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Geochemical anamolies and Isotopic ages in the Willow Creek mining district, southwestern Talkeetna Mts., Alaska

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Geochemical anamolies and Isotopic ages in the Willow Creek mining district, southwestern Talkeetna Mts., Alaska

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Introduction

The Willow Creek mining district, in southern Alaska, is in the southwestern part of the Talkeetna Mountains which are located south of the Alaska Range and north of the Chugach Mountains. The Talkeetna mountains are extremely rugged and heavily glaciated, with elevations in the Willow Creek area between 300 and 2200 meters. The mining district produced nearly $18,000,000 in gold and minor silver from mineralized quartz veins between 1909 and the early 1950's. Because of the occurrence of large amounts of copper in quartz veins which cut granitic rocks in the mining district and similarities of the geologic environment at Willow Creek with that in the Nabesna quadrangle to the northeast where numerous porphyry type disseminated copper deposits occur in similar granitic rocks (Richter and others, 1975a) a reconnaissance geochemical sampling program was carried out in the Willow Creek area. Approximately 150 samples of vein quartz and sheared and altered granitic rock were collected from mines, prospects and outcrop. To date, analytical results are available on about 100 of the samples and are summarized here.

Samples for K-Ar age determination were collected from granitic rocks, their intruded country rocks, and from veins and alteration selvages surrounding them to determine the age relationships between granitic intrusion, metamorphism of the country rocks and gold mineralization. Preliminary results of the geochronological study are reported here.

Geology

Much of the Talkeetna Mountains, and nearly all of their southern margin are underlain by a northeast-trending batholithic complex which ranges in age from Jurassic to late Cretaceous and early Tertiary (Csejtey, 1974). Individual plutons in the batholithic complex range in composition from hornblende diorite and tonalite to granite and biotite granite. Age assignment of the plutons is based on approximately 25 K-Ar ages summarized in Csejtey and others (1978, in press). Bedrock north of the batholithic complex is chiefly late Paleozoic metavolcanic rocks and less abundant late Mesozoic meta-graywackes. Mesozoic sedimentary rocks and volcanic rocks underlie most of the terrain south of the complex (Csejtey, 1974).

Figure 2 is a generalized geologic map of the southwestern part of the Talkeetna Mountains, modified from Csejtey and others (1978, in press). The area is underlain by plutons of the batholithic complex, quartz-mica schist of Paleozoic or Mesozoic age, ultramafic rocks of Cretaceous (?) age, and sedimentary rocks of the Arkose Ridge Formation of Cretaceous(?) age, and the Chickaloon Formation of Paleocene age. The schist is intruded by the Cretaceous and early Tertiary tonolite pluton, and by the Cretaceous (?) ultramafic rocks. The Arkose Ridge Formation unconformably overlies the schist and the plutons of the batholithic complex. The Chickaloon Formation is in fault contact with the Arkose Ridge Formation. The Jurassic hornblende diorite is medium to coarse grained and generally shows some shearing and/or alteration associated with migmatites and amphibolite grade metamorphic rocks. The biotite-granite is a medium grained granitic textured rock with minor muscovite along with the biotite. It is believed to be a more felsic differentiate of the parent magma that produced the tonolite, which appears to be of approximately the same age (Csejtey and others, 1978, in press). The tonolite is a medium to coarse grained granitic textured rock containing hornblende and minor biotite. Some variations in grain size occur in the tonolite, and it is possible that the pluton in this area is composite. Mapping has not been done in sufficient detail in the present study to determine whether this is one pluton or a series of composite bodies. Ray (1954) indicates that the finer grained tonalite (quartz-diorite of Ray, 1954) is near the southern margin, and represents a primary feature of a single pluton, the finer grain size probably representing the margin of the pluton. The tonolite is cut by dikes and irregular intrusions of pegmatite, aplite, lamprophyre and diabase (Ray, 1954).

Metamorphosed roof pendants and chalcedonic gossan zones along the northern border of the batholithic complex suggest that erosion has exposed only the upper portions of the complex (Csejtey, 1974). In the eastern Alaska Range, lithologically similar but more deeply eroded granitic batholiths contain many porphyry-type, disseminated copper deposits (Richter and others, 1975a, b).

The schist is a uniform, medium grained quartz-muscovite-chlorite-minor biotite rock of greenschist facies metamorphism. Relicts of hornblende and garnet, now replaced by chlorite, suggest that it was originally metamorphosed to amphibolite facies, perhaps in the Jurassic, but was later subjected to retrograde metamorphism, perhaps in the Cretaceous. There is no geometric relationship of the metamorphism of the schist to the contact with the granite which intrudes it. The ultramafic bodies that intrude the schist are now metamorphosed to serpentine, talc and actinolite.

Mineralization

Production in the Willow Creek mining district came from mineralized quartz veins most of which occur in the tonolite of the batholithic complex (Ray, 1954; Csejtey, 1974). Some of the gold bearing quartz veins also occur in the Jurassic hornblende diorite and in the schist. Complex post-mineralization faulting has affected the entire area. The productive veins are offset along faults and mining was extremely difficult because of the discontinuous nature of the lodes. All of the dikes which cut the tonolite, with the exception of the diabase are also offset along faults.

Most of the dikes are not associated with mineralization, but in the northern part of the district (at the Holland Prospect) a 1.5 meter wide composite pegmatite has heavy concentrations of chalcopyrite and bornite in the sheared quartz that comprises its center.

The gold-bearing veins of the district contain sulfide and sulfosalt mineral assemblages. Pyrite, galena, chalcopyrite, and sphalerite occur in the productive veins, whereas pyrite, chalcopyrite, molybdenite and arsenopyrite occur in the "barren" veins (Ray, 1954). The association of gold-silver and base-metal sulfides in the productive and barren veins suggests relatively high levels in a mineralized hydrothermal system.

The gold and silver, associated with base metal sulphides, while not restriced to this occurrence, are suggestive of the mineralogical and trace metal zoning patterns found peripheral to porphyry type disseminated copper deposits (Jerome, 1966; Lowell and Guilbert, 1970; Theodore and Nash, 1973)

There are wide, but irregularly distributed areas of propylitic alteration in the tonalite, including one along the contact with the schist. Narrow (several cm to several m) sericitic alteration selvages adjacent to the mineralized quartz veins also occur in the tonalite. Alteration selvages surrounding veins in the schist appear largely to be characterized by oxidation, however, most cross cutting veins in the schist are found in shear zones and faults, which are relatively permeable, and have probably allowed access of groundwater. This probably caused oxidation of sulphides in the quartz veins and their wall rocks. Other veins in the schist appear to be oriented largely along planes of foliation, and are without noticeable alteration envelopes.

Analyses

All geochemical samples were prepared and analyzed under the supervision of R. M. O'Leary at the U.S. Geological Survey's Field Services laboratory at Anchorage, Alaska. Cu, Pb, Zn were analyzed by atomic absorption methods (Ward and others, 1969) by M. Criswell. Semi-quantitative spectrographic analyses for 30 elements were also done on all samples. The analytical results on approximately 100 of the samples are summarized on figures 3 through 7. Approximately 50 additional samples were collected after the initial sampling and their analytical results will be added to the present set of data when analyses are completed. All data will be reported elsewhere.

Results

The distribution of Cu, Pb, and Zn mostly from quartz vein samples are shown on the accompanying maps. Enrichment factors for Cu and Pb defined as Cu/(Cu+Pb+Zn) and Pb/(Cu+Pb+Zn) are also shown. These ratios were calculated to attempt to show areas of relative copper enrichment.

The technique applied to bedrock samples has proven useful in locating exploration targets for copper mineralization where moderate to strong base-metal anomalies exist. (Silberman and others, 1974).

Copper content ranges from 0 to 0.8 percent. It is consistently highest in the northern part of the sampled area, in the vicinity of the Black and the Holland prospects, and near the Schroff-O'Neil and Marion Twin mines at the head of Craigie and Purches Creeks. Samples with Cu contents greater than 1,000 ppm occur only here and at one other location, about 1 km east of the Gold Cord mine. Copper content is moderately high (as much as 700 ppm) in several samples from near the head of upper Willow Creek, and in two samples from the large mines in the east fork of Fishhook Creek (up to 500 ppm).

Lead content ranges from 0 to about 0.5 percent, and is generally lower than copper content. It is highest (as much as 5,000 ppm, but generally lower than 1,000 ppm) in samples from the large mines in the east fork of Fishhook Creek. In the northern area where copper content is highest, lead values do not occur above the crustal average for intermediate rocks, about 30 ppm (Parker, 1967). Low, but still anomalous amounts of lead are found in a few samples near the eastern and western margins of the mining district.

Zinc content is low, with the highest values of 600 to 700 ppm in two samples from the large mines in Fishhook Creek. Only three other samples, towards the eastern and southwestern margins of the mining district, have Zn greater than crustal average for intermediate rocks, about 70 ppm (Parker, 1967).

High values for the copper enrichment factor (greater than 0.75) are found in the northern part of the sampled area, in an area of about 5 km^2. The highest copper values occur near the heads of Craigie and Purches Creeks, and near the north end of the east fork Fishhook Creek, northeast of the large mines. Another and probably separate area of copper enrichment is at the head of Upper Willow Creek, where copper content is moderately high. Copper enrichment ratios appear to drop off to the east and southwest of the highs in this calculated value. Two samples from outside these high copper areas on the west side of Archangel Creek and at the bend of Grubstake Gulch yielded high copper enrichment ratio values, but small to moderate amounts of total base metals. Accordingly, the high copper ratios of these samples should be considered less reliable.

Pb enrichment values are somewhat more erratic, but are consistently above 0.5 largely in samples from the large mines on the west side of the east fork of Fishhook Creek. There is an overlap of the areas of Pb and Cu enrichment (figure 8), but where this overlap occurs, the copper enrichment factor is lower than 0.75, and the copper content is lower than its maximum values which are found to the north of the overlap area.

Figure 8 attempts to show areas of relative copper and lead enrichment in the Willow Creek mining area. The patterns are interpretive, and both Pb and Cu enrichment zones are characterized by values of the respective factors greater than 0.5. There appears to be a strong correlation between Pb enrichment factor and Pb content and productive Au mineralization. The area of the east Fork of Fishhook Creek was one of the most productive for gold in the mining district (Ray, 1954).

Two other factors about this figure should be noted. First, the copper enrichment zone has been extended along Bullion Mountain to the southwest of the main high copper area. Copper content of samples from this southwest area are actually relatively low (between 50 and 100 ppm but still anomalous relative to crustal abundance levels (Parker, 1967)), but Zn and Pb contents are even lower. Second, the eastern area of Pb enrichment is also characterized by low values of the metal (between about 50 and 250 ppm) but here the Cu content is even lower.

Geochronology

K-Ar ages run on mineral separates from the tonalite, the schist, and from metamorphosed ultra-mafic bodies intrusive into the schist from the immediate Willow Creek area are summarized on table 1, (locations are shown on figure 2). Additional K-Ar age data from the Talkeetna Mountains are reported in Csejtey and others, (1978, in press) and Csejtey and others (1977). The tonalite and biotite-granite give essentially concordant mineral pair ages (biotite-hornblende, and biotite-muscovite) but these range between 60 and 78 m.y., throughout the plutons and in the Willow Creek area one the range of mineral ages from unaltered tonalite is 70 to 78 m.y. The K-Ar ages of micas from the schist are uniformly lower than the K-Ar ages of the tonalite and biotite-granite by up to 22 m.y. However, two actinolite ages from metamorphosed mafic rocks intruded into the schist yielded concordant ages of 89 and 91 m.y. which are older than all of the ages of the granitic rocks. Amphiboles in general are much more retentive of argon during post-crystallization thermal events, and the actinolite dates probably better represent the time of pro-grade metamorphism of the schist terrain than muscovite dates, of the schist itself.

The total set of data, particularly the rather large spread of the ages in both the schist and the tonalite, we believe, indicates some resetting due to argon loss from the minerals, due to one or more thermal events after the crystallization of the batholith. The schist ages, do not reflect simple metamorphism by intrusion of the tonalite, since they are younger than the ages given by minerals from that unit itself.

A K-Ar age of 56 m.y. from muscovite, in a quartz-sericite selvage adjacent to a gold-bearing vein at the Bullion Mine (location #10, and table 1) suggests one possible thermal episode that has affected the area. Quartz veins are pervasively distributed throughout the tonalite

(Ray, 1954). The range of age of the veins has to be further defined by additional dates on other samples, which are in progress, but tentatively, we suggest that a mineralization-alteration episode at about 56 m.y. may have affected some of the ages from the tonalite.

Quartz veins and boudins are also very common in the schist. We suggest that some of these, at least, may result from the same episode of vein emplacement that occurred in the tonalite. The apparently greater effect on the ages of schist may be due to two factors. The greater permeability of the schist due to its foliation may have allowed greater heating of the unit by circulating thermal waters, and the finer grain size of the micas in the schist may have permitted greater argon loss than occurred in the coarser grained minerals of the tonalite. The older ages of the actinolites from the metamorphosed mafic rocks intruded into the schist, may simply be due to the greater argon retentivity of the amphiboles than the micas, and also due to the lower permeability of the meta-mafics than the schist.

Whether an episode of hydrothermal activity and alteration would be so pervasive as to affect an area as large as that of the southern part of figure 1, is certainly open to question. Ages of the schist have evidently been reduced even outside of the area of the mining district (Figure 2). It is impossible that the resetting of the ages, the retrograde metamorphism, and hydrothermal activity themselves are effects of some other major tnermal event in the region. Possibly the numerous dikes and irregular intrusions of aplite, pegmatite, lamprophyre and diabase that intrude the tonalite are another manifestation of this event. Samples of all of these units have been collected for age determination. A preliminary age, obtained on hornblende separated from one of the lamprophyre dikes of 66+2 m. y., however falls within the range of ages from the tonalite and biotite granite suggesting that at least one set of these intrusions is related to the main episode of plutonic activity.

Significance of the geochemical and isotopic data

Batholithic porphyry-type disseminated copper and molybdenum deposits occur in the large composite plutons of the eastern Alaska Range, near Nabesna, several hundred kilometers to the east of Willow Creek (Richter and others, 1975A). As mentioned earlier, erosion levels of the batholithic complex in Talkeetna Mountains are believed to be shallower than those of the Alaska Range. Other than that the environments and rock types are quite similar. Based on these similarities and the indications of considerable copper in some of the veins at Willow Creek, it was suggested that a porphyry-copper deposit could underlie the Willow Creek area (Silberman and others, 1976).

Many porphyry-type disseminated copper deposits are spatially associated with poly-metallic base metal veins that contain precious metals or vein deposits that contain significant amounts of copper in outer or upper zones, for example, Morococha (Peterson, 1965; Eyzaguire and others, 1975), and Battle Mountain (Theodore and Nash, 1973). These deposits frequently display mineralogical and trace metal zoning patterns characterized by a central area of high copper content and peripheral areas of high lead, zinc and precious metal contents (Jerome, 1966; Lowell and Guilbert, 1970; Theodore and Nash, 1973).

At Willow Creek, similarities to this pattern exist. The high copper content of samples in the northern part of the sampled area drops off peripherally. Lead content in precious metal content appears to be highest south of the main copper anomaly. Because of the restricted sample coverage, it cannot yet be demonstrated that a complete zoning pattern exists, but our geochemical data suggest that it may well be present.

There are several factors involved in the evaluation of any disseminated copper prospect. Among these are: geochemical zoning (Jerome, 1966; Theodore and Nash, 1973), high salinity fluid inclusions with numerous daughter minerals (Theodore and Nash, 1973; Nash, 1970, and zoned patterns of alteration and mineralogy (Lowell and Guilbert, 1970). In addition to these factors, K-Ar age studies of porphyry copper deposits have routinely demonstrated that hydrothermal alteration and mineralization occurs most usually within the cooling history of the magmatic rocks that host the mineralization, or are spatially associated with the mineralization (Damon and Mauger, 1966; Theodore and others, 1973). These general observations have again been confirmed, in Alaska, by a detailed study of the geochronology of porphyry-type copper deposits in the east Alaska Range near Nabsena (Silberman and others, 1977), in an environment again, believed to have similarities with that at Willow Creek.

It was proposed that the Au bearing veins with base metal sulphides of the Willow Creek mining district may represent a high level in a hydrothermal system that may have disseminated copper mineralization at depth (Silberman and others, 1976). If this interpretation is correct the age of emplacement of the veins at Willow Creek should have been close to the age of emplacement of the host rock, the tonalite. The situation may not be quite this simple, but determination of the age of emplacement of the Au bearing veins was significance. The age relations at Willow Creek do not appear to be favorable to this interpretation. The hydrothermal activity that produced the gold mineralization appears to have occurred considerably later than the emplacement of the tonalite pluton. It is thus unlikely that the Au bearing veins represent an outer zone of trace metal, concentration that is related to base metal mineralization at greater depth in the tonalite system itself. However, heavy copper sulphide concentrations are found in at least one of the pegmatite dikes (the Holland Prospect, in the high copper zone at the north end of the district). Other pegmatites were sampled that showed secondary copper staining (analyses not yet completed). Should the pegmatite, aplite, and diabase dikes all yield ages in the range of about 56 m.y., the age of Au mineralization, then in all probability, these dikes may be the surface manifestation of significant post tonalite igneous intrusion at depth beneath the district.

Of the several characteristics of porphyry copper deposits mentioned earlier, Willow Creek has only a representation of the first-trace element zoning. The pattern of alteration zoning may not be strictly applicable here because as mentioned, Willow Creek appears to be at a high level in a mineralized system, probably above the level where classic K-silicate, phyllic, argillic and propylitic alteration zoning would be expected (Lowell and Guilbert, 1971).

A cursory examination of several thin sections of quartz veins and tonalite has not shown the presence of highly saline brines in fluid inclusions, a characteristic of many porphyry copper systems (Theodore and Nash, 1973), but no detailed systematic examination of all of the samples from the district has yet been made.

Further evaluation of the possibility of disseminated mineralization at depth must await completion of ongoing analyses from additional samples taken in the mining district for geochemistry and isotopic ages from the quartz veins and the varied suite of dike rocks. Detailed fluid inclusion studies would also be helpful in evaluation.

In conclusion, the Willow Creek mining district does evidence the type of trace metal zoning frequently associated with disseminated copper mineralization. Other factors looked for in exploration for this type of deposit are either not present, or are equivocal at both the present state of our knowledge and the exposed level of erosion. Further work is certainly called for however, to complete the evaluation.

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K-Ar Ages of Granitic Rocks, Schist and Hydrothermal alteration, Willow Creek Mining District

LOCATION	ROCK TYPE	MINERAL	AGE
1[1)]	Tonalite	Biotite	69 ± 2
		Hornblende	73 ± 2
2[1)]	Tonalite	Biotite	72 ± 2
		Hornblende	74 ± 2
3[1)]	Biotite-granite	Biotite	65 ± 2
		Muscovite	67 ± 2
4[3)]	Tonalite	Biotite	78 ± 2
5[2)]	Schist	Muscovite	60 ± 2
6[2)]	Schist	Muscovite	66 ± 2
7[2)]	Schist	Muscovite	59 ± 2
8[3)]	Serpentinite	Actinolite	89 ± 5
9[3)]	Serpentinite	Actinolite	91 ± 5
10[3)]	Altered tonalite	Muscovite	56 ± 2
11[3)]	Lamprophyre	Hornblende	66 ± 2

1) Csejtey and others, 1978, (in press)

2) Csejtey and Smith, 1975

3) This work

Figure 1 Map showing the location of the Talkeetna Mountains in Alaska

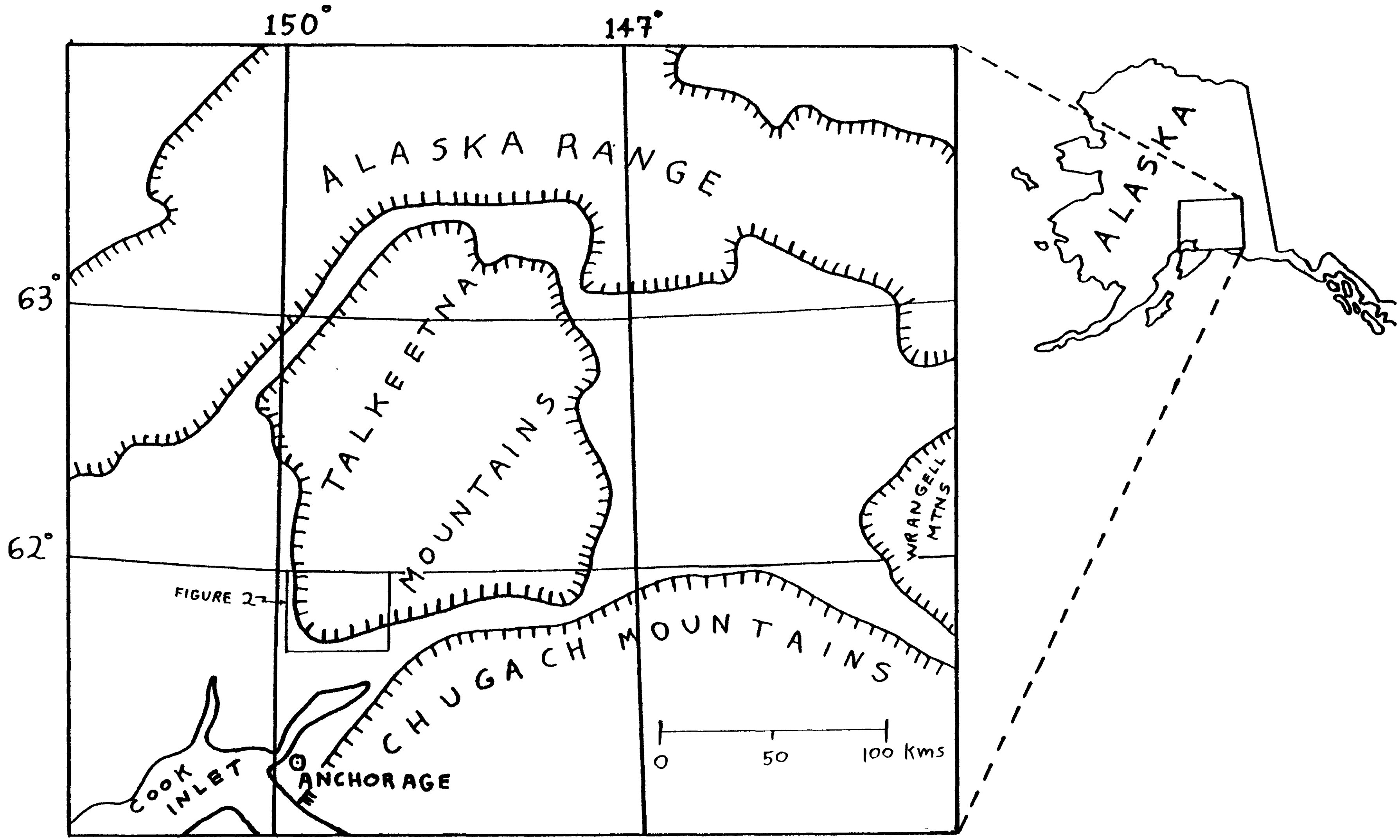

150°
147°
63°
62°
ALASKA RANGE
TALKEETNA
MOUNTAINS
CHUGACH MOUNTAINS
WRANGELL MTNS
FIGURE 2
COOK INLET
ANCHORAGE
0
50
100 Kms
ALASKA

FIGURE 1

Figure 2 Generalized geologic map of the southwestern part of the Talkeetna Mountains, Alaska, modified from Csejtey and others (1978, in press).

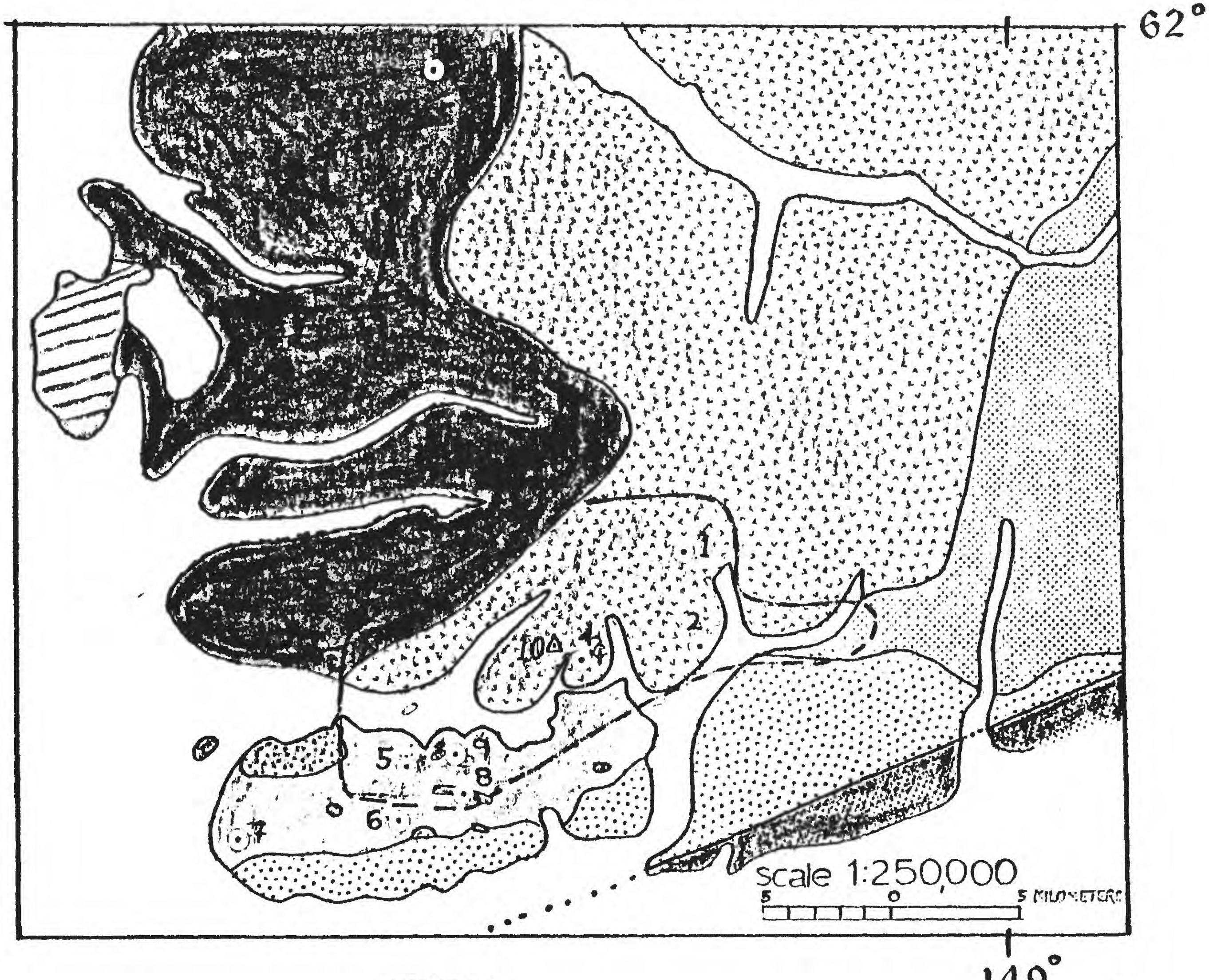


FIGURE 2

EXPLANATION

CENOZOIC

QUATERNARY

SURFICIAL DEPOSITS
(Quaternary)

TERTIARY

MAFIC VOLCANICS
(Tertiary)

CHICKALOON FORMATION
(Paleocene)

MESOZOIC

CRETACEOUS

ARKOSE RIDGE FORMATION
(Cretaceous ?)

BIOTITE GRANITE AND TONALITE
(Late Cretaceous and early Tertiary)

ULTRAMAFIC ROCK
(Cretaceous)

JURASSIC

HORNBLENDE DIORITE TO TONALITE
(Jurassic)

PALEOZOIC

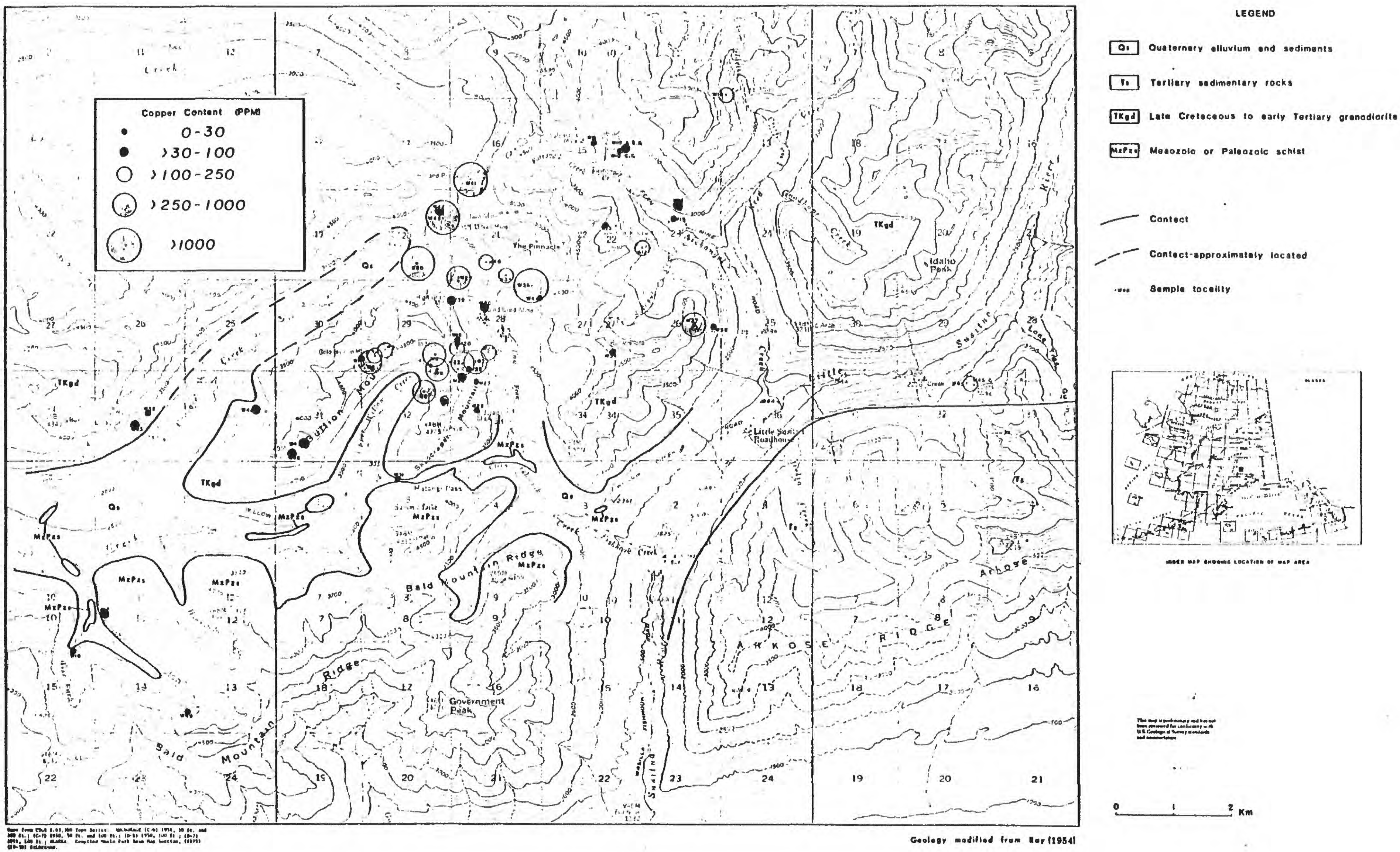
QUARTZ-MICA SCHIST
(Paleozoic or Mesozoic)

FAULT

• ROCK DATE

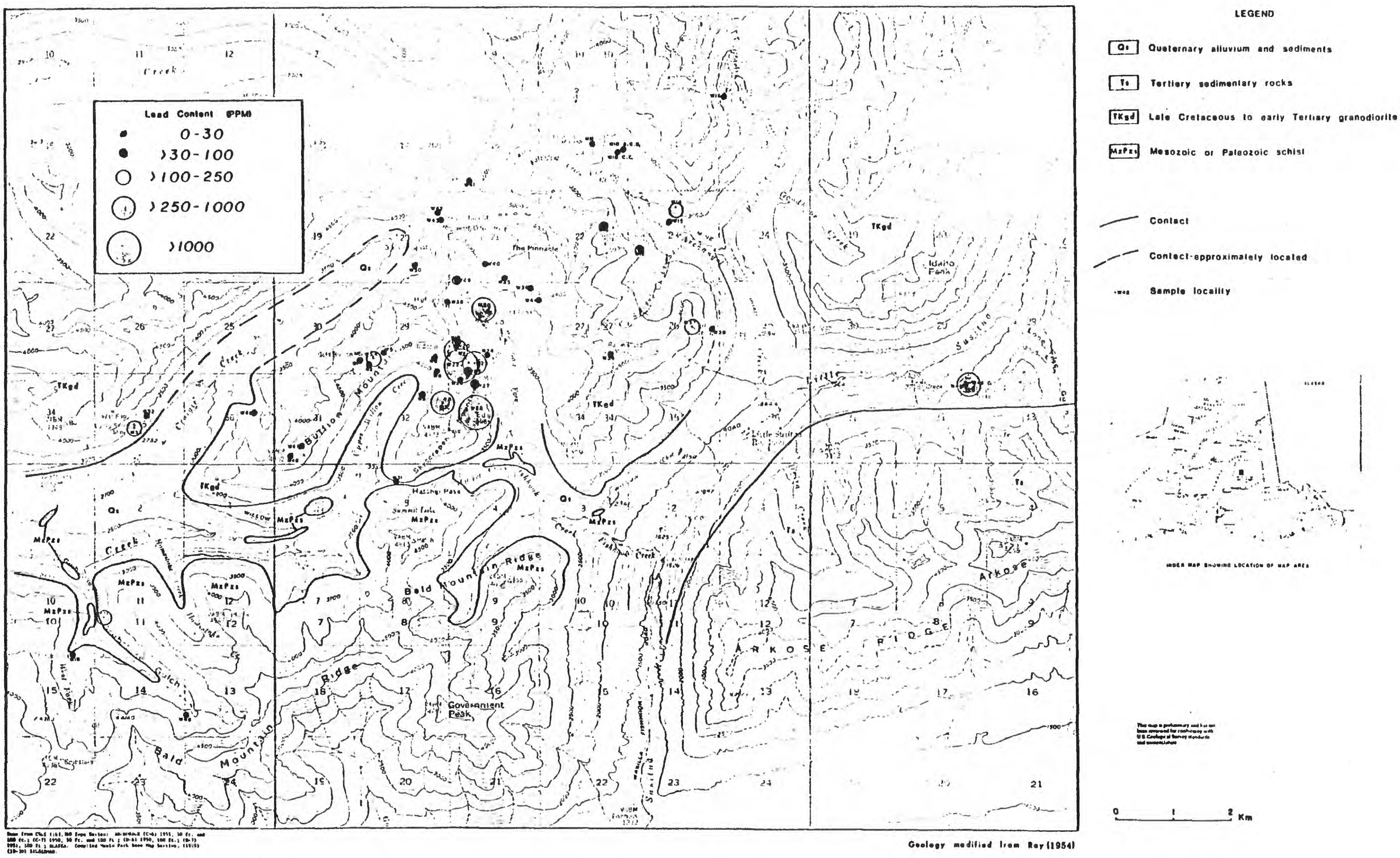
△ MINERALIZATION DATE

APPROX. OUTLINE of WILLOW CREEK MINING DISTRICT



GEOCHEMICAL ANOMALIES IN THE WILLOW CREEK MINING DISTRICT, SOUTHERN TALKEETNA MOUNTAINS, ALASKA
— DISTRIBUTION OF COPPER IN THE WILLOW CREEK MINING DISTRICT

Figure 3



GEOCHEMICAL ANOMALIES IN THE WILLOW CREEK MINING DISTRICT, SOUTHERN TALKEETNA MOUNTAINS, ALASKA
— DISTRIBUTION OF LEAD IN THE WILLOW CREEK MINING DISTRICT

Figure 4

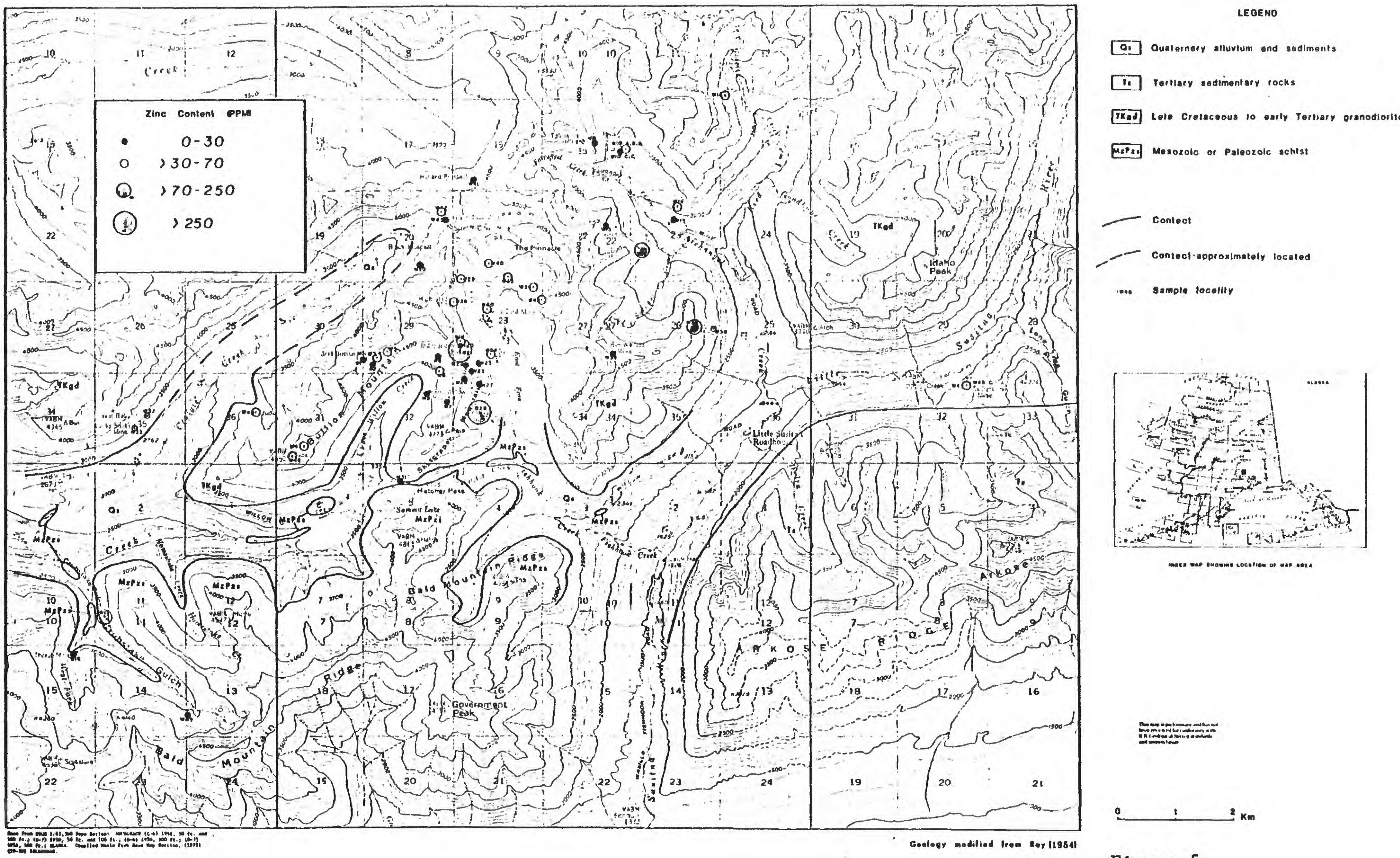


Figure 5

GEOCHEMICAL ANOMALIES IN THE WILLOW CREEK MINING DISTRICT, SOUTHERN TALKEETNA MOUNTAINS, ALASKA

— DISTRIBUTION OF ZINC IN THE WILLOW CREEK MINING DISTRICT

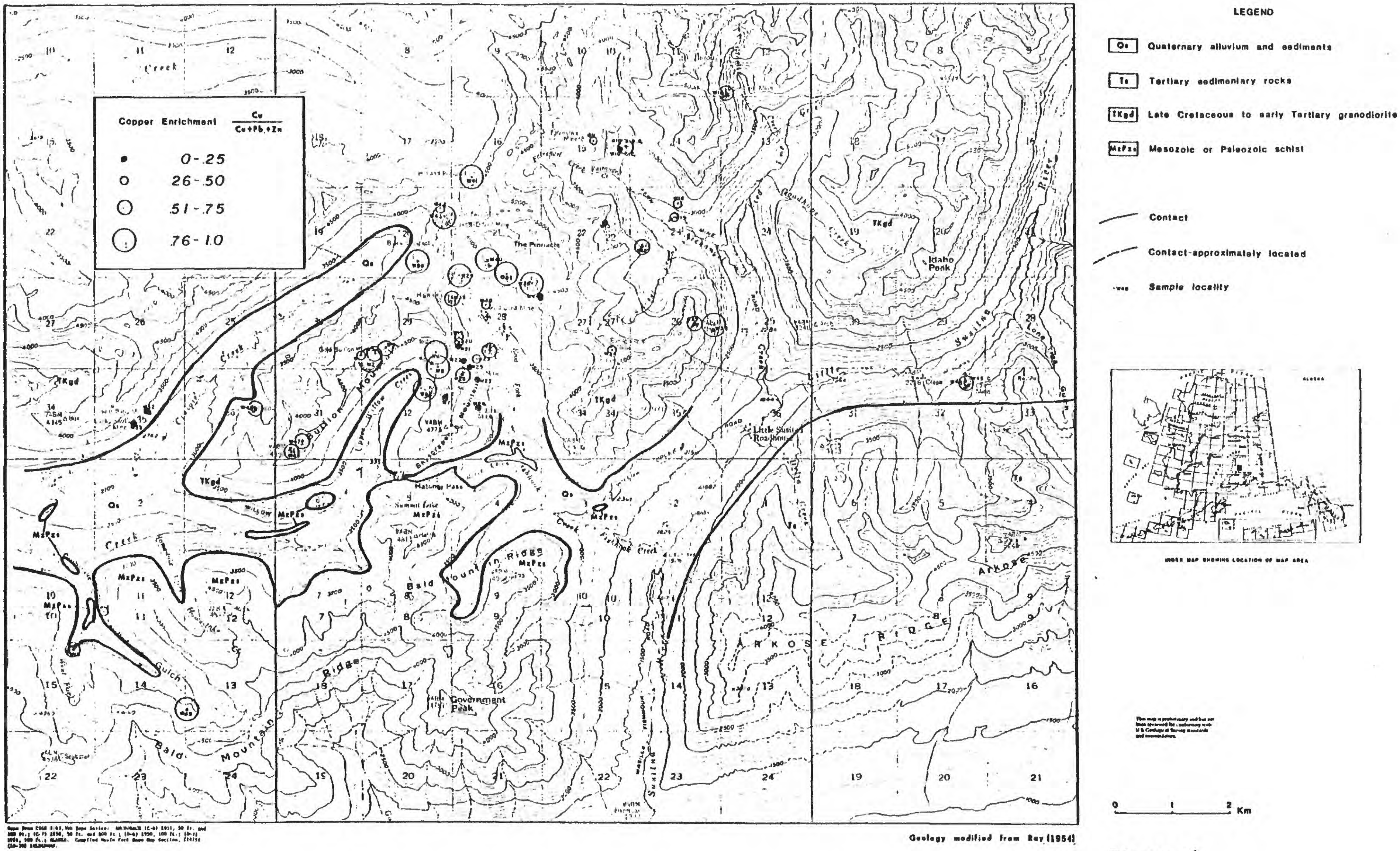


Figure 6

GEOCHEMICAL ANOMALIES IN THE WILLOW CREEK MINING DISTRICT, SOUTHERN TALKEETNA MOUNTAINS, ALASKA

-COPPER ENRICHMENT $\left[\frac{Cu}{Cu+Pb+Zn}\right]$ IN THE WILLOW CREEK MINING DISTRICT

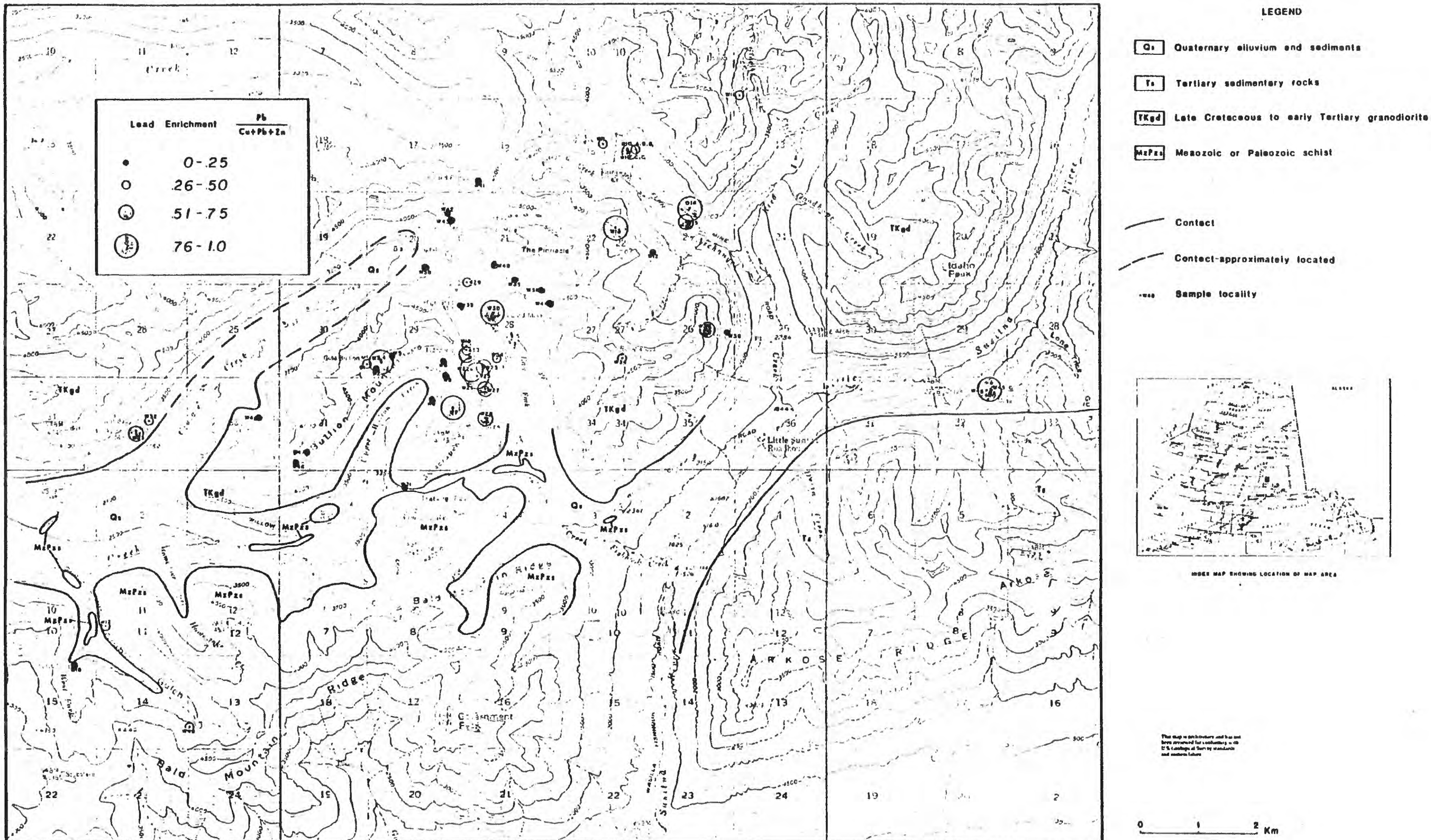


Figure 7

GEOCHEMICAL ANOMALIES IN THE WILLOW CREEK MINING DISTRICT, SOUTHERN TALKEETNA MOUNTAINS, ALASKA

— LEAD ENRICHMENT $\left[\frac{Pb}{Cu+Pb+Zn}\right]$ IN THE WILLOW CREEK MINING DISTRICT

Figure 8 Map showing areas of copper and lead enrichment in the Willow Creek mining district. Same scale as figures 3 through 7.

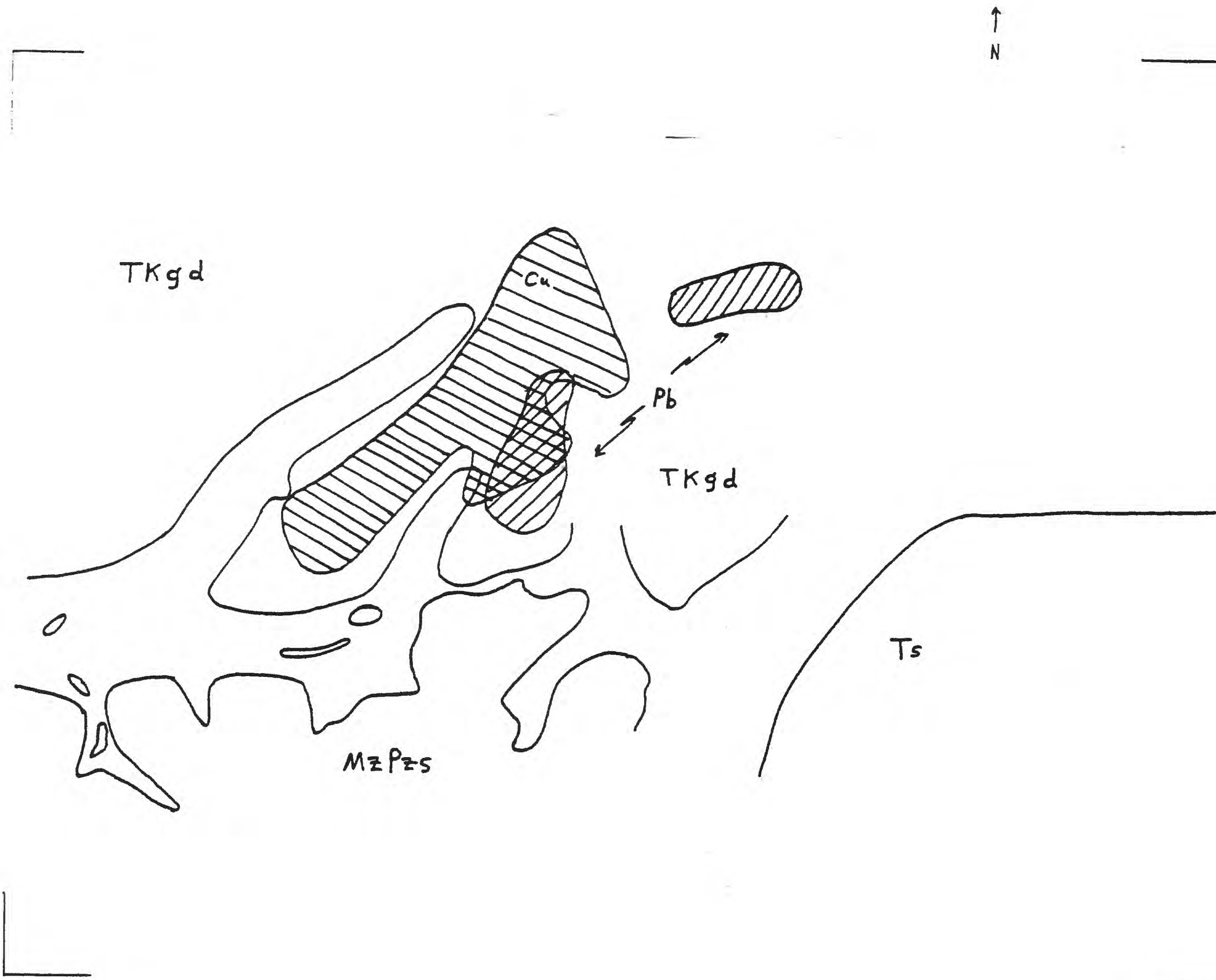


FIGURE 8