UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Epigenetic uranium deposits in Tertiary sedimentary rocks in Ventura County, California: a preliminary report

by

K. A. Dickinson[1]

Open-File Report 82-818B

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

1/U.S. Geological Survey, Golden, Colorado

CONTENTS

ILLUSTRATIONS

TABLES

Epigenetic uranium deposits in Tertiary sedimentary rocks in Venture County, California: a preliminary report

by

Kendell A. Dickinson

INTRODUCTION

Epigenetic uranium deposits have been found in several Tertiary sedimentary settings in Ventura County, California. The purpose of this report is to determine the origin of the occurrences that have been discovered and to evaluate the potential for commercial deposits.

The uranium deposits are found in rocks of late Eocene, early Oligocene, Miocene, and Plicocene age. The late Eocene, early Oligocene deposits are found at the base of the late Eocene to early Miocene Sespe Formation. Several deposits are located on Superior Ridge, a topographic high about 5 km long that is located just south of White Ledge Peak and 10-15 km west of Ojai, California (fig. 1). For this report, these deposits are called the Superior Ridge deposits. A single deposit, about 5 km south of Superior Ridge is called the Laguna Ridge deposit. Both the Superior Ridge and the Laguna Ridge deposits were included in what Bowes and Myerson (1957) called the White Ledge Peak district. Additional deposits have been found near the base of the Sespe Formation in the vicinity of Hartman Ranch on State Highway 33, 15 km northwest of Wheeler Springs (fig. 1). These deposits are located on Sespe Creek and are identified as the upper Sespe Creek deposits.

The Miocene deposit is located 8 km northwest of Simi Valley, California in Happy Camp Canyon, and in this report it will be referred to as the Happy Camp Canyon deposit. The host rock for this deposit is diatomaceous shale and related sedimentary rock of the Monterey Formation. The Pliocene occurrence is in the Quatal Formation in Quatal Canyon about 5 km northeast of State Highway 33 in the Cuyama River Valley (fig 1).

Most of the uranium exploration and development activity in Ventura County took place between 1954 and 1960. Airborne radiometric surveys and hand-held gieger counters were the primary exploration tools. Trenches dug by hand or by bulldozer were used to expose the deposits. Exploration reached the drilling stage only on Superior Ridge where about 30 holes were drilled to depths ranging to about 380 feet.

Several previously reported deposits were not relocated during the present study because: 1) the original pits and exposures have been grown over by brush, 2) exact locations of occurrences have not been recorded, and 3) limited time was available. Both mineralized samples of host rocks and non-mineralized samples of potential host rock were collected (fig 6). Samples of some potential source rocks were also collected. All samples were analyzed for uranium and thorium by delayed neutron (Millard, 1976). Mineralogy of the samples was studied mainly by X-ray diffraction. Chemical analyses were made by six-step semi-quant spectrometry of both mineralized and non-mineralized host rock (Dickinson and others, (1984).

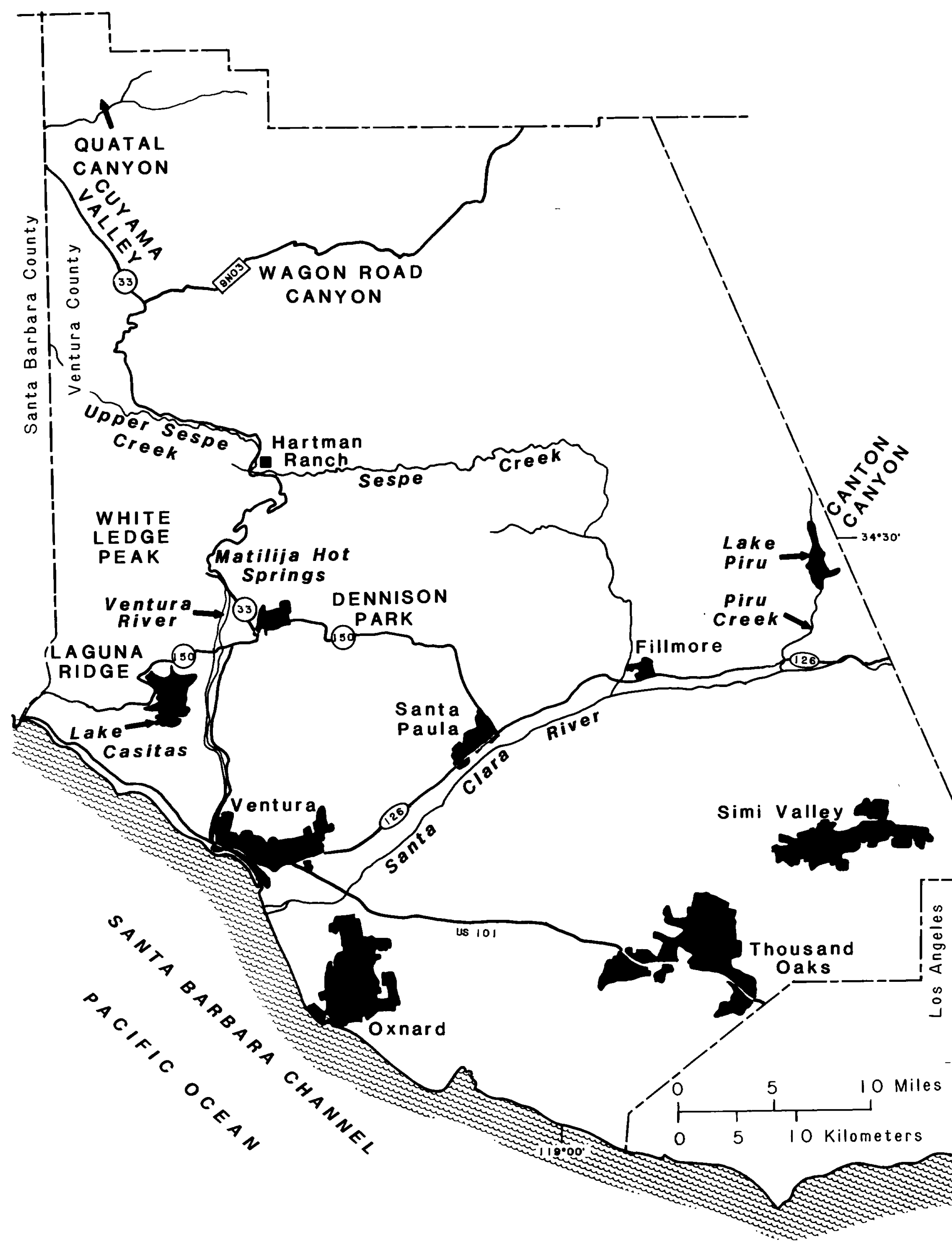

Figure 1.--Area of the report.

DISCUSSION OF GEOLOGY
Stratigraphy

The geology of the Superior Ridge and Ojai area has been compiled by Moser and Frizzell (1982) and the general stratigraphic sequence in three areas in Ventura County is shown in figure 2. The oldest rock in the area, which is Upper Cretaceous, is overlain by about 4500 m of marine Eocene rock. Most of the Eocene marine deposition was abyssal, but shoaling occurred in late Eocene time during which the lowermost part of the nonmarine late Eocene to early Miocene Sespe Formation was deposited. This lowermost part of the Sespe is the primary uranium host rock in Ventura County.

Epigenetic uranium enrichment is also present in rocks that are older and younger than the Sespe. Among the older rocks containing uranium are the Eocene Matilija Formation that contains slight uranium enrichment (see table 1) and the Eocene Coldwater Formation that may have some uranium enrichment near the top where it is in contact with the lower Sespe Formation. Among the younger rocks, the Miocene Monterey and the Pliocene Quatal Formations contain occurrences of epigenetically enriched uranium, and slight enrichment was detected in the Miocene Rincon Shale.

Sespe Formation

The Sespe Formation was originally named from the Sespe Creek area 6 miles north of Fillmore by Watts (1897) who called it the "Sespe Brownstone." The formation was later revised by Kew (1924) to extend the term throughout the depositional basin. The Sespe is a nonmarine deposit that followed Eocene marine deposition and was followed by Miocene marine deposition.

The Sespe rests on the Eocene Coldwater Sandstone with apparent conformity in most areas. In a few areas the contact is a disconformity or slight angular unconformity. The upper contact of the Sespe with the Miocene Vaqueros Formation is conformable in most areas, but a slight disconformity or angular unconformity is found in others.

A basal conglomeratic member of the Sespe Formation was recognized by Dickinson and Lowe (1966) in upper Sespe Creek area. This basal member is apparently limited in areal extent to the western margin of the Sespe depositional basin. Bowes and Myerson (1957) recognized a lower member in the Superior Ridge area. Their lower member was apparently below the main conglomeratic facies included in the basal member of Dickinson and Lowe (1966) and was interpreted to be transitional with the underlying Coldwater Sandstone. The lower member of Bowes and Myerson (1957) is nonmarine, but it intertongues with a marine facies of the Coldwater Sandstone (Moser and Frizzell, 1982), and it is the main uranium host rock at Superior Ridge. In this report the lower member of Bowes and Myerson (1957) will be referred to as the lower transitional Sespe.

The lower part of the Sespe is more conglomeratic than the upper part which contains more red beds. The clastic composition of the Sespe is mainly lithic arkose. The ratio of plagioclase to orthoclase in the Sespe generally exceeds one, based on whole rock X-rays, and the ratio appears to increase to the east where a more mafic igneous provenance was demonstrated by Bohannon

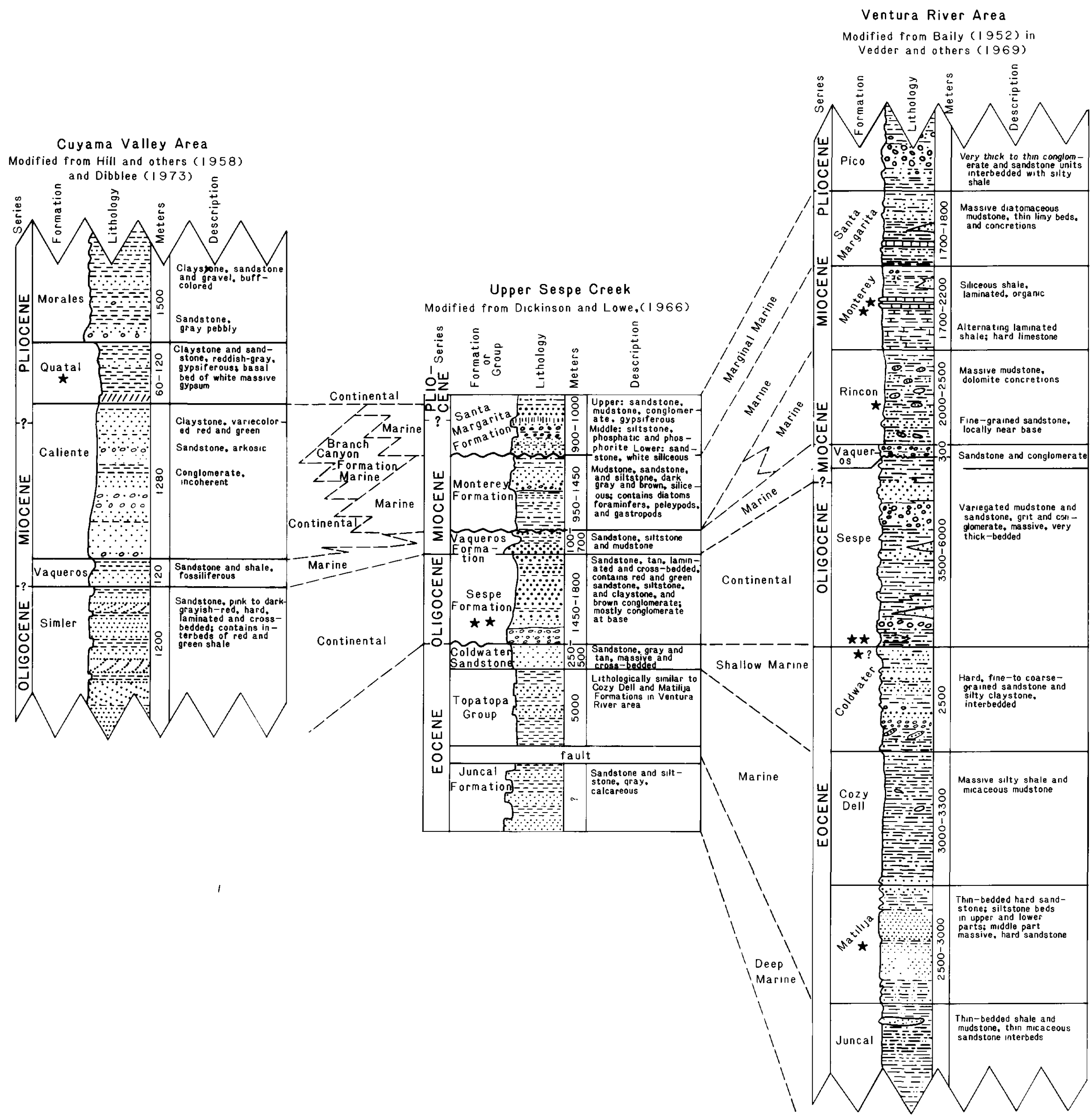

Figure 2.--Stratigraphic columns showing uranium occurrences (★★>0.1% U_3O_8, ★>0.001% <0.1% U_3O_8). Thickness and correlations are approximate.

Table 1.--Summary of uranium claims

Area Claim Section/Township/Range	Maximum Uranium Values eU_3O_8	Uranium Minerals	V_2O_5	Petrology of Host Rock	Stratigraphy	Strike/dip
Superior ridge Beer Can #12 2 4N 24W	0.19	Carnotite	.67	Sandstone, gray, lt. brown, arkosic, cross-bedded, fluvial, contains black carbonaceous pods and veinlets	Lower Sespe Formation	40^{o} S. dipping beds
Payoff** 10 4N 24W	2.18	Carnotite	NA*	Sandstone, gray, lt. brown, micaceous, poorly sorted, fluvial, with carbonaceous trash	Lower Sespe Formation	Strike Northeast
Chismahoo East #1 10 4N 24W	0.23	Carnotite	NA*	Sandstone, gray to lt. brown, poorly sorted, contains conglomerate lenses and carbonized wood	Lower Sespe Formation	N 70^{o} E, 40^{o} N
Coyote #1 4 4N 24W	0.16	Carnotite	NA*	Sandstone, gray, coarse-grained, micaceous, fluvial	Lower Sespe Formation	N45-70^{o}E, 30-40^{o}S
Gamma Queen 6 4N 24W	0.07	Autunite	.09	Sandstone, buff-colored, fine-grained micaceous, contains pockets of carbonaceous material and interbedded conglomerate, siltstone and red and green shale	Lower Sespe Formation	N85^{o}W, 45-50^{o}SW
Lamar 7 4N 24W	0.03			Sandstone, carbon trash	Lower Sespe Formation	NA*
Laguna Ranch Hoot Mon #4 20 4N 24W	NA*	Carnotite	NA*	Sandstone, buff to lt. gray, fluvial, contains carbon trash	Lower Sespe Formation	NA*
Sespe Creek Area Bertram lode 2 5N 23W	0.64	NA	NA*	Sandstone, containing uraniferous concretions and interbedded shale	Upper Eocene	N 60-70^{o}E, 30^{o}S
Lucky Saddle 31 6N 22W	0.51	NA	NA*	Sandstone, gray, micaceous, fluvial, contains carbonaceous material long bedding planes,	Lower Sespe Formation	
Happy Camp Area Strathearn Cattle Co. 13 3N 19W	0.48	NA*	NA*	Siltstone, sandstone, fine-grained, loosely consolidated; and diatomaceous shale	Monterey Shale	N 90^{o}E, 42-57^{o}S Near minor fault
Quatal Valley Hidden Springs 31 9N 23W	0.03	Schroekingerite	NA*	Sand, gravel, and clay, non-marine, gypsiferous, calcareous, stained with iron oxide	Quatal Formation	N 0^{o}E, 35^{o} W

* Not available

** Later included in the Payore Claims

(1976). Total feldspar exceeds quartz in most of the samples. The predominant clay mineral in the uranium host rocks at Superior Ridge is montmorillonite (Bowes and Myerson, 1957) but the clay suite also includes chlorite, and possibly mixed layer chlorite-montmorillonite and illite. Bailey (1947) reports a maximum thickness of the Sespe of 7,500 feet (2300 m) but in most of the Ventura basin it ranges from 3,000 to 5,000 feet (914 to 1524 m) in thickness. The lower member as defined by Bowes and Myerson (1957) ranges from 225 feet (69 m) to 450 feet (137 m) in thickness. The Sespe generally thins westward in the Ventura Basin.

The Late Eocene to Early Miocene age of the Sespe is based mainly on its stratigraphic position although it contains some vertebrate fossils (Rheinhart, 1928; Yerkes and Campbell, 1979). The lower transitional Sespe may be predominantly Late Eocene.

On the basis of paleocurrent work by Bohannon (1976) the sediment source of the Sespe in the upper Sespe Creek area was from the west northwest and north and, in the Canton Canyon area, farther east, the source was from the north, northeast, and east. These data are not corrected for tectonic rotation as proposed by Luyendyk, Kamerling, and Terres (1980). The conglomerate clasts in the Sespe Creek area are mainly volcanic rock of rhyodacitic composition, granitic rock and sandstone, and in the Canton Canyon area to the east the main clast types are granite, syenite, anorthosite and gabbro (Bohannon, 1976).

The Sespe Formation was deposited predominately in a fluvial environment (Reed, 1929; Reinhart, 1928; Bailey, 1947; Dickinson and Lowe, 1966). Bohannon (1976) described fining upward sequences in the upper Sespe Creek area that he attributed to meandering and braided streams on a flood plain. In the Canton Canyon area Bohannon (1976) suggested deposition in a broad alluvial fan. Some possible lacustrine beds have been reported (Reed, 1929, p. 503). At Dennison Park east of Ojai laminated beds containing gypsum suggest that minor amounts of the Sespe were deposited in evaporitic lakes.

Bailey (1947) suggested that a major stream flowed westward through the Sespe depositional basin with tributaries entering from both the north and the south. The paleocurrent data of Bohannon (1976) and McCracken (1969) generally support this hypothesis. McCracken (1969) suggested that a trunk stream existed in the approximate the position of the Santa Clara River and that it reached the present coast near Point Rincon.

Rocks older than Sespe

The oldest sedimentary rocks in the area of this report are Upper Cretaceous. These rocks are overlain by an Eocene marine sequence that consists of, in ascending order, the Juncal Formation, the Matilija Sandstone, the Cozy Dell Shale, and the Coldwater Sandstone. This sequence begins with deep ocean sedimentation in the Juncal and lower Matilija Formations and ends in shallow water nearshore deposition of the Coldwater Sandstone.

Rocks younger than the Sespe Formation

Marine sedimentation followed deposition of the Sespe Formation and continued until the Pleistocene in the Ventura River Valley. In this area the formations include the Miocene Vaqueros, Rincon, and Monterey, the largely Micocene Santa Margarita, and the Pliocene Pico (fig. 2). According to Dickinson and Lowe (1966), the Rincon Formation is missing in an otherwise similar sequence in the upper Sespe Creek area to the northwest, but mapping by Moser and Frizzell (1982) indicates its presence there. Still further northwest in the Cuyama Valley area the upward sequence of formations is the Miocene Vaqueros, the Miocene to Pliocene Caliente, and the Pliocene Quatal and Morales. The nonmarine Caliente Formation generally replaces the Monterey and Santa Margarita Formations in this area.

Structure

The structural evolution important to the history of uranium mineralization began with the end of the Eocene uplift that created the nonmarine basin in which the Sespe Formation was deposited. Minor folding may have occurred during or near the end of the Miocene as evidenced locally by a slight disconformity between the Sespe Formation and overlying units and perhaps also by conglomeratic lenses within the Sespe. These movements, although minor and difficult to measure or map, may have had a crucial effect on uranium mineralization because of their effect on paleohydrology. The most severe orogeny occurred in the Pleistocene prior to deposition of the Santa Barbara Formation (Jackson and Yeats, 1982). This orogeny, which produced the Superior anticline and related faults as well as the overturned anticlines both east and west of the Superior anticline, probably modified existing uranium deposits and uplifted and subsequently exposed the uranium deposits along Superior and Laguna Ridges.

URANIUM DEPOSITS

Superior Ridge Deposits

The Superior Ridge deposits are the largest and most extensive uranium deposits known in Ventura County. These deposits were first discovered during 1954 by using aerial radiometrics (Bowes & Myerson, 1957). During 1954 and 1955 many claims were filed in an area about 8 km long and 1 km wide (fig 3). These claims included the Gamma Queen, the Coyote, the Chismohoo, the Payoff (later consolidated into the Payore), the LaMar and the Beer Can (table 1).

All of the Superior Ridge deposits (White Ledge Peak deposits of Bowes and Myerson, 1957) were found in the lower part of the Sespe Formation (figs. 3, 4). In the Superior Ridge area, the lower part of the Sespe Formation consists mainly of yellowish-brown or pinkish-gray medium to coarse-grained poorly sorted arkosic sandstone that exhibits plane and cross bedding. This facies is below the main conglomeratic facies (fig 2). Additional stratigraphic details of the lower uranium producing part of the Sespe are shown in figure 5 which was originally published by Bowes and Myerson, (1957). In decreasing order, the common rock minerals in the lower Sespe sandstone are quartz, plagioclase, orthoclase, smectite, illite-muscovite and chlorite. The combined plagioclase and orthoclase contents probably exceed that of quartz in many of these samples (table 2; Reed, 1929).

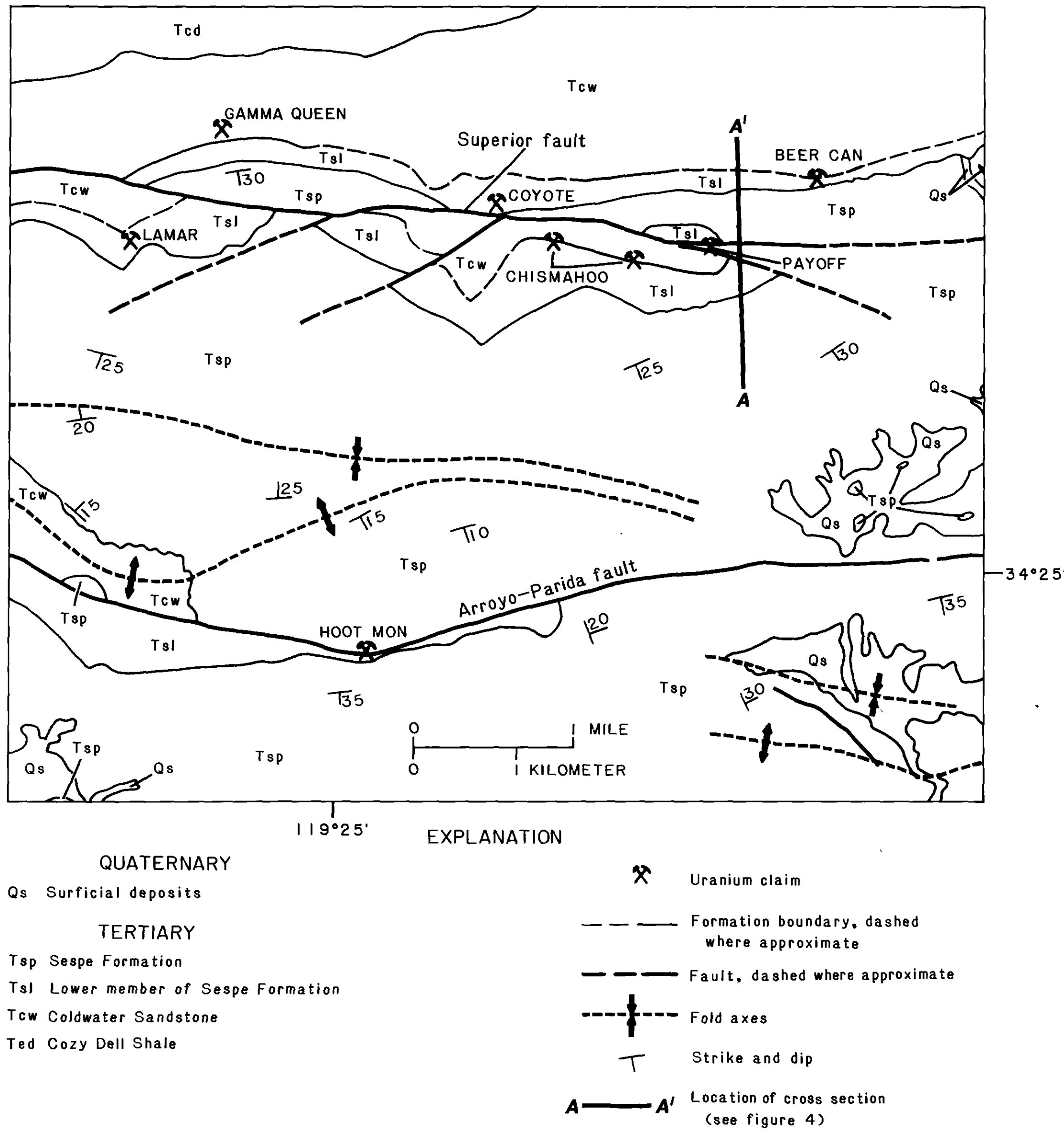

Figure 3.--Geologic map, cross section location, and uranium claim localities in Superior Ridge and Laguna Ridge areas. Geology compiled by Moser and Frizzell (1982).

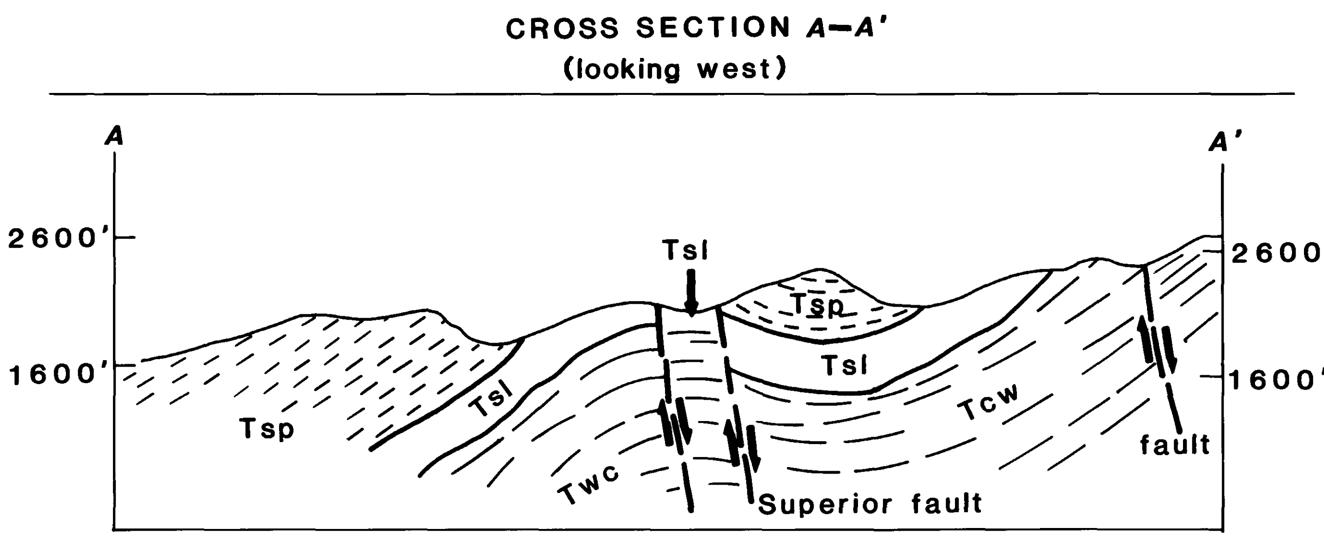

Figure 4.--Cross section of Superior Ridge (modified slightly from Bowes and Myerson, 1957). Coldwater Sandstone, Tcw; lower Sespe Formation, Tsl; Sespe Formation, Tsp.

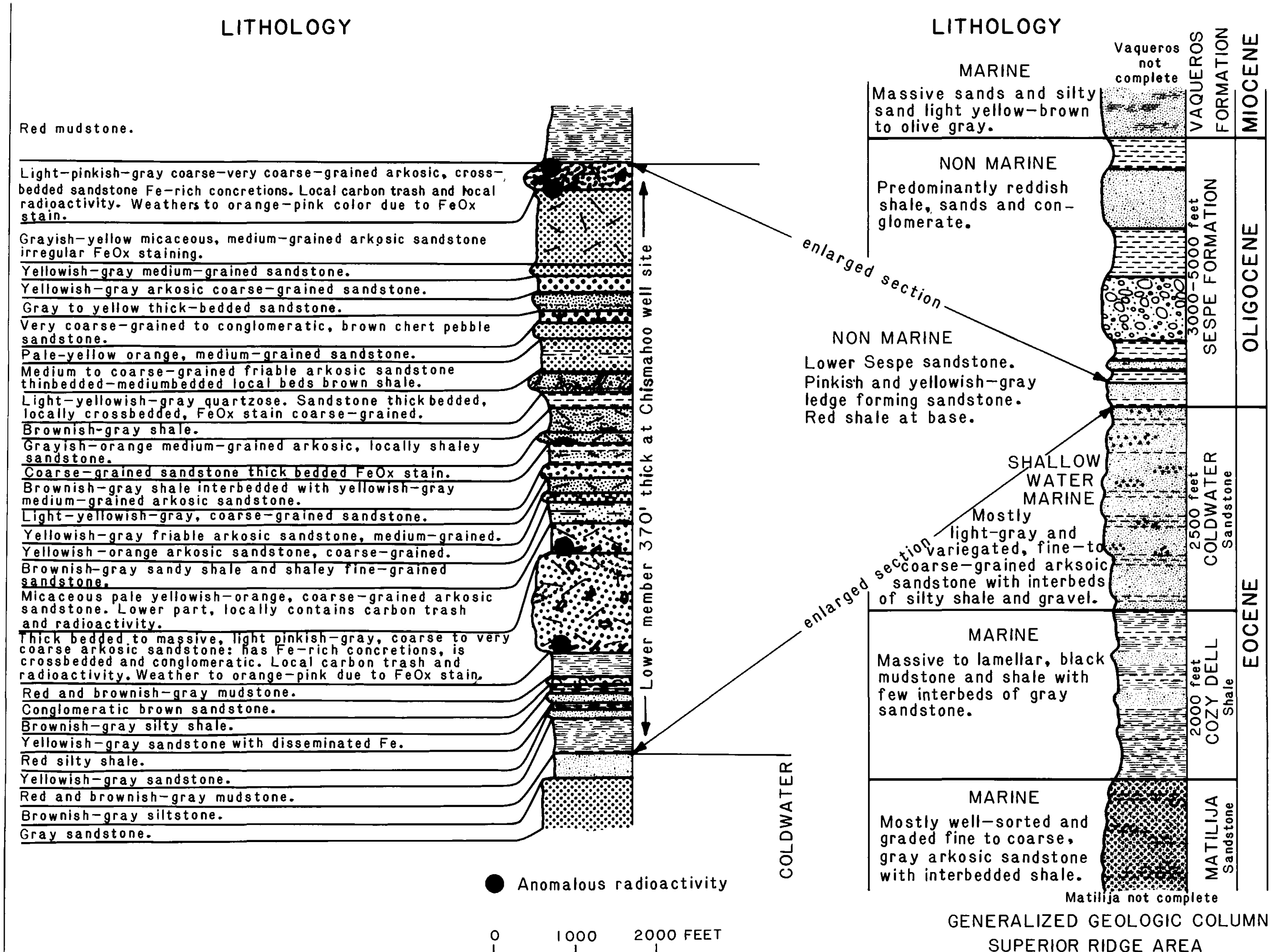

Figure 5.--Stratigraphic detail from the lower part of the Sespe Formation at Superior Ridge. (Modified slightly from Bowes and Myerson, 1957).

Table 2.--Sample data from the Sespe Formation

Locality	Sample[3] Number	Uranium (ppm)	Thorium (ppm)	Th/U	Proximity to Mineralization[4]	Vanadium[1] (ppm)	Molybdenum[1] (ppm)	Field Description	Mineralogy as determined by whole-rock X-ray diffraction in general order of decreasing proportion[2]
Superior Ridge	6381-1A	162.	<27.0			1500	30	Sandstone, light yellow-brown, medium-grained; contains carbonaceous fragments	Q, P, O, S, I
	1C	84.5	<16.0			1000	30	Sandstone, light yellow-brown, medium-grained	No date
	1E	93.8	<17.0			500	50	Sandstone, light yellow-brown, medium-grained	No data
	2	8.8	13.2	1.5	P	50	N	Sandstone, pink, fine- to medium-grained friable	No data
	3	2.8	6.2	2.2	P	30	N	Sandstone, light yellow-brown, fine-grained, hard, slightly calcareous	Q, P, O, S, I, Ch
	6581-1	10.7	<3.9			50	N	Sandstone, gray, fine- to coarse-grained, conglomeratic, cross-bedded	Q, P, O, S, I, Ch
	2	6.4	<3.2			50	N	Siltstone, light yellow-brown, hard	Q, P, O, S(?), I, Ch
	3	2870.0	<640.0			5000	50	Sandstone, light yellow-brown, medium- to coarse grained, contains carb. frags.	Q, O, P, S(?), I, Ch
	4	6.2	8.2	1.3	P	30	N	Sandstone, light yellow-brown, medium- to coarse grained, thin bedded	Q, O, P, S(?), I, Ch
	5	5.2	>2.7			70	N	Sandstone, tan, medium- to coarse grained, poorly srted, calcareous	Q, C, P, S
	61381-3	1.8	7.3	4.0	R	30	N	Conglomerate, reddish brown, argillaceous; contains seashell fragments	C, Q, P, Ch, S
	61381-4	1.0	3.9	3.9	R	30	N	Sandstone, red, coarse-grained, conglomeratic crumbly	Q, P, O, Ch, S
	61381-6	19.2	<5.3			70	L	Sandstone, buff, medium-grained, hard contorted bedding	Q, O, P, I, S,
Wilsie Canyon	6881-1	7.9	10.9	1.4	P?	20	N	Sandstone, reddish-brown, conglomeratic weathered	Q, O, P, S
Hartman Ranch	6982-2A	15.7	<6.1			50	N	Sandstone, reddish-gray, medium-grained; contains carbonaceous fragments	O, P, Q, I, Ch
	-18	3.9	13.0	3.4	R	30	N	Sandstone, reddish-gray, medium-grained; contains carbonaceous fragments	Q, P, O, S, I
Dennison Park	61181-1	2.3	9.2	3.9	R	70	N	Siltstone and very fine-grained sandstone, red, laminated, calcareous	Q, P, O, G, S, I
	-2	1.5	5.3	3.6	R	30	N	Sandstone, pink, evenly bedded, calcareous, micaceous	Q, P, O, G, S, Ch
	-3	2.0	8.4	4.2	R	30	L	Sandstone, red, medium-grained medium to thick bedded	Q, P, O, C
	-4	2.5	9.5	3.7	R	70	N	Sandstone, reddish brown to buff, fine- to medium-grained cross bedded	Q, P, O, I, Ch
Sespe Oil Field Area	61181-5	1.8	10.8	6.1	R	30	N	Sandstone, red, fine- to medium grained, medium bedded conglomeratic	Q, P, O, I, Ch
	-6	2.1	9.0	4.3	R	50	N	Sandstone, buff, fine-grained, silty non-calcareous	Q, P, O, I, S
	-7	3.3	14.0	4.3	R	70	N	Sandstone, gray, weathered brown very fine- to fine-grained, banded	Q, P, O, Ch, S, I
	-8	1.8	8.7	4.8	R	30	N	Sandstone, red, hard, medium-grained, micaceous	Q, P, O, S, I
Laguna Ridge	61281-1	1.7	9.1	5.4	R	50	N	Sandstone, light tan, hard, evenly thin to thick bedded	Q, P, O, S
West Casitas Pass	61281-4	2.6	11.0	4.2	R	30	N	Sandstone, buff, medium-grained, evenly thin to thick bedded	Q, P, O, S, I
	61281-5	2.1	8.1	3.9	R	50	N	Sandstone, light reddish brown evenly thin to thick bedded	Q, P, O, S, Ch, I

1/ N=not detected, L=detected, but below limit of determination; detection limit for molybdenum was 3 ppm and for vanadium it was 7 ppm. (Millard, 1976)

2/ Q=Quartz, P=Plagioclase, O=Orthoclase, S=Smectite, I=Illite or mica, ch=chlorite, G=gypsum, C=calcite

3/ See Fig. 6

4/ R = remote, P = proximal.

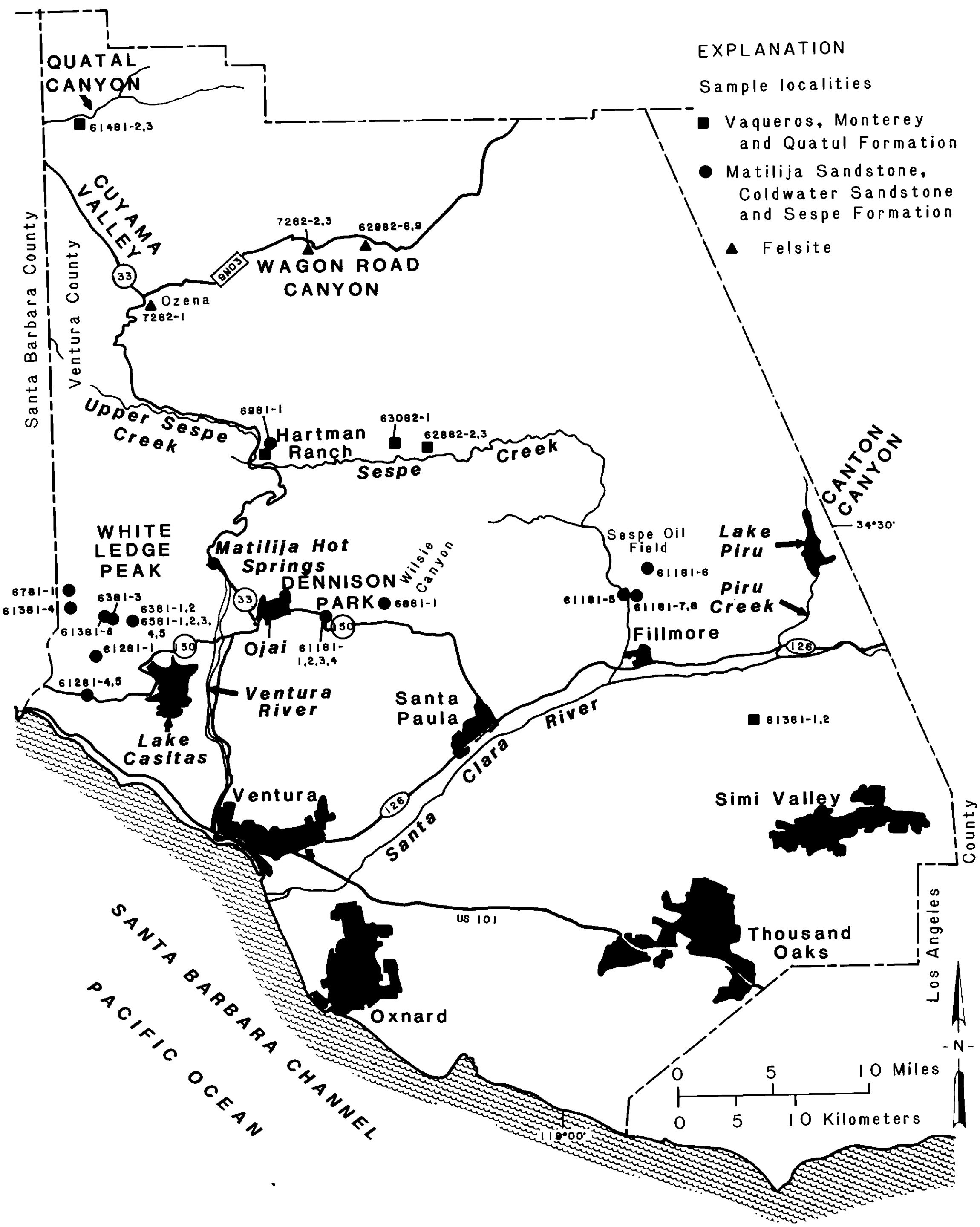

Figure 6.--Sample localities.

The most common uranium mineral in the Superior Ridge deposits is carnotite [K $(UO_2)_2$ $(VO_4)_2$. $3H_2O)$]. Becquerelite [CaU_6 O_{19} . 11 H_2O], Autunite [Ca $(UO_2$ $(PO_4)_2$. 10-12 H_2O] and a black uranium oxide (possibly pitchblende) are also present. These uranium bearing minerals are found in lenses and concretions, most commonly associated with carbonized wood or other carbonaceous material. Bowes and Myerson (1957) described an occurrence from the Payoff claim as follows "The concretions, along with irregular carbonaceous streaks and disseminations, form local lenticular clusters of ore grade material along bedding of a size approximating 10 by 10 by 2 feet [3 by 3 by 0.6 meters]." At the base of the Beer Can deposit, according to Bowes and Myerson (1957), "Radioactivity is associated with an irregular 7 by 4 feet [2.1 by 1.2 meters] pod of black carbonaceous lignite-like material that occurs in veinlets near its margin. Similar material is found in irregular narrow streaks along the bedding plane for 50 feet." This black material probably originated as humate as is discussed below.

A correlation between vanadium and uranium occurs in the Superior Ridge deposits. A correlation between molybdenum and uranium probably also exists, but it is less evident. Elemental correlations for all the samples are discussed on pages 30 and 31.

The Superior Ridge uranium deposits are found in the crest and on both flanks of a faulted anticline (figs 3 and 4). The fault parallels the Arroyo-Parida fault to the south and the Santa Inez fault to the north and is downthrown to the north. While it is tempting to suggest that mineralization is related to this structure which mostly formed during the Pleistocene, the uranium mineralization, however, most likely was more widespread in the lower Sespe at an earlier age and the role of the anticline was only to expose a mineralized area to erosion and other modification.

Nine holes drilled on the Payore claims near the east end of Superior Ridge encountered discontinuous ore horizons at a depth of between 320 and 380 feet. Homestake mining Company estimated undiluted reserves of 57,167 lbs U_3O_8 based on data obtained from the claim owners. These data consisted of eU_3O_8 measurements from drill holes.

Laguna Ridge Deposit

The Laguna Ridge deposit is located about 5 km south of the Superior Ridge deposits (fig 1, table 1). One claim the Hoot Mon (table 1) was filed on Laguna Ridge. This deposit is very similar to those found on Superior Ridge. It is in the lower Sespe, transitional beds (the lower member of Bowes and Myerson, 1957) as are the Superior Ridge deposits. In the Laguna Ridge area the lower Sespe is exposed where thrust to the surface along the Arroyo-Parida fault. The Laguna Ridge deposit, which was not sampled for this study, contains carnotite associated with carbon trash (Bowes and Myerson, unpublished data, 1956).

Upper Sespe Creek Deposits

Two uranium claims, Bertram Lode and Lucky Saddle #1 were staked on upper Sespe Creek near Hartman Ranch near State Highway 33 (table 1). These deposits were not located during the present study, but samples with weak uranium mineralization were collected in the area (table 2). The host rock is micaceous arkosic sandstone of the lower part of the Sespe Formation. The transitional beds of the lower part Sèspe have not been recognized in this area (Dickinson and Lowe, 1969). Sandstone samples from the Lucky Saddle #1 contained as much as 0.1 percent U_3O_8 (chemically determined). Carbonaceous samples from this deposit contained as much as 0.8 percent U_3O_8 (chemically determined). Radioactivity of the Bertram Lode was associated with iron-stained concretions.

Happy Camp Deposit

The host rock for the Happy Camp uranium deposits is part of the Monterey Formation. According to W. A. Bowes and G. M. Hazelton, (unpublished data 1955), the mineralization is in brown siltstone, diatomaceous shale, and loosely consolidated sandstone. They reported chemically determined uranium values as high as .48 percent U_3O_8. Three samples were collected during this study (table 3). One sample of diatomaceous mudstone contained 67 ppm uranium and 1000 ppm vanadium. The uranium minerals have not been determined for this deposit although the high vanadium content suggests carbonatite. Durham (1979) described uranium deposits in the Monterey Formation in the Temblor Range in western Kern County about 100 km northwest of the Ventura County occurrence. Meta-autunite was identified in the Kern County deposits and Durham (1979) suggested seawater as the source of the uranium. The source of uranium for the Ventura County occurrence is unknown, but it may have been pre-existing uranium deposits in older rocks such as the Sespe Formation because, like the older deposits, the Monterey deposits have anomalous amounts of vanadium and molybdenum (tables 2 and 3). The ratio of vanadium to uranium in the Ventura County uranium occurrence averages about 29; in seawater the ratio is only about 0.67 (Goldberg, 1963).

Apparently the diatomaceous sediments contain enough organic material to produce a chemically reducing environment that was favorable for trapping uranium.

Quatal Canyon Deposit

Uranium deposits have been reported in the largely Pliocene nonmarine sedimentary rock in Quatal Canyon (fig. 1). The host rock is conglomerate, sandstone and claystone, of the Quatal Formation (fig. 2). The uraniferous rock which dips 35^{o} west also contains gypsum and iron oxide together with quartz, orthoclase, and plagioclase (table 3). Based on analyses by the U.S. Bureau of Mines, the uranium mineral, schroeckingerite was found at this deposit (G. M.Haselton, unpublished data, 1955). During this study no additional data were obtained from the original discovery pits in the Quatal Canyon area. However, data from samples collected about 3 km west of the occurrence are listed in table 3.

Other Areas of Slight Mineralization

Slight uranium mineralization was detected in the Eocene Matilija Sandstone in the Matilija Hot Springs area and in the Rincon Shale in upper Sespe Creek. The Matilija Sandstone uranium occurrence was associated with a small pocket of highly oxidized sandstone and probably occurred around carbonaceous material. The occurrence in the Rincon Shale was in a sample of grayish-brown hard mudstone that was collected near a radiometric high

Table 3.--Sample data for various Tertiary Formations

Locality	Formation	Sample Number	Uranium (ppm)	Thorium (ppm)	Th/U	Vanadium[1] (ppm)	Molybdenum[1] (ppm)	Field Description	Mineralogy as determined by whole-rock X-ray diffraction in general order of decreasing proportion[2]
Quatal Canyon	Quatal	61481-2	2.8	12.3	4.4	30	N	Sandstone, gray, fine-grained, hard; contains carbonaceous fragments	Q, P, O, Ch, S
	"	61481-3	2.5	10.4	4.2	30	N	Sandstone, light gray, fine-grained, hard	Q, P, O, Ch, S, I
Happy Camp	Monterey	61281-1A	11.0	29.5	2.7	70	L	Diatomite, light gray porous	Amorphous silica
	"	61381-1B	67.6	<25	-	1000	100	Mudstone, light-brown diatomaceous	Q, P, G, O, I, S
	"	61381-2	2.3	<2.6	-	150	N	Mudstone, light gray, calichified	No data
Upper Sespe Creek	Rincon	62882-2	11.6	<5.3	-		No data	Mudstone, grayish brown, hard	Q, P, O, S, Ch
	"	62882-3	6.1	9.7	1.6		No data	Sandstone, light brown, fine-grained, clayey, hard	Q, P, O, S
	"	63082-1	2.9	5.3	1.8		No data	Sandstone, light brown, fine- to coarse-grained, friable	Q, P, O, I, S
Divide Peak	Coldwater	6781-1	2.5	6.6	2.6	20	N	Sandstone, light-buff, fine- to medium-grained, poorly sorted	Q, O, P, I
Matilija Hot Springs	Matilija	6481-1	19.1	<5.4	-	70	5	Sandstone, gray, fine-grained, hard; contains carb. frags. and Fe-O stain	Q, O, P, S, Ch
	"	6481-2	2.5	9.5	3.75	30	N	Sandstone, gray, fine-grained, hard	Q, P, O, S, Ch

1/ N=not detected, L=detected, but below limit of determination; detection limit for molybdenum was 3 ppm and for vanadium it was 7 ppm (Millard, 1976).

2/ Q=Quartz, P=Plagioclase, O=Orthoclase, S=Smectite, I=Illite, Ch=Chlorite, G=Gypsum, C=Calcite.

(Dickinson and others, 1982). Such isolated occurrences are probably common in Eocene through Miocene sedimentary rock in the Ventura County. They may have resulted from redeposition of minor amounts of uranium during modification of other deposits and they are believed to be commercially insignificant.

MODEL FOR URANIUM MINERALIZATION IN THE SESPE FORMATION

The model for uranium mineralization in the Sespe Formation like similar models consists of several elements. These elements, which include source of uranium, leaching, paleohydrology, host rock, and reductant, are discussed below. In addition preservation is discussed because it is important in terms of the present deposit even though it is not strictly part of the model for mineralization. Hypothetical physical aspects of the model are shown in figure 7.

Source of Uranium

Much of the clastic material in the Sespe was apparently from volcanic and granitic rock from uplands that surrounded the depositional basin (Bohannon, 1976; McCracken, 1969; Reed, 1929). Uranium leached from this clastic material was apparently the source of uranium for deposits in the Sespe. If samples of the Sespe are divided into two groups, one taken from localities or stratigraphic positions that are, in general, remote from mineralization and one group proximal to but not within areas of mineralization, the Th/U ratio for the remote group averages about 4.1 and for the proximal group it averages about 1.6. This relationship suggests that the part of the Sespe represented by the remote group samples lost uranium through leaching and may have provided the uranium source for the deposits.

Most of the samples designated as remote group on table 2 (14 samples) are reddish-brown, and based on color are more highly oxidized than the proximal group. These samples average 9.1 ppm thorium and 2.2 ppm uranium. Two of these samples, numbers 61381-3 and 61381-4 were collected near the uranium deposits on Superior Ridge, but their color suggests that they were leached.

The proximal group of samples represent rock that was neither leached nor enriched in uranium and they provide a base line for comparisons. Only four samples were included in this group (table 2), which averages 6.4 ppm uranium and 9.6 ppm thorium. Three of the four samples in this group are light yellowish-brown. Chemically reducing conditions apparently prevailed in parts of the Sespe not only where mineralization occurred, but also in surrounding areas represented by the proximal samples. These conclusions must remain tentative until additional samples are evaluated and, in addition, the validity of this reasoning depends on the validity of the separation of mineralized versus unmineralized samples as discussed below.

Neither felsic tuff nor alkaline granite, perhaps the most favorable uranium source rocks, are present in great abundance near any of the uranium deposits. Late Tertiary volcanic rock in the Ventura basin and Western Transverse Range area is mostly basaltic (Moser and Frizzell, 1982) and such rocks are not a likely source of uranium. Basaltic volcanic rock of Miocene (?) age, however, occurs near the Happy Camp uranium deposit in the Monterey

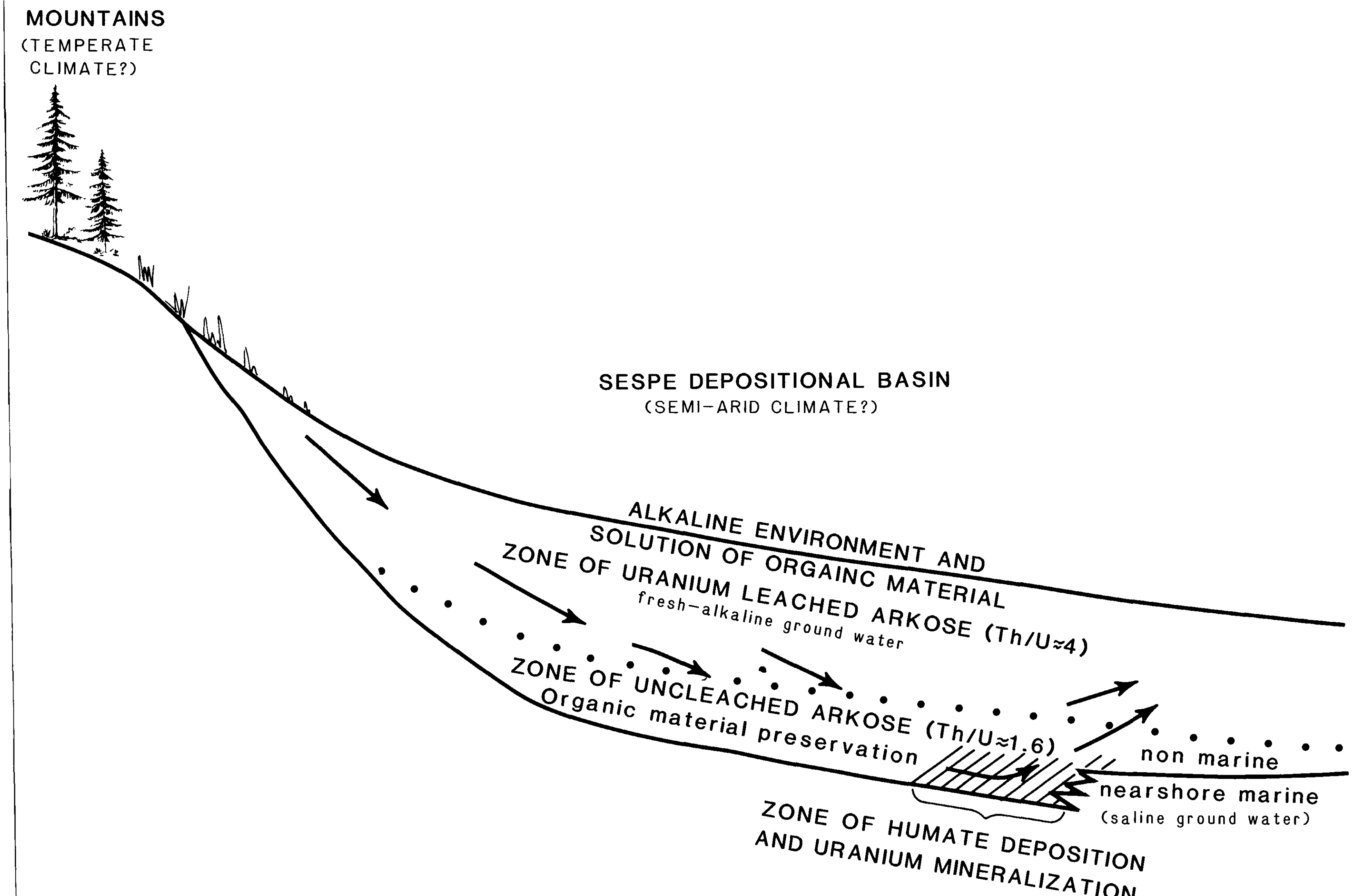

Figure 7.--Schematic diagram showing hypothetical conditions resulting in uranium mineralization in the lower part of the Sespe Formation; arrows indicate ground water movement.

Formation. A Miocene felsic tuff is found near the Frazier Borox Mine in Cuddy Valley. This tuff is of very limited extent and probably was not within the Sespe depositional basin. Volcanic ash was a strong contribution to phosphatic sediments of the Santa Margarita Formation in upper Sespe Creek (Lowe, 1969). Uranium content of phosphatic sediment collected from the Santa Margarita Formation near Pine Mountain by Vercoutere (unpub. data, 1983) averaged about 30 ppm. The possibility that uranium from this formation played a role in the Sespe mineralization cannot be eliminated, and it needs further study.

Pliocene felsic rocks occur north of the Pine Mountain Fault near Ozena Ranger Station and also in Wagon Road Canyon north of the Pine Mountain Fault. Seven samples of this felsite were analyzed for uranium and thorium (fig. 8). Based on samples from the western part of Wagon Road Canyon and from near Ozena Ranger Station (table 4), the thorium average 9.4 ppm and the uranium 8.3 ppm giving a Th/U ratio of a little over one. This ratio is unusually low for rocks of this type. Granitic rocks generally have a Th/U ratio ranging from 3.5 to 6.3. Rogers and Adams (1978). The uranium content of the Ozena felsites seems fairly high, however, since most granitic rocks have uranium contents averaging from 3 to 6 ppm. Two samples were not included in the calculations, number 7282 1A because it has nearly three times the average thorium of the other samples and number 7282 2A because only an upper limit was determined for thorium. Two samples from eastern Wagon Road Canyon, 62982-8 and 62982-9, contained about the average for thorium but uranium was much lower. The average Th/U ratio for these samples was 5.3 suggesting, perhaps that they had lost uranium through leaching or late stage magmatic processes. In addition, the samples of the felsite from western Wagon Road Canyon contain about two times the average uranium for felsites, and they suggest that the unit contained ample uranium to serve as a source rock. While the data presented here are too few for confident conclusions, the limited extent and questionable position of the felsic intrusive in regard to the Sespe Formation do not identify it as a probable uranium source for the Sespe uranium deposits.

Leaching

Uranium is dissolved from source rock in its oxidized valence state, VI, and commonly carried in solution in equilibrium with a di-or tri-carbonate ion. For these reasons uranium leaching occurs under oxidizing and alkaline environments. These chemical environments are favored by arid or semi-arid climatic conditions which preserve the abundance of relatively soluble alkalies and by the presence of volcanic glass which tends to release alkaline metals upon hydration. Reed (1929) suggested that the Sespe was deposited under conditions not very arid because of the commonness of red beds in the sequence. The red color, however, apparently resulted from diagenetic alteration of ferromagnesium minerals to hematite (McCracken 1969). However, it was likely deposited under semi-arid conditions as suggested by Reinholt (1928), who based his opinion on the freshness of the feldspar. In addition, the upper part of the Sespe contains gypsum and lacustrine limestone, indicators of an evaporative climate.

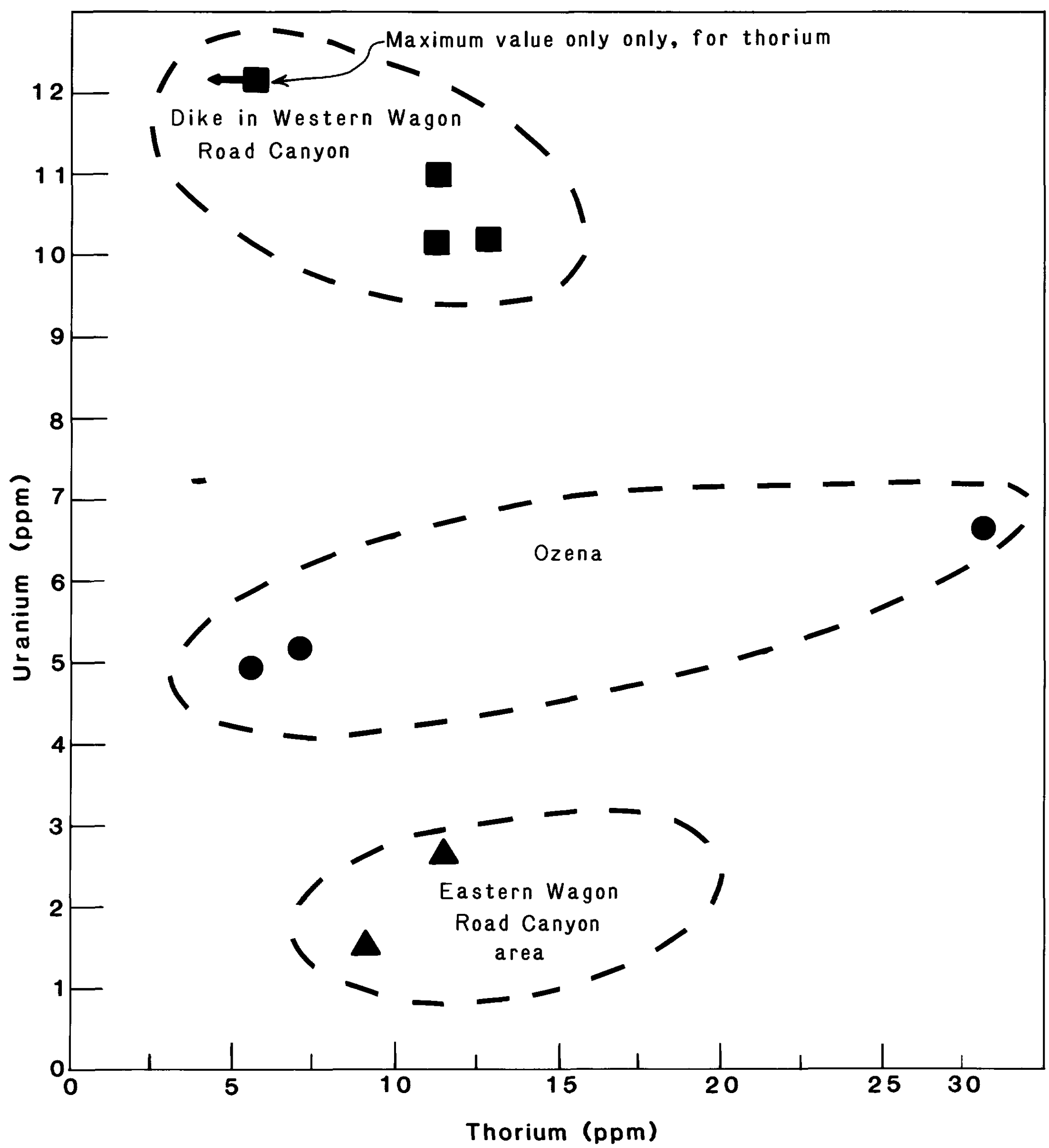

Figure 8.--Scatter diagram of uranium versus thorium in Pliocene felsitic intrusives.

Table 4.--Pliocene felsites

Field Number	Th	U	Th/U	Locality
7282-1A	28.0	6.7	4.11	Ozena Ranger Station
8292-1B	6.8	5.2	1.31	
7282-1C	5.6	5.0	1.12	
7282-2A	<5.4	12.1	<	
7282-2B	11	10.2	1.08	
7282-2C	13	10.2	1.24	Western Wagon Road Canyon
7282-3	11.0	11.0	1.0	
62982-8	11.0	2.6	4.32	Eastern Wagon Road Canyon
62982-9	9.0	1.5	6.30	

Paleohydrology

Accurate knowledge about the paleohydrology during the main period of mineralization which is believed to be the Oligocene is not available. In part this information is not available because there may have been a certain amount of warping going on during deposition of the Sespe. The best assumption is that the hydrologic head was generally parallel to stream flow (Butler, 1969). Bailey (1947) suggested that a major westward flowing river was draining the Sespe depositional basin during deposition and that tributaries entered this stream from both the north and south. Paleocurrent directions which were determined in the upper Sespe Creek area by McCracken (1969) and by Bohannon (1976) generally confirm this pattern. The Superior Ridge deposits are probably the result of uranium deposition in sandstone bodies formed by deposition in tributaries flowing south to the main river. These sandstone bodies may have served as ground-water conduits. Paleostream flow in the upper Sespe Creek area was to the southwest (Bohannon, 1976) and traces of uranium that was deposited along upper Sespe Creek, probably also were deposited in sandstone bodies formed in channels of south-flowing tributaries.

Paleo ground-water flow in the lower transitional Sespe was probably southward in the Superior Ridge area, inasmuch as this area lies north of Bailey's (1947) major stream. The uranium host rock in this area was deposited close to the beach; marine shells are found in lower Sespe gravels. Ground-water movement in these sediments would have been sluggish shortly after deposition because of the low hydrologic head near sea level. This sluggishness may have been contributory to preservation of the reducing environment in these rocks.

Host Rock

The main host rocks for uranium deposition are fluvial sandstone beds of the lower transitional Sespe Formation. These lower beds, laterally intertongue with nearshore marine sandstone of the underlying Coldwater Sandstone. No porosity or permeability measurements were made on the uranium host rocks, but they are reasonably well-sorted fluvial sandstones and as such probably had reasonably high initial permeability. The host rock is for the most part yellowish or pinkish gray medium-to coarse grained arkosic sandstone.

Reductant

The uranium mineralization and concretions are commonly centered around carbonized plant trash and other carbonaceous material that may have originated as humate. The carbonaceous material apparently provided the reductant because nearly all of the mineralization is associated with it. A stagnant reducing and possibly acidic environment was apparently maintained in the lower beds of the Sespe near the marine coastline.

The humate was apparently formed by the precipitation of humic substances dissolved in the ground water. The physical and chemical conditions that flocculated or precipitated modern humate along the Florida coast may have included adsorption of cations, complexing with clay colloids, or a lowering of the pH (Swanson and Palacas, 1965). These conditions may have been supplied during deposition of the lower transitional Sespe by intermingling of marine and fresh ground and surface waters near the coast. The origin of humate deposits in the Sespe may have been similar to that of the Florida humates.

Preservation

Uplift during the Oligocene and Miocene was probably not sufficient to expose the uranium deposits to destruction although modification of the deposits might have occurred. Large-scale tectonic events which elevated and exposed some of the lower Sespe beds to destructive alteration such as is presently occurring at Superior Ridge probably did not happen until the Pleistocene. Present uranium deposits appear to be only erosional remnants of what previously existed and this condition may be the most limiting factor in the presence now of widespread favorable ground.

Summary of Model

The source of uranium for the Sespe deposits is believed to be the granitic and volcanic material that makes up the clasts in the Sespe. Uranium leaching apparently occurred under semi-arid conditions in which alkaline bicarbonate rich oxidizing ground water formed. Ground-water movement, following paleo drainage patterns, was probably southward and westward through the Sespe sediments. Sandstone bodies deposited in channels, tributary to a main trunk stream or emptying directly into the sea, served as host rock. The reductant was probably plant material and humate trapped in channel sandstone bodies near the sea coast where encroachment of marine water altered chemical conditions in the ground water and precipitated the humate (fig. 7). Initial mineralization occurred shortly after and maybe even during Sespe deposition, before significant structural warping and before diagenetic formation of iron oxide in the upper part of the Sespe.

AIRBORNE RADIOMETRIC AND SOIL GAS MEASUREMENTS

Part of the area was surveyed with airborne radiometric instruments. Variation in radiometric background levels appear to make the data somewhat equivocal, nevertheless, certain generalizations can be made (Dickinson, Frizzell and Morrone, 1983). A rather distinct anomaly reaching 5.87 ppm eU_3O_8 occurs over the Payoff claims on Superior Ridge even though the background radiation level in this area seems to be relatively low. A slight radiation high also occurs over the Hartman Ranch area where minor uranium mineralization is known in the lower Sespe. The radiation high at Hartman Ranch reaches a maximum of only 4.07 ppm eU_3O_8, which is lower than various other anomalies scattered around the area. The Coldwater Sandstone projects a regional radiometric low. Other units do not seem to be consistently high or low including the lower part of the Sespe Formation. A prominent series of radiometric highs extends northwestward through the Wheeler Springs 7 1/2-minute quadrangle and a broad high is present in the east central part of the Ojai 7 1/2-minute quadrangle over the Miocene Rincon and Monterey Formations. The relation between these highs any possible uranium deposits is not known.

Unpublished work by Bowles and Reimer (1983) on helium in soil gases suggests a relation between helium and the radiometric anomalies. They have suggested that the radiometric anomalies are caused by radon gas associated with the helium gas that is generated by uranium deposits. The gases migrate away from the rocks that produced them ,and ,for this reason, the radiometric anomalies may not accurately reflect the surficial geology or the location or size of uranium deposits.

ELEMENTAL ASSOCIATIONS

For slightly mineralized and mineralized rocks, it is not possible to determine which has been mineralized and which has not from the uranium content alone. There is a strong correlation between uranium and vanadium and between uranium and molybdenum in rocks that have been mineralized, and for this reason higher vanadium and molybdenum values in a particular sample are evidence that it has been mineralized. In addition, the Th/U ratio is low for mineralized rocks, and generally if the rock is mineralized only an upper limit for thorium can be determined (Millard, 1976). Examination of the data in tables 2 and 3, suggests that rock with over 10 ppm uranium has been mineralized. Some samples with between 5 and 10 ppm uranium may also been slightly mineralized.

The correlation coefficient for uranium and vanadium in samples containing more than 10 ppm uranium is +.86 which establishes a correlation at above the 99 percent confidence level for 10 samples. The correlation between uranium and vanadium in samples containing less than 10 ppm uranium is -.03 which is insignificant for 25 samples. In all the samples listed in tables 2 and 3 the coefficient of correlation between uranium and thorium is +.38 which is significant at the 95 percent confidence level for 35 samples. A correlation also apparently exists between uranium and molybdenum. Only one sample with over 10 ppm uranium shows undetectable molybdenum and only one sample with less than 10 ppm uranium shows detectable molybdenum. The correlation between both uranium and vanadium and uranium and molybdenum is common in epigenetic uranium deposits. (Shoemaker and others, 1959). Correlations between uranium and other elements may exist, for instance the two uranium mineralized samples of Monterey Formation contain more than 10 times the amount of copper found in the other mineralized samples, but too little data is available to establish a link between copper and uranium in the Monterey samples.

FAVORABLE AREAS

Although minor uranium enrichment has been found in different geologic formations in the Ventura area the only known deposits of potentially commercial interest are the Superior Ridge deposits. For this reason, only the lower transitional part of the Sespe is considered to have potential for such deposits. Based on the uranium mineralization model for the Sespe, presented here, the south-westerly movement of uranium bearing ground water apparently encountered sufficient reductants in fluvial sediment near the ancestral marine coast. For this reason the most favorable areas for uranium deposition are in the lower part of the Sespe Formation in the western part of the Ventura Basin. Porous channel sandstones with sufficient chemical reductant are predictable in an area that includes 5-10-km-wide belt extending from Ojai westward and passing north of Rincon point on the Pacific coast. Favorable rock is mostly in the subsurface in this area and uranium exploration will be expensive because deposits cannot be found without drilling. Nevertheless, industry exploration would be expected in parts of this favorable area during periods of high uranium demand.

The upper Sespe Creek area is also favorable for uranium deposits, but less so than the Superior Ridge area. The original discovery there, of samples containing as much as 0.64 percent uranium, the presence of the Coldwater-Sespe contact, and the presence of a minor radioactive anomaly in the vicinity of Hartman Ranch (Dickinson and others, (1984) suggest that it is a favorable area. Certainly the possibility of commercial deposits there cannot be ruled out, but on the other hand, certain characteristics of the Upper Sespe Creek area are unfavorable. The radioactive anomaly over the Hartman Ranch area is not as prominent as several other anomalies in the upper Sespe Creek area the lower Transitional member of the Sespe Formation is not present in the Upper Sespe Creek Area; and the lower contact with the Coldwater Sandstone is locally unconformable. Humate deposition that would have localized uranium deposition would have been unlikely in this environment and no carbonaceous material likely to have had a humate precursor was found.

In several areas where the Coldwater Sandstone-Sespe contact crops out in the northern and eastern parts of the Ventura Basin no indication of uranium mineralization was found nor were airborne radiometric measurements anomalously high in these areas (Dickinson and others (1984).

In summary, the only favorable area of definite commercial interest, is the Superior Ridge area. Commercial deposits in other areas while less likely cannot be ruled out completely.

REFERENCES

Bailey, T. L., 1947, Origin and migration of oil into Sespe Redbeds, California: Amer. Assoc. Petroleum Geologists, v. 31, n. 11, p. 1913.

Bohannon, R. G. 1976, Mid-Tertiary rocks along the San Andreas Fault in southern California: Ph. D. dissertation, University of California (Santa Barbara), 311 p.

Bowes, W. A., and Myerson, B. L., 1957, Sandstone-type uranium occurrences in White Ledge Peak area, Ventura County, California: U.S. Atomic Energy Commission, RME 2073 20 p.

Butler, A. P. Jr., 1969, Ground water as related to the origin and search for uranium deposits in sandstone in R. B. Parker, editor Contributions to Geology: Wyoming Geological Assn. v. 8 n. 2 pt. 1 p. 81-85.

Dibblee, T. W., Jr., 1972, Stratigraphy of the southern coast ranges near the San Andreas Fault from Chalome to Maricopa, California: U.S. Geological Survey, Prof. paper 764, 45 p.

Dickinson, K. A., Frizzell, V. A., Jr., Bowles, C. G., and Morrone, J. F., (1984) Airborne radiometric survey, geochemical data, and uranium occurrences in west-central Ventura County, California: U.S. Geological Survey, Open-File Report, 82-818C.

Dickinson, W. R., and Lowe, D. R., 1966, Stratigraphic relations of phosphate- and gypsum-bearing upper Miocene strata, upper Sespe Creek, Ventura County, California: Amer. Assoc. of Petroleum Geologists Bulletin, v. 50, no. 11, p. 2464-2481.

Durham, D. L., 1979, Uranium occurrences in the Temblor Range, Kern and San Luis Obispo Counties, California: U.S. Geol. Survey, Map MF-1047.

Goldberg, E. O. 1963, The Oceans as a chemical system, in Hill, M. N., ed., The Sea: New York Interscience, v. 2, p. 3-25.

Hill, M. L., Carlson, S. A., and Dibblee, T. W., Jr., 1958, Stratigraphy of Cuyama Valley-Caliente Range area, California: Amer. Assoc. of Petroleum Geologists, v. 42, no. 12, p. 2973-3000.

Jackson, Patrick A., and Yeats, Robert S., 1982, Structural evolution of Carpenteria Basin, Western Transverse Ranges, California: Amer. Assoc. Petroleum geol., Bull., v. 66, n. 7, p. 805-829.

Kew, W. S. W., 1924, Geology and oil resources of part of Los Angeles and Ventura Counties, California: U.S. Geol. Survey Bull. 753, 202 p.

Lowe, D. R., 1969, Santa Margarita Formation (upper Miocene), upper Sespe Creek area, Ventura County, California in upper Sespe Creek 1969 field trip, W. R. Dickinson, Chairman: Soc. Econ. paleontologists and mineralogists, Pacific Coast Section, p. 56-61.

Luyendyk, B. P., Kamerling, M. J., and Terres, Richard, 1980, Geometric model for Neogene crustal rotations in southern California: Geological Society of America Bulletin, Part 1, v. 91, p. 211-217.

McCracken, Willard A., 1969a, Sedimentary structures and Paleocurrent analysis of Sespe Formation, Ventura Basin, California: American Association of Geologist, Bull. v. 53, p. 463.

McCracken, Willard A., 1969b, Sespe Formation on upper Sespe Creek, in Taylor, J. C., and Dickinson, W. R., chairmen, Upper Sespe Creek, 1969 Field trip: Soc. Economic Paleontologists and Mineralogists, Pacific Coast Section, p. 41-48.

Millard, H. T., Jr., 1976, Determinations of uranium and thorium in U.S.G.S. standard rocks by the delayed neutron technique: U.S. Geol. Survey Prof. Paper 840, p. 61-65.

Moser, Fredrika C., and Frizzell, Virgil A., Jr., 1982, Geologic Map of the Lion Canyon, Matilija, Ojai, Wheeler Springs, and White Ledge Peak Quadrangles, California: U.S. Geological Survey, Open-File Map 82-818A.

Reed, R. D., 1929, Sespe Formation, California: Amer. Assoc. petroleum Geologists, Bull. v. 13, n. 5, p. 489-507.

Reinhart, P. W., 1928, Origin of the Sespe Formation of South Mountain, California: Bull. A.A.P.G. v. 12, p. 743-746.

Rogers, J. J. W. and Adams, J. A. S., 1978, Thorium: abundance in common igneous rocks, in Wedepohl, K. H., ed. Handbook of Geochemistry v. II/5, Chapter 90, p. EI-3.

Rogers, J. J. W. and Richardson, K. A., 1964, Thorium and uranium contents of some sandstones: Geochim Cosmo chim Acta 28, 2005.

Shoemaker, E. M., Miesch, A. T., Newman, W. L. and Riley, L. B., 1959, Part 3. Elemental composition of the sandstone-type deposits in Garrels and Larsen: U.S. Geol. Survey Prof. paper 320, p. 25-54.

Swanson, V. E. and Palacas, James G., 1965, Humate in Coastal sands of northwest Florida: U.S. Geological Survey Bulletin 1214 B, p. B-1 - B-29.

Vedder, J. G., Wagner, H. C., and Schoellhamer, J. E., 1969, Geologic framework of the Santa Barbara Channel region: U.S. Geol. Survey, Prof. Paper 679A, p. 6-7.

Watts, W. L. 1897, Oil and gas yielding formations of Los Angeles, Ventura and Santa Barbara Counties [Calif.]: California Min. Bur. Bull. 11, p. 22-28.