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METALLOGENIC AND TECTONIC SIGNIFICANCE OF OXYGEN ISOTOPE DATA AND WHOLE-ROCK POTASSIUM-ARGON AGES OF THE NIKOLAI GREENSTONE, MCCARTHY QUADRANGLE, ALASKA

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METALLOGENIC AND TECTONIC SIGNIFICANCE OF WHOLE-ROCK POTASSIUM-ARGON AGES OF THE NIKOLAI GREENSTONE, MCCARTHY QUADRANGLE, ALASKA

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ABSTRACT

The Middle and (or) Late Triassic Nikolai Greenstone, part of the allochthonous terrane of Wrangellia, is typically altered and locally metamorphosed to prehnite-pumpellyite facies with chlorite and epidote as the most common secondary minerals. Intrinsic copper content averages 155 ppm, and two types of concentrations of copper in the Nikolai are common: (1) native copper fillings of amygdules and rubble zones typically near flow tops, and (2) veins and thin replacement zones that contain native copper and copper-iron sulfides in quartz-epidote or calcite gangue in faults and fractures. Oxygen isotope data from quartz and epidote from three copper-bearing veins yield calculated ore fluid temperatures of approximately 200°C and $\delta^{18}O$ of approximately +1 per mil in agreement with a metamorphic-segregation origin of these deposits, as suggested by Sinclair (1977).

Seven K-Ar ages of chloritized greenstone, including those adjacent to veins fall on an initial argon diagram with a zero intercept and a slope which yields an isochron age of 112 $\pm$ 11 m.y. The ages define a Cretaceous thermal-metamorphic episode which is responsible for alteration and mineralization. The episode is younger than a major Jurassic orogeny, accompanied by granitic intrusion, in the area, and appears to be unaffected by minor granitic intrusion in the middle to late Tertiary. We believe the Cretaceous event is related to accretion of Wrangellia to its present relative position in North America. This age of accretion agrees with stratigraphic and structural

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evidence cited by other workers.

INTRODUCTION

The Nikolai Greenstone, a thick sequence of tholeiitic, dominantly subaerial basalt flows exposed in the Wrangell Mountains and nearby areas of southern Alaska and the Yukon Territory (fig. 1) forms an important part of the allochthonous terrane of Wrangellia. On the basis of paleomagnetic data (Hillhouse, 1977), Wrangellia is believed to have formed at low latitudes, within 15 degrees of the equator, and to have been tectonically transported to its present position (Jones and others, 1977). Allochthonous terranes with lower Mesozoic stratigraphy similar to that of Wrangellia in the McCarthy quadrangle, are juxtaposed against different lower Mesozoic and older rocks from southern Alaska to Vancouver Island and possibly in the Hell's Canyon area of Oregon-Idaho, and are believed to be the disrupted remnants of a once coherent sub-continental block (Jones and others, 1977). In the McCarthy area, emplacement of Wrangellia appears to have been accompanied by frictional heating, which caused alteration and (or) low grade metamorphism of the Nikolai Greenstone, and the generation of copper-bearing vein deposits related to fluids of metamorphic-segregation origin. These veins are localized along pre-existing structures. This report includes preliminary stable isotope data which bear on the conditions of origin of the deposits and on the alteration/metamorphism of the greenstone, and K-Ar whole rock ages which we believe date the time of arrival of Wrangellia to its present position relative to adjacent terranes.

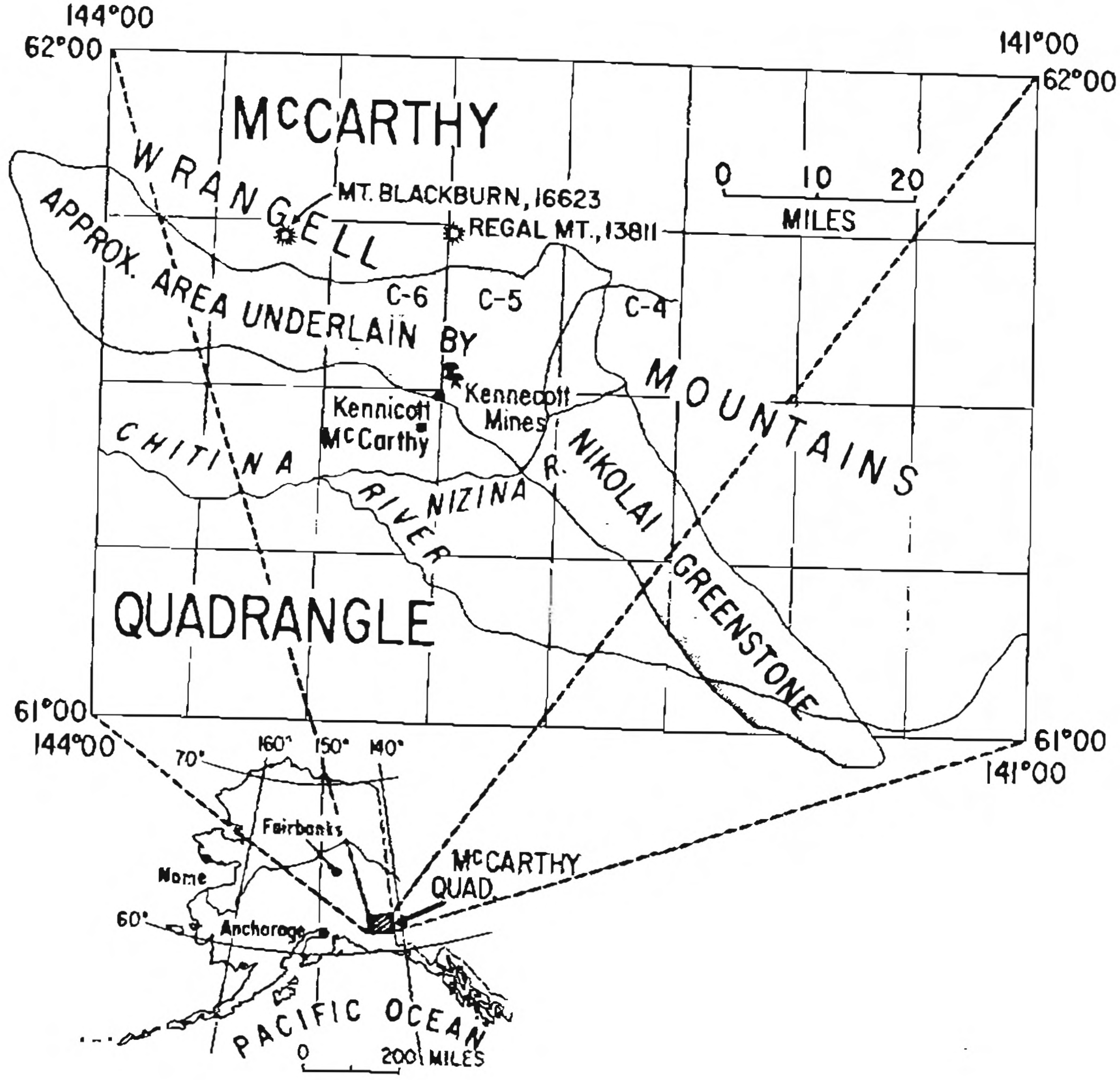

Figure 1.--Maps showing location of McCarthy quadrangle, the Wrangell Mountains and the distribution of the Nikolai Greenstone.

WRANGELLIA AND THE GEOLOGY OF THE WRANGELL MOUNTAINS

The oldest rocks known in Wrangellia in the Wrangell Mountains and elsewhere consist of slightly metamorphosed upper Paleozoic sedimentary and volcanic rocks (fig. 2), believed to represent an upper Paleozoic Island arc, formed largely on oceanic crust (MacKevett, and others, 1977; MacKevett, 1978). The upper Paleozoic rocks are uncomformably overlain by more than 3000 m of Triassic subaerial tholeiitic flows and minor subaqueous pillow lavas of the Nikolai Greenstone. Fossils in underlying and overlying rocks indicate that the Nikolai Greenstone flows were extruded in the Middle and (or) Late Triassic (MacKevett, 1978). The Nikolai is disconformably overlain by thin, inner platform carbonate rocks, the Chitistone and Nizina Limestones of Late Triassic age. Thick sequences of Triassic basalts and overlying platform carbonate are a distinctive characteristic of all terranes believed to be part of Wrangellia (Jones and others, 1977). These carbonate rocks were deposited in a marginal sea which developed in the Late Triassic and persisted into the Late Jurassic. Late Triassic and Jurassic sedimentary rocks deposited in this basin include shales and impure cherts of the McCarthy Formation of Late Triassic and Early Jurassic age. A major orogeny began in the Wrangell Mountains in Late Jurassic time and probably culminated in the Early Cretaceous. Orogenic activity included thrust faulting, folding, formation of conglomerates and intrusion of granitic rocks of the Chitina Valley Batholith and related bodies (mostly in the western and southern parts of the quadrangle, not shown on figure 2) which give late Jurassic K-Ar ages (MacKevett, 1978).

Lower and Upper Cretaceous sedimentary rocks unconformably overlie the Jurassic and older sedimentary and volcanic rocks and the Jurassic granitic

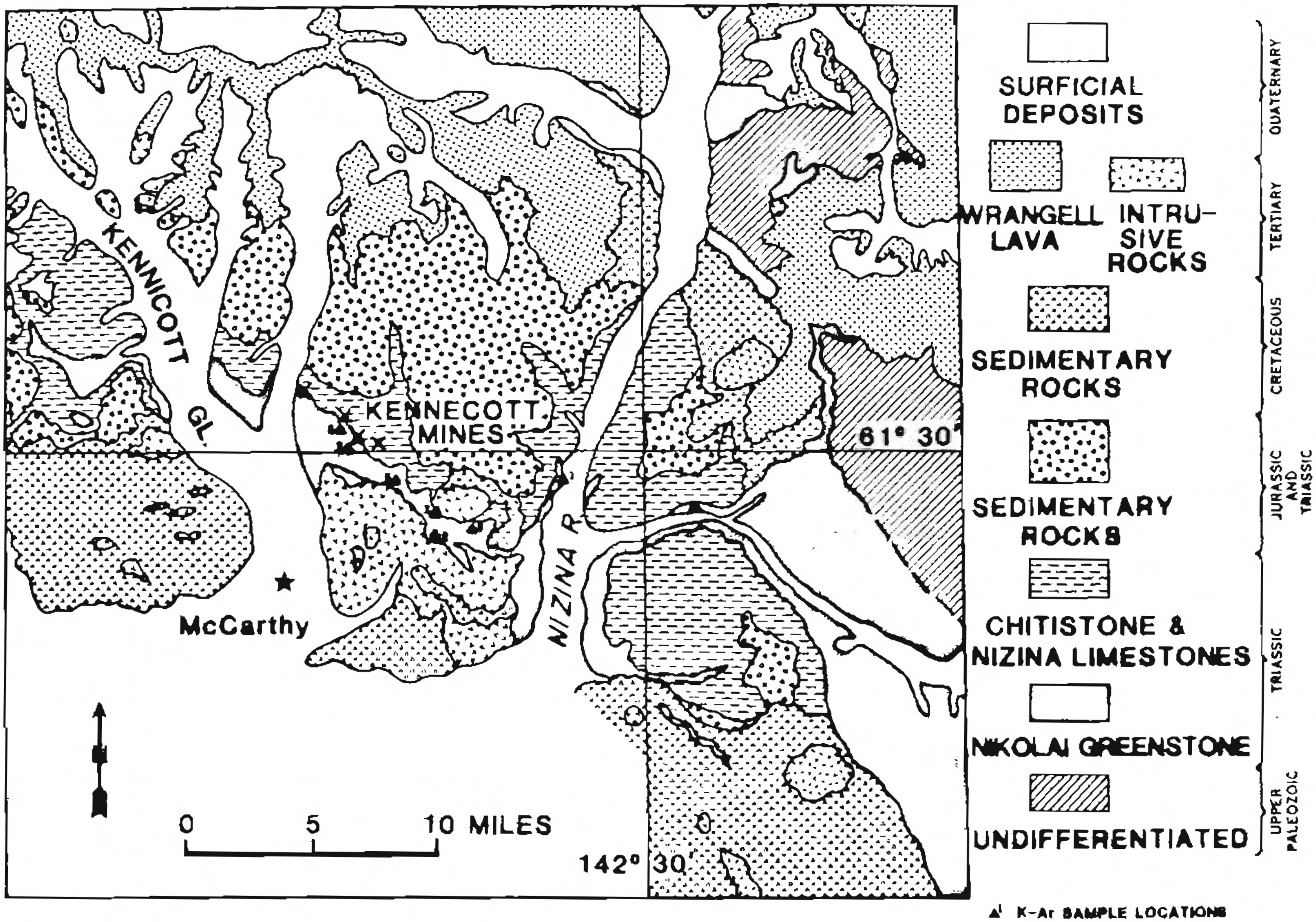

Figure 2.--Generalized geology of part of the McCarthy quadrangle, Alaska.

rocks. The Cenozoic history of the area is dominated by the extrusion of volcanic rocks of the Wrangell Lava which is widely distributed in the northern part of the quadrangle and gives K-Ar ages of between about 3 and 10 m.y. (MacKevett, 1978).

Hypabyssal granitic and intermediate intrusions related to the Wrangell volcanic activity occur throughout the quadrangle and give K-Ar ages between about 14 and 7 m.y. (MacKevett, 1978; E. M. MacKevett and M. L. Silberman, unpub. data, 1980). No major deformation accompanied this Tertiary igneous activity.

The lower Mesozoic rocks of the McCarthy area summarized in the stratigraphic column of figure 3 are characteristic throughout Wrangellia (Jones and others, 1977), and contrast strongly with those of adjacent terranes. Later Mesozoic and younger superjacent strata differ from area to area, suggesting that Wrangellia shared its post-early Mesozoic history with adjacent terranes (Jones and others, 1977).

Characteristics of the Nikolai Greenstone

The Nikolai Greenstone, as exposed in the McCarthy quadrangle (fig. 1), is mostly subaerial, porphyritic, tholeiitic basalt, consisting dominantly of intermixed pahoehoe and aa flows which are characteristically amygdaloidal, and between 0.2 and 15 m in thickness. Locally it exceeds 3900 m in cumulative thickness (MacKevett, 1970; 1978). The basalt is mostly fine-grained, containing phenocrysts of labradorite and augite and sparse olivine in an intergranular groundmass composed chiefly of plagioclase and augite. Primary minerals in order of decreasing abundance are plagioclase, augite, relict olivine, opaque minerals, sphene and apatite (MacKevett, 1971).

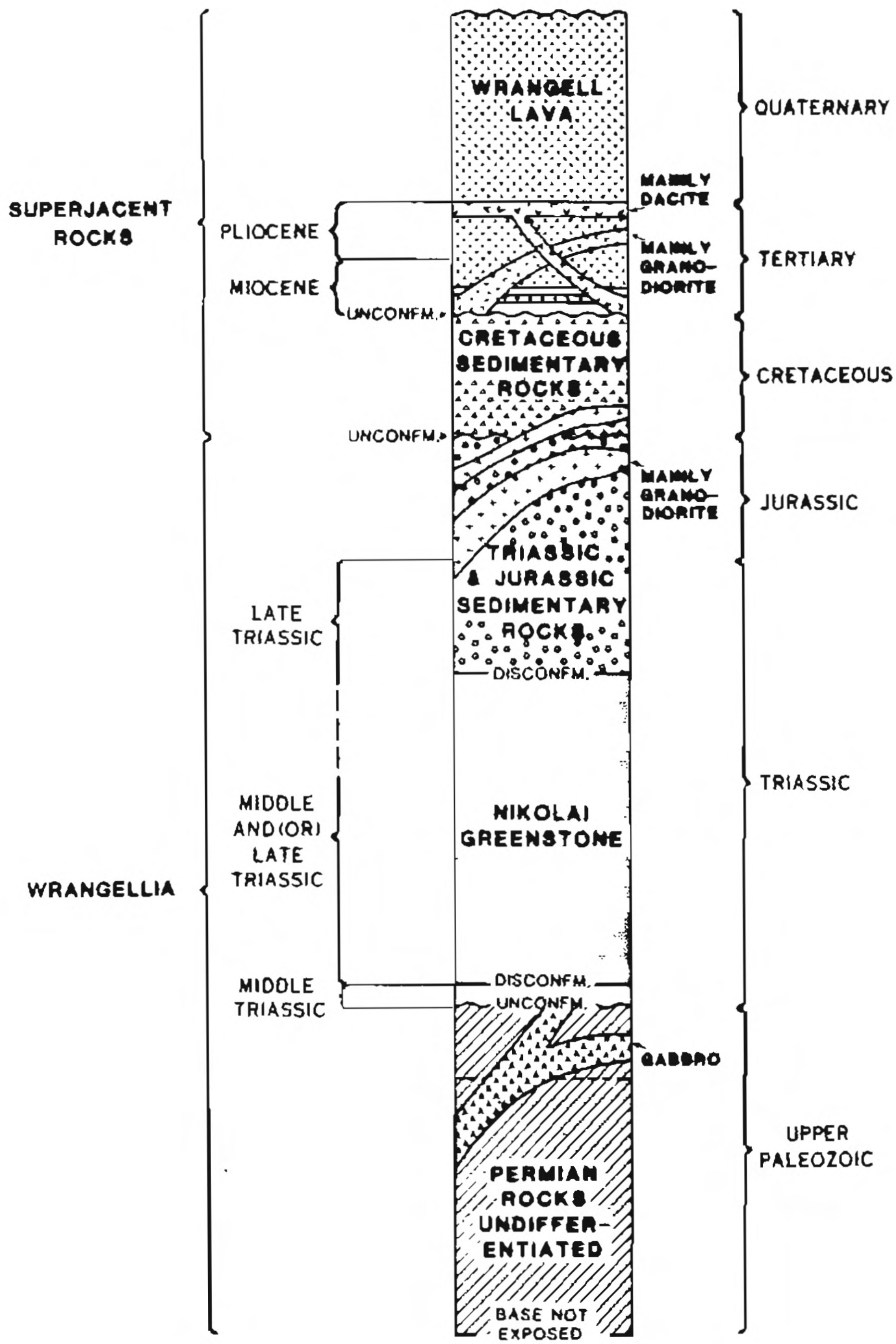

Figure 3.--Stratigraphic column for the Wrangell Mountains in the McCarthy quadrangle.

Nikolai basalts are generally slightly quartz normative tholeiites, with some having olivine in the norm (MacKevett and Richter, 1974). The chemical analysis (table 1) is an average of 39 samples of the Nikolai Greenstone collected in the region.

Most of the Nikolai basalts have been altered or metamorphosed locally to prehnite-pumpelleyite facies assemblages. The most common secondary minerals are, in order of decreasing abundance: chlorite, iron oxides, epidote, clay minerals, sericite, prehnite, serpentine minerals, pumpelleyite, quartz and zeolites. Most of the amygdules in the basalt now contain chlorite $\pm$ calcite, the rest are rich in chalcedonic quartz and epidote. A few contain zeolites, prehnite or native copper (MacKevett, 1971; 1978). Primary volcanic textures are preserved despite the pervasive nature of the alteration/metamorphism.

Mineralization in the Nikolai Greenstone

The Nikolai Greenstone is intrinsically rich in copper. The mean copper content in 140 Nikolai Greenstone samples from the McCarthy quadrangle is 157 ppm (MacKevett and Richter, 1974). Small copper concentrations of economic and subeconomic grade are common in the Nikolai and are of two main types: (1) thin veins and narrow replacement zones and genetically affiliated deposits such as small pods and local disseminations which are characteristically localized along faults and fractures. The veins are small, from a few centimeters to approximately a meter in width and are rarely traceable for more than 200 m along strike. Mineralogy of these deposits consists largely of bornite, chalcopyrite, minor chalcocite and native copper, with quartz, calcite and epidote as the chief gangue minerals (Bateman and McLaughlin, 1920; MacKevett, 1976). A few veins contain some sphalerite and galena or less commonly stibnite and realgar or molybdenite. Minor amounts of

Table 1.--Chemical composition and CIPW norms for "average" Nikolai Greenstone

[From MacKevett and Richter, 1974.]

Oxide	Weight percent	CIPW norms	
SiO_2	47.90	Qtz	0.91
Al_2O_3	14.50	Or	2.84
Fe_2O_3	5.20	Ab	26.25
FeO	6.40	An	24.25
MgO	6.90	Wo	7.50
CaO	9.40	En	17.20
Na_2O	3.10	Fs	5.48
K_2O	.48	Mt	7.55
$H_2O\pm$	3.76	Il	2.66
TiO_2	1.40	Ap	.38
P_2O_5	.16	Cc	1.23
MnO	.18		
CO_2	.54		
Sum	99.92	Sum	96.25

Differentiation index 30.0. Irvine and Barager classification (1971), tholeiitic basalt.

silver and some gold are also present in some deposits (MacKevett, 1976). (2) The second major type of occurrence consists of native copper as fillings in amygdules or in brecciated or rubbly upper zones of certain flows. A few flows contain broad but erratic disseminations of finely particulate native copper (Bateman and McLaughlin, 1920; MacKevett, 1976). The veins and associated deposits of the type (1) occurrence were believed by MacKevett (1976) to be products of hydrothermal processes related to Late Jurassic or

Tertiary plutonic activity that affected the area. MacKevett (written commun., 1980) in particular believes that veins containing stibnite, realgar, molybdenite and most of the gold are geologically related to the Tertiary intrusions.

The calcite - quartz - epidote mineralogy of many of the veins and in the adjacent wall rocks along with chlorite and other minerals charcteristic of low grade metamorphism suggest to us that the origin of the veins might be related to metamorphic-hydrothermal process that caused segregation of the intrinsically high copper content of the basalt into fractures and shear zones. The veins, where we have seen them, lack selvages or zones that differ in mineralogy from the greenstone itself suggesting to us that little or no temperature differences existed between the veins and their wall rocks. The shear zones were more permeable than the surrounding unbroken rock and probably represented areas of collection of heated waters which had dissolved copper from the wall rocks. The native copper concentrations of the type (2) occurrences are believed to be related either to terminal stages of the original magmatic activity - deuteric alteration and mineralization, or to metamorphism where copper was concentrated in hydrated parts of the lava pile (MacKevett, 1976).

Sinclair (1977) described a copper deposit hosted by the Nikolai Greenstone in the White River area of the southwest Yukon Territory that has many similarities to those in the Nikolai in the McCarthy quadrangle. The deposit consists of copper sulphide minerals and native copper in amygdules, rubble zones, cross cutting fractures and local disseminations in the Nikolai, which is metamorphosed to prehnite-pumpelleyite facies mineral assemblages. He suggests that the ore fluids were derived by metamorphic dehydration with some component originating from connate waters derived from the underlying upper Paleozoic sedimentary rocks. We will attempt to show a similar origin for the small copper-containing vein deposits in the Nikolai Greenstone in McCarthy area.

STABLE ISOTOPE RESULTS

We performed standard oxygen isotope analyses on samples of the Nikolai Greenstone and on veins contained within it. The data (table 2) include oxygen isotopic composition of quartz and epidote separated from grab samples of three mineralized veins that cut the upper part of the Nikolai Greenstone near the Kennecott mines. Trace element chemical data for these veins are listed in table 3. The veins are composed mostly of quartz and epidote with minor amounts of disseminated bornite, chalcopyrite and native copper. Oxygen isotopic composition of 5 whole rock samples of the Nikolai Greenstone, including two samples taken adjacent to quartz epidote veins are listed in table 4. Our objectives in this study are to determine the origins of the ore fluids and the temperatures of vein formation, as well as the origin of fluids in equilibrium with the alteration/metamorphic mineral assemblage of the Nikolai Greenstone and its temperature of metamorphism. Fluid inclusions are present in the quartz of the veins, but their small size precluded quantitative measurement of filling temperatures. Isotopic fractionation of oxygen between quartz and epidote as a function of temperature has not yet been determined experimentally or calculated from theoretical considerations, although experimental studies in the system zoisite-water are presently in progress (Alan Matthews, unpub. data, 1980).

Table 2.--Oxygen isotope composition of quartz and epidote from copper bearing veins in Nikolai Greenstone

[Delta values are reported in parts per mil.]

Sample number	Location	$\delta^{18}O$ for quartz	$\delta^{18}O$ for epidote	Δ^{1}
E3	Erie Mine	+16.5	+7.2	+9.3
9	Bonanza Mine	+16.1	+6.0	+10.1
18	Bonanza Ridge	+15.7	+7.4	+8.3

[1]Average fractionation ($\delta Q - \delta Ep$) = +9.2 per mil.

Table 3.--Partial chemical analyses for trace elements in quartz-epidote veins of the Nikolai Greenstone

[Reported in ppm.]

Sample number	Width of vein (in cm)	Ag[1]	Co[1]	Cr[1]	Cu[1]	Ni[1]	Pb[1]	Sr[1]	Zn[2]	As[3]	Sb[2]
E3	10	30	15	70	>20,000	15	N(10)	1,500	10	N(10)	L(1)
18	1	.5	30	150	300	50	N(10)	500	15	N(10)	N(1)
9	30	2	15	70	5,000	30	10	3,000	10	20	N(1)

[1]Semi-quantitative spectrographic analyses, results reported in the series 1, 1.5, 2, 3, 5, 7, 10 and so on. N = Not detected at limits of detection given in parenthesis, L= detected, but below limit of determination, at or below value shown. Analyst: E. L. Mosier.

[2]Zn and Sb by atomic absorbtion analytical methods. Analysts: R. M. O'Leary and J. A. Criswell.

[3]As by colorimetric analytical method. Analyst: R. M. O'Leary.

Table 4.--Oxygen isotope composition of typical whole-rock Nikolai Greenstone samples

[Delta values are reported in parts per mil.]

Sample number	Location	$\delta^{18}O$	Average $\delta^{18}O$
N1	Nikolai Creek	+10.7	
18A[1]	Bonanza Ridge	+9.6	
8	Bonanza Mine	+8.1	+ 9.5 $\pm$ 0.4[2]
9A[1]	Bonanza Mine	+9.1	
11C	Bonanza Mine	+10.1	

[1]Adjacent to quartz-epidote vein.

[2]Standard error.

We have estimated the temperatures of formation of the quartz-epidote veins in the Nikolai from comparison with published data on oxygen isotope fractionation between quartz and epidote in natural environments where the temperature of equilibration is known from independent evidence (Taylor and O'Neil, 1977; Heaton and Sheppard, 1977). The results of our temperature estimates, and calculations based on these temperatures of the ore fluid oxygen isotopic composition are listed in table 5. Our calculations suggest that the veins were deposited at approximately 200°C from a fluid of $\delta^{18}O$ = 1 per mil. Preliminary results of the zoisite-water oxygen isotope fractionation experiments suggest that this temperature estimate is accurate (Alan Matthews, unpub. data, 1980).

Table 5.--Calculated temperature and fluid oxygen isotope composition for copper bearing quartz-epidote veins in Nikolai Greenstone

[Delta values are reported in parts per mil.]

Approximate temperature of fractionation	$\delta^{18}O$ (quartz)	$\delta^{18}O$ (epidote)	$d_q - d_{ep}$
Assume linear relationship between $d_q - d_{ep}$ and $1/T^2$ (Urey, 1947; Bigeleisen and Mayer, 1947) and use published data on quartz and epidote oxygen isotopic fractionation from natural environments where temperature is known. Extrapolate linear relationship to measured Nikolai quartz-epidote fractionations to calculate temperature, and use Bottinga and Javoy (1973) quartz-water fractionation to calculate ore fluid $\delta^{18}O$.			
480° to $550^\circ C$ (Osgood Mts., Nevada, scarn data of Taylor and O'Neil, 1977)	+13.6	+8.1	+5.5
	+14.0	+9.3	+4.7
		Average	+5.1
340° to $400^\circ C$ (Quartz-epidote veins in Troodos Complex, Cyprus, data of Heaton and Sheppard, 1977)	+9.5	+3.4	+6.1
	+6.4	.0	+6.4
		Average	+6.3

Sample number	Calculated temperature ($^\circ C$)	Calculated $\delta^{18}O$ ore fluid
9	170	-1.1
18A	230	+3.4
E3	190	+1.3
	Average	+1.2

The +8 to +11 per mil, oxygen isotope composition of the greenstone samples (table 4), lies within the range of $\delta^{18}O$ reported for the upper parts of ophiolite sequences that were metamorphosed at temperatures between about 50°C and 350°C by the action of heated sea water, (Spooner, and others, 1974; 1977; Heaton and Sheppard, 1977). We lack $\delta^{18}O$ data for individual minerals from the greenstones, so it is not possible to calculate metamorphic equilibration temperatures. Because the mineral assemblages of our greenstone samples collected in the vicinity of the Kennecott mines area (fig. 2) do not vary with distance from quartz-epidote veins, we believe that no large temperature differences existed between the veins and their wall rocks when the veins were emplaced. The temperature limits for zeolite facies metamorphism are about 100°C to 300°C (Miyashiro, 1973; Winkler, 1976); we consider this a reasonable range of temperatures for formation of the quartz-epidote veins as well as for the greenstone mineral assemblage.

Plagioclase and chlorite are the dominant minerals in the Nikolai Greenstone samples. Spooner and others (1977) suggest that the muscovite-water oxygen isotope fractionation relationship with temperature could be used to approximate oxygen isotopic alteration of basalts and greenstones since oxygen isotopic fractionation between muscovite and water is intermediate between that of chlorite-water, and feldspar-water (Taylor, 1974). Using the oxygen isotope fractionation vs. temperature relationship for muscovite-water from Bottinga and Javoy (1973) and the temperature calculated for the formation of the quartz-epidote veins, we estimate that the oxygen isotopic composition of the fluid in equilibrium with the metamorphosed greenstones (average $\delta^{18}O$ = +9.5 per mil) was +4 per mil. At 200°C, the temperature considered most likely for the formation of the veins, a shift of the fluid oxygen isotope composition to heavier $\delta^{18}O$ would be required if the same fluids were involved in metamorphism of the basalt and formation of the veins. If the fluids were using the fractures that now localize the veins as channelways, and then diffused out into the wall rocks during the metamorphic process, and the water to rock ratio was relatively low (<1), an oxygen shift to higher values would be expected (O'Neil and Silberman, 1974; Spooner and others, 1977).

Although our calculated isotopic compositons of the fluids are based on several assumptions, we believe that it is possible for the same fluid that generated the quartz-epidote veins to be involved in metamorphism of the basalts. The low temperature of vein formation results in a calculated ore fluid composition that would essentially be dominated by "modified connate" water (Taylor, 1974). Thus, on the basis of available, albeit incomplete, stable isotope data, our interpretation is that the copper bearing vein deposits in the Nikolai Greenstone could have formed by the process suggested by Sinclair (1977). Further support for that process is given by the results of the K-Ar age determinations.

K-Ar AGE DETERMINATIONS

Seven samples of the Nikolai Greenstone were chosen for whole rock K-Ar age determination from near the vicinity of the Kennecott Mines (fig. 2; table 6). The samples were ground to -60 +100 mesh, but were otherwise untreated. The mineral assemblage of the samples is typical of the metamorphosed Nikolai Greenstone. The dominant minerals in all samples are chlorite and altered plagioclase with subordinate amounts of the other common minerals of the greenstone. The K-Ar ages range from 91 to 131 m.y., and although the ages

Table 6.--K-Ar ages of whole rock Nikolai Greenstone samples

Location number (fig. 2)	Field number	Location	K_2O (percent)[1]	Age (m.y.)
1	Swan	Swan Lake	0.448	90.9 ± 4.5
2	N1	Nikolai Creek	.531	105 ± 5
3	N2[2]	Nikolai Creek	.285	111 ± 6
4	N4	Nikolai Creek	.814	109 ± 6
5	18A[3]	Bonanza Ridge	.268	120 + 6
6	8	Bonanza Ridge	1.29	131 ± 7
7	11C	Bonanza Ridge	.932	113 ± 6

[1]All K_2O analyses by Paul Klock, U.S. Geological Survey, Menlo Park, CA.

[2]Sample N2, argon analysis run at U.S. Geological Survey, Menlo Park, CA. Analysts: M. L. Silberman and C. L. Connor. Other samples run by Teledyne Isotopes, Westwood, NJ. Analyst: Georgiana Kalechitz.

[3]Adjacent to quartz-epidote vein.

tend to cluster somewhat in any given area, they are apparently unaffected by proximity to the late Tertiary hypabyssal, Wrangell Lava-related, plutons in the region, which give K-Ar ages of 7 to 15 m.y. (M. L. Silberman and E. M. MacKevett Jr., unpub. data, 1980). This episode of Tertiary magmatism apparently was unaccompanied by other than very local thermal effects. One sample, no. 18A (table 6) was collected immediately adjacent to one of the quartz-epidote veins of table 2 (sample no. 18).

Of particular importance is the lack of any significant age difference between the sample collected adjacent to the quartz-epidote vein and those collected long distances away from any veins. If the veins were emplaced significantly later than metamorphism of the basalt, for example in the late Tertiary as a hydrothermal effect of intrusion of the Wrangell plutons as suggested by Bateman and McLaughlin (1920), then we should have obtained a younger age from the vein wall rock sample. K-Ar age studies have documented that volcanic wall rocks adjacent to hydrothermal vein deposits formed at temperatures similar to those calculated for the Nikolai veins yield wall rock ages that are reset to the age of mineralization if this process is significantly younger than the age of the host rocks (Silberman and others, 1972; Ashley and Silberman, 1976; Morton and others, 1977). We interpret our age results to indicate that metamorphism and quartz-epidote veining were nearly simultaneous. These age data support our conclusions based on our stable isotope data, which suggest to us that the same fluids responsible for deposition of the quartz-epidote veins were also involved in metamorphic recrystallization of the Nikolai Greenstone.

Range in the individual ages is relatively large, perhaps due to local differences in metamorphic temperature history, but is unrelated to potassium content of the samples. We plotted the K and Ar analytical results on an initial argon diagram (Shafiqullah and Damon, 1974) to examine the systematics of the data (fig. 4). On this type of diagram the slope of a regression line through the points is proportional to the age of crystallization of the system and the intercept on the argon axis indicates whether there is extraneous argon, or argon loss in the samples. The use of isochron analysis has the implicit assumption that all of the plotted samples contain non-radiogenic argon of the same composition at the time of metamorphic recrystallization

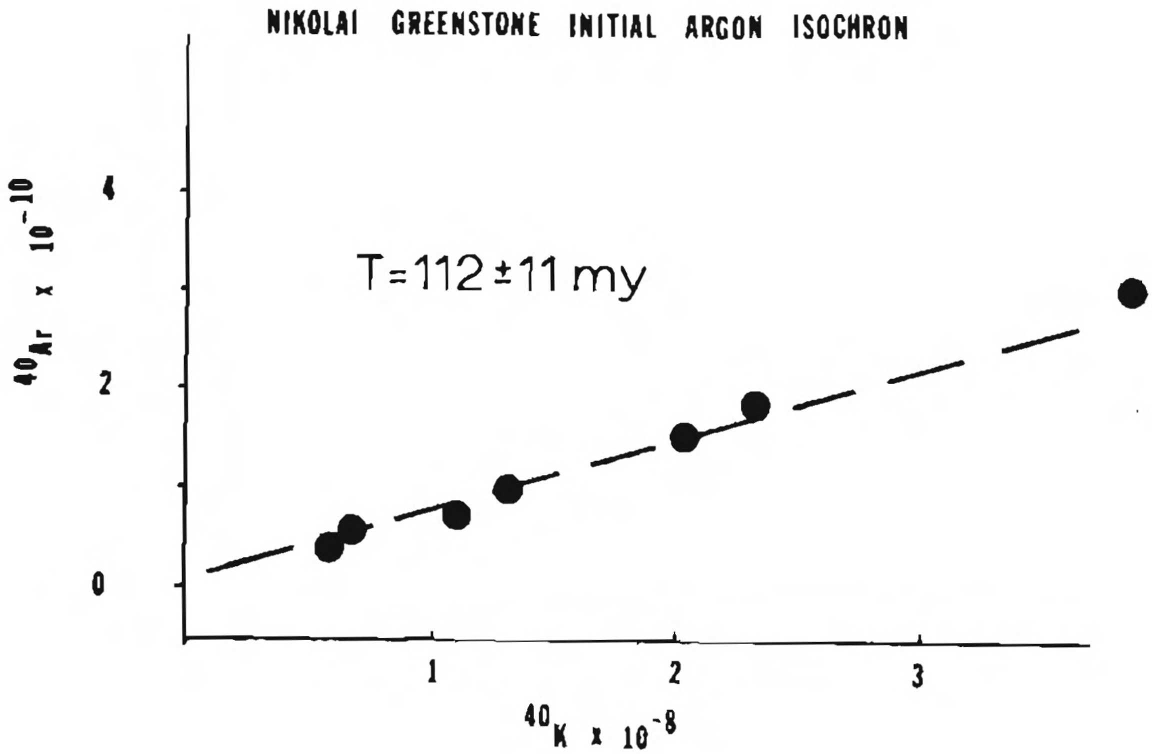

Figure 4.--Initial argon diagram for Nikolai Greenstone whole rock K-Ar data.

(Shafiqullah and Damon, 1974; Turner and others, 1979). Because all of our samples come from a restricted area, and are of similar mineralogy, this assumption, for this particular case, is probably valid.

The slope of the regression line through the points and its statistical uncertainty yield an isochron age of 112 $\pm$ 11 m.y., and an intercept of zero. These relations indicate that there has been no loss of argon from the samples since crystallization of the present mineral assemblage in the middle Cretaceous. Agreement of the "slope" age and the average age of the samples is another indication that a true crystallization event has been dated (Shafiqullah and Damon, 1974). We conclude that the Nikolai Greenstone crystallized to its present mineral assemblage during a thermal episode in the middle Cretaceous and has been essentially unaffected by significant argon loss since that time.

The age of formation of the Nikolai Greenstone, Middle and (or) Late Triassic, would by the time scale in use by U.S. Geological Survey (Geologic Names Committee, 1980) be about 210 to 220 m.y. Two other regional thermal events, besides the original volcanic extrusion, could have affected the Nikolai Greenstone. The first was caused by intrusion of the granitic rocks of the Chitina Valley batholith into the Wrangell terrane in the late Jurassic (MacKevett, 1978). The metamorphism of the Nikolai Greenstone is clearly younger than that. The second thermal event, the Late Tertiary intrusion of the Wrangell Lava related plutons appears to have had no effect on the Nikolai K-Ar ages.

Granitic rocks also occur in the northern part of the Wrangell terrane in the eastern Alaska Range. Two large composite plutons of greater than 100 km^2 outcrop area, with associated hydrothermal alteration and porphyry copper and molybdenum occurrences, and smaller satellitic plutons have given ages of 80 to 120 m.y. (Richter and others, 1975; Silberman and others, 1977). These granitic rocks occur in the Nabesna quadrangle and the northeastern part of the McCarthy quadrangle, over 80 km distant from the nearest dated Nikolai Greenstone sample. No granitic rocks of this age have been found elsewhere in the McCarthy quadrangle, and it is our opinion that thermal effects of these plutons could not have possible have affected our Nikolai K-Ar results. However, plutons of this age do have bearing on the limits for age of accretion of the Wrangell terrane in southern Alaska.

DISCUSSION

Jones and Silberling (1979) believe that the bulk of tectonic activity that formed the accretionary mosaic of disparate terranes in southern Alaska, including Wrangellia (fig. 5), occurred in the middle to late Cretaceous. The arrival of Wrangellia to its present relative position in southern Alaska represents only part of a very complex and poorly understood history of deposition, tectonic transport, accretion, and large-scale structural juxtaposition. Figure 5 illustrates just a few of the over 25 discrete tectonostratigraphic terranes that make up southern and central Alaska (Jones and Silberling, 1979). Approximate limits on the time of arrival of Wrangellia to its present relative position are based on widespread and locally intense deformation of Upper Jurassic and Lower Cretaceous flysch deposits that are exposed througout southern Alaska (fig. 5). Stratigraphic and structural studies by Csejtey and St. Aubin (1980) in the Talkeetna Mountains demonstrate that upper Paleozoic and Triassic rocks of the Wrangell terrane are thrust over severely deformed argillite and graywacke. Granitic

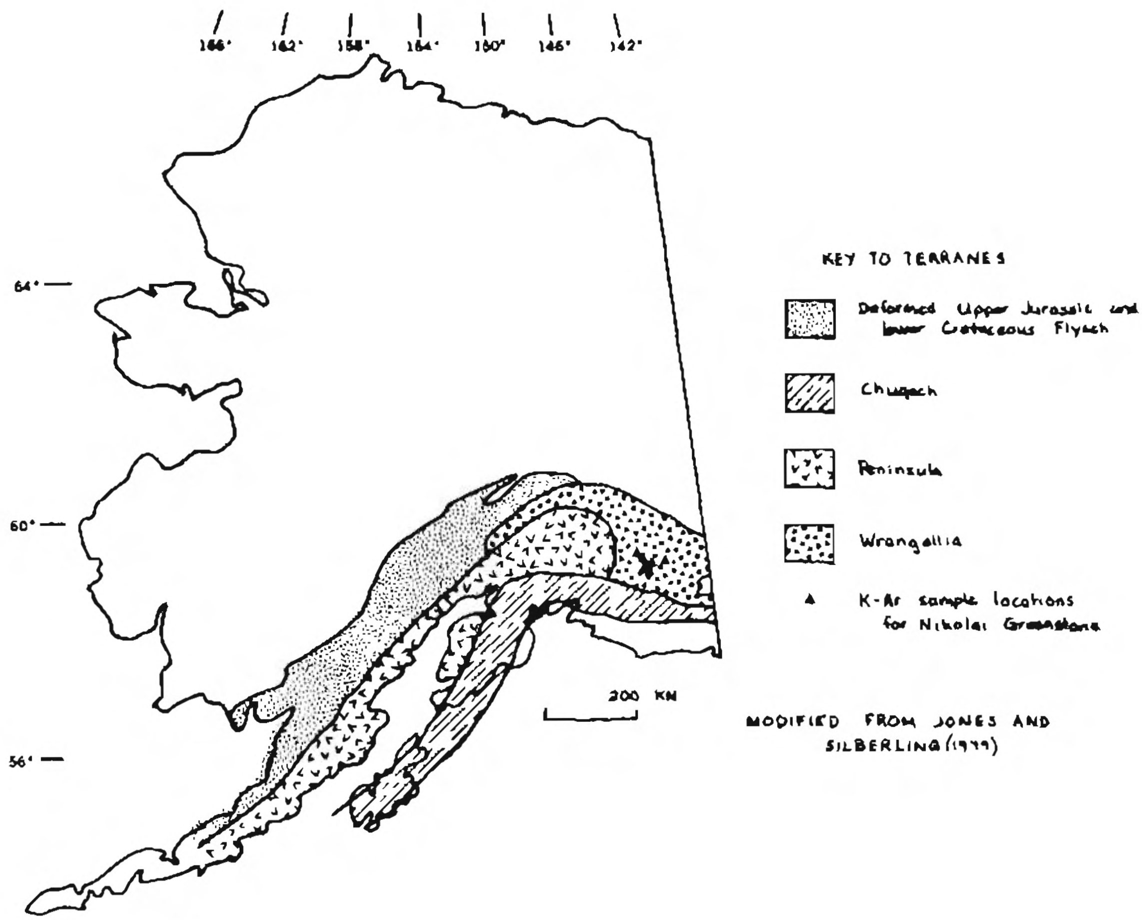

Figure 5.--Map showing distribution of selected Mesozoic terranes in southern Alaska, including Wrangellia.

plutons intrude the deformed sedimentary rocks, are undeformed themselves, and give Late Cretaceous to Paleocene K-Ar ages (Csejtey and others, 1978; Csejtey and St. Aubin, 1980).

Additional constraints on the timing of juxtaposition of Wrangellia and adjacent terranes comes from the granitic plutons in the Nabesna area. These middle and upper Cretaceous plutons are part of the Nutzotin-Chichagof belt of plutonic rocks, one of five such belts in southern and southeastern Alaska defined by Hudson (1979a), who believes that they may represent parts of magmatic arcs, although -- "the data are inconclusive or simply too scarce for a definitive interpretation" (Hudson, 1979a, p. 231). The plutons that form the Nutzotin-Chichagof belt intrude rocks of three different terranes, including Wrangellia, the Alexander terrane and the Gravina-Nutzotin sedimentary and volcanic belt (Berg, 1972; Hudson, 1979b). In the northern part of the Nutzotin-Chichagof plutonic belt, the granitic rocks, including the plutons near Nabesna, are large complex epizonal bodies that intrude Wrangell terrane rocks, rocks of Precambrian(?) to upper Paleozoic and lower Mesozoic age assigned to the Alexander terrane, and sedimentary and volcanic rocks of the middle Jurassic to lower Cretaceous Gravina-Nutzotin belt, which depositionally overlie rocks of the two older terranes (Berg, 1972).

If these plutons represent a magmatic arc, then the arc developed on a basement composed of disparate terranes that were juxtaposed, or were reasonably close to each other by at least Early Cretaceous time, and were intruded together by Middle Cretaceous time (Berg, 1972).

Regional structural, stratigraphic, and plutonic history in southern Alaska thus suggests that juxtaposition of several of the tectonostratigraphic terranes, including Wrangellia, occurred by Late Jurassic -- Early Cretaceous or Late Cretaceous-Paleocene time. We believe that the 112 m.y.

recrystallization age for the Nikolai Greenstone in the McCarthy area resulted from heating of the terrane caused by accretion of Wrangellia to its present relative position. The McCarthy area is some distance away from the boundaries of Wrangellia, and is unlikely to have been affected directly by thermal effects of Cretaceous plutonism. Alteration/metamorphism of the Nikolai, and copper mineralization that appears to be of metamorphic segregation origin, from ore fluid derived by upward migration of evolved connate waters from the underlying upper Paleozoic sedimentary rocks, appear to have occurred during the process of accretion.

This report documents two important points. The first, discussed by Berg (1979) is that the process of accretion itself may give rise to certain types of mineral deposits, or result in modification of pre-existing mineral deposits. The second is that it may be possible to determine the age of accretion of allocthanous terranes by application of conventional K-Ar geochronology to low grade metamorphic, or altered rocks. By extending this reasoning, it may be possible to determine the age of accretion by dating the gangue minerals of certain types of mineral deposits, such as fracture-and shear-controlled base metal sulphide deposits, if by geologic mapping and isotopic work they can be related to metamorphic remobilization and concentration of ore metals. We plan on testing this technique further in areas where independent evidence constrains the timing of accretion in greenstone-bearing allochthonous terranes, such as the Chugach and Prince William terranes.

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