RECONNAISSANCE SURVEY OF UPPER NEOGENE STRATA IN THE BOUSE FORMATION, HUALAPAI LIMESTONE, AND LOWER GILA RIVER TROUGH, WESTERN ARIZONA AND DIRECTLY ADJACENT SOUTHEASTERN CALIFORNIA

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INTRODUCTION

Radon is a naturally occurring, colorless, odorless, radioactive gas that is produced during the radioactive decay of uranium. The average person in the US receives more radiation from decay of short lived radon daughter products than all other sources of radiation combined. Virtually all of this exposure is to the lungs, and lung cancer is the only known consequence of exposure. The US Environmental Protection Agency has supported research on the distribution of geologic materials with elevated concentrations of uranium in order to identify areas that are at significant risk for elevated indoor radon levels. Over the past decade surveys of uranium in Arizona by the Arizona Geological Survey have identified Neogene (≈2 to 25 million years old) calcareous lake sediments as the most common rock type in the state that is associated with elevated uranium concentrations (Spencer, 1992, 1993).

Neogene sediments and sedimentary rocks are exposed at the Earth's surface or buried in the subsurface over much of western Arizona. The Bouse Formation in particular is exposed over a large area of rapid population growth and contains calcareous sedimentary strata. The Bouse Formation has been considered to be marine on the basis of paleontological studies, and consequently has not been the target of uranium surveys because marine calcareous strata generally do not contain elevated concentrations of uranium. Recent strontium isotopic analyses support a non-marine origin, however (Spencer and Patchett, unpublished manuscript submitted to GSA Bulletin), and prompted a re-evaluation of the Bouse Formation and related strata as potential sources of hazardous radon gas. This report presents several sets of data, as follows: (1) *in situ* measurements of uranium in the Bouse Formation and Hualapai Limestone (Harris), (2) oxygen and carbon isotopic analyses of two barnacle fragments from the Bouse Formation that were done to assess its marine versus non-marine character (Dettman), (3) strontium isotopic analyses of two subsurface samples of gypsum from water wells in the lower Gila River trough that were done to assess the marine versus non-marine character of these sediments and to assess any relation to the Bouse Formation (Patchett), and (4) logs of water wells in the lower Gila River trough that were recorded to assess the potential subsurface extent of calcareous sediments (Harris). Our general conclusion is that the Bouse Formation and Hualapai Limestone are both non-marine and both contain elevated concentrations of uranium. Limestone and marl like that in the Bouse Formation and Hualapai Limestone was not, however, recognized in the subsurface in the lower Gila River trough.

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BOUSE FORMATION URANIUM SURVEY

Overview

Calcareous sedimentary strata at the base of the Bouse Formation contain fossils that have been interpreted as indicating deposition in an estuary (Metzger, 1968; Smith, 1970). In contrast, recently acquired Sr isotopic data support a lacustrine origin, and reveal no evidence of marine water input into the Bouse basin, even in the areas of its southernmost exposures that were presumably closest to the proto-Gulf of California at the time of deposition (Spencer and Patchett, unpublished manuscript submitted to GSA Bulletin). Calcareous lacustrine strata commonly have anomalously high uranium levels and are the single most important rock type in Arizona with regard to radon gas production. The Bouse marl is widespread in the lower Colorado River trough, either in exposures or in the subsurface, and is in an area of rapid population growth (Metzger and Loeltz, 1973; Metzger and others, 1973).

Because of the possibly lacustrine nature of the Bouse Formation and its aerial extent and location, the Bouse marl was surveyed for uranium levels to assess its significance as a potential source of radon gas, a known geologic hazard (Table 1; Figure 1). Uranium measurements were made by Ray Harris using a portable gamma-ray spectrometer. Techniques used were the same as for many earlier surveys (Duncan and Spencer, 1993). It was found that uranium levels are moderate and commonly anomalous in the Bouse Formation marl, and are in fact typical of Cenozoic calcareous lake beds in Arizona. The average level of 14 measurements was 5.6 ppm U. Six measurements were greater than 6 ppm U, which is considered the maximum level for non-anomalous rocks in Arizona (Duncan and Spencer, 1993). The highest of the fourteen measurements, 14 ppm U, is not greatly anomalous, but is sufficiently high that the likelihood of anomalous radon levels in homes built on these sediments is significantly increased (Spencer, 1993).

The Hualapai Limestone member of the Muddy Creek Formation (Blair and Armstrong, 1979) was also surveyed for uranium in two fairly small areas (Table 2). Seven measurements made in one area averaged 102 ppm U, with the highest measurement at 151 ppm U. Three measurements in another area averaged 11 ppm U. The Hualapai Limestone is largely within the Lake Mead Recreation area and is not likely to be the site of many new homes and buildings. If any should be built on it, however, our very brief survey suggests that anomalous radon levels have a significantly increased probability of developing in overlying buildings.

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Table 1

Cibola Area (Bouse Formation)

Site	U counts	Th counts	U (ppm)
(1) Cibola 7.5-min quad	4.22	2.57	7
T2S R23W sec 16 nw,nw; elev 400'	4.56	2.40	
light-colored marl 20' below top of hill			
(2) Cibola 7.5-min quad			
T2S R23W sec 16 nw,nw; elev 420'	3.30	2.53	1
(a) 100 yds south of #1, near top	3.43	2.45	
coarse barnacle hash			
(b) same unit, top of mesa	2.66	2.55	0
	2.90	2.45	
(3) Cibola quad			
T2S R23W sec 9 sw,sw; elev 300'	4.54	2.47	7
NE of wash intersection	4.45	2.57	
white marl, middle of section			
(4) Cibola quad			
T2S R23W sec 9 sw,sw; elev 350'	4.57	2.96	5
(a) white marl, 1-2 ft thick, below orange layer	4.22	3.12	
(b) orange layer - gravel	4.91	3.65	5
(5) Cibola quad			
T2S R23W sec 9 se,sw, elev 360'	4.26	2.60	6
100 yds north of #4	4.19	2.41	
(a) white marl above orange layer			
(b) barnacle hash above white marl	3.56	2.61	2
(6) Cibola quad			
T2S R23S sec 16 sw,ne, elev 375'	4.07	3.15	2
silt layers in gravel	3.94	3.49	

Parker Area (Bouse Formation)

site	U counts	Th counts	U (ppm)
Osborne Wash, Crossroads 7.5-min quad			
T9N R19W sec 1 sw, elev 600'			
(1) Osborne Wash at Shea Road	5.46	3.04	10
(a) white marl	5.97	3.12	
(b) same location	4.67	4.54	2
brown clay above white marl	5.07	4.69	
	5.15		
(2) first small drainage south of #1	5.40	2.96	9
same white marl as #1a	5.47	3.23	
		3.16	
(3) bench in small drainage, 100 yds W of #2	5.29	3.02	8
white marl	5.20	3.13	
(4) Parker 7.5-min quad			
T1N R25E sec 24 (in California), elev 400'	6.12	3.66	14
Highway intersection at Earp, CA	7.56	3.39	
yellow marl	6.14		

Table 2

Lake Mead - Temple Bar Area (Hualapai Limestone)

Site	U counts	Th counts	U (ppm)
Senator Mountain NW 7.5-min quad			
T20N R20W sec 22 (unsurveyed):			
(1) 50 ft to right of prospect adit, elev 2000'	36.56	4.96	151
alternating white and brown marl	37.46	4.73	
	36.55		
(2) at prospect adit	30.25	4.0	122
10' stratgraphically below #1	29.92	4.64	
alt. red-brown and white marl	30.67		
(3) 100' left (SE) of adit	36.51	4.66	150
5' strat. above #1	36.74	4.72	
white marl			
(4) first road intersection below adit, elev 1960'	19.65	3.51	74
strat. above(?) #3 (layers are in anticline)	19.57	3.13	
marl			
(5) road cut at lower saddle, elev 2050'	8.47	2.67	24
white marl, some gypsum crystals	8.86	3.26	
	8.60		
(6) road intersection at second saddle (near top)	35.77	3.67	147
marl; elev 2100'	35.16	4.29	
(7) road up toward top, elev 2130'	13.41	3.31	45
green cherty layer above tuff	13.14	3.0	
Senator Mountain 7.5-min quad			
T30N R19W sec 20, nw, center, elev 2000':			
(1) marl slabs at bottom of hill	6.06	2.66	9
(blocks that fell from top of hill)	5.55	2.94	
(2) silt near bottom	5.52	3.04	10
	5.73	3.07	
(3) red clay-silt	7.10	3.42	15
1/2 way up hill	6.97	3.35	

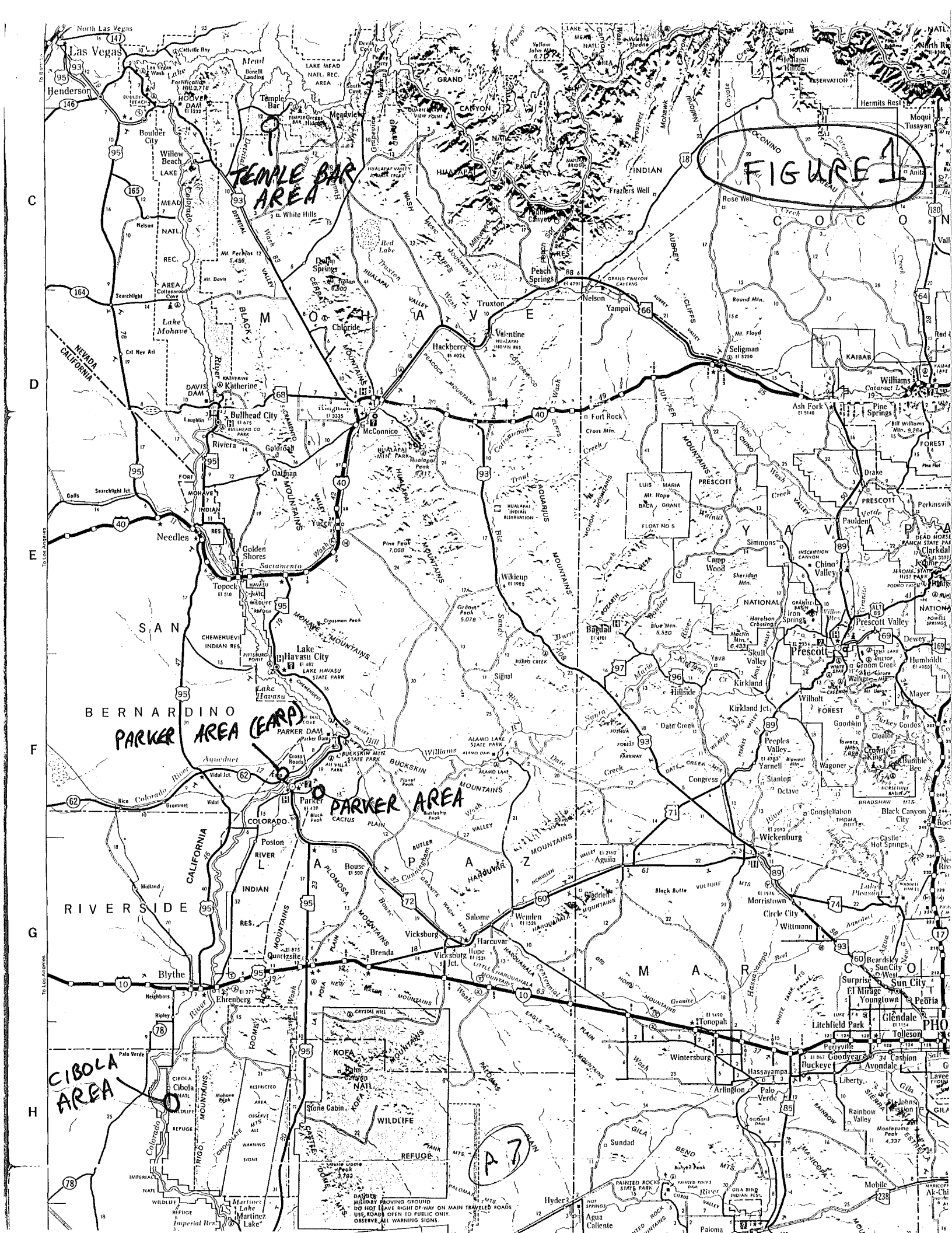
FIGURE 1
TEMPLE BAR AREA
PARKER AREA (EARP)
PARKER AREA
CIBOLA AREA
A 7
Las Vegas
North Las Vegas
Henderson
Boulder City
Temple Bar
Meadview
Willow Beach
Nelson
White Hills
Dolan Springs
Chloride
Kingman
Hackberry
Valentine
Truxton
Peach Springs
Yampai
Seligman
Williams
Ash Fork
Fort Rock
Drake
Prescott
Prescott Valley
Chino Valley
Paulden
Perkinsville
Jerome
Clarkdale
Cottonwood
Camp Wood
Simmons
Skull Valley
Kirkland
Hillside
Wilhoit
Kirkland Jct.
Date Creek
Congress
Wickenburg
Morristown
Circle City
Wittmann
Aguila
Gladden
Wenden
Salome
Vicksburg
Brenda
Quartzsite
Blythe
Ehrenberg
Parker
Poston
Bouse
Harcuvar
Hope
Tonopah
Wintersburg
Hassayampa
Arlington
Palo Verde
Buckeye
Goodyear
Avondale
Litchfield Park
Glendale
Peoria
Youngtown
Surprise
El Mirage
Sun City
Beardsley
Cashion
Tolleson
Liberty
Rainbow Valley
Sundad
Stone Cabin
Needles
Topock
Lake Havasu City
Golden Shores
Bullhead City
Katherine
Riviera
Oatman
Yucca
McConnico
Fort Mohave
Searchlight
Cottonwood Cove
Lake Mohave
Lake Mohave
Lake Havasu
Lake Havasu City
Lake Mead
Hoover Dam
Grand Canyon
Hualapai Hilltop
Supai
Hermits Rest
Moqui Tusayan
Anita
Rose Well
Frazers Well
Round Mtn.
Mt. Floyd
Kaibab
Pine Springs
Drake
Bagdad
Wikieup
Signal
Alamo Lake State Park
Cibola
Martinez Lake
Imperial Res.
Palo Verde
Agua Caliente
Paloma
Hyder
Mobile
Gila Bend
Sundad
Stone Cabin
Kofa Wildlife Refuge
Colorado River
Gila River
Bill Williams Mtn. 9,264
Mt. Perkins 5,456
Mt. Davis
Hualapai Peak
Pine Peak 7,068
Groom Peak 5,078
Crossman Peak
Blue Mtn. 5,550
Sheridan Mtn.
Mazatzal Mtn. 6,433
Mt. Hope
Kaibab Lake
Lake Mohave
Lake Havasu
Lake Havasu State Park
Alamo Lake State Park
Buckskin Mts. State Park
Parker Dam
Cross Roads
Vidal Jct.
Aqueduct
Colorado River
Gila River
Bill Williams River
Santa Maria River
Date Creek
Williams Wash
Kofa Mountains
Castle Dome Mts.
Dome Rock Mts.
Chocolate Mts.
Cibola Wildlife Refuge
Kofa Wildlife Refuge
Imperial Wildlife Refuge
Martinez Lake
Yuma Proving Ground
Military Proving Ground
Do not leave right of way on main traveled roads
Use roads open to public only.
Observe all warning signs.
Nevada
California
Arizona
Riverside
San Bernardino
Coconino
Mohave
Yavapai
Maricopa
Pima
Pinal
Gila
Yuma
To Los Angeles
To Barstow

STABLE ISOTOPE ANALYSIS OF TWO BARNACLE FRAGMENTS

Paleontologic studies have supported a marine origin for the Bouse Formation (Metzger, 1968; Smith, 1970) whereas Sr isotopic studies support a non-marine origin (Buising, 1988; Spencer and Patchett, unpublished manuscript submitted to GSA Bulletin). To further assess the marine versus non-marine origin of the Bouse Formation, two samples of barnacles were analyzed for oxygen isotopes by D. Dettman (Table 3). The samples were also analyzed for carbon isotopes (Table 3).

Approximately 0.1 mg of carbonate were drilled from two barnacle fragments for stable isotope analysis. The two fragments were taken from the samples used in $^{87}Sr/^{86}Sr$ measurements by P.J. Patchett and reported by Spencer and Patchett (unpublished manuscript). Samples were heated at 380°C in vacuum to drive off any volatile compounds and analyzed on a Finnigan MAT 251 gas-ratio mass spectrometer with an automated carbonate preparation line ("Kiel Device") at the University of Michigan. Measurement accuracy, based on daily measurement of standard carbonates, is ± 0.1‰ for $\delta^{18}O$ and ± 0.05‰ for $\delta^{13}C$ (1σ).

Table 3

Sample	$\delta^{18}O$ (PDB)	$\delta^{13}C$ (PDB)
95BS-3 (Cibola area)	-5.6	0.15
95BS-17 (Milpitas Wash)	-8.8	1.25

The oxygen isotope composition of biogenic calcite is controlled by three factors, as follows: (1) isotopic composition of the water, (2) temperature, (3) biological effects. Biological effects refer to differences between the $\delta^{18}O$ of shell calcite and the $\delta^{18}O$ of inorganic calcite precipitated in the same environment. Although biological effects in barnacles have not been studied closely, it seems that they are small. Killingley and Newman (1982), the only study to date that has examined biological effects in barnacles, measured a constant positive offset of 1.3‰. Temperature affects the $\delta^{18}O$ of calcite at a rate of 4 or 5°C for each 1‰. Thus an increase of ~ 4.5°C will decrease the $\delta^{18}O$ of shell by 1‰. Changes in the isotopic composition of ambient water are reflected on a 1 to 1 basis in the isotopic composition of the shell. (See Anderson and Arthur [1983] for an introduction to stable isotopes in shelled organisms.)

The $\delta^{18}O$ of these two samples is much more negative than the few measurements in the literature of marine barnacles. Wefer (1985) reports a range of -0.18‰ to +1.05‰ for barnacles collected in Harrington Sound, Bermuda, growing at temperatures of 20 to 28°C. Killingley (1980) reports values ranging from 0 to +1‰ for the most recent shell growth of *Cryptolepas* barnacles collected from a whale beached near San Diego. The 6 to 9‰ difference between our samples and the modern marine barnacles is too large to be attributable solely to temperature (-6‰ suggests waters 27°C warmer, -9‰ suggests 40°C). The most reasonable explanation is that the isotopic composition of the waters in which the barnacles were growing was much more negative than either modern seawater (averaging 0.0‰ SMOW) or Mio-Pliocene seawater (~ -0.3‰ SMOW; Savin et al, 1985). The large difference between the two samples suggests that they came from two different bodies of water, separated in time or space, with very different isotopic compositions. If we assume no biological effects and that the shells grew in warm water (28°C), the isotopic composition of the water was -6.1‰ SMOW for sample 95BS-17 and -2.9‰ SMOW for sample 95BS-3 (using the calcite fractionation in Friedman and O'Neil, 1977). For comparison, modern rainfall in the Tucson basin averages -6‰ SMOW, Colorado River water in southern Arizona varies between -11 and -12‰ SMOW, the Salton Sea is approximately 0.0‰ SMOW (Dettman, unpublished data) and open ocean water ranges from -0.4 to 0.6‰ (Craig and Gordon, 1965).

Diagenesis can modify the isotopic composition of calcite, almost always leading to more negative $\delta^{18}O$ values. In thin section, the barnacles are appear virtually identical to modern barnacle fragments from the Salton Sea except that the Bouse barnacles contain a very small fraction of sparry calcite encrustation. Diagenetic alteration of the oxygen isotopes is possible, but petrographic examination reveals so little evidence of

recrystallization that it seems highly unlikely that the oxygen isotopic composition of the barnacles is substantially modified. We conclude that the barnacles were not derived from seawater.

The carbon isotope composition of barnacles is the result of a mixture of dissolved inorganic carbon and metabolic (food) carbon (Tanaka et al., 1986). This results in a very wide range of possible $\delta^{13}C$ values in either marine or fresh waters. As a result the $\delta^{13}C$ tells us little about the body of water in which these barnacles lived.

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TWO Sr ISOTOPIC MEASUREMENTS OF GYPSUM FROM WELLS IN THE LOWER GILA RIVER TROUGH

Overview

Both the Bouse Formation north of the Chocolate Mountains and the marine strata and shells in the Salton Trough have distinctive $^{87}Sr/^{86}Sr$. Eighteen samples of Bouse Formation sediments and shells yielded $^{87}Sr/^{86}Sr$ between 0.7102 and 0.7114 (0.7108±0.0006; 15 samples analyzed by P. J. Patchett [reported by Spencer and Patchett, unpublished manuscript submitted to GSA Bulletin] and three samples from Buising, 1988). Modern Colorado River water, with $^{87}Sr/^{86}Sr$ of 0.71075 (Goldstein and Jacobsen, 1987) is close to the center of the range of $^{87}Sr/^{86}Sr$ for the Bouse Formation. These values are all far removed from late Neogene sea water (0.7090±0.0001; DePaolo, 1986; Hodell and others, 1990). Two analyses of shell fragments from the subsurface near Yuma, from within sediments correlated with the Bouse Formation by Eberly and Stanley (1978), yielded $^{87}Sr/^{86}Sr$ within the range of late Neogene seawater Sr (Spencer and Patchett, unpublished manuscript submitted to GSA Bulletin).

Two subsurface samples of gypsum from the lower Gila River trough were analyzed by P.J. Patchett for $^{87}Sr/^{86}Sr$ to determine if these sediments are marine or are related to the Bouse Formation (Table 4). The analyses yielded $^{87}Sr/^{86}Sr$ of about 0.7101 which is outside the range of both Bouse Formation samples and late Neogene seawater. The gypsum is therefore considered to be derived from a different source and was likely deposited in terrestrial basins that included playas where the gypsum was deposited.

Sample preparation and analytical methods

Chemical separations followed published techniques (Patchett and Ruiz, 1987). Measurements from the Department of Geosciences VG-354 multicollector mass spectrometer at the University of Arizona have shown a significant shift in $^{87}Sr/^{86}Sr$ since 1987, coupled with an increased variance for measurements of Sr standard NBS-987. Nineteen runs of NBS-987 with the samples of this study and that of Spencer and Patchett (unpublished manuscript) gave $^{87}Sr/^{86}Sr = 0.710224$ with one standard deviation of 0.000023, and $^{84}Sr/^{86}Sr = 0.056606$ with one standard deviation of 0.000053. $^{87}Sr/^{86}Sr$ measurement included dynamic gain-canceling and exponential mass fractionation corrections. $^{84}Sr/^{86}Sr$ was measured in static mode using a gain calibration. The mean $^{87}Sr/^{86}Sr$ is approximately 0.000025 less than our collectors yielded before 1991, and the range of results is 1.5-2 times wider.

In order to compare our measurements to Neogene sea water, we normalized our $^{87}Sr/^{86}Sr$ values to the NBS-987 value used by Hodell and others (1990; 0.710235) by adding 0.00001 to the ratios given in Table 1. We dealt with the problem of increased variance in our $^{87}Sr/^{86}Sr$ results by analyzing several samples in duplicate or triplicate. In one case (95BS-3), the three results show the full 0.00005 range of standard $^{87}Sr/^{86}Sr$ values, but all others agree much better than this, presumably a fortuitous effect. We assign an overall ±0.000030 error to mean $^{87}Sr/^{86}Sr$ for all samples, noting that this is a conservative error estimate in most or all cases. Rb and Sr concentrations were not measured because gypsum contains far more Sr than Rb and the samples are fairly young (<10 Ma). Measured $^{87}Sr/^{86}Sr$ is thus very close to initial $^{87}Sr/^{86}Sr$.

TABLE 4. Sr ISOTOPIC DATA (N.D. = no data)

Sample	Description	Rb (ppm)	Sr (ppm)	$^{87}Rb^{86}Sr$	$^{87}Sr/^{86}Sr$ [§]	$^{87}Sr/^{86}Sr_o$
Lower Gila River Valley						
Well 2149, 700'	gypsum	N.D.	N.D.	N.D.	0.710043±10	N.D.
Well 3079, 810'	gypsum	N.D.	N.D.	N.D.	0.710119±36	N.D.

[§] Errors given for individual measurements are in-run 2σ values only and apply to last two digits of measurement. Overall error in $^{87}Sr/^{86}Sr$ is ca. ±0.000030.

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WELL LOGS FROM THE LOWER GILA RIVER TROUGH

Overview

The following well logs (Table 5; Figures 2, 3) were produced by R.C. Harris during examination of well cuttings at the Arizona Geological Survey well cuttings storage facility (McGarvin and Trapp, 1994). The cuttings were examined with special attention to calcareous sedimentary rocks that could contain anomalous uranium levels and that could represent equivalents of the Bouse marls. In addition, special care was taken in searching for tuffaceous rocks that could be dated by geochronologic methods. Calcareous silt and clay are common in these well cuttings. Their calcareous nature was recognized by application of dilute HCl to small samples which, if calcareous, resulted in effervescence ("fizz" in logs). None of the calcareous material resembled the Bouse marls. Tuffaceous and other volcanic debris were recognized and were mixed with non-volcanic material, but no material was identified that contained potassium-bearing phenocrysts that could be used for geochronologic studies. Gypsum was also recognized in several wells, and two samples were analyzed for Sr isotopes (see above). The absence of marl and the abundance of gypsiferous sediments distinguish this unit from the Bouse Formation and suggest that the two are not correlative. Most likely, these sediments were deposited in non-marine basins and the gypsum was deposited in playas.

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Table 5: Well Logs (Depth in feed given in left-hand column; Locations shown in Figures 2 and 3)

Well 786 Auguste Casaretto T5S R11W sec 2 b
Cabinet C-40 815'-1000'

815	rock fragments (volc ?)
825	" " "
835	fine sand, mostly qtz
845-935	rock frag (volc?)
945-965	rock frag (qtz, volc)
975	clay, silt; strong fizz
985	fine rock frag, some clay, strong fizz in clay
995	similar, more clay
1000	mostly clay with some fine rock frag

Well 1130 Anderson Development T5S R10W sec 16
Cabinet D-37 60'-1150'

60	clay & silt, v strong fizz
80	1/2 clay, strong fizz; 1/2 white fine-grained frag (tuff?), weak fizz
90	mostly clay, strong fizz; some tuff(?) frag
100-150	mostly clay; some fine rock frag 110'
150	1/3 brown silt, 1/3 brown clay, 1/3 white tuff(?); mod fizz
150-500	clay & silt, strong to v strong fizz
500-950	-no samples-

950	qtz frag, minor clay (drill mud??, weak fizz)
950-1000	rock frag, minor clay
1010	clay, strong fizz; minor rx
1020-1150	rock frag

Well 2149 Caliente Farms T5S R10W sec 28 dcb

Cabinet E-44 175'-1218'

(irregular sample intervals)

175-255	v fine sand (lots of qtz, mica), slight fizz
255-500	-no samples-
500-605	silt with gypsum roses; slight fizz
650-755	clay with gypsum roses; barely fizzes (Sr isotopic measurement from this interval; see Table 4)
800-905	clay with gypsum roses; strong fizz
955-927	v f sand with gypsum; strong fizz
1000-1055	v f sand, minor gyp; weak fizz
1091-1093	gypsum roses, calcite; very strong fizz
1100-1105	clayey marl(?), gyp, white tuff(?), v f sand
1150-1205	v f sand, some gyp; mod fizz
1205-1213	volc frag with calcite in vesicles
1218	red vesicular cinders

Well 3079 Yuma Proving Grounds T5S R15W sec 29 adc

Cabinet J-20 (10-860), J-22 (870-1010), J-23 (1020-1450)

10-70	med sand
80-200	v f sand; slight fizz (small calcite frag)
200-420	silt, clay; v str fizz
420-510	clay-silt, gyp; str fizz
520-540	clay, minor gyp; str fizz
550-600	-missing-
610-750	clay, silt, gyp
750-800	silt, clay, no gyp
800-840	clay, clear gyp (Sr isotopic measurement from this interval; see Table 4)
850-860	silty clay, mod fizz; frag of volc ash (??), no fizz
870-920	clay, minor silt; str fizz
930	silt, str fizz
940	silt to v f sand; mod str fizz
950-1170	v f sand; v weak to no fizz
1180	silt, v f sand, calcite frag; str fizz
1190-1220	fine to med sand (dark volc)
1230-1250	clay, silt, v f sand; str fizz
1260	clay, gyp, silt; str fizz
1260-1300	similar, increasing silt, less clay, less gyp, less fizz
1300-1450	similar, increasing v f sand

Well 3195 Bureau of Sport Fish & Wildlife T5S R10W sec 23 dcc
Cabinet J-51 10'-400'

10-40	rock frag (granite, volc, gneiss)
50-80	" " (dark volc)
90-110	brown sand
120-230	med sand to gravel
240-280	med sand
290- 400	coarse rock frag

Well 3164A White Wing Ranch #18 T5S R12W sec 9 cca
Cabinet J-44 10'-1600'

10-530	rock frag
530	silt to fine sand; slight fizz
560-820	rock frag, lt gray
820-920	brown volc frag
930-1350	red volc frag
1360-1600	pink volc frag
	(**sequence of 530-1600 similar to sequence in wells 399 and 400**)

Well 783 Gila River Ranches T5S R5W sec 23 c or d
Cabinet C-40 31 samples 100'-1475'

100-175	silt to v f sand; wk to mod fizz
175-225	clay, silt, gravel; mod fizz
450	clay-silt (marly?); v str fizz
550	silty sand; mod fizz
575	sand & f gravel; v wk fizz
600	silt, sand, f grav
750	gravel
950, 975	fine grav, sand (mostly qtz) no fizz
1000	silt, sand; no fizz
1050	silt, minor sand; wk fizz
1125	silt, fine sand; wk fizz
1150	silt, minor v f sand; no fizz
1200	fine to med sand, minor silt; no fizz
1225	gravel
1250, 1275	med sand
1300-1475	v f sand to gravel; no fizz

Well 3737A J. Hadley T5S R5W sec 21 cdc
Cabinet O-7 156 samples 40'-1600'
Same location as well 3759A

50-80	sand, gravel

90-100	calcite-cemented silt & clay; str fizz
110-160	sand to f gravel
170	calite-cem. sand & vf sand
180	fine gravel
190-230	calcite-cem. silt-clay
240-end	coarse sand, gravel, rock frag
	(610' bedrock (??) - volc rock frag)
	(640' pink tuff)
	(990' rounded sand)
	(1000' volc frag)
	(1010' rounded sand)
	(1090' weathered volc or soil(?))
	(1440' v fine sand)

Well 3864 Bond T5S R5W sec 16 cdd
Cabinet M-16 54 samples 30'-560'

30-160	sand to fine gravel
170	silty clay (marl??), minor sand; v str fizz
180-270	sand, gravel (granitic & qtz)
280, 290	-no samples-
300-440	sand, gravel (granitic & qtz)
460-560	sand, v f gravel (dark volc)

Well 2484 No Name T5S R5W sec 23 dcd
Cabinet H-19 43 samples 80'-550'

80-150	gravel
160-210	fine sand, some gravel
220-360	gravel
370-420	fine sand, some gravel
430-500	gravel

Well 3759A J. Hadley T5S R5W sec 21 acc
Cabinet O-12 163 samples 60'-1680'
Same location as well 3737A

60-70	gravel
80	calcite-cemented sand to v f gravel
90-160	coarse sand to fine gravel
170	clay-silt; v str fizz
180	coarse sand
190-210	silt; v str fizz
210-260	coarse sand to fine gravel
270	silty clay; v str fizz
280	med sand
290	clayey silt; v str fizz
300-510	sand, gravel
520	-bedrock ??-

520-1680	volc rock frag (550 red-pink tuff) (1290 weathered(?) tuffaceous volc) (1300 f to med volc sand) (1310-1390 green volc (tuff?)) (1400-1520 volc frag) (1530 red, weathered volc or soil?) 1540-1630 volc frag)

Well 2859 Melvin Taylor T9S R17W sec 3 da
Cabinet I-36 400'-510'

400-510	fine to med sand, clean, some biotite, minor fizz

Well 61 US Bureau of Reclamation T8-9S R17-21W
Cabinet B-3

precise locations not given
all holes apparently 44 feet deep
some holes have brown to pink clay-silt

Well 399 Chapman and Lynch Well #1 T6S R14W sec 27 baa
Cabinet C-65 280'-900'

280-320	fine sand, calcite-cemented, clear gypsum; str fizz
320-340	silt-sand, " " " "
340-460	similar, less gyp, more clay, str fizz
460-620	same; clear gyp
620-640	similar, less gyp, more silt, minor fine qtz sand
640-680	silt to v f sand, str fizz; minor qtz sand and rock frag
680-700	rock frag (volc?)
700-780	rock frag, volc (weathered?)
780-840	red volc rock frag
840-900	light gray to pink tuff + red-pink volv (** 680'-900' similar to volc section in wells 3164A and 400**)

Well 400 Chapman and Lynch Well #2 T6S R14W sec 12 caa
Cabinet C-65 100'-750'

100-120	silt to v f sand, cemented with calcite, str fizz; minor med sand, rock frag
180-260	silt to v f sand, 1/3 gyp; str fizz
280-400	2/3 gyp, 1/3 silt; v str fizz
480-500	1/3 gyp, 1/3 silt, 1/3 v f sand; v str fizz
580-600	1/3 gyp, 2/3 silt, minor v f sand; "
600-610	light gray to pink tuff + red-pink volc frag
640-650	red-pink volc + lt gray tuff

690-700	tuff + volc
740-750	same
	(** volc section similar to wells 399 and 3164A ? **)

Well 3223 US Army - Yuma Proving Grounds T6S R15W sec 15 cab
Cabinet K-3 10'-1100'

10	soil (?)
20-30	volc frag
40	silt to v f sand, calcite cement, str fizz
50	2/3 silt to v f sand, 1/3 white marl(?); v str fizz
60	1/2 med sand, calcite cement, str fizz; 1/2 clean rock frag
70-100	sand
110-170	pea gravel
130	1/2 pea gravel, 1/2 limy silt; str fizz
140-280	silt to clay with calcite cement; v str fizz
280	limy clay, gypsum
280-1100	limy clay with increasing gyp to 850, then decreasing to end

Well 3240 Yuma Proving Ground T6S R18W sec 32 cbd
Cabinet K-5 10'-730'

10-730	sand to gravel, mostly volc + qtz (alluvium??); no clay, no fizz

Well 397 Howard P. Johnson T7S R12W sec 24 bdd
Cabinet C-65 20'-480'

20-180	sand to pea gravel (1/3 calcite-cemented sand); minor limy silt
200	coarse sand to gravel
220	sand, limy clay (marl?), v str fizz
8240	same
260	sand to pea gravel (volc)
280	same
300	fine sand, limy, str fizz; some clean coarse sand
340-480	sand to pea gravel, no fizz

Well 780 Chapman et al T7S R14W sec 24 c
Cabinet C-41 (20'-380'), C-50 (390'-1380')

20-230	coarse sand to gravel
240-260	limy clay (marl??), v str fizz
270	gravel
280-760	limy clay, v str fizz
	(minor gyp 500-530; more gyp 530-580, 690, 730)
	(some gravel 660-670; minor sand, gravel 720)
770-800	sand to gravel

810	sand + calcite-cemented silt to sand, str fizz
820	same
850	rock frag, silt
870	limy silt, v str fizz
880-1000	silt & pea gravel
1020-1340	clay (marl??), v str fizz, minor gyp
	(incr. silt 1200; minor v f sand 1250-1300)
1350-1380	>1/2 clay (marl??); <1/2 sand to gravel

Well 969 Dr. R.G. Barfoot T7S R15W sec 9/16
Cabinet C-49 20'-900'

20, 40	sand, gravel
60	clay (marl??); v str fizz
80-160	clay & gravel
180-670	clay (marl??), v str fizz
	(incr. silt to vf sand 360-600)
680-740	sand, gravel, clay
760-800	calcite-cemented sand and silt, v str fizz
820	same + some gravel
840	gravel
860	clay-silt (marl??); v str fizz
880-900	mostly gravel, minor limy silt

Well 1313 Desert Drilling/Keoughan Drilling #1 State T7S R13W sec 16 aa
Cabinet D-19 5 samples 490'-3250'

490-520	clay (marl??), gypsum; v str fizz
1690-1700	same
2780-?	1/2 limy clay; 1/2 rock frag
3000-3010	volc rock frag
3240-3250	same

Well 1575 No Name T7S R14W sec 24 aaa
Cabinets D-55 (205'-545'), D-56 (545'-685')

205-235	limy clay; minor gypsum, v f sand; str fizz
295-305	gypsum, clay; v str fizz
335-345	v f sand, weak fizz
455-465	gyp, limy silt, v f sand
475-485	gyp, minor silty clay; str fizz
485-495	gyp, limy clay; v str fizz
495-505	calcite-cemented silt, fine, round sand, minor gyp
525-685	limy clay, gypsum (roses); str fizz

Well 1676 Desert Drilling #1 State T7S R13W sec 16 aa
Cabinet E-2 1300'-6760'
Oil exploration hole

1300-1608	pink limy clay (marly??); v str fizz
1690-2350	pink-gray limy clay (marly??); v str fizz (minor sand, rock frag 2340)
2350-2400	red limy clay (marly??); v str fizz; minor silt, v f sand
break	
5000-5050	chocolate brown limy clay; v str fizz (looks like melted dark chocolate)
5050-6760	light gray volc frag (5510-5520 has some pink-gray clay - contamination???)

Well 1399 Rowe T4S R10W sec 3 aaa
Cabinet D-39 12 samples 198'-455'

198-455	sand, fine gravel, motly volc; no fizz

Well 1508 No Name T4S R10W sec 10 aa
Cabinet D-39 9 samples 198'-394'

198	sand; wk fizz
198-290	sand, fine gravel
290-330	sand; limy clay-silt frag, str fizz
333-351	clay-silt, rock frag; str fizz
351-374	silt, sand, fine gravel; wk fizz
374-394	silt, clay, fine sand; mod fizz

Well 2153 Max Christianson T4S R10W sec 21 bbb
Cabinet E-45 100 samples 150'-1280'

150-350	v f sand (no fizz except small calcite particles 210-220, 220-230)
360	fine gravel
370-600	v f sand
610-660	v f sand, fine gravel
670-1280	rock frag, mostly volc

Well 484 Theba #3 T6S R6W sec 1 ccb
Cabinet C-77 36 samples 185'-1513'

185-1513	similar throughout: mostly clay with silt, sand, gravel; no to wk fizz

WELL 1791 Gila Bend Feedlot T6S R6W sec 11 dc
Cabinet E-9 78 samples 160'-1130'

160-1130	entire hole fine sand, sand, gravel layers (180-230 fine sand, some calcite-cemented silt-clay & calcite grains) (270-280 same)

Well 2943 No Name T6S R6W sec 11 dcc
Cabinet I-43 46 samples 120'-1100'

120-240	sand , gravel
260-520	sand, minor pea gravel
530-660	fine gravel
680-800	sand , fine gravel
820-1100	fine gravel

Well 485 Short #2 T5S R6W sec 31 ddd
Cabinet C-77 580'-1554'

580-1554	similar throughout: mostly clay with silt, sand, gravel; no to wk fizz

Well 1838 USAF Gila Bend #3 T6S R5W sec 26 aaa
Cabinet E-15 66 samples 0'-650'

0-650	entire hole sand and gravel

Well 971 M.F. Permenter T4S R11W sec 12
Cabinet C-50, 51 40 samples 60'-1229'

60-193	fine to med sand, minor silt, wk fizz
193-910	med sand to gravel
920	clay-silt, v str fizz
942	sand to v f gravel; v wk fizz
960	silty sand
973-1229	sand; minor silt-clay

Well 2147 John Niedfelt T4S R11W sec 34 abb
Cabinet E-44 67 samples 100'-810'

100-230	gravel
230-250	fine sand
260-450	gravel
450-570	fine sand
570-580	gravel
580-600	fine sand
600-610	gravel

610-630	fine sand
630-760	silt, v f sand, gypsum (roses); weak fizz
760-810	gypsum, silt, minor v f sand; mod fizz

Well 2295 John Niedfelt T4S R11W sec 34 abb
Cabinet F-12 59 samples 800'-1495'
(** ?? deepening of well 2147 ??)

800-955	gypsum, clay, silt; str fizz
960-965	sand, fine gravel
970-975	calcite-cemented silt-clay, gyp, fine sand; v str fizz
980-1495	sand to fine gravel

Well 2178 Virgil Merril T4S R11W sec 21 bbb
Cabinet F-1 107 samples 205'-1300'

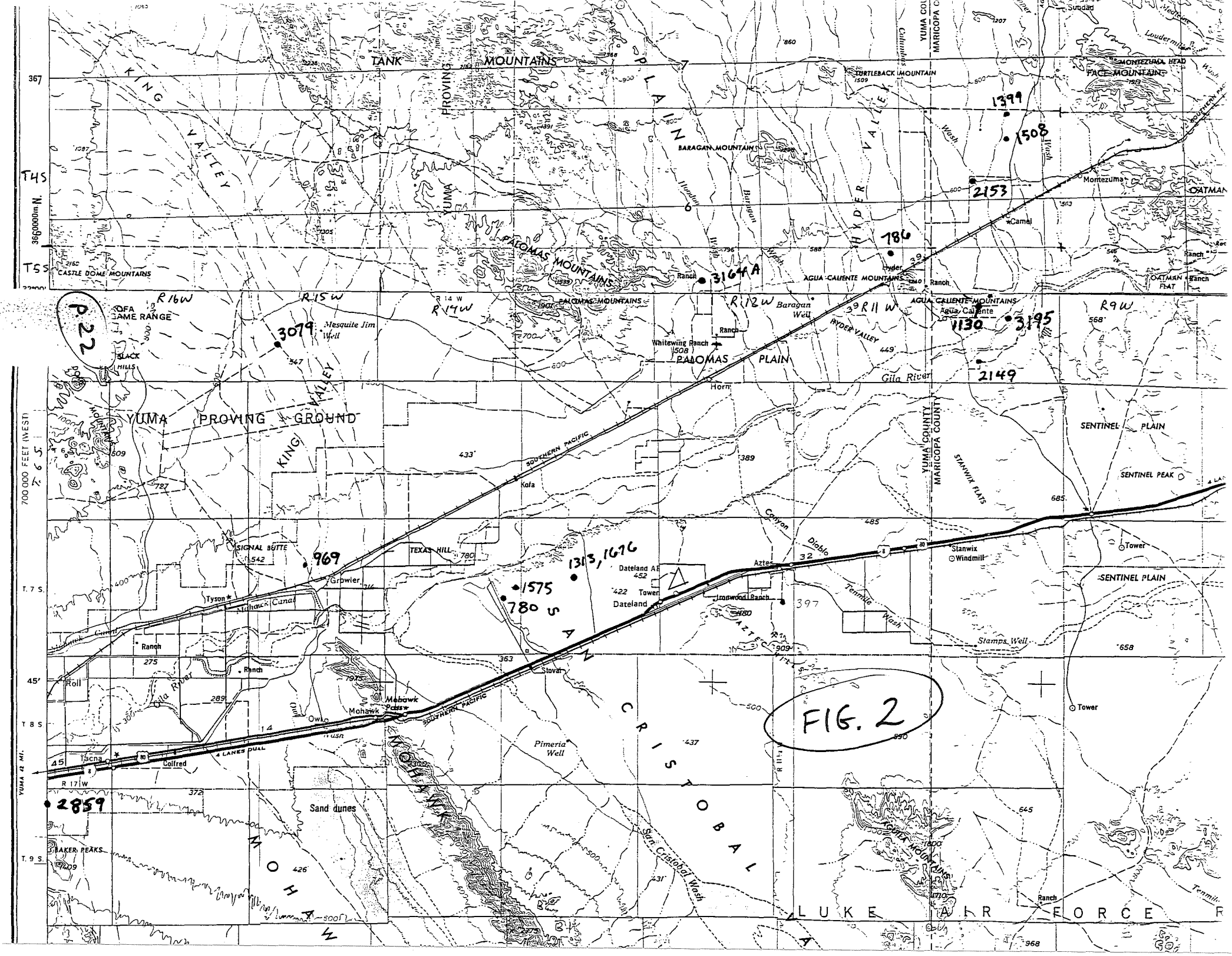
204-425	coarse sand to med gravel
425-450	v fine sand, clean, well-sorted
450-495	fine sand , fine gravel
495-545	fine sand
545-615	gravel, fine sand
615-625	gravel
625-785	fine sand
785-795	gravel
795-825	fine sand
825-1300	sand, gravel

Well 2181 Olson T4S R11W sec 23 bbb
Cabinet E-53 193 samples 10'-2000'

10-120	sand to fine gravel
120-130	sand, calcite-cemented silt
140-190	fine sand
200-260	coarse sand, minor fine sand
270-600	sand to fine gravel
600-700	v f sand
700-770	coarse sand to fine gravel
770-2000	sand to gravel

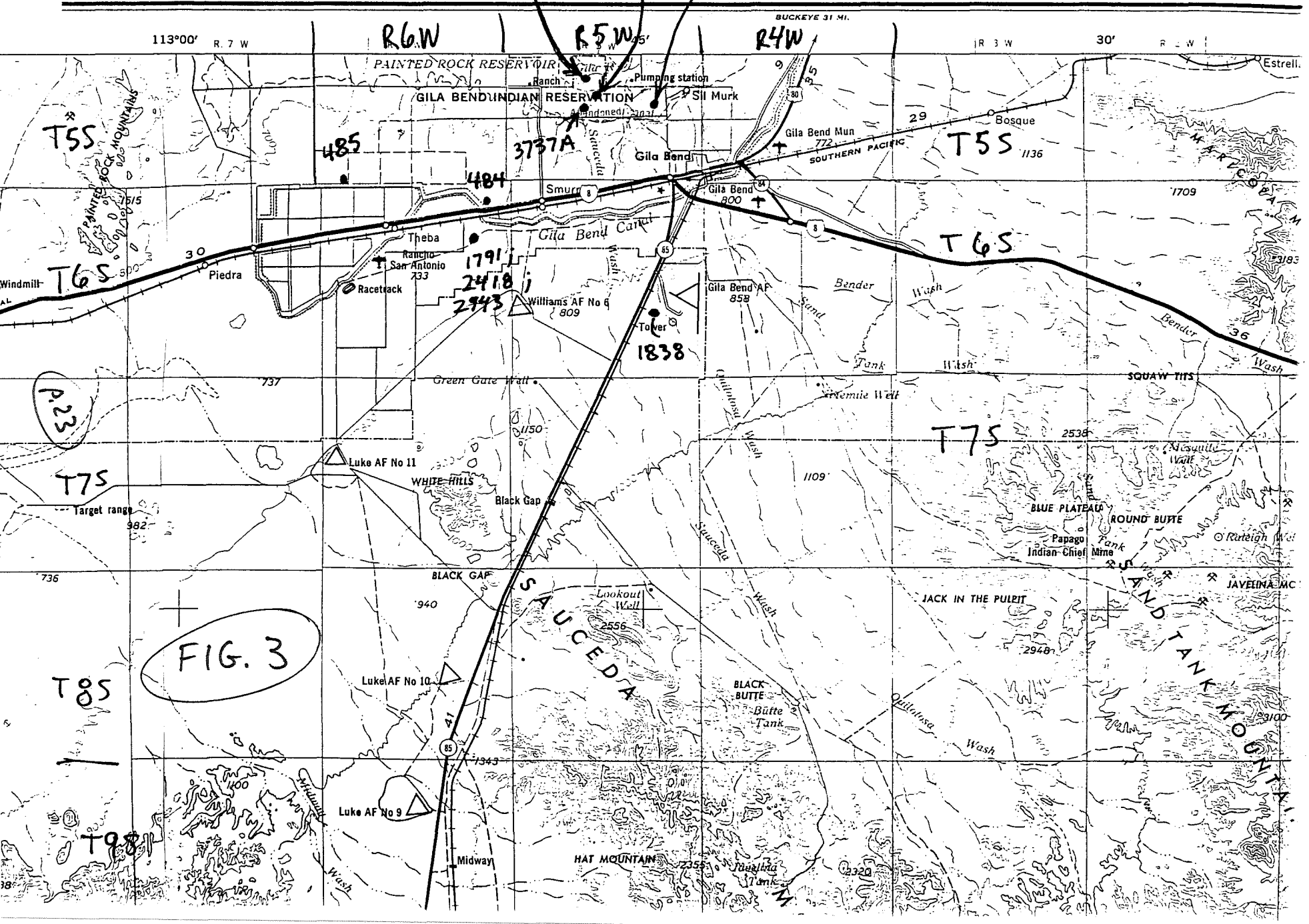
Well 2182 Virgil Merril T4S R11W sec 21 bcb
Cabinet E-53 36 samples 195'-555'

195-375	coarse sand to gravel
375-555	fine to med sand



TANK MOUNTAINS
KING VALLEY
YUMA PROVING GROUND
PALOMAS MOUNTAINS
PALOMAS PLAIN
HYDER VALLEY
AGUA CALIENTE MOUNTAINS
BARAGAN MOUNTAINS
TURTLEBACK MOUNTAIN
FACE MOUNTAIN
MONTEZUMA HEAD
CASTLE DOME MOUNTAINS
KOFA GAME RANGE
BLACK HILLS
SIGNAL BUTTE
TEXAS HILL
SENTINEL PLAIN
SENTINEL PEAK
STANWIX FLATS
SAN CRISTOBAL
MOHAWK
LUKE AIR FORCE
Gila River
Mohawk Canal
Mohawk Pass
Pimeria Well
Sand dunes
BAKER PEAKS
Tacna
Colfred
Tyson
Growler
Kofa
Stoval
Dateland
Aztec
Stanwix
Windmill
Tower
Montezuma
Camel
Hyder
Agua Caliente
Whitewing Ranch
Baragan Well
Mesquite Jim Well
Stamps Well
Ranch
Roll
Horn
Canyon Diablo
Tenmile Wash
San Cristobal Wash
YUMA COUNTY
MARICOPA COUNTY
SOUTHERN PACIFIC
4 LANES DUAL
R 16 W
R 15 W
R 14 W
R 12 W
R 11 W
R 9 W
R 17 W
T 4 S
T 5 S
T. 7 S.
T 8 S.
T. 9 S.
3660000m N.
700 000 FEET (WEST)
P.22
1399
1508
2153
786
3164 A
3079
1130
3195
2149
969
1313, 1676
1575
780
2859
FIG. 2

AJO 1°x2°


3864
3759A
783; 2484
R6W
R5W
R4W
R 7 W
R 3 W
113°00'
30'
BUCKEYE 31 MI.
PAINTED ROCK RESERVOIR
Ranch
Pumping station
GILA BEND INDIAN RESERVATION
Sil Murk
Abandoned canal
Saucedia
3737A
485
484
Gila Bend
Gila Bend Mun
772
SOUTHERN PACIFIC
Bosque
Estrell.
T5S
T6S
T7S
T8S
PAINTED ROCK MOUNTAINS
Smurr
Gila Bend Canal
Theba
Rancho San Antonio
733
Racetrack
Piedra
Windmill
1791
2418
2943
Williams AF No 6
809
Gila Bend AF
858
Tower
1838
Bender Wash
Sand Tank Wash
Green Gate Well
Quilotosa Wash
Jeremie Well
SQUAW TITS
Luke AF No 11
WHITE HILLS
Black Gap
Target range
BLUE PLATEAU
ROUND BUTTE
Papago Indian Chief Mine
Raleigh Well
BLACK GAP
Lookout Well
JACK IN THE PULPIT
JAVELINA MC
SAUCEDA
SAND TANK MOUNTAINS
Luke AF No 10
BLACK BUTTE
Butte Tank
Luke AF No 9
Midway
HAT MOUNTAIN
Jaulina Tank
FIG. 3
P.23