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# Anomalous Concentrations of Several Metals in Iron-Formation of the Blue Lead Mountain Area, Pennington County, South Dakota

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ABSTRACT

Geochemical sampling of bedrock has revealed anomalous copper, silver, molybdenum, gold, arsenic, mercury, zinc, and cobalt in meta-iron-formation in the Blue Lead Mountain area 5 miles (8 kilometres) north-northwest of Keystone, S. Dak. The anomalies are in complexly folded and faulted iron-formation. Metal content decreases sharply in the surrounding rocks. The extent and intensity of the anomalous areas, despite evidence that previous mining had little success, are sufficient to make this area an interesting target for exploration.

## INTRODUCTION

Metamorphosed iron-formation is the host rock of many of the gold prospects and small mines as well as of the one truly large deposit — the Homestake mine — in the Black Hills of western South Dakota. The area surrounding the village of Keystone, which is 15 miles (24 km) southwest of Rapid City in the Mount Rushmore quadrangle, has an unusual number of sizable bodies of grunerite-quartz iron-formation. In times past, Keystone itself has been a center of gold mining and exploration in a northwesterly trending belt several miles long, containing mineralized iron-formation, gold-quartz veins, and many folds and faults.

In 1971 W. H. Raymond conducted a geochemical sampling program of the Keystone region, especially in localities with iron-formation and associated rocks, which previously had been mapped by J. J. Norton. As might be expected, iron-formation near Keystone contains anomalous amounts of several metals, and so does iron-formation elsewhere in the region.

This report describes the outcome of work around Blue Lead Mountain, 5 miles (8 km) north-northwest of Keystone, where exploration in the past may not have been as comprehensive as is warranted. The geology and the outline of the area studied are shown in figure 1. Additional samples were collected from here in 1973 by Raymond and R. U. King. The area is mostly in the Black Hills National Forest, but a portion at Sheridan Lake and for 2 miles (3 km) south of it is either in a recreational area closed to mineral entry or is privately owned.

For information about roads and for more geographic detail than is shown in figure 1, the best source is the Mount Rushmore topographic map (scale1:24,000) in the photorevised edition of 1971. The principal roads are U.S. Highway 16, which crosses the southeast part of the area shown in figure 1, and Sheridan Lake Road, which crosses the area near its north border. Roads of lesser quality, ranging down to nearly impassable old logging trails, make most of the area accessible. A few roads were extensively washed out during the flood of June 9, 1972, as a result of about 14 inches (360 mm) of rainfall.

The principal workings, as shown in figure 1, are at the Blue Lead and Dakota Calumet mines, about 1 mile (1.6 km) south of Blue Lead Mountain, and at a locality 2 miles (3.2 km) farther to the southeast known as the Wealthy mine according to Francis Michaud (oral commun., 1974).

The Wealthy mine, which almost certainly was opened for gold, seems to have been mentioned in the published record only on a map by Scott (1897).

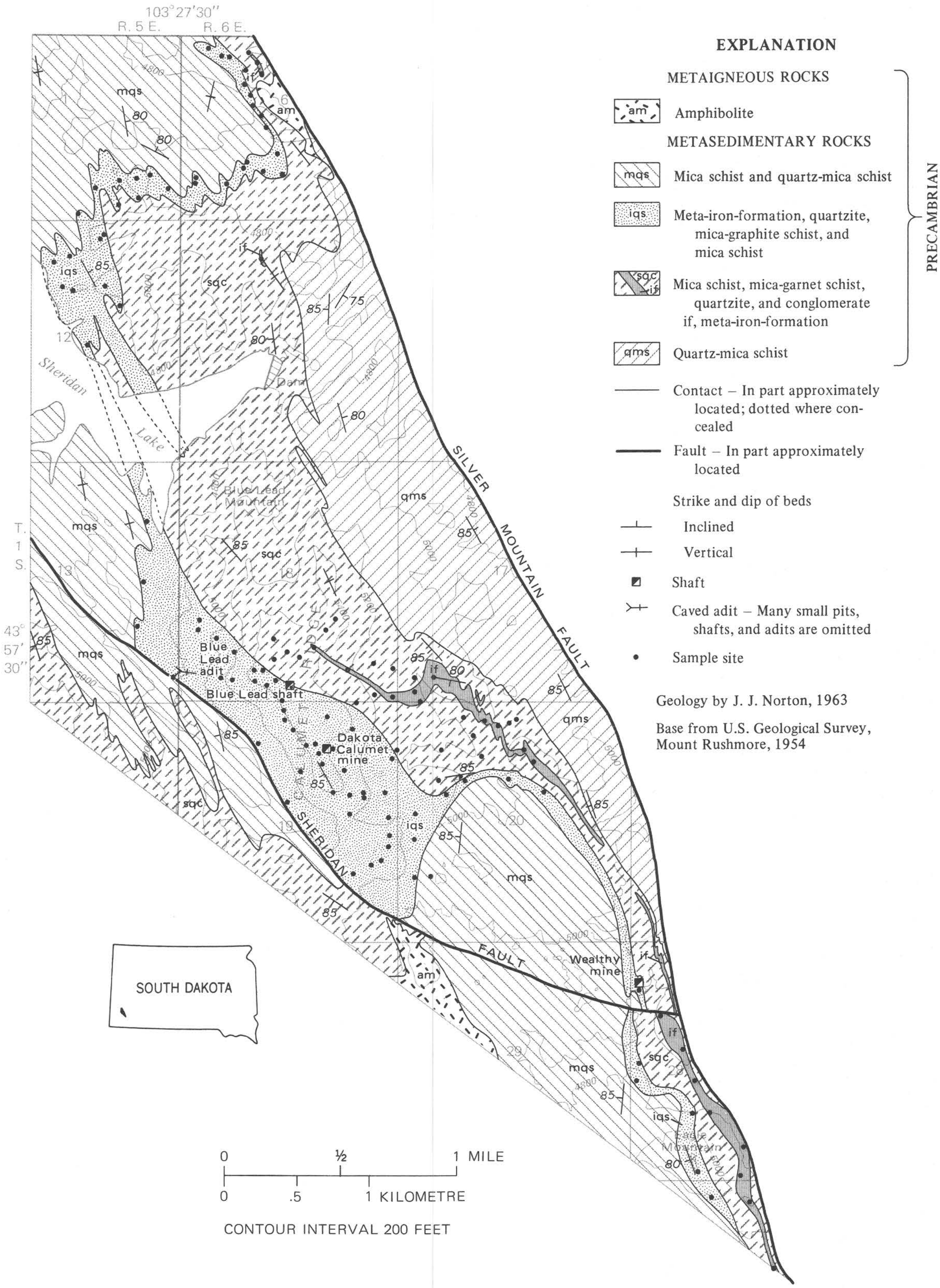


FIGURE 1. — Geologic map of the Blue Lead Mountain area, Pennington County, S. Dak.

It has a shaft at least 100 feet (30 m) deep, and the size of the dump indicates an additional 200–300 feet (60–90 m) of underground workings.

Better information is available for the Blue Lead and Dakota Calumet copper mines in reports by Connolly and O'Harra (1929, p. 209–210) and the U.S. Bureau of Mines (1955, p. 32–33), though both of these reports were written long after activities at these sites had ended. The Blue Lead mine has a 1,610-foot (490-m) adit and a 260-foot (80-m) vertical shaft. The Dakota Calumet shaft is 850 feet (260 m) deep and has an 1,170-foot (357-m) crosscut with nine drifts presumably of modest length. Ore was processed in a small matte smelter, of which only ruins now remain. Mining operations began as early as 1879 and continued intermittently until 1919.

Prospect pits, small open pits, and short adits are common in iron-formation in the area covered by the map, though not as common as in most other parts of the Keystone region. They are especially sparse on rubble-covered slopes of Calumet Ridge. Apparently the early gold prospectors found little cause for enthusiasm, and the evident lack of success of copper mining is also discouraging. Yet a considerable thickness of grunerite iron-formation exists over a distance of several miles, with only a few thousand feet of exploration workings, no drill holes, and almost no record of what was found. These circumstances, together with our geochemical results, indicate that more work might be worthwhile.

## GENERAL GEOLOGY

All of the rocks shown on the geologic map (fig. 1) are of Precambrian age. Most of them are on the east limb of a long narrow syncline that has been mapped by Norton for several miles to the south-southeast. The rocks southwest of the Sheridan fault from the center of section 29 to the west limit of the map are on the west limb of this same syncline. All the folds shown on the map are subsidiary structures superimposed on the main syncline.

Whether the syncline is in fact a syncline rather than an anticline is not certain. Bedding on the two limbs is generally parallel in both strike and dip, and unambiguous evidence of tops of beds is sparse both here and elsewhere in the Keystone region. For the purposes of this report the question is unimportant.

### STRATIGRAPHY

The oldest unit is a lenticular body of quartz-mica schist cut off by the Silver Mountain fault along the east border of the map. The rock is the metamorphic equivalent of an impure sandstone, now consisting mainly of quartz, muscovite, biotite, and plagioclase, with accessory microcline, garnet, and other minerals.

The succeeding unit consists mostly of mica schist and of occasional layers of mica-garnet schist in which both muscovite and biotite as well as quartz are abundant, but the most prominent outcrops are of massive beds of clastic quartzite. Few of the quartzite beds are more than 5 feet (1.5 m) thick or can be traced more than 100 feet (30 m) along strike; some of the premetamorphic lenses of sandstone may have been much longer than this but were sheared off by intense folding or were separated by the development of boudinage. Most of the quartzite is gray, but it ranges to nearly white, and some has a bluish cast. The name Blue Lead undoubtedly comes from the bluish quartzite and the miner's term "lead."

In the spillway of the Sheridan Lake dam, near the base of this unit, is a large exposure of conglomerate with boulders of quartzite in a matrix of mica schist. Similar conglomerate is common elsewhere in the Keystone region, but generally its nature is obscured by weathering and a cover of lichens. At all known localities the conglomerate fragments are virtually all of quartzite; close search reveals pebbles of schist and occasionally of amphibolite, but no vein quartz forming convincing pebbles has ever been detected. Though some of the quartzite fragments are round, they generally are ellipsoidal, with the long axis plunging nearly vertically, parallel to the predominant minor folds of the region. The size of the quartzite fragments ranges from small pebbles to masses tens of feet long, differing in no obvious way from nearby quartzite beds. These observations suggest that the rock may be a pseudoconglomerate, originating through deformation that separated quartzite beds into small pieces. A more plausible interpretation, however, is that the rock is in fact a true conglomerate, but also contains lenses of sand formed from the same source rock as the quartzite pebbles. During metamorphism the sand lenses would have acquired the same appearance as the true pebbles. The contact with the underlying quartz-mica schist may be a major unconformity.

Layers and lenses of meta-iron-formation are common features in this part of the stratigraphic sequence throughout the Keystone region. The thick meta-iron-formation unit that crosses Calumet Ridge and extends to the north and south borders of the geologic map is merely an unusually large example, though it is treated on the geologic map as a separate stratigraphic unit because of its central importance in the geochemical sampling done for this report. Its lithology can be described with that of the smaller bodies of meta-iron-formation nearby.

The predominant rock is grunerite schist containing lenses and layers of metamorphosed cherty quartzite. At the surface, and perhaps in some mineralized segments in the subsurface, the rock is generally limonitic and earthy. Most such rock is probably a result of nearly lateritic weathering prior to Upper Cambrian sedimentation. The iron-formation can grade along strike into grunerite schist with only a slight amount of quartzite, where the iron content may be about 30 percent, or it can grade into nearly pure quartzite with streaks of graphite, mica, garnet, or other accessory minerals. South of the Wealthy mine, just beyond the Sheridan fault, is the best example of thick-streaked quartzite in the area shown in figure 1, but adjoining areas contain many localities of such quartzite. The grunerite schist of the Blue Lead Mountain area has not been examined in thin section, but observations elsewhere suggest that it probably also contains common hornblende and possibly actinolite.

Other rocks interlayered with iron-formation are chiefly micaceous and graphitic schists. Gray quartzite, possibly of clastic origin, appears in places on the west slope of Calumet Ridge, but these may represent unmapped infolds of the quartzite-bearing unit lying to the east.

Where iron-formation is of greatest thickness, the cause is duplication by tight folding, as can be seen on the geologic map just north and south of Sheridan Lake. Fault movement along shear zones reported in underground workings (U.S. Bureau of Mines, 1955, p. 32–33) may increase the exposed thickness of Calumet Ridge. The actual structure of the iron-formation beneath Calumet Ridge is probably far more complicated than is indicated by the map of the surface.

The youngest metasedimentary unit, which occupies the center of the syncline, consists of mica schist and muscovite, biotite, quartz, plagioclase, and sparse garnet interlayered with massive beds that are more quartzose and less micaceous.

The amphibolite of the region is a hornblende-plagioclase rock of approximately gabbroic composition. Much of it is fine grained and probably a metabasalt. The amphibolite in the NW¼ section 29 is the northeast extremity of a large body that is for the most part so coarse grained that it may be called metagabbro. It is, however, probably a volcanic pile. Virtually all the amphibolite in the Keystone region is within or near the stratigraphic level of iron-formations, quartzites, and associated rocks that cross Calumet Ridge and Blue Lead Mountain. Thus these metasedimentary rocks are probably the same age as the metaigneous assemblages.

The valleys of the Blue Lead Mountain area contain only intermittent streams with narrow flood plains underlain by a meager quantity of Quaternary alluvium. Terrace gravels of older age are so sparse that they hardly merit being mentioned; the only sizable one extends for about 1,000 feet (305 m) along a ridge at the border of sections 1 and 12 east of the meta-iron-formation.

Bog iron was exposed by the flood June 9, 1972, in a few places scattered along a 0.5 mile (0.8 km) stretch of a valley in the N½ section 20. It probably continues northeast into section 17. The maximum width is at least 100 feet (30 m) and the thickness is as much as 6 feet (2 m).

## STRUCTURAL GEOLOGY

The principal structures are three categories of folds, presumably of different ages. One is the main syncline. Another consists of the isoclinal folds southwest of the Sheridan fault and of the folds near Sheridan Lake and north of it. And the third is the rather open folds east and southeast of Calumet Ridge.

Though the main syncline has been mapped several miles to the south-southeast, its structure is inexactly known. Dips are nearly vertical on both limbs, and though the strike of bedding can be highly changeable from later deformation, the overall trend of stratigraphic units on the two limbs is nearly parallel or slightly divergent to the north. Hence this is an isoclinal fold. Presumably the plunge is gentle, although no small folds of gentle plunge have been noticed.

The folds observed in many outcrops plunge very steeply — from about 70° south to 80° north. These are associated with the set of folds shown on figure 1 near Sheridan Lake and southwest of the Sheridan fault. Such folds tend to be nearly or quite isoclinal, and can cause a single unit to be overthickened by being folded against itself several times, as probably happened in the iron-formation crossing Calumet Ridge. A notable characteristic of these folds is their right-hand movement pattern on the east limb of the major syncline and left-hand pattern on its west limb, which implies that they are merely subsidiary folds or "drag folds" associated with the syncline. The steep plunge, however, argues otherwise: a syncline many miles long cannot plunge vertically without causing serious geometric problems at depth. More likely the small folds were formed in beds that were already dipping vertically. Conceivably, in the development of the large synclines and anticlines of the Keystone region, these small folds represent a late stage in which shear forces shifted in orientation to create a nearly horizontal compressional effect parallel to the axial planes of the larger folds.

The last set of folds consists of the rather open folds with a left-hand movement pattern east or southeast of Calumet Ridge. Folds of this kind, though sparse in the Keystone region, have also been mapped on the west limb of the major syncline. Strike and dip observations on bedding in the large fold in section 20 indicate a nearly vertical plunge.

The Silver Mountain fault, along the east side of the geologic map, is one of several large north-northwesterly striking faults in the Keystone region. Younger rocks crop out northeast of the fault, indicating that it is downthrown on that side, but that it probably also has a large lateral displacement. The Sheridan fault also generally has younger rocks on its northeast side, though it has an odd relation to the iron-formation on Calumet Ridge, brought about by the crossfolds in section 20. The faults have steep dips and nearly straight traces, showing they are younger than the folds, but neither fault shows evidence of being younger than the metamorphism.

## MINERALIZATION

Information about the mineralized parts of the Blue Lead and Dakota Calumet mines is meager. The chief sources are brief descriptions by Connally and O'Harra (1929, p. 209–210) and the U.S. Bureau of Mines (1955, p. 32–33), based on observation of the dumps and on information probably originally obtained mostly from men who had worked in these mines.

The Blue Lead adit cut an ore-bearing shear zone, 1,400 feet (430 m) from the entry, that strikes N. 25° W. and dips 60° to 70° east. The Dakota Calumet workings entered a mineralized shear zone of similar attitude and 50 to 200 feet wide. Presumably it is the same shear zone as in the Blue Lead adit. The shear zone has not been recognized at the surface, perhaps because it is covered by rubble on the west side of Calumet Ridge, and whatever surface evidence of shearing one might observe would ordinarily be attributed to tight folding.

Metalliferous minerals in unaltered ore include pyrite, pyrrhotite, and chalcopyrite. Locally oxidized ore contains azurite, malachite, chrysocolla, cuprite, tenorite, and native copper. Analyses of our samples indicate as much as 0.3 percent arsenic, implying that arsenopyrite is also in the ore. No molybdenum or zinc minerals have been recognized, even though geochemical samples from near these mines contain as much as 70 ppm (parts per million) molybdenum and 2,000 ppm zinc.

## GEOCHEMICAL ANOMALIES

Figures 2–9 show the distribution of geochemical anomalies detected by analyses of 135 samples of bedrock or large float blocks. Most of the samples came from in or near iron-formation. The maps for copper, molybdenum, zinc, and cobalt are based on semiquantitative spectrographic analyses; similar analyses were made for many other constituents but were not sufficiently informative to be recorded here. Mercury, gold, and silver were determined by atomic absorption, and arsenic was by colorimetric analyses.

Four localities show anomalies. The most pronounced concentration of metals is on Calumet Ridge. A generally subdued anomaly is in the small unit of iron-formation east of this ridge. Another place yielding anomalous results is 1 mile (1.6 km) north of Sheridan Lake dam, and still another is near Eagle Mountain.

Copper produces a conspicuous anomaly on Calumet Ridge, which is not surprising when it is considered that this was the site of efforts to mine copper. Ten samples have a copper content of 2 percent or more, which is the upper limit for determining copper by the analytical method used. Most of these samples are in the northwest-trending group along or near the crest of Calumet Ridge (fig. 2). Another rich sample (containing visible malachite) is from just southeast of the top of Eagle Mountain. Elsewhere near Eagle Mountain, copper is rather uniformly distributed in amounts of 200–500 ppm. North of Sheridan Lake, however, the copper content of iron-formation ranges from a few tens of ppm to several hundreds of ppm without any conspicuous pattern.

The gold results are low, but detectable gold has the same distribution as other anomalous metals (fig. 3). The greatest amount found at Calumet Ridge is 0.25 ppm and the greatest amount found elsewhere is 0.15 ppm, in a sample from southeast of Eagle Mountain. This is in striking contrast to the Rochford district, 18 miles (29 km) to the northwest, where many samples of similar rocks contain more than 5 ppm gold (Bayley, 1972, pl. 2).

Silver, in amounts of 1–3 ppm, has approximately the same pattern as copper on Calumet Ridge (fig. 4). The amount of silver is comparable to that at Rochford, though some samples there are much richer (Bayley, 1972, pl. 3). North of Sheridan Lake the distribution of silver, like copper, is uneven, ranging from a trace to 3 ppm. Near Eagle Mountain several samples have 0.5–4.0 ppm silver; the rest yield smaller results.

Mercury, which is commonly used as an indicator of hydrothermal mineralization, is at levels of 1–10 ppm in many samples, especially in the vicinity of the Dakota Calumet and Blue Lead mines. It closely follows the patterns of copper, silver, and other metals (fig. 5). The amount of mercury is unimpressive north of Sheridan Lake and at Eagle Mountain.

Molybdenum is the only metal that yielded wholly unexpected analytical results. More than 40 percent of all samples contain 10–70 ppm molybdenum, and in the Calumet Ridge and Eagle Mountain localities nearly two-thirds of the samples are in this range. The Calumet Ridge anomaly includes six samples which contain 30–70 ppm molybdenum. Clearly, molybdenum is sufficiently anomalous in the Blue Lead area to justify further investigation. Molybdenum was of little commercial interest in the years when exploration and mining were active in this area, and its existence in mineralized rock of the underground workings would probably have been overlooked.

The remaining maps — figures 7, 8, and 9 — show anomalies in arsenic, zinc, and cobalt. The arsenic content, which commonly is several hundred or a few thousand ppm, suggests the presence of arsenopyrite. Zinc attains levels of as much as 2,000 ppm, thus indicating that some hitherto undetected zinc mineral is probably an accessory constituent of the mineralized rock. Cobalt occurs in amounts of 100–500 ppm in 11 samples on Calumet Ridge (mainly in samples high in other metals), and ordinarily is in amounts of 0–20 ppm elsewhere. All three of these metals occur in patterns generally similar to other metals discussed here.

## SUMMARY

Though the reason for undertaking this geochemical investigation was to find evidence for a gold deposit, the results give little cause for optimism on this score. Any gold deposits are likely to be small and of modest grade.

Nevertheless, one can be optimistic about the existence of some kind of metal deposit. Mercury analyses yield results that imply sulfide mineralization in the area, and anomalous amounts of other metals in a similar pattern indicate that mineralization may have been of considerable magnitude. Molybdenum is perhaps the most promising of the constituents analyzed, but copper and silver, despite the lack of success of early exploration, are not beyond hope. The body of iron-formation crossing Calumet Ridge has an average thickness of about 0.4 miles (0.6 km) for a distance of 1.5 miles (2.4 km). Shafts and crosscuts having a total length of only about 4,000 feet (1,200 m), with few surviving records of the results, seem insufficient to explore a body of rock of this size.

The Blue Lead adit, except at its caved portal, probably is open for most of its 1,610 feet (490 m), and thus could be rehabilitated sufficiently well for geologic mapping and sampling. Trenching to bedrock is also likely to be informative, especially on the west slope of Calumet Ridge. Because much of the ridge is so thickly covered with rubble and with a dense growth of pine trees, both our geologic mapping and sampling probably give oversimplified results.

Eventually subsurface exploration will be required for adequate evaluation of the mineral potential of the Blue Lead Mountain area.

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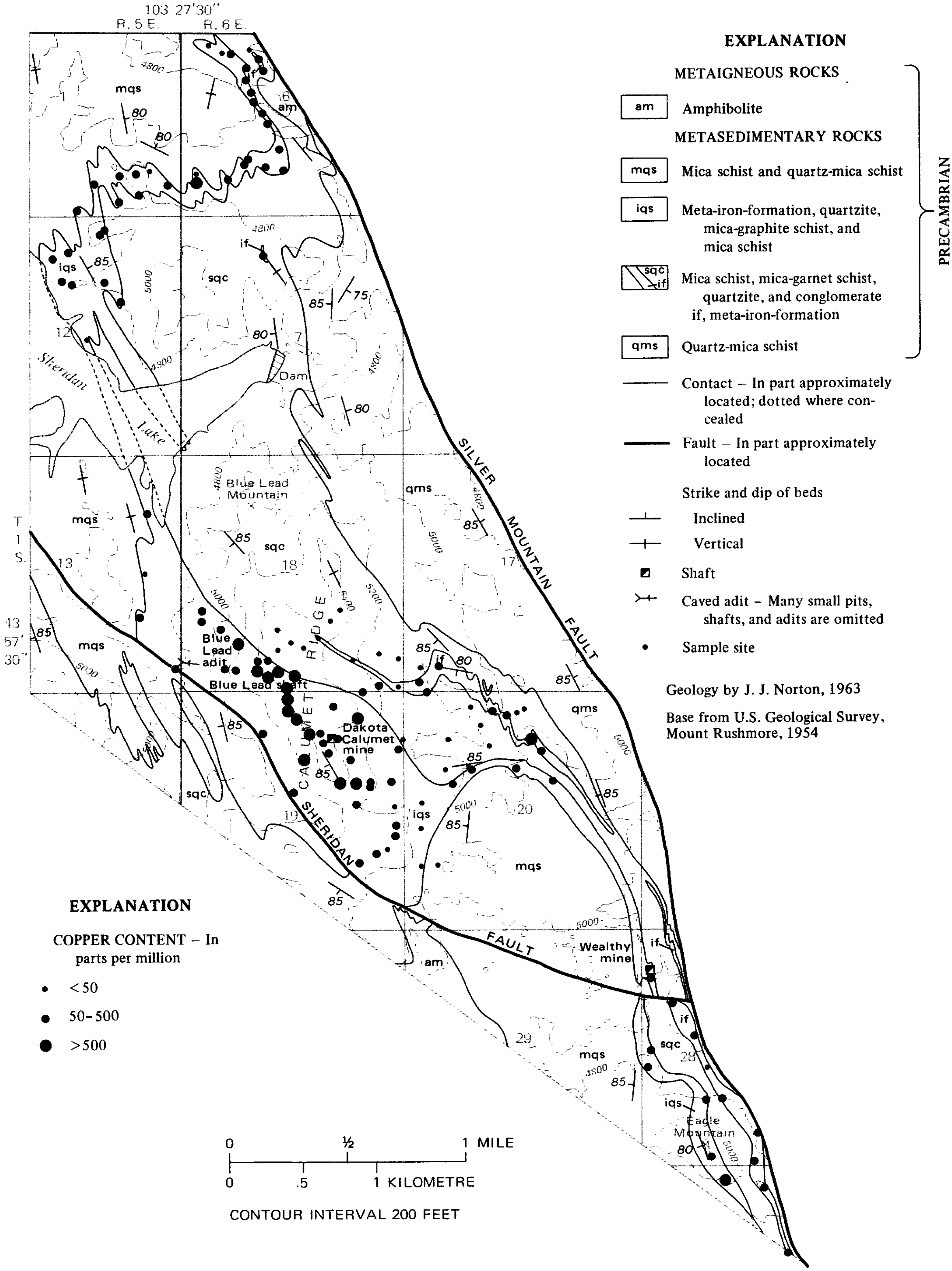


FIGURE 2. — Copper content, by semiquantitative spectrographic analyses.

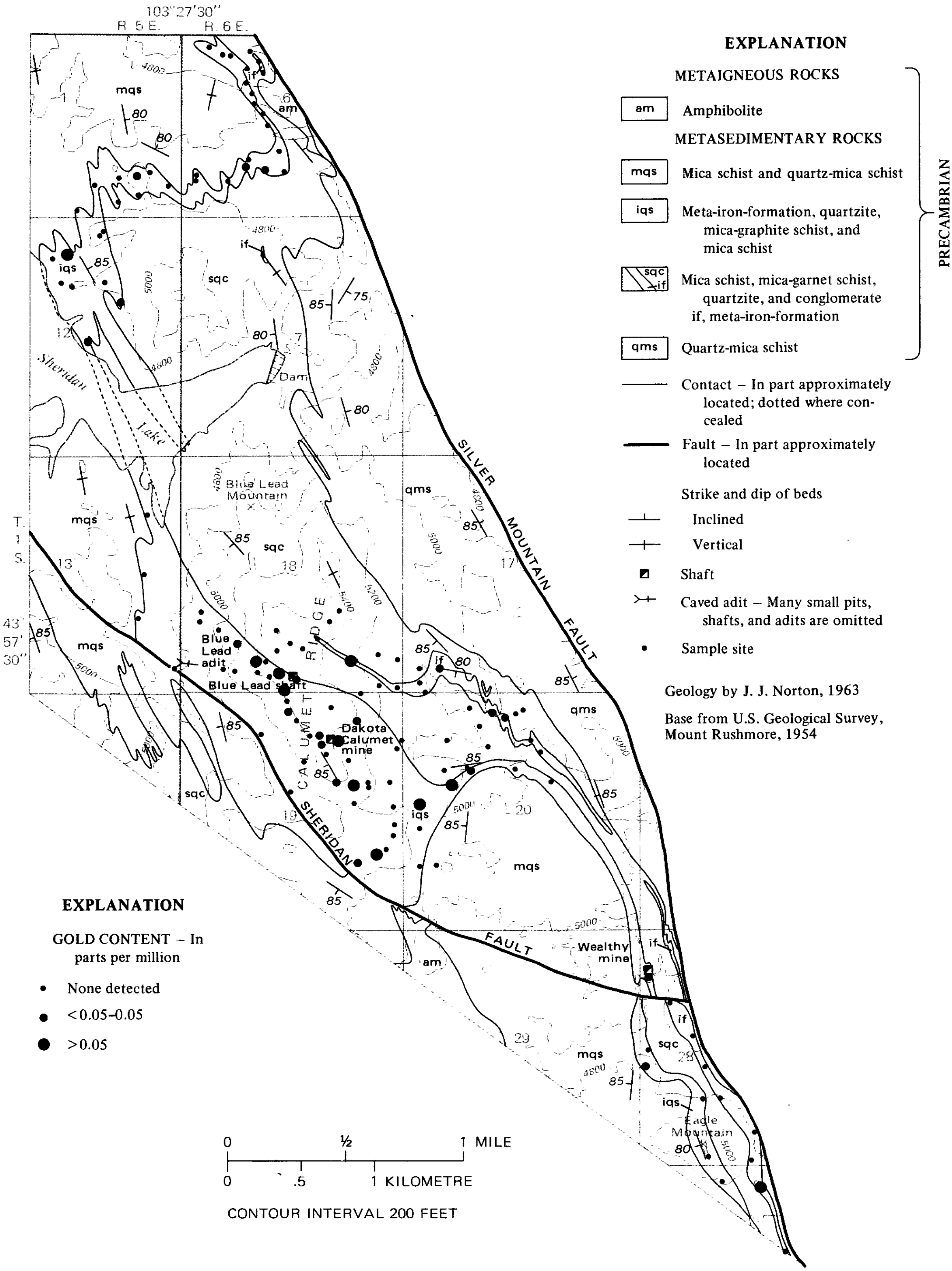


FIGURE 3. — Gold content, by atomic absorption analyses.

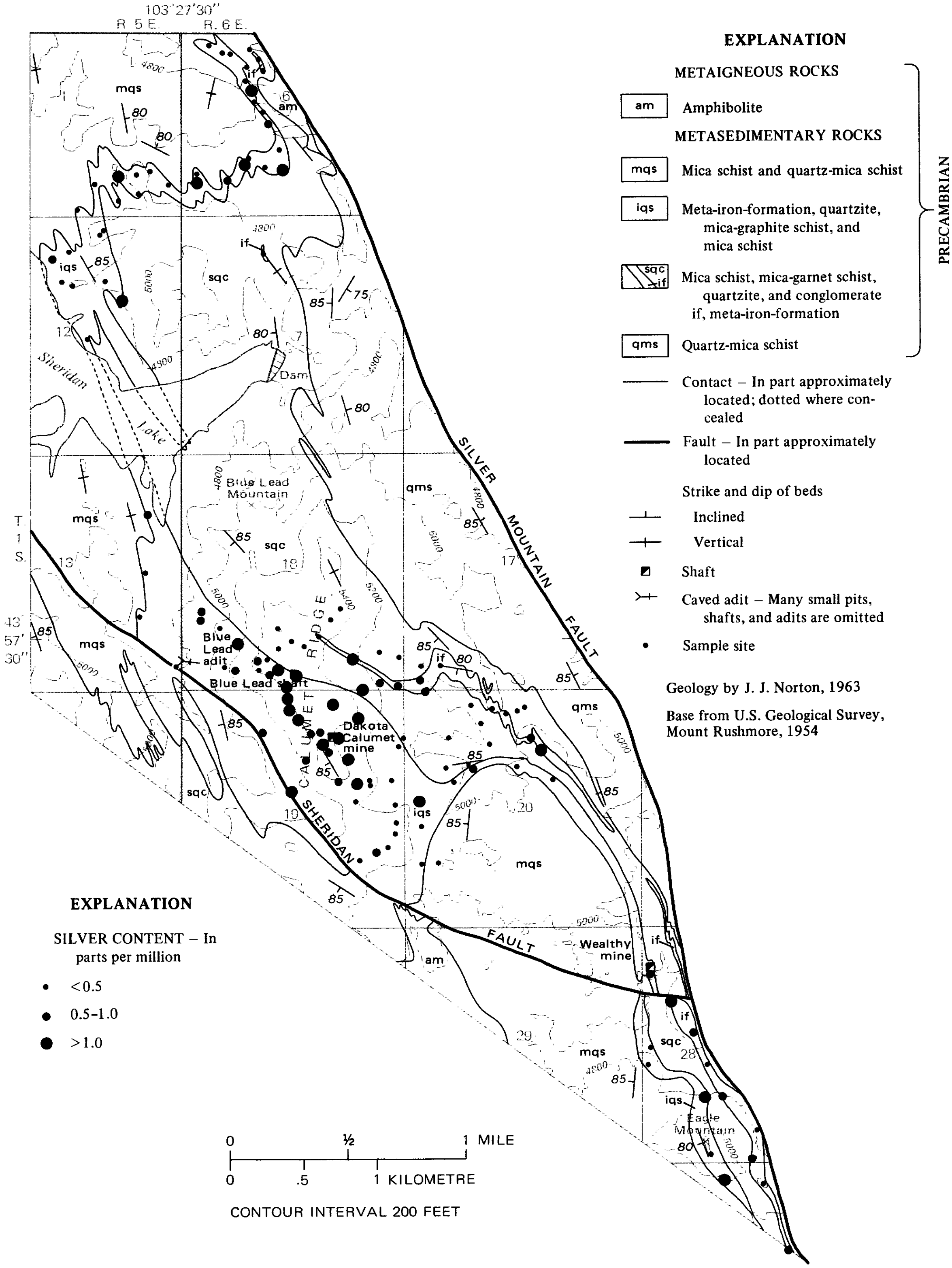


FIGURE 4. — Silver content, by atomic absorption analyses.

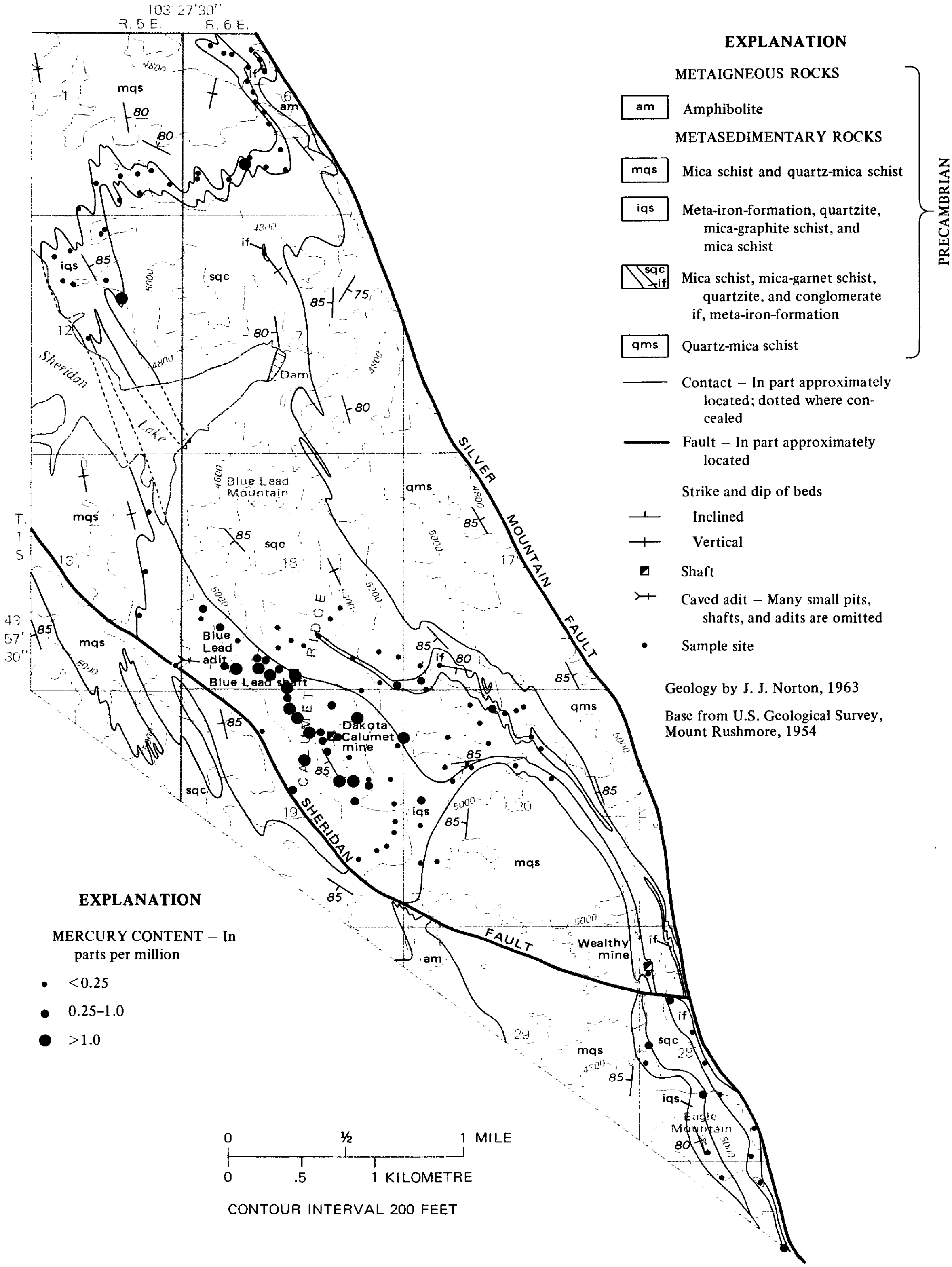


FIGURE 5. — Mercury content, by atomic absorption analyses.

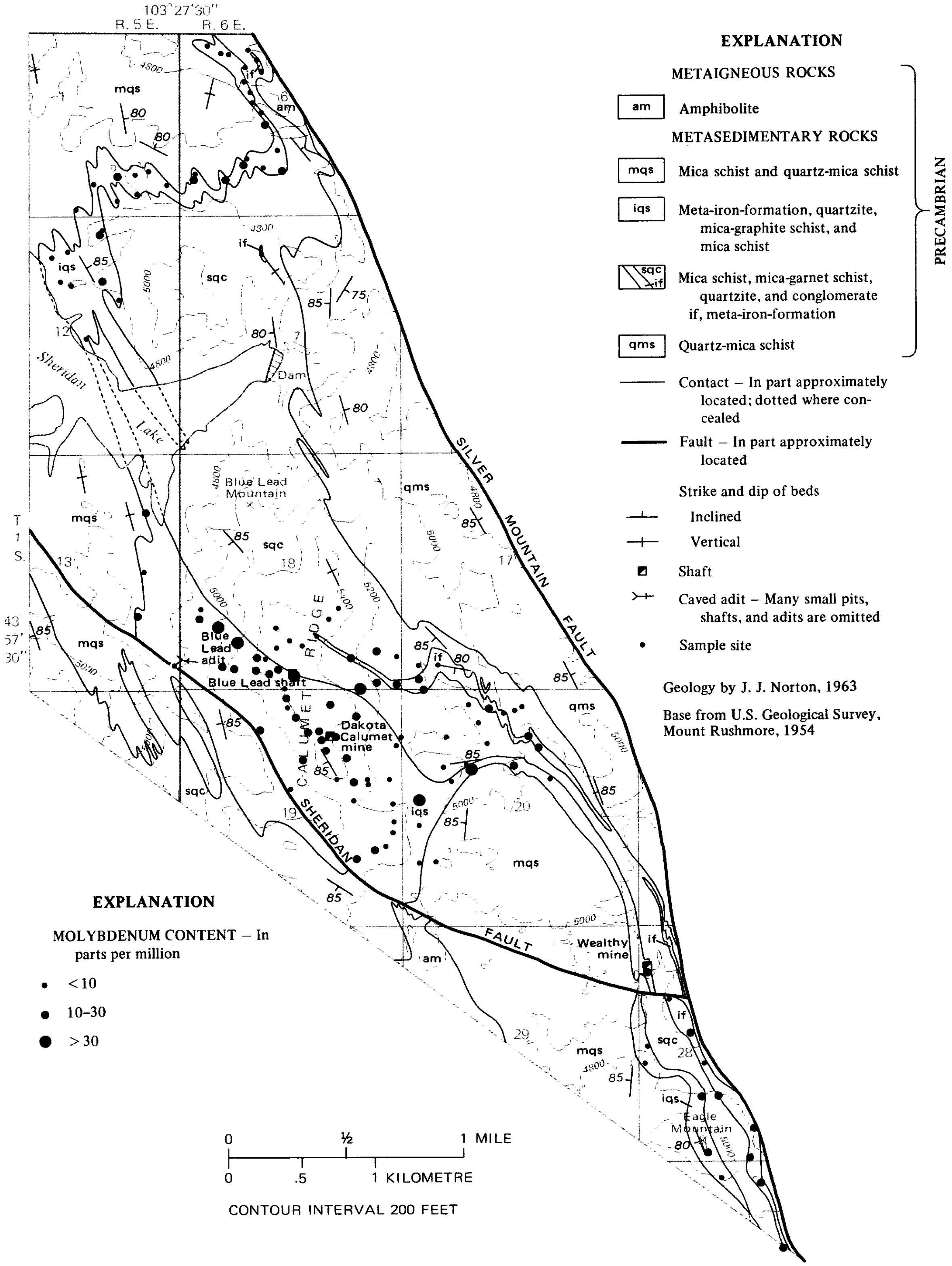


**FIGURE 6.** — Molybdenum content, by semiquantitative spectrographic analyses.

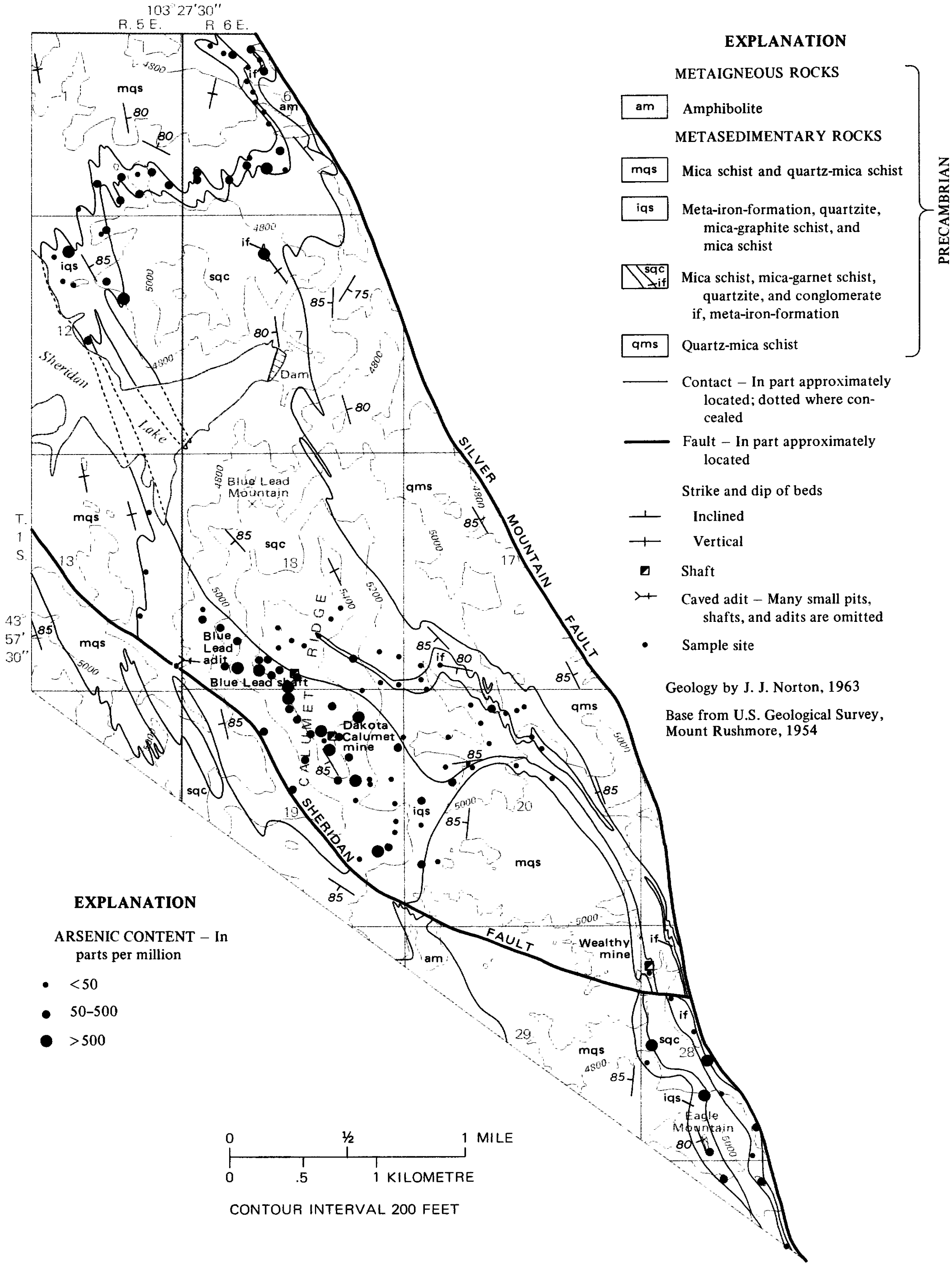


**FIGURE 7. — Arsenic content, by colorimetric analyses.**

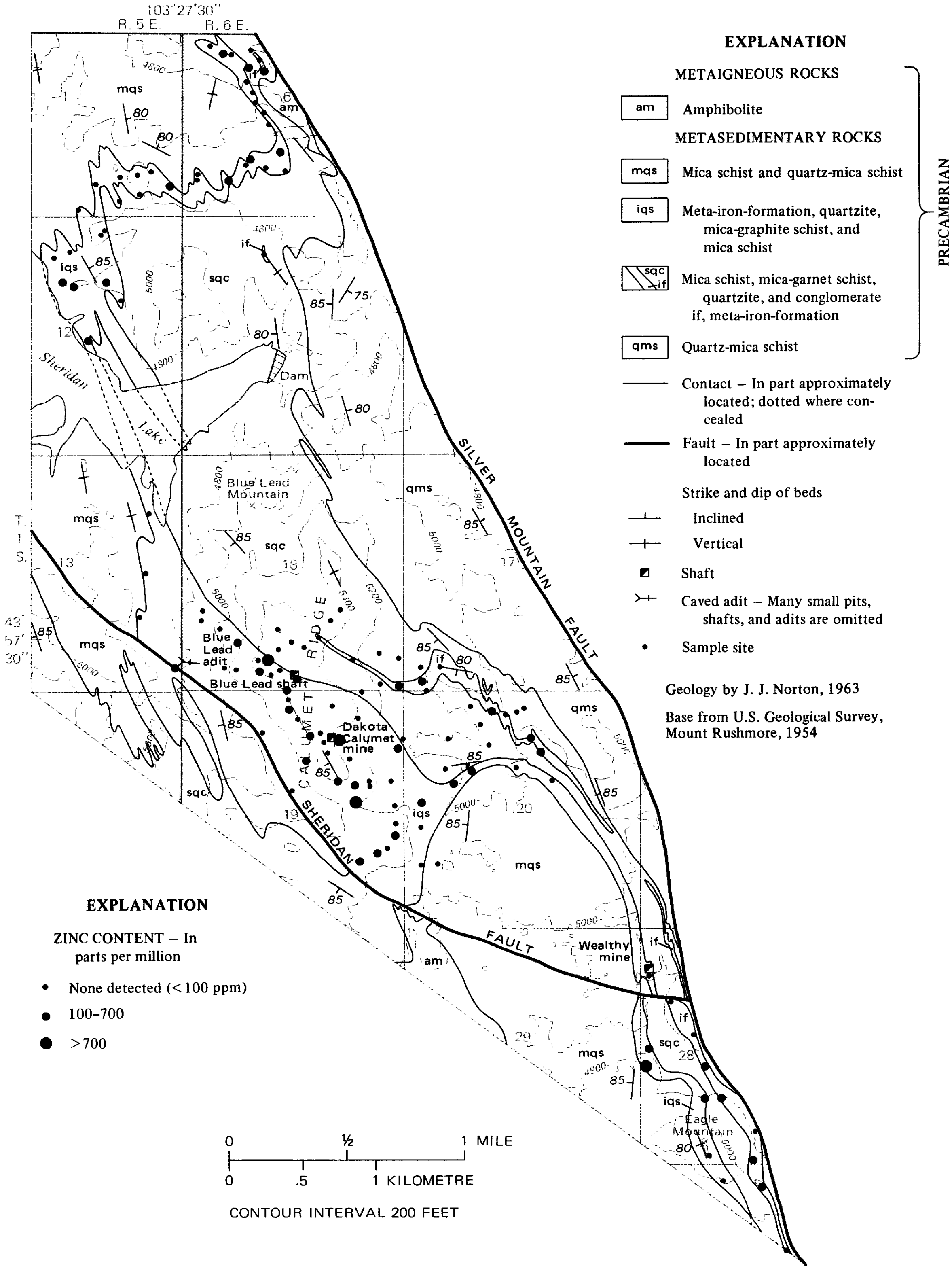


FIGURE 8. — Zinc content, by semiquantitative spectrographic analyses.

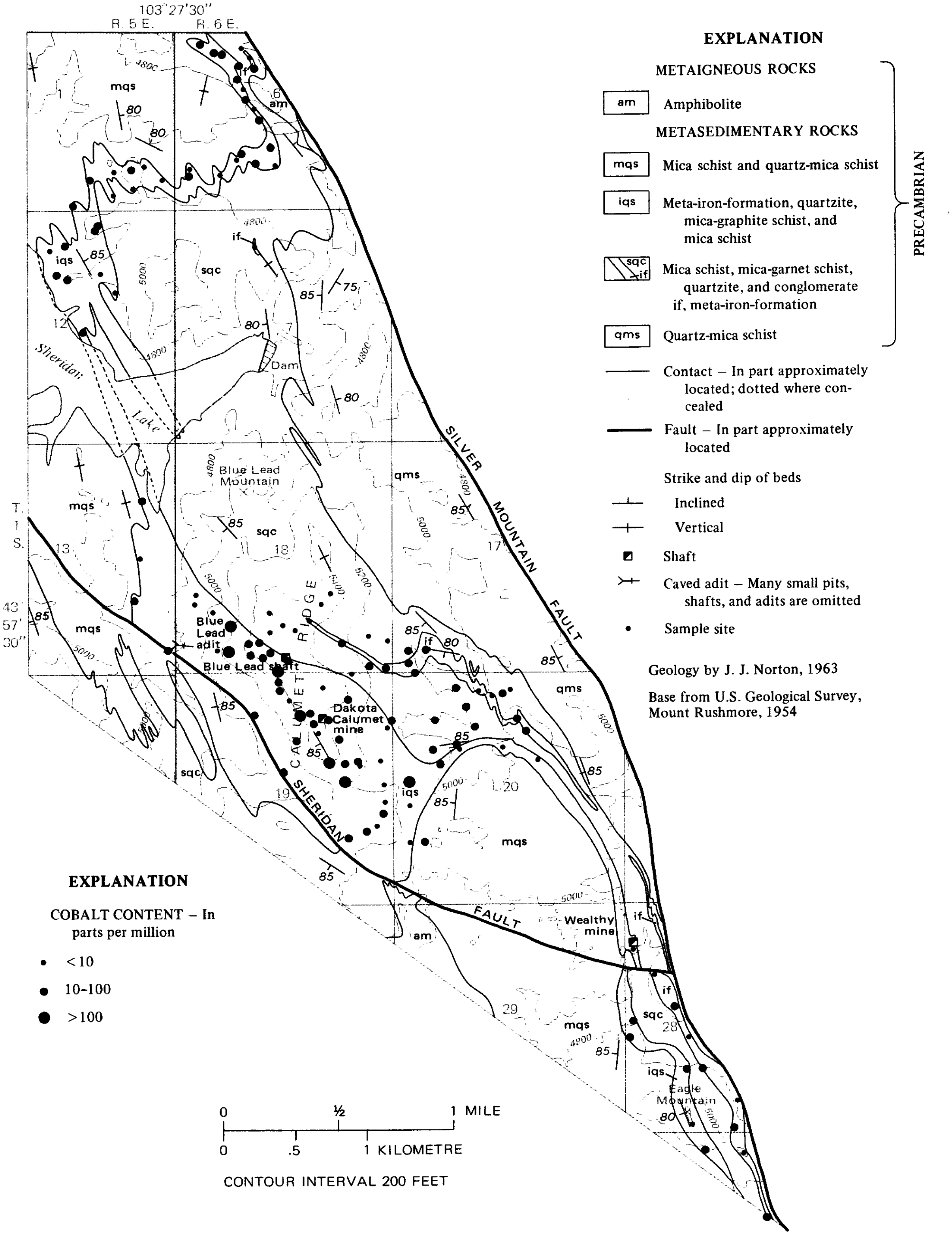


**Figure 9.** — Cobalt content, by semiquantitative spectrographic analyses.



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