Soil Gas Studies Along the Trans-Challis Fault System near Idaho City, Boise County, Idaho

By J.H. McCarthy *and* T.H. Kiilsgaard

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Metric Conversion Factors

Multiply	By	To obtain
Miles	1.609	Kilometers
Feet	0.3048	Meters
Inches	2.54	Centimeters
Tons	1.016	Metric tons
Short tons	0.907	Metric tons
Troy ounces	31.103	Grams
Ounces	28.35	Grams

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Abstract

Soil gases were sampled along several traverses that cross the Trans-Challis fault system in central Idaho. Anomalous carbon dioxide, hydrogen, oxygen, hydrocarbon, and sulfur gas concentrations coincide with faults and known mineralized areas. Anomalies in areas not known to be mineralized may reflect undiscovered mineral deposits or concealed faults. Soil gases may be a useful exploration guide for mineral deposits in this terrane.

Introduction

The study described herein was designed to test the usefulness of soil gases as a guide to identifying faults and mineral deposits in the area of the Trans-Challis fault system, where precious- and base-metal deposits have been emplaced along northeast-trending faults and dikes (Kiilsgaard and Lewis, 1985; Kiilsgaard and others, 1989). Some of the known faults and mineralized areas are covered by varying thicknesses of soil, grus, alluvium, or terrace gravels. Gases detected at the surface have been used as exploration guides for mineral deposits that are concealed by post-mineral or barren overburden (Glebovskaya and Glebovskii, 1960; Lovell and Hale, 1983; McCarthy and others, 1986; Kesler, 1990). Carbon dioxide and sulfur gases such as sulfur dioxide, carbonyl sulfide, and hydrogen sulfide are produced when oxygenated ground waters react with sulfide minerals (Taylor and others, 1982). These gases, when detected at the surface, may indicate oxidizing sulfide deposits at depth (Hinkle, 1986; Reid and Rasmussen, 1990). These and other gases migrate along faults because fault zones commonly are more permeable than the surrounding rock and act as conduits through which gases escape to the surface. Plots of gases measured at the surface can indicate the location and extent of faults (Kita and others, 1980; Sugisaki and others, 1983; Scherbakov and Koslova, 1986) and the mineral deposits emplaced along them. In this study, gases were analyzed at about 70 sites along several traverses that cross part of the Trans-Challis fault system.

Geology

The study area is located mostly in the northwestern part of the Hailey 1°×2° quadrangle and includes a series of northeast-trending faults that were mapped by Kiilsgaard and Lewis (1985) and Kiilsgaard and others (1989) in the Trans-Challis fault system. The area is underlain by Cretaceous plutonic rocks of the Idaho batholith, mainly biotite granodiorite and muscovite-biotite granite. The Cretaceous rocks have been intruded by younger plutonic rocks, chiefly diorite, porphyritic quartz monzodiorite, and biotite granite, of Eocene age. Intruding all plutonic rocks are a myriad of Tertiary dikes that range from andesite to rhyolite in composition. The dikes and the Eocene plutonic rocks were intruded along the pre-existing Trans-Challis fault system. The same northeast-trending fault system controlled the emplacement of a series of mineralized veins that form a discontinuous northeast-trending belt subparallel with the northeast-trending faults. The belt passes near the abandoned town of Quartzburg about 4 km northwest of Placerville. The geology of the Hailey 1°×2° quadrangle was mapped by Worl and others (1991).

Mines along the northeast-trending belt have been the principal producers of lode gold in this area and erosion of the veins has produced much of the placer gold that was mined in the Boise Basin, the principal gold-producing area in Idaho (Kiilsgaard and others, 1989).

A northeast-trending belt of muscovite-biotite (two-mica) granite plutons in biotite granodiorite crosses the northwestern part of the Hailey 1°×2° quadrangle, (Kiilsgaard, Lewis, and Bennett, in press). Generally there is a gradational contact between the two-mica granite and the biotite granodiorite; however, in places the two-mica granite is in fault contact with the biotite granodiorite. Both the biotite granodiorite and the two-mica granite weather to grus, which can be as deep as a few meters. Along major faults both rock types have been intensively hydrothermally altered; primary mafic minerals have been altered to iron oxide minerals and feldspars to sericite and clay. Quartz appears to be unaffected. Where alteration is intense, the protolith is difficult or impossible to identify.

A swarm of porphyritic dikes and plutonic stocks previously described as the "porphyry belt" (Lindgren, 1898; Jones, 1916; Ballard, 1924; Ross, 1934; Anderson, 1947) extends through Quartzburg and continues northeast to Grimes Pass and beyond. The porphyry belt is approximately 3 km wide and more than 16 km long; emplacement of dikes and stocks in this belt was guided by faults of the Trans-Challis fault system (Worl and others, 1991; Kiilsgaard, Lewis, and Bennett, in press). Elsewhere, in the vicinity of Idaho City, a series of small, northeast-trending stocks and large dikes of Eocene porphyritic quartz monzodiorite grading to granodiorite extend along the

west side of Mores Creek and continue northeast past Idaho City (Lewis and Kiilsgaard, 1991).

A swarm of dikes ranging from andesite to rhyolite in composition is exposed along the porphyry belt (Anderson, 1947; Kiilsgaard, Lewis, and Bennett, in press). The dikes range from about 2 m to more than 30 m in thickness and from about 30 m to more than 1,600 m in strike length and have irregular shapes. Most of the dikes trend subparallel with the trend of the porphyry belt, but a few strike northwest across the belt.

Quaternary sand and gravel a few meters thick cover the bottoms of most gulches in the area, and west of the Mayflower mine older gravel mantles the foothill slopes of the Boise Ridge (Kiilsgaard, Scanlan, and Stewart, in press). Many of these gulch bottom and older gravel deposits have been placered.

Northeast-striking faults of the Trans-Challis fault system are the principal geologic structures of the area. Near the western part of the Hailey 1°×2° quadrangle, the northeast-trending faults are cut by the younger, north-trending Boise Ridge fault (fig. 1).

The Mineral Mountain fault (fig. 1) is the principal northeast-trending fault in the vicinity of Quartzburg. It is marked by a zone of shearing on the west side of Mineral Mountain, which is aligned with another shear zone exposed in the road bank of the Woof Creek road south of Alder Creek Summit. To the southwest, the location of the fault is obscured by dense vegetation and a heavy cover of grus. Trenches and pits on and near the Hilda Mae property, near the head of California Gulch, show sheared and altered biotite granodiorite several hundred meters wide, but the area also contains other smaller northeast-trending faults and veins, all of which aggregate a width of more than 500 m. Projected further southwest, down the gulch near the mouth of the Iowa mine adits, the fault would extend into the shear zone that Ballard (1924) described as comprising several fissure veins, approximately parallel with the Gold Hill vein, that define a shear zone 800 m or more wide. No trace of the Mineral Mountain fault was found west of the Boise Ridge fault. None of the major northeast-trending faults (Mineral Mountain, Ophir Creek, Clear Creek, or Wild Goat Creek, (fig. 1) was found west of the Boise Ridge fault.

The Boise Ridge fault, first postulated by Lindgren (1898) and mapped near Quartzburg by Anderson (1947), extends along the eastern foot of Boise Ridge (fig. 1). It continues 40 km to the north and 10 km south of Quartzburg (Worl and others, 1991). It is a young fault that offsets Miocene basaltic rocks of the Columbia Plateau (Kiilsgaard, Scalan, and Stewart, in press). Remnant caps of basalt east of the fault have been downdropped. North of the study area, and north of the town of Crouch in Garden Valley, movement along the northern extension of the fault has tilted black shale of the Miocene Payette Formation (Fisher and others, 1992). A small, remnant patch of cobbles and gravel on top of Boise Ridge, south of Hawley Mountain Lookout, may correlate with the Pleistocene high gravel in the area west of Quartzburg, in which case movement along the Boise Ridge fault could be of Pleistocene age. An extensive mineralized zone exposed at the Newburg prospect and the Belshazzar and Mountain Chief mines, west of the fault and west of the map boundary (fig. 1), could be the southwest extension of the vein zone developed at the Mayflower and Gold Hill mines.

Mineral Deposits

Placer mining along Grimes Creek, Granite Creek, and Woof Creek in the vicinity of Placerville, and along many tributaries in the area, led to the discovery of gold veins near the site that subsequently became known as Quartzburg (fig. 1). Of these, the Gold Hill vein was the most productive, although it is but one of a belt of discontinuous mineralized veins that trends northeast through the Quartzburg area. The belt extends from the vicinity of the Mountain Chief mine, southwest of Quartzburg, 40 km to the northeast. The belt approximately parallels trends of faults of the Trans-Challis fault system, Eocene plutonic rocks, and Tertiary dikes, although mineralized material in the veins is younger than most of these rocks. The various veins in the belt have been explored primarily for their gold and silver potential. Veins at the Gold Hill mine have been the most productive, although mining operations at the Gold Hill mine have been inactive since the late 1930's. Intermittent mineral exploration has been conducted in the belt of veins in recent years but no ore has been mined.

The veins are true fissure veins and are discontinuous and somewhat en echelon in outcrop pattern. Four veins in the vicinity of the Mayflower mine (fig. 1) strike about N. 40° E., in an area more than 450 m wide. Northeast of the Mayflower shaft, the strike of the vein pattern swings more to the east, and one vein, the Confederate vein, may continue on as the Gold Hill vein. The Last Chance vein parallels the Gold Hill vein, about 30 m to the north.

Ballard (1924) describes lower parts of the Gold Hill vein and other veins that split off into the hanging wall (to the south), all of which were mined through the Pioneer shaft. He also describes other prominent fissure veins in the vicinity that parallel the Gold Hill vein, which are 60–200 m apart, and together define a shear zone 800 m or more wide. From surface indications, it is likely that the Gold Hill pattern of veins does not extend northeast of the ridge on the southwest side of California Gulch; however, near the head of California Gulch another group of comparable veins, offset to the north, has been explored by the Hilda Mae, Tip Top, Kennebec, and Bluestone prospects (fig. 1). These veins probably constitute another set of the discontinuous northeast-trending veins in the same system. The Etna-Black Bear prospects, and the Mountain Queen, Mineral Hill, and Buckskin veins (fig. 1) also may be part of a discontinuous northeast-trending vein system.

Northeast-trending veins in the vicinity of Quartzburg are mineralogically similar. Quartz is the principal mineral in the veins and locally forms conspicuous outcrops. Concentrations of gold and various silver-bearing minerals in the quartz form ore shoots that have been mined locally along the veins. Ross (1934) noted that other sulfide minerals in the ore shoots include pyrite, sphalerite, galena, tetradymite, and galenobismutite. Native gold was found in the pyrite (Ballard, 1924). At the Gold Hill mine, significant ore shoots occur at intersections of the Gold Hill vein and rhyolite dikes. The brittle dike rocks were fractured and shattered by faults that predated mineralization along the Gold Hill vein and mineralizing solutions in the resulting voids formed in the ore shoots.
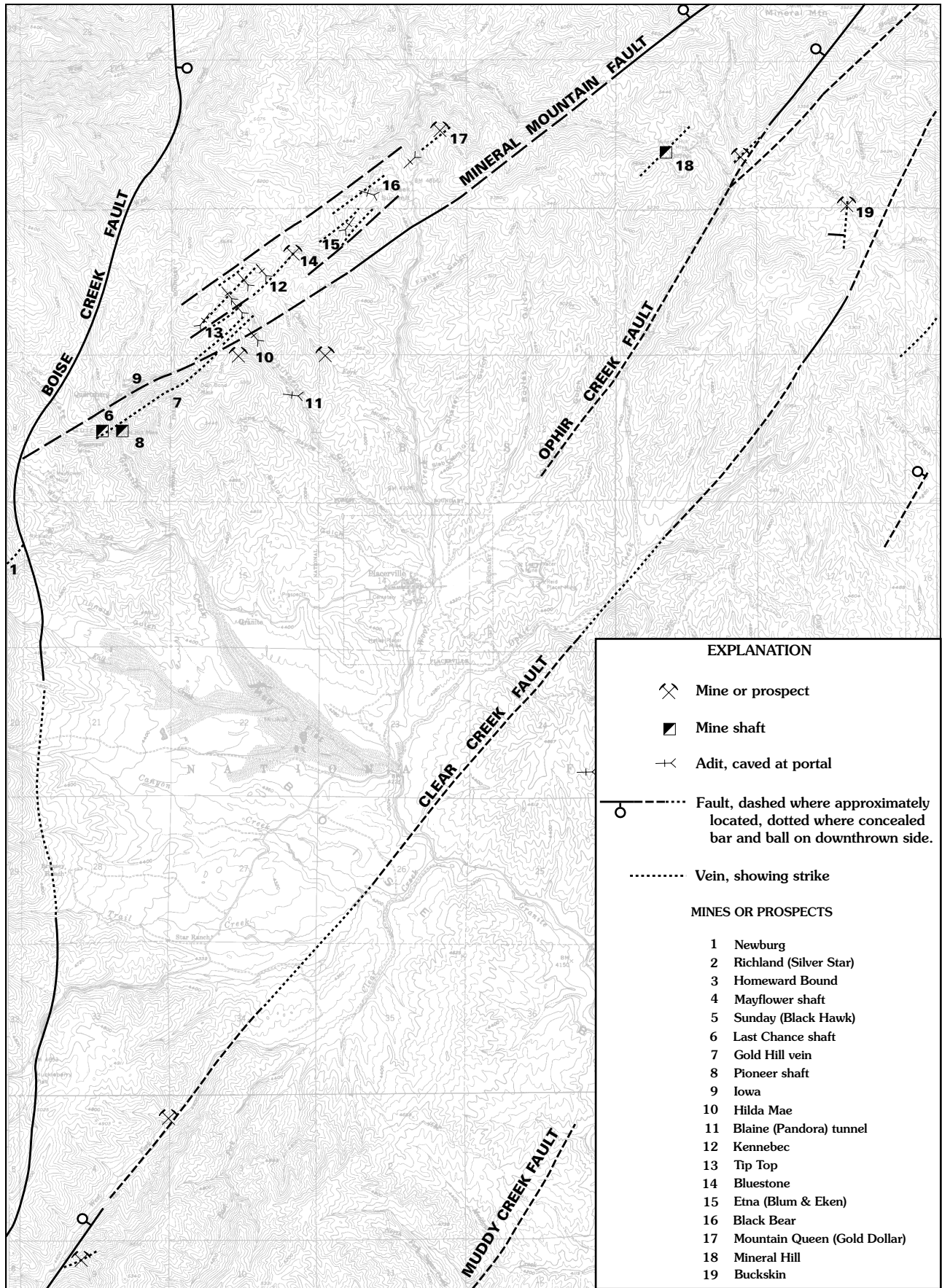
EXPLANATION

⚒ Mine or prospect

◨ Mine shaft

⊢⊁ Adit, caved at portal

Fault, dashed where approximately located, dotted where concealed bar and ball on downthrown side.

·········· Vein, showing strike

MINES OR PROSPECTS

1 Newburg
2 Richland (Silver Star)
3 Homeward Bound
4 Mayflower shaft
5 Sunday (Black Hawk)
6 Last Chance shaft
7 Gold Hill vein
8 Pioneer shaft
9 Iowa
10 Hilda Mae
11 Blaine (Pandora) tunnel
12 Kennebec
13 Tip Top
14 Bluestone
15 Etna (Blum & Eken)
16 Black Bear
17 Mountain Queen (Gold Dollar)
18 Mineral Hill
19 Buckskin

Figure 1. Map showing faults, veins, mines, and prospects in the northwestern corner of the Hailey 1°×2° quadrangle, Idaho.
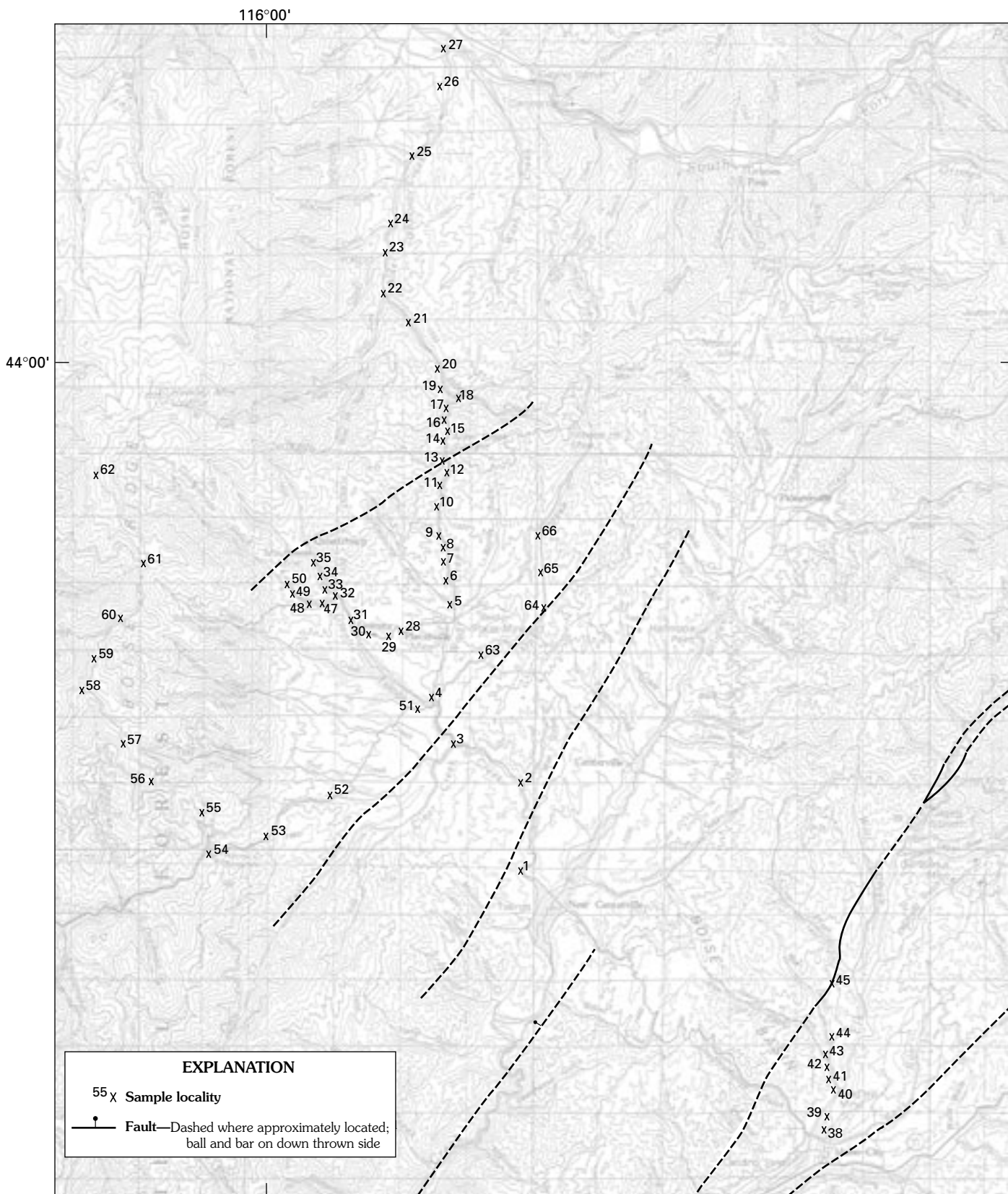
Figure 2. Map showing soil and gas sample localities in the vicinity of the Trans-Challis fault system near Idaho City, Idaho.

Soil Gas Studies

Soil gases were sampled at about 1,600- and 300-m intervals along roads and trails that cross the Trans-Challis fault system. On average, about 10 samples per day were collected and analyzed; sample sites and numbers are shown in figure 2. Widely spaced samples were taken at sites beyond the inferred boundary of the fault system to see whether gas anomalies can

be used to delineate the Trans-Challis fault system. Closely spaced samples were taken at sites near individual mineral deposits and mapped faults to determine whether gas anomalies coincide with these features. One sample traverse extended along the county road from New Centerville, across Alder Creek Summit, to the South Fork of the Payette River. This traverse crosses the Trans-Challis fault system and extends about 8 km north of the inferred boundary. Another traverse extends from Star Ranch southwest to the Harris Creek Summit and along the Boise Ridge to Hawley Mountain, again crossing part of the fault system and extending beyond it. Close-spaced samples were taken along traverses 2–3 km in length from Placerville to the Mayflower and Gold Hill mines and along the Elk Creek drainage north of Idaho City.

Soil gas samples were collected by driving a small-diameter hollow steel probe into the ground to a depth of 0.75 m. Five cubic centimeters of soil gas was withdrawn from that depth and analyzed at the site using a truck-mounted quadrupole mass spectrometer powered by a heavy-duty truck alternator (McCarthy and Bigelow, 1990). The analyzer is programmed to measure atomic and molecular gases from 2 to 100 atomic mass units (AMU) and the relative concentration of individual gases are recorded for storage and plotting.

Results

Anomalous concentrations of carbon dioxide, oxygen, sulfur gases, and hydrocarbon gases were found along the Trans-Challis fault system. Concentrations of most of these gases are higher over the fault system than in the surrounding areas and highest concentrations appear to parallel the northwest boundary of the fault. Maps of selected gas levels in relation to the faults are shown on figures 3–8.

Concentrations of hydrogen (H_2) are anomalous only over the Trans-Challis fault zone (fig. 3). Hydrogen anomalies coincide with northeast-trending shear zones that extend through the Alder Creek Summit area. Other anomalies occur along the Boise Ridge, near the Mayflower and Gold Hill mines, and in the Elk Creek drainage just north of Idaho City.

Carbon dioxide (CO_2) concentrations are anomalous over the Trans-Challis fault system as well as at sites several miles north of the inferred boundary, toward Garden Valley (fig. 4). Anomalous concentrations of carbon dioxide were found in samples from the vicinity of the Elk Creek fault north of Idaho City and from northeast-trending shear zones south of Quartzburg and near Alder Creek Summit. Carbon dioxide is commonly produced in oxidizing sulfide deposits and may reflect such deposits in the underlying bedrock.

Values for the ratio of CO_2 to O_2 are anomalous at fewer sites than values for CO_2 alone. The ratio of these gases more specifically indicates oxidizing sulfides than does the concentration of either gas alone. The ratio is anomalous at Alder Creek Summit, in the area of the Mayflower and Gold Hill mines, in the Elk Creek drainage north of Idaho City and at several sites along Alder Creek, south of Garden Valley (fig. 5).

All carbonyl sulfide (COS) anomalies are within the Trans-Challis fault system (fig. 6). Most anomalies are near Alder Creek Summit and at other sites near Harris Creek Summit and in the Elk Creek drainage north of Idaho City.

Methane (CH_4) anomalies coincide with northeast-trending shear zones that extend through the Alder Creek Summit area (fig. 7). Some methane anomalies to the southwest, along Boise Ridge, correlate roughly with shear zones that cross the ridge and extend to the southwest.

Anomalous concentrations of propane (C_3H_8) are anomalous at sites only within the boundary of the fault system and generally coincide with areas of known mineral deposits (fig. 8). Two anomalous sites on Boise Ridge (the same sites at which methane is anomalous) are not near any known mineral deposits. Most of the hydrocarbon gas anomalies coincide with areas of known mineral deposits.

Discussion

Anomalous concentrations of all of the gases sampled are found along the Trans-Challis fault system, and most are associated with mineral deposits (Rose and others, 1979; Kesler, 1990) and faults.

Hydrogen is one of the gases found in volcanic emanations and, in some cases, is of deep-seated origin (Sherbakov and Kozlova, 1986). It is also produced by serpentinization, when water reacts with ferrous iron minerals (Coveney and others, 1987), and by the breakdown of water, catalyzed by contact with fresh rock surfaces, such as along faults (Kita and others, 1980; Sugisaki and others, 1983). Hydrogen gas concentrations can be used, in areas covered by overburden, to map faults and, where mineral deposits are located along faults, may be a useful exploration guide. In the study area, hydrogen anomalies such as that found where northeast-trending faults cross Alder Creek Summit (fig. 3) probably reflect the belt of Tertiary hypabyssal igneous rocks and (or) shear zones that trend northeast from Quartzburg (Ballard, 1924; Kiilsgaard and others, 1989).

Carbon dioxide is commonly associated with oxidizing sulfide deposits (Lovell and others, 1983; McCarthy and others, 1986; Reid and Rasmussen, 1990). It is produced when acid ground waters react with calcareous minerals. Oxygen is consumed in this reaction, resulting in lowered concentrations of oxygen and elevated concentrations of carbon dioxide in the same soil gas sample. In the study area, carbon dioxide anomalies, as well as sulfur gas anomalies, probably result from oxidation of pyrite and other sulfide minerals along the Trans-Challis fault system. Where precious metals are associated with the pyrite, for example in auriferous pyrite in the Gold Hill mine (Kiilsgaard and others, 1989), the carbon dioxide anomalies may be useful guides to ore. Carbon dioxide anomalies are shown in figure 4, and sites at which these anomalies coincide with low oxygen values are shown in figure 5. Most of these anomalous sites occur in areas of known mineral deposits, but not all. However, all anomalous sites may be underlain by oxidizing sulfide deposits. The anomalies along the Elk Creek drainage, just north of Idaho City, may indicate pyrite (auriferous?) in bedrock beneath the terrace gravels and alluvium.

The sulfur gases, COS, SO_2, H_2S and CS_2, have been found over disseminated gold deposits (Kesler and others, 1990),
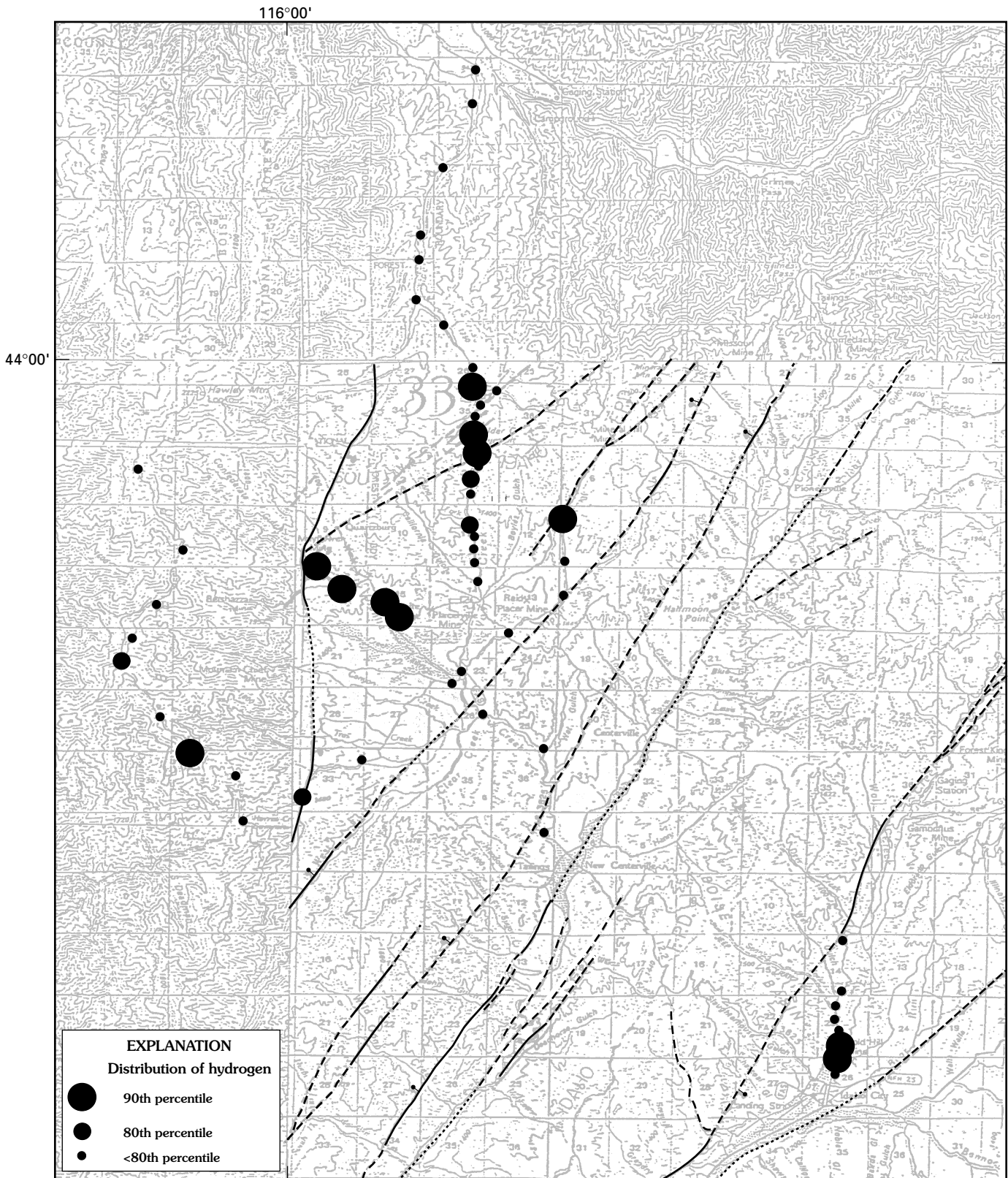
Figure 3. Map showing the distribution of hydrogen in the vicinity of the Trans-Challis fault system near Idaho City, Idaho.

massive sulfide deposits (Hinkle, 1986), and porphyry copper deposits (Hinkle and Dilbert, 1984). Both COS and CS_2 have been produced in laboratory experiments with sulfide minerals (Taylor and others, 1982). Most sulfur gas anomalies in the study area are within the inferred boundary of the Trans-Challis fault system. Where ore minerals are present as sulfides, or in association with sulfide minerals, sulfur gas anomalies can be useful geochemical indicators. They cannot, however, be used to distinguish barren sulfide deposits from those that contain ore minerals.
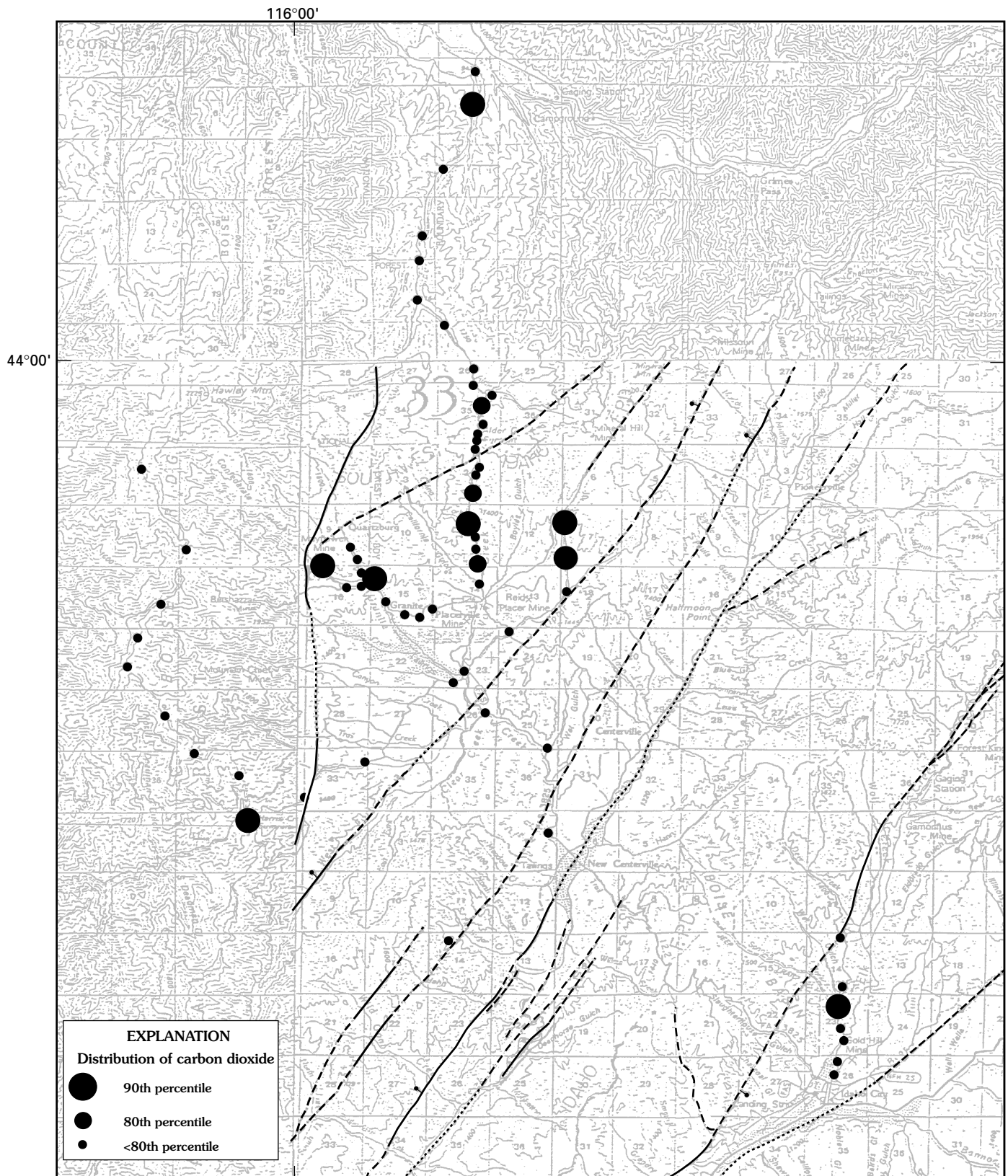
Figure 4. Map showing distribution of carbon dioxide in the vicinity of the Trans-Challis fault system near Idaho City, Idaho.

Hydrocarbon gases are associated with base-metal deposits (Disnar, 1990) and gold deposits (Clifton, 1986; Kessler and others, 1990). One explanation offered for the presence of hydrocarbon gases around mineral deposits is that they result from thermal maturation of organic matter in host or wallrock by the hydrothermal solutions that introduced the ore and gangue minerals, a process that has been termed "hydrothermal catagenesis" (McCarthy and Bigelow, 1990). Alternatively, the
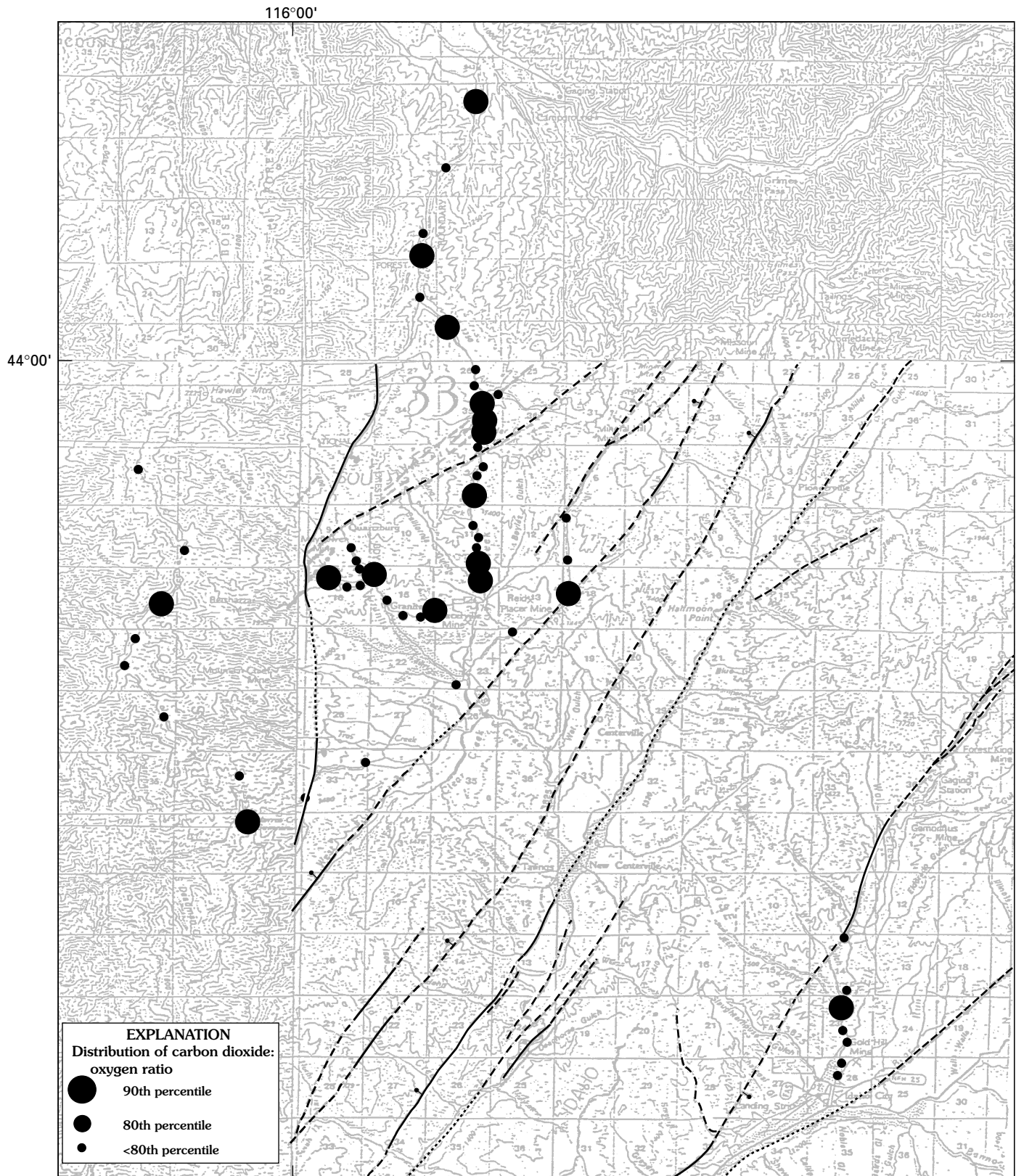
Figure 5. Map showing distribution of carbon dioxide-to-oxygen ratios in the vicinity of the Trans-Challis fault system near Idaho City, Idaho.

hydrocarbons may have been generated elsewhere and transported in the hydrothermal solutions. In either event, they can be useful geochemical guides. Methane, propane, butane, and pentane anomalies were identified along the northeast-trending shear zones that extend through the Alder Creek Summit area, as well as to the southwest along Boise Ridge where they correlate roughly with shear zones that cross the ridge and extend to the southwest. All of the hydrocarbon gas anomalies are within
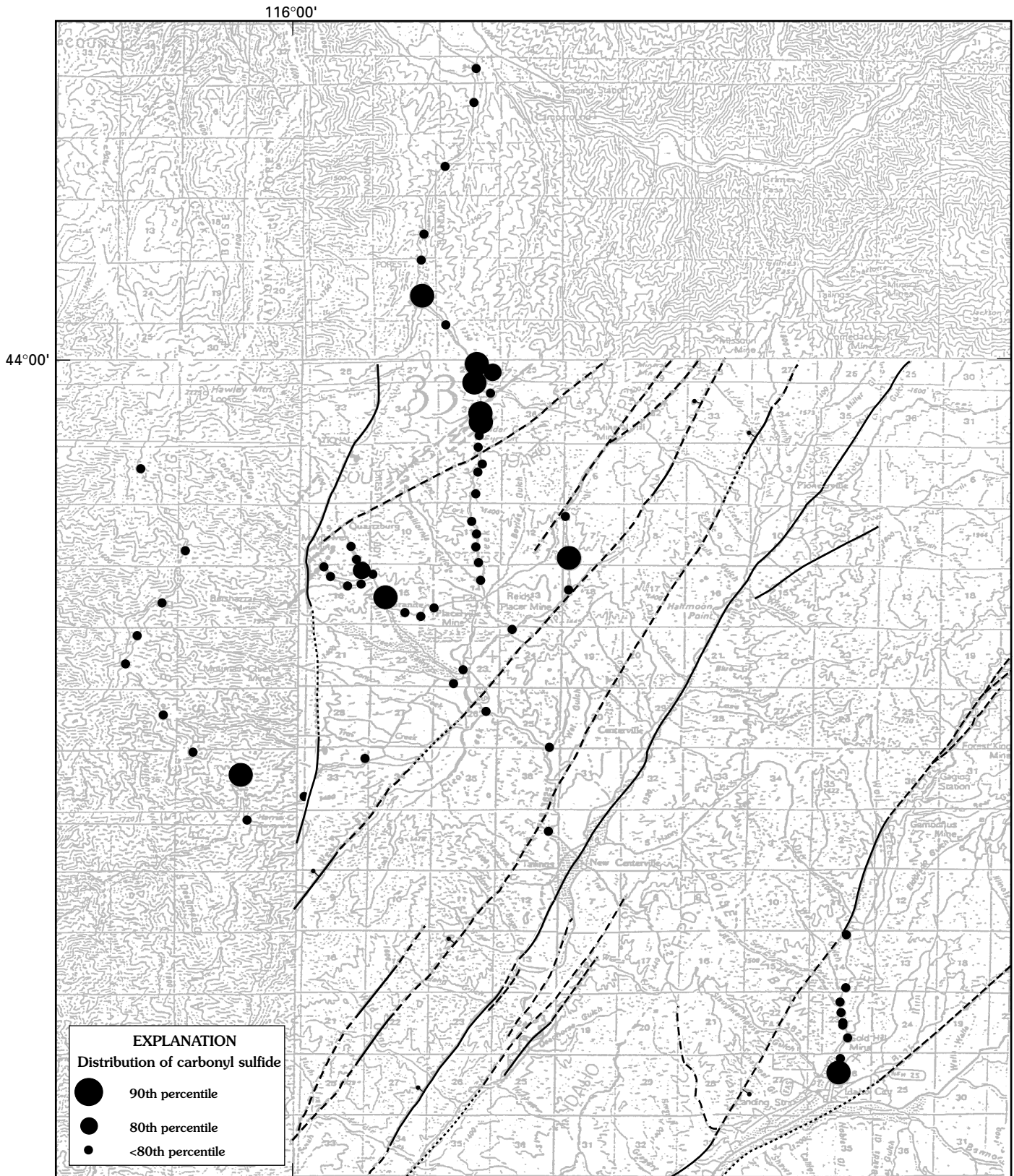
Figure 6. Map showing distribution of carbonyl sulfide in the vicinity of the Trans-Challis fault system near Idaho City, Idaho.

the inferred boundary of the Trans-Challis fault system. There is mounting evidence for the spatial, and perhaps genetic, relationship of organic matter to mineral deposits (Dean, 1986).

The soil gas analysis indicates that arsine gas (AsH_3) is present in some of the samples. This volatile compound could be

a useful indicator, considering the common association of arsenic with hydrothermal ore deposits. Arsenopyrite is a common gangue mineral in precious-metal deposits in the area. For example, at the Mountain Chief mine arsenopyrite contained 0.55 ounces of gold per ton (Ballard, 1924).
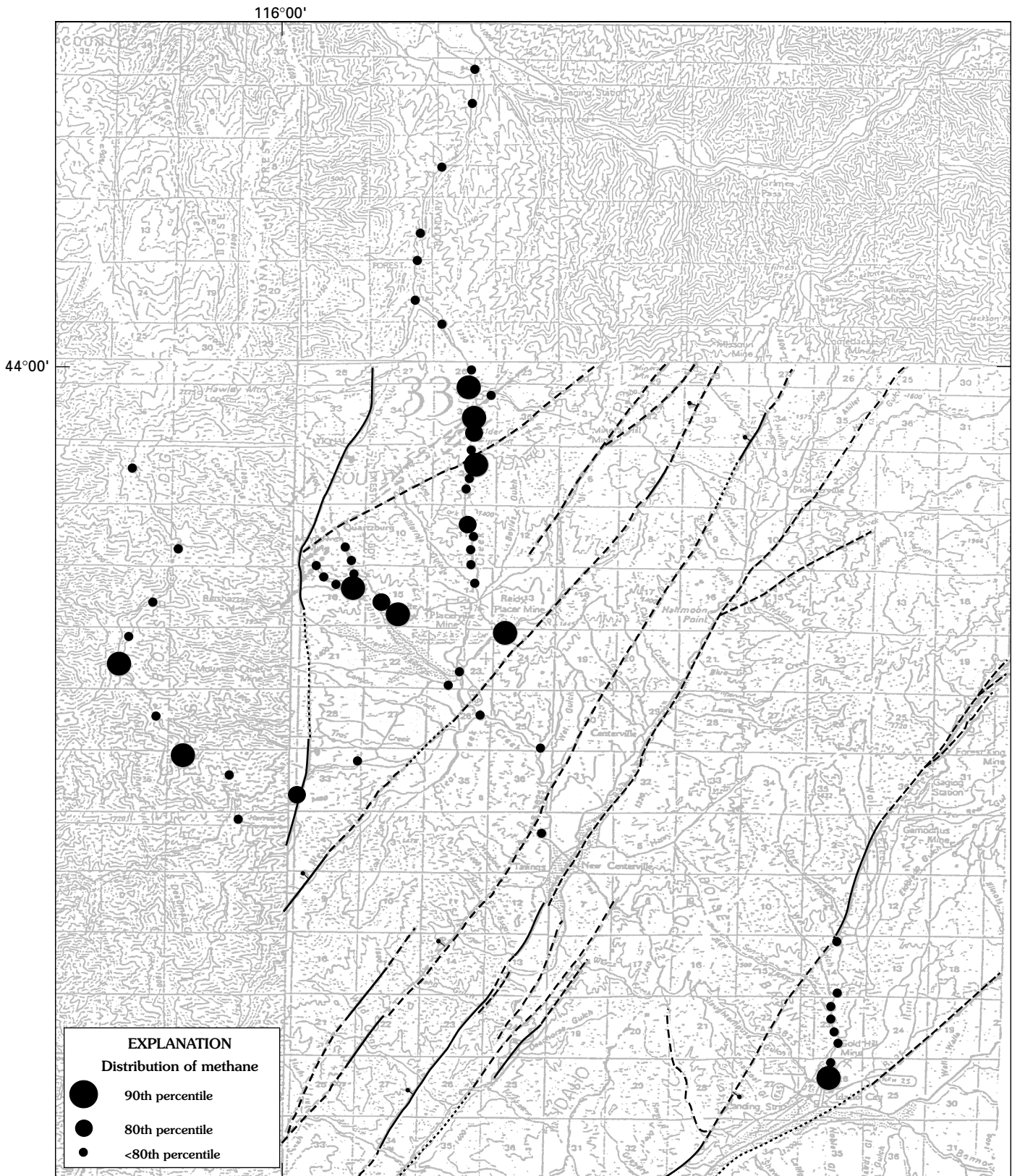
Figure 7. Map showing distribution of methane in the vicinity of the Trans-Challis fault system near Idaho City, Idaho.

Ammonia was detected in soil gases over mineralized areas in the Trans-Challis fault system. Ammonia has been found in association with base and precious-metal deposits in clay minerals and feldspars (Bloomstein and others, 1987), and it may be another useful indicator gas in the area.

Conclusions

Anomalous concentrations of soil gases delineate the Trans-Challis fault system in the study area. Soil gas anomalies also coincide with known mineral deposits and mineralized
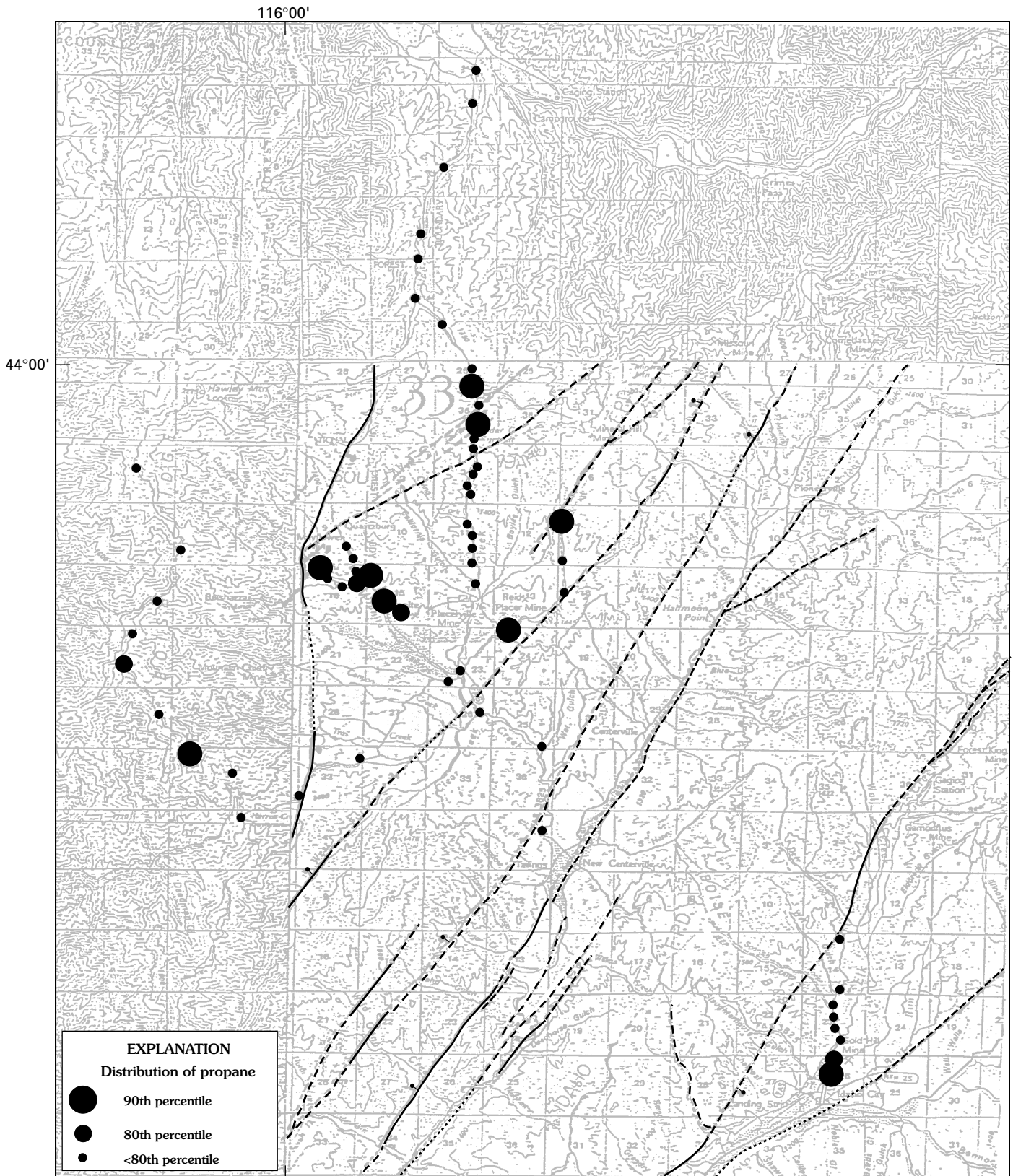
Figure 8. Map showing distribution of propane in the vicinity of the Trans-Challis fault system near Idaho City, Idaho.

areas. Carbon dioxide-oxygen ratios, sulfur gas concentrations, and hydrocarbon gas concentrations correlate with known mineral deposits whereas hydrogen concentrations are probably the best indicator of faults. Carbon dioxide-to-oxygen ratios are anomalous at sites that extend along the Alder Creek drainage south of Garden Valley and may indicate concealed sulfide deposits. Similar anomalies in the Elk Creek drainage just north of Idaho City may indicate sulfide deposits in bedrock beneath the gravel deposits. Soil gases may be useful guides for tracing faults and mineral deposits in this terrane.

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