UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Ages and geologic relationships in the Willow Creek gold mining district, southwestern Talkeetna Mountains, southern Alaska

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Open-File Report 87-143

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1987

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INTRODUCTION

The Willow Creek gold mining district is in the Peninsular terrane, on the southwestern margin of the Talkeetna Mountains batholith (fig. 1). The mining district exposes two plutons of the batholith, a tonalite (unit TKt) and an adamellite (unit TKa) (Csejtey and others,1978). These plutons are in contact with an older metamorphic unit mapped as Jurassic(?) pelitic schist (unit Jps). The tonalite and schist both host gold-bearing quartz veins, but the adamellite is not mineralized. The southern part of the tonalite in the Willow Creek district is intruded by the adamellite, however, the nature of the contact between the tonalite and the schist is uncertain. We interpret the contact as a fault, rather than an intrusive contact. In addition to uncertainty about the contact, the nature and origin of the schist are uncertain, as is the timing of mineralization. To answer these questions, we mapped the contact between the schist and plutons, mapped rock types within the schist, studied thin sections of the units, and did K-Ar age determinations. As a result of this study, we suggest three alternate series of events which are possible in light of present knowledge. Among the three, we favor one series of events and describe it in more detail than the others. Our interpretations are constrained by regional considerations, local field relationships, and K-Ar age determinations.

SUMMARY OF AGE AND FIELD DATA

Age Data

K-Ar age determinations from the Willow Creek district have been reported by Silberman and others (1977), Csejtey and others (1978), Silberman and others (1978), Silberman and others (1979), and Csejtey and Evarts (1979); they are summarized in (table 1). The geologic significance of these ages is discussed below, with a discussion of the units. The chronology of the development of the units is discussed in three alternative hypotheses (table 2).

Field Data

Schist

The schist is the oldest unit in the Willow Creek mining district. Csejtey and Smith (1975) described the schist as an enigmatic unit that went through a complex and poorly understood geologic history. Our field and petrographic studies have shown that the schist is a heterogeneous unit of metamorphosed shale, less abundant sandstone, and minor mafic tuff and igneous hypabyssal and plutonic rocks. Most of the unit is well foliated, metasedimentary chlorite-muscovite schist, with relict biotite and garnet. The presence of relict biotite and garnet suggests that the unit was metamorphosed to amphibolite facies at one time. The biotite and garnet are partly to completely replaced by chlorite, indicating retrogressive metamorphism of the schist to greenschist facies. In addition to the predominant chlorite-muscovite schist, the metasedimentary parts of the unit consist of biotite-muscovite schist, biotite-albite schist, chlorite-albite schist, and minor serpentine-actinolite schist which we interpret to be a metamorphosed mafic tuff. The schist contains at least two surfaces of foliation, which intersect at angles of 60°-90° in thin section. The presence

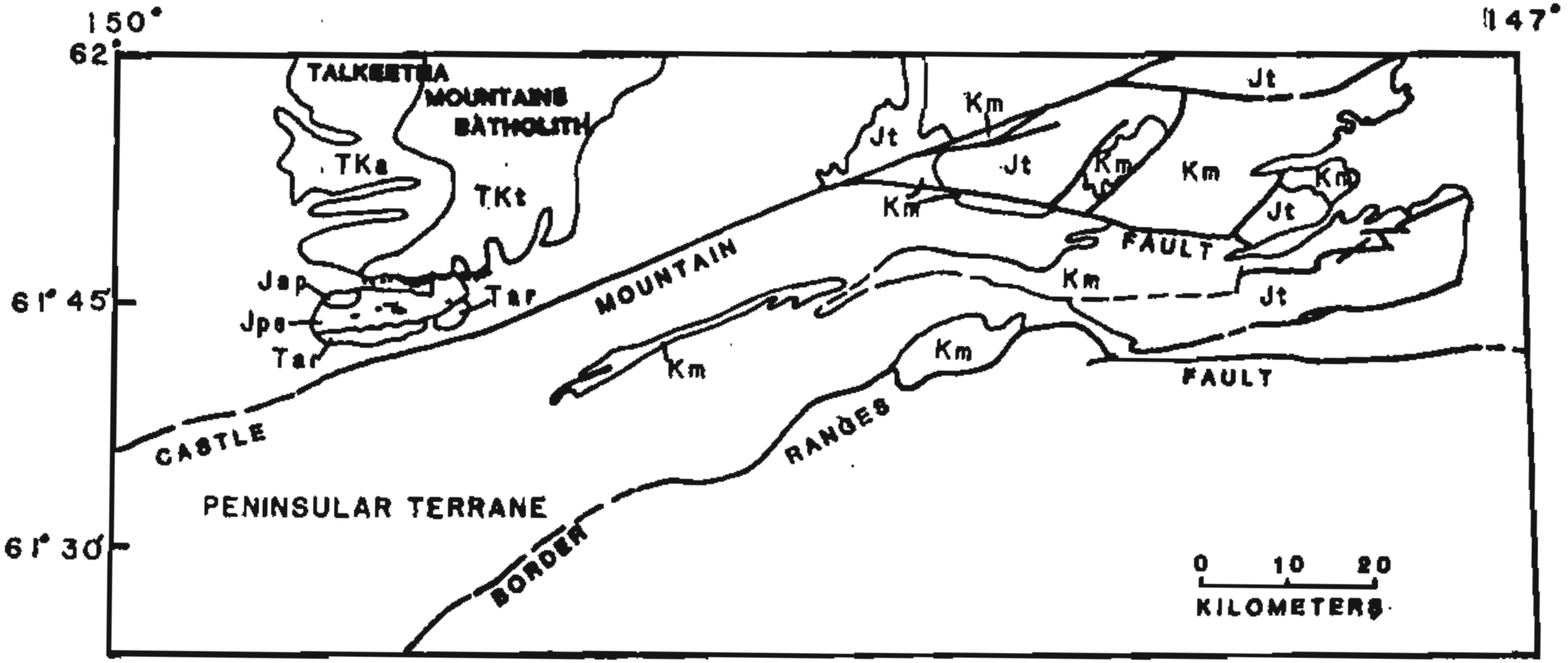


Figure 1.--Geologic sketch map of the northern part of the Anchorage quadrangle. Simplified from Csejtey and others (1978). Tar, Tertiary Arkose Ridge Formation; TKa, Tertiary or Cretaceous adamellite; TKt, Tertiary and Cretaceous tonalite; Km, Cretaceous Matanuska Formation; Jt, Jurassic Talkeetna Formation; Jsp, Jurassic(?) serpentinite; and Jps, Jurassic(?) pelitic schist. The Tertiary and Cretaceous tonalite is Paleocene to the north of the Willow Creek gold mining district. The tonalite may be a composite of plutons.

of the two surfaces suggests that at least two metamorphic events deformed the schist.

The age of the protolith of the schist is not known, because the unit is well foliated and lacks fossils. Csejtey and Smith (1975) suggested that the protolith may be late Paleozoic, perhaps Permian in age, based on regional correlation with lithologically similar units exposed about 200 km to the east. These similar units include the Pennsylvanian and Early Permian Skolai Group (Richter and Dutro, 1975) and the Strelna Formation, both exposed in the Wrangell Mountains; and the Middle Pennsylvanian to Early Permian Mankomen Group, exposed in the southeastern Alaska Range. These correlations were discussed by MacKevett and Plafker (1974). Alternatively, the schist of Willow Creek may have been a part of the Peninsular terrane ever since the deposition of its protolith. In this case, it has been through several periods of deformation and metamorphism along with the rest of the terrane. Periods of regionally recognized deformation of the Peninsular terrane occurred in the very Early Jurassic as recorded in units south of the Castle Mountain fault (Pavlis, 1983), and in the Early to Middle Jurassic, Middle to Late Cretaceous, and middle Paleogene to Quaternary (Csejtey and others, 1978). During the Early to Middle Jurassic deformation, plutonism and high T-P regional metamorphism to amphibolite facies occurred in the Peninsular terrane (Csejtey and others, 1978). Because of the regional evidence for high-grade metamorphism of Jurassic age, and the uncertainty about the age of the protolith of the schist, Csejtey and others (1978) considered the unit to be of Jurassic(?) age.

In addition to metasedimentary rocks, the schist contains bodies of serpentinite, which probably were derived from dunite, which is entirely altered to talc and serpentine; from plagioclase-bearing dunite, which is mostly altered to serpentine; and from very altered wehrlite-lherzolite which now consists mostly of talc, serpentine, and two pyroxenes. Amphibolite-facies mineral assemblages of hornblende, plagioclase, and epidote are rare. Large bodies of serpentinite exposed low on the walls of canyons and on the sides of ridges are overlain by chlorite-muscovite schist. This relationship suggests that ultramafic rocks underlie some of the schist. Large bodies of serpentinite also compose the low-lying, gentle ridge-and-valley topography in the northwestern outcrop area of the schist unit. In smaller scale occurrences, in outcrop and even in thin section, the serpentinite is foliated parallel to foliation in the schist, and the foliation is folded. This relationship suggests that the ultramafic rocks were in place within the schist during at least one, and possibly two, deformational events. One event produced a foliation, and another event folded it. This interpretation differs from that of Csejtey and Evarts (1979), who reported only that the serpentinite bodies cut foliation in the schist, and therefore were emplaced late in its deformational history in the Cretaceous. We suggest that relatively young, Tertiary and/or Quaternary faults preferentially formed along the borders of serpentinite, obscuring the older relationship between the serpentinite and schist and providing the appearance of late emplacement of the serpentinite. Rather than late emplacement of the serpentinite, we suggest that it was in place well before the Cretaceous orogeny occurred in the Peninsular terrane. In addition, we suggest that the serpentinite and schist underwent regional metamorphism together before or during the early part of the Late Cretaceous, as indicated by amphibolite-facies mineral assemblages and by K-Ar ages from actinolite at the margins of serpentinite in the schist.

Actinolite from the margins of two separate exposures of serpentinite (numbers 15 and 16, table 1) provided early Late Cretaceous K-Ar ages of 91-89 Ma. This is the time when the amphibole crystal structures closed to the loss of argon, and we suggest that this is the minimum age of high T-P, regional metamorphism recorded in the schist. This interpretation is supported by field observations of serpentinite grading into actinolite schist and folded into micaceous schist. Evidence for high T-P metamorphism is provided by the presence of relict garnets and biotite in micaceous schist, and by the outlines of amphibole altered to chlorite which were reported by Csejtey and Smith (1975). A relatively young age for this regional, high T-P metamorphic event presents geologic problems when considering the other units in the terrane.

An early Late Cretaceous age of metamorphism is inconsistent with the geology of the terrane in this area. If such a high-grade, regional metamorphic event occurred as late as the early Late Cretaceous, then older units such as the Lower Jurassic Talkeetna Formation and the Cretaceous Matanuska Formation should have been affected. However, they were not affected, and a plausible explanation for this is that the schist was emplaced in its present structural position following its regional metamorphic event. This suggests that the maximum age of emplacement of the schist next to the tonalite may be less than 90-89 Ma. A corresponding minimum age of emplacement of late Paleocene is provided by the age of the overlying Arkose Ridge Formation (Silberman and Grantz, 1984; Grantz, Silberman, and Wolfe, USGS, 1979, written commun.). The Arkose Ridge probably was derived locally from the schist and the adjacent plutonic rocks of the Talkeetna Mountains batholith, and was deposited on a nonconformity overlying the schist (Winkler, 1978).

In addition to serpentinite, the schist contains felsic dikes of at least two generations. An older generation of dikes is foliated, whereas a younger generation is not foliated. The older, foliated dikes are metamorphosed tonalite with relict biotite and garnet; the younger unfoliated dikes are very altered granodiorite. The older, foliated dikes intruded the schist before metamorphism, prior to 91-89 Ma, whereas the younger, unfoliated dikes intruded the schist after metamorphism. Age data are not yet available from the dikes in the schist.

Plutonic units, and constraints on timing of emplacement of the schist

The age of emplacement of the schist may be constrained by the ages of the two plutons, the tonalite and the adamellite (table 1). K-Ar ages from the tonalite may provide the maximum age of emplacement, because field evidence suggests that the schist was faulted next to the tonalite after the pluton cooled. The ages of 74-73 Ma determined from hornblende are interpreted as being closer to the age of crystallization of the tonalite than the ages determined from biotite, because hornblende is more resistant than biotite to the loss of argon during post-crystallization events (Everenden and Kistler, 1970; Dalrymple and Lanphere, 1969). The age of 67-65 Ma (biotite and muscovite) for the adamellite may provide the minimum age of emplacement of the schist, because the preferential distribution of gold-vein mineralization near the contact between the schist and tonalite suggests that they already were in contact and mineralized before intrusion of the adamellite. This series of events is our favored hypothesis concerning the timing of emplacement of the schist and of mineralization. The favored hypothesis is listed as number one in table 2, where we present all three alternate hypotheses. The evidence for the timing of emplacement is discussed below.

The first piece of evidence is the nature of the contact between the schist and the tonalite. This contact originally was mapped as intrusive (Csejtey and others, 1978). However, Silberman and others (1978) suggested that the contact may be a fault. The contact is not well exposed, although the southern margin of the tonalite is cataclastically deformed and propylitically altered where it is well exposed on Hatcher Pass (nos. 9 and 11, fig. 2), and nearby outcrops of the schist contain mylonitized zones which were identified in thin section. The deformation of the tonalite and schist suggests that the contact is indeed a fault. Another piece of field evidence for post-intrusion faulting is suggested by the distribution of metamorphic grade in the schist. The schist does not appear to have been affected by contact metamorphism, even though it is in close contact with the tonalite. For example, the distribution of retrogressive greenschist-facies mineral assemblages shows no spatial relationship to the contact with the tonalite. In fact, relict garnet in the schist is preserved within 20 m of the tonalite. An additional piece of evidence for a fault contact is the distribution of ages in the schist and tonalite (table 1). The ages of both units are reduced near the contact. These reduced ages are as follows: chlorite and altered plagioclase from tonalite are 57 Ma and 55 Ma; and muscovite and chlorite from the schist are 55 Ma and 51 Ma, in contrast with the ages of 66-59 Ma some distance from the contact (table 1). Thus, evidence from field and age data suggest that the tonalite did not intrude the schist, but rather that the schist was emplaced after the tonalite cooled enough to be broken and sheared along the fault.

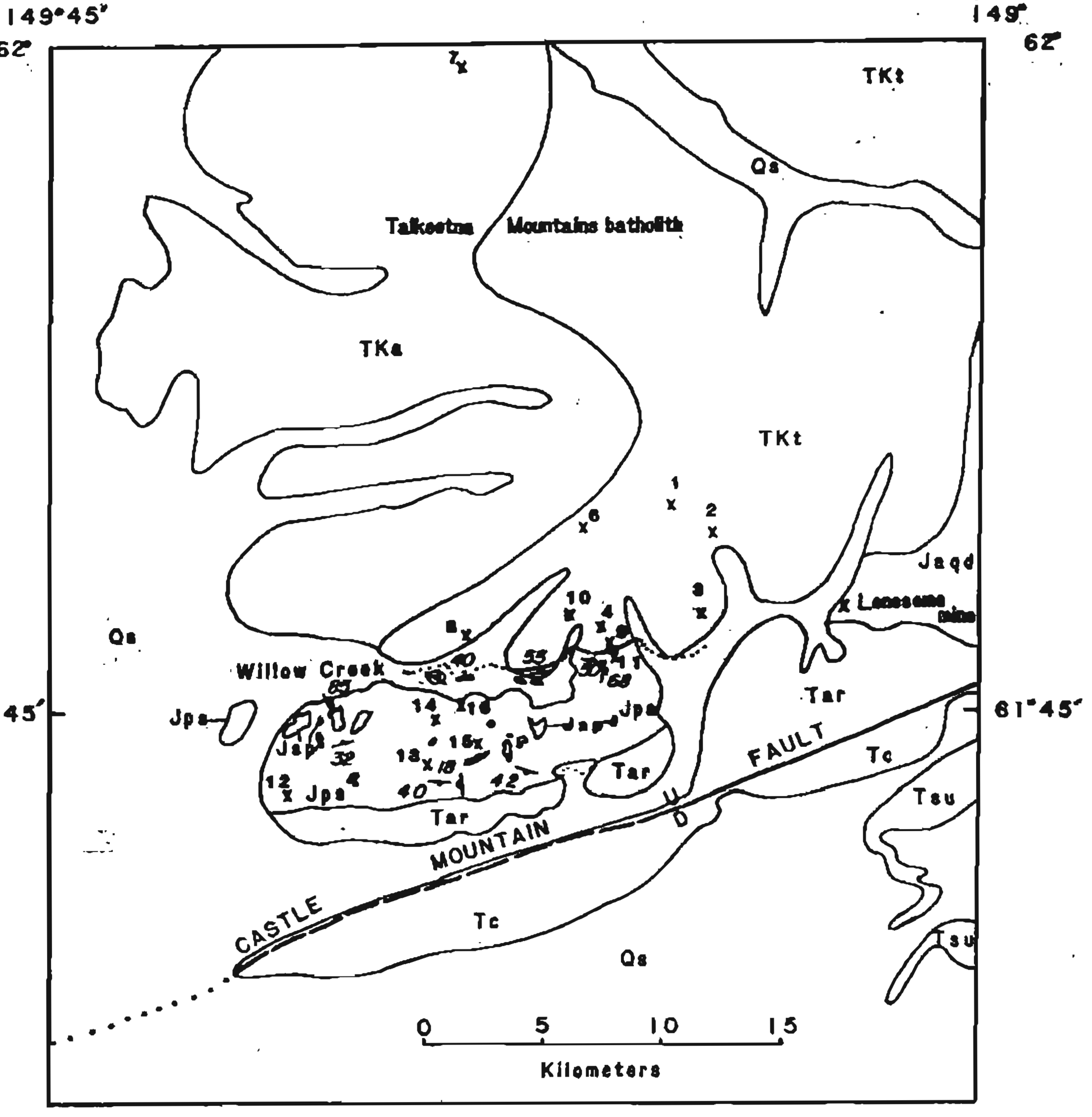
Field evidence suggests that the fault between the schist and the tonalite dips to the north. The evidence consists of the trace of the contact on the geologic map (fig. 2), and the orientation of the predominant foliation in outcrops of the schist which are near the contact. This foliation dips 40°-60° to the north (fig. 2).

The schist could have been emplaced very soon after the tonalite formed and cooled rapidly (hypothesis 1, table 2). Rapid cooling is suggested by the limited number of K-Ar ages from hornblende-biotite pairs (table 1). Although the ages from one sample are reversed, the ages of biotite generally are 2 m.y. younger than the ages of hornblende. This suggests a relatively rapid rate of cooling between the closing of hornblende and biotite to the loss of argon from their crystal structures (Dodson and McClelland-Brown, 1985). Sometime after 72-69 Ma when the tonalite had cooled through the closing temperature for biotite, the schist was emplaced along a fault. The fault between the schist and tonalite may represent a paleo-trace of the Castle Mountain fault that is located to the north of the present trace (figs. 1 and 2).

A minimum age for movement along the fault, and emplacement of the schist, may be provided by the age of 67-65 Ma for intrusion of the adamellite (hypothesis 1, table 2). If the tonalite and schist both were mineralized in one event, which is the simplest hypothesis, then they had to be in contact before mineralization. The unmineralized adamellite may have formed after mineralization of the district, and therefore after emplacement of the schist. The age of the adamellite (67-65 Ma) is about the same as the ages of dikes and veins which cut the tonalite.

The tonalite is cut by dikes of pegmatites, aplite, lamprophyre, and diabase; and mineralized and unmineralized quartz veins. Ages were obtained from some of these dikes and veins (table 1). The age of a lamprophyre dike

Figure 2. Geologic sketch map of the southwestern Talkeetna Mountains, modified from Csejtey and others (1978). x 1, location of potassium-argon sample. Map-unit symbols: Qs, Quaternary surficial deposits; Tc, Tertiary Chickaloon Formation; Tar, Tertiary Arkose Ridge Formation; Tsu, Tertiary sedimentary rocks, undivided; TKa, Tertiary or Cretaceous adamellite; TKt, Tertiary and Cretaceous tonalite; Jsp, Jurassic(?) serpentinite; Jps, Jurassic(?) pelitic schist; Jaqd, Jurassic amphibolite and quartz diorite.



(no. 5, table 1), a mineralized pegmatite dike at the Holland prospect (no. 6, table 1), and one mineralized quartz vein at the Lucky Shot mine (no. 8, table 1) is about 66 Ma; whereas sericite from altered tonalite adjacent to another mineralized quartz vein in the Gold Bullion mine (no. 10, table 1) is only 57 Ma. The similarity in the first three ages of about 66 Ma suggests that the lamprophyre and pegmatite are co-magmatic with the adamellite. In contrast, the younger age from sericite in the Gold Bullion Mine suggests that a much later thermal event occurred in the tonalite (Silberman and others, 1977), after intrusion of the adamellite.

Mineralization in the Willow Creek mining district was discussed by Ray (1954). Many mineralized quartz veins are distributed near the contact between the schist and the tonalite. The simplest hypothesis for the timing of the main phase of this mineralization is that it occurred in both the tonalite and the schist, together, at about 66 Ma (hypotheses 1 and 3, table 2). In the favored hypothesis (hypothesis 1, table 2), mineralization occurred along already existing zones of weakness generated during emplacement of the schist. The fault emplacement caused brittle fracturing of the tonalite which provided sites for mineralization in the pluton. Following fault emplacement, the unmineralized adamellite formed either after or during mineralization. The adamellite intruded the tonalite and schist, and it may have provided heat and fluids for mineralization. The fluids mobilized and mixed with metals from the host rocks, themselves, which may be why the geochemical composition of the veins in the schist differs from the composition of veins in the tonalite. The veins reflect the geochemical composition of their host rocks, as observed by Silberman (written commun., 1985). Long after intrusion of the adamellite, a younger thermal event occurred at about 55-57 Ma (Silberman and others, 1977). The evidence for this event consists of the ages of two samples of altered tonalite and one sample of schist (nos. 9-11, table 1). This younger event may have involved remobilization of material in previously mineralized zones.

CONCLUSIONS

Regional considerations, combined with the field and age data from the Willow Creek mining district, allow for at least three alternative hypotheses about the timing of mineralization and of emplacement of the schist (table 2). Hypothesis 1, which we prefer, involves fault emplacement of the schist before the main event of gold mineralization at 66 Ma, and it is considered the simplest hypothesis. Hypothesis 2 involves fault emplacement of the schist after 66 Ma; and hypothesis 3 involves intrusion of the tonalite into the schist, followed by later fault movement along the originally intrusive contact. Both hypotheses 1 and 2 postulate a paleo-Castle Mountain fault, located between the schist and the Talkeenta Mountains batholith.

The first hypothesis involves fracturing of the tonalite during emplacement of the schist, providing sites for mineralization in the tonalite; and it provides a reason for the distribution of the major mineral deposits near the contact between the schist and tonalite, in fractured and sheared zones. This hypothesis also allows for mineralization of both the schist and tonalite during one event at 66 Ma, and it explains why the adamellite is unmineralized. Hypothesis 1 also provides a fault conduit for thermal fluids at 57-55 Ma, but it may not provide an explanation for why the fluids were hot enough to reset the ages of rocks along the fault and adjacent to a mineralized quartz vein in the Gold Bullion mine. In contrast to hypothesis 1, hypothesis 2 does provide a simple explanation for why the rocks were reheated to provide these relatively young ages.

Hypothesis 2 involves emplacement of the schist at 57-55 Ma, and thus relates faulting to a thermal event at that time. Movement along faults has been shown to cause loss of Ar from crystal structures of hornblende, biotite, and muscovite, and to reset apparent ages (Lee and others, 1970; Silberman and others, 1974). Problems with hypothesis 2 are as follows: before 66 Ma, there is no fault mechanism for fracturing the tonalite to provide sites for mineralization; the schist is not intruded by either the tonalite or the adamellite, so there is no immediate igneous source for the unfoliated, felsic dikes in the schist; it is not clear why the adamellite is unmineralized; and very little time is allowed between emplacement of the schist and deposition of the overlying, locally derived Arkose Ridge Formation, which contains clasts of schist (A. Grantz in Winkler,1977).

Hypothesis 3 involves intrusion of the tonalite into the schist, followed by fault movement along the intrusive contact. Problems with hypothesis 3 are as follows: as with hypothesis 2, there is no fault mechanism for fracturing the tonalite before 66 Ma, so as to create sites for mineralization; there is no explanation for the distribution of most of the major mineral deposits near the contact between the schist and tonalite; and the amount of fault movement would have had to be minor so as not to offset the schist and tonalite from each other, but such minor movement may not have been enough to reset ages. Thus, this hypothesis does not provide a simple explanation for the relatively young ages of 57-55 Ma of the rocks along the contact between the schist and tonalite.

The three hypotheses are all possible, given the data which is available. However, we favor the first of these three. Therefore, it is described below, whereas the other two are simply listed in table 2. Hypothesis 1 is similar to the other two, in that it begins with formation of the schist. The schist may have been deposited during Permian time as marine shale, sandstone, and mafic tuff. It then was intruded in the Jurassic(?) by felsic plutonic and ultramafic rocks which sent felsic dikes into the schist. Following the intrusion of the felsic dikes, the unit was metamorphosed to amphibolite facies during a regional metamorphic event in the early Late Cretaceous. The high T-P metamorphism occurred at a lower structural level than the one that is presently exposed. In an unconnected event, at 73-74 Ma, the tonalite formed. Following rapid cooling of the tonalite, by about 72-69 Ma, as indicated by the ages of biotite (table 1), the schist moved along a major fault into its present structural position adjacent to the tonalite. Faulting may have occurred along a paleo-trace of the Castle Mountain fault. In its present structural position along the fault, the schist is the only local unit that records any evidence of the regional metamorphic event of early Late Cretaceous age. The schist was emplaced and in contact with the tonalite before mineralization occurred in the Willow Creek gold mining district. The unmineralized adamellite was coincident with or postdated mineralization. Thus, the age of the adamellite constrains the time of emplacement of the schist. During intrusion of adamellite, felsic dikes may have invaded weak zones in both of the older units. The unfoliated felsic dikes in the schist may record the intrusion of the adamellite. The young ages of muscovite in the schist (59-66 Ma) may partly reflect retrogressive metamorphism during intrusion of the adamellite, though they are a bit young. The distribution of retrogressive greenschist-facies mineral assemblages in the schist does not suggest that there was contact metamorphism near the main body of adamellite during its intrusion. Age data suggest that intrusion of the adamellite coincided with mineralization in the Willow Creek district. The adamellite could have provided a source of heat and fluids to mobilize and combine with metals from the schist and tonalite themselves. The mineralizing fluids entered the schist and tonalite along zones of weakness at their contact, and mineralization radiated outward from the fault. The fault zone between the tonalite and schist is therefore a potential target for further gold exploration. Following mineralization in the earliest Tertiary, a later hydrothermal event occurred, and again the areas adjacent to the contact between the schist and tonalite were the most affected. Regionally, this hydrothermal event coincided with volcanic activity recorded by volcanic rocks in the Arkose Ridge Formation (Silberman and Grantz, 1984), and the initiation of movement along the Castle Mountain fault (Grantz, Silberman, and Wolfe, in prep.). The hydrothermal activity may have led to a new phase of mineralization, or it may have remobilized the constituents in older, mineralized veins. The effects of this activity would have been particularly strong in fractured rocks near the fault contact between the schist and tonalite.

If either hypothesis 1 or 2 is correct, then the contact between the schist and the tonalite represents a major, latest Cretaceous fault which was present during mineralization in the Willow Creek gold mining district. The fault may have provided a conduit for fluids during mineralization at 66 Ma and 55-57 Ma, and it would be a potential target for further mineral exploration. More evidence for this fault in the form of sheared rocks may occur in rocks mapped as Lower and Middle Jurassic(?) amphibolite and quartz diorite exposed to the east. These older rocks should have been cut by the later fault movement. These rocks host gold along shear zones in highly fractured gabbro in the Lonesome mine, which lies to the east of the main Willow Creek gold mining district (Ray, 1954).

REFERENCES CITED

Csejtey, Bela, Jr., and Evarts, R. G., 1979, Serpentinite bodies in the Willow Creek district, southwestern Talkeetna Mountains, Alaska: U.S. Geological Survey Circular 804-B, p. B92-B93.

Csejtey, Bela, Jr., Nelson, W. H., Jones, D. L., Silberling, N. J., and Silberman, M. L., 1978, Reconnaissance geologic map and geochronology, Talkeetna Mountains quadrangle, northern part of Anchorage quadrangle, and southwest corner of Healy quadrangle, Alaska: U.S. Geological Survey Open-File Report 78-558-A, 60 p.

Csejtey, Bela, Jr., and Smith, J. G., 1975, Petrography, tentative age, and correlation of schist, Willow Creek, Talkeetna Mountains, southern Alaska, in Yount, M.E., ed., United States Geological Survey Alaska Program, 1975: U.S. Geological Survey Circular 722, p. 48.

Dalrymple, G. B., and Lanphere, M. A., 1969, Potassium-argon dating: W. H. Freeman and Co., San Francisco, 258 p.

Dodson, M. H., and McClelland-Brown, E., 1985, Isotopic and paleomagnetic evidence for rates of cooling, uplift, and erosion, in Snelling, N. J., ed., The Chronology of the Geologic Record: British Geological Survey, Memoir No. 10, Blackwell Scientific Publications, Boston, Palo Alto.

Everenden, J. F., and Kistler, R. W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geological Survey Professional Paper 623, 42 p.

Lee, D. E., Marvin, R. F., Stern, T. W., and Peterman, Z. E., 1970, Modification of potassium-argon ages by Tertiary thrusting in the Snake Range, White Pine County, Nevada: U.S. Geological Survey Professional Paper 700-D, p. D92-D102.

MacKevett, E. M., Jr., and Plafker, G., 1974, The Border Ranges Fault in south-central Alaska: U.S. Geological Survey Journal of Research, v. 2, no. 3, p. 323-329.

Pavlis, T. L., 1983, Pre-Cretaceous crystalline rocks of the western Chugach Mountains, Alaska: Nature of the basement of the Jurassic Peninsular Terrane: Geological Society of America Bulletin, v. 94, p. 1329-1344, 9 figs., 2 tables.

Ray, R. G., 1954, Geology and ore deposits of the Willow Creek mining district, Alaska: U.S. Geological Survey Bulletin 1004, 85 p.

Richter, D. H., and Dutro, J. T., Jr., 1975, Revision of the Type Mankomen Formation (Pennsylvanian and Permian), Eagle Creek area, eastern Alaska Range, Alaska: U.S. Geological Survey Bulletin 1395-B, p. B1-B25.

Silberman, M. L., Berger, B. R., and Koski, R. A., 1974, K-Ar age relations of granodiorite emplacement and tungsten and gold mineralization near the Getchell mine, Humboldt County, Nevada: Economic Geology, v. 69, p. 646-656.

Silberman, M. L., Csejtey, Bela, Jr., and Connor, C. L., 1978, K-Ar ages of metamorphic rocks, granitic rocks and hydrothermal alteration-mineralization in the Willow Creek area, southwestern Talkeetna Mountains, Alaska: Geological Society of America, Abstracts with Programs, v. 11, no. 3, p. 128.

Silberman, M. L., Csejtey, Bela, Jr., Smith, J. G., Lanphere, M. A., and Wilson, F. H., 1978, New potassium-argon data on the age of mineralization and metamorphism in the Willow Creek mining district, southern Talkeetna Mountains, Alaska, in Blean, K. M., ed., The United States Geological Survey in Alaska--Accomplishments during 1976: U.S. Geological Circular 751-B, p. B65-B69.

Silberman, M. L., and Grantz, A., 1984, Paleogene volcanic rocks of the Matanuska Valley area and the displacement history of the Castle Mountain Fault: U.S. Geological Survey Circular 868, p. 82-86.

Silberman, M. L., O'Leary, R. M., Csejtey, Bela, Jr., Smith, J. G., and Conner, C. L., 1978, Geochemical anomalies and isotopic ages in the Willow Creek mining district, southwestern Talkeetna Mountains, Alaska: U.S. Geological Survey Open-File Report 78-233, 32 p.

Winkler, G. R., 1978, Framework grain mineralogy and provenance of sandstones from the Arkose Ridge and Chickaloon Formations, Matanuska Valley, in Johnson, K. M., ed., The United States Geological Survey in Alaska--Accomplishments during 1977: U.S. Geological Survey Circular 772-B, p. B70-B73.

TABLE 1.--Potassium-argon ages of metamorphic and plutonic rocks, and mineralized veins in the Willow Creek gold mining district, Anchorage quadrangle

	ROCK TYPE	MINERAL	AGE (Ma)	REFERENCE
Ages of tonalite (unit TKt)				
1.		Hornblende	73.1 ± 2.2	(1)
2.		Biotite	69.0 ± 2.1	(1)
		Hornblende	73.3 ± 2.2	(1)
3.		Biotite	72.0 ± 2.0	(1)
		Hornblende	74.4 ± 2.2	(1)
4.		Biotite	78.8 ± 2.4	(2,3)
		Hornblende	72.2 ± 2.2	(5)
Ages of dikes which cut tonalite				
5.	Lamprophyre	Hornblende	66.2 ± 2.0	(3)
6.	Pegmatite at Holland prospect	Muscovite	66.8 ± 2.0	(4,5)
		Alkali Feldspar	64.7 ± 1.9	(4,5)
Ages of adamellite (unit TKa), biotite granite phase				
7.		Muscovite	67.2 ± 2.0	(2,3)
		Biotite	65.0 ± 2.0	(2,3)
Ages of hydrothermally altered tonalite and quartz vein				
8.	Quartz vein in Lucky Shot mine	Muscovite	66.3 ± 2.0	(4,5)
9.	Propylitically altered tonalite near fault, Hatcher Pass	Plagioclase	54.7 ± 1.6	(5)
		Chlorite	56.6 ± 1.7	(5)
		Hornblende	70.2 ± 2.1	(5)
10.	Sericitized tonalite in Gold Bullion mine	Muscovite	56.6 ± 1.7	(4,5)
Ages of schist (unit Jps) and serpentinite (unit Jsp)				
11.	Schist near fault, Hatcher Pass	Muscovite	54.5 ± 1.6	(5)
		Chlorite	50.6 ± 2.5	(5)
12.	Schist	Muscovite	59.0 ± 1.8	(1)
13.	Schist	Muscovite	65.9 ± 2.0	(1)
14.	Schist	Muscovite	59.6 ± 1.8	(1)
15.	Serpentinite	Actinolite	88.9 ± 4.4	(2,3)
16.	Serpentinite	Actinolite	91.0 ± 4.6	(2,3)

References:
(1) Csejtey and others (1978)
(2) Silberman, Csejtey, Smith, Lanphere, and Wilson (1978)
(3) Silberman, O'Leary, Csejtey, Smith, and Conner (1978)
(4) Silberman, Csejtey, and Conner (1979)
(5) This paper

|Ages are from K-Ar data listed in table 1. Tar, Arkose Ridge Formation; TKa, adamellite; TKt, tonalite; Jps, pelitic schist]

AGE, Ma	Hypothesis 1 - Fault Contact	Hypothesis 2 - Fault Contact	Hypothesis 3 - Intrusive Contact
57-55	Thermal event occurs, as indicated by ages of altered tonalite and schist near the fault contact, and by the age of altered tonalite in a gold mine (nos. 9-11, Table 1). Coincident with deposition of lower part of unit Tar, minor volcanism in unit Tar, mineralization, and initiation of the Castle Mountain fault.	Unit Jps is emplaced next to unit TKt, along a major fault, coincident with early movement along the Castle Mountain fault; emplacement of schist leads to a thermal event, which causes new mineralization or remobilization of earlier mineral deposits; ages of unit TKt and unit Jps locally are reset to younger ages.	Same as hypothesis 1.
66-59	Unit Jps goes through partial, retrogressive metamorphism to greenschist facies, and ages of muscovite are reset;	Same as hypothesis 1.	Same as hypothesis 1.
67-65	Unit TKa intrudes unit Jps and unit TKt; mineralization occurs in unit Jps and unit TKt;	Unit TKa intrudes unit TKt; mineralization occurs in unit TKt;	Same as hypothesis 1.
73-67	Unit Jps is emplaced next to unit TKt along a major fault;	------------------------------	------------------------------
74-73	Unit TKt intruded;	Unit TKt intruded;	Unit TKt intrudes unit Jps; mineralization(?) occurs in unit Jps;
89-74	------------------------------	------------------------------	Unit Jps emplaced into its present position along a major fault;
>91-89	Ultramafic rocks and felsic dikes intrude or are emplaced in unit Jps; unit Jps metamorphosed to amphibolite facies;	Same as hypothesis 1.	Same as hypothesis 1.