Diagenesis and Uranium Mineralization of the Lower Tertiary Kootznahoo Formation in the Northern Part of Admiralty Trough, Southeastern Alaska

By KENDELL A. DICKINSON and APRIL VULETICH

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CONTENTS

FIGURES

TABLES

Diagenesis and Uranium Mineralization of the Lower Tertiary Kootznahoo Formation in the Northern Part of Admiralty Trough, Southeastern Alaska

By Kendell A. Dickinson and April Vuletich

Abstract

The Lower Tertiary Kootznahoo Formation, a clastic unit, crops out in scattered areas in the Admiralty Trough, southeastern Alaska. The formation consists mainly of arkosic sandstone, conglomerate, and lesser amounts of coal and shale. Samples were collected and outcrops described from three main outcrop localities in an area beginning in the Kootznahoo Inlet area on the west-central side of Admiralty Island and extending southward to the Keku Strait area between Kuiu and Kupreanof Islands. X-ray diffraction, optical mineralogy, scanning electron micrographs, and stable isotope and other chemical analyses were utilized during sample studies.

Three stages of diagenesis were recognized. Stage I occurred under the conditions of nonmarine fluvial and paludal deposition and was characterized by development of sideritic concretions and cement. Stage II was characterized by local uplift of the formation and the entrance of oxygenated meteoric ground water, which resulted primarily in kaolinization. Stage III was characterized by the deposition of calcite and dolomite apparently in response to subsidence and the invasion of the unit by ground water of marine origin.

Uranium mineralization associated with carbonaceous material has been found only where diagenesis to stage II has occurred. Scattered carbonized wood fragments enriched to as much as 0.2% uranium were found in a sandstone bed in the Kootznahoo Formation near Kadake Bay on Kuiu Island. The source of the uranium appears to be a heavy-mineral zone within the sandstone. Parts of the Kootznahoo where stage II diagenesis has occurred are favorable uranium-exploration targets, but exposures are poor and the probability of finding commercial-size deposits is low.

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INTRODUCTION

The Kootznahoo Formation is a lower Tertiary nonmarine clastic unit that crops out in southeastern Alaska. The main outcrop areas are found in a belt that stretches from Zarembo Island and the north end of Prince of Wales Island on the south, northward to the Angoon area, on west-central Admiralty Island (fig. 1). The formation consists mostly of arkosic conglomerate and sandstone. Three outcrop areas were studied for this report. They are the Keku Strait area, which includes outcrops in the northwest part of Kupreanof Island and the northern part of Kuiu Island, the Pybus Bay area on the southeast coast of Admiralty Island, and the Kootznahoo Inlet area in the west-central part of Admiralty Island. The purpose of this report is to describe the rock and present interpretations of diagenetic alteration including uranium mineralization.

A regional petrographic study of the Kootznahoo Formation is limited in this report by the dearth of outcrops, the limited number of samples from some critical areas, and by the lack of detailed stratigraphic correlation between areas. Most of the samples for this study were collected from the beach, indeed many from the intertidal zone, because of limited access to outcrops in interior parts of the islands.

Methods

Twenty-nine samples from the outcrop areas were analyzed for uranium and thorium by neutron activation (Millard, 1976), for trace elements by inductively coupled plasma spectroscopy (ICP; Crock and others, 1983) or by six-step semiquantitative spectroscopy (SSQ; Myers and others, 1961), and for minerals by X-ray diffraction (XRD) of bulk samples. These results together with results from the Zarembo Island area

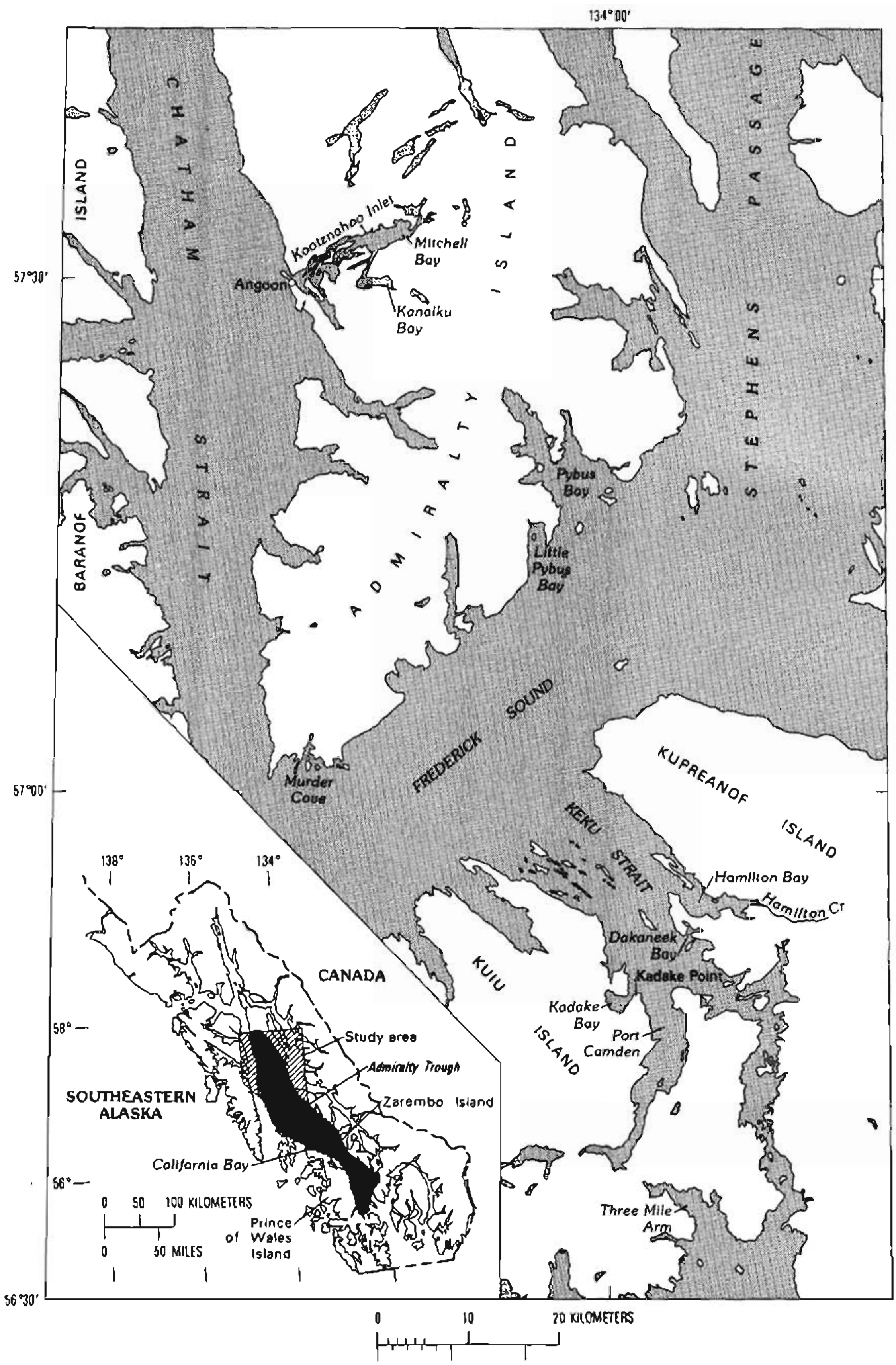


Figure 1. Index map showing study areas in the northern part of Admiralty Trough, southeastern Alaska.

(Dickinson and Campbell, 1984) and chemical data from Karl and others (1985) were treated statistically by Dickinson and Pierson (1989). Additional qualitative chemical analyses were done by energy-dispersive X-ray fluorescence spectroscopy (EDXRF) on the scanning electron microscope (SEM). Additional X-ray analyses, petrographic thin sections studies, and scanning electron microscope studies were carried out on some of the samples. Oriented clay mineral mounts for XRD were used primarily to verify the distinction between kaolinite and chlorite and to detect the presence of expandable lattice clays. Information on sample localities and on chemical and mineralogic data can be found in Dickinson and Pierson (1989). In this report the term illite will be used for minerals that are responsible for the 10 Å XRD peak, and the term montmorillonite will be used for the expandable lattice clays that are otherwise unidentified. The 10 Å group probably is a mixture of illite and mica.

Stable isotopes of oxygen and carbonate carbon were analyzed in four samples containing carbonate minerals, mainly siderite. The samples were digested in concentrated phosphoric acid for total carbonate (for determination of $\delta^{13}C$ and $\delta^{18}O$). Agreement between replicate preparations was within ±0.5 ‰. The equilibrated CO_2 gas was analyzed on a Finnigan MAT 251, 90 degree sector isotope ratio mass spectrometer (Pratt and Threlkeld, 1984).

GEOLOGY

The Kootznahoo Formation consists mostly of nonmarine poorly sorted arkosic and lithic sandstone, conglomerate, and lesser amounts of shale and coal. It was deposited in fluvial and paludal environments in the Admiralty Trough, an elongate depression about 320 km long and 50 km wide (fig. 1; Miller and others, 1959). Only scattered erosional remnants of the original formation remain, and it is not known whether Kootznahoo sediments were deposited in smaller basins in segments of the trough as suggested by Brew and others (1984) or whether deposition was in a single continuous basin as

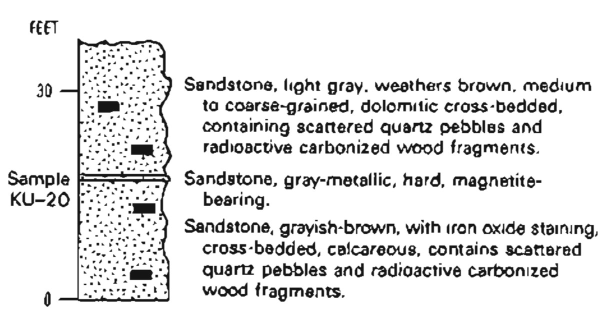


Figure 2. Exposed section of the Kootznahoo Formation at Kadake Point on Kuiu Island. Black rectangles represent carbonized wood fragments.

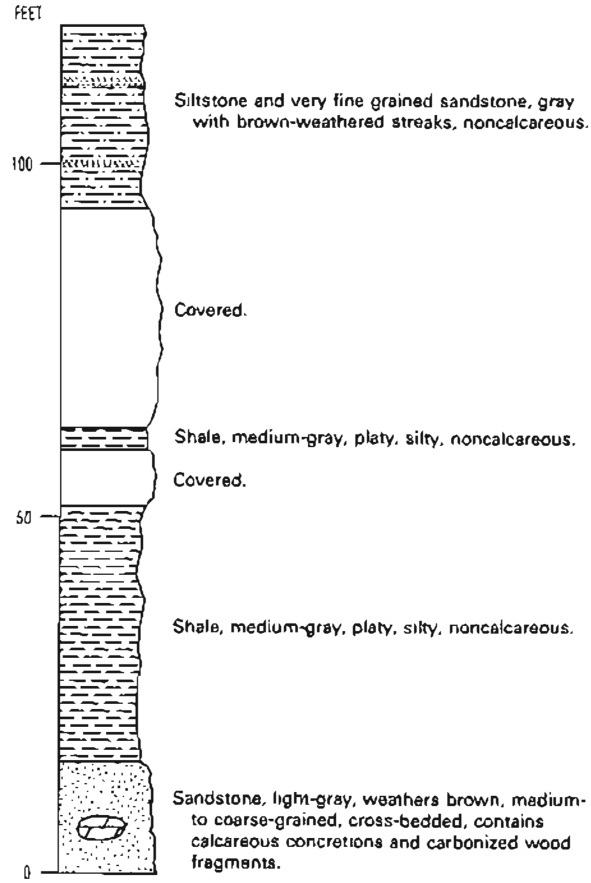


Figure 3. Partial section of the Kootznahoo Formation at Hamilton Bay on Kupreanof Island. Black rectangles represent carbonized wood fragments.

suggested by Buddington and Chapin (1929). Four main outcrop areas are known (Dickinson and Pierson, 1989), but only three—the Keku Strait area, the Pybus Bay area, and the Kootznahoo Inlet area—are covered in this report (fig. 1). The fourth area, the Prince of Wales–Zarembo Island area, has been described by Dickinson and Campbell (1984). Detrital sediments in each outcrop area reflect local source terranes, and mixing of sediments from one part of the trough to another was apparently limited.

Keku Strait area

In the Keku Strait area (fig. 1), which includes the Kadake Bay–Port Camden area on Kuiu Island and the Hamilton and Dakaneek Bay areas on Kupreanof Island, the Kootznahoo Formation consists mostly of poorly sorted light brown or gray fluvial sandstone together with a few beds of dark gray shale that generally dip about 10° southeastward (see figs. 2–5, this report; Buddington and Chapin, 1929; Muffler, 1967). The sandstone con-

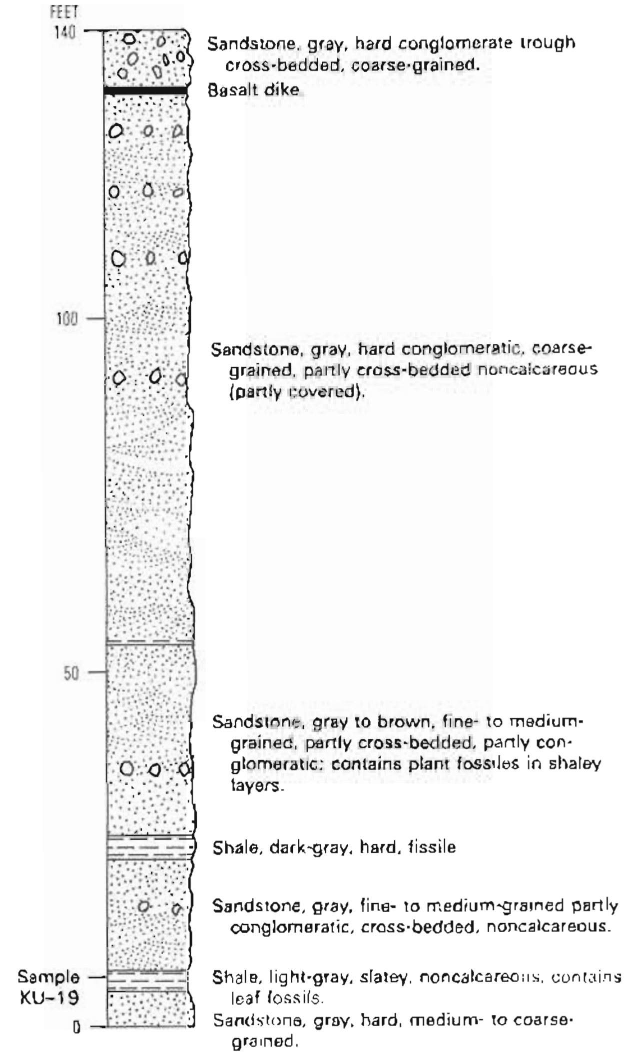
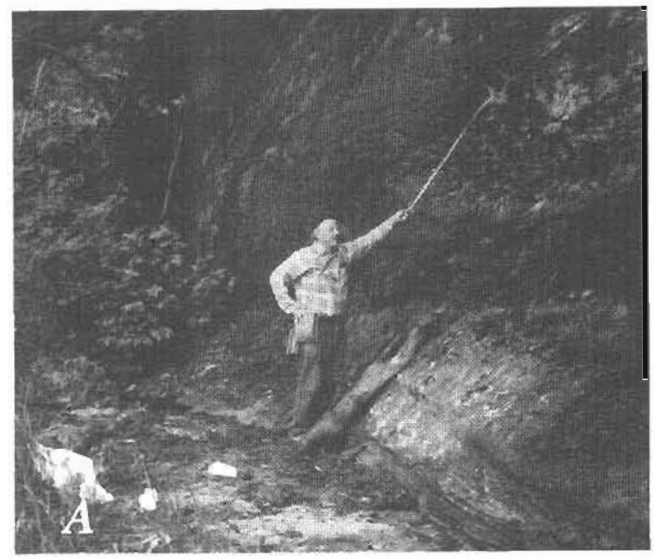


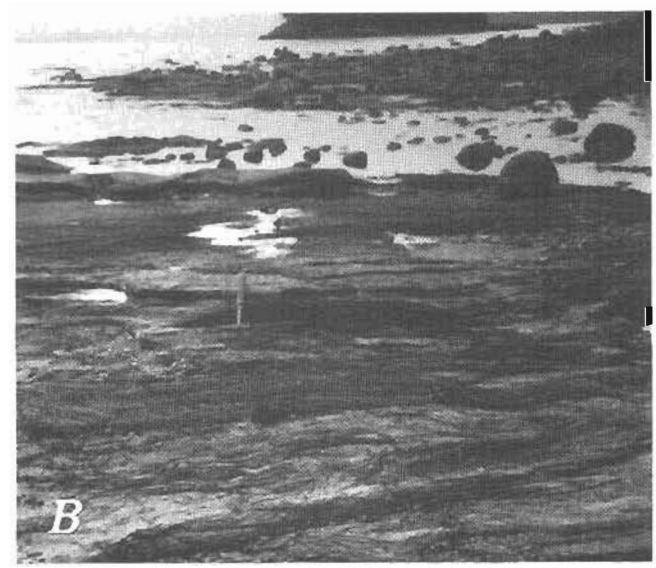
Figure 4. Partial section of the Kootznahoo Formation at Dakaneek Bay on Kupreanof Island.

tains abundant carbonized wood fragments, spotty calcareous concretions and cement, and kaolinite or chlorite and illite. The shale is platy and contains abundant plant fossils.

Except for 3 samples containing montmorillonite, the only clay mineral in 9 sandstone samples from the Kootznahoo Formation from the Kadake Bay and Kadake Point areas (fig. 2) is kaolinite. All of the 6 samples of the Kootznahoo from 6 to 8 miles across the Strait, in the Dakaneek Bay and Hamilton Bay areas (figs. 1, 3, 4), contained chlorite and illite but no kaolinite. Three of these samples also contained montmorillonite. In 9 of 11 mostly sandstone samples from the Keku Strait area a distinct plagioclase XRD peak was observed, and in 7 of these samples a distinct K-feldspar peak was observed. A dolomite XRD peak was observed in 8 of the 11 samples, a siderite peak in 2 and a calcite peak in 1 (Dickinson and Pierson, 1989).



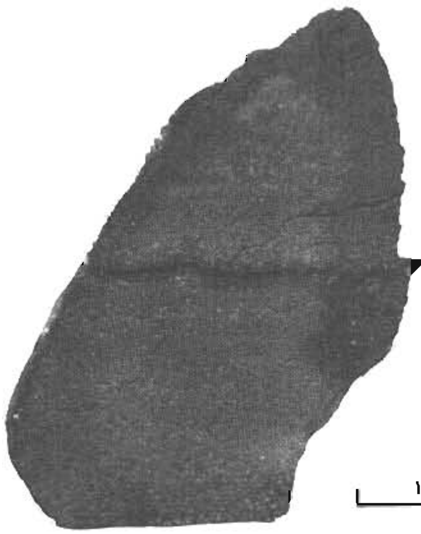
A, Man points to uraniferous carbonized wood fragment at Kadake Point.



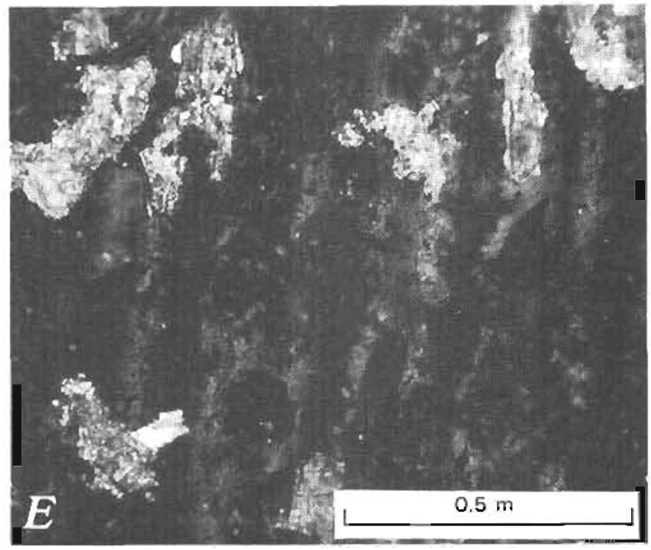
B, Kadake Point Kootznahoo outcrop at low tide. This outcrop contains scattered fragments of uraniferous carbonized wood (Dickinson, 1979).

Figure 5. SANDSTONE OF THE KOOTZNAHOO FORMATION FROM THE KEKU STRAIT AREA.

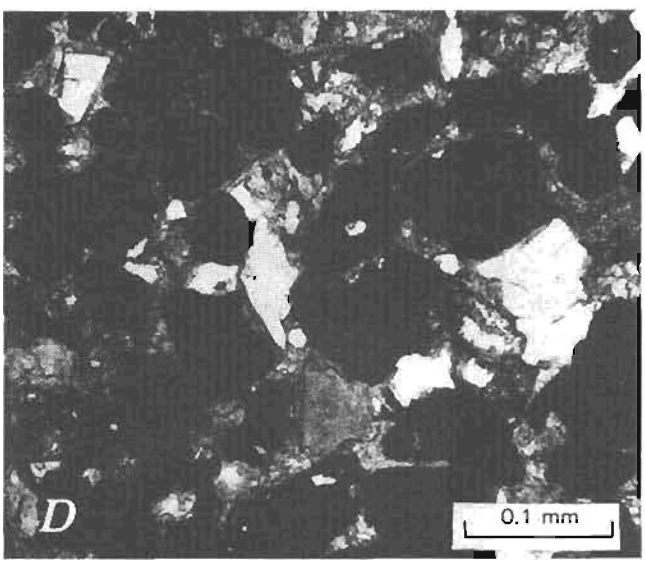
The Kootznahoo sandstone sequence at Kadake Point (fig. 2) contains carbonized wood fragments enriched in uranium and a thin bed (1 to 2 inches thick) of very hard heavy-mineral-bearing sandstone, containing abundant magnetite (figs. 5*C*, 5*D*). This bed also contains ilmenite, apatite, pyrite, rutile, zircon, siderite and a manganese oxide mineral identified by optical properties and by SEM-EDXRF analyses (probably manganite). The heavy-mineral layer contains 21 ppm (parts per million) uranium and 144 ppm thorium, and



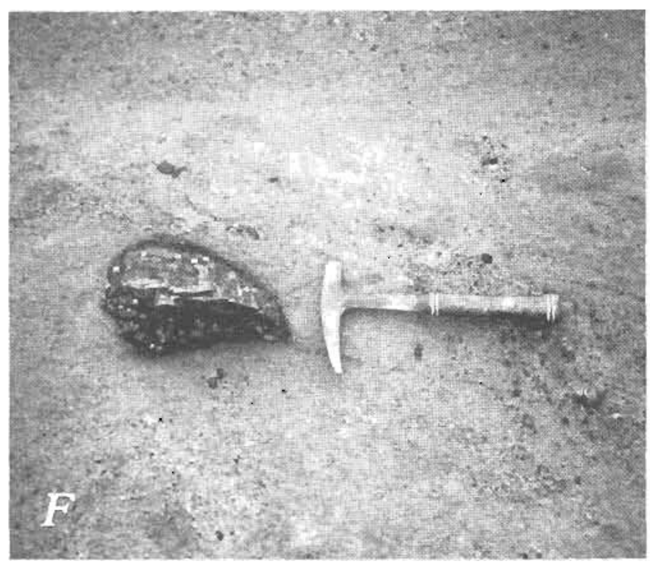
C, Sandstone fragment from outcrop at Kadake Point containing dark layer that consists mostly of magnetite. Altered outer rind contains hematite. This sample contains 21 ppm uranium and 144 ppm thorium.



E, Photomicrograph of sandstone from outcrop in 5*A*, showing kaolinite (fine, dark grains) and calcite (light-colored grains) as an alteration of plagioclase (under crossed polarizers).



D, Photomicrograph of sandstone from upper part of sandstone fragment shown in 5*C*. Opaque grains are predominantly magnetite.



F, Nonradioactive (measured by hand-held scintillometer) carbonized log in fluvial sandstone at Hamilton Bay.

Figure 5. SANDSTONE OF THE KOOTZNAHOO FORMATION FROM THE KEKU STRAIT AREA—Continued.

the carbonized wood, which is characterized by thin white dolomite veins, contains as much as 2,000 ppm uranium. The most common calcareous cement in the sandstone of the Kootznahoo Formation at Kadake Bay is dolomite. A carbonized wood fragment from Hamilton Bay contained both dolomite and calcite but was not enriched in uranium.

In the Keku Strait area the Kootznahoo overlies Triassic volcanic rock, is intruded by Tertiary microgabbro and basalt, and is overlain by Tertiary volcanic flows and conglomerate. The reported thickness of the Kootznahoo in this area is 1,350 feet (Buddington and Chapin, 1929).

Pybus Bay area

In the western Pybus Bay and in the Little Pybus Bay areas the Kootznahoo Formation consists of gently dipping conglomerate, arkosic and lithic sandstone, and minor amounts of shale (fig. 6). In this area the conglomerate to sandstone ratio is about three. The rounded cobbles of the conglomerate are composed mainly of argillite and plutonic rock. The matrix of the conglomerate is sandstone. The sandstone is characterized by an abundance of chlorite-bearing phyllite fragments (fig. 6*D*), and it generally contains less than 15% quartz (Loney, 1964; Lathram and others, 1965). Carbonized wood fragments are common in the sandstone (fig. 6*B*). Of 11 samples from the Pybus Bay area that were analyzed by XRD, none contained siderite, 1 contained dolomite, and 6 contained calcite. Among the clay mineral samples, none contained kaolinite, 10 contained illite, and 10 contained chlorite (Dickinson and Pierson, 1989). All the samples from Pybus Bay displayed a plagioclase peak on the diffractograms, but only 1 sample showed a distinct K-feldspar peak.

The 2,000-foot thick Kootznahoo sequence dips about 15° to the west and unconformably overlies strongly deformed rocks of the Upper Jurassic and Lower Cretaceous Seymour Canal Formation and the Paleozoic Cannery Formation. It is overlain by basaltic and andesitic flows and sills. Fossil leaves present in the Kootznahoo Formation in this area suggest an early Eocene age (Wolfe, in Lathram and others, 1965).

Kootznahoo Inlet area

In the Kootznahoo Inlet area (figs. 1, 7–8), the type locality of the Kootznahoo Formation (Lathram and others, 1965), the unit is comprised of a conglomerate facies to the north and west and a finer grained facies to the east. The conglomerate contains pebbles and cobbles of chert, quartz, argillite, graywacke, slate, schist, and plutonic rocks. The matrix is partly calcareous arkosic to lithic sandstone. The conglomerate is massive to indistinctly bedded and contains a few thin interbeds of sandstone and shale. The sandstone in the finer grained facies is light brown to light gray, poorly sorted, conglomeratic, lithic to arkosic, and crossbedded. The shale is gray and carbonaceous. Lenses of coal ranging from 1 inch to 4 feet in thickness are present in the finer grained facies. Of 7 samples from the Kootznahoo Inlet area analyzed by XRD, all contained illite, 4 contained chlorite and 3 contained kaolinite (Dickinson and Pierson, 1989). Both chlorite and kaolinite were not found in the same sample, however. Siderite was found in 4 of 7 samples where it generally forms cement in sandstone or concretions in mudstone. Four of the 7 samples also contain dolomite, but only 2 contained both siderite and dolomite. All these samples contain plagioclase, but a distinct XRD peak for K-feldspar was found in only 1 sample.

The Kootznahoo is approximately 5,000 feet thick and overlies deformed plutonic and metamorphic Paleozoic and Mesozoic rocks in this area. Beds of the Kootznahoo dip 30°–45° to the southeast (Lathram and others, 1965). The fossil flora here indicate an Eocene to early Miocene age (Wolfe, in Lathram and others, 1965).

Provenance

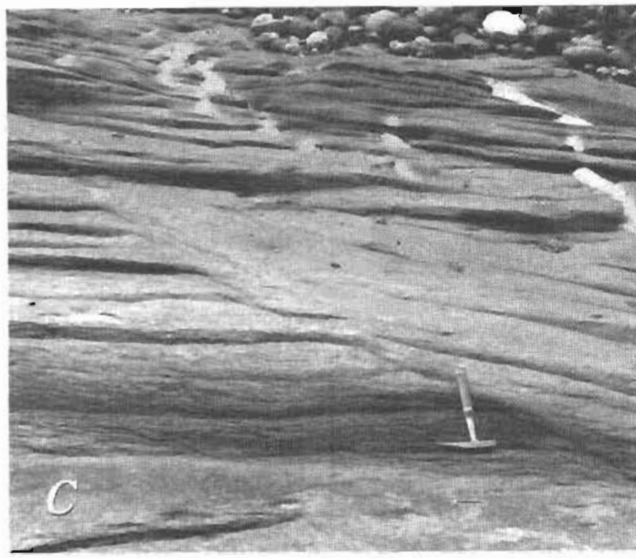
Detailed knowledge of the source of the sediments cannot be determined because of the lack of enough samples and petrographic data. In addition, only a few outcrops are known. Nevertheless, certain relations can be determined. For instance, the orthoclase to plagioclase ratio is higher in the Keku Strait area and in the Zarembo Island area than farther north in Pybus Bay and Kootznahoo Inlet areas. This suggests that the source rocks for the Kootznahoo sediments were more mafic in the northern parts of the Admiralty Trough. It should be mentioned, however, that the orthoclase to plagioclase ratio as determined from XRD data, may have been affected by differential alteration of the feldspars during diagenesis.

DIAGENESIS

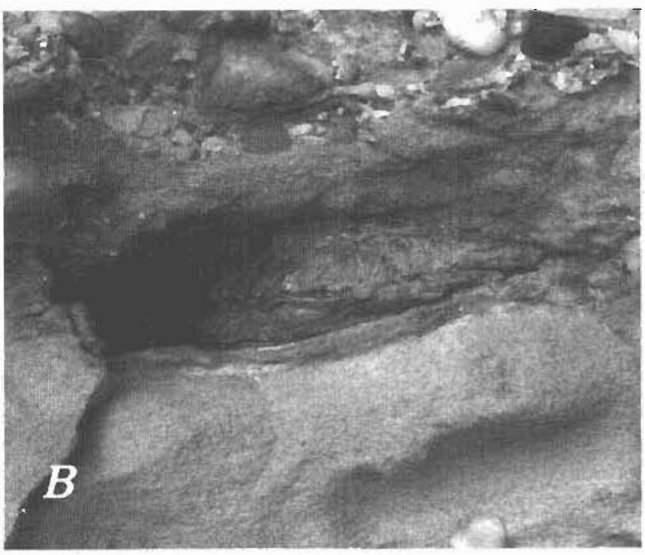
Diagenetic alteration of the Kootznahoo sediments and sedimentary rock occurred to some extent everywhere in the unit. The diagenetic minerals are primarily kaolinite, iron oxide, and the carbonates—siderite, dolomite, and and calcite. The detrital minerals are quartz, orthoclase, plagioclase, chlorite, and illite-muscovite; they are, for the most part, in the form of discrete clastic grains in the sandstone samples. Chlorite occurs as a matrix clay mineral in some of the rocks and could be partly diagenetic, but it is thought to be mostly detrital because, together with illite-muscovite, it occurs in detrital grains and because it correlates negatively with kaolinite, which is believed to be an alteration mineral (Dickinson and Pierson, 1989).

Diagenetic minerals in the Kootznahoo provide a record of postdepositional physical and chemical events. Three stages are recognized. During the first stage early diagenetic events were controlled by a nonmarine depositional environment. In the second stage, the formation was apparently uplifted in some areas, and, where the rock was permeable, diagenesis was dominated by the influx of meteoric water low in dissolved solids and high in oxygen. The third and final stage occurred when the formation was inundated by marine water. The first stage, the nonmarine stage, was dominated by deposition of siderite and partial destruction of chlorite and illite. The second stage was characterized by kaolinization, by

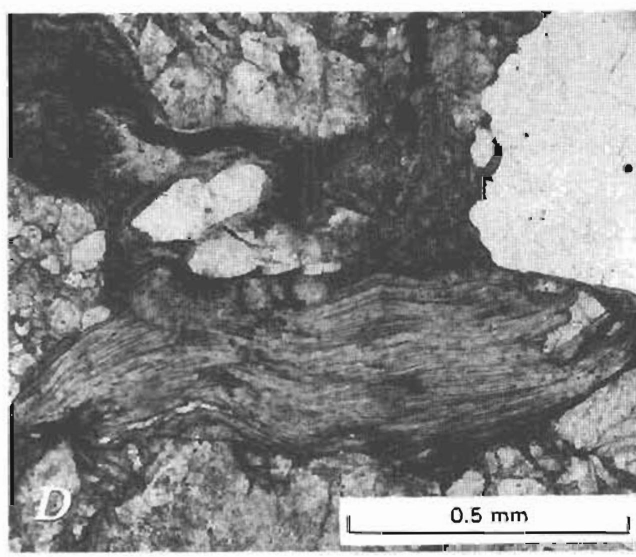
A, Gently dipping beds of sandstone of the Kootznahoo Formation at Little Pybus Bay. The hills in the background are Admiralty Island Volcanics.



C, Fluvial cross-bedding in sandstone of the Kootznahoo.



B, Carbonized log between beds of conglomerate and sandstone in the Kootznahoo Formation. Log is approximately three inches in diameter.



D, Photomicrograph of detrital chloritic phyllite grain surrounded by grains of quartz, feldspar and lithic material.

Figure 6. KOOTZNAHOO FORMATION IN THE PYBUS BAY AREA.

the destruction of the remainder of the illite and chlorite, and by epigenetic uranium mineralization. The third stage occurred when dolomite and calcite cement was deposited.

Stage I

Stage I occurred in a nonmarine environment shortly after deposition of the sediments when geochemical conditions still were predominantly those of the depositional environment and favorable for the deposition of siderite especially methanogenic siderite. Siderite, which generally forms in nonmarine environments (Curtis and Coleman, 1986), formed both as concretions (fig. 8) and as cement in the Kootznahoo. The formation of siderite requires moderately alkaline iron-rich solutions that are relatively low in oxygen, calcium, and sulfur. If too much oxygen is present, iron oxides will form; if too much calcium is present, calcite will form; and if too much sulfur is present, pyrite will form

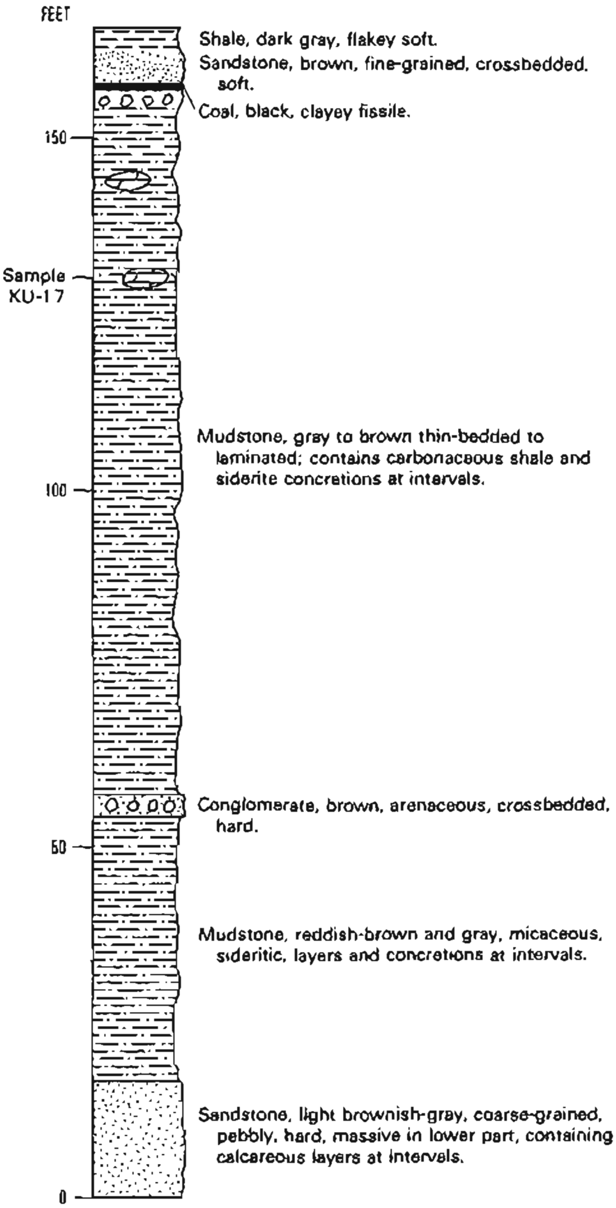


Figure 7. Partial section of the Kootznahoo Formation at Kanalku Bay in Kootznahoo Inlet area.

(Berner, 1971, p. 200; Curtis and Coleman, 1986). In as much as neither calcite nor pyrite were deposited during stages I and II, marine waters, which generally contain relatively large amounts of both calcium and sulfur, were apparently not in contact with the formation during early postdepositional time.

One concretion that was studied in some detail is shown in figure 3. Most of the siderite in this concretion consists of fine anhedral grains. Some of the siderite in the concretion, however, forms stacks of plates (fig. 8*B*). In some of these stacks (fig. 8*C*) chlorite lamellae still separate the siderite plates. Figure 8*D* shows siderite grains that apparently grew between lamellae of a detrital grain of chlorite. These chlorite-siderite relations suggest that some of the chlorite was destroyed during stage I. Some of the iron for the siderite could have been derived from the chlorite.

Analysis of the stable isotopes of carbon (table 1) suggest a somewhat different origin between the cement siderite and the concretion siderite. The $\delta^{13}C$ from a sample of the concretion (number 17) was relatively heavy ($\delta^{13}C = 7.25‰$). This indicates that some of the carbonate resulted from methanogenic fermentation (Murata and others, 1972; Irwin and Curtis, 1977). The other three samples (listed in table 1) of sideritic sandstone had carbon that averaged about $\delta^{13}C = 0.0‰$, suggesting a more abiotic origin for the carbonate in the sideritic cement (Irwin and others, 1977). The stable isotopes for oxygen, which were similar for the four samples, averaged $\delta^{18}O = -12‰$, typical for a freshwater carbonate (Garlick, 1969; Hoefs, 1980, p. 37).

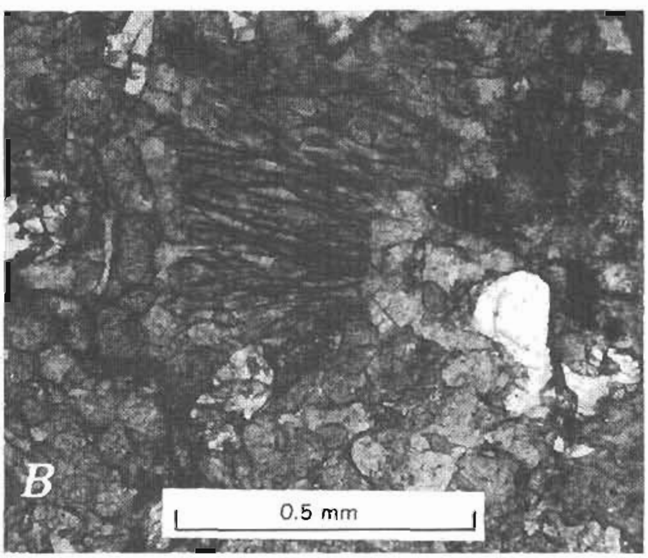
A strong statistical correlation (table 2) between siderite and other minerals was not found (Dickinson and Pierson, 1989). A rather weak negative correlation (−0.29, valid at the 90% confidence level) was found between siderite and plagioclase (table 2). This may indicate destruction of plagioclase during sideritization or that siderite is more common in the clayey rocks without the sand-size detrital grains in which plagioclase dominates.

The sideritization in the Kootznahoo Formation was most common in the Kootznahoo Inlet area which is characterized by high iron content. The Kootznahoo averaged 12.6% Fe in the Kootznahoo Inlet area compared with 2.9% in the Pybus Bay area and 5% in the Keku Strait area. Much of this iron is found in the form of siderite and ferroan dolomite. Sideritic cement is also found in sandstone of the Kootznahoo Formation around Kadake Bay.

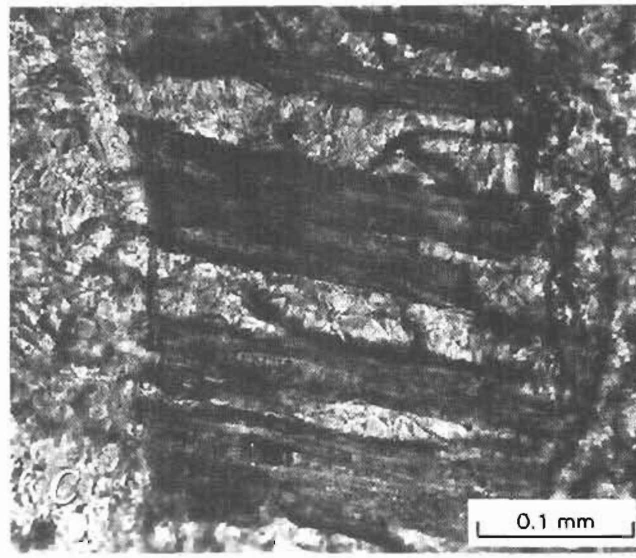
Stage II

Stage II rocks are characterized by the presence of kaolinite, iron oxide, and uranium enrichment in carbonized wood fragments. Kaolinization is believed to have been related to the input of large amounts of meteoric water low in dissolved solids. According Pettijohn and others (1973, p. 409), the diagenetic kaolinite may represent a slightly acidic environment. Uranium is commonly mobilized in an oxidizing environment because of its plus 6 valence, and magnetite was altered to hematite in a sample from this facies. These reactions and conditions are consistent with an uplifted formation and the movement of meteorically derived oxygenated ground water through the more permeable layers. At least part of the kaolinite formed from plagioclase (fig.

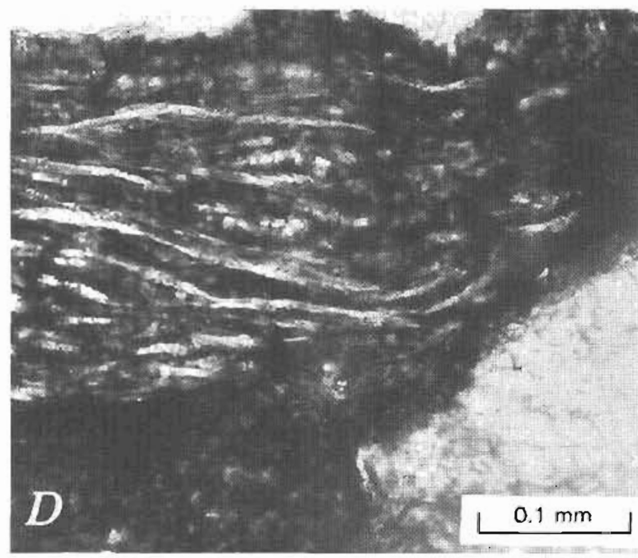
A, Sideritic concretion in mudstone that contains heavy carbon isotopes.



B, Photomicrograph of sideritic concretion showing granular and stacked plates of siderite (plane polarized light).



C, Photomicrograph of chlorite plates separated by authigenic siderite in concretion (plane polarized light).



D, Photomicrograph of authigenic grains of siderite that apparently grew between plates of chlorite (plain polarized light).

Figure 8. KOOTZNAHOO FORMATION ROCKS FROM KANALKU BAY IN THE KOOTZNAHOO INLET AREA.

5*E*), but a strong negative correlation between kaolinite and illite and chlorite (table 2), suggests that, where kaolinite formed, illite and chlorite were destroyed, or were altered to kaolinite. Kaolinite correlates positively with K-feldspar (table 2). A relationship that could be explained by the formation of both in the same authigenic environment. However, no evidence for authigenic feldspar was seen in the thin sections, and the correlation could be explained by the formation of kaolinite from K-feldspar if the amount of kaolinite that formed depended upon the amount of K-feldspar originally present.

Alteration to stage II was most prevalent in the Kootznahoo sandstones of the Kadake Bay–Port Camden part of the Keku Strait area. Some kaolinite was found at California Bay in the Zarembo Island area and some in the Kootznahoo Inlet area. No kaolinite was found in the rocks at Pybus Bay.

Table 1. Stable isotopes for carbon and oxygen from sideritic samples of the Kootznahoo Formation.

[The results are reported in the usual $\delta^{13}C‰ = [(R_{sample}/R_{std})-1] \times 10^3$ where R is the ratio of ^{13}C to ^{12}C (or corresponding ^{18}O and ^{16}O) relative to the PDB standard (Craig, 1957).]

Sample No.	Lithology	$\delta^{13}C$	$\delta^{18}O$
15	Reddish brown and gray sandstone	-1.71	-12.32
17	Reddish brown sideritic concretion	7.25	-11.3
18	Reddish brown and gray sideritic mudstone	0.38	-10.53
20	Hard, fine-grained reddish brown sandstone containing magnetite	-0.81	-13.72

Stage III

Stage III is characterized by calcite and dolomite deposition. The calcite occurs in two different modes: as cement filling pore spaces, and as alteration of plagioclase (fig. 5*E*). Calcite does not correlate strongly with any of the other minerals (table 2). Its occurrence is widespread, but it was not found with siderite. Dolomite is also widespread in small amounts as cement or concretions, but its most interesting occurrence is as vein filling in carbonized wood fragments. This explains its positive correlation with uranium that is concentrated in these wood fragments. Most dolomite and calcite probably formed after the formation was inundated with marine water, although some of the dolomite, which is ferroan in nature, could have formed in conjunction with the siderite in stage I.

URANIUM MINERALIZATION

In the area of this report the most significant uranium mineralization was found in the carbonaceous material in the Kadake Bay area (Dickinson, 1979). Slight uranium mineralization was also found in a coal bed in California Bay on the north end of Prince of Wales Island (Dickinson and Campbell, 1984). The uranium mineralization at Kadake Bay and at California Bay

Table 2. Linear correlations from XRD peak heights and uranium by neutron activation

[41 sample pairs, r. for 95% confidence level = 0.31 (Dickinson and Pierson, 1989)]

	Uranium	Siderite	Dolomite	Calcite	Chlorite	Plag.*	K-feld.*	Illite	Quartz	Kaolinite
Uranium	1.00									
Siderite	0.16	1.00								
Dolomite	0.36	0.18	1.00							
Calcite	-0.15	-0.20	-0.25	1.00						
Chlorite	-0.24	-0.25	-0.41	0.26	1.00					
Plag.*	-0.00	-0.29	-0.00	0.14	0.04	1.00				
K-feld.*	0.08	-0.21	0.23	0.03	-0.37	0.03	1.00			
Illite	-0.29	-0.11	-0.18	-0.01	0.62	-0.08	-0.38	1.00		
Quartz	-0.27	0.02	-0.13	0.17	0.10	0.26	-0.02	0.03	1.00	
Kaolinite	0.04	0.08	0.29	-0.17	-0.46	-0.27	0.43	-0.33	0.17	1.00

* Plag. = plagioclase, K-feld. = K-feldspar

apparently occurred during stage II diagenesis because kaolinite of probable diagenetic origin was also found in both uranium areas. The oxidizing conditions related to the uplift and the entrance of oxidizing surface water promoted the oxidation of the uranium by the ground water and its mobilization as a uranyl or carbonate ion.

For the Kadake Bay area uranium occurrence, the source of the uranium appears to have been a heavy mineral layer (mostly magnetite) in Kootznahoo sandstone. A sample of this layer contained 21 ppm U and 144 ppm Th, which yields a Th/U ratio of about 6. These figures are high compared to average sandstones. The average U content for the sandstone of the Tertiary Kenai Group in south central Alaska is about 2 ppm U and 6 ppm Th, which yields a Th/U ratio of about 3, a ratio typical of igneous rocks as well (Wedepohl, 1971; Dickinson and Campbell, 1978). The high Th/U ratio (6) for the sample at Kadake Bay could be the result of leaching U from heavy mineral beds in the Kootznahoo. Some of the magnetite grains in the sample have been altered to hematite suggesting oxidizing conditions.

The uranium found in the carbonized wood fragments was probably absorbed from the ground water by ion exchange or by chelation (Breger, 1974; Leventhal, 1980). Later, during maturation of the carbonaceous material the uranium probably entered as some reduced uranium mineral, such as uraninite. Tiny fissures that developed in the carbonized wood may have aided entrance of the uranium. Later, probably during stage III diagenesis, these fissures were filled with dolomite.

SUMMARY

1. Three diagenetic stages characterized by (a) siderite, (b) kaolinite and, (c) calcite and dolomite are recognized.
2. Stage I occurred when pore water chemistry was controlled by the nonmarine depositional environment and conditions were mildly alkaline and reducing.
3. Stage II followed and was limited to areas of uplift where the porous beds were charged with oxygenated ground water low in dissolved solids.
4. Stage III occurred after subsidence and invasion of the unit by ground water derived from the marine environment.
5. Known areas of uranium mineralization are limited to areas where kaolinite is found (stage II diagenesis) when oxidizing ground waters mobilized the uranium.
6. A possible source of uranium at Kadake Bay is a thin bed of heavy minerals within the Kootznahoo and a few feet from mineralized samples.
7. Uranium exploration in the Kootznahoo should be confined to areas of stage II diagenesis, heavy mineral beds, and abundant carbonized wood; however, the probability of finding commercial-size deposits is low.

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