UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Occurrence of Uranium in Rocks of the Ekiek Creek Complex, Western Alaska

by

Alan R. Wallace

Open-File Report 79-1653

1979

CONTENTS

Figures

Tables

Occurrence of Uranium in Rocks of the Ekiek Creek Complex, Western Alaska

by Alan R. Wallace

ABSTRACT

Uranium in the Ekiek Creek Complex of western Alaska is related to a niobium-rich pyrochlore in the nepheline syenite of the complex. The complex consists of an aegirine-phlogopite pyroxenite that has been intruded and partly replaced by nepheline syenite. The contact zone between the two igneous units varies from a sharp contact to a diffuse zone where the pyroxenite has been metasomatically replaced by the syenite. The entire complex was intruded into an older Cretaceous monzonite.

The pyrochlore occurs as an accessory mineral in the syenite, and is visible in rocks containing over 50 ppm uranium. Chemical analyses indicate that, in all samples of syenite, there is a positive correlation between uranium and niobium; this suggests that the uranium-pyrochlore association persists even when pyrochlore is not readily visible in thin section. The small amount of pyrochlore, and its refractory nature, make the complex an unfavorable source for secondary uranium leaching or heavy-mineral concentration.

INTRODUCTION

The Ekiek Creek Complex in western Alaska consists of alkaline intrusive rocks which contain relatively high amounts of uranium and thorium in comparison with similar rocks in the world (Murphy and others, 1978). The current study of the uranium occurrence and of the petrography of the igneous rocks in the complex supplements ground radiometric and geophysical studies of the complex. Preliminary results of both petrographic and geophysical studies were reported by Wallace and Cady (1977). This paper defines the occurrence and mineralogy of uranium in the rocks, and describes in more detail the petrography of the complex.

ACKNOWLEDGMENTS

The field work and sampling for this study were done in 1975 by John Cady and Steve Hackett of the U.S. Geological Survey. Cady's advice and guidance during the earlier phases of this petrographic study were immensely helpful. Alexander Gunow assisted with the electron-microprobe analyses, and Jim Nishi helped with the electron-microscope instrumentation.

REGIONAL AND GEOLOGIC SETTING

The Ekiek Creek Complex is part of a belt of alkaline intrusive rocks that extends from Siberia into west-central Alaska (Miller, 1972). The complex is one of several alkaline complexes in the Kobuk-Selawik Lowland (fig. 1). Potassium-argon dates of three alkaline bodies in western Alaska give ages of between 105 and 107 m.y., or mid-Cretaceous time, although Miller (1972) suggests the possibility of some younger alkaline bodies in the southeastern Seward Peninsula. The Hunt Complex in the Kobuk-Selawik Lowland has been dated at 107 ± 3 m.y.

The four alkalic complexes of the Kobuk-Selawik Lowland were intruded into rocks of a geologic province containing older Cretaceous metasedimentary

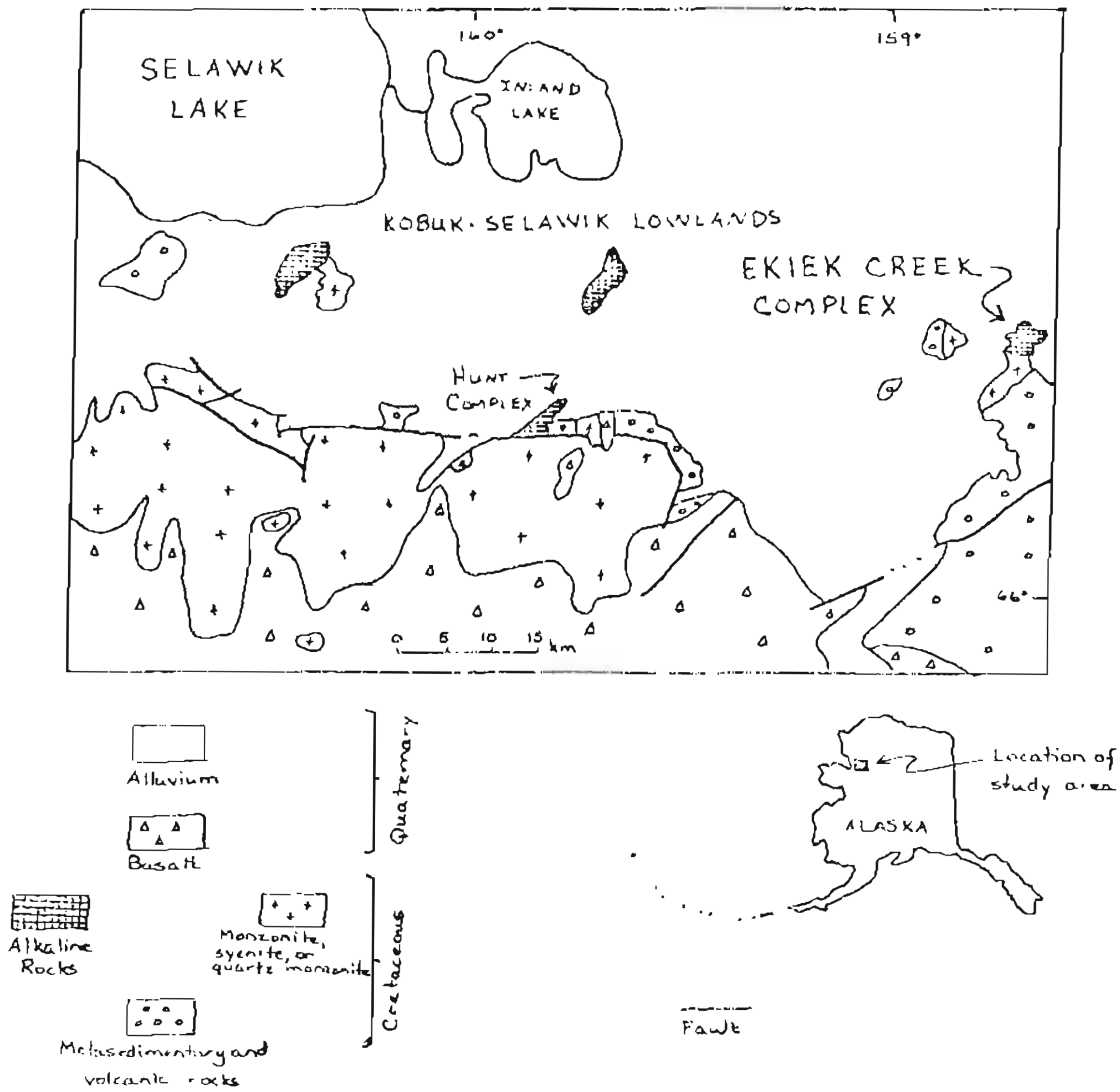

Figure 1.--Location and general geology of the Kobuk-Selawik Lowlands, including the Ekiek Creek Complex (modified from Miller, 1972).

and andesitic volcanic rocks and mid-Cretaceous monzonite, syenite, and quartz monzonite plutonic rocks (Patton and Miller, 1968). Quaternary alluvium and basalts cover at least half of the bedrock, so that mid-Cretaceous intrusive relations are largely unknown. Miller (1972), on the basis of sharp, non-transitional contacts between alkaline and other intrusive rocks, and alkaline dikes cutting the older Cretaceous monzonite along the southern contact of the Ekiek Creek Complex, suggested that the alkaline rocks were magmatic and younger than other mid-Cretaceous igneous rocks.

The alkaline rocks in the Kobuk-Selawik Lowlands are subsilicic, and are dominated by alkali feldspar, nepheline/kalsilite, and alkaline mafic minerals. Lithologic varieties range from pulaskites (composed largely of alkali feldspar) to pyroxenites (composed mostly of mafic minerals), with essentially all intermediate, nepheline-bearing members (Miller, 1972). Many of the rocks contain melanite, a titanium-rich andradite, which is commonly present as a major constituent of the rocks. Rapid-rock analyses of the rocks (Miller, 1972) show that the rocks are generally high in alkalies and Al_2O_3, and contain less than 60 percent silica; nepheline, olivine, and leucite commonly appear in the norms of the analyzed samples.

Many of the alkaline complexes in western Alaska contain relatively high amounts of uranium and thorium. Samples of syenite from the Selawik Hills, southwest of the Ekiek Creek Complex, contain as much as 20 ppm uranium and 65 ppm thorium. Samples of high-potassium, low-silica rocks from the Selawik Lowlands contain as much as 30 ppm uranium and 180 ppm thorium (Miller, 1976).

METHODS OF STUDY

Field work for this study was done by John Cady and Steve Hackett of the USGS for 3 weeks during the summer of 1976 as part of a detailed ground geophysical and radiometric study of the Ekiek Creek Complex. As part of this study the samples collected in the field were analyzed by delayed neutron methods for uranium and thorium, and by semiquantitative emission-spectrographic methods for 60 additional elements. Thin sections of 53 rock samples were studied by the author, and mineral identifications were supplemented by X-ray diffraction. Selected minerals were analyzed with an electron microprobe and scanning electron microscope, each utilizing an energy-dispersive unit for analysis.

GEOLOGY

The Ekiek Creek Complex is composed largely of a melanite-bearing nepheline syenite with lesser pyroxenite and intermediate rock types. The complex is bounded to the south by a mid-Cretaceous monzonite stock, and on all other sides by Quaternary alluvium. There are few outcrops, but related float is abundant over the igneous bedrock (fig. 2).

All workers (Miller, 1972; Wallace and Cady, 1977) agree that dikes of nepheline syenite cut the monzonite to the south. Miller (1972) reports that within the complex, the pyroxenite is cut by syenite in the northern part of the complex, and that the southern part is largely melanite-bearing syenite with mafic septa(?) of wallrock and minor pyroxenite. However, Wallace and Cady (1977), based upon ground geophysics, define three or more north-trending bands of pyroxenite, each 10-100 m wide, which traverse the syenite (fig. 2).

Lithologies intermediate in composition between syenite and pyroxenite occur between the syenite and pyroxenite in the field, suggesting possible contact zones. In addition, a fine-grained phonolite dike crops out in the southern part of the complex.

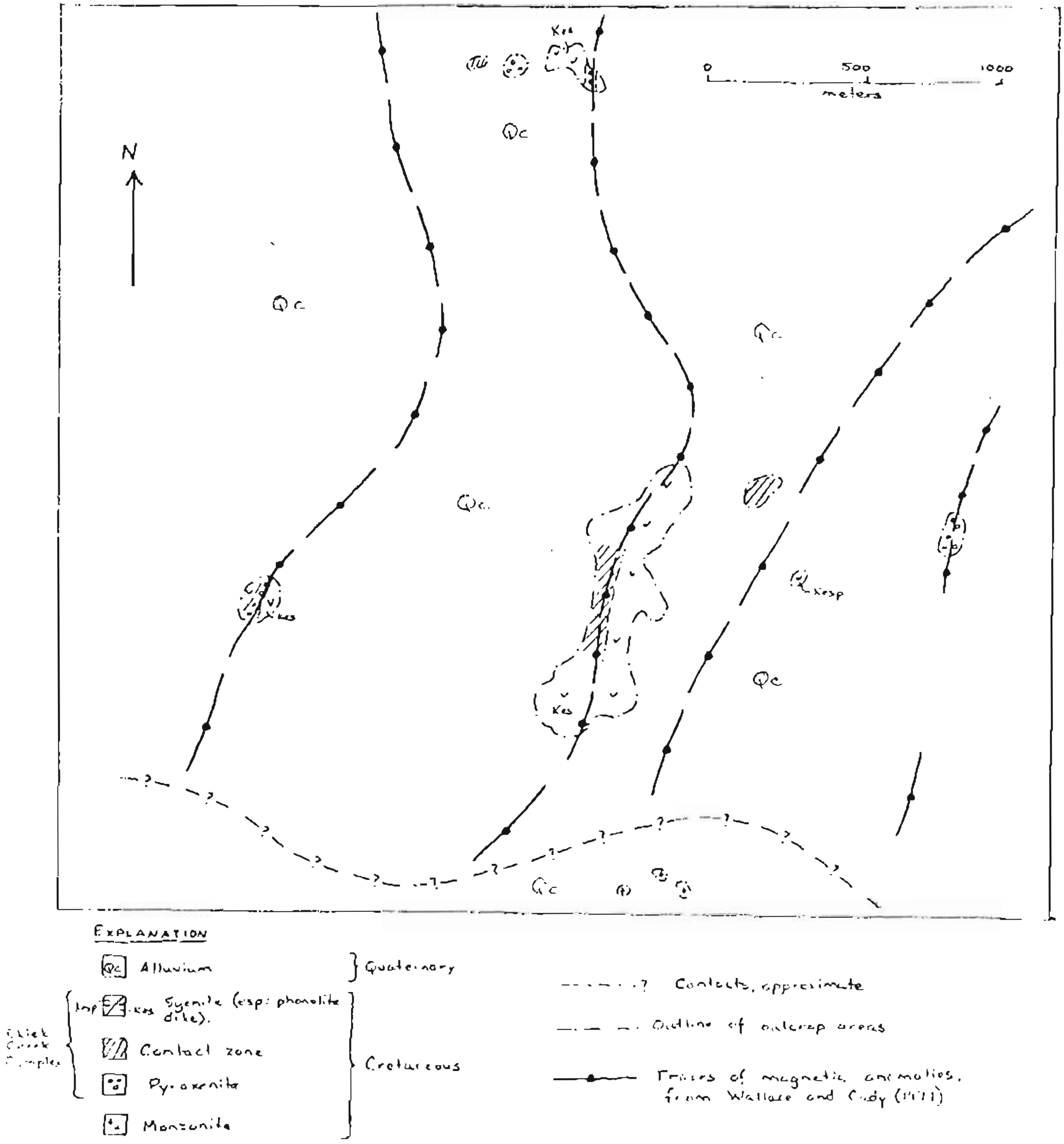

Figure 2.--Diagrammatic illustration of field relations, Ekiek Creek Complex. Areas designated by the unit Qc contain locally derived float. Magnetic anomalies represent zones of magnetic highs as determined from ground magnetometer surveys by John Cady and Steve Hackett (written commun., 1976), and may represent areas of pyroxenite (Wallace and Cady, 1977).

Petrography

The rocks of the Ekiek Creek Complex include three major types, based upon their mineralogy and textures. They include orthoclase-nepheline syenite; pyroxenite; and rocks containing components of both mafic and felsic rock types, but with definite replacement textures. The complex intruded monzonite on the south. The major minerals in the complex include orthoclase, nepheline/kalsilite, aegirine, phlogopite, and melanite.

Orthoclase-nepheline syenite

The orthoclase-nepheline syenite probably forms at least half of the intrusive complex (Cady, oral commun., 1976). The rock is hypidiomorphic-granular, and is fine to medium grained. Orthoclase, nepheline/kalsilite, phlogopite and melanite are the major minerals; zeolites, aegirine, sphene, magnetite, and fluorite are less abundant. Orthoclase and nepheline intergrowths (pseudoleucite?) suggest the original presence of leucite in the rocks (Bowen, 1928).

Orthoclase is the only feldspar in the syenite. It is fresh and nonperthitic. X-ray diffraction patterns of orthoclase show that the feldspar has a composition of $Or_{84}Ab_{16}$ (84 percent orthoclase, 16 percent sodic feldspar) (based upon tables in Wright, 1968). Orthoclase is most commonly medium grained, but occasionally forms phenocrysts 1 cm across in some leucocratic rocks.

Nepheline/kalsilite is a common feldspathoid in the syenite, with textures similar to that of orthoclase. It is usually replaced by cancrinite or zeolites. X-ray patterns indicate that some nepheline/kalsilite grains contain between 19 and 27 percent mole fraction of kalsilite (based upon tables in Wellman, 1970). Elemental scans with the electron microprobe of other nepheline/kalsilite grains show little or no sodium and abundant potassium.

Compositional variations are obviously great, but no systematic variation could be detected.

Orthoclase and feldspathoids coexist both in hypidiomorphic-granular textures and as extremely fine, delicate intergrowths resembling pseudoleucite; both textures occur in the same rocks. The intergrowths consist of feldspathoid exsolutions in orthoclase, and many of the feldspathoids are replaced by zeolites and cancrinite. The intergrowths, as discrete grains, replace nonintergrowth orthoclase, which, in turn, replaces the nonintergrowth feldspathoids. The areas of intergrowths are roughly the same grain sizes as the grains of coarser orthoclase and feldspathoid. Although the presence of the intergrowths might indicate primary leucite, it is not possible to tell if the original leucite or the later pseudoleucite(?) replaced the orthoclase. X-ray analyses of orthoclase in the intergrowths show that it is much more potassic (Or_{96}) than in the nonintergrowth phases (Or_{84}). Nepheline has approximately 19 percent mole fraction kalsilite in nepheline.

Phlogopite is the most abundant mafic mineral. It is strongly pleochroic, with X=gold, Y=greenish-brown, and Z=dark brown to opaque; 2V is 0-3°. Inclusions of apatite and zircon are common. X-ray diffraction patterns identify the mica as phlogopite. However, the strong pleochroism suggests a more iron-rich mica, and microprobe analyses of the mica show a Fe/(Fe+Mg) ratio of 0.405. The micas also contain 2.23 percent fluorine.

The pyroxenes in the syenite are aegirine and aegirine-augite, based upon X-ray analyses. Many of the pyroxenes are zoned, with a colorless core and pleochroic green rim. Microprobe scans indicate an increase in iron and magnesium away from the cores.

Melanite is abundant in the syenites, and usually occurs as coarse euhedral crystals. Some rocks contain as much as 16 modal percent melanite.

Melanite is abundant in the syenites, and usually occurs as coarse euhedral crystals. Some rocks contain as much as 16 modal percent melanite. The melanite is commonly embayed by later felsic minerals, and is usually associated with sphene and magnetite. Microprobe scans show that the melanite contains major Ca, Fe, and Ti.

Other minerals include sphene, magnetite, fluorite, pyrite, and galena(?). Sphene is common, and occurs as euhedral grains. Colorless fluorite occurs as a primary mineral, and purple fluorite is an alteration product of aegirine. Sparse grains of pyrite and one of possible galena, detected with the scanning electron microscope, are present.

The average modal composition of the syenite is shown in table 1.

One sample of syenite from the northern end of the complex contains nepheline, orthoclase perthite, and plagioclase. The plagioclase rims and replaces the orthoclase. Pyroxene, phlogopite, and fluorite are common. With the exception of the possible albitization of the orthoclase, the rock is very similar to other samples of syenite.

The phonolite dike found in the southern part of the complex is a fine-grained porphyry with phenocrysts of nepheline in a matrix of orthoclase and nepheline. The orthoclase has a composition of Or_{71}, and the nepheline phenocrysts contain 0.2 mole percent kalsilite. The dike is presumed to be a hypabyssal equivalent of the syenite.

Mica pyroxenite

The pyroxenite of the Ekiek Creek Complex is a fine- to medium-grained hypidiomorphic rock containing phlogopite and aegirine, with lesser amounts of orthoclase and feldspathoids, and accessory sphene, zeolites, apatite, zircon, fluorite, and magnetite. Melanite is absent from the pyroxenite.

Table 1.--Average modal compositions (with minimum and maximum values in parentheses) of syenite and pyroxenite, Ekiek Creek Complex, western Alaska; 1000 point counts per sample

Mineral	Syenite (%)	Pyroxenite (%)
Orthoclase	62 (38-82)	17 (0.4-44)
Nepheline	20 (3-45)	2.3 (0.15-8)
Phlogopite	4 (0-16)	36 (20-57)
Aegirine	0.3 (0-2)	35 (23-45)
Melanite	5 (0-16)	0
No. Samples	16	5

Phlogopite and aegirine compose over seventy percent of the rock. Both are optically similar to those minerals in the syenite, and X-ray patterns are identical to those of phlogopite and aegirine from the syenite. Microprobe scans of the aegirine show that it has more iron and magnesium around the rim than at the core, and probe analyses show an Fe/(Fe+Mg) ratio of 0.51 at the rim; calcium is also present in the core. The phlogopite contains 1.5 percent F and an Fe/(Fe+Mg) ratio of 0.58. Inclusions of apatite and zircon in the rocks are surrounded by pleochroic halos in the phlogopite.

Orthoclase and feldspathoids form less than twenty percent of the pyroxenite. Both are fine grained and interstitial to the mafic minerals. Intergrowths between orthoclase and feldspathoids are present, and are similarly interstitial to the phlogopite and aegirine.

The average modal composition of the pyroxenite is shown in table 1.

Contact Zone Rocks

The contacts between the two major rock types range from sharp to gradational with broad transitional zones several tens of meters wide. Rocks within the gradational contact zones are extremely variable in composition and texture, but the component minerals are the same as in the two major rock units.

Hand-specimen and thin-section samples of rocks from the sharp contacts contain numerous veinlets and thin dikes of syenite cutting the pyroxenite. In thin section, the contacts are sharp; a few samples contain broken pyroxene grains in the pyroxenite along the contacts with the syenite. Neither rock type is visibly different from similar rocks outside of the contact zones. Some breccia, with xenoliths of pyroxenite in syenite, occurs along the contact zone.

Many rocks within the more gradational contact zones bear little or no textural relationship to the parent-rock types, although less-affected rocks are present. In most cases, aegirine and phlogopite are corroded and replaced, often extensively, by fine-grained granular melanite and medium-grained orthoclase and felsic intergrowths. In some extreme cases, the texture is gneissic, with felsic layers separating layers of altered mafic minerals. Aggregates of pyroxene grains are commonly rimmed by aggregates of phlogopite or melanite grains. In one sample, nepheline and phlogopite replace both pyroxenite and a syenite veinlet in the pyroxenite.

Monzonite

Several samples of monzonite from the stock south of the Ekiek Creek Complex were examined. Orthoclase perthite is common, and is strongly replaced and rimmed by albite. Laths of plagioclase (An_{45}) are also common. Biotite and augite are the mafic minerals, and sphene and quartz are minor minerals. Melanite and feldspathoids are absent. The rocks are medium grained, and have a hypidiomorphic-granular texture.

Ferric iron oxide is present in all samples. The iron oxide fills fractures in feldspars, and coats pyroxene grains. No samples from the Ekiek Creek Complex contain hematite.

Uranium occurrence and distribution

Forty-two samples were analyzed for uranium and thorium by delayed-neutron methods. The results (table 2) show that the syenite contains considerably more uranium and thorium than any of the other rock types in the complex and country rocks.

Radioluxographs were prepared of thin sections of the most uranium-rich syenite sample (89 ppm) and pyroxenite sample (22 ppm). The pyroxenite did not produce any areas of concentrated radiation, nor were any uranium minerals

Table 2.--Average uranium and thorium values in parts per million (with minimum and maximum values in parentheses) of major rock types, Ekiek Creek Complex, western Alaska

[Analyzed by delayed neutron methods by H. Millard, Jr., C. Shields, C. Ellis, R. Nelms, and C. Ramsey]

Rock Type	U	Th	No. Samples
Syenite	30.7 (4-89)	93.9 (10.2-233)	15
Pyroxenite	8.5 (2.7-22)	40.5 (8.9-115)	5
Contact Zone	18.0 (9.4-37)	78.0 (24.4-162)	17
Monzonite	6.7 (3.8-41)	42.6 (25.3-56.4)	5

observed in thin section. The radioluxograph of the syenite showed several concentrations of radioactive bombardment about 0.05 mm across. Under the microscope, a yellow mineral occupies the areas of radiation. The grains are transparent, and have high relief. They are euhedral to subhedral with cubic and prismatic shapes. All are isotropic or nearly so. Each grain is surrounded by a pleochroic halo if the host mineral is orthoclase or fluorite (fig. 3). Halos in fluorite are deep purple; those in orthoclase are dark brown. The grains look very similar to sphene, but do not have the pebbly texture of that mineral.

Elemental point analyses of the radioactive grains with the scanning electron microscope show that the mineral contains major niobium and uranium, lesser titanium, with minor calcium, silica, and lead. A grain enclosed by sphene contains major Ca, Ti, Si, and Nb, but no uranium; the enclosing sphene contains major Ca, Si, and Ti.

X-ray diffraction patterns of the grains indicate that the mineral is pyrochlore. This agrees with the chemistry and optical properties of the grains. Based upon the major niobium and uranium, the mineral is more specifically called uranopyrochlore (Hogarth, 1977).

Petrographic examinations of other syenite samples show that the U-Nb mineral is present in samples containing over 50 ppm uranium. The extremely small size of even the largest grains suggests that the apparent absence of the mineral from other syenites may be due to the difficulty of detection. The plagioclase-bearing syenite from the northern part of the complex contains 43 ppm uranium, and pyrochlore is associated with fluorite in that rock. No pyroxenite or contact zone rocks contain visible grains of pyrochlore.

Fluorite is always present in rocks containing pyrochlore, although it also occurs in some rocks lacking the radioactive mineral. There does not

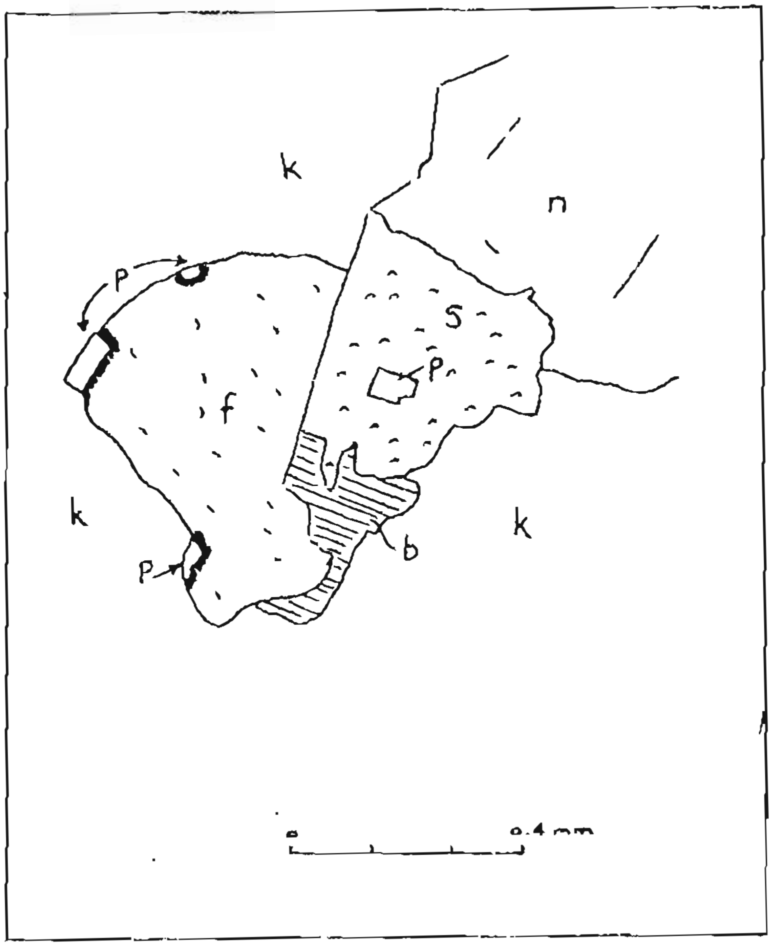

Figure 3.--Sketch of mineral relationships in syenite containing 89 ppm U. Pyrochlore, p; fluorite, f; sphene, s; potassium feldspar, k; nepheline, n; and biotite, b. Note pleochroic halos in fluorite, but not in sphene, around pyrochlore grains.

appear to be any other correlation between the mutual presence of pyrochlore and other rock minerals. There is a rough correlation between the concentrations of niobium and uranium in the syenite, especially with increasing amounts of uranium (fig. 4).

Most of the samples containing higher amounts of uranium are from the southern part of the complex, with the exception of the plagioclase-bearing syenite to the north. The distribution of pyrochlore is similar to that of uranium.

The phonolite dike, which is exposed in the southern part of the complex, contains 54 ppm U. No pyrochlore was observed in thin section, although the sample contains 50 ppm Nb, indicating a U-Nb relationship similar to that in the syenite (fig. 4).

Radiometric ground traverses showed that the highest total count radioactivity was concentrated along the contact zones between the pyroxenite and syenite (Wallace and Cady, 1977). The petrographic and chemical evidence do not support the radiometric evidence, although some contact zone rocks contain up to 37 ppm uranium.

DISCUSSION

The rocks of the Ekiek Creek Complex are undersaturated, potassium-rich, and alkaline, based upon their mineralogy and modal and chemical compositions. Aegirine, feldspathoids, melanite, and phlogopite are typical constituents of undersaturated alkaline rocks. The preponderance of orthoclase reflects a large amount of potassium.

The relatively high amount (2.2 percent) of fluorine in the phlogopite suggests high temperatures and low volatile pressures typical of volcanic environments (Carmichael and others, 1974). The possible pseudoleucite also suggests a low pressure environment, as leucite cannot form at high volatile

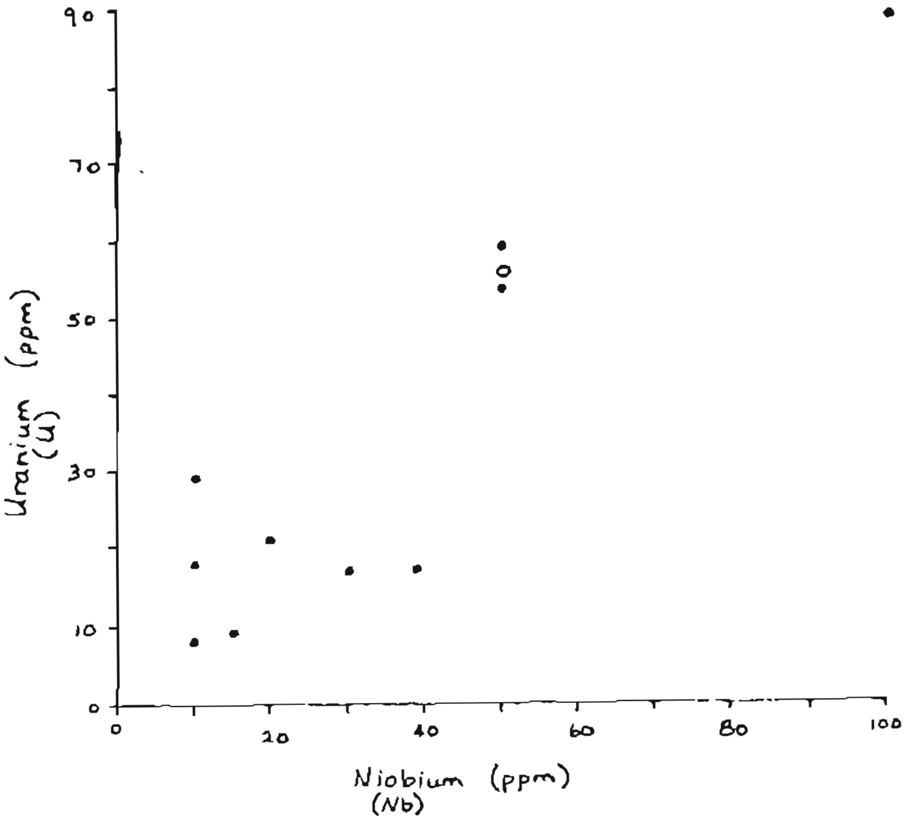

Figure 4. Relationship between uranium and niobium in syenite (solid dots) of the Ekick Creek Complex, western Alaska. Samples containing over 50 ppm U contain visible phrochlore. Open circle indicates phonolite dike. Niobium analyses by Mollie Jane Malcolm; uranium analyses same as for table 2.

pressures (Fudali, 1963); the pseudoleucite(?) presumably formed by subsolidus breakdown of the leucite. However, without detailed electron-microprobe analyses of the feldspar and feldspathoid in the intergrowths, caution must be taken in even calling the textures in these rocks pseudoleucite, as compared with feldspar-feldspathoid intergrowths formed by other possible mechanisms of formation (Davidson, 1970).

Observations in this study support the conclusions of Miller (1972) that the syenite dikes intruded the pyroxenite. They do not support the observations of Wallace and Cady (1977) that show three or more north-trending dikes of pyroxenite apparently cutting the syenite. It is conceivable that the syenite was intruded by pyroxenite dikes, with partial melting of the syenite along the contact and subsequent reintrusion into the quenched pyroxenite. This would explain both the dike-like form of the pyroxenite, and the intrusion of syenite into pyroxenite. There is, however, no petrographic evidence to wholly support that idea. Two points are clear: (1) the syenite did, in some manner, intrude the pyroxenite; and (2) the general intrusive sequence of alkaline rocks in western Alaska is an early mafic and later felsic event (Miller, 1972).

The broad contact zones often found between syenite and pyroxenite may be indicative of zones of metasomatic replacement of the pyroxenite by the syenite. The introduction of nepheline, melanite, and possibly phlogopite, all in varying amounts, is clearly visible in the contact zone rocks. The corrosive and blastic textures, and the nucleation rims of phlogopite and melanite around pyroxene are typical of metasomatism related to the intrusion of a felsic rock into an existing mafic body (Borodin and Pavlenko, 1974). The original volume of pyroxenite may have been much greater than it is now. Subsequent syenite intrusion, with a corresponding spread of the replacement zones, would have reduced the pyroxenite body into smaller tabular areas resembling dikes. This would possibly resolve the debate between Miller's (1972) syenite intrusion and the pyroxenite dike of Wallace and Cady (1977).

Uranium is clearly related to pyrochlore in the nepheline syenite of the complex, and the close correlation between uranium and niobium in the rocks indicates that the two elements behaved similarly during the crystallization of the melt. Pyrochlore formed relatively early, preceding even euhedral sphene. The lack of uranium in the grain surrounded by sphene, then, is unusual. This might, at first glance, suggest post-sphene uranium enrichment, but analyses of uranophyrochlore clearly show that uranium is an integral component of that mineral rather than occurring as a surface or fracture-filling element.

The refractory nature of pyrochlore precludes uranium leaching and secondary enrichment elsewhere. Also, the small amount of pyrochlore in the rocks makes the reconcentration of these heavy minerals, either locally or in surrounding basins, economically unfeasible.

REFERENCES

Borodin, L. S., and Pavlenko, A. S., 1974, The role of metasomatic processes in the formation of alkaline rocks, in Sorensen, H., ed., The Alkaline Rocks: New York, John Wiley & Sons, p. 515-534.

Bowen, N. L., 1928, The evolution of the igneous rocks: Princeton, Princeton University Press (reprinted by Dover Publications, Inc., 1956, 332 p.

Carmichael, I. S. E., Turner, F. J., and Verhoogen, J., 1974, Igneous Petrology: New York, McGraw-Hill Book Co., 739 p.

Davidson, A., 1970, Nepheline-K-feldspar intergrowth from Kaminak Lake, Northwest Territories: Canadian Mineralogist, v. 10, p. 191-206.

Fudali, R. F., 1963, Experimental studies bearing on the origin of pseudoleucite and associated problems of alkalic rock systems: Geological Society of America Bulletin, v. 74, p. 1101-1126.

Hogarth, D. D., 1977, Classification and nomenclature of the pyochlore group: American Mineralogist, v. 62, p. 403-410.

Miller, T. P., 1972, Potassium-rich alkaline intrusive rocks of western Alaska: Geological Society of America Bulletin, v. 83, p. 2111-2128.

______1976, Hardrock uranium potential in Alaska: U.S. Geological Survey Open-File Report 76-246, 7 p.

Murphy, M., Wollenberg, H., Strisower, B., Bowman, H., Flexser, S., and Carmichael, I., 1978, Uranium in alkaline rocks: Earth Sciences, Div., Lawrence Berkeley Lab., Univ. of Calif. LBR-7029 (prepared for the U.S. Dept. of Energy, contract W-7405-ENG-8), 185 p.

Patton, W. W., Jr., and Miller, T. P., 1968, Regional geologic map of the Selawik and southeastern Baird Mountains Quadrangles, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-530.

Wallace, A. R., and Cady, J. W., 1977, Geophysical and petrologic studies of radioactive contact zones of pyroxenite dikes in nepheline syenite of the Ekiek Creek pluton, western Alaska; in Campbell, J. A., ed., Short Papers of the U.S. Geological Survey Uranium-Thorium Symposium: U.S. Geological Survey Circular 753, p. 6-8.

Wellman, T. R., 1970, The stability of sodalite in a synthetic syenite plus aqueous chloride fluid system: Journal of Petrology, v. 11, p. 49-71.

Wright, T. L., 1968, X-ray and optical study of alkali feldspar: II. An X-ray method for determining the composition and structural state from measurement of 2θ values for three reflections: American Mineralogist, v. 53, p. 88-104.