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National Uranium Resource Evaluation

URANIUM DISTRIBUTION IN RELATION TO SEDIMENTARY FACIES, KERN LAKE, CALIFORNIA

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GEOLOGICAL SURVEY OF WYOMING

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Resource Applications
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SUMMARY

Kern Lake, in the southern San Joaquin Valley, California, was studied with the objective of examining the factors controlling distribution and fixation of uranium in modern lacustrine sediments. Kern Lake and adjacent Buena Vista Lake received sediment principally from the Kern River drainage of the Sierra Nevada until the Kern River was diverted for agricultural use during the last century. Kern Lake is now dry except following periods of exceptionally heavy rainfall. The drainage basin of Kern and Buena Vista Lakes includes 3300 square miles of bedrock composed of granitic, metamorphic, volcanic and consolidated sedimentary rocks. Uranium deposits have been reported from each of the bedrock types. The most significant uranium occurrence is in the Miracle Mine area within the Mesozoic basement complex of the Sierra Nevada.

Field work consisted of ground radiometric measurements, trench and drill hole lithologic logging, and collection of over 200 water and sediment samples for laboratory analysis. No significant correlation could be seen between lake facies and ground radiometric equivalent uranium concentrations, which varied from 3 ppm to 10 ppm equivalent uranium. However, equivalent thorium values showed a clear increase toward the lake center.

Seven water samples were collected from the Kern River between the western front of the Sierra Nevada and Lake Isabella. Uranium content in the water ranged from 0.5 to 1.0 parts per billion, except for a sample from Hobo Creek, a tributary of Kern River with a well-known anomalous uranium content, which contained 8.3 ppb uranium.

Trench excavations and drill holes within the Kern Lake Bed encountered interbedded clay, silt and sand. Toward the lake margins, clay and silt grade into interbedded clay, silt and sand. The nearshore facies grades to predominantly sand on the north margin of the lake, which represents the distal facies of the Kern River distributary fan, and around the outlet of Old South Fork, a former course of Kern River.

Grain size, carbon content and uranium content of sediment samples were determined; uranium was measured by delayed neutron activation analysis. Carbon constitutes up to two percent by weight of the sediments and is predominantly organic. Uranium content ranges from 2 ppm to 23 ppm

the highest values being generally associated with the finer grained facies. The uranium content in fresh biotite from the sand fraction of one sample contained 45 ppm uranium, and altered biotite from the same sample contained 35 ppm uranium, suggesting that most of the uranium in the sand fraction for that sample is contained within the biotite. Additional samples from Buena Vista Lake and the slough connecting Buena Vista and Kern Lakes yielded uranium and organic carbon values within the same ranges as the Kern Lake sediments.

Uranium concentration in whole samples compared to grain size shows the best correlation with the mud fraction (silt and clay). A poorer correlation was found between uranium and clay and silt individually. To ascertain whether uranium is concentrated to a greater degree in the sand, silt or clay fractions, three samples were split into sand-, silt- and clay-size fractions and the uranium content determined for the sand and clay fractions. The sand fraction contained 13 to 23 percent of the uranium in the samples, and the clay fraction 50 to 60 percent. The remaining 26 to 32 percent of the total uranium in the samples was assumed to be present in the silt fraction.

Selected Kern Lake sediment samples were subjected to a leaching procedure to determine the proportion of detrital and authigenic uranium and whether the authigenic uranium is organically complexed or adsorbed. The method requires two successive leaches. An acid leach first separates the adsorbed uranium from the sample. The second leach oxidizes the organically complexed uranium and separates it from the detrital fraction. The total authigenic fraction ranged from 50.3 to 82.3 percent. Of this, the adsorbed uranium predominated, ranging from 1.4 to 11.4 ppm, with a mean of 5.17 ppm. Organically complexed uranium ranged from 0.02 to 3.85 ppm, with a mean of 0.96 ppm. The detrital uranium ranged from 0.05 to 5.35 ppm, with a mean of 3.48 ppm. A statistical treatment of these data showed that uranium ppm values for each fraction (adsorbed, organic, detrital) all have positive correlation coefficients with the total uranium, i.e., as the uranium content increases, the uranium in each fraction also increases.

Organically bound uranium shows a poor correlation with organic carbon but correlates well with clay. It also has a positive correlation with silt, but this may be only an indirect function owing to a correlation of silt with clay. The distinction between organically bound and adsorbed uranium may not be a true distinction, because much of the organic

matter may be adsorbed on mineral surfaces, and may have been removed by the leaching process. If the adsorbed organic matter contained complexed uranium it would be a significant factor in explaining the lack of apparent correlation between organically complexed uranium and organic carbon.

A multiple regression analysis on the Kern Lake sample data shows two distinct groupings, uranium-rich samples and uranium-poor samples. The uranium-rich samples tend to occur in the center and also in the northern part of the lake. Samples near the lake center contain a high proportion of adsorbed uranium and a low proportion of detrital uranium; those in the northern part of the lake are relatively high in detrital uranium but lower in adsorbed uranium. This distribution may be controlled by the location of the samples relative to the Kern River inlet.

CONTENTS

	Page
SUMMARY	ii
INTRODUCTION	1
Purpose of Study	1
Uranium in Fluvial-Lacustrine Sediments	1
GEOLOGIC SETTING AND RECENT HISTORY OF SOUTHERN SAN JOAQUIN VALLEY	4
FIELD WORK AND SEDIMENTARY FACIES	9
Ground Radiometric Measurements	9
Subsurface Excavations	13
Sedimentary Facies	13
SAMPLING AND ANALYSIS	14
Grain Size	14
Mineralogy	14
Carbon	17
Uranium	17
Distribution of Uranium by Lithologic Facies	21
Geochemical Mode of Uranium Occurrence at Kern Lake	24
Statistical Evaluation of Detrital Versus Authigenic Uranium	31
Uranium in Biotite	40
Multiple Regression Analysis	41
CONCLUSIONS	47
REFERENCES	48
ANNOTATED BIBLIOGRAPHY OF LACUSTRINE URANIUM OCCURRENCES	52
ACKNOWLEDGMENTS	62
APPENDIX (Microfiche in pocket)	
Test Pit Logs	A-1
Additional Results of Laboratory Analyses	A-56

ILLUSTRATIONS

Figure 1 - Interior drainage of Kern and Buena Vista Lakes	5
Figure 2 - Map of Kern River Delta	7
Figure 3 - Distribution of clastic sediments in interval 50 - 100 cm depth, Kern Lake area	10
Figure 4 - Equivalent uranium concentrations (ppm) from field radiometric measurements, Kern Lake Bed	11
Figure 5 - Equivalent thorium concentrations (ppm) from field radiometric measurements, Kern Lake Bed	12

	Page
Figure 6 - Location of samples from Buena Vista Lake and connecting slough	18
Figure 7 - Uranium concentrations and sample lithology plotted on sedimentary facies map	20
Figure 8 - Water sample localities	22
Figure 9 - Bivariate plot, uranium (ppm) vs. sand (%)	26
Figure 10 - Bivariate plot, uranium (ppm) vs. silt (%)	27
Figure 11 - Bivariate plot, uranium (ppm) vs. clay (%)	27
Figure 12 - Diagram of uranium leach analyses	30
Figure 13 - Trivariate plot of the uranium distribution in adsorbed, organic, and detrital fractions of six samples	33
Figure 14 - Bivariate plot, adsorbed plus organically bound uranium (ppm) vs. total uranium (ppm)	36
Figure 15 - Bivariate plot, adsorbed uranium (ppm) vs. total uranium (ppm)	36
Figure 16 - Bivariate plot, organically bound uranium (ppm) vs. total uranium (ppm)	37
Figure 17 - Bivariate plot, detrital uranium (ppm) vs. total uranium (ppm)	37
Figure 18 - Bivariate plot, adsorbed and organically bound uranium (%) vs. total uranium (ppm)	38
Figure 19 - Bivariate plot, adsorbed uranium (%) vs. total uranium (ppm)	38
Figure 20 - Bivariate plot, organically bound uranium (%) vs. total uranium (ppm)	39
Figure 21 - Bivariate plot, detrital uranium (%) vs. total uranium (ppm)	39
Figure 22 - Uranium residuals (observed minus predicted) from multiple regression	43
Figure 23 - Map showing percent detrital uranium and percent organic uranium for leached samples	45

TABLES

Table 1 - Results of Laboratory Analyses	15
Table 2 - Uranium and organic carbon in samples from Buena Vista Lake and slough connecting Kern and Buena Vista Lakes	19

	Page
Table 3 - Matrix of correlation coefficients of all variables measured and all samples analyzed	23
Table 4 - Correlation matrix for the 31 samples analyzed for both uranium and textural characteristics and correlation matrix for 26 samples analyzed for uranium, texture, and organic carbon	25
Table 5 - Uranium content in sand, silt, and clay fractions of three high-uranium samples	28
Table 6 - Results of sample leaching	32
Table 7 - Matrix of correlation coefficients for samples analyzed for adsorbed, organic, and detrital uranium fractions	34
Table 8 - Residuals for the multiple regression of uranium with texture data and texture data plus organic carbon	42
Table 9 - Correlation matrix for the uranium-rich group and the uranium-poor group	46

INTRODUCTION

Purpose of the Study

Economic deposits of authigenic or epigenetic uranium have been discovered in lacustrine sediments at several locations throughout the world. However, the recent search for uranium in contemporary lake beds and playas in the southwestern United States has not resulted in announced proven reserves. By analogy with known uraniferous lacustrine deposits, uranium concentrations should be localized in particular sedimentary facies. Additional knowledge of the relationships between uranium concentrations and lacustrine facies is required to aid in the identification of suitable exploration targets within lake beds and playas. This is especially true for Recent occurrences owing to the potential disequilibrium character of daughter-products associated with the uranium mineralization.

The purpose of the present study is to ascertain whether uranium has been concentrated authigenically and where this may have occurred in a Recent dry lake system where the hydrologic and geologic setting is more clearly understood than in the case of ancient deposits. Kern Lake in the southern San Joaquin Valley of California was selected for study, primarily because considerable subsurface data were available as a result of a recent project to study earthquake deformed strata under a contract with the U.S. Geological Survey (Lamar *et al.*, 1979 ab). Furthermore, Kern and Buena Vista Lakes are sinks for an area of interior drainage encompassing granitic and sedimentary bedrock with several known economic uranium occurrences. Weathering and erosion of this terrane since late Pliocene must have provided significant quantities of uranium to Kern and Buena Vista Lakes.

Uranium in Fluvial-Lacustrine Sediments

Placer concentrations of uranium minerals are not the primary concern of the present study; however, resistate or partly decomposed transported minerals may contribute to observed uranium concentrations in fluvial and lacustrine sediments. Models which suggest specific target facies for authigenic, penecontemporaneous or epigenetic concentrations of uranium in

Recent and older fluvial-lacustrine environments are briefly described below. An annotated bibliography of uranium occurrences in lacustrine sediments appears at the end of this report.

1. Purely Syngenetic Concentrations

- a. Organic muds and bogs. Contemporaneous accumulation of organic materials and fixation of uranium have taken place by adsorption, chelation or complexing. Such occurrences are known, e.g., in the central parts of contemporary Canadian lakes and in bogs in the United States (Bowes et al, 1957), Sweden (Armands, 1967) and Russia (Lopatkina, 1967). Some uraniferous lignites, coals and non-marine carbonaceous shales may be of this origin.

Evaporites. Surficial concentrations, such as the schroe-kingerite occurrences on the Red Desert of Wyoming and elsewhere, result from simple evaporation of ephemeral flood waters. They tend to occur with the finest grained facies, to be thin, unstable, and readily carried away by the wind or redissolved. They are unlikely to constitute ore in themselves but might contribute to concentrations elsewhere. The ratios U/Na or U/K may be useful in recognition of simple evaporative concentrations.

2. Syngenetic-Diagenetic Concentrations

- a. Lacustrine-humate model. In the Salt Wash member of the Morrison formation, uranium deposits occur as discontinuous tabular bodies within braided stream and marginal lacustrine sandstones in proximity to overlying, underlying, or laterally occurring offshore gray mudstones (Peterson, 1977). Uranium mineralization in the lacustrine rocks of the Newark basin in Pennsylvania and New Jersey occurs in both offshore black mudstones and nearshore sandstones of the Stockton formation (Turner-Peterson, 1977). Peterson and Turner-Peterson (1979) have proposed that humic and fulvic acids generated in the offshore muddy sediments of humus-bearing lakes may be expelled by compaction or seepage into nearby sandy facies

and form humate deposits. Uranium transported by ground water may be fixed and concentrated in the humate deposits. The process is considered to take place shortly after burial.

- b. Diagenetic liberation of uranium. Economic mineralization occurs in Tertiary lake beds at the Anderson Mine in the Artillery Peak-Date Creek basin of west-central Arizona (Reyners et al, 1956; Otton, 1977; Sherborne et al, 1979). Unoxidized (coffinite?) and oxidized (carnotite) mineralization occurs principally in thinly bedded lower to middle Miocene lacustrine siltstones and mudstones interbedded with fine tuffaceous sedimentary rocks, freshwater marlstones and limestones and a few thin sandstones. Finely comminuted carbonaceous plant material and abundant silicified rushlike plant remains and mollusks are present in many of the beds. Mineralization is continuous across facies boundaries, and the extension of mineralization beyond carbonaceous sediments suggests fixation of uranium by lateral migration of H_2S gas. The host tuffaceous lacustrine rocks are believed to be the principal source of uranium, released during diagenesis, transported in ground water and precipitated in adjacent carbonaceous beds (Sherborne et al, 1979).
- c. Calcrete deposits. Uranium occurs as carnotite in an entirely oxidizing environment in association with nonpedogenic Ca/Mg calcrete in a geomorphically stable, uniquely evaporative setting (Carlisle et al, 1978). Uranium is derived by weathering of granitic rocks and lateral transport in vadose and phreatic waters. Precipitation results mainly from evaporative concentration of U, V and K, destabilization of uranyl carbonate complexes, and oxidation of tetravalent V to five-valent V, especially in areas where ground water rises toward the surface. Reconcentration of initially contemporaneous carnotite and carbonate may be essential for ore grades. Major ore bodies occur in valley calcretes but deltaic and lake-margin calcretes

also contain significant mineralization. Large nonpedogenic calcretes have not been reported in North America.

3. Epigenetic Concentrations

- a. Roll front deposits. Uranium is precipitated in relation to a geochemical cell or roll front with oxidizing water moving progressively down an aquifer sandstone between impermeable beds. Tetravalent uranium mineralization occurs at the transition from oxidized to non-oxidized sandstone. Deposits are discordant to bedding within the sandstone and curvilinear to irregular along strike. The host sediments are typically fluvial rather than lacustrine but may be marginal-lacustrine, deltaic or lagoonal in character.
- b. Peneconcordant deposits (Colorado-Plateau type). Uranium is controlled by lithology and occurs in gently dipping to flat-lying sandy units. Although the uranium accumulations are similar to roll-front deposits, they are typically, though not invariably, associated with minor erosional unconformities and with accumulations of vegetal or amorphous organic material. Ore rolls may be present; however, the direction of flow of mineralizing ground waters is not readily inferred nor clearly related to the geochemical cell or roll geometry. Primary mineralization is tetravalent. Fluvial to marginal-lacustrine facies are likely hosts, but situations can also be conceived where center-lake accumulations of organic and other fine-grained materials may adsorb, reduce and fix uranium from epigenetic mineralizing waters.

GEOLOGIC SETTING AND RECENT DEPOSITIONAL HISTORY OF SOUTHERN SAN JOAQUIN VALLEY

Figure 1 illustrates the geologic setting of the drainage basin of Kern and Buena Vista Lakes in the southern San Joaquin Valley. Marine deposits accumulated in the southern San Joaquin Valley from late Cretaceous through early Pliocene time. During late Pliocene, the sea withdrew from the area; continued elevation of upland areas and subsidence of the valley from late

Fig. 1 - Interior drainage of Kern and Buena Vista Lakes, generalized geology (from Jennings, 1977) and uranium prospects and mines (from Troxel and Morton, 1962; Goodwin, 1958). Abbreviations: M: Miracle Mine area; O: Owen claim

Pliocene to the present has been accompanied by the accumulation of 8,000 to 10,000 feet of lacustrine, alluvial plain and alluvial fan deposits (Hoots, Bear and Kleinpell, 1954). Kern and Buena Vista Lake Beds are natural sumps for the interior drainage of the southern San Joaquin Valley (Figure 1). Davis and Green (1962) have shown that these lake beds are the sites of structural downwarps where a lacustrine environment was maintained until diversion of the Kern River for irrigation interrupted the principal source of water (Croft, 1972).

During earlier periods of high water, Kern and Buena Vista Lakes overflowed to the north into Goose and Tulare Lakes. Because of diversion of water from the tributary streams for irrigation, the lakes are now dry except following periods of exceptionally heavy precipitation. By analogy with uranium occurrences in lacustrine sediments, conditions may have been favorable for uranium concentration in these lake deposits or connate waters.

Before drainage was controlled by irrigation projects, the Kern River changed its course many times in the San Joaquin Valley. New channels formed during floods because existing channels and distributaries were choked with alluvial debris which had accumulated during low stages (Wood and Dale, 1964). Because of irrigation works and reclamation of formerly inundated lands for agriculture, the drainage pattern in the southern San Joaquin Valley is much different from that which existed under natural conditions. Figure 2 shows the locations of Kern River distributaries from the west edge of the Sierra Nevada to Kern and Buena Vista Lakes. For an unknown period before the flood of 1862, water from the Kern River entered Kern Lake via Old South Fork and overflowed through the connecting slough into Buena Vista Lake. The channel of Old South Fork can be seen in Section 7, T32S, R28E, and channels of other distributaries terminate along the north margin of the lake bed (Figure 2).

Contemporary accounts indicate that the 1861-62 winter was the wettest in the recorded history of the San Joaquin Valley (Grunsky, 1898; Evans, 1944; Boyd, 1972, p. 89 and 156). During the floods of 1861-62, the Old River became the main distributary, and flow was probably equally divided between Kern and Buena Vista Lakes. The present Kern River channel which empties into Buena Vista Lake was formed during the floods of 1867-68 (Grunsky, 1898) and for a time water flowed eastward through the connecting

Modified after California State Engineering Department, 1886

EXPLANATION

- Swamp and overflow lands
- Abandoned river channels and sloughs
- Uplands

Fig. 2 - Map of Kern River delta (from Wood and Dale, 1964) showing major drainage features during pioneer stages of irrigation development and area covered by Fig. 3.

slough into Kern Lake. Since then the river has been controlled in one main channel, and many of the distributaries have been modified for use as irrigation canals.

The Kern River has probably been the principal source of surface water and sediment in Kern Lake. The flow of streams from Wheeler Ridge, south of Kern Lake, and the Temblor Range to the southwest, is usually absorbed by permeable alluvium before reaching Kern Lake. However, these ephemeral streams have caused major flood damage during intense storms; damage during the floods of January and February 1969 totaled \$484,000 (Kern County Water Agency, 1975). Thus the drainage to the south of Kern lake has probably been the source of some coarse sediments along the southern margin of the lake. Gullies in Sections 33, 34 and 35, T32S, R27E (Coal Oil Canyon Quadrangle) may have been the locus of Holocene discharge into Kern Lake from the south.

As indicated in Figure 1, the drainage basin of Kern and Buena Vista Lakes includes 3300 square miles of bedrock composed of granitic, metamorphic, volcanic and consolidated sedimentary rocks. Uranium deposits have been reported from each of the bedrock types (Troxel and Morton, 1962). The most significant uranium occurrence within the drainage basin is in the Miracle Mine area (Figure 1), where a total of 400 tons of uranium ore, ranging in grade from 0.15 to 0.62 percent U_3O_8 , was shipped by November 1957. The uranium occurs in clayey gouge and altered zones in sheared Mesozoic quartz diorite (Troxel et al, 1957).

Following the discovery of the Miracle Mine area, several additional prospects (Figure 1) were found within the Mesozoic basement complex of the southern Sierra Nevada within the Kern-Buena Vista Lakes drainage basin (Troxel and Morton, 1962; Goodwin, 1958). Uranium concentrations also occur in intimate association with Recent and contemporaneous plant material at an elevation of 5000 feet about 6 miles northwest of the Miracle Mine (Bowes et al, 1957). On the eastern flank of the Temblor Range but slightly north of the Buena Vista watershed, secondary uranium minerals, such as autunite, are concentrated in shear zones within middle to upper Miocene marine shale and organically rich paleo soil horizons. Fifty tons of ore containing 0.16 percent U_3O_8 were shipped from the Owen claim near Taft in mid-1956 (Troxel et al, 1957). Other uranium prospects occur in similar

rocks along the southwest side of the San Joaquin Valley within Buena Vista Lake watershed (Troxel and Morton, 1962). The uranium occurrences indicate source areas and the interior drainage since the late Pliocene may have provided suitable conditions for the accumulation of uranium within Kern and Buena Vista Lakes.

FIELD WORK AND SEDIMENTARY FACIES

Field studies included (1) a reconnaissance overflight of Kern and Buena Vista Lakes and the Kern River drainage upstream to the vicinity of Miracle Mine, (2) surface and trench radiometric surveys of Kern Lake, (3) drill hole and trench logging and sampling of Kern Lake, and (4) supplementary sampling at Buena Vista Lake and the slough between Kern and Buena Vista Lakes with a pipe sampler. Field work and sampling were carried out mainly within the Kern Lake Bed. The location of subsurface excavations and radiometric survey transects was based upon the interpretation of drainage patterns and knowledge of the sedimentary facies determined from a prior study (Lamar et al, 1979a); sample locations are shown on Figure 3.

Ground Radiometric Measurements

Field radiometric measurements were made at the surface and in shallow trench excavations with a Geometrics Model GR-410 gamma ray spectrometer. Counts were made for 30 seconds or 60 seconds. These data were reduced to equivalent uranium and thorium using a calibration and stripping ratio derived from standard K-U-T pads at Pelindaba, Republic of South Africa. Equivalent uranium in ppm is shown in Figure 4. Values ranged from 3 ppm to 10 ppm equivalent uranium. No significant correlation between the lake facies and equivalent uranium concentrations can be seen. This result is not surprising because of the recent age of the surface materials. Likewise, no correlations were found between spectrometer readings in trench excavations and lake facies.

Equivalent thorium values shown in Figure 5, however, show a clear increase toward the lake center. Equivalent thorium values range from 10 ppm in the sandy facies to 30 ppm at the lake center. Both the clay fraction and organic carbon increase toward the lake center. Whether either, both or some other factor is controlling the thorium concentration is beyond

Fig. 3 - Distribution of clastic sediments in interval 50-100 cm depth, Kern Lake area. Explanation: fine stipple: silt and clay; medium stipple: interbedded clay, silt and sand; coarse stipple: sand. Numbered dots are locations of trench excavations; numbered triangles are drill hole locations.

Fig. 4 - Equivalent uranium concentrations (ppm) from field radiometric measurements, Kern Lake.

Fig. 5 - Equivalent thorium concentrations (ppm) from field radiometric measurements, Kern Lake.

the scope of the present study and has not been ascertained. A similar apparent concentration of thorium with clay fractions has been observed on the Red Desert, Wyoming (M. McNeil, Bendix Field Engineering Corporation, personal communication, 1979).

Subsurface Excavations

Five drill holes to depths of 10 and 15 m and 48 backhoe pits 2-3 m deep were excavated in and around the Kern Lake Bed. The logs of the excavations are appended to this report. The excavations penetrated soil and interbedded clay, silt and sand. The soil layer is normally about 30 m thick, but in places artificial disruption and mixing reaches depths up to 90 cm where deep plowing has occurred.

Sedimentary Facies

Figure 3 illustrates the distribution of clastic sediments in the depth interval 50-100 cm. This interval was chosen because it was penetrated in most of the pits and lies below zones of soil and cultivation at most locations. In the central and southern portion of the lake, this interval consists mainly of silts and clays, which are commonly massive or mottled with fragments of silt in a clay matrix. Scattered salt crystals are common and pelecypod and gastropod shells are abundant in a few places.

Toward the lake margins, clay and silt grade into interbedded clay, silt and sand. Individual beds range from thin laminae to tens of centimeters in thickness. In the southern part of the lake, notably at Pit 2, liquefaction structures, presumably the result of earthquakes and consisting mainly of diapiric intrusions and load casts, have been described in this nearshore facies (Lamar et al, 1979 ab).

The nearshore facies grades to predominantly sand on the north margin of the lake (distal facies of Kern distributary fan) and around the outlet of Old South Fork. Insufficient excavations were made south of the lake bed to determine the lithology. The sands are mostly very fine-grained or fine-grained, and rarely medium- or coarse-grained. Commonly the sands are massive, but in places faint parallel laminae are observable. Rare small-scale cross bedding, mostly with an amplitude of about 1 cm, was observed in a few pits. Clay rip-ups up to 2 cm in diameter and a few pelecypod and gastropod shells were also noted in the sands.

SAMPLING AND ANALYSIS

Approximately 200 1-kg bag samples were collected from the pits and drill holes. From these, aliquots were selected for laboratory analysis. The samples were selected to represent the principal sedimentary facies within the study area and the different lithologies within individual pits.

Several additional samples were collected with a pipe sampler from the slough between Kern and Buena Vista Lakes and from the margin and center of Buena Vista Lake. In addition, seven water samples were collected from the Kern River east of Bakersfield. Each water sample was acidified at the time of collection.

Grain Size

Aliquots of approximately 4 grams for grain size analysis were soaked for 24 hours in acetone:water (1:1) to disperse. The supernatant was decanted and the sample rinsed three times with distilled water to remove soluble salts. After rinsing, the aliquot was wet sieved (63 μ m screen opening) into a 1000 ml graduated cylinder. The sand fraction that remained on the screen was weighed and set aside for possible later use. Grain size distributions within the sand fractions were not determined.

For determination of the silt and clay fractions subsequent to wet sieving, the graduated cylinder was made up to 900 ml with distilled water, and sodium hexametaphosphate added to preclude flocculation. After standing for 24 hours, as a test for flocculation, the graduated cylinder was made up to 1000 ml and a pipet analysis conducted. Standard procedures were followed for the pipet analysis, except that an abbreviated sampling was used. After agitation, pipet samples were withdrawn at 2 minutes (silt and clay fractions) and at 120 minutes (clay fraction). Normal methods for data reduction described by Folk (1965) were used. Sample locations are shown on Figure 3 and an abbreviated list of these results, which were used in the multivariate analysis, is given in Table 1. Additional results of laboratory analyses are appended to this report.

Mineralogy

The sand fraction of one sample (33-03) with a high uranium content was separated into four magnetic fractions using a Franz Isodynamic Magnetic Separator. The fraction of highest magnetic susceptibility consisted primarily

Table 1 - Results of Laboratory Analyses

A. Results for samples from Kern Lake used in the multivariate analysis

Trench Sample	Depth Below Surface (cm)	U (ppm)	Sand %	Silt %	Clay %	Total Carbon %	Organic Carbon %	Inorganic Carbon %
2-30	135	2.8	59.1	33.4	7.5			
2-39	63	3.5	38.7	43.0	18.3			
2-44	155	2.7	55.9	23.6	20.5			
20-05	150	22.7	1.5	46.9	51.7	0.50	0.45	0.05
21-02	172	2.3	62.3	27.2	10.5			
22-01	161	19.7	0.7	41.7	57.6	0.77	0.75	0.02
24-02	200	12.3	5.9	34.2	59.9	0.54	0.52	0.02
27-02	130	9.9	1.7	36.7	61.5	0.88	0.84	0.04
28-05	110	6.0	6.2	35.2	58.6	0.46	0.46	0.00
31-03	110	6.0	21.5	55.0	23.5	0.24	0.22	0.02
32-01	45	2.4	100.0	00.0	00.0	0.00	0.00	0.00
32-02	85	4.9	93.8	3.5	2.7	0.06	0.00	0.06
33-03	105	21.9	13.1	66.1	20.8	0.78	0.73	0.05
34-03	200	11.4	8.7	50.2	41.1	1.34	0.30	1.04
35-01	10	11.9	39.8	30.6	29.6	1.12	1.05	0.069
35-03	165	6.4	29.6	33.1	37.3	0.54	0.36	0.18
36-03	116	7.8	70.3	22.3	7.4	0.11	0.02	0.09
37-03	90	8.7	58.5	23.3	18.2	0.25	0.25	0.00
40-04	175	5.8	45.6	31.7	22.7	1.71	0.59	1.12
41-03	150	5.8	49.6	37.6	12.8	0.61	0.40	0.21
42-01	10	10.8	58.8	23.9	17.4	1.46	1.44	0.018
42-02	95	17.1	11.2	41.8	47.0	1.13	1.13	0.00
50-01	40	8.4	13.8	81.0	5.1	0.94	0.88	0.063
50-02	140	5.1	31.1	39.1	29.8	0.61	0.35	0.26
51-03	200	6.6	8.7	83.0	8.3			

Table 1, (Continued)

Drill Hole Sample	Depth (ft.)	U	% Sand	% Silt	% Clay	% Total Carbon	% Organic Carbon	% Inorganic Carbon
1-40	40	2.9	45.8	31.7	22.5	0.78	0.40	0.38
3-25	25	4.1	10.1	33.7	56.2	1.30	0.42	0.884
4-05	5	5.9	13.5	25.6	60.9	0.36	0.18	0.18
4-40	40	5.5	17.9	31.7	50.4	1.05	0.36	0.687
5-05	5	5.8	21.7	47.4	30.8	0.71	0.68	0.34
5-40	40	3.8	45.3	30.2	24.5	0.11	0.03	0.085

B. Samples from 5-cm intervals, Kern Lake, Pit 2.
Sample numbers indicate depth in cm below ground surface

Sample	U (ppm)	Sample	U (ppm)	Sample	U (ppm)	Sample	U (ppm)
35	3.7	80	3.4	125	2.5	170	3.6
40	3.6	85	4.7	130	2.5	175	3.7
45	2.8	90	3.7	135	3.7	180	3.8
50	3.5	95	3.0	140	4.3	185	3.8
55	3.6	100	3.9	145	1.8	190	3.7
60	3.8	105	3.6	150	3.4	195	3.5
65	4.1	110	3.3	155	3.9	200	3.6
70	3.2	115	4.0	160	3.4	205	3.9
75	3.3	120	3.0	165	3.6	210	3.7

C. Biotite from sample 33-03

	Uranium (ppm)
Fresh biotite fraction	44.6
Altered biotite fraction	35.1

of biotite. The second and third fractions, which were analyzed by X-ray diffraction, contained biotite, muscovite, chlorite, illite, plagioclase and quartz. The fourth and least magnetic fraction contained quartz and feldspar. Uranium-bearing minerals, such as monazite and xenotime, were not observed. It should be noted, however, that owing to the sensitivity of the X-ray diffraction method, constituents making up less than about 10 percent of the fraction would probably not be detected.

Carbon

For carbon analysis, aliquots of original samples were weighed into LECO crucibles and combusted in the induction furnace, with the resultant CO₂ trapped. Samples for total carbon (organic carbon plus carbonate carbon) were determined separately, with the difference representing the total organic carbon present. Samples for carbon determination were acidified using warm HCl with the evolved CO₂ trapped in the LECO gas lines. Measurements were made by normal LECO procedures. The results for samples from Kern Lake used in the multivariate analysis are given in Table 1A. For the majority of the samples the carbon content is predominantly organic carbon and ranges from an undetectable amount to nearly 1.5 percent. Carbon content in samples from Buena Vista Lake and the interconnecting slough are located on Figure 6 and given in Table 2. Organic carbon in the slough samples, which from their appearance were expected to be rich in organic matter, did not differ significantly from the Kern Lake samples.

Uranium

Uranium concentrations were determined by delayed neutron activation by Uranium West Laboratories, Santa Monica, California. Uranium concentrations for Kern Lake sediment samples are listed on Table 1A and plotted along with sample lithology on Figure 7. Concentrations range from 2 to 23 ppm, the highest values being generally associated with the finer grained facies.

The 36 samples shown in Table 1B were collected at 5 cm intervals from a depth of 35 to 210 cm in Pit 2 (Figure 3). The purpose of these analyses was to determine if there was a consistent relationship between uranium concentration and depth that might be attributed to the application of fertilizers or to a dependence on climatic variation during the past 1000

Fig. 6 - Location of samples from Buena Vista Lake and connecting slough.

Table 2 - Uranium and organic carbon in samples from Buena Vista Lake and slough connecting Kern and Buena Vista Lakes (see Figure 6 for location)

Sample Number	Depth (cm)	U (ppm)	Organic Carbon (%)
1	120-150	8.4	0.7
2	150-180	12.8	0.2
3	140-150	8.7	0.4
4B	30-60	6.4	0.5
4A	60-100	6.5	0.7
4D	100-150	3.8	0.1
5	100-150	19.3	0.5
6B	100	12.3	0.5
7	100-150	5.1	0.3
8	100-180	17.0	1.8
9	100-180	16.6	1.2
10A	100	11.3	1.1
10B	120	3.9	0.2
10C	140-150	4.3	0.2
6C	180-210	2.9	0.0
11	100-120	5.2	0.4
12	100-120	14.7	2.1

Fig. 7 - Uranium concentrations (ppm) and sample lithology plotted on sedimentary facies map.

years as suggested by Kalil (1976). The values are consistently low and no significant variation with depth is apparent.

The uranium concentration was determined for the biotite from sample 33-03 which has a relatively high total uranium content. The sand fraction was separated using the Franz Isodynamic Separator. The fresh biotite fraction (magnetic setting of 0.5 amps and a tilt of 15 degrees) contained 44.6 ppm uranium (Table 1C), and the more altered micaceous fraction (non-magnetic at 0.5 amps but magnetic at 1.0 amps) contained 35.1 ppm uranium.

Uranium content of samples from Buena Vista Lake and the connecting slough are given in Table 2. The values are within the range of the Kern Lake sediments. The slough samples, therefore, are neither enriched significantly in uranium nor in organic carbon.

The water samples were prepared for delayed neutron activation analysis by use of ion exchange resins. One hour was allowed for exchange onto the resins with an estimated yield of 99.9 percent. A millipore filter was used to separate the resin from the water, after which the resin and filter paper were analyzed by delayed neutron activation.

The results of the analyses and the location of the samples are shown on Figure 8. Except for Sample No. 6, collected from Hobo Creek, the concentrations ranged from 0.5 to 1.0 parts per billion uranium. This range is within that for streams in this part of the Sierra Nevada, i.e., 0.1 to 1.0 ppb (D. Carlisle, unpublished data). Samples 1 to 4 are from 6.5 to 34 km downstream from Miracle Mine and the mine dumps on the river bank. Hobo Creek, from which Sample No. 6 was taken, has long been known to contain anomalous uranium concentrations. Yet Sample No. 7, taken in Kern River 30 m below its confluence with Hobo Creek, contains only 0.5 ppb uranium. Streams with anomalous concentrations up to 60 ppb uranium are known in the Sierra Nevada (D. Carlisle, unpublished data), but to our knowledge, no streams with such levels of uranium are known in the Kern River drainage below Lake Isabella.

Distribution of Uranium by Lithologic Facies

Table 3 is a correlation matrix showing all samples from Kern Lake for which uranium concentrations have been determined. Similar matrices

Fig. 8 - Water sample localities. Sample No. 6 is from Hobo Creek; sample No. 7 is 30 m below Hobo Creek. Uranium concentrations, parts per billion, are in parentheses.

Table 3 - Matrix of correlation coefficients (r) of all variables measured and all samples analyzed; number of samples (N) in parenthesis.*

	1	2	3	4	5	6	7
1. Sand (%)	--						
2. Silt (%)	-.827(90)	--					
3. Clay (%)	-.817(90)	.352(90)	--				
4. Total Carbon (%)	-.516(41)	.500(41)	.405(41)	--			
5. Organic Carbon (%)	-.496(50)	.497(50)	.390(50)	.759(41)	--		
6. Inorganic Carbon (%)	-.256(41)	.214(41)	.231(41)	.636(41)	.000(41)	--	
7. Uranium (ppm)	-.513(31)	.356(31)	.386(31)	.207(26)	.483(26)	-.243(26)	--

* At the 95% confidence level r is significant when its absolute value is equal to or greater than: 0.40 when N is 26, 0.37 when N is 31, 0.32 when N is 41, 0.28 when N is 50, and 0.22 when N is 90 (Dixon and Massey, 1969, p. 565).

were prepared using subsets of the data base (Table 4, A and B). These matrices list the correlation coefficient (r) which ideally may vary from -1.0 (inversely correlated) to +1.0 (positively correlated). A coefficient of 0.0 indicates that the two variables are independent. The confidence level used in this report is 95 percent in all cases, and was calculated using procedures outlined by Dixon and Massey (1969).

In Tables 3 and 4, the uranium content shows its highest absolute value of r (-0.513, Figure 9) versus the sand fraction (%) with lesser values of r versus silt (0.356, Figure 10) and clay (0.386, Figure 11) fractions. A plot of combined silt plus clay, or mud fraction, would be a mirror image of the sand fraction (since sand plus mud always equals 100%) and would have a correlation coefficient of +0.513. Since each of the silt and clay fractions by themselves have lower correlation coefficients, this suggests that the uranium is not consistently enriched in either silt or clay.

For the above analysis, uranium concentrations were determined for whole samples prior to separation of sand, silt and clay fractions. In order to ascertain directly whether uranium is preferentially concentrated in the sand, silt or clay fractions, three samples with the highest uranium values were first split into grain-size fractions. The uranium content was determined for the sand and clay fractions which are easily separated. The uranium content of the silt fraction was calculated as indicated on Table 5. An increase in the uranium content with decreasing grain size is apparent.

Geochemical Mode of Uranium Occurrence at Kern Lake

The uranium in the lake sediments may occur either as resistate detrital grains or as authigenic uranium. Authigenic uranium may be loosely adsorbed on fine-grained materials or materials with a high base exchange capacity, such as ferric hydroxide, lignite, montmorillonite, kaolinite and biotite. It may also be present in part as organically complexed hexavalent polymers, such as uranyl humates or fulvates, or it may occur as discrete authigenic uranium minerals. In the present study no discrete authigenic uranium minerals were observed, and the small uranium concentrations of the samples do not suggest their presence.

A strong association between uranium and organic compounds is well

Table 4 - A. Correlation matrix for the 31 samples analyzed
for both uranium and textural characteristics*

B. Correlation matrix for the 26 samples analyzed
for uranium, texture and organic carbon *

A.

N=31	1	2	3	4
1. Sand (%)	--			
2. Silt (%)	-.687	--		
3. Clay (%)	-.759	.048	--	
4. Uranium (ppm)	-.513	.356	.386	--

B.

N=26	1	2	3	4	5
1. Sand (%)	--				
2. Silt (%)	-.706	--			
3. Clay (%)	-.806	.151	--		
4. Organic Carbon (%)	-.356	.379	.180	--	
5. Uranium (ppm)	-.476	.436	.301	.483	--

* At the 95% confidence level r is significant when its absolute value is equal to or greater than:
0.40 when N is 26, and 0.37 when N is 31 (Dixon and Massey, 1969, p. 565).

Fig. 9 - Bivariate plot, uranium (ppm) vs. sand (%). Uranium-rich samples, determined by multiple regression analysis described in a later section of report, are circled. The same samples are also circled on Figs. 11 and 12. The plotted numbers (1,2) indicate the number of values plotting at that point. "N" is the total number of samples. "COR" is the correlation coefficient (r). The mean and standard deviation, as well as the regression lines, are given for the X and Y variables. The regression lines are indicated by Y's on the borders of the graph for the equation of Y as a function of X and by X's for the equation of X as a function of Y.

Fig. 10 - Bivariate plot, uranium (ppm) vs. silt (%).
Uranium-rich samples from Fig. 9 are
circled. See Fig. 9 for explanation.

Fig. 11 - Bivariate plot, uranium (ppm) vs. clay (%).
Uranium-rich samples from Fig. 9 are
circled. See Fig. 9 for explanation.

Table 5 - Uranium content in sand, silt and clay fractions of three high-uranium samples. All values were determined by laboratory analysis, except f, which was calculated from $f = \frac{d-ae-cg}{b}$.

Sample	Size Fractions Expressed as Decimals			Total U ppm d	U Concentration (ppm) in Each Fraction		
	Sand a	Silt b	Clay c		Sand e	Silt f	Clay g
35-01	.398	.306	.296	11.9	4.9	10.8	22.5
33-03	.131	.661	.208	21.9	11.7	20.7	32.1
42-02	.112	.418	.470	17.1	10.5	11.6	23.6

documented and has been reviewed by Kolodny (1969). Some black shales, for example, contain 100 to 200 ppm uranium. The uranium in black shales, coals, and soils is associated with the alkali organic fraction humic acids. At sea water pH values, uranium is strongly bound by fulvic acids. As in the case of iron hydroxides, phosphorites and clays, the maximum adsorption of uranium on organic matter occurs in the pH range of 5-6. Whether the uranium-organic matter association is a result of adsorption or the formation of uranyl humates and fulvates has not been resolved (Kolodny, 1969).

Laboratory tests were performed on Kern Lake sediment samples to determine the proportion of detrital and authigenic uranium, and whether the authigenic uranium is organically complexed or adsorbed. The procedures used were essentially those of Kolodny (1969). Authigenic uranium, including that which is organically complexed or adsorbed, is separable from detrital uranium by leaching. Two successive leaches are required. The first, an acid leach, separates the adsorbed uranium from the sample. The second leach oxidizes all organic matter in the sample, and liberates uranium that may be organically complexed. Uranium contained in discrete authigenic uranium minerals, if any, may be present in one or the other leachate. The final residue is assumed to contain only detrital uranium.

The sample is first leached with 500 ml 1N HCl made 0.25M in hydroxylamine hydrochloride ($\text{NH}_2\text{OH}\cdot\text{HCl}$). A 1000 ml Erlenmeyer flask is used in an ice bath and nitrogen atmosphere to prevent oxidation. After one hour, the sample is filtered using an 0.5 micron millipore filter, with the filtrate containing the adsorbed uranium in the sample.

The residue from the hydroxylamine hydrochloride leach is washed with distilled water and then leached with 250 ml of 30 percent hydrogen peroxide, added slowly to prevent violent oxidation. The reaction is carried out under an ultraviolet light for 48 hours. The mixture is filtered and washed with the filtrate containing the organically complexed uranium. The residue from the second leach is assumed to contain the detrital uranium fraction of the sample. The procedure is shown diagrammatically in Figure 12.

A number of assumptions are inherent in the analytical process depicted on Figure 12. The most important assumption is that the first two leachates contain all authigenic uranium, and the residue contains all of the detrital

Fig. 12 - Flow diagram of uranium leach analyses; DNAA: delayed neutron activation analysis.

uranium. Discrete authigenic uranium minerals are assumed in this instance to be absent or of minimal importance. It is possible that some uranium may have been leached from detrital minerals during the two leaching processes. However, based on studies by Gad and LeRiche (1966) the amount is considered insignificant.

It is further assumed that uranium leached by hydroxylamine hydrochloride is derived mainly from two sources: (1) the uranium adsorbed on organic matter and clays which is released by the strong acidity of the reagent, and (2) tetravalent uranium hydroxide which, if present, will dissolve in 1N HCl.

The hydrogen peroxide leach destroys organic material and pyrite. From the standpoint of uranium mass balance, only the oxidation of the organic material is important. It may be argued that the hydrogen peroxide leachate also includes uranium solubilized by oxidation of insoluble tetravalent and hexavalent uranium. However, it is reasonable to assume that all the tetravalent uranium, if present as a hydroxide or oxide, was dissolved in the acid leach. An additional uncertainty in the discrimination of organically bound and adsorbed uranium is discussed in the next section.

Ten representative samples, including the six with the highest uranium concentrations, were selected for leaching. The results of the leaching tests are listed in Table 6 and summarized on the trivariate diagram (Figure 13). Total authigenic fraction ranges from 50.28 to 82.3 percent. Adsorbed uranium predominates; it ranges from 1.4-11.4 ppm with a mean of 5.17 ppm. Organically complexed uranium ranges from 0.02-3.85 ppm with a mean of 0.96 ppm, and detrital uranium ranges from 0.05-5.35 ppm, with a mean of 3.48 ppm.

Statistical Evaluation of Detrital versus Authigenic and Organically Bound vs. Adsorbed Uranium

Statistical treatment of the data provides additional insight into the occurrence of uranium in Kern Lake sediments. The matrix of correlation coefficients for samples analyzed for adsorbed, organic and detrital uranium is shown in Table 7. Total authigenic uranium (sum of adsorbed and organically bound uranium) was also considered in the analysis.

Table 6 - Results of Sample Leaching

Sample Number	Depth (cms)	Authigenic U Adsorbed Fraction (%)	Organic U Fraction (%)	Residual U Detrital Fraction (%)	% Sand	% Silt	% Clay	Total U (ppm)	Ads. (ppm)	Org. (ppm)	Detr. (ppm)	% Organic Carbon
35-01	10	70.5*		29.6	39.8	30.6	29.6	11.9	8.4*		3.52	1.05
22-01	161	58.1	19.6	21.8	0.7	41.7	57.6	19.6	11.4	3.85	4.28	0.45
24-02	200	48.8	11.9	39.3	5.9	4.2	59.9	12.3	6.01	1.46	4.84	0.52
20-05	150	82.2*		17.7	1.5	46.9	51.7	22.6	18.6*		4.03	--
42-02	95	74.3*		25.7	11.2	41.8	47.0	17.1	12.7*		4.41	1.13
42-01	10	50.1	0.14	49.7	58.8	23.9	17.4	10.8	5.4	0.02	5.35	1.44
36-03	116	60.8	0.19	38.8	70.3	22.3	7.4	7.76	4.73	0.03	3.01	0.02
32-01	45	59.1	4.9	35.9	≈100	0	0	2.38	1.40	0.13	0.85	0.00
32-02	85	52.3	0.4	47.3	93.8	3.5	2.7	4.88	2.55	0.03	2.30	0.02
37-03	90	75.8	2.43	19.7	58.5	23.3	18.2	8.17	4.69	1.17	2.30	0.00

* Authigenic fraction not separated.

Fig. 13 - Trivariate plot of the uranium distribution in adsorbed, organic and detrital fractions of six samples.

Table 7 - Matrix of correlation coefficients for samples analyzed for adsorbed, organic and detrital uranium fractions. Unless otherwise noted, N equals 9.^c

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Uranium	--												
2. Sand	-.897	--											
3. Silt	.946	-.963	--										
4. Clay	.825	-.983	.897	--									
5. Organic Carbon	.671 ^b	-.467 ^b	.564 ^b	.825 ^b	--								
6. Adsorbed and Organic U (%)	.728	-.689	.706	.649	.074 ^b	--							
7. Adsorbed U (%)	-.297 ^a	.263 ^a	-.151 ^a	-.319 ^a	-.612 ^a	.570 ^a	--						
8. Organic U (%)	.665 ^a	-.822 ^a	.691 ^a	.864 ^a	-.008 ^a	.852 ^a	.056 ^a	--					
9. Detrital U (%)	-.726	.690	-.706	-.649	-.068 ^b	-1.000	-.572 ^a	-.851 ^a	--				
10. Adsorbed and Organic U (ppm)	.981	-.862	.907	.794	.547 ^b	.831	-.075 ^a	.824 ^a	-.829	--			
11. Adsorbed U (ppm)	.981 ^a	-.921 ^a	.979 ^a	.847 ^a	.442 ^a	.513 ^a	-.117 ^a	.698 ^a	-.517 ^a	.980 ^a	--		
12. Organic U (ppm)	.770 ^a	-.875 ^a	.783 ^a	.893 ^a	.061 ^a	.817 ^a	.023 ^a	.979 ^a	-.818 ^a	.909 ^a	.809 ^a	--	
13. Detrital U (ppm)	.633	-.638	.678	.583	.791 ^b	-.010	-.688 ^a	.079 ^a	.012	.472	.630 ^a	.187 ^a	--

^a N = 6

^b N = 8

^c At the 95% confidence level, r is significant when its absolute value is equal to, or greater than: 0.82 when N is 6, 0.71 when N is 8, and 0.67 when N is 9 (Dixon and Massey, 1969, p. 565).

Uranium in these fractions is shown both as a percentage of total uranium in the sample and as uranium in ppm. Uranium in percent and uranium in ppm are not simply related, because uranium percent is a function of fraction size and ppm values are not.

The matrix (Table 7) shows that the uranium ppm values for each fraction (adsorbed, organic, detrital) all have positive correlation coefficients with the total uranium. As uranium content increases, so does each fraction in ppm (Figures 14-17). When the percentage of total uranium is considered, the organic fraction shows a positive correlation whereas the adsorbed and detrital fractions show negative correlations with uranium content (Figures 18-21). Owing to the above, the uranium ppm value shows no correlation with the uranium percent value for both the adsorbed fraction ($r = -.117$) and the detrital fraction ($r = .012$).

In this analysis, a great number of the independent variables are strongly dependent upon one another. Silt and clay show a strong positive correlation (Table 7, $r = .897$), and because sand is the complement of combined silt and clay, sand is negatively correlated with each ($r = -.963$ and $-.983$, respectively). Organic carbon is positively correlated with clay content (.825). A correlation of organic carbon with the finer sized sediments has been known since Trask (1932) and has been shown by many other workers more recently (Thomas, 1969; Kemp, 1971; Folger, 1972; Gross et al, 1972; Pinet and Frey, 1977; Anderhalt and Reed, 1978).

Organically bound uranium shows a poor correlation with organic carbon but correlates well with clay (Table 7). It also has a positive correlation with silt, but this may be only an indirect function owing to the correlation of silt with clay. The distinction between organically bound and adsorbed uranium may be largely an artifact, because much of the organic matter in sediments is adsorbed on mineral surfaces (Muller and Suess, 1977; Meyers and Quinn, 1971, 1973). The leaching procedure which removed the adsorbed uranium will have also removed adsorbed organic matter. This adsorbed organic matter may also have had some uranium complexed with it and is probably a significant factor in explaining the lack of correlation between organically bound uranium and organic carbon.

Although the adsorbed fraction (ppm) actually shows a slightly higher

Fig. 14 - Bivariate plot, adsorbed plus organically bound uranium (ppm) vs. total uranium (ppm). See Fig. 9 for explanation.

Fig. 15 - Bivariate plot, adsorbed uranium (ppm) vs. total uranium (ppm). See Fig. 9 for explanation.

Fig. 16 - Bivariate plot, organically bound uranium (ppm) vs. total uranium (ppm). See Fig. 9 for explanation.

Fig. 17 - Bivariate plot, detrital uranium (ppm) vs. total uranium (ppm). See Fig. 9 for explanation.

Fig. 18 - Bivariate plot, adsorbed plus organically bound uranium (%) vs. total uranium (ppm). See Fig. 9 for explanation.

Fig. 19 - Bivariate plot, adsorbed uranium (%) vs. total uranium (ppm). See Fig. 9 for explanation.

Fig. 20 - Bivariate plot, organically bound uranium (%) vs. total uranium (ppm). See Fig. 9 for explanation.

Fig. 21 - Bivariate plot, detrital uranium (%) vs. total uranium (ppm). See Fig. 9 for explanation.

correlation and a steeper regression line with silt content than with clay content, it probably is more logical to view the adsorption of uranium as an indirect function of silt content also, and a more direct function of clay content in light of the increased surface area and cation exchange capacity of clays (Grim 1968).

For the size fractions, the detrital uranium fraction (ppm) shows its strongest correlation with the silt content. This is likely due to an enrichment of uraniferous minerals in the silt fraction. Detrital uranium actually shows a slightly stronger correlation with organic carbon.

Uranium in Biotite

The biotite from the sand fraction of sample 33-03 was found to contain 45 ppm uranium for the fresh biotite and 35 ppm uranium for altered biotite. Biotite is estimated to comprise 20-25 percent of the sand fraction for that sample. The uranium per equivalent weight of the sand fraction is 11.7 ppm (Table 5); therefore, most of the uranium in the sand fraction of that sample is contained in the biotite.

The uranium in the biotite may occur (1) within the crystal structure of the biotite, (2) in inclusions, such as zircon, sphene, and allanite, which are common in biotite (Heinrich, 1965) or (3) adsorbed on the biotite, for example, as organically complexed uranium. Larson and Gottfried (1961) reported uranium analyses from 21 biotites separated from plutonic rocks, mostly from California. Only 7 of the 21 exhibited more than 10 ppm uranium, and only 2 showed more than 20 ppm. By comparison, the uranium content of biotite from sample 33-03 is high.

Some portion of uranium in the biotite may be complexed by organic matter adsorbed on the biotite. Both fresh biotite and its alteration products effectively adsorb organic matter. For example, a sand fraction from a sediment sample collected offshore from Oceanside, California was magnetically separated in a similar way to that used for sample 33-03. The more magnetic fraction contained 2 percent organic carbon and the less magnetic fraction contained 5 percent organic carbon (R. Anderhalt, unpublished data). Further investigation of the biotite was considered beyond the scope of the present study, but the high uranium content of the biotite may help to explain the better correlation of both adsorbed and detrital uranium with the silt fraction, which is likely to contain appreciable biotite, and also the unexpectedly high correlation between

detrital uranium and organic carbon.

Multiple Regression Analysis

In multiple regression an equation is calculated which is similar to the equations shown in the bivariate plots (Figures 9-11, 14-21) except that terms for additional variables are added. The equation can be used to predict a value for a dependent variable, in this case uranium. The predicted value of uranium for a sample can be subtracted from its observed value to give a residual. Because the predicted is subtracted from the observed, a positive residual indicates a sample has more uranium than predicted, or that it is more uranium-rich than would be expected based upon a consideration of the measured independent variables. Conversely, when a residual is negative, it may be considered uranium poor.

Residuals are shown (Table 8) for all samples on which uranium was measured with two different groups of independent variables: one in which the textural variables (sand, silt and clay) are used; and the other when the textural variables are used in conjunction with organic carbon. In both cases, the clay content was found to explain no additional variation that could not be explained with the other variables and it does not appear in the equations at the bottom of Table 8. Correlation matrices for the variables and samples used in these regressions are shown in Table 4, A and B.

Two groups of residuals can easily be discriminated: positive, or uranium-rich, and negative, or uranium-poor. In both regressions shown, all samples which are positive on textural regression are also positive on texture plus organic carbon regression with the lone exception of sample 42-01 (Table 8). This sample is relatively rich in organic carbon (1.44%) which caused a large increase in the predicted uranium content and a negative residual. Otherwise, the two sets of residuals are in very good agreement. The 12 samples which have a positive residual based upon the texture data are the same 12 samples which plot above the regression line in the sand versus uranium bivariate plot (Figure 9). To determine if there was an observable pattern to the residuals, the residuals were plotted on a map of the sample locations (Figure 22). Even though the uranium content of these sediments is low on an absolute basis, there is

Table 8 - Residuals for the multiple regression of uranium with texture data and texture data plus organic carbon; N = number of samples.

Trench Samples	Texture (N=31) ^a	Texture and Organic Carbon (N=26) ^b
2-30	-2.59	--
2-39	-4.05	--
2-44	-3.00	--
20-05	11.25	11.92
21-02	-2.74	--
22-01	8.18	7.45
24-02	1.34	1.87
27-02	-2.20	-3.28
28-05	-4.93	-4.13
31-03	-3.38	-2.73
32-01	1.37	1.34
32-02	3.21	3.05
33-03	11.62	9.52
34-03	0.70	1.70
35-01	4.50	0.65
35-03	-2.08	-1.80
36-03	3.61	4.13
37-03	3.27	3.09
40-04	-1.00	-2.69
41-03	-0.59	-1.67
42-01	5.40	-1.23
42-02	6.68	3.39
50-01	-1.84	-5.32
50-02	-3.23	-3.19
51-03	-4.18	--
Drill Samples		
1-40	-3.88	-4.55
3-25	-6.42	-5.54
4-05	-4.24	-1.94
4-40	-4.20	-3.30
5-35	-3.54	-5.11
5-40	-3.03	-1.63

^a $U = 11.50 - (0.105 \times \text{sand}) + (0.002 \times \text{silt})$
 $r = 0.513$ (Significant at 95% confidence level).

^b $U = 6.65 - (0.056 \times \text{sand}) + (0.038 \times \text{silt}) + (5.39 \times \text{organic carbon})$
 $r = 0.588$ (Significant at 95% confidence level).

Fig. 22 - Uranium residuals (observed minus predicted) from multiple regression. Area covered is the same as that in Fig. 3 and Fig. 7.

a pattern of occurrence (Figure 22) in which these samples are relatively enriched. Samples collected from the northern sandy facies (Figure 3) show somewhat higher than predicted uranium concentrations. This may reflect a higher proportion of detrital uranium ($\geq 30\%$), as indicated in Table 6 and shown on Figure 23. The two samples near the lake center show a positive uranium enrichment (Figure 22), yet possess a lower proportion ($\geq 20\%$) of detrital uranium (Figure 23). The positive enrichment of these two may represent a higher proportion of adsorbed or complexed uranium. Even at lower lake levels, these sites would still be submerged and the amount of adsorbed uranium should positively correlate with the length of time in which the sediment is in contact with the lake water. Conversely, the lake margin is exposed during the lower lake levels and is not as likely to contain as much adsorbed uranium. Moreover, the higher proportion of detrital uranium in the northern samples (Figure 23) may reflect influx from the Kern River source.

In Table 4A a correlation matrix of uranium and the textural parameters was presented for the 31 samples for which these data were available. The strength of these correlations may be obscured by the combination of more than one group of samples which differ with respect to their depositional environment and other factors influencing their uranium content. Table 9 shows the correlation matrices of uranium and textural data for the two groups previously described, the uranium-rich samples ($N = 12$), and the uranium-poor samples ($N = 19$). Although the correlation coefficients are not significantly improved, if all samples (Table 4A; $N = 31$) are compared with the uranium-poor groups, a substantial improvement appears in the uranium-rich group. In Table 9A (uranium-rich group) strong correlation coefficients are characteristic for uranium content vs. sand, silt and clay, and indicate that uranium content is more strongly correlated with the finer grain sizes, silt and clay, in the uranium-rich group (the circled points in Figures 9-11). Since the grain size statistics all correlate so well with one another, it is difficult to determine from a correlation matrix (Table 9) or from bivariate plots (Figures 9-11) which parameter exerts the strongest control. Because of the high cation-exchange capacity and high surface area of the clay minerals, the clay fraction should have the most direct control on uranium content of any of the size fractions.

Fig. 23 - Map showing percent detrital uranium and percent organic uranium (values in parentheses) for leached samples (from Table 7) and sedimentary facies. Area shown is same as that in Fig. 3 and Fig. 7.

Table 9 - Correlation matrices for uranium-rich
and uranium-poor groups^b

A. Uranium-rich group

N=12	1	2	3	4	5
1. Sand	--				
2. Silt	-.893	--			
3. Clay	-.917	.693	--		
4. Organic carbon	-.426	.396	.377	--	
5. Uranium	-.867	.881	.701	.479	--

B. Uranium-poor group

N=19	1	2	3	4	5
1. Sand	--				
2. Silt	-.442	--			
3. Clay	-.661	.417	--		
4. Organic carbon	-.374 ^a	.535 ^a	-.083 ^a	--	
5. Uranium	-.755	.519	.316	.680 ^a	--

^a N=14

^b At the 95% confidence level (r is significant when its absolute value is equal to or greater than: 0.58 when N=12, 0.53 when N=14, and 0.46 when N=19 (Dixon and Massey, 1969, p. 565)).

Organic carbon shows a much poorer correlation with uranium ($r = .479$).

The uranium-poor group shows correlations with uranium content which are weaker than the uranium-rich group. The weaker correlation may be due to location of the uranium-poor samples near the lake margin where sub-aerial exposure after deposition, and mixing and alteration of different depositional environments, such as lake margin and beach with alluvial facies could result in greater variability in uranium content.

CONCLUSIONS

Kern Lake has served as a sink for drainage from the southern Sierra Nevada and, in lesser amounts, from the southern Temblor Range. Both areas contain significant uranium source rocks. The uranium content in Holocene Kern Lake sediments correlates best with the mud (silt and clay) fraction. It correlates less well with organic carbon. Biotite grains could account for much of the uranium in the sand fraction, and perhaps the silt fraction as well. The data suggest that fixation of uranium by adsorption on mineral grains is a dominant process in this lake system. Further work is required to determine the importance of cation-exchange of uranium on clays and micas and of organically complexed uranium adsorbed to mineral surfaces. These findings also raise the question of whether uranium transport down the Kern River occurs largely as uranium adsorbed to mineral surfaces.

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Boone, J.L., 1978, Lacustrine depositional systems of Dockum Group in Tule Canyon, Texas Panhandle (abs.): Amer. Assoc. Petroleum Geologists Bull., vol. 62, p. 499.

The Dockum Group of Upper Triassic age is characterized by a generally fining-upward or transgressive lake-margin deposits. Depositional systems represented in the sequence include a basal fan-delta system, a conglomerate valley fill, a coarse-grained meander-belt fluvial system, and imbricated lacustrine deltaic systems. The Dockum Group is a target for uranium exploration, and the results of this study may help to narrow the search to certain facies or parts of the stratigraphic section that exhibit the greatest host-rock potential.

Bowes, W.A., W.E. Bates and G.M. Haselton, 1957, Geology of the uraniferous bog deposit at Pettit Ranch, Kern County, California: U.S. Atomic Energy Commission, RME-2063 (Pt. 1).

Uranium associated with peat humus occurs in a boggy meadow in the Sierra Nevada. The uranium is confined to organic material and probably exists as a metallo-organic complex. The bog is presently accumulating in a fault-depressed area continuously moistened by a series of springs. The spring waters contain an average of 0.11 ppm uranium, over 10 times that of local drainage waters. The radioactive material is characterized by extremely low gamma radioactivity which may be due to the recent emplacement of uranium by spring waters.

Carlisle, D., 1978, The distribution of calcretes and gypcretes in southwestern United States and their uranium favorability based on a study of deposits in Western Australia and South West Africa (Namibia): Final report for U.S. DOE under subcontract No. 76-022E between Bendix Field Engineering Corp. and Univ. of California, Los Angeles, 274 p.

Probable economic uranium mineralization in lacustrine and marginal fluvial deposits has been discovered in Western Australia at North Lake Way and Lake Maitland. Precipitation of carnotite occurs entirely in an oxidizing environment. Changes in pH and increased concentration of potassium and vanadium in ground water and salt lake margins may control carnotite

precipitation. Changes in partial pressure of CO_2 and evaporite concentration in areas of constricted flow where waters are forced close to the surface may also influence carnotite precipitation.

Childers, M.O. and R.V. Bailey, 1977, Applied mineral exploration with special reference to uranium: Westview Press, Boulder, Colorado, 542 p.

Carbonaceous shales which represent mudflats and shallow nearshore lacustrine muds of Tipton and Laman age in the area southeast of Oregon Buttes (northwest of Great Basin Divide) contain anomalous amounts of uranium disseminated over a large area. Field relations suggest a syngenetic origin. Drill data indicate that uranium is isolated in impermeable strata.

Culbert, R.R. and D.G. Leighton, 1978, Uranium in Alkaline water - Okanagan area, British Columbia: Can. Inst. Min. Met. Bull., vol. 71, no. 793, p. 103-110.

Uranium concentrations of several ppm are present in alkaline lake and stream waters. Uranium content is controlled by bicarbonate content and sediment composition. Young, near-surface, uranium deposits in disequilibrium with daughter products are forming from these uraniferous lake waters.

Cupp, C.M., S.H. Leedom, T.P. Mitchell and D.R. Allen, 1977, Geology, uranium deposits, and uranium favorability of the Hartford Hill Rhyolite and Truckee formation, southwestern Washoe County, Nevada, and eastern Lassen County, California: Bendix Field Engineering Corp., GJBX-16 (77).

Uranium occurrences in fluvial and lacustrine sediments of Tertiary basins of Nevada are described at six localities: Virgin Valley area (Virgin Valley formation), northern Reese River (Truckee formation), East Walker River area (Aldrich Ranch, Coal Valley, and Morgan Ranch formation), Carol "R" prospect (Esmeralda formation), Coaldale area (Esmeralda formation) and Meadow Valley area (Panaca formation). A principal role may have been played by water released during diagenesis and ground water, which leached uranium from Tertiary volcanic rocks. Lacustrine sediments provided a variety of environments for possible supergene uranium deposits.

Davis, D.L. and D.L. Hetland, 1956, Uranium in clastic rocks of the Basin and Range Province: Proc. Intern. Conf. on the peaceful uses of atomic energy, vol. 6, Geology of Uranium and Thorium, p. 387-391.

Uranium minerals occur in bentonitic clay beds in the tuffaceous horizon of the late Pliocene or early Pleistocene lacustrine sediments of the Coso formation. The uranium may have been deposited syngenetically with the tuffaceous material and later leached by ground water and reprecipitated in the bentonitic clay beds.

Finch, W.I., 1967, Geology of epigenetic uranium deposits in sandstone in the United States: U.S. Geol. Survey Prof. Paper 538, 121 p.

Table 3 lists lacustrine formations of the United States known to contain uranium.

Galloway, W.E., 1978, Catahoula Formation of the Texas Coastal Plain: depositional systems, composition, structural development, ground-water flow history, and uranium distribution: Bendix Field Engineering Corp., GJBX-125 (78).

Uranium occurrences in Texas coastal plain fluvio-lacustrine system are described. Oxidizing uranium-enriched ground waters enter in areas of recharge and deposit uranium where geochemical and/or sedimentary facies changes occur.

Gladney, E.S., J.W. Owens and J.W. Starner, 1976, Determination of uranium in natural waters by neutron activation analysis: Analytical Chemistry, vol. 48, p. 973-975.

A rapid procedure has been developed for the measurement of uranium in natural waters using thermal neutron activation and anion-exchange separation of radio-uranium from ethanol/HCl solvent mixtures. Detection limits of 0.05 ppb have been achieved with analytical precisions of plus or minus 10-30%. Results of uranium analyses by this procedure and by fluorometry are compared for natural water samples from Alaska and New Mexico. (Auth)

Hayashi, S., 1970, Uranium occurrences in small sedimentary basins in Japan: Proc. of a panel on uranium exploration geology, Vienna, 13-17 April 1970, Intern. Atomic Energy Agency, Vienna, p. 233-241.

Uranium deposits occur in Neogene Tertiary sediments containing carbonaceous material at lake margins deposited from uranium-bearing waters originating in basement rocks.

Hayashi, S., 1974, Uranium occurrences in small sedimentary basins in Japan, in Formation of uranium ore deposits: Proc. of a symposium, Athens, p. 233-241.

Uranium occurrences in lacustrine deposits in Japan are described. Mode of uranium deposition is poorly understood.

Hetland, D.L., B.J. Sharp and R.O. Warner, 1969, Uranium deposits in Oligocene, Miocene and Pliocene sediments west of the Rocky Mountains: Soc. Mining Eng., Amer. Inst. Mining, Met. and Pet. Engineers, preprint no. 69-I-322.

Carnotite deposits in tuffaceous lake beds of the Pliocene Panaca formation and earlier beds up to 1400 feet (427 meters) thick are described.

Holder, B.E., 1975, LLL uranium hydrogeochemical survey project highlights for July, 1975: Lawrence Livermore Lab., UCID-16883, 7 p.

Status of the LLL hydrogeochemical survey of Winnemucca Lake, Smoke Creek Desert, Cave Valley and Roach Lake basins in Nevada is reported. About 100 sediment samples were taken from alluvial fans and dry stream channels of Walker Basin. Preliminary survey analyses were performed on 24 samples from Walker River and its tributaries.

Hostetler, P.B. and Garrels, R.M., 1962, Transportation and precipitation of uranium and vanadium at low temperatures, with special reference to sandstone-type uranium deposits: Economic Geology, vol. 57, p. 137-167.

Uranium and vanadium in sandstone-type deposits of the western United States apparently have been transported to their present environment from external sources by low-temperature aqueous solutions. In this paper an attempt is made to interpret the characteristics of aqueous solutions capable of transporting significant quantities of uranium and vanadium through

continental sedimentary rocks, and the changes in these characteristics that might result in precipitation of uraninite and other ore minerals in concentrations of ore grade. On the basis of present knowledge, the transportation environment is shown to be that of weakly alkaline, moderately reducing ground water, with an average or larger than average concentration of dissolved carbonate species. Precipitation is induced by reduction, probably by carbonaceous material or hydrogen sulfide, or both. Uranium is transported mainly in the form of the highly stable uranyl dicarbonate and tricarbonato complexes. Precipitation results from reduction of hexavalent aqueous uranium species to form uraninite, reduction of tetravalent vanadium to form montroseite, and fixation of uranyl ions by combination with potassium ions and quinquivalent vanadium to form the mineral carnotite. (Auth)

Jones, C.A., 1978, A classification of uranium deposits in sedimentary host rocks: 1977 NURE Uranium Geology Symposium, Abstracts and Visual Presentations, Bendix Field Engineering Corp., GJBX-12 (78). See also Mickel, 1978.

Uranium deposits in sedimentary rocks are divided into two groups, syngenetic and epigenetic. Syngenetic deposits are formed contemporaneously with deposits of the enclosing sediment; they include detrited uranium minerals and uranium adsorbed or absorbed at the sediment-water interface. Epigenetic deposits are formed by the precipitation of uranium from solutions moving through pre-existing rock or previously deposited sediment. Source of the uranium may be connate water, meteoric water or hydrothermal solutions.

Kalil, E.K., 1976, The distribution and geochemistry of uranium in Recent and Pleistocene marine sediments: Univ. of California, Los Angeles, Ph.D. Thesis.

Uranium highs correspond to glacial periods in recent marine and non-marine sediments in California. Highs at 300 and 1000 years B.P. relate to stages of the Little Ice Age.

Levinson, A.A., C.J. Bland and G.R. Parslow, 1978, Possible pitfalls in the search for uranium deposits using lake sediments and lake water: Can. Inst. Min. Met. Bull., vol. 71, no. 796, p. 59-62.

The organic-rich sediments from the centers of Canadian lakes are a valuable sampling medium in the search for uranium. However, because of the young age of hydromorphically transported uranium in these sediments, which must post-date the last period of glaciation, there has been insufficient time for the isotope ^{214}Bi to reach equilibrium with the ancestor ^{238}U . This results in equivalent uranium (eU) values significantly lower than actual uranium values determined by fluorometry or delayed neutron activation analysis.

Lowell, J.D., 1955, Applications of cross stratification studies to problems of uranium exploration, Chuska Mountains, Arizona: *Economic Geology*, vol. 50, p. 177-185.

Uranium ore bodies in the lower part of the Morrison formation of Jurassic age in the Chuska Mountains area in northeastern Arizona are elongated in the direction of ancient stream channels. Intersections of ancient stream systems appear to be favorable loci for the deposition of uranium ore. These stream directions and intersections can be reconstructed and projected by mapping and analysis of cross-stratification. Mineral-bearing solutions appear to have followed networks of paleochannel scour-fills, moving through them along the path of greatest permeability. Where the velocity of the moving solutions was reduced by especially permeable rocks, uranium ore was deposited, provided that a suitable geochemical environment existed. (Auth)

MacDonald, J.A., 1968, Lake water, a guide to uranium: *Can. Mining Jour.*, vol. 89, p. 89-90, 99-100 (April).

The hydrochemical survey in the Beaverlodge area of Canada indicates that zones of secondary uranium mineralization can readily be delineated by lake water sampling. Because the secondary migration of uranium is greatly enhanced in a carbonate-rich environment, pH and bicarbonate determinations provide necessary criteria for establishing the significance of uranium assay results. The specific conductance of surface waters can provide a useful, though indirect, guide to areas of mineralization. (Auth)

Mankiewicz, P.J., 1975, An organic geochemical investigation of a glacial sequence at Searles Lake, California: Univ. of California, Los Angeles, M.S. Thesis, 122 p.

Uranium concentration is both a function of stratigraphic position and carbonate mineralogy. Higher concentrations are found in samples containing greater amounts of pirssonite and aragonite. Low uranium values occur in samples containing gaylussite and in samples containing abundant halite. Dolomite appears intermediate in its relationship to uranium content.

Mapel, W.J. and W.J. Hail, Jr., 1959, Tertiary geology of the Goose Creek District, Cassia County, Idaho; Box Elder County, Utah; and Elko County, Nevada: U.S. Geol. Survey Bull. 1055-H, p. 217-254.

Uranium is believed to have been derived from volcanic ash and concentrated in carbonaceous lake beds of the Pliocene Salt Lake formation.

Mickle, D.G. (ed.), 1978, A preliminary classification of uranium deposits: Bendix Field Engineering Corp., GJBX-63 (78).

Most uraniferous non-marine carbonaceous rocks were deposited in structural basins, at least in the western United States; most are stratigraphically associated with tuffs or tuffaceous sedimentary rocks or are within the drainage basin of rocks known or likely to contain uranium. Origin of uranium has been attributed to precipitation from uraniferous ground water (epigenetic), concentration by plant material (syngenetic) or precipitation from hydrothermal solutions. The only known economic evaporative precipitates are the Australian calcrete deposits, but hypothetical possibilities include Sabkha and playa deposits. Epigenetic uranium is also known from lacustrine sandstones. The presence of mudstone and organic material is an important criterion. The mudstone slows or acts as a barrier to groundwater movement; organic material is the reducing agent.

Mickle, D.G. and G.W. Mathews (eds.), 1978, Geologic characteristics of environments favorable for uranium: Bendix Field Engineering Corp., GJBX-67 (78).

Lacustrine facies may be associated with the uranium-bearing lignites of the Paleocene Fort Union formation of the Williston basin, deposited in a coastal flood-plain environment. Uranium mineralization was probably

supergene (epigenetic). Uranium originally held by volcanic ash in overlying Oligocene and Miocene formations may have been leached by ground water and carried downward to underlying lignites.

Myerson, B.L., 1956, Uranium occurrence near Panaca, Lincoln County, Nevada: U.S. Atomic Energy Comm., RME-2052, 12 p.

Uranium occurrences in the Pliocene tuffaceous lake beds of the Panaca formation are described.

Otton, J.K., 1977, Geology of uraniferous Tertiary rocks in the Artillery Peak-Date Creek Basin, west-central Arizona, in Campbell, J.A. (ed.), Short papers of the U.S. Geological Survey Uranium-Thorium Symposium, 1977: U.S. Geol. Survey Circ. 753, p. 35-36.

Economic uranium mineralization occurs in Tertiary lake beds at the Anderson Mine. Carnotite occurs principally in thinly bedded lower Miocene (?) lacustrine siltstones and mudstones rich in carbonaceous or silicified plant material.

Peterson, F., 1977, Uranium deposits related to depositional environments in the Morrison formation (upper Jurassic), Henry Mountains mineral belt of southern Utah, in Campbell, J.A., (ed.), Short papers of the U.S. Geological Survey Uranium-thorium Symposium, 1977: U.S. Geol. Survey Circ. 753, p. 45-47.

A model is proposed in which uranium was transported by oxidized ground water that flowed through fluvial sands and was precipitated at the distal end of the alluvial plain in braided stream or marginal lacustrine sands in places where braided streams emptied directly into lakes, and where meandering stream sands and nearshore lacustrine red beds were not present. Precipitation occurred in sands at the interface between the oxidized uranium-bearing water and reducing pore or compaction fluids from offshore-lacustrine gray muds.

Peterson, F. and C.E. Turner-Peterson, 1979, Lacustrine humate model for uranium mineralization in the upper Jurassic Salt Wash member of the Morrison formation, Henry Mountains mineral belt, southern Utah: U.S. Geol. Survey Open-file Report 79-1088.

Humic and fulvic acids generated in the offshore muddy sediments of humus-

bearing lakes were expelled by compaction or seepage into nearby sandstone beds where the acids were fixed as tabular humate deposits. Subsequently, uranium-bearing ground water passed through the sandstone where the humate fixed and concentrated the uranium, forming tabular sandstone uranium deposits.

Pudlik, K.P., B.E. Holder and C.F. Smith, 1977, Raw data report, Roach Lake Basin orientation study, Lawrence Livermore Lab., hydrogeochemical and stream sediment reconnaissance: Univ. of California (NURE), GJBX-48 (78), 22 p.

Hydrogeochemical data taken at Roach Lake, Nevada, are described. Areas of highest uranium concentration are on lake margins.

Reyner, M.L., W.R. Ashwell and R.L. Robinson, 1956, Geology and uranium deposits of Tertiary lake sediments of southwest Yavapai County, Arizona: U.S. Atomic Energy Comm., RME-2057.

The carnotite occurrences at Anderson mine, discovered by airborne scintillation, was first described in this report. Uranium also occurs at Artillery Mountains; at least two uranium-bearing carbonaceous zones are present in the Eocene Artillery Peak Formation. Origin of the uranium is considered obscure, but probably hypogene and related to Pliocene (?) faults.

Sherborne, J.E., Jr., W.A. Buckovic, D.B. Dewitt, T.S. Hellinger and S.J. Pavlak, 1979, Major uranium discovery in volcanoclastic sediments, Basin and Range Province, Yavapai County, Arizona: Amer. Assoc. Petroleum Geologists Bull., vol. 63, p. 621-646.

The Anderson Mine uranium deposit occurs in carbonaceous mudstones and siltstones interbedded with fine tuffaceous sedimentary rocks, freshwater marlstones and limestones, and a few thin sandstones. The sequence is underlain by Eocene (?) andesitic volcanic rocks and overlain by Miocene sedimentary rocks and basalt. Mineral grades range from 0.03 to 0.10 percent U_3O_8 , with an average grade of approximately 0.07 percent. Molybdenum, sulfur, vanadium and organic carbon are concentrated with the uranium mineralization. Uranium-bearing tuffaceous sediments were deposited marginal to an expanding Miocene lake. During subsequent compaction and dewatering of these uranium-rich lake sediments, the expelled alkaline

fluids came in contact with strongly reducing paludal sediments causing the precipitation and fixation of uranium. Associated zeolitization, silicification and argillic alteration indicate an early diagenetic origin for the primary coffinite (?) mineralization.

Turner-Peterson, C.E., 1977, Uranium mineralization during early burial, Newark Basin, Pennsylvania-New Jersey, in Campbell, J.A. (ed.), Short papers of the U.S. Geological Survey Uranium-Thorium Symposium, 1977, U.S. Geol. Survey Circ. 753, p. 3-4.

Uranium mineralization occurred in the offshore lacustrine black mudstones of the Lockatong formation and the nearshore lacustrine sandstones of the Stockton formation. Mineralization in the Stockton occurred shortly after deposition. It is proposed that the reducing agents generated within black muds (humic acid and aqueous sulfide) were expelled during compaction into the adjacent more permeable nearshore sands, providing the reductants necessary for uranium fixation. Uranyl ions were carried into the basin by ground water from uranium-rich crystalline rocks.

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