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GEOLOGY OF THE TIN CREEK ZINC-LEAD SKARN DEPOSITS, McGRATH B-2 QUADRANGLE, ALASKA

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ABSTRACT

Several centers of Cu-Zn-Pb-Ag skarn and replacement bodies occur in a 500 km^2 area near Farewell, in the McGrath Quadrangle, Alaska. Interests in these deposits, especially in their extent and localization, has led to a detailed examination of the skarns in upper Tin Creek, one of the major mineralized areas.

Host rocks for skarns are mid-Paleozoic sedimentary rocks that are contact metamorphosed, folded, faulted, and overlain and intruded by Tertiary igneous rocks. Skarns in the Tin Creek area are small (up to 3 m wide) discontinuous bodies of exoskarn found along dike contacts and as endoskarn in the dikes. Skarns also form mantos in marble and irregular bodies along thrust and high angle faults. Semi massive to massive sulfide mantos are present in calc-silicate hornfels. Many dikes do not have skarn along their contacts, while others have skarn along only one margin. These relations indicate that dikes and faults are structural conduits for later metasomatic fluids and are not directly responsible for skarn formation.

The skarn deposits are dominantly of two types: 1) pyroxene (Hd_{15-66}) skarns with sphalerite and minor chalcopyrite ± pyrite, and 2) garnet (Ad_{12-100}) skarns with chalcopyrite and minor sphalerite. Locally, the dominant skarn minerals are amphibole and/or epidote. Endoskarn is generally epidote rich. Pyroxene dominant skarns exhibit textural and compositional zoning as coarse, Fe-Mn salite (pyroxene) rich zones along the marble front; pyroxene becomes finer grained and more Mg-rich near the intrusive contact. Garnet is also compositionally zoned with Mg-rich metamorphic cores rimmed by progressively more Fe-rich metasomatic garnet. Zoning is also present on a larger scale, with pyroxene-sphalerite dominant skarns distal to and garnet-chalcopyrite dominant skarns proximal to dike swarm centers.

The Tin Creek skarn prospects compare favorably to other zinc-lead skarns and can be further classified with zinc-lead skarns that form near dikes. The deposits have features, such as structural control of metasomatic fluids, and textural and compositional zoning common to Zn-Pb skarns worldwide.

INTRODUCTION

The Tin Creek skarn prospects are located near the upper reaches of Tin Creek in the McGrath B-2 Quadrangle, approximately 16 km southeast of Farewell, a Federal Aviation Agency station (figs. 1 and 2). The study area is in rugged mountains of the northwest flank of the southern Alaska Range. Elevations range from 670 m in the Tin Creek drainage (section 24) to 1,765 m along the ridge line defining the western extent of the project area. Most

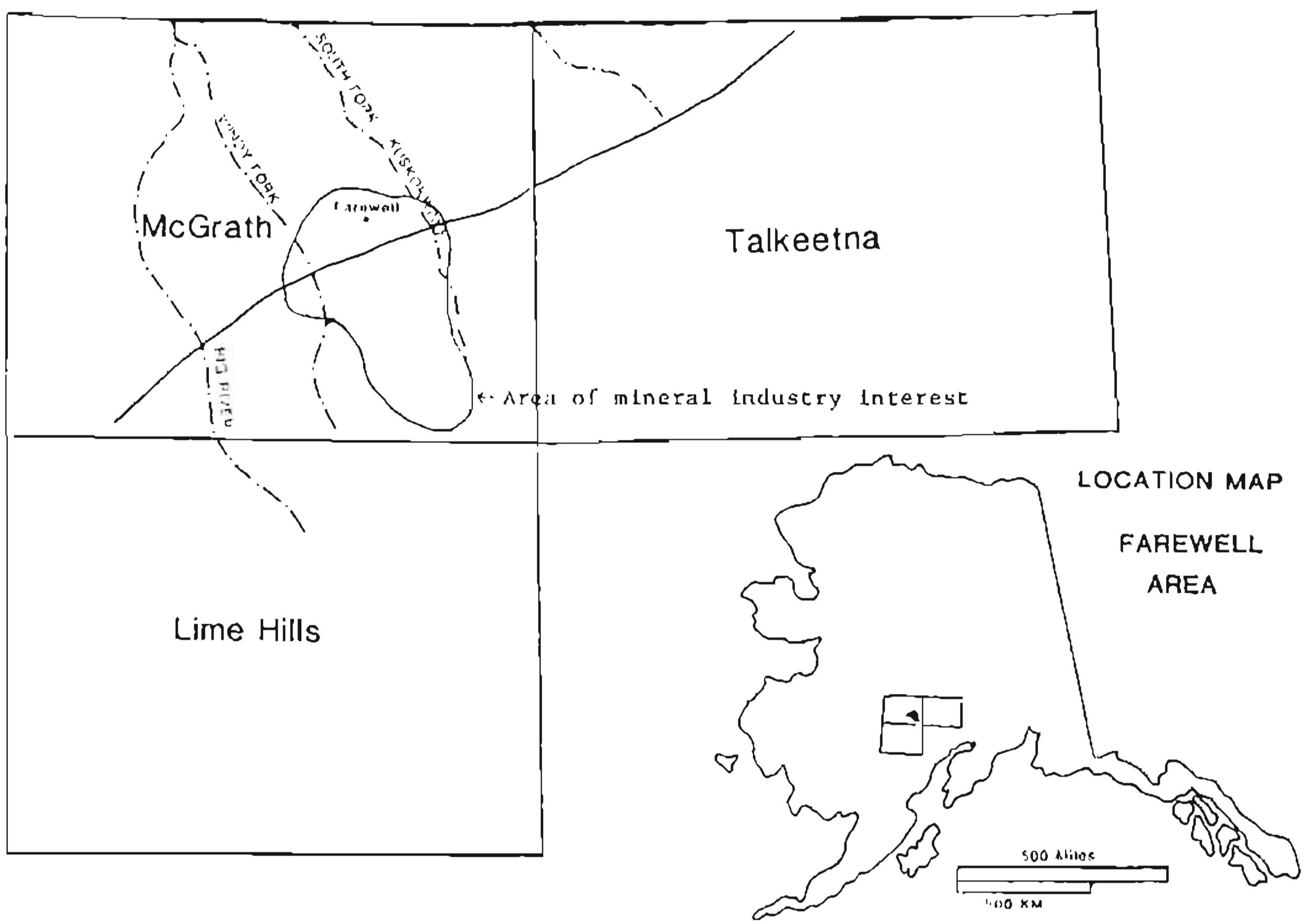


Figure 1. Location map, Farewell project area.

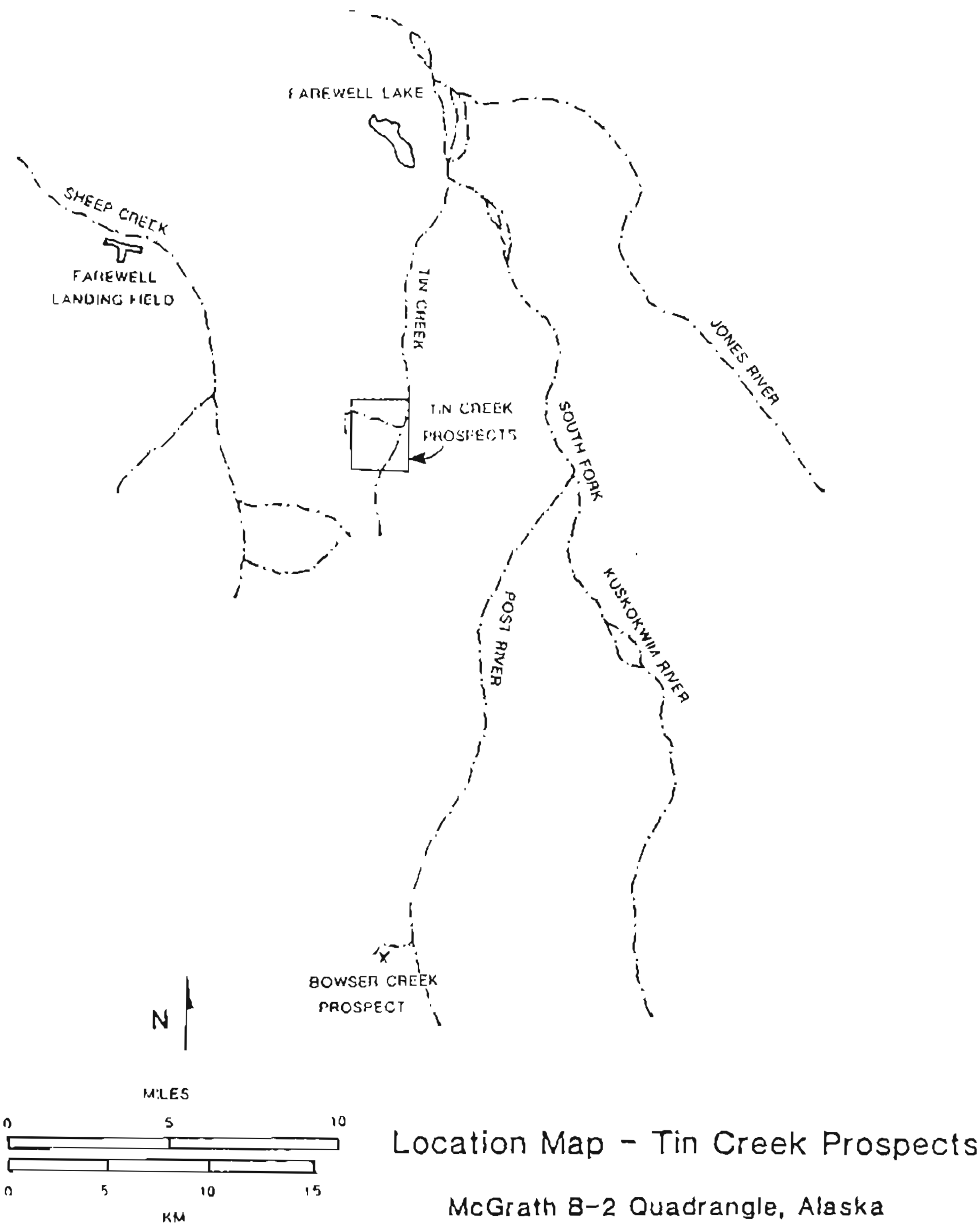


Figure 2. Location map, Tin Creek prospects, McGrath B-2 Quadrangle, Alaska.

of the area is above timberline, with generally excellent bedrock exposure. Access to the prospect area is via helicopter or floatplane to Veleska Lake 1 mi to the east.

The present investigation is related to thesis work for a M.S. degree at the University of Alaska-Fairbanks. Fieldwork on this area was conducted from mid June to mid August, 1983. The author spent 43 days mapping and sampling in the Tin Creek prospects. Fieldwork was augmented with thin- and polished-section examination, X-ray diffraction analyses, and electron microprobe study. Geochemical analyses were performed at the DGGS laboratory and Chemex Labs, Ltd., Vancouver, B.C.

ACKNOWLEDGMENTS

Many people have helped make possible this project. The author expresses special appreciation to R.J. Newberry for guidance throughout this project, T.K. Bundtzen and R.E. Kell for sharing their extensive knowledge of the McGrath region, G.L. Allegro for electron microprobe analyses, and DGGS and Anaconda Minerals Company for logistical support. Funding for thin sections, polished sections, geochemical, major oxide analyses and K-Ar ages were provided by DGGS. Bundtzen designed the professional services agreement that makes this report possible. The author sincerely thanks M.S. Robinson (DGGS) for reviewing this manuscript.

PREVIOUS WORK

The Tin Creek area had not been geologically explored until 1967. Reed and Elliot (1968) located some stream sediment geochemical anomalies within the Tin Creek drainage, but they did not find the source of these anomalies. Rob Kell of Anaconda Mineral Co. discovered significant mineralization along Tin Creek in 1980. Detailed work by Anaconda within the Farewell area has continued to the present. A 1:40,000 scale geologic map of the McGrath B-2 Quadrangle is provided by Bundtzen and others (1982).

REGIONAL GEOLOGY

The Farewell fault, a major right lateral, strike-slip feature, is the westernmost extension of the Denali fault system in the Alaska Range, with right lateral displacement of approximately 60 km (Reed and Lamphere, 1974) North of the study area the Farewell fault juxtaposes younger undeformed Devonian shallow-water carbonates to the northwest against polydeformed basin and slope deposits of early to mid Paleozoic age to the southeast (Bundtzen and others, 1982).

Early Ordovician to Late Pennsylvanian stratified rocks comprise the section south of the Farewell fault. The Ordovician section, approximately 100-250 m thick, consists of shale, siltstone, black chert, and thin volcaniclastic sand intervals (Bundtzen and others, 1982). Overlying the Ordovician sequence is a thick sequence, approximately 1,500 m thick, of Silurian clastic units. The Silurian clastics consist of rhythmically layered medium to coarse-grained sandstone, siltstone, laminated limestone, and shale which grade upward into fine grained siltstone and shale (Bundtzen and others, 1982). Units of the Silurian clastic sequence are the oldest units mapped at the Tin Creek prospects.

A thick structurally thickened sequence of primarily limestones with some shale is interbedded with the Silurian clastic section. Recent faunal collections indicate that this limestone is Wenlockian (Middle Silurian) in age (T.K. Bundtzen, personal commun, 1984). This limestone sequence is host for the Tin Creek skarns. The carbonate-clastic sequence is overlain by a Devonian-Pennsylvanian sequence consisting of algal limestone, shale, chert, and clastic rocks, the youngest bedded rocks south of the Farewell Fault (Bundtzen and others, 1982). The general stratigraphic sequences described above suggest that shallow platform carbonates prograded over a deeper shelf margin during mid-Paleozoic time (Bundtzen and Gilbert, 1983).

Igneous rocks in the McGrath B-2 Quadrangle range in age from Late Cretaceous to Middle Tertiary (Bundtzen and others, 1982). Intrusive rocks range in size from dikes to small plutons, dominantly with intermediate compositions. As in the Tin Creek area, dike swarms are complexly intertwined with hornfelsed Paleozoic sedimentary rocks. Two volcanic complexes also occur in the McGrath B-2 Quadrangle, with the Veleska Lake volcanic complex, dominantly of dacite composition, defining the western edge of the present study area.

STRUCTURE

The Farewell fault is the major structural feature in the Farewell area. The Paleozoic sedimentary rocks south of the Farewell fault have been multiply folded. Rob Kell (1980) has interpreted three folding events. The earliest event (F_1) is isoclinal recumbent folding associated with regional thrust faulting, followed by deformation into upright fold structures (F_2). The F_2 event formed the Tin Creek synclinorium and the adjacent Sheep Creek anticlinorium. The last major deformational event (F_3) produced broad regional warping due to drag along the Farewell fault. The deformational sequence is similar to that worked out by Bundtzen and others (1982) and Gilbert and others (1982).

GEOLOGY OF THE TIN CREEK SKARN DEPOSITS

Silurian Clastic Unit

Silurian clastics are the oldest units mapped within the study area. Most of the clastic unit in the Tin Creek area has been contact metamorphosed to a banded cal-silicate hornfels. The hornfels has been mapped as a separate unit and is described elsewhere. Small outcrops of the unmetamorphosed clastics are exposed along Tin Creek (pl. 1). The clastic unit consists of interbedded lithic sandstone, gray phyllite, and black marble with calcite veins. The beds strike north-northeast with beds dipping approximately 50° to the northwest. The contact between these interbedded clastics and the marble to the west is obscured, but the thrust fault exposed in lower Tin Creek should extend between these units.

Paleozoic Marble Units

Nine marble units were defined during 1:5,000 scale geologic mapping (pl. 1). Most of these units are not traceable for more than a hundred meters along strike due to poor exposure and structural complications. Each marble unit most likely does not represent a separate entity, but rather many are probably metamorphosed equivalents or local facies changes.

The most abundant marble units in outcrop are the Pms and the Pmg units (pl. 1). The marble with silt partings unit (Pms) is more common at lower elevations and farther from the area of greatest igneous dike density. The Pms unit lies in thrust fault contact with the banded calc silicate hornfels in exposures on the west side of Tin Creek. This marble is gray, medium to thick bedded, highly fractured, and folded. Folding is generally asymetric and very tight in some outcrops. Fracture sets are more steeply dipping than bedding altitudes, indicating that the Pms unit is right side up. The Pms unit contains thin shaley interbeds in some areas and there it is mapped as Pmss. The prevalent bedding altitudes are north-northwest strikes and moderate to steep dips to the northwest.

Marble with garnet bands (Pmg) is the most areal extensive marble unit. Pmg represents a higher metamorphic stage of the Pms unit in which original silty layers within the marble are metamorphosed to light green garnet bands. The Pmg unit is especially prevalent in the areas of abundant igneous dikes and sometimes along the margin of dikes, grading out into Pms.

Much of the marble is easily weathered and forms scree slopes throughout the study area. Most of this material has been mapped as marble undifferentiated (Pma). Other marble units recognized within the Tin Creek area (pl. 1) include black, fine grained marble with calcite veinlets (Pbm), black marble with shaley interbeds (Pbms), gray silty marble interbedded with siliceous hornfels (Pmh), and a marble clast breccia with calcite cement (Pbmx). One other unit included with the marble units is a gray to dark gray, fine to medium grained, calcareous siltstone (Pcs) which weathers to an olive-green color. Graded bedding is occasionally found within the Pcs unit.

Tertiary Igneous Rocks

Veleska Lake Volcanic Complex

Volcanics cap the ridge on the western boundary of the study area, overlying the Paleozoic marble units (pl. 1). In many places the volcanics overlie a thin, black, paleosol mudstone with abundant fossil leaves and plant debris with a maximum thickness of 0.6 m. Above this is a 0.5 m wide tuff breccia, a 6-10 m thick lapilli breccia, and a white to greenish gray andesitic ash fall tuff which is approximately 80 m thick. Overlying all of these is a greenish gray quartz latite flow of undetermined thickness.

Igneous Dikes

Igneous dikes intrude through sedimentary, metasedimentary, and volcanic units. Dikes trend overall from roughly N. 60 W. to E-W, with moderate to steep dips to the north. Plate 1 shows that the dike trends are irregular with much pinching and swelling of the dikes. Dikes range in width from less than a meter to about 50 m.

Most dikes exhibit chilled margin effects, with textures changing from porphyry to porphyritic to aphanitic as a section is traversed from the center of the margin to the dike. Gray to green, aphanitic, sucratic textured dikes appear to be analogous to the chilled margins of these zoned dikes.

Compositions of igneous dike type have been calculated into normative mineral assemblages from major oxide analyses. Compositions are plotted on figure 3. Dikes in the Tin Creek area can be categorized into two compositional types - granodiorite/tonalite dikes and andesite (monzodiorite/diorite) dikes.

Granodiorite Porphyry Dikes

Granodiorite porphyry is the most abundant dike type in the Tin Creek region. Fresh granodiorite porphyry (Tgp) has an overall grayish white to gray color. Plagioclase is the dominant phenocryst, approximately 50 percent of the total phenocrysts, and it occurs in lath to equant shapes up to 1 cm in length. Hornblende, comprising 35 percent of the total phenocrysts, ranges from black to dark green in color and up to 1 cm long. Biotite content varies considerably between individual dikes, ranging from no phenocrysts up to 15 percent of the total. Quartz phenocrysts, generally 5 to 10 percent of the phenocrysts, are usually about 1 mm in diam. Some granodiorite porphyry dikes have common xenoliths of porphyritic, fine grained quartz monzodiorite.

Porphyritic Dacite Dikes and Porphyritic Hornblende-rich Dacite Dikes

Normative mineral calculation plots of these dikes place them in the same field as the granodiorite porphyry dikes (fig. 3). However, these dikes are significantly different in texture when compared to the granodiorite porphyry dikes. Porphyritic dacite dikes (Td) consist of gray, aphanitic groundmass with phenocrysts of plagioclase, hornblende, biotite, and quartz. Plagioclase is the dominant phenocryst, totaling 70 to 80 percent of the total phenocrysts. Hornblende occurs as 15-25 percent of the total phenocrysts, while the maximum biotite and quartz phenocryst content is 5 percent. Some dikes (Thd) also have two distinctly different hornblende textures-short equant black hornblende and larger, longer, rectangular green hornblende.

Many of the dikes (both Td and Tgp) are propylitically altered with a greenish cast in the groundmass and a whitish "ghost" alteration replacing plagioclase phenocrysts. Some dikes are sericitically altered to a minor degree with sericite along fractures. Mafic minerals are generally partially to completely altered to epidote, chlorite, and calcite. Epidote is common along fracture surfaces. All dikes contain pyrite ± pyrrhotite, with sulfides occurring in clots replacing mafic minerals.

Andesite Dikes

Andesite dikes comprise a minor percentage of the dikes in the Tin Creek area. Andesite dikes are not traceable farther than 25 m along strike.

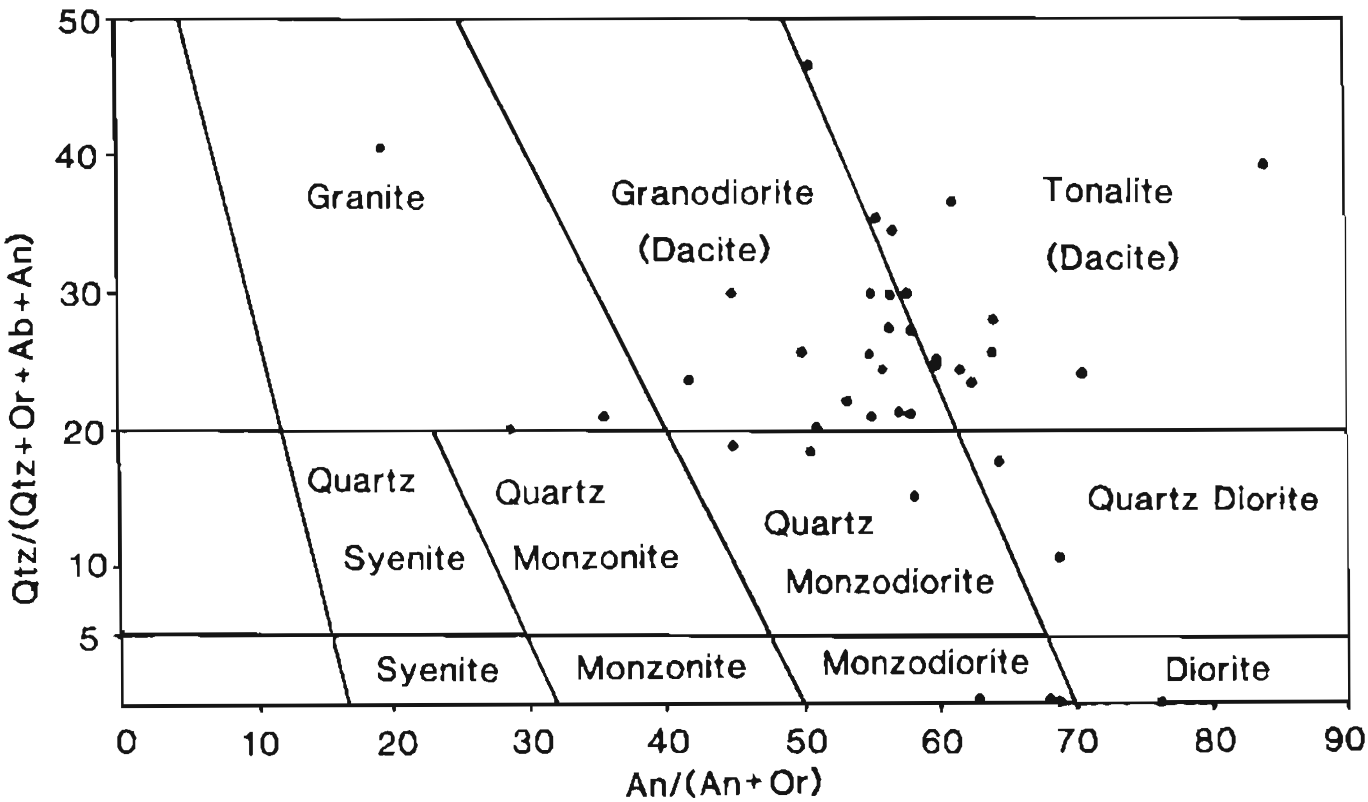


Figure 3. Normative mineral ratios from igneous dikes, Tin Creek region.

These dikes appear to be older than the intermediate composition dikes because andesitic dikes are apparently altered (sometimes silicified) by the dacite and granodiorite dikes. Fresh andesite varies from green to dark green in color. Andesite dikes are usually altered, with "ghost" phenocrysts of plagioclase and chloritized mafic minerals. Some dikes contain up to 15 percent sulfides, predominantly pyrrhotite with minor pyrite and traces of chalcopyrite. The sulfides occur in clots and masses with needle-like shapes or as disseminated grains. Sulfides appear to be replacing the original mafic minerals. Weathering of sulfide bearing andesite dikes produces conspicuous red stained outcrops.

Igneous Matrix Breccia Dike

Igneous matrix breccia dikes are the youngest dikes identified within the study area. The dikes crosscut and occasionally form an envelope around the terminus of intermediate composition dikes. Igneous matrix breccia dikes increase in frequency in the northern part of the study area, where other igneous dikes also increase in frequency.

Igneous matrix-breccia dikes have a white, aphanitic igneous matrix with quartz phenocrysts. Clasts within this matrix vary from rounded to angular in shape and from pinhead to 5 cm in diam. Clasts are mostly metasedimentary hornfels, but some are granodiorite porphyry and marble. Some breccia dikes also have clasts of mineralized skarn and endoskarn. This evidence, plus outcrops in which skarn bodies are cut by breccia dikes, lead to conclusions that igneous matrix breccia dikes formed as a late event.

Metamorphic and Metasomatic Units

Banded Calc-silicate Hornfels

Silurian clastic rocks have been transformed into banded calc-silicate hornfels by contact metamorphism. The banded hornfels have been bimetosomatically altered, whereby there has been a net transfer between two unlike adjacent lithologies but no net transfer of chemical components with the surrounding environment. The banded hornfels consists of alternating gray-green and dark brown fine grained, compact layers, dominantly consisting of garnet and pyroxene alternating with quartz and biotite, respectively. The upper 7 to 10 m of the calc-silicate hornfels is thinly banded, with bands averaging 2 to 3 cm. Most of the banded hornfels has banding ranging in thickness from 5 cm to 0.5 m.

The banded calc-silicate hornfels unit preserves some of the characteristics, mentioned by Bundtzen and others (1982), of the Silurian clastic sequence including Bouma intervals, graded bedding, and cross-bedding. Graded bedding and cross-bedding indicate that the section is right side up with upsection to the northwest. Remnant bedding altitudes are consistent in the calc-silicate hornfels, with strikes almost due north and dips steeply to the west-southwest.

Hornfels

The hornfels map unit identifies metamorphosed siliceous rocks which are not banded. These hornfels units are generally interbeds within the marble sequence. Hornfels is a very fine grained, compact rock which usually has a conchoidal fracture.

Skarnoid

Several areas of skarnoid have been mapped within the Tin Creek drainage. Skarnoid is a rock formed by metamorphic and metasomatic processes where neither process is dominant and the actual origin is uncertain or complex (Einaudi and Burt, 1982). There has been some transfer of components through fluids and/or volatiles. Skarnoid exposed in Tin Creek is a grayish brown rock and weathers brown or sometimes green. Pods of calcite range up to 5 cm in diam. The majority of the rock is fine grained clinopyroxene, with epidote, chlorite, quartz, medium-grained clinopyroxene, and calcite in subequal amounts. Some veinlets of pyrite with coarse clinopyroxene, quartz, and calcite crosscut through the skarnoid. It appears that metamorphic processes have been slightly overprinted by metasomatic processes.

Endoskarn

Endoskarn is formed by the calc-silicate replacement of intrusive rocks through metasomatic fluid interaction. Dikes in the Tin Creek area display varying degrees of endoskarn development. Overall endoskarn development is minor in the dikes and no endoskarn is present in the Veleska Lake volcanic complex. Dikes in the northern-part of the study area typically contain pink clinozoizite replacing plagioclase and calcite + chlorite replacing mafic minerals. Epidote, chlorite, clinopyroxene, and quartz are the common minerals present within all endoskarn. Endoskarn is not thoroughly developed in the dikes, typically only the edges of some dikes are replaced. Unlike skarn, endoskarn is devoid of appreciable ore mineralization at Tin Creek.

Skarn

Skarn, as used here, is formed by large scale transfer of components between hydrothermal fluids of magmatic input and predominantly carbonate rocks (Einaudi and Burt, 1982). Skarns occur throughout the study area, but generally their size is too small to be shown on plate 1. Skarns have a zoned distribution pattern, with garnet dominant skarns near the center of the Tin Creek dike system and pyroxene dominant skarns peripheral to the garnet skarns. Calc-silicate minerals in skarns also depend on the composition of the lithology that is metasomatized. The southern Tin Creek area is dominated by pyroxene rich skarns within calcareous rocks, while adjacent siliceous calc-silicate hornfels produce garnet skarns.

Skarn bodies are small, with maximum widths of 5 m and traceable for a maximum of 35 m along trend. Skarn bodies are discontinuous and commonly pinch and swell along structures and dikes, as shown in figure 4 where endoskarn and skarn are irregularly developed along a dacite dike contact

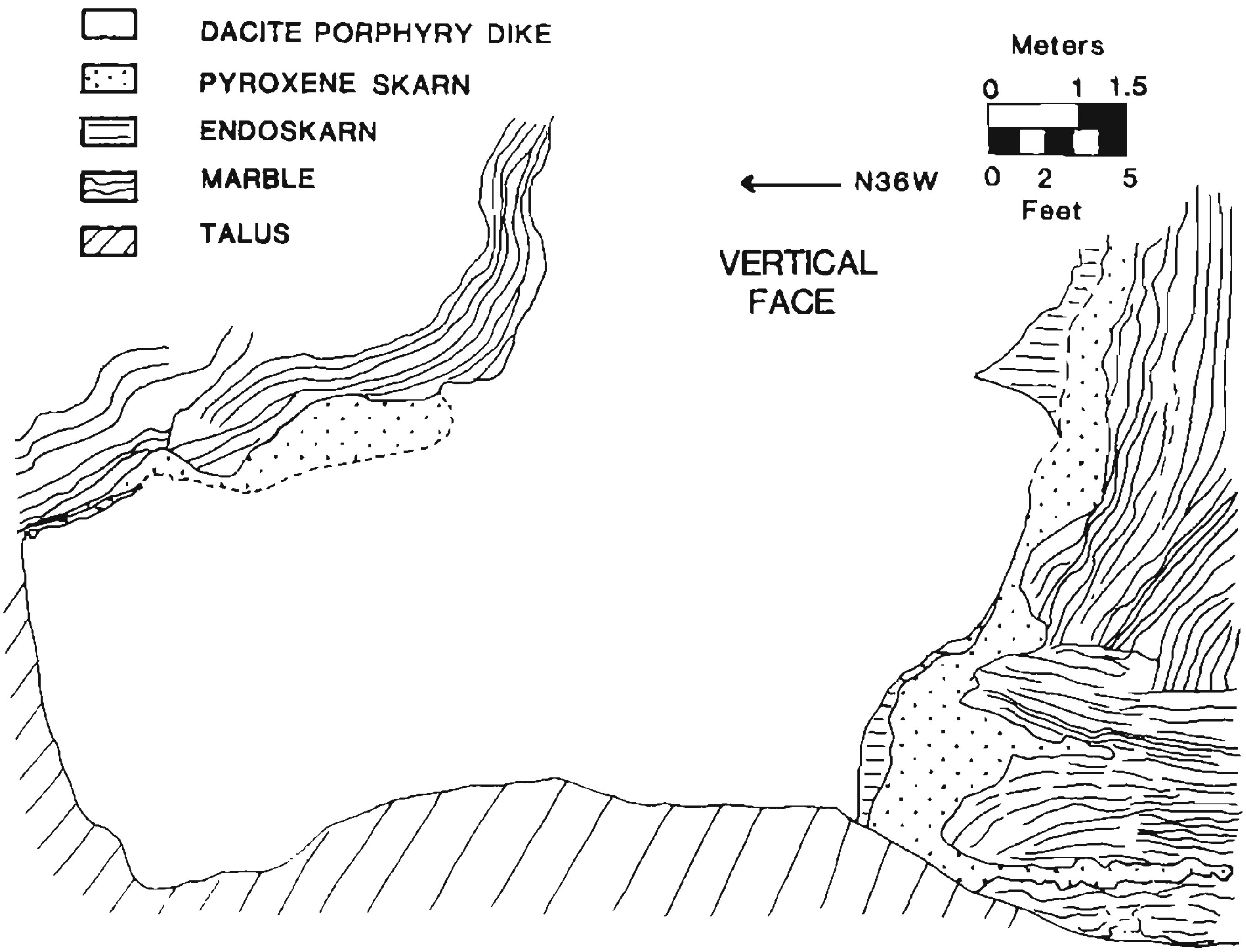


Figure 4. Map of a typical Tin Creek Skarn zone; specific locality indicated on plate 1 as SK.

with marble. This figure also shows the development of skarn manto bodies where metasomatic fluids have infiltrated along bedding in the marble.

Skarn forms along marble contacts with granodiorite porphyry dikes, porphyritic dacite dikes and porphyritic hornblende rich dacite dikes. Many dikes do not have skarn developed along their margins, while sometimes skarn is present along one side of a dike but not on the other. Skarn mineralization is also controlled by faults, clearly exposed in outcrop along Tin Creek. The thrust fault which juxtaposes marble over banded calc-silicate hornfels has pyroxene dominant skarn discontinuously developed along its length. A high angle fault to the west of the thrust fault also has skarn developed along it. This skarn appears to have been retrograded to chlorite + calcite + quartz with sphalerite + pyrite + chalcopyrite.

Skarn mineralization localization is due to structural control. Metasomatic fluids used dikes and faults as conduits. Skarns formed as a result of reaction between these metasomatic fluids and the surrounding carbonate rocks. The dikes in the Tin Creek area are too small to have a significant heating effect on the surrounding lithologies, so that there are no local metamorphic aureoles around individual dikes.

Pyroxene Skarn

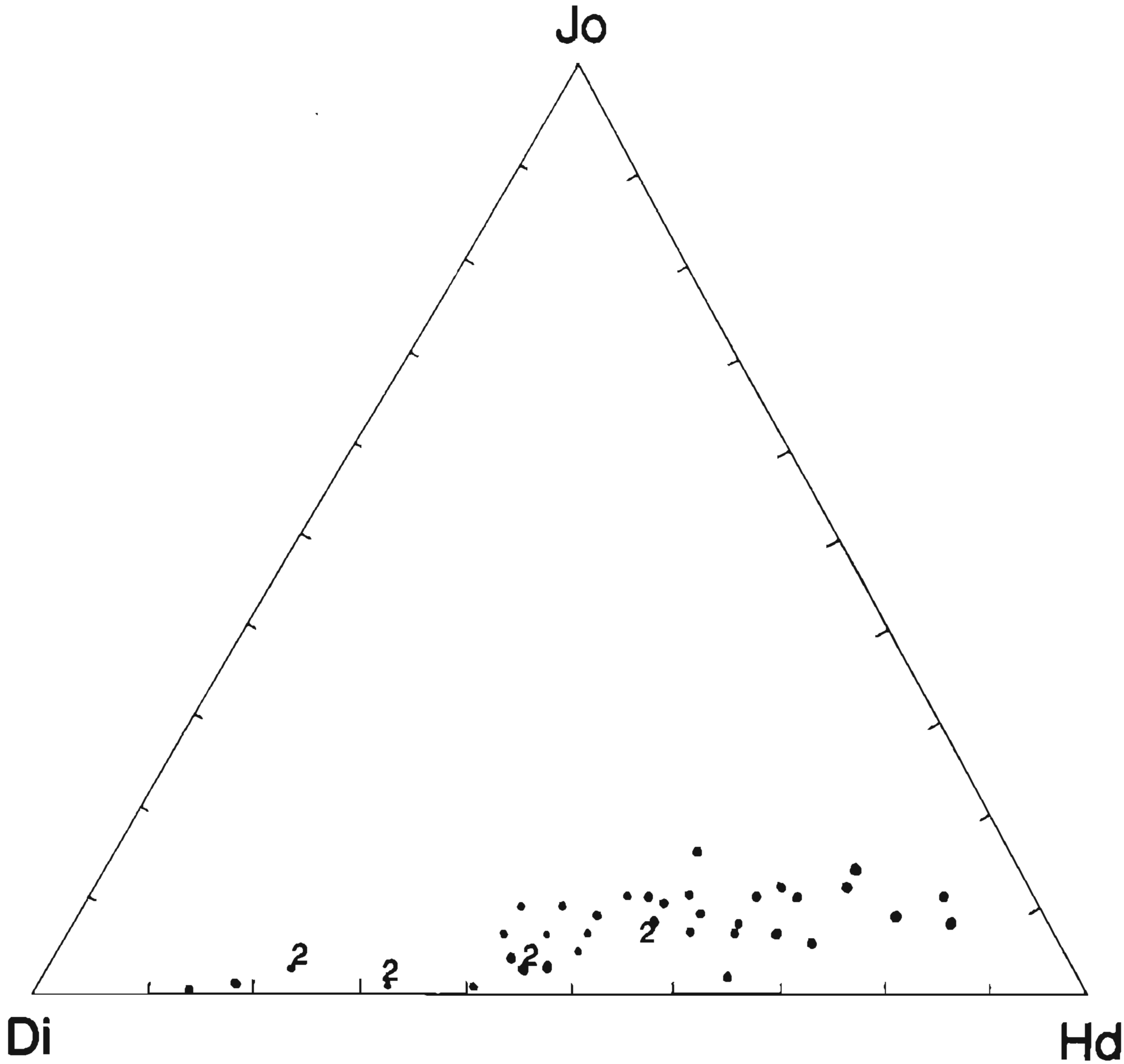
Pyroxene dominant skarns exhibit textural and compositional zoning as coarse, Fe-Mn rich salite occurs along the marble front and clinopyroxene becomes finer grained and more Mg-rich near the intrusive contact. Hedenbergitic pyroxene at skarn marble contacts can occur as green prismatic crystals up to 7 cm long. Most pyroxene in skarn bodies occurs as fine to extremely fine grained masses which produce hard compact outcrops.

Pyroxene compositions from skarn samples at the Tin Creek prospects are shown in figure 5. These compositions are expressed as mole percent of end members, based on electron microprobe analyses. Pyroxenes range from Hd_{12} to Hd_{83} with an increase in the Jo endmember as Hd increases. Analyses of samples collected during detailed mapping initiate that pyroxenes generally have maximum Hd + Jo content at the marble front, corresponding to coarse grained salite. Pyroxene analyses show a Fe + Mn enrichment paragenesis, with fine grained diopsidic pyroxene overprinted and veined by coarser hedenbergitic pyroxene grains.

Garnet Skarn

Garnet dominant skarns are restricted to the center of the Tin Creek system occurring throughout the top half of section 23 and some of the ridge in section 14. Garnet skarns weather red-brown to brown and fresh surfaces are green. Small garnet faces are visible throughout these skarns.

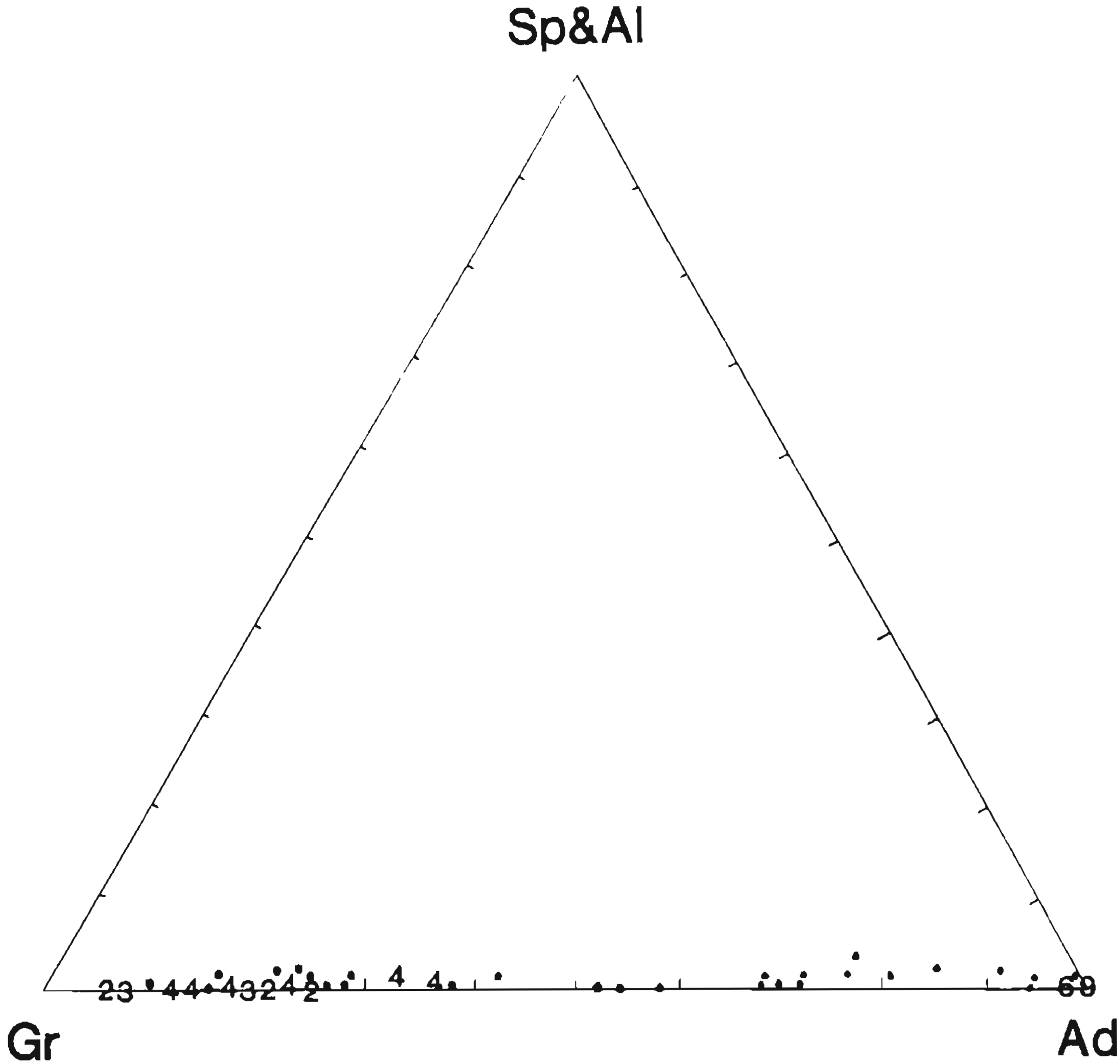
Garnet compositions show an even more systematic change through time than the pyroxenes. Garnet compositions, like pyroxenes, shown an Fe enrichment during the evolution of the metasomatic system. Compositions of garnets, plotted as mole percent of the end members, are plotted in figure 6. Garnets from the Tin Creek region are essentially restricted to grossular-



Jo - Johannsenite $CaMnSi_2O_6$
Di - Diopside $CaMgSi_2O_6$
Hd - Hedenbergite $CaFeSi_2O_6$

Numbers on plot refer to number of analyses at that point.

Figure 5. Pyroxene compositions from skarns, Tin Creek.



Sp & Al - Spessartine & Almandine - $Mn_3Al_2(SiO_4)_3$ & $Fe_3Al_2(SiO_4)_3$
Gr - Grossular - $Ca_3Al_2(SiO_4)_3$
Ad - Andradite - $Ca_3Fe_2(SiO_4)_3$

Numbers on plot refer to number of analyses at that point.

Figure 6. Garnet compositions from skarns, Tin Creek.

andradite composition join, with spessartine + almandine composition at a maximum of 6 percent. Metamorphic garnet is grossular rich, with an average andradite content of 12 percent. Clear metasomatic garnet, formed after and generally rimming metamorphic garnet, has an average composition of Ad_{18}. The latest garnet formed is brown colored and has an average composition of Ad_{58}. Brown garnet formed during the main stage skarn event and compositions have a large range. Brown garnet likely represents a long period of skarn formation, with individual garnet grains showing several periods of chemical reversals during garnet growth; for example, high Fe brown garnet formed, then later lower Fe brown garnet formed, and then the process repeats itself. Figure 7 summarizes microprobe data for the garnets.

Other minerals are commonly found in both pyroxene and garnet skarns. Epidote-clinozoisite is present in all of the endoskarns examined and almost all of the skarns. In some areas, epidote is the dominant skarn mineral, occurring as a late event (fig. 8). Chlorite, quartz, and calcite were prevalent in almost every thin section examined. Amphibole, as a retrograde product of the coarser grained clinopyroxene, is occasionally present as "shreddy" grains or mats with clinopyroxene cores.

Mineralization

Mineralization consists predominantly of massive to disseminated sphalerite and chalcopyrite, with minor amounts of galena, pyrite, and pyrrhotite, and rare arsenopyrite, covellite, chalcocite, and magnetite. Silver is present in the ore minerals but its form and localization has not yet been determined. Sulfides occur as fine to coarse grains, generally associated with calc-silicate assemblages. Ore minerals are present in skarn bodies, as sulfide mantos within the calc-silicate hornfels, as mineralized skarn clasts in the igneous matrix breccia dikes, and as minor veins with quartz and calcite in the calc-silicate hornfels.

Sulfide mantos in the banded calc-silicate hornfels are the only significant mineralization within this unit and the only significant mineralization that is not hosted by skarns. Mineralization occurs immediately below the thrust fault exposed in Tin Creek. About a dozen mineralized layers, conformable to banding (relic bedding) in the hornfels, are exposed over a stratigraphic distance of 6 m. Individual mantos vary in thickness from 2 cm to 1 m. Semimassive to massive sulfides, dominantly sphalerite and pyrite, with chalcopyrite and galena are associated with sparry calcite and some quartz. Sulfide mantos may be the replacement of original thin limestone beds within the metasiliceous clastic unit.

Sulfide deposition is intimately associated with skarn calc-silicates. Petrographic studies of altered rocks at Tin Creek have led to a paragenetic model which is summarized in figure 9. Metamorphic garnet and pyroxene (grossularitic and diopsidic, respectively) form without any sulfide phases. Early metasomatic garnet and pyroxene are accompanied by minor amounts of sphalerite and chalcopyrite. Overall, it is seen that skarn mineral formation and sulfide deposition are not contemporaneous in most of the skarn bodies studied.

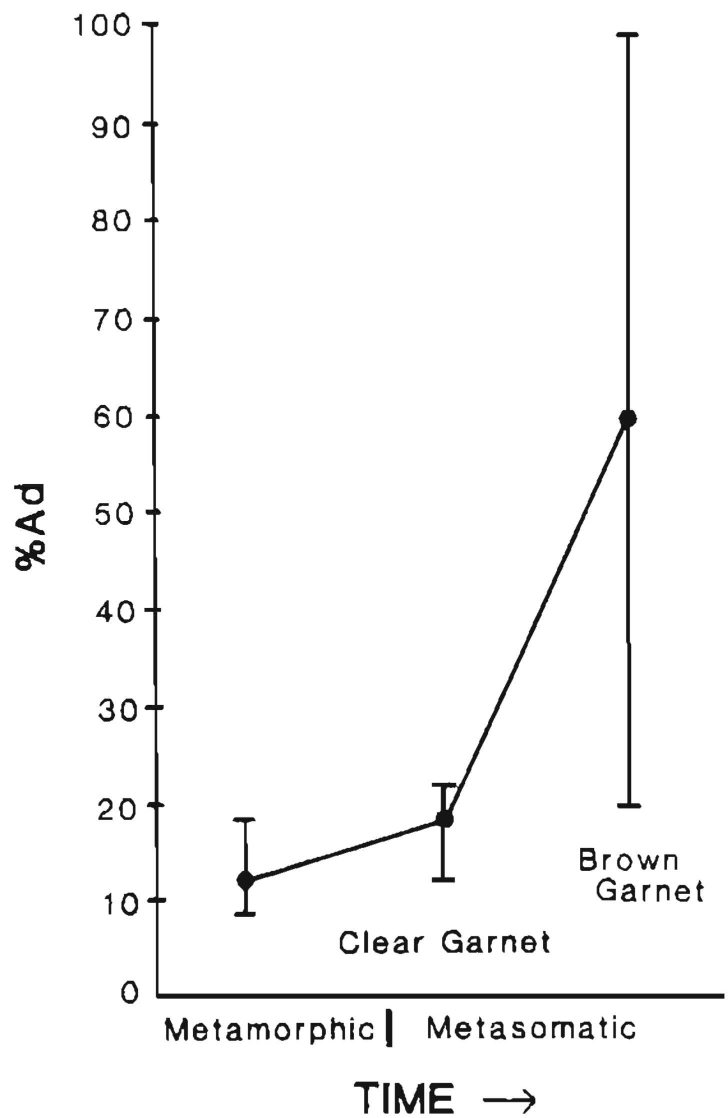


Figure 7. Evolution of garnet compositions through time, Tin Creek skarns.

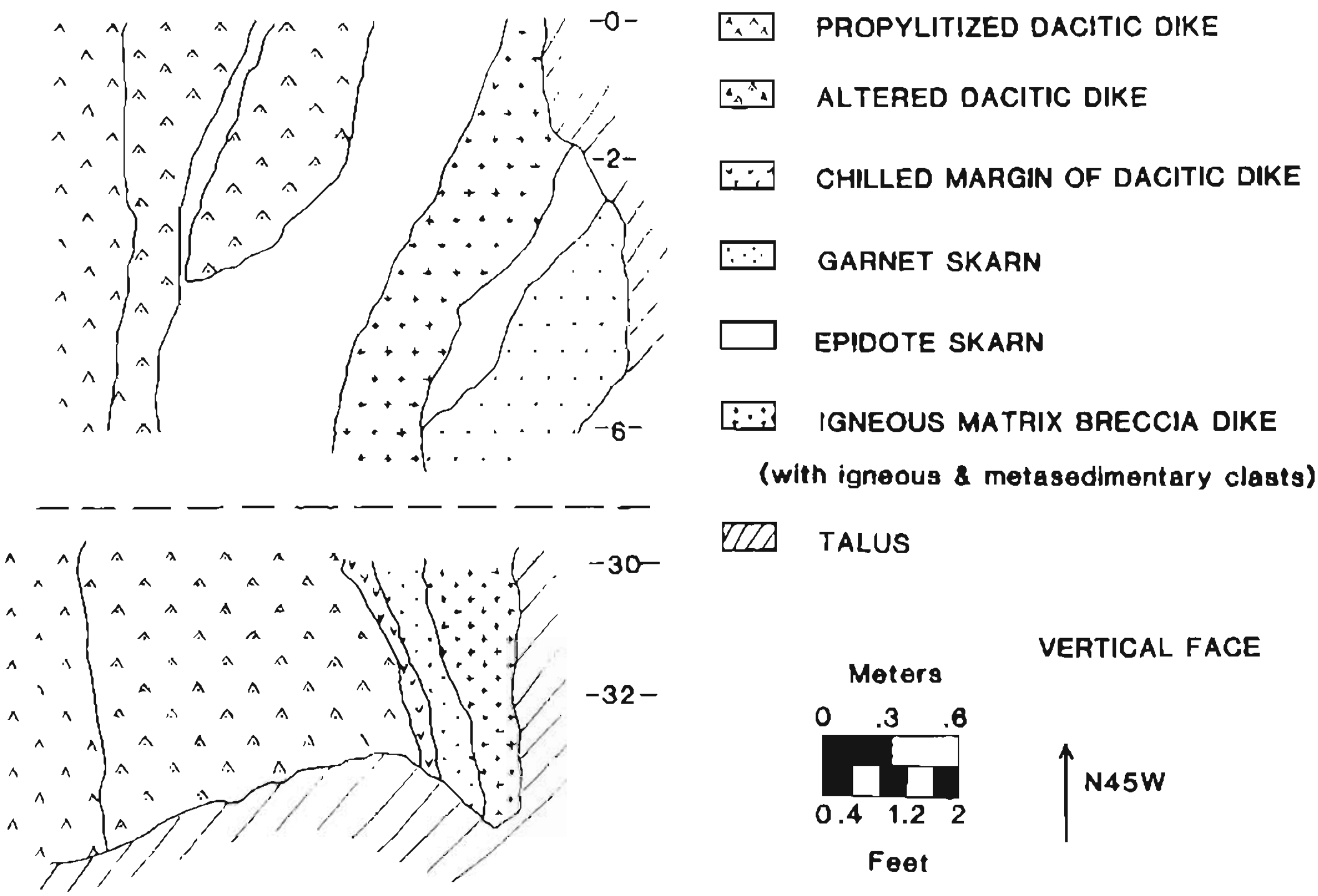


Figure 8. Examples of epidote rich skarn zones, Tin Creek, indicated on plate 1 as E.

METAMORPHIC	METASOMATIC		
GARNET + PYROXENE	GARNET + PYROXENE +(SPL + CP)	GARNET + PYROXENE REPLACED BY SPL + CP	GARNET + PYROXENE $\longrightarrow$ AMPH.- EPI - QTZ REPLACED BY SPL + CP + GL

PYROXENE (HD RICH) $\longrightarrow$ SPHALERITE + QUARTZ + CALCITE

GARNET (AD RICH) $\longrightarrow$ CHALCOPYRITE + CALCITE + QUARTZ

Figure 9. Sequential diagram showing skarn formation and sulfide deposition.

In almost every case where ore minerals occur in skarns, the nearby calc-silicate minerals are partially to completely destroyed. The main period of sulfide deposition is contemporaneous with the waning formation of garnet and pyroxene. Sulfides are commonly accompanied by quartz and calcite, and replace garnet and pyroxene. Sulfides occur in calcite dominant veins and pods throughout many of the examined skarns. The dominant ore minerals present in the Tin Creek skarns are sphalerite and chalcopyrite. Even though sphalerite and chalcopyrite occur with both pyroxene and garnet in some cases, the sulfides and metasomatic calc-silicates usually have a preferential association. Hedenbergitic pyroxene is commonly replaced by sphalerite, while andraditic garnet is preferentially replaced by chalcopyrite. Cu/Zn ratios increase from the distal pyroxene-sphalerite dominant skarns towards the proximal garnet-chalcopyrite dominant skarns. Maximum Cu/Zn ratios are at the center of the exposed metasomatic system, where garnet skarns are associated with chalcopyrite and magnetite.

Retrograde alteration of garnet and pyroxene to epidote and amphibole with quartz is sometimes postdated by late sulfide formation. Unlike the main sulfide deposition event, where much of the sulfide is a replacement of the calc-silicates, late sulfide deposition is dominated by crosscutting veins. Galena, where it is present in skarns, is commonly associated with calcite in veins which crosscut all earlier features. Sphalerite and chalcopyrite also occur as veins which crosscut amphibole and epidote, although these occurrences are minor due to the low retrograde alteration of the skarns.

TIN CREEK SKARNS - RELATED TO PORPHYRY COPPER SYSTEM

It has been suggested that the Tin Creek skarn prospects may be overlying a porphyry copper deposit. This hypothesis is a difficult one to address due to the lack of exposure of any stock. Additionally, no deep drilling has been completed in the prospect area. However, the following observations support or disagree with the porphyry copper hypothesis.

Pro

-metamorphic aureole most likely produced by a hidden stock. Stock may have porphyry Cu mineralization since some exposed dikes have disseminated sulfides.

-intense quartz stockwork veining at the Tin Creek systems center (unpublished Anaconda data)

-actinolite(?) bearing veins are found in hornfels near the center. Actinolite-bearing veins are absent in skarn not associated with K-silicate altered stocks

-many examples in literature (ex. Einaudi and others, 1981) in which Zn-Pb skarns are peripheral to porphyry systems.

Con

-metal ratios of igneous rocks at Tin Creek are not like metal ratios of igneous rocks associated with porphyry systems. Figure 10 compares Tin Creek data to data from the Kalamazoo deposit (Chaffee, 1982).

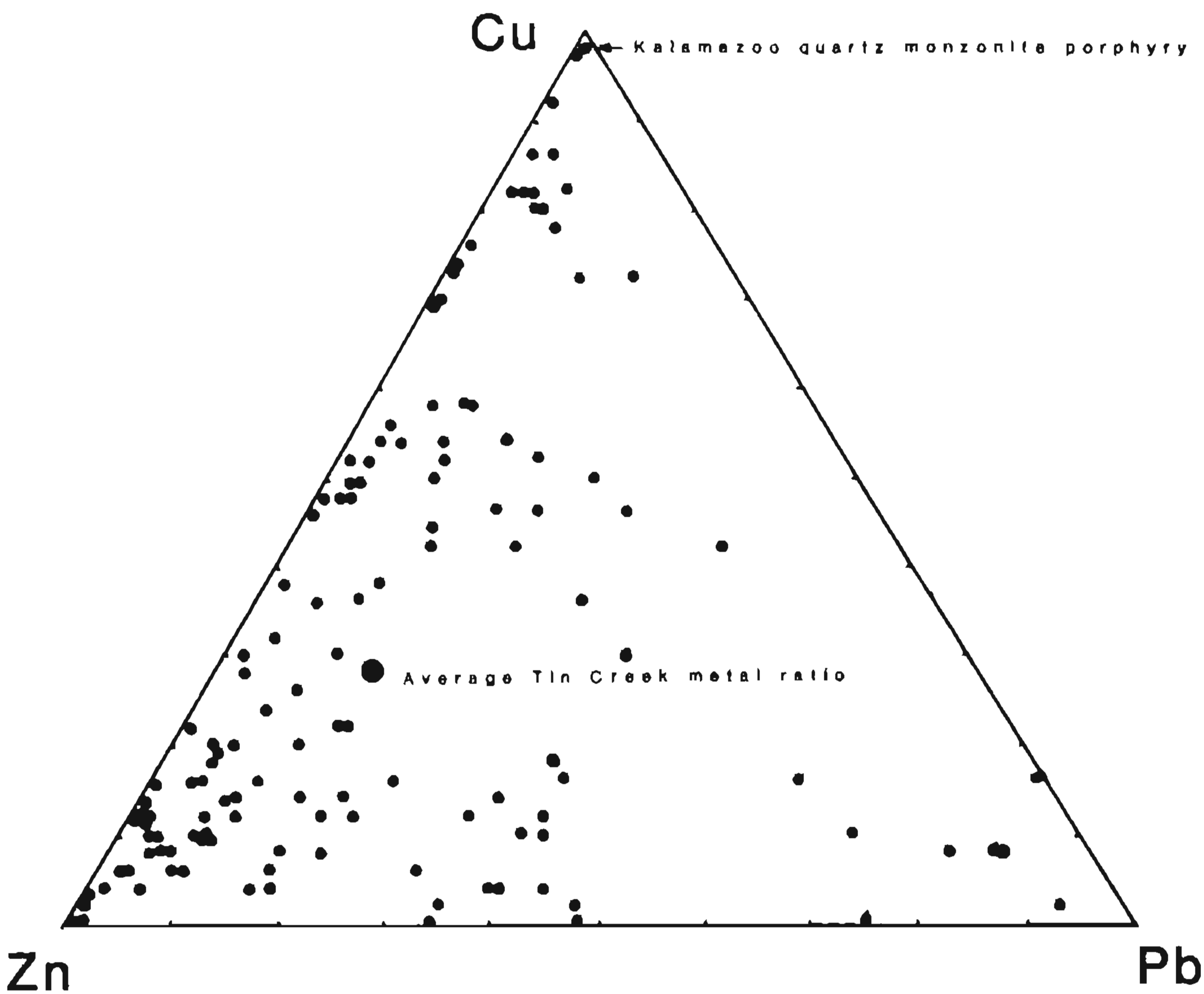


Figure 10. Comparison of intrusive rock-metal ratios at Tin Creek with the average for the Kalamazoo (Arizona) porphyry copper system.

-Mo mineralization, which is commonly found with porphyry Cu systems, is not present at Tin Creek

-exposed igneous plutons of intermediate compositions around the Tin Creek region have not been found to contain significant porphyry mineralization

-Tin Creek skarns are usually not retrograded, while porphyry related skarns have strong retrograde alteration (Einaudi and others, 1981)

-igneous dikes do not have the intense alteration assemblages characteristic of porphyry systems. Igneous-rocks in the study area are mostly popyllitically altered, with very minor sericitic alteration.

Though the question of whether there is a hidden porphyry system is important in understanding the Tin Creek area, it is relatively unimportant economically at the present time. Silver grades will determine whether these prospects are economically feasible given the present conditions. Silver is not appreciably concentrated in porphyry Cu systems, so the present or absence of a porphyry will not affect economic considerations of the Tin Creek prospects.

COMPARISON OF THE TIN CREEK PROSPECTS TO ZN-PB SKARN DEPOSITS

Skarn deposits are classified according to the dominant economic metal present. There are six general subclasses: iron-gold, tungsten, copper, zinc-lead-silver, molybdenum, and tin. Variations within these subclasses are recognized as a function of magma type, environment of emplacement, and host rock composition (Einaudi and others, 1981). Zinc and silver are the dominant economic metal at Tin Creek, so comparisons have been made with zinc-lead-silver skarns, in Tables 1 and 2. Tables 1 and 2 show that the Tin Creek prospects have many characteristics of the Zn-Pb skarn class and the prospects are properly classified as Zn-Pb skarns. Zn-Pb skarns have been further divided by proximity to plutonic bodies by Einaudi and others (1981). Table 3 lists some Zn-Pb skarns which formed near dikes, correlative to the Tin Creek skarns.

Estimating the grade and tonnage of potential skarn deposits in the Farewell area is a difficult task. The Tin Creek skarn prospects are one of the best explored areas in the McGrath Quadrangle, yet there has been limited drilling and detailed geologic mapping to date. Estimates based only on local knowledge would be tenative at best due to the high uncertainties involved.

Grade tonnage estimates for the Tin Creek area can be postulated by examining data from a worldwide collection of zinc-lead skarn deposits. An inherent bias in this approach is the assumption that the Tin Creek area actually contains a skarn deposit and that this deposit is similar to an average of zinc-lead skarn deposits.

Table 4 provides estimates on grade and tonnage potential for a zinc-lead skarn deposit in the Forewell area. Data used for these estimations is from Singer and Mosier (1983). Numbers given in each column of Table 4 are statistical parameters developed from the worldwide data base. The numbers in the 10th percentile column are minimum grades or tonnage for 90 percent

Table 1. Calcic Zn-Pb skarns (from Einaudi and others, 1981).

Number of deposits	Relatively abundant
Typical size	0.2 - 3 million tons
Typical grade	9% Zn, 6% Pb, 5 oz/ton Ag
Metal association (minor metals)	Zn, Pb, Ag (Cu, W)
Tectonic setting	Continental margin, synorogenic to late orogenic
Associated igneous rocks	Granodiorite to granite; diorite to syenite
Co-genetic volcanics	Absent or uncommon
Intrusive texture	Coarse grained to aphanitic, equigranular to porphyritic
Intrusive morphology	Large stocks or dikes
Intrusive alteration	Local, but intense endo-skarn; epidote-pyroxene-garnet
Mineralogy:	
Prograde	Johannsenitic pyroxene, andraditic garnet, bustamite, local idocrase
Retrograde	Mn - actinolite, ilvaite, epidote, chlorite, dannemorite (amphibole)
Ore	Sphalerite, galena, chalcopyrite, arsenopyrite

Table 2. Similarities between Tin Creek and other zinc-bearing skarns.

-Skarns associated with structural pathways

-Distinctive manganese - and iron-rich calc-silicate mineralogy

-Absence of a skarnoid stage

-Relatively minor degree of retrograde alteration

-Pyroxene is usually dominant prograde calc-silicate mineral

-Dominant ore sulfides associated with pyroxene

-Calc-silicate minerals contain significant amounts of both ferrous and ferric iron - pyroxenes (ferrous), garnet (ferric)

-Sulfide mineralogy simple - <u>sphalerite</u>, galena, (chalcopyrite), ((pyrite, pyrrhotite, magnetite))

-FeS content in sphalerite 12-20 mole % FeS (compare to Tin Creek's 14-20 mole % FeS in sphalerite)

Table 3. Some examples of Zn-Pb skarns formed near dikes (from Einaudi and others, 1981).

Locality	Metals	Tonnage[2] grade	Host rocks	Intrusive	Prograde[1] minerals	Retrograde minerals	Opaque minerals	Skarn morphology	Alteration in intrusive
Groundhog, Central Mining dist., N. Mex.	Zn, Pb (Cu, Ag)	3 m.t. 12% Zn 4% Pb 1% Cu 2 oz Ag	Carboniferous limestone	Tertiary(?) granodiorite porphyry dikes	Pyx(Hd_{40-45} Jo_{30-50}) Gar (Ad_{80-100}) bustamite	Ilvaite, cummingtonite, amphibole, chlorite	Sphalerite, galena, chalcopyrite, pyrite, magnetite	Along lithologic and dike contacts	Extensive epidote-chlorite endoskarn
San Antonio, Chihuahua, Mexico	Pb, Zn (Cu, Sn, Ag)	3 m.t. 1.5% Sn	Cretaceous limestone	Tertiary(?) rhyolite dikes	Pyx(Hd_{94}) andraditic garnet	Epidote, cummingtonite, ilvaite, fluorite	Galena, sphalerite, chalcopyrite, magnetite cassiterite	Along contact and distal to rhyolite dikes	Sericite, topaz
Santa Eulalia, Chihuahua, Mexico	Zn, Pb (Ag)	1.2 m.t. 11% Zn 10% Pb 6 oz Ag	Cretaceous limestone underlain by evaporites	Rhyolite dikes and sills underlain by quartz monzonite stock	Olv(Fa_{75} Tp_{25}) hedenbergitic pyroxene, rhodonite	Ilvaite, amphibole, chlorite	Sphalerite, galena, pyrite chalcopyrite, magnetite, pyrrhotite, arsenopyrite	Along fault and dike contacts, in chimneys	Minor sericite
Naica, Chihuahua, Mexico	Zn, Pb (Cu, W)	10 m.t. 10% Zn 11% Pb 13 oz Ag	Cretaceous limestone, shale	Tertiary(?) rhyolite dikes	Gar(Ad_{20-98} Sp) Pyx(Hd_{40} Jo_{40}) wollastonite, idocrase bustamite	Sericite, chlorite, amphibole	Sphalerite, galena, chalcopyrite, pyrite, arsenopyrite, pyrrhotite, magnetite, molybdenite	Along dike and fault contacts	Garnet-idocrase endoskarn
[illegible] mine, Chihuahua, Mexico	Zn, Pb (Ag, Cu)	0.5 m.t./yr 8% Zn 5% Pb 0.6% Cu 5 oz Ag	Cretaceous shale	Tertiary(?) rhyolite dikes	Pyroxene	Amphibole ilvaite, epidote, fluorite	Sphalerite galena, chalcopyrite, pyrite, arsenopyrite	Veins cutting shale	
Hidalgo, Santa Barbara, Chihuahua, Mexico	Zn, Pb (Ag)	? 10% Zn 15% Pb [illegible] Cu 8 oz Ag	Cretaceous limestone, shale	Tertiary(?) rhyolitic dikes	Garnet, pyroxene, idocrase(?)	Fluorite, epidote	Sphalerite, galena, chalcopyrite, pyrite, arsenopyrite	Along fault and dike contacts	Clay after feldspar

[1]Pyroxene (Pyx) composition expressed as mole percent hedenbergite (Hd) and johannsenite (Jo); remainder is diopside. Garnet (Gar) composition expressed as mole percent andradite (Ad) and spessartine (Sp); remainder is grossularite. Olivine (Olv) composition expressed as mole percent fayalite (Fa) and tephroite (Tp); remainder is forsterite.
[2]Tonnage represents estimate of total ore, or yearly production, in millions of tons (m.t.)

Table 1. Some examples of Zn-Pb skarns formed near dikes (from Einaudi and others, 1981).

Locality	Metals	Tonnage grade	Host rocks	Intrusive	Prograde minerals[1]	Retrograde minerals	Opaque minerals	Skarn morphology	Alteration in intrusive
Groundhog, Central Mining dist., N. Mex.	Zn, Pb (Cu, Ag)	3 m.t. 12% Zn 4% Pb 1% Cu 2 oz Ag	Carboniferous limestone	Tertiary(?) granodiorite porphyry dikes	$Pyx(Hd_{40-45}Jo_{30-50})$ Gar (Ad_{80-100}) bustamite	Ilvaite, cummingtonite, amphibole, chlorite	Sphalerite, galena, chalcopyrite, pyrite, magnetite	Along lithologic and dike contacts	Extensive epidote-chlorite endoskarn
[illegible], Chihuahua, Mexico	Pb, Zn (Cu, Sn, Ag)	3 m.t. 1.5% Sn	Cretaceous limestone	Tertiary(?) rhyolite dikes	Pyx(Pb[illegible]) andradite garnet	Epidote, cummingtonite, ilvaite, fluorite	Galena, sphalerite, chalcopyrite, magnetite, cassiterite	Along cut faults and distal to rhyolite dikes	Sericite, topaz
Santa Eulalia, Chihuahua, Mexico	Zn, Pb (Ag)	3.2 m.t. 11% Zn 10% Pb 6 oz Ag	Cretaceous limestone underlain by evaporites	Rhyolite dikes and sills underlain by quartz monzonite stock	$Olv(Fa_{75}Tp_{?})$ hedenbergitic pyroxene, rhodonite	Ilvaite, amphibole, chlorite	Sphalerite, galena, pyrite chalcopyrite, magnetite, pyrrhotite, arsenopyrite	Along fault and dike contacts, in chimneys	Minor sericite
Naica, Chihuahua, Mexico	Zn, Pb (Cu, W)	10 m.t. 10% Zn 13% Pb 13 oz Ag	Cretaceous limestone, shale	Tertiary(?) rhyolite dikes	$Gar(Ad_{20-98}Sp_{2-7})Pyx(Hd_{40}Jo_{40})$ wollastonite, idocrase bustamite	Fluorite, chlorite, amphibole	Sphalerite, galena, chalcopyrite, pyrite, arsenopyrite, pyrrhotite, magnetite, molybdenite	Along dike and fault contacts	Garnet-idocrase endoskarn
Frisco mine, Chihuahua, Mexico	Zn, Pb (Ag, Cu)	0.5 m.t./yr 8% Zn 5% Pb 0.6% Cu 5 oz Ag	Cretaceous shale	Tertiary(?) rhyolite dikes	Pyroxene	Amphibole ilvaite, epidote, fluorite	Sphalerite galena, chalcopyrite, pyrite, arsenopyrite	Veins cutting shale	
Hildago, Santa Barbara, Chihuahua, Mexico	Zn, Pb (Ag)	? 10% Zn 15% Pb 2% Cu 8 oz Ag	Cretaceous limestone, shale	Tertiary(?) rhyolite dikes	Garnet, pyroxene, idocrase(?)	Fluorite, epidote	Sphalerite, galena, chalcopyrite, pyrite, arsenopyrite	Along fault and dike contacts	Clay after feldspar

[1]Pyroxene (Pyx) composition expressed as mole percent hedenbergite (Hd) and johannsenite (Jo); remainder is diopside. Garnet (Gar) composition expressed as mole percent andradite (Ad) and spessartine (Sp); remainder is grossularite. Olivine (Olv) composition expressed as mole percent fayalite (Fa) and tephroite (Tp); remainder is forsterite.
Tonnage represents estimate of total ore, or yearly production, in millions of tons (m.t.).

Table 3. Some examples of Zn-Pb skarns formed near dikes (from Einaudi and others, 1981).

Locality	Metals	Tonnage grade	Host rocks	Intrusive	Prograde minerals[1]	Retrograde minerals	Opaque minerals	Skarn morphology	Alteration in intrusive
Groundhog, Central Mining dist., N. Mex.	Zn, Pb (Cu, Ag)	3 m.t. 12% Zn 4% Pb 1% Cu 2 oz Ag	Carboniferous limestone	Tertiary(?) granodiorite porphyry dikes	Pyx($Hd_{40-45}Jo_{30-50}$) Car (Ad_{80-100}) bustamite	ilvaite, cummingtonite, amphibole, chlorite	Sphalerite, galena, chalcopyrite, pyrite, magnetite	Along lithologic and dike contacts	Extensive epidote-chlorite endoskarn
San Antonio Chihuahus, Mexico	Pb, Zn (Cu, Sn, Ag)	3 m.t. 1.5% Sn	Cretaceous limestone	Tertiary(?) rhyolite dikes	Pyx($Hd_{64}Jo_{16}$) andraditic garnet	Epidote, cummingtonite, ilvaite, fluorite	Galena, sphalerite, chalcopyrite, magnetite cassiterite	Along contacts and distal to rhyolite dikes	Sericite, topaz
Santa Eulalia, Chihuahus, Mexico	Zn, Pb (Ag)	3.2 m.t. 11% Zn 10% Pb 6 oz Ag	Cretaceous limestone underlain by evaporites	Rhyolite dikes and sills underlain by quartz monzonite stock	Olv($Fa_{75}Tp_{25}$) hedenbergitic pyroxene, rhodonite	ilvaite, amphibole, chlorite	Sphalerite, galena, pyrite chalcopyrite, magnetite, pyrrhotite, arsenopyrite	Along fault and dike contacts, in chimneys	Minor sericite
Nalca, Chihuahus, Mexico	Zn, Pb (Cu, W)	10 m.t. 10% Zn 13% Pb 13 oz Ag	Cretaceous limestone, shale	Tertiary(?) rhyolite dikes	Gar($Ad_{20-98}Sp_{2-7}$)Pyx($Hd_{40}Jo_{40}$)wollastonite, idocrase bustamite	Fluorite, chlorite, amphibole	Sphalerite, galena, chalcopyrite, pyrite, arsenopyrite, pyrrhotite, magnetite, molybdenite	Along dike and fault contacts	Garnet-idocrase endoskarn
Frisco mine, Chihuahus, Mexico	Zn, Pb (Ag, Cu)	0.5 m.t./yr 8% Zn 5% Pb 0.6% Cu 5 oz Ag	Cretaceous shale	Tertiary(?) rhyolite dikes	Pyroxene	Amphibole ilvaite, epidote, fluorite	Sphalerite galena, chalcopyrite, pyrite, arsenopyrite	Veins cutting shale	
Hildago, Santa Barbara, Chihauhua, Mexico	Zn, Pb (Ag)	? 10% Zn 15% Pb 2% Cu 8 oz Ag	Cretaceous limestone, shale	Tertiary(?) rhyolitic dikes	Garnet, pyroxene, idocrase(?)	Fluorite, epidote	Sphalerite, galena, chalcopyrite, pyrite, arsenopyrite	Along fault and dike contacts	Clay after feldspar

[1] Pyroxene (Pyx) composition expressed as mole percent hedenbergite (Hd) and johannsenite (Jo); remainder is diopside. Carnet (Car) composition expressed as mole percent andradite (Ad) and spessartine (Sp); remainder is grossularite. Olivine (Olv) composition expressed as mole percent fayalite (Fa) and tephroite (Tp); remainder is forsterite. Tonnage represents estimate of total ore, or yearly production, in millions of tons (m.t.).

Table 4. Grade and tonnage parameters from 47 zinc-lead skarn deposits.

	10th percentile	50th percentile	90th percentile
Tonnage (millions of tons)	18.0	2.1	.25
Zinc grade (percent)	14.0	5.8	2.8
Copper grade (percent)	1.2	0.079	---
Lead grade (percent)	11.0	3.6	.54
Silver grade (grams/ton)	390.0	98.0	---

of the lead-zinc skarns examined. The 50th percentile column corresponds to the mean or average for these deposits.

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