the Hurricane fault area and Iron Springs district, Utah: Geological Society of America Bulletin, v. 78, no. 9, p. 1063-1076.

Cook, K.L., Montgomery, J.R., Smith, J.T., and Gray, E.F., 1975, Simple Bouguer gravity anomaly map of Utah: Utah Geological and Mineral Survey Map 37, scale 1:1,000,000.

Cordova, R.B., Sandberg, G.W., and McConkie, Wilson, 1972, Ground-water conditions in the central Virgin River basin, Utah: U.S. Geological Survey Open-File Report, 72 p.

Cornwall, H.R., Lakin, H.W., Nakagawa, H.M., and Stager, H.K., 1967, Silver and mercury geochemical anomalies in the Comstock, Tonopah, and Silver Reef districts, Nevada-Utah in, U.S. Geological Survey Research 1967, Chapter B: U.S. Geological Survey Professional Paper 575-B, p. B10-B20.

Cox, D.P., and Singer, D.A., 1986, editors, Mineral deposit models: U.S. Geological Survey Bulletin 1693, 379 p.

Crawford, A.L., ed., 1963, Oil and gas possibilities of Utah, re-evaluated: Utah Geological and Minerals Survey Bulletin 54, p. 311-317.

Crawford, A.L., and Buranek, A.M., 1948, Halloysite of agalmatolite type, Bull Valley district, Washington County, Utah: Utah Geological and Mineral Survey Bulletin 35, 12 p.

Detra, D.E., Kilburn, J.E., Jones, J.L., and Fey, D.L., 1988a, Analytical results and sample locality map of stream-sediment, heavy-mineral-concentrate, and rock samples from the Cottonwood Canyon Wilderness Study Area, Washington County, Utah: U. S. Geological Survey Open-File Report 88-274, 16 p.

Detra, D.E., Kilburn, J.E., Jones, J.L., and Fey, D.L., 1988b, Analytical results and sample locality map of stream-sediment, heavy-mineral-concentrate, and rock samples from the Red Mountain Wilderness Study Area, Washington County, Utah: U.S. Geological Survey Open-File Report 88-248.

Detterman, J.S., 1956a, Photogeologic map of the Kanab SE quadrangle, Kane County, Utah, and Mohave and Coconino Counties, Arizona: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-137, scale 1:24,000.

Detterman, J.S., 1956b, Photogeologic map of the Johnson SW quadrangle, Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-164, scale 1:24,000.

Detterman, J.S., and Hackman, R.H., 1957, Photogeologic map of the Johnson SE quadrangle, Kane County, Utah, and Coconino County, Arizona: U. S. Geological Survey Miscellaneous Geologic Investigation Map I-248, scale 1:24,000.

Dobbin, C.E., 1939, Geologic structure of St. George district, Washington County, Utah: American Association of Petroleum Geologists Bulletin, v. 23, no. 2.

Doelling, H.H., 1974, Geology and mineral resources of Garfield County, Utah: Utah Geological and Mineralogical Survey Bulletin 107.

Doelling, H.H., 1983, Non-metallic mineral resources of Utah: Utah Geological and Mineral Survey Map 71, scale 1:750,000.

Doelling, H.H., 1987, Geologic map of the Elephant Butte quadrangle, Kane County, Utah: Utah Geological and Mineral Survey Open-File Report 113, scale 1:24,000.

Doelling, H.H., 1989 [in press], Geology and mineral resources of Kane County, Utah: Utah Geological and Mineral Survey Bulletin 124, 233 p.

Doelling, H.H., and Graham, R.L., 1972, Southwestern Utah coal fields: Alton, Kaiparowitz Plateau, and Kolob-Harmony: Utah Geological and Minerals Survey Monograph 1, 333 p.

Doelling, H.H., and Tooker, E.W., 1983, Utah mining districts and principal metal occurrences: Utah Geological and Mineral Survey Map 70, scale 1:750,000.

Dutrizac, J.E., Jambor, J.L., and Chen, T.T., 1986, Host minerals for the gallium-germanium ores of the Apex mine, Utah: Economic Geology, v. 81, p. 946-950.

Eaton, G.P., Wahl, R.R., Prostka, E.J., Mabey, D.R., and Kleinkopf, M.D., 1978, Regional gravity and tectonic patterns: their relation to Late Cenozoic epeirogeny and lateral spreading in the western Cordillera, in Smith, R.B., and Eaton, G.P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 51-92.

Ekren, E.B., Orkild, P.P., Sargent, K.A., and Dixon, G.L., 1977, Geologic map of the Tertiary rocks, Lincoln County, Nevada: U. S. Geological Survey Miscellaneous Investigations Map I-1041, scale 1:250,000.

Fitch, E.C., and Brady, M.W., 1982, Geology of the Escalante Silver Mine, Utah: Presented at the 99th annual Northwest Mining Association Convention, Spokane, Washington, 13 p. (reprint of presentation).

Fix, P.F., Nelson, W.B., Lofgren, B.E., and Butler, R.G., 1950, Ground water in Escalante Valley, Beaver, Iron, and Washington Counties: Utah State Engineer Technical Publication 6 in, Tracy, J.M., State of Utah, 27th Biennial Report p. 109-210.

Fox, R.C., 1968, A gravity survey of south-central Utah, including gravity profiles across the Paunsaugunt fault: University of Utah, M.S. thesis, 81 p.

Geodata International, Inc., 1980, Aerial radiometric and magnetic survey, Cedar City, Utah: U. S. Department of Energy Publication GJBX-93, map scales 1:500,000.

Goode, H.D., 1964, Reconnaissance of water resources of a part of western Kane County, Utah: Utah Geological and Mineralogical Survey Water-Resources Bulletin 5.

Goode, H.D., 1973a, Preliminary geologic map of the Bald Knoll quadrangle, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-520, scale 1:24,000.

Goode, H.D., 1973b, Preliminary geologic map of the Skutumpah Creek quadrangle, Utah: U. S. Geological Survey Miscellaneous Field Studies Map MF-521, scale 1:24,000.

Grant, S.K., and Proctor, P.D., 1988, Geology of the Antelope Peak quadrangle, Iron county, Utah: Utah Geological and Mineral Survey Open-File Report 130, scale 1:24,000.

Grant, T.C., 1979, Geology of the Spry intrusion, Garfield County, Utah: Kent State University, M.S. thesis, scale 1:24,000.

Gray, R.C., 1966, Crustal structure from the Nevada Test Site to Kansas as determined by a gravity profile: University of Utah, M.S. thesis, 97 p.

Green, R.T., and Cook, K.L., 1981, Gravity survey of the southwestern part of the southern Utah geothermal belt: U.S. Department of Energy Report DOE/ID/12079-18, 116 p.

Gregory, H.E., 1939, A geologic and geographic sketch of Zion National Park: Zion-Bryce Museum Bulletin 3, fig. 8. 1:250,000.

Gregory, H.E., 1948, Geology and geography of central Kane County, Utah: Geological Society of America Bulletin, v. 59, no. 3.

Gregory, H.E., 1949, Geologic and geographic reconnaissance of eastern Markagunt Plateau, Utah: Geological Society of America Bulletin, v. 60, no. 6.

Gregory, H.E., 1950a, Geology of eastern Iron County, Utah: Utah Geological and Mineralogical Survey Bulletin 37, 153 p.
Gregory, H.E., 1950b, Geology and geography of the Zion Park region, Utah and Arizona: U. S. Geological Survey Professional Paper 220, 200 p.
Gregory, H.E., 1951, The geology and geography of the Paunsaugunt region, Utah: U. S. Geological Survey Professional Paper 226, 116 p.
Gregory, H.E., and Williams, N.C., 1947, Zion National Monument, Utah: Geological Society of America Bulletin, v. 58, no. 8.
Grimes, J.G., 1984, NURE HSSR geochemical sample archives transfer report, geochemical analysis, prepared for the U.S. Department of Energy and U.S. Geological Survey by Martin Marietta Energy Systems, Inc., Oak Ridge Gaseous Diffusion Plant, Oak Ridge, Tennessee, Report Number K/UR-500, Part 3.
Gustason, E.R., 1987, Depositional history of the mid-Cretaceous Dakota Formation and early foreland basin evolution, so. Utah [abs.]: Geological Society of America, Abstracts with Programs, v. 19, n. 7, p. 687.
Hackman, R.J., 1957a, Photogeologic map of the Buckskin Gulch NW quadrangle, Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-251, scale 1:24,000.
Hackman, R.J., 1957b, Photogeologic map of the Buckskin Gulch SW quadrangle, Kane County, Utah, and Coconino County, Arizona: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-244, scale 1:24,000.
Hackman, R.J., 1957c, Photogeologic map of the Buckskin Gulch NE quadrangle, Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-259, scale 1:24,000.
Hackman, R.J., 1957d, Photogeologic map of the Johnson NE quadrangle, Kane County, Utah: U. S. Geological Survey Miscellaneous Geologic Investigation Map I-245, scale 1:24,000.
Hamilton, W.L., 1978, Geologic map of Zion National Park, Utah: Zion Natural History Association, Springdale, Utah.
Harris, A.D., and Ryan, G.S., 1984, Mineral Investigation of the Starvation Point Wilderness Study Area, Mohave County, Arizona, and Washington County, Utah: U.S. Bureau of Mines Open-File Report MLA 27-84.
Haynes, S.A., 1983, Geomorphic development of Virgin River near Hurricane, Utah: Salt Lake City, University of Utah, M.S. thesis, scale 1:31,680.
Heyl, A.V., 1978, Silver Reef, Utah, ores and the possibilities of unoxidized ores at greater depths, <u>in</u> Shawe, D. R., and Rowley, P. D., eds., Guidebook to mineral deposits of southwestern Utah: Utah Geological Association Publication 7, p. 65.
Hintze, L.F., 1963, Geologic map of southwestern Utah: Salt Lake City, Utah Geological and Mineralogical Survey, one sheet, scale 1:250,000.
Hintze, L.F., 1980, Geologic map of Utah: Utah Geological and Mineral Survey Special Map, two sheets, scale 1:500,000.
Hintze, L.F., 1985a, Geologic map of the Shivwits and West Mountain Peak quadrangles, Washington County, Utah: U.S. Geological Survey Open-File Report 85-119, scale 1:24,000.
Hintze, L.F., 1985b, Geologic map of the Castle Cliff and Jarvis Peak quadrangles, Washington County, Utah: U.S. Geological Survey Open-File Report 85-120, scale 1:24,000.

Hintze, L.F., 1986, Stratigraphy and structure of the Beaver Dam Mountains, southwestern Utah, in Griffen, D.T., and Phillips, W.R., eds., Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 1-36.

Houser, B.B., Jones, J.L., Kilburn, J.E., Blank, H.R., Jr., Wood, R.H., and Cook, K.L., 1988a, Mineral resources of the Cottonwood Canyon Wilderness Study Area, Washington County, Utah: U. S. Geological Survey Bulletin 1746, Chapter C, 14 p.

Houser, B.B., Jones, J.L., Kilburn, J.E., Blank, H.R., Jr., Wood, R.H., and Cook, K.L., 1988b, Mineral resources of the Red Mountain Wilderness Study Area, Washington County, Utah: U.S. Geological Survey Bulletin 1746, Chapter D, 13 p.

Huntington, Ellsworth, and Goldthwait, 1904, Hurricane fault in the Toquerville district: Harvard College Museum of Comparative Zoology Bulletin, v. 43, scale 1:93,750.

IAPG (Intermountain Association Petroleum Geologists), 1952, Cedar City, Utah, to Las Vegas, Nevada: Utah Geological and Mineralogical Survey Guidebook 7.

Iivari, T.A., 1979, Cenozoic geologic evaluation of the east-central Markagunt Plateau, Utah: Kent State University, M.S. thesis.

James, L.P., 1987, Geological and geochemical character of Cenozoic-age gold and silver deposits in the northeasternmost Great Basin, a review, in Kopp, R.S., and Cohenour, R.E., eds., Cenozoic geology of western Utah, sites for precious metal and hydrocarbon accumulations: Utah Geological Association Publication 16, p. 437-450.

James, L.P., and Newman, E.W., 1986, Subsurface character of mineralization at Silver Reef, Utah, and a possible model for ore genesis, in Griffen, D.T., and Phillips, W.R., eds., Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Associated Publication 15 p. 149-158.

Judy, J.R., 1974, Cenozoic stratigraphic and structural evolution of the west-central Markagunt Plateau, Utah: Kent State University, M.S. thesis, scale 1:63,360.

Keith, J.D., 1980, Miocene porphyry intrusions, volcanism and mineralization, southwestern Utah and eastern Nevada: Madison, University of Wisconsin, unpublished M.S. thesis, 166 p.

Keith, J.D., Shanks, W.C., III, and Archibald, D.A., 1986, Volcanic and intrusive history of the Pine Grove porphyry molybdenum system, southwestern Utah: Economic Geology, v. 81, no. 3, p. 553-577.

Kemp, J.F., 1909, The iron ores of the Iron Springs district in southern Utah: Economic Geology, v. 4, p. 701-782.

Kerns, R.L., Jr., 1986, Review of the petroleum activity of the Utah portion of the Great Basin, in Kopp, R.S., and Cohenour, R. E., eds., Cenozoic geology of western Utah, sites for precious metal and hydrocarbon accumulations: Utah Geological Association Publication 16, p. 487-526.

Kinkel, A.R., Jr., and Granger, A.E., 1951, Preliminary report on the Apex and Paymaster mines, Washington County, Utah: U.S. Geological Survey Open-File report.

Klauk, R.H., and Gourley, Chad, 1983, Geothermal assessment of a portion of the Escalante Valley, Utah: Utah Geological and Mineral Survey Special Study 63, 57 p.

Knight, R.V., 1985, Geologic thesis map index of Utah: Utah Geological and Mineral Survey Map 86.

Lawton, T.F., 1987, Stratigraphic evidence for onset and timing of thrust events in the Sevier orogenic belt, central Utah [abs.]: Geological Society of America, Abstracts with Programs, v. 19, no. 7, p. 742.
Lee, W.T., 1907, The Iron County coal field, Utah: U.S. Geological Survey Bulletin 316E, p. 359-375.
Leith, C.K, 1910, Iron ores of the Iron Springs, Utah, (reply): Economic Geology, v. 5, p. 188-192.
Leith, C.K., and Harder, E.C., 1908, The iron ores of the Iron Springs district, southern Utah: U.S. Geological Survey Bulletin 338, 102 p.
Lewis, A.E., 1958, Geology and mineralization connected with the intrusion of a quartz monzonite porphyry, Iron Mountain, Iron Springs district, Utah: Pasadena, California Institute of Technology, unpublished Ph.D. dissertation, 75 p., scale 1:9,900.
Limbach, F.W., and Pansze, A.J., 1987, Volcanic geology and mineralization, western Bull Valley Mountains, Utah, in Kopp, R.S., and Cohenour, R.E., Cenozoic geology of western Utah--sites for precious metal and hydrocarbon accumulations: Utah Geological Association Publication 16, p. 471-477.
Lindsey, D.A., Glanzman, R.K., and Naeser, C.W., 1981, Upper Oligocene evaporites in basin fill of Sevier Desert region, western Utah: American Association of Petroleum Geologists Bulletin, v. 65, no. 2, p. 251-260.
Lovejoy, E.M.P., 1964, The Hurricane fault zone and the Cedar Pocket-Shebit-Gunlock fault complex, southwestern Utah and northwestern Arizona: Tucson, University of Arizona, Ph.D. dissertation, scale 1:125,000.
Lundin, E.R., 1987, Thrusting of the Claron Formation, the Bryce Canyon region, Utah: Tucson, University of Arizona, unpublished M.S. thesis, 51 p.
Mabey, D.R., and Budding, K.E., 1987, High-temperature geothermal resources of Utah: Utah Geological and Mineral Survey Bulletin 123, 64 p.
Mackin, J.H., 1947, Some structural features of the intrusions in the Iron Springs district: Utah Geological Society Guidebook to the Geology of Utah, no. 2, 62 p.
Mackin, J.H., 1952a, Hematite veinlets in an ignimbrite in the Iron Springs district, southwestern Utah [abs.]: Geological Society of America Bulletin, v. 63, p. 1337-1338.
Mackin, J.H., 1952b, Correspondence between composition of replacement iron ore and limestone in the Iron Springs district, southwestern Utah [abs.]: Economic Geology, v. 47, p. 124.
Mackin, J.H., 1954, Geology and iron ore deposits of the Granite Mountain area, Iron County, Utah: U.S. Geological Survey, Mineral Investigations Field Studies Map MF-14, scale 1:12,000'.
Mackin, J.H., 1955, Exploration for replacement deposits of iron ore in the Iron Springs district Utah [abs.]: American Institute of Mining Engineers, Annual Meeting, Abstracts, Mineralogy, Geology, and Geophysics Division, p. 38-39.
Mackin, J.H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: American Journal of Science, v. 258, p. 81-131.
Mackin, J.H., 1968, Iron ore deposits of the Iron Springs district, southwestern Utah, in Ridge, J. D., ed., Ore deposits of the United States, 1933-1967 (Graton-Sales volume), v. 2: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, p. 992-1019.
Mackin, J.H., and Ingerson, E., 1960, An hypothesis for the origin of ore-forming fluid, in Short Papers in the Geological Sciences: U.S. Geological Survey Professional Paper 400-B, p. B1-B2.

Mackin, J.H., and Rowley, P.D., 1975, Geologic map of the Avon SE quadrangle, Iron County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1294, scale 1:24,000.
Mackin, J.H., and Rowley, P.D., 1976a, Geologic map of the Three Peaks quadrangle, Iron County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1297, scale 1:24,000.
Mackin, J.H., Nelson, W.H., and Rowley, P.D., 1976b, Geologic map of the Cedar City NW quadrangle, Iron County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1295, scale 1:24,000.
Marshall, C.H., 1956a, Photogeologic map of the Virgin NW quadrangle, Washington County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-149, scale 1:24,000.
Marshall, C.H., 1956b, Photogeologic map of the Virgin NE quadrangle, Washington County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-161, scale 1:24,000.
Marshall, C.H., 1956c, Photogeologic map of the Virgin SW quadrangle, Washington County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-147, scale 1:24,000.
McCarthy, W.R., 1959, Stratigraphy and structure of the Gunlock-Motoqua area, Washington County, Utah: Seattle, University of Washington, M.S. thesis, scale 1:31,680.
McHugh, J.B., Miller, W.R., and Ficklin, W.H., 1984, Maps showing distribution of pH, copper, zinc, uranium, molybdenum, arsenic, and sulfate in water, Richfield 1° X 2° quadrangle, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1246-L.
McIntosh, W.L., and Eister, M.F., 1979 (reprinted 1983), Geologic map index of Utah: U.S. Geological Survey.
Minard, J.P., 1957, Photogeologic map of the Buckskin Gulch SE quadrangle, Kane County, Utah, and Coconino County, Arizona: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-260, scale 1:24,000.
Montgomery, J.R., 1973, A regional gravity survey of western Utah: University of Utah, Ph.D. thesis, 132 p.
Morris S.K., 1980a, The geology and ore deposits of Mineral Mountain, Washington County, Utah: Provo, Brigham Young University, M.S. thesis, scale 1:12,000 (summarized in BYU Geology Studies, v. 27).
Morris, S.K., 1980b, Geology and ore deposits of Mineral Mountain, Washington County, Utah: Brigham Young University Geology Studies, v. 27, pt. 2, p. 85-102.
Nielson, R.L., 1976, The geomorphic evolution of the Crater Hill volcanic field of Zion National Park: Provo, Brigham Young University, M.S. thesis, (also BYU Geology Studies, v. 24, pt. 1, p. 55-70), scale 1:47,000.
Nielson, R.L., and Johnson, J.L., 1979, the Timpoweap Member of the Moenkopi Formation, Timpoweap Canyon, Utah: Utah Geology, v. 6, no. 1, p. 17-28.
Oak Ridge Gaseous Diffusion Plant, 1982, Hydrogeochemical and stream sediment reconnaissance basic data for Cedar City Quadrangle, Utah: U.S. Department of Energy Grand Junction Office Report Number GJBX-53(82).
Orkild, P.P., 1957, Photogeologic map of the Rainbow Point SW quadrangle, Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-257, scale 1:24,000.
Pe, Win, and Cook, K.L., 1980, Gravity survey of the Escalante Desert and vicinity, Iron and Washington Counties, Utah: Earth Science Laboratory/University of Utah Research Institute Report No. DOE/ID/12079-14, 169 p.

Perry, L.I., 1976, Gold Springs mining district, Iron County, Utah: Utah Geology, v. 3, no. 1, p. 23-57, spring, 1976.
Petersen, E.U., and Rasmussen, J.D., 1988, The Ga, Ge, Cu, Pb, Ag, and U deposits of southwestern Utah and the Arizona strip: Road Log, October 27-October 29, 1988, Field trip associated with the 1988 Annual Meeting of the Geological Society of America and Society of Economic Geologists: Geological Society of America Field Trip Guide, October 31-November 3, 1988, 43 p.
Peterson, E.U., Bowling, D.L., Mahin, R.A., and Bowman, J.R., 1988, Geology, mineralogy, and genesis of the Apex Ga-Ge deposit, Tutsagubet district, Utah, in Torma, A.E., and Gundiler, I.H., eds., Precious and Rare Metal Technologies, Amsterdam, Elsevier Publishing Co., p. 511-530.
Pillmore, C.L., 1956a, Photogeologic map of the Orderville Canyon NW quadrangle, Kane and Washington Counties, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-188.
Pillmore, C.L., 1956b, Photogeologic map of the Virgin SE quadrangle, Washington County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-179, scale 1:24,000.
Pillmore, C.L., 1956c, Photogeologic map of the Springdale SW quadrangle, Kane and Washington Counties, Utah, and Mohave County, Arizona: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-132, scale 1:24,000.
Pillmore, C.L., 1956d, Photogeologic map of the Springdale NE quadrangle, Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-148, scale 1:24,000.
Pillmore, C.L., 1956e, Photogeologic map of the Springdale SE quadrangle, Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-131, scale 1:24,000.
Pillmore, C.L., 1956f, Photogeologic map of the Kanab SW quadrangle, Kane County, Utah, and Mohave County, Arizona: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-138, scale 1:24,000.
Podwysocki, M.H., Segal, D.B., and Abrams, M.J., 1983, Use of multispectral scanner images for assessment of hydrothermal alteration in the Marysvale, Utah, mining area: Economic Geology, v. 78, p. 675-687.
Poehlmann, E.J., and King, E.N., 1953, Report of wagon drilling for uranium in the Silver Reef (Harrisburg) District, Washington County, Utah: U.S. Atomic Energy Comm. RME-2004, pt. 1.
Pomeroy, J.S., 1957, Photogeologic map of the Rainbow Point SE quadrangle, Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-258, scale 1:24,000.
Pomeroy, J.S., 1958, Photogeologic map of the Johnson NW quadrangle, Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-267, scale 1:24,000.
Proctor, P.D., 1949, Geology of the Harrisburg (Silver Reef) mining district, Washington County, Utah: Indiana Univ. Ph.D. dissertation, (also Utah Geological and Mineral Survey Bulletin 44), scale 1:31,680.
Proctor, P.D., 1950, Reconnaissance examination of copper-uranium deposits west of the Colorado River: U.S. Atomic Energy Commission RMO-659.
Proctor, P.D., 1953, Geology of the Silver Reef (Harrisburg) mining district, Washington County, Utah: Utah Geological and Mineral Survey Bulletin 44, 169 p.

Proctor, P.D., and Brimhall, W.H., 1986, Silver Reef mining district, revisited, Washington County, Utah, in Griffen, D.T., and Phillips, W.R., eds., Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 159-177.
Proctor, P.D., and Brimhall, W.H., 1987, Silver in the Springdale (Silver Reef) Sandstone, Jurassic Moenave Formation, Utah, N. Arizona, and S. Nevada [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 6, p. 441.
Purcell, F.A., Jr., 1961, The geology of the western half of the Hurricane quadrangle, Utah: University of Southern California, M.A. thesis, scale 1:48,000.
Ratte, C.A., 1963, Rock alteration and ore genesis in the Iron Springs-Pinto mining district, Iron County, Utah: Tucson, University of Arizona, unpublished Ph.D. dissertation, 222 p.
Reber, S.J., 1951, Stratigraphy and structure of the south-central and northern Beaver Dam Mountains, Washington County, Utah: Provo, Brigham Young University, M.S. thesis, scale 1:35,200.
Robison, R.A., 1963, A reconnaissance survey of the coal resources of southwestern Utah: Utah Geological and Mineral Survey Special Studies 3, 28 p.
Robison, R.A., 1964, Progress Report on the coal resources of southern Utah - 1963: Utah Geological and Mineral Survey Special Studies 7, 34 p.
Robison, R.A., 1966, Geology and coal resources of the Tropic area, Garfield County, Utah: Utah Geological and Mineral Survey Special Studies 18, 47 p.
Rowan, L.D., Wetlaufer, P.H., Goetz, A.F.H., Billingsley, F.C., and Stewart, J.H., 1974, Discrimination of rock types and detection of hydrothermally-altered areas in south central Nevada by the use of computer-enhanced ERTS images: U.S. Geological Survey Professional Paper 883, 35 p.
Rowley, P.D., 1968, Geology of the southern Sevier Plateau, Utah: Austin, University of Texas, Ph.D. dissertation, scale 1:63,360.
Rowley, P.D., 1975, Geologic map of the Enoch NE quadrangle, Iron County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1301, scale 1:24,000.
Rowley, P.D., 1976, Geologic map of the Enoch NW quadrangle, Iron County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1302, scale 1:24,000.
Rowley, P.D., Anderson, J.J., and Williams, P.L., 1975, A summary of Tertiary volcanic stratigraphy of the southwestern High Plateaus and the adjacent Great Basin, Utah: U.S. Geological Survey Bulletin 1405-B, 20 p.
Rowley, P.D., and Threet, R.L., 1976, Geologic map of the Enoch quadrangle, Iron County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1296, scale 1:24,000.
Rowley, P.D., Anderson, J.J., Williams, P.L., and Fleck, R.J., 1978, Age of structural differentiation between the Colorado Plateaus and Basin and Range provinces in southwestern Utah: Geology, v. 6, p. 51-55.
Rowley, P.D., and Barker, D.S., 1978, Geology of the Iron Springs mining district, Utah, in Shawe, D.R., and Rowley, P.D., eds., International Association on Genesis of Ore Deposits, Guidebook to the mineral deposits of southwestern Utah: Utah Geological Association Publication 7, p. 49-58.

Rowley, P.D., Lipman, P.W., Mehnert, H.H., Lindsey, D.A., and Anderson, J.J., 1978, Blue Ribbon lineament,an east-trending structural zone within the Pioche mineral belt of southwestern Utah and eastern Nevada: U.S. Geological Survey Journal of Research, v. 6, no. 2, p. 175-192.

Rowley, P.D., Steven, T.A., Anderson, J.J., and Cunningham, C.G., 1979, Cenozoic stratigraphic and structural framework of southwestern Utah: U.S. Geological Survey Professional Paper 1149, 22 p.

Rowley, P.D., Steven, T.A., and Mehnert, H.H., 1981, Origin and structural implications of upper Miocene rhyolites in Kingston Canyon, Piute County, Utah: Geological Society of America Bulletin, Part I, v. 92, p. 590-602.

Rush, F.E., 1983, Reconnaissance of the hydrothermal resources of Utah: U.S. Geological Survey Professional Paper 1044-H, p. H1-H49.

Sable, E.G., and Anderson, J.J., 1985, Tertiary tectonic slide megabreccias, Markagunt Plateau, southwestern Utah [abs.]: Geological Society of America Abst. with Programs, v. 17, no. 4, p. 263.

Sargent, K.A., and Philpott, B.C., 1985, Geologic map of the Johnson quadrangle, Kane County, Utah, Coconino County, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1602.

Sargent, K.A., and Philpott, B.C., 1987, Geologic map of the Kanab quadrangle, Kane County, Utah, Mohave and Coconino Counties, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1603.

Sauck, W.A., and Sumner, J.S., 1970, Total intensity aeromagnetic map of Nevada: University of Arizona, scale 1:1,000,000.

Shawe, D.R., and Stewart, J.H., 1976, Ore deposits as related to tectonics and magmatism, Nevada and Utah: American Institute of Mining and Metallurgical Engineers Transactions, v. 260, p. 225-252.

Shubat, M.A., and McIntosh, W.S., 1988, Geology and mineral potential of the Antelope Range mining district, Iron County, Utah: Utah Geological and Mineral Survey Bulletin 125, 26 p.

Shubat, M.A., and Siders, M.A., 1986, Strike-slip and normal faulting in the Silver Peak quadrangle, Iron County, Utah, related to extensional tectonics--a shear zone in southwestern Utah [abs.]: Geological Society of America Abst. with Programs (Rocky Mountain section), v. 18, no. 5, p. 413.

Shubat, M.A., and Siders, M.A., 1988, Geologic map of the Silver Peak quadrangle, Iron County, Utah: Utah Geological and Mineral Survey Map 108, 13 p., two sheets, scale 1:24,000.

Shuey, R.T., Schellinger, D.K., and Johnson, E.H., 1973, Aeromagnetics and the transition between the Colorado Plateau and Basin-Range provinces: Geology, v. 1, no. 3, p. 107-110.

Siders, M.A., 1985a, Geologic map of the Pinon Point quadrangle, Iron County, Utah: Utah Geological and Mineral Survey Map 84, 12 p., two sheets, scale 1:24,000.

Siders, M.A., 1985b, Geologic map of the Beryl Junction quadrangle, Iron County, Utah: Utah Geological and Mineral Survey Map 85, 11 p., two sheets, scale 1:24,000.

Siders, M.A., 1986, Geologic map of the Mount Escalante quadrangle, Iron County, Utah: Utah Geological and Mineral Survey Open-File Report 93, scale 1:24,000.

Siders, M.A., and Shubat, M.A., 1986, Stratigraphy and structure of the northern Bull Valley Mountains and Antelope Range, Iron County, Utah, in Griffen, D.T., and Phillips, W.R., eds., Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 87-102.

Smith, R.L., and Sbar, M.C., 1974, Contemporary tectonics and seismicity of the western United States with emphasis on the Intermountain Seismic belt: Geological Society of America Bulletin, v. 85, p. 1205-1218.

Steven, T.A., 1989, Mosaic faulting as a guide to mineral exploration in the Richfield 1° X 2° quadrangle, western Utah: Program, Fifth Annual V.E. McKelvey Forum on Mineral and Energy Resources, USGS Mineral Resources Research, January 24-26, 1989, Reno, Nevada.

Steven, T.A., Cunningham, C.G., Naeser, C.W., and Mehnert, H.H., 1979, Revised stratigraphy and radiometric ages of volcanic rocks and mineral deposits in the Marysvale area, west-central Utah: U.S. Geological Survey Bulletin 1469, 40 p.

Steven, T.A., and Morris, H.T., 1984, Mineral resource potential of the Richfield 1° X 2° quadrangle, west-central Utah: U.S. Geological Survey Open-file Report 84-521, 53 p.

Steven, T.A., and Morris, H.T., 1987, Summary mineral resource appraisal of the Richfield 1° X 2° quadrangle, west-central Utah: U.S. Geological Survey Circular 916, 24 p.

Stewart, J.H., Moore, W.J., and Zietz, Isidore, 1977, East-west patterns of Cenozoic igneous rocks, aeromagnetic anomalies, and mineral deposits, Nevada and Utah: Geological Society of America Bulletin, v. 88, no. 1, p. 67-77.

Stouffer, S.G., 1964, Landslides in the Coal Hill area, Kane County, Utah: University of Utah, M.S. thesis, scale 1:6,000.

Stugard, Frederick, Jr., 1951, Uranium resources in the Silver Reef (Harrisburg) district, Washington County, Utah: U.S. Geological Survey Open-File report.

Thomas, H.E., 1947, Geology of Cedar City and Parowan Valleys, Iron County, Utah: University of Chicago, Ph.D. dissertation, (also U.S. Geological Survey Water Supply Paper 993), scale 1:63,360.

Thomson, K.C., and Perry, I.I., 1975, Reconnaissance study of the Stateline mining district, Iron County, Utah: Utah Geology, v. 2, no. 1, p. 27-47.

Threet, R.L., 1952, Geology of the Red Hills Area, Iron County, Utah: Seattle, University of Washington, Ph.D. dissertation, scale 1:62,000.

Threet, R.L., 1958, Crater Hill lava flow, Zion National Park, Utah: Geological Society of America Bulletin, v. 69, no. 8.

Tobey, E.F., 1976, Geology of the Bull Valley intrusive-extrusive complex and genesis of the associated iron deposits: Eugene, University of Oregon, unpublished Ph.D. dissertation, 244 p., scale 1:1,200.

U.S. Geological Survey, 1972, Aeromagnetic map of parts of the Richfield and Cedar City 1° X 2° quadrangle, Utah: U.S. Geological Survey Open File Report 72, scale 1:250,000.

Utah Geological and Mineral Survey, compilers, 1983, Energy resources of Utah: Utah Geological and Mineral Survey Map 68.

Van Kooten, G.K., 1988, Structure and hydrocarbon potential beneath the Iron Springs laccolith, southwestern Utah: Geological Society of America Bulletin, v. 100, no. 10, p. 1533-1540.

Van Loenen, R.E., Sable, E.G., Blank, H.R., Jr., and Turner, R.L., 1988a, Mineral resources of the Canaan Mountain and The Watchman Wilderness Study Areas, Washington and Kane Counties, Utah: U.S. Geological Survey Bulletin 1746A, 26 p.

Van Loenen, R.E., Sable, E.G., Blank, H.R., Jr., Barton, H.N., and Cook, K.L., 1988b, Mineral resources of the Parunuweap Canyon Wilderness Study Area, Kane County, Utah: U.S. Geological Survey Bulletin 1746B, 22 p.

Van Loenen, R.E., Sable, E.G., Blank, H.R., Jr., Barton, H.N., and Briggs, P.H., Zelten, J.E., and Cook, K.L., 1989a, Mineral resources of eight wilderness study areas bordering Zion National Park, Washington and Kane Counties, Utah: U.S. Geological Survey Bulletin 1746E.

Van Loenen, R.E., Blank, H.R., Jr., Sable, E.G., Lee, G., Zelten, J.E., and Cook K.L., 1989b, Mineral resources of the Spring Creek Canyon Wilderness Study Area, Iron County, Utah: U.S. Geological Survey Bulletin 1746F.

Verbeek, E.R., Grout, M.A., Van Gosen, B.S., and Sutphin, H.B., 1987, Structure of the Apex mines, southwestern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 5, p. 340.

Walenga, K., 1988a, Steel production quickly doubles projections, Boss credits market breaks, high esprit de corps and good products: Pay Dirt (April), no. 103, p. 6A-7A.

Walenga, K., 1988b, Hecla makes offer to take over troubled St. George Mining: Pay Dirt (July), p. 3A and 17A.

Webb, Loren, 1988, Tenneco hopes to break ground by June: St. George Spectrum, Tuesday, March 29, 1988.

Wells, F.G., 1938, The origin of the iron ore deposits in the Bull Valley and Iron Springs districts, Utah: Economic Geology, v. 33, p. 477-507.

Wenrich, K.J., 1985, Mineralization of breccia pipes in northern Arizona: Economic Geology, v. 80, p. 1722-1735.

Wenrich, K.J., Verbeek, E.R., Sutphin, H.B., Van Gosen, B.S., and Modreski, P.J., 1987, The Apex Mine, Utah--a Colorado Plateau-type solution collapse breccia pipe: U.S. Geological Survey Circular 995, p. 73-74.

Wenrich, K.J., Sutphin, H.B., and Van Gosen, B.S., 1988, Distribution of Redwall Limestone-hosted breccia pipes across NW Arizona and the geochemistry and mineralogy of their ore bodies [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 7, p. A139.

Wernicke, Brian, and Axen, G.J., 1988, On the role of isostasy in the evolution of normal fault systems: Geology, v. 16, no. 9, p. 848-851.

Wernicke, Brian, Axen, G.J., and Snow, J.K., 1988, Basin and Range extensional tectonics at the latitude of Las Vegas, Nevada: Geological Society of America Bulletin, v. 100, no. 11, p. 1738-1757.

Whitley, W.W., 1978, Anderson Junction oil field, in Oil and gas fields of the Four Corners area, v. 2, Four Corners Geological Society.

Wiley, M.A., 1963, Stratigraphy and structure of the Jackson Mountain-Tobin Wash area, southwest Utah: Austin, University of Texas, unpublished M.S. thesis, 104 p., scale 1:24,000.

Willden, Ronald, and Adair, D.H., 1986, Gold deposits at Goldstrike, Utah, in Griffen, D.T., and Phillips, W.R., eds., Thrusting and extensional structures and mineralization in the Beaver Dam Mountains, southwestern Utah: Utah Geological Association Publication 15, p. 137-148.

Willis, J.P., Jr., 1961, Geology of the eastern portion of the Hurricane quadrangle, Utah: University of Southern California, M.A. thesis, scale 1:48,000.

Wilson. M.T., and Thomas, H.E., 1964, Hydrology and hydrogeology of Navajo Lake, Kane County, Utah: U.S. Geological Survey Professional Paper 417-C.

Young, W.E., 1947, Iron deposits, Iron County, Utah: U.S. Bureau of Mines, Report of Investigation 4076, 102p.

Zietz, Isidore, Shuey, R.T., and Kirby, J.R., Jr., 1976, Aeromagnetic map of Utah: U.S. Geological Survey Investigative Map GP-907, scale 1:1,000,000.

Zietz, Isidore, Gilbert, F.P., and Kirby, J.R., Jr., 1978, Aeromagnetic map of Nevada--color coded intensities: U.S. Geological Survey Investigative Map GP-922, scale 1:1,000,000.
Zimbeck, D.A., 1965, Gravity survey along northward-trending profiles across the boundary between the Basin and Range province and Colorado Plateau: University of Utah, M.S. thesis, 111 p.

Section 10 APPENDICES

Appendix 1.--Outline of sampling and analytical methods used for NURE samples collected in the Cedar City quadrangle.

Details on NURE sample collection methods are found in Cook and Fay (1982) and those on analytical methods are found in Grimes (1984). A listing of the NURE analytical data for the Cedar City quadrangle is found in a publication of the Oak Ridge Gaseous Diffusion Plant (1982).

Stream-sediment samples were collected either by or under the direction of Savannah River Laboratories personnel. Sieved sediments collected include two size fractions: minus-100-mesh samples and minus-16- to plus-100-mesh samples. At each site, at least five sub-samples were composited from the active stream bed, yielding a 400 g sample.

Stream sediments were analyzed at the Oak Ridge Gaseous Diffusion Plant. For the minus-100-mesh samples, a 0.25 g aliquot was dissolved in nitric and hydrofluoric acids and analyzed by inductively-coupled plasma atomic emission spectrography (ICP-AES) for Ag, Al, B, Ba, Be, Ca, Ce, Co, Cr, Cu, Fe, Hf, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Sc, Sr, Th, Ti, V, Y, Zn, and Zr. For a few samples, another 2 g aliquot was analyzed for U, Dy, Eu, Lu, Sm, and Yb by delayed neutron counting neutron activation (NAA).

No information was found detailing sampling or analytical procedures for the minus-16-mesh to plus-100-mesh stream sediment, talus, hot springs sinter, or minus-100-mesh soil sample media. Presumably the same analytical procedures used for minus-100-mesh stream sediment samples were used for these sample media.

Water samples were collected from springs, wells, and streams in the Cedar City quadrangle. Information on exactly what was sampled, how in was prepared, and how it was analyzed was not found. Presumably these samples were collected and prepared using methodology described for NURE "water samples" in the regional report by the Oak Ridge Gaseous Diffusion Plant (1984). Savannah River lab personnel collected the samples and analyses were performed at both the Savannah River and Oak Ridge labs. Samples were filtered in the field through 0.8 micron filters and placed in 2-liter plastic bottles. No mention of sample acidification was found. The samples were apparently split in the lab for analysis. Samples analyzed at Savannah River were mixed with an ion exchange resin and the resin was analyzed by NAA for Al, Br, Cl, Dy, F, Mg, Mn, Na, U, and V. Helium was apparently analyzed from the same sample by mass spec (Averett, 1984). Samples analyzed at the Oak Ridge labs were analyzed directly by ICP-AES for Ag, Al, B, Ba, Be, Ca, Ce, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Sc, Si, Sr, Ti, V, Y, Zn, and Zr. The same samples were analyzed at Oak Ridge for As and Se by flameless atomic absorption. The same group of samples analyzed at Oak Ridge were also analyzed for Nb and Th, although no information was found concerning the analytical method used.

Appendix 2.--Basic statistics for 90 NURE minus-100-mesh stream-sediment samples collected in the Cedar City quadrangle. Values are in parts per million unless noted otherwise. [B, not analyzed; L, analyzed but below determination limit; DL, reported lower determination limit]

	Univariate Statistics							
Element	Minimum	Maximum	Mean***	Standard Deviation	Valid	B	L	DL*
Ag	2.0	2.0	---	---	2	3	86	2
Al %	.61	7.7	3.6	1.7	90	0	0	.05
B	10	100	---	13	59	2	29	10
Ba	110	820	390	140	88	2	0	2
Be	1.0	3.0	1.0	.35	76	2	12	1
Ca %	.20	12	3.9	3.0	88	2	0	.05
Ce	10	490	45	53	89	0	1	10
Co	4.0	19	---	4.0	53	2	35	4
Cr	6.0	82	28	16	88	2	0	3
Cu	4.0	49	12	7.4	88	2	0	2
Dy	2.4	2.4	---	---	1	88	1	2
Eu	---	---	---	---	0	88	2	3.7
Fe %	.32	9.0	2.0	1.6	90	0	0	.05
Hf	4.0	21	---	5.5	8	0	82	15
K %	.15	2.1	1.0	.42	88	2	0	**
La	5.0	260	22	28	90	0	0	2
Li	9.0	53	22	7.9	88	2	0	1
Lu	.30	.30	---	---	2	88	0	.3
Mg %	.15	4.8	1.2	.89	88	2	0	.05
Mn	69	1400	400	270	90	0	0	4
Mo	5.0	5.0	---	---	1	2	87	4
Na %	.05	1.5	.45	.45	79	0	11	.05
Nb	4.0	100	---	12	67	2	21	4
Ni	2.0	40	12	6.4	87	2	1	2
P	130	1300	450	230	88	2	0	5
Pb	10	37	---	6.9	44	2	44	10
Sc	1.0	19	4.7	3.2	90	0	0	1
Sm	2.0	4.0	---	1.4	2	88	0	.5
Sr	34	590	170	130	88	2	0	**
Th	2.0	46	8.4	6.4	72	0	18	2
Ti	490	9900	2200	1800	88	2	0	10
U	2.0	2.7	---	.49	2	88	0	.02
V	12	280	60	52	90	0	0	5
Y	4.0	140	12	15	88	2	0	2
Yb	1.3	1.6	---	.21	2	88	0	.5
Zn	12	110	46	24	88	2	0	2
Zr	17	110	49	19	88	2	0	2.4

* Lower determination limits listed represent optimum conditions; limits may vary as a function of composition of sample.
** No lower determination limit reported.
*** Means are calculated on unqualified data only and are not reported for elements having 20% or more qualified values ("L").

Appendix 3.--Basic statistics for 97 NURE surface stream-water samples collected in the Cedar City quadrangle. Values are in parts per billion, except for alkalinity (milliequivalents per liter) and pH. [B, not analyzed; L, analyzed but below determination limit; DL, reported lower determination limit]

	Univariate Statistics							
Element	Minimum	Maximum	Mean**	Standard Deviation	Valid	B	L	DL*
pH	7.2	9.1	8.2	.35	97	0	0	---
Alk	.56	11	4.1	1.8	97	0	0	---
Ag	2.0	9.0	---	1.6	31	2	64	2
Al	14	2200	100	230	97	0	0	10
As	1.0	12	---	2.4	37	2	58	1
B	5.0	1200	91	180	95	2	0	8
Ba	3.0	600	110	120	95	2	0	2
Be	---	---	---	---	0	2	95	1
Br	11	1100	130	230	32	65	0	.3
Ca	12000	470000	73000	69000	95	2	0	3
Ce	31	57	---	12	4	2	91	30
Cl	1600	130000	13000	23000	97	0	0	11
Co	2.0	8.0	---	1.8	39	2	56	2
Cr	4.0	12	---	2.6	10	2	85	4
Cu	2.0	260	7.5	29	79	2	16	2
Dy	.05	.05	---	---	1	0	96	.02
F	18	670	110	120	83	14	0	2
Fe	10	2700	87	300	87	0	8	10
K	1000	21000	2900	3400	89	6	0	.4
Li	2.0	480	26	58	92	0	3	2
Mg	2000	330000	39000	45000	95	0	0	.1
Mn	2.0	260	14	32	90	0	5	2
Mo	4.0	16	---	3.0	24	0	71	4
Na	1000	630000	31000	84000	95	0	0	2
Nb	4.0	27	---	5.3	38	0	57	4
Ni	4.0	18	---	3.7	35	0	60	4
P	42	190	---	39	18	0	77	40
Sc	1.0	1.0	---	---	15	0	80	1
Se	1.0	2.0	1.2	.40	11	84	0	.2
Si	2000	31000	9400	7200	95	0	0	3.4
Sr	38	6900	590	1200	95	0	0	14
Th	5.0	24	---	7.1	7	0	88	5
Ti	2.0	20	---	2.8	60	0	35	2
U	.07	40	2.3	5.3	87	0	10	.002
V	.20	34	3.5	5.8	77	0	20	.1
Y	1.0	4.0	---	.60	27	0	68	1
Zn	4.0	370	20	45	78	0	17	4
Zr	2.0	9.0	---	1.8	35	0	60	2

* Lower determination limits listed represent optimum conditions; limits may vary as a function of composition of sample.

** Means are calculated on unqualified data only and are not reported for elements having 20% or more qualified values ("L").

Appendix 4--Factor analysis interpretation for NURE geochemical factors not likely related to mineral deposits.

Factor 1 for NURE stream sediments and soils contains groups of elements unlikely to be found together in nature (table 8). Factor 1 in coarse stream sediments contains both a mafic group (Cr, Ni, Co, V, Sc, Fe, Ti, Zn, Mn, Cu) and a felsic group (Ce, Y, La, Zr, Nb, P) of elements. Normally, these two groups of elements would be expected to behave antithetically. The plot of scores for this factor is random. Factor 1 in soils also contains a mafic assemblage (Ti, V, Sc, Fe, Mn), although common mafic elements Cr and Ni curiously do not occur in this assemblage. Like the stream sediments, factor 1 in soils contains a felsic group of elements (Ce, Y, La, Zr, Na, P). All of the soils with high factor 1 scores plot in an area of homogenous Miocene intermediate calc-alkaline volcanic rocks in the northeastern part of the quadrangle.

Factor 1 for both the coarse stream sediments and soils is not interpretable. It likely represents unidentified systematic noise (analytical?, sampling?, preparation?). If this is true, then more than 50 percent of the variance in both data sets is due to noise (table 8). Nevertheless, subsequent factors for both data sets appear to have a geologic basis and are useful in this study.

High scores for coarse stream sediment factor 2 (K-Ba-Na-Al) are randomly distributed, except for three clusters of samples: (1) samples from undifferentiated Tertiary volcanic rocks north of Panguitch Lake in the northeastern part of the quadrangle, (2) samples from calc-alkaline, silicic, and undifferentiated Tertiary volcanic rocks west of Beryl Junction, and (3) a smaller group of samples from Jurassic Carmel Formation east of Orderville, in the southeastern part of the quadrangle. The K-Ba-Na-Al assemblage could reflect feldspar (K-spar?, albite?) or clays due to alteration of feldspar.

Factor 3, Ca-Mg dominant in both coarse stream sediments and soils, has two large clusters of samples: one cluster occurs exclusively in Tertiary Claron Formation, in the northeastern quarter of the quadrangle, and the second cluster occurs in a large area along the southern boundary of the quadrangle. Samples from the second cluster are commonly derived from the Triassic Moenkopi Formation. The Claron and Moenkopi Formations are locally calcareous and contain limestone interbeds. However, other abundant limestones and calcareous sedimentary rocks are not indicated by factor 3; the delineation of Claron and Moenkopi Formations suggests that these rocks are chemically unique (possibly a higher Mg content?, locally dolomitic?).

Samples with high scores for factor 4 in soils (Cr-Ni-Cu) almost invariably are located on or adjacent to Quaternary basalts. Thus, the Cr-Ni-Cu factor probably reflects mafic minerals (olivine?, pyroxene?) derived from these basalts.

Table 1.--Data summary for BLM wilderness study areas within the Cedar City quadrangle. [R, rock; SS, stream sediment; HMC, nonmagnetic heavy-mineral concentrate; RPC, raw panned concentrate containing magnetic fraction.]

Wilderness Study Area	Size	Samples Collected	Anomalous Elements	Comments	USGS Contact	Publications
Beartrap Canyon	40 acres 0.06 mi2	none	none reported	---	R. Van Loenen (CMR) Greg Lee (BGC)	Van Loenen and others, 1989a.
Canaan Mountain	32,800 acres 51.3 mi2	74 -80 mesh SS 74 HMC 45 R	Ag--3 sites Sb, As, Zn--2 sites	Ag, Sb, As, and Zn; attributed to high background levels in Chinle Formation	B. Turner (BGC)	Adrian and others, 1988. Van Loenen and others, 1988a.
Cougar Canyon	16000 acres 25 mi2	5 -80 mesh SS 5 HMC	none in SS; other data not available	only 20 % of WSA lies within Cedar City sheet; only 5 sample sites lie in Cedar City sheet; analyses pending	H. King (BGC)	Conrad and others, in preparation.
Cottonwood Canyon	9853 acres 15.4 mi2	37 -80 mesh SS 37 HMC 26 R	Ba--numerous sites Mo--1 site	barite identified in HMC	J. Jones (BGC) J. Kilburn (BGC)	Detra and others, 1988a. Houser and others, 1988a.
Deep Creek	3320 acres 5 mi2	8 -80 mesh SS 8 HMC	none	---	H. Barton (BGC)	Bullock and others, 1988. Van Loenen and others, 1989a.
Goose Cr. Canyon	89 acres 0.1 mi2	1 -80 mesh SS	none	---	Greg Lee (BGC)	Van Loenen and others, 1989a.
La Verkin Creek	440 acres 0.7 mi2	7 -80 mesh SS 7 HMC	none	---	H. Barton (BGC)	Bullock and others, 1988. Van Loenen and others, 1989a.
North Fork Virgin River	1040 acres 1.6 mi2	2 -80 mesh SS 2 HMC	none	---	H. Barton (BGC)	Bullock and others, 1988. Van Loenen and others, 1989a.
Orderville Canyon	1750 acres 2.7 mi2	7 -80 mesh SS 7 HMC	none	---	H. Barton (BGC)	Bullock and others, 1988. Van Loenen and others, 1989a.

Table 1.--(continued).

Wilderness Study Area	Size	Samples Collected	Anomalous Elements	Comments	USGS Contact	Publications
Paria-Hackberry	135822 acres 212 mi2	47 -80 mesh SS 47 HMC 15 to 20 R	unknown; work in progress	about 50 % of study area is within the Cedar City sheet; study in progress (sampling complete, analyses in progress)	B. Turner (BGC)	none--work in progress
Parunuweap Canyon	14100 acres 22 mi2	30 -80 mesh SS 30 HMC	none	---	H. Barton (BGC)	Bullock and others, 1988. Van Loenen and others, 1988b.
Red Butte	804 acres 1.3 mi2	5 -80 mesh SS 4 RPC 1 R	Ag, As, Cu, and U all at 1 rock sample site	mineralized rock sample is from Chinle Fm.	Greg Lee	Van Loenen and others, 1989a.
Red Mountain	17450 acres 27.3 mi2	38 -80 mesh SS 38 HMC 32 R	Ba--numerous sites Sr--2 sites Sn--4 sites W, As, Sb--1 site	barite identified in HMC; W-As-Sb anomaly due to Mn oxide	J. Jones (BGC) J. Kilburn (BGC)	Detra and others, 1988b. Houser and others, 1988b.
Spring Creek Canyon	4433 acres 6.9 mi2	18 -80 mesh SS 13 RPC 8 R	Ag, As, Cd, Cu, Ge, Mn, Mo, Sb, U, V, W, and Zn--in several rock samples from prospects	---	Greg Lee (BGC)	Van Loenen and others, 1989b.
Taylor Creek Canyon	35 acres 0.05 mi2	1 -80 mesh SS 1 RPC	none	---	Greg Lee (BGC)	Van Loenen and others, 1989a.
The Watchman	600 acres 0.9 mi2	---	---	studies of this WSA are combined in the Canaan Mountain WSA reports	B. Turner (BGC)	Adrian and others, 1988. Van Loenen and others, 1988a.

Additional Note:
About 5% of the Paria Canyon-Vermillion Cliffs Wilderness lies within the Cedar City 1 X 2 sheet. Bush and Lane (1982a) collected 9 stream sediments and 4 rocks within the Cedar City sheet. A scan of data for these samples revealed no anomalous values and Bush and Lane (1982a, 1982b) do not discuss geochemistry nor mineral potential for the part of the Wilderness within the Cedar City sheet.

Table 2.--NURE geochemical sample information for the Cedar City quadrangle. [TAL, talus; HTSS, hot springs sinter; SOIL, soil; STSDL, stream sediment less than 100 mesh; STSDG, stream sediment greater than 100 mesh, but less than 16 mesh; SSTWA, surface stream water; WELWA, well water; SPRWA, spring water]

Media	TAL	HTSS	SOIL	STSDL	STSDG	SSTWA	WELWA	SPRWA
Collected	2	4	1394	181	1693	97	141	244
Analyzed	1	2	721	90	836	97	141	244
Not Analyzed	1	2	673	91	857	0	0	0

Table 3.--Basic statistics for 836 NURE minus-16 mesh to plus-100 mesh stream sediment samples collected in the Cedar City quadrangle. Values are in parts per million unless noted otherwise. [B, not analyzed; L, analyzed but below determination limit; DL, reported lower determination limit]

Element	Univariate Statistics Minimum	Maximum	Mean***	Standard Deviation	Valid	B	L	DL*
Ag	2.0	15	---	3.2	37	2	797	2
Al %	.48	8.2	4.0	1.7	836	0	0	.05
B	10	125	20	10	664	2	170	10
Ba	25	1300	440	170	834	2	0	2
Be	1.0	7.0	1.3	.73	700	2	134	1
Ca %	.05	19	3.2	3.2	830	2	4	.05
Ce	10	530	48	35	812	0	24	10
Co	4.0	67	---	7.0	573	2	261	4
Cr	3.0	430	31	32	831	2	3	3
Cu	2.0	790	15	29	831	2	3	2
Dy	---	---	---	---	0	834	2	2
Eu	---	---	---	---	0	834	2	3.7
Fe %	.08	37	2.3	2.3	836	0	0	.05
Hf	15	85	---	15	56	0	780	15
K %	.03	2.9	1.3	.45	834	2	0	**
La	2.0	280	23	18	834	0	2	2
Li	1.0	76	23	9.2	834	2	0	1
Lu	.40	.50	---	.07	2	834	0	.3
Mg %	.05	4.7	1.0	.75	833	2	1	.05
Mn	16	2100	430	280	836	0	0	4
Mo	4.0	23	---	7.2	12	2	822	4
Na %	.05	7.7	5.8	5.6	811	0	25	.05
Nb	4.0	62	10	6.8	712	2	122	4
Ni	2.0	100	13	10	826	2	8	2
P	26	4800	450	310	833	2	1	5
Pb	10	1400	---	61	536	2	298	10
Sc	1.0	31	5.1	3.4	835	0	1	1
Sm	2.0	3.0	---	.71	2	834	0	.5
Sr	7.0	2000	200	170	834	2	0	**
Th	2.0	98	9.4	7.4	678	0	158	2
Ti	65	27000	2600	2400	835	1	0	10
U	2.4	2.6	---	.14	2	834	0	.02
V	5.0	1000	69	83	835	0	1	5
Y	2.0	61	11	5.6	833	2	1	2
Yb	4.1	4.1	---	---	1	834	1	.5
Zn	6.0	800	52	42	834	2	0	2
Zr	3.0	420	58	26	834	2	0	2.4

* Lower determination limits listed represent optimum conditions; limits may vary as a function of composition of sample.

** No lower determination limit reported.

*** Means are calculated on unqualified data only and are not reported for elements having 20% or more qualified values ("L").

Table 4.--Basic statistics for 721 NURE soil samples collected in the Cedar City quadrangle. All values are in parts per million unless noted otherwise. [B, not analyzed; L, analyzed but below determination limit; DL, reported lower determination limit]

Element	Minimum	Maximum	Mean***	Standard Deviation	Valid	B	L	DL*
			Univariate Statistics					
Ag	2.0	62	---	10	33	75	613	2
Al %	.51	9.7	4.5	1.8	718	3	0	.05
B	10	82	21	10	518	75	128	10
Ba	54	1300	460	170	646	75	0	2
Be	1.0	6.0	1.2	.47	567	75	79	1
Ca %	.05	19	3.4	3.2	638	75	8	.05
Ce	10	380	48	25	689	3	29	10
Co	4.0	320	---	15	495	75	151	4
Cr	1.0	170	27	18	636	75	10	1
Cu	2.0	11000	32	420	646	75	0	2
Dy	2.0	8.7	---	1.9	16	651	54	2.0
Eu	4.0	4.0	---	---	1	649	71	3.7
Fe %	.10	18	2.4	1.8	718	3	0	.05
Hf	15	48	---	7.0	64	6	651	15
K %	.12	2.7	1.3	.44	646	75	0	**
La	2.0	180	23	12	714	3	4	2
Li	5.0	78	23	9.2	646	75	0	1
Lu	.10	.70	.39	.14	69	652	0	.3
Mg %	.05	6.3	.98	.68	645	75	1	.05
Mn	16	2200	490	330	714	7	0	4
Mo	4.0	140	---	41	10	75	636	4
Na %	.05	2.1	.70	.50	681	21	19	.05
Nb	4.0	56	9.1	4.3	569	75	77	4
Ni	2.0	270	14	13	631	75	15	2
P	59	8000	560	420	646	75	0	5
Pb	10	18000	---	870	434	75	212	10
Sc	1.0	19	5.7	3.1	718	0	3	1
Sm	1.0	8.0	3.8	1.2	70	651	0	.5
Sr	13	1900	240	190	646	75	0	**
Th	2.0	39	8.8	4.8	597	3	121	2
Ti	74	13000	2600	1700	676	45	0	10
U	1.0	3.8	2.8	.53	75	646	0	.02
V	4.0	330	65	51	717	4	0	5
Y	2.0	37	11	4.7	646	75	0	2
Yb	.80	5.7	2.6	1.0	65	650	6	.5
Zn	5.0	13000	76	530	646	75	0	2
Zr	6.0	190	56	21	646	75	0	2.4

* Lower determination limits listed represent optimum conditions; limits may vary as a function of composition of sample.
** No lower determination limit reported.
*** Means are calculated on unqualified data only and are not reported for elements having 20% or more qualified values ("L").

Table 5.--Basic statistics for 385 NURE groundwater (spring and well) samples collected in the Cedar City quadrangle. Values are in parts per billion, except for alkalinity (milliequivalents per liter) and pH. [B, not analyzed; L, analyzed but below determination limit; DL, reported lower determination limit]

Element	Minimum	Maximum	Univariate Statistics Mean***	Standard Deviation	Valid	B	L	DL*
pH	4.3	10	7.7	.5	385	0	0	---
Alk	.60	11	3.9	1.7	385	0	0	---
Ag	2.0	6.0	---	1.0	100	6	279	2
Al	11	6600	120	410	376	6	3	10
As	1.0	45	---	5.0	256	7	122	1
B	10	2100	130	230	379	6	0	8
Ba	2.0	570	80	95	379	6	0	2
Be	1.0	4.0	---	1.2	7	6	372	1
Br	9.0	1800	140	230	137	248	0	.3
Ca	9000	570000	86000	88000	379	6	0	3
Ce	30	42	---	3.0	12	6	367	30
Cl	1300	900000	35000	94000	380	5	0	11
Co	2.0	100	---	8.7	131	6	248	2
Cr	4.0	11	---	2.1	41	6	338	4
Cu	2.0	91	7.3	9.9	336	6	43	2
Dy	.03	1.6	---	.51	9	145	231	.02
F	2.0	6000	230	550	328	57	0	2
Fe	10	3300	94	260	348	6	31	10
He	1200	18000	200	2400	147	238	0	2.2
K	1000	97000	4600	6900	365	20	0	.4
Li	2.0	1200	44	120	363	6	16	2
Mg	2000	890000	42000	72000	379	6	0	.1
Mn	2.0	1600	37	140	374	6	5	2
Mo	4.0	17	---	2.7	106	6	273	4
Na	1900	890000	44000	110000	383	2	0	2
Nb	4.0	27	---	4.7	152	6	227	4
Ni	4.0	150	---	12	137	6	242	4
P	40	650	---	130	83	6	296	40
Sc	1.0	5.0	---	.66	76	6	303	1
Se	1.0	4.0	1.9	.99	26	359	0	.2
Si	1000	49000	15000	8500	379	6	0	3.4
Sr	25	12000	840	1700	379	6	0	14
Th	5.0	15	---	3.2	33	6	346	5
Ti	2.0	18	---	2.6	278	6	101	2
U	.04	35	---	4.5	291	0	94	.002
V	.20	44	4.6	5.5	310	0	75	.1
Y	1.0	58	---	5.2	120	6	259	1
Zn	4.0	3100	90	260	368	6	11	4
Zr	2.0	9.0	---	1.9	127	6	252	2

* Lower determination limits listed represent optimum conditions; limits may vary as a function of composition of sample.

** Means are calculated on unqualified data only and are not reported for elements having 20% or more qualified values ("L").

Table 6.--Correlation matrix for 834 samples and 28 variables in stream sediments (minus-16-mesh to plus-100-mesh) from the Cedar City quadrangle. The following elements are excluded because of inadequate analytical sensitivity: Ag, Dy, Eu, Hf, Lu, Mo, Sm, U, and Yb. Values recorded as less than the lower limit of analytical determination ("L") have been arbitrarily replaced as indicated in the table at the bottom of the correlation matrix.

	Al	B	Ba	Be	Ca	Ce	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn	Na	Nb	Ni	P	Pb	Sc	Sr	Th	Ti	V	Y	Zn	Zr
Al	1.0	.04	.71	.55	-.20	.63	.58	.45	.14	.56	.56	.60	.49	.01	.75	.78	.60	.50	.52	.02	.76	.55	.31	.59	.47	.76	.51	.59
B		1.0	.02	.02	.12	-.14	-.23	-.19	.00	-.21	.30	-.11	.56	.16	-.13	-.05	-.01	-.09	-.04	.01	-.13	-.03	.13	-.23	-.24	.00	-.11	.03
Ba			1.0	.29	-.25	.47	.41	.32	.10	.38	.53	.46	.25	-.12	.58	.53	.35	.40	.37	.02	.51	.38	.22	.44	.32	.51	.33	.51
Be				1.0	-.19	.46	.27	.15	.06	.31	.46	.46	.41	-.10	.46	.53	.75	.15	.17	.04	.28	.21	.43	.33	.24	.65	.35	.41
Ca					1.0	-.19	-.11	-.05	.02	-.11	-.41	-.20	.16	.80	-.10	-.20	-.02	-.04	.04	.03	-.05	.21	-.02	-.13	-.07	-.12	-.05	-.25
Ce						1.0	.50	.43	.08	.55	.34	.98	.19	-.09	.61	.56	.64	.39	.39	.04	.54	.33	.49	.60	.49	.83	.46	.67
Co							1.0	.81	.22	.92	.05	.41	.04	.11	.83	.49	.33	.74	.48	.06	.85	.52	.16	.85	.91	.46	.68	.39
Cr								1.0	.14	.76	-.01	.36	.06	.15	.62	.33	.27	.87	.44	.01	.70	.35	.09	.68	.75	.38	.53	.30
Cu									1.0	.15	.03	.07	.07	.11	.15	.12	.08	.19	.12	.90	.17	.13	.02	.13	.13	.11	.73	.10
Fe										1.0	.07	.48	.05	.08	.81	.49	.37	.63	.46	.02	.77	.46	.10	.92	.96	.49	.70	.39
K											1.0	.37	.47	-.28	.28	.44	.39	.07	.15	.02	.15	.14	.30	.11	-.02	.45	.15	.38
La												1.0	.22	-.12	.55	.53	.66	.36	.37	.04	.46	.28	.51	.55	.40	.83	.43	.67
Li													1.0	.26	.26	.32	.43	.20	.20	.00	.20	.27	.29	.04	-.03	.45	.17	.26
Mg														1.0	.11	-.02	.01	.16	.20	.07	.19	.33	-.02	.03	.09	.02	.11	-.09
Mn															1.0	.64	.51	.59	.52	.03	.83	.54	.21	.81	.76	.65	.64	.55
Na																1.0	.58	.35	.38	.05	.59	.54	.30	.52	.42	.62	.43	.48
Nb																	1.0	.33	.27	.05	.37	.31	.58	.47	.29	.77	.40	.46
Ni																		1.0	.46	.04	.67	.35	.17	.57	.57	.42	.50	.34
P																			1.0	.01	.56	.41	.16	.46	.40	.52	.38	.35
Pb																				1.0	.02	.01	.02	.02	.01	.04	.64	.05
Sc																					1.0	.59	.15	.76	.76	.58	.58	.47
Sr																						1.0	.17	.44	.44	.36	.36	.26
Th																							1.0	.13	.05	.51	.14	.37
Ti																								1.0	.90	.52	.66	.48
V																									1.0	.39	.66	.31
Y																										1.0	.49	.70
Zn																											1.0	.36
Zr																												1.0

REPLACED VALUES USED IN COMPUTING THE STREAM SEDIMENT CORRELATION MATRIX

Element	B	Be	Ca	Ce	Co	Cr	Cu	La	Mg	Na	Nb	Ni	P	Pb	Sc	Th	V	Y
Lower Limit of Analytical Determination, ppm	10	1	.05%	10	4	3	2	2	.05%	.05%	4	2	5	10	1	2	5	2
Replaced Values for "L"	7	.7	.03%	7	3	2	1.5	1.5	.03%	.03%	3	1.5	3	7	.7	1.5	3	1.5
Number of Replaced Values	170	134	4	24	261	3	3	2	1	25	122	8	1	298	1	158	1	1

Table 7.--Correlation matrix for 646 samples and 28 variables in soils (minus-100-mesh) from the Cedar City quadrangle. The following elements are excluded because of inadequate analytical sensitivity: Ag, Dy, Eu, Hf, Lu, Mo, Sm, U, and Yb. Values recorded as less than the lower limit of analytical determination ("L") have been arbitrarily replaced as indicated in the table at the bottom of the correlation matrix.

Al	B	Ba	Be	Ca	Ce	Co	Cr	Cu	Fe	K	La	Li	Mg	Mn	Na	Nb	Ni	P	Pb	Sc	Sr	Th	Ti	V	Y	Zn	Zr	
1.0	-.05	.72	.47	-.19	.62	.20	.37	-.05	.71	.41	.61	.30	.08	.81	.88	.54	.14	.43	-.06	.86	.64	.23	.82	.68	.79	-.02	.69	Al
	1.0	-.04	.08	.09	-.06	-.10	-.04	-.01	-.22	.31	.00	.53	.20	-.15	-.15	.09	.02	.00	-.01	-.17	-.21	.09	-.23	-.25	.04	-.02	.06	B
		1.0	.36	-.27	.55	.33	.36	.17	.52	.56	.57	.22	-.02	.58	.69	.43	.31	.33	.16	.58	.50	.28	.61	.49	.53	.19	.50	Ba
			1.0	-.18	.52	.07	.23	-.03	.26	.36	.57	.33	-.02	.37	.41	.58	.14	.26	-.03	.35	.13	.35	.31	.24	.58	-.02	.32	Be
				1.0	-.15	.00	-.12	.04	-.03	-.44	-.17	.18	.70	-.09	-.14	.09	-.04	.07	.04	-.08	.20	-.09	-.10	-.03	-.03	.04	-.13	Ca
					1.0	.21	.41	-.01	.59	.31	.97	.30	.08	.50	.58	.58	.30	.74	-.02	.58	.36	.37	.53	.56	.80	.01	.36	Ce
						1.0	.24	.94	.50	-.04	.18	.04	.18	.24	.19	.11	.83	.24	.93	.26	.46	.06	.26	.32	.20	.94	.14	Co
							1.0	.06	.39	.12	.40	.23	.08	.29	.22	.40	.54	.24	.05	.50	.16	.14	.49	.51	.39	.07	.34	Cr
								1.0	.18	-.06	.00	.04	.13	-.03	-.04	-.01	.76	.05	1.0	-.04	.27	.04	-.03	.00	-.02	1.0	-.03	Cu
									1.0	.06	.51	.05	.21	.75	.68	.35	.40	.54	.17	.83	.67	.01	.82	.92	.66	.21	.49	Fe
										1.0	.38	.40	-.25	.21	.37	.31	.03	.13	-.07	.14	.01	.24	.16	.04	.31	-.06	.27	K
											1.0	.37	.04	.45	.55	.63	.30	.71	-.01	.51	.29	.41	.48	.47	.81	.01	.37	La
												1.0	.33	.18	.14	.40	.23	.30	.03	.14	.04	.22	.04	.00	.46	.04	.27	Li
													1.0	.17	.06	.15	.16	.29	.13	.20	.30	-.10	.11	.18	.21	.14	.11	Mg
														1.0	.79	.42	.12	.44	-.03	.84	.64	.09	.83	.73	.68	.01	.66	Mn
															1.0	.49	.05	.42	-.04	.77	.73	.20	.78	.65	.68	-.01	.56	Na
																1.0	.23	.31	-.02	.42	.27	.39	.49	.33	.67	.00	.45	Nb
																	1.0	.27	.76	.18	.23	.12	.17	.24	.23	.77	.13	Ni
																		1.0	.04	.45	.38	.05	.40	.49	.61	.06	.28	P
																			1.0	-.05	.27	.04	-.04	-.01	-.03	1.0	-.03	Pb
																				1.0	.65	.11	.88	.84	.76	-.01	.66	Sc
																					1.0	.04	.65	.62	.47	.30	.41	Sr
																						1.0	.06	-.02	.32	.05	.10	Th
																							1.0	.90	.64	.00	.66	Ti
																								1.0	.59	.03	.48	V
																									1.0	.01	.62	Y
																										1.0	.00	Zn
																											1.0	Zr

REPLACED VALUES USED IN COMPUTING THE SOIL CORRELATION MATRIX

Element	B	Be	Ca	Ce	Co	Cr	La	Mg	Na	Nb	Ni	Pb	Sc	Th
Lower Limit of Analytical Determination, ppm	10	1	.05%	10	4	1	2	.05%	.05%	4	2	10	1	2
Replaced Values for "L"	7	.7	.03	7	3	.7	1.5	.03	.03	3	1.5	7	.7	1.5
Number of Replaced Values	128	79	8	29	151	10	4	1	19	77	15	212	3	121

Table 8.--Listing of factors for coarse stream sediments and soils, resulting from R-mode varimax factor analysis. Number in parenthesis beneath factor # indicates the percentage of total variance explained by that factor.

STREAM SEDIMENTS Factor #	 Elements In Factor*	SOILS Factor #	 Elements In Factor*
1 (57%)	Cr-Ni-Co-V-Sc-Fe- Ti-Zn-P-Mn-Cu-Ce-Al-La-Y- Sr-Na-Zr-Ba-Nb	1 (53%)	Ti-Al-V-Sc-Na-Fe-Mn-Sr- Co-Ba-Zn-Y-Ce-Zr-P-La Nb-Be-Cu-K
2 (9%)	 K-Ba-Na-Al- Sr-Mn-Zr-Ti-Be	4 (6%)	Cr-Ni Cu
3 (8%)	Ca-Mg- Sr	3 (8%)	Ca-Mg
4 (4%)	Th Nb-La-Be-Ce-Y- Zr	5 (4%)	Th- La-Nb-Ce-Be
5 (4%)	Pb- Cu	6 (4%)	Pb- Cu
6 (3%)	B- Li- K	2 (9%)	B- Li- K
85% = total % variance explained by 6-factor model for coarse stream sediments		84% = total % variance explained by 6-factor model for soils	

* Elements are listed in order of decreasing importance in the factor. Elements on the first line dominate the factor; correlations (loadings) between these elements and the factor are all above 0.8. Correlations between the factor and elements on the second line are between 0.6 and 0.8. Correlations between the factor and elements on the third line are between 0.4 and 0.6.

Table 9.--Stratigraphic section related to known and potential resources.

ROCK UNIT AND AGE	KNOWN AND POTENTIAL(*) RESOURCES
UNCONSOLIDATED DEPOSITS	
Quaternary deposits: miscellaneous lacustrine fluvial and eolian surficial deposits	placer Au(*), Ti(*), Zr(*), Fe(*) sand and gravel, dune sand, quartz sand, gypsum dunes, saline minerals, monazite(*)
SEDIMENTARY ROCKS	
Quaternary and Tertiary deposits: Semi-lithified poorly sorted gravelly deposits of uncertain age	placer Au(*), Ti(*), Zr(*), Fe(*)
Sevier River Formation (Pliocene and Miocene)	zeolites(*)
Muddy Creek Formation (Miocene)	zeolites(*)
Claron Formation (Eocene and/or Paleocene)	Au, Sb, Ag, Pb, Zn, Cu (veins and replacements)
Grapevine Wash Formation (Tertiary? and/or Cretaceous)	none recognized
Cretaceous rocks, undivided (Upper Cretaceous)	oil, gas, and coal
Iron Springs Formation (Upper Cretaceous)	Fe, coal (minor) Ag, Cu, Pb, Zn (Antelope Range District)
Tropic Formation (Upper Cretaceous)	bentonite clay, coal
Dakota Formation (Upper Cretaceous)	oil, coal, U, petrified wood
Carmel Formation, upper member (Upper? and Middle Jurassic)	gypsum, minor Fe
Carmel Formation, limestone member (Middle Jurassic)	Fe, Ag, minor Au, gypsum, limestone, base metals
Jurassic rocks, undivided (Middle? and Lower Jurassic)	ironstone, quartz sand, dimension stone, colored sand, picture rock, red sandstone (all in Navajo Sandstone)
Moenave Formation (Lower Jurassic)	Ag, minor Au, U, minor V, base metals(*)
Chinle Formation (Upper Triassic)	U, petrified wood Mn, picture sandstone, minor Ag, base metals(*)

Table 9.--(continued).

ROCK UNIT AND AGE	KNOWN AND POTENTIAL(*) RESOURCES
SEDIMENTARY ROCKS (continued)	
Moenkopi Formation (Middle? and Lower Triassic)	oil, gas, gypsum
Kaibab Limestone (Lower Permian)	oil
Lower Permian rocks, undivided (Lower Permian)	U(*), Cu(*), Pb(*), Zn(*) (collapse breccia) (minor As, Goldstrike District)
Callville Limestone Au, (Pennsylvanian)	oil, Ga, Ge, Cu, Pb, Zn, Ag, minor limestone, marble
Redwall Limestone (Lower Mississippian)	oil(*), Ag(*), Cu(*), Pb(*), Zn(*), U(*), Au(*)
Devonian to Cambrian rocks (undivided)	Au(*), Cu(*), Ag(*)
VOLCANIC ROCKS	
Basalt (Quaternary to Miocene?)	volcanic cinder, scoria
Rhyolite, trachyte, and dacite (Upper Miocene)	Mo(*), Be(*), Sn(*), Au(*), Ag(*)-veins
Miocene volcanic rocks (undivided Miocene)	Ag, minor Au, base metals, Fe
Quichapa Group (Miocene)	Ag, minor Au, base metals
Tertiary volcanic rocks, undivided (Miocene and Oligocene)	Ag, minor Au, base metals, agate, alunite, pumice, green chalcedony
Oligocene volcanic rocks, undivided	Ag, minor Au, base metals
INTRUSIVE ROCKS	
Porphyritic quartz monzonite plutons (Miocene)	Fe precious metal veins
METAMORPHIC ROCKS	
Crystalline rocks, undivided (Proterozoic X)	Cu, Au, Ag, W(*)

Table 10.--Summary of production, ore deposit models, and the critical geologic factors involved in ore genesis in the Cedar City quadrangle.

MINING DISTRICT[1]	EXAMPLE DEPOSIT(S)	MODEL NUMBER[2]	PRODUCTION RECORD	FACTORS CRITICAL TO OCCURRENCE
Antelope Range	Blair	25b 36a	unknown small (1890-1905)	hydrothermal system; rhyolite/dacite domes; high-angle faults; hydrothermal circulation
Bull Valley	Pilot	18d 18x	none	permeable volcanics; deep faults; limestone (minor); high level quartz monzonite porphyry
Escalante hydrothermal system; faults	Escalante	25b Silver Mine	13K T	rhyolite domes; @ 11 oz/ton Ag in 1966;high-angle 5M T @ 10 oz/ton Ag, 1981-88
Gold Springs (just off quadrangle) margin (?)	Aetna Vein	25c 25d	9335 oz Au 28,000 oz Ag 36a	high-angle faults; hydrothermal system; @ 1 oz/ton Au caldera and 3 oz/ton Ag
Stateline (just off quadrangle)	Bargain	25c 25d	unknown 36a	quartz veins; volcaniclastics; silicification
Goldstrike	Hamburg	25b, c Bull Run	unknown 26a, 25d, 39a	jasperoid (w/Au); basal Claron Fm. (sandstone and conglomeratic ss); high-angle faults
Iron Springs and Pinto	Pioche- Vermillion	18d Desert Mound Granite Mtn. Rex	84M T @50% Fe	Tertiary quartz monzonite plutons; Carmel Limestone; intrusion-related deformation
Mineral Mtn.	Emma Mine	18d	none 18b,c	Tertiary granite pluton and dikes; Paleozoic carbonates
Modena	minor	25b,c Au/Ag veins	none	hydrothermal system; high-angle faults; rhyolite domes

Table 10.--(continued).

MINING DISTRICT[1]	EXAMPLE DEPOSIT(S)	MODEL NUMBER[2]	PRODUCTION RECORD	FACTORS CRITICAL TO OCCURRENCE
Paria		unknown		placer environment for Au?, U?, and Cu?; unknown source rocks
Silver Reef (Harrisburg)	White Buckeye Butte	30b 30c "reefs"	7M oz Ag pre-1900	Paleostream channels in Moenave Formation; thrust faulting which stacked ore; saline brines; anticline;
Tutsagubet	Apex	32c Paymaster	7000 mT Cu 37b	Callville Limestone; 400 mT Pblocal "warps"
in rocks			180,000 troy oz Ag Ga, Ge	causing breccia pipe development; strongly oxidizing environment

1 From Doelling and Tooker (1983).
2 Model numbers refer to models in Cox and Singer (1986); models are listed at the end of the table. Mineral deposit models having potential for occurring within the quadrangle are in italics.

KEY TO MODEL NAMES AND NUMBERS FROM COX AND SINGER (1986):

18b	Cu Skarn
18c	Zn/Pb Skarn
18d	Iron Skarn
18x	Iron deposits in volcanics (not in Cox and Singer, 1986)
25b	Creede Epithermal Silver Veins
25c	Comstock Epithermal Veins
25d	Sado Epithermal Veins
26a	Carbonate-Hosted Au-Ag
30b	Sediment-Hosted Cu
30c	Sandstone (roll front) U (silver rich variety)
32c	Breccia Pipe (Wenrich, 1985; Wenrich and others, 1987) also Kipushi Cu-Pb-Zn (Ga,Ge)
36a	Low-Sulfide Au-quartz veins
37b	Gold on Flat Faults
39a	Placer Au-PGE and Paleo-placer gold