RECONNAISSANCE GAMA-RAY SPECTROMETER SURVEY OF RADON-DECAY PRODUCTS IN SELECTED POPULATED AREAS OF ARIZONA

by

Dudley F. Emer [1], Jonathan D. Shenk, and Jon E. Spencer

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Arizona Geological Survey
416 W. Congress, Suite #100, Tucson, Arizona 85701

[1]*Reynolds Electric and Engineering Co.,*
P.O. Box 98521, Las Vegas, NV 89193

This report is preliminary and has not been edited
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Dudley F. Emer — Reynolds Electric and Engineering Co., P.O. Box 98521, Las Vegas, NV 89193

Jonathan D. Shenk
Jon E. Spencer — Arizona Geological Survey, 845 N. Park Ave., Tucson, AZ 85719

ARIZONA GEOLOGICAL SURVEY

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DUDLEY F. EMER
Geophysicist
Operational Research Projects
Radioactive Waste Management
Environmental Sciences Department

Reynolds Electrical & Engineering Co., Inc.

M/S 738
P.O. Box 98521
Las Vegas, Nevada 89193-8521
702-295-7808 FTS 295-7808
AN EG&G COMPANY

INTRODUCTION

The objective of this survey was to characterize, in terms of their uranium content, random and selected rock units that are either known or suspected to have a potential for radon gas generation, and are located in populated areas. This survey was not designed to find and delineate all source rocks that meet this criteria, rather only examine in general terms the range of uranium content of selected rock types found through out the state. Due to budget limits the survey was limited to several major population centers and surrounding rural towns. No detailed examination of any one particular rock type was attempted. The values reported only reflect the uranium content as found at some convenient location and should not be construed as to represent the highest or lowest or average value for that rock type in that area.

Variations in the uranium content of any particular rock type depend strongly on the chemistry of the rock at the time the uranium was emplaced as well as the chemical history of the rock and its environment through time. For an example, in the Granite Dells located in Prescott Arizona, the uranium content varies from below detectable limits to 39.7 ppm (13.2 pCi/g) with an average value of 8.8 ppm (2.9 pCi/g) as determined by a detailed survey of 146 grid stations (Proctor 1987). The survey conducted for this report obtained 10 stations and three continuous profiles along roads within the Dells. These stations show an average uranium content of 13.8 ppm (4.6 pCi/g) with a low of 3.2 ppm (1.1 pCi/g) and a high of 21.2 ppm (7.1 pCi/g). The enrichment in uranium and thorium in localized areas occurred at the time of crystallization of the late stage magma. The subsequent removal of uranium is due to weathering and leaching of uranium by infiltrating ground water. In general this can be seen in the lower measured uranium content of decomposed granite and soils compared to the uranium content of relatively fresh granites as noted in the geologic descriptions in this report. It is therefore important to distinguish between the depletion of uranium by weathering (oxidation) as opposed to a naturally low

uranium content of the rock unit at the time of formation. It should also be borne in mind that this radiometric survey represents only the uranium and thorium content of the material located at the surface and assumes that their daughter nuclides are in secular equilibrium. Clearly for oxidizing conditions this assumption may not be valid and the uranium content may increase with depth. Consequently, radon gas from such sources may still present a problem to structures built on these areas even though the measured equivalent uranium values appear low.

The uranium decay series produces 14 major daughter nuclides including radon-222 and bismuth-214. Because uranium itself does not produce a suitable gamma ray peak for detection the gamma ray from the bismuth-214 daughter at 1.764 Mev is used instead. Consequently the amount of uranium present, as measured by bismuth-214 is only correct if the deposit is in secular equilibrium, that is, none of the chemically different daughter nuclides have been selectively removed from the deposit geochemically. It is interesting to note that radium, one of the daughters of uranium, produces radon-222 gas which has a half life of 3.6 days. Radon decays through a series of short lived daughter products to bismuth-214. The decay of bismuth-214 to polonium-214 emits the gamma ray of 1.764 Mev which is used to measure the amount of bismuth-214 (and therefore uranium) present, but also and more accurately reflects the amount of radium and radon-222 present as well. For the purposes of this report it is assumed that the uranium decay series is in equilibrium and therefore the activity of any one daughter product implies the same activity (in picocuries not ppm) for all the other daughters and their names may be freely exchanged. ie; uranium and radium.

The thorium decay series has 11 daughter nuclides and is almost always found in equilibrium. The gamma ray peak at 2.615 Mev due to thallium-208 is used to identify the amount of thorium present. The thorium decay series like the uranium series decays through radium and produces radon gas as the radioisotope radon-220 (sometimes called thoron gas) which has a half life of 55 seconds. Because of the short half life, which limits mobility, thoron gas is usually not as prevalent a problem as radon-222.

The reported values in this survey are radiometrically determined assuming equilibrium and are reported as equivalent radium, uranium, or thorium (eRa, eU, eTh). In situ radiometric measurements tend to

indicate higher concentrations than laboratory methods due to source conditions, inhomogeneous distributions, disequilibrium, and the ambient radiation field (Marutzky 1986).

METHODOLOGY

For this survey two survey instruments were used; a portable McPhar model 44 Gamma Ray Spectrometer using a 3in. x 3in. thallium activated sodium iodide crystal and a jeep mounted Scintrex GAD-6 Gamma Ray Spectrometer using three thallium activated sodium iodide crystals of approximately 5 liters total volume. Both of these instruments measure 4 energy channels simultaneously. The specifications for each instrument and channel are detailed below:

Channel 1	Total Count - Measures changes in gamma radiation in the range 0.15 - 2.77 Mev for the GAD-6 and all energies greater than 0.4 Mev for the McPhar 44. This channel provides the most sensitivity to overall changes in gamma radiation. It will also detect man-made gamma radiation sources (cesium-137, cobalt-60, etc.) within its energy band.
Channel 2	Potassium - Measures the potassium-40 peak located at 1.461 Mev. The GAD-6 window extends between 1.380 to 1.560 Mev while the McPhar 44 extends between 1.66 to 1.86 Mev.
Channel 3	Uranium - Measures the bismuth-214 peak located at 1.764 Mev. The GAD-6 counting window extends between 1.660 to 1.900 Mev while the McPhar 44 extends between 1.66 to 1.86 Mev.
Channel 4	Thorium - Measures the thallium-208 peak located at 2.615 Mev. The counting window of the GAD-6 extends between 2.440 to 2.770 Mev while the McPhar 44 extends between 2.42 to 2.82 Mev.

These spectrometers while having a high sensitivity, will respond only to very near surfaces radiation sources due to the attenuation

effects of various materials on gamma radiation. For example, about 3 feet of water or 1.5 feet of rock will almost completely shield out any uranium or thorium radiation present. Therefore the survey requires either near surface mineralization in outcrop or as weathered in place soils, or upwardly migrating radon gas depositing daughter products in the very near surface material to be effective.

The spectrometers used on this survey were calibrated for background, potassium, uranium, and thorium at the United States Department of Energy's Walker Field calibration facility, located in Grand Junction, Colorado on September 1-2, 1987. U.S. Environmental Protection Agency and Department of Energy In Situ Gamma Ray Measurement Protocol (GJ/TMC-06 UC-70A) were adhered to in the operation and reporting of this radiometric survey. A daily calibrate was performed prior to field operations to insure the instrument was in calibration and operating correctly. Periodic calibrations were performed through out the day to insure the instruments had minimal drift due to temperature changes. Base station checks were obtained periodically to monitor instrument drift. With the exception of a large temperature change that required recalibration in Prescott, no operational problems were encountered.

Daily calibrations for the McPhar 44 spectrometer are straight forward and used the characteristic 660 kev photopeak of a cesium-137 source to align the spectrometer's calibration window to the sodium iodide crystal. The calibration of the custom designed GAD-6 system requires that each of the three sodium iodide crystals must be gain matched to each other and the spectrometer's pulse height analyzer. This calibration is accomplished by using the 2.625 Mev photopeak of a thorium oxide calibration source in a fixed geometry with detector #1 and adjusting the gain of the spectrometer's pulse height analyzer to shift the 2.615 Mev photopeak from the detector into the calibration window. Once the thorium peak from detector #1 is properly aligned in the calibration window the respective energy peaks representing potassium, uranium, and thorium will fall into their preset windows within the spectrometer. When the pulse height analyzer has been calibrated to detector #1 (the standard) detector #1 is turned off and the thorium oxide source is used to calibrate detector #2. The gain of detector #2 is then adjusted to shift its thorium peak to match that of detector #1. Detector #3 is calibrated in a similar manner which results in the thorium peak

from each detector properly aligned for the pulse height analyzer and each channel centered in the pulse height analyzer.

The spectral data collected on this survey have been corrected for compton scattering of the higher energy gamma rays. Compton stripping corrections are necessary to remove the effects of the interferences between the spectra of each of the radionuclides of interest. This interference is due to the compton continuum and superposition of multiple spectra. The compton continuum occurs when a high energy gamma ray, say for example from thorium at 2.615 Mev, is not completely captured by the sodium iodide crystal and leaves only a portion of its energy in the crystal with the remaining portion passing through as a lower energy gamma ray. The portion of the energy expended within the crystal is seen as a lower energy photon and is counted on a lower energy channel, say for example the uranium channel at 1.76 Mev. Clearly this photon is not due to uranium and the uranium channel must be corrected for the count rate due to thorium. This correction is called compton stripping. For series equilibrium the equivalent uranium (radium) can be determined by:

$$eRa = k2 \; [\; C(U) - a \; C(Th) \;]$$

where eRa = equivalent radium in picocuries/gram (pCi/g)
k2 = proportionality constant (pCi/g / counts/sec)
a = compton stripping coefficient for Thorium on Uranium
C(U) = count rate - background in the uranium channel
C(Th)= count rate - background in the thorium channel

For Thorium, which has no significant natural interference, equivalent thorium is determined by:

$$eTh = k3 \; [\; C(Th) \;]$$

where eTh = equivalent thorium in picocuries/gram (pCi/g)
k3 = proportionality constant (pCi/g / counts/sec)
C(Th) = count rate - background in the thorium channel

The compton stripping coefficients and proportionality constants were determined at the Department of Energy's Calibration facility in Grand Junction, Colorado by taking measurements of the individual count rates produced in all channels by a known source of thorium,

radium and potassium in series equilibrium.

General data discussion

For remedial action work at uranium mill tailings and industrial sites the EPA has set a standard (CFR 10 192.12a) for clean up of 5 picocuries/gram (pCi/g) Ra-226 above background levels in the first 15 cm. of soil below the surface, averaged over an area of 100 sq. meters. However, there is no standard that specifies acceptable natural background levels. Background levels vary considerably depending on rock type, mineralization and weathering history. In general, igneous rocks have a higher uranium content than sedimentary rocks. In this radiometric reconnaissance of Arizona it was found that precambrian granites range from 0.7 pCi/g to 13 pCi/g eRa-226 (2 to 39 ppm eRa-226) and typically average between 1.2 and 1.5 pCi/g eRa-226 (3.6 to 4.5 ppm). Volcanic rocks range from about 1.0 to about 3.8 pCi/g eRa-226 (2.9 to 11.4 ppm) with an average of about 1.3 pCi/g (3.9 ppm). Sedimentary rocks in Arizona are generally low (1.1 pCi/g) with the exception of some black shales and limestone lake beds. These limestone lake beds are generally marly or silty and typically exhibit an eRa-226 content in excess of 2 pCi/g where as a normal limestone would average about 0.7 pCi/g (2 ppm) eRa-226. These limestones can exceed 27 pCi/g (81 ppm) eRa-226 in some parts of the state. Black shales are also known for their higher than average uranium content and average approximately 2.7 pCi/g eRa.

The activity of basin fill material depends on the source rock and its weathering history. Typical ranges for alluvial fill in southern Arizona range from 0.5 pCi/g to 1.8 pCi/g (1.5 to 5.4 ppm) eRa-226 with an average of 1.3 pCi/g (3.9 ppm).

In general, material containing over 2.0 pCi/g eRa-226 should be considered elevated while values in excess of 3 pCi/g may be considered mineralized. As mentioned previously the EPA requires clean up at its remedial action sites (mill tailings) to 5 pCi/g above background. Any amount of radium, through radioactive decay, will produce radon gas which can build up in the soil. The amount of radon gas in a residential structure depends primarily on how well the structure is coupled to the soil gas rather than how high the radium or radon content of the soil is. Therefore no direct relationship between soil radium (radon) content and a residential

structure's radon gas content can be drawn with out determining the degree of coupling between the structure and the soil gas present. However, for a given coupling coefficient between the soil gas and the structure (entry ability of soil gas through cracks and pipes) any increase in the soil radium content will also increase the radon gas content within the structure itself from diffusion or advection due to the increased concentration gradient. Elevated radon levels have been found in residences with average and below average soil radium content due to excellent coupling with the ground and a low air exchange rate of the residence.

Dudley F. Emer
Geophysicist

References

P. D. Proctor, K. S. Fleck, and A. N. Shanin, 1987, Radiometric and petrochemical characteristics of the Dells granite, Yavapai county, Arizona: State of Arizona Bureau of geology and Mineral Technology, Open File Report 87-8.

Y. Onishi, R.J. Serne, E.M. Arnold, C.E. Cowan, F.L. Thompson, 1980, Critical review: radionuclide transport, sediment transport, and water quality mathematical modeling; and radionuclide adsorption/desorption mechanisms:NUREG/CR-1322 PNL-2901 RE, Pacific Northwest Laboratory, Richland Washington.

S.J. Marutzky, H.L. Fleischhauer, P.R. Engelder, 1986, Comparison of in-situ and laboratory measurement methods for radium-226 in soils:GJH/TMC-24, UC-70A; U.S. Dept. of Energy, Technical Measurements Center, Grand Junction, Colorado.

S.J. Marutzky, W.D. Steele, B.N. Key, K. Kosanle, 1984, Surface gamma ray measurement protocol:GJ/TMC-06, UC-70A, U.S. Dept of Energy, Bendix Field Engineering Corporation, Grand Junction, Colorado.

R.L. Rock and R.T. Beckman, 1979, Radiation monitoring U.S. Dept. of Labor, Mine Safety & Health Administration.

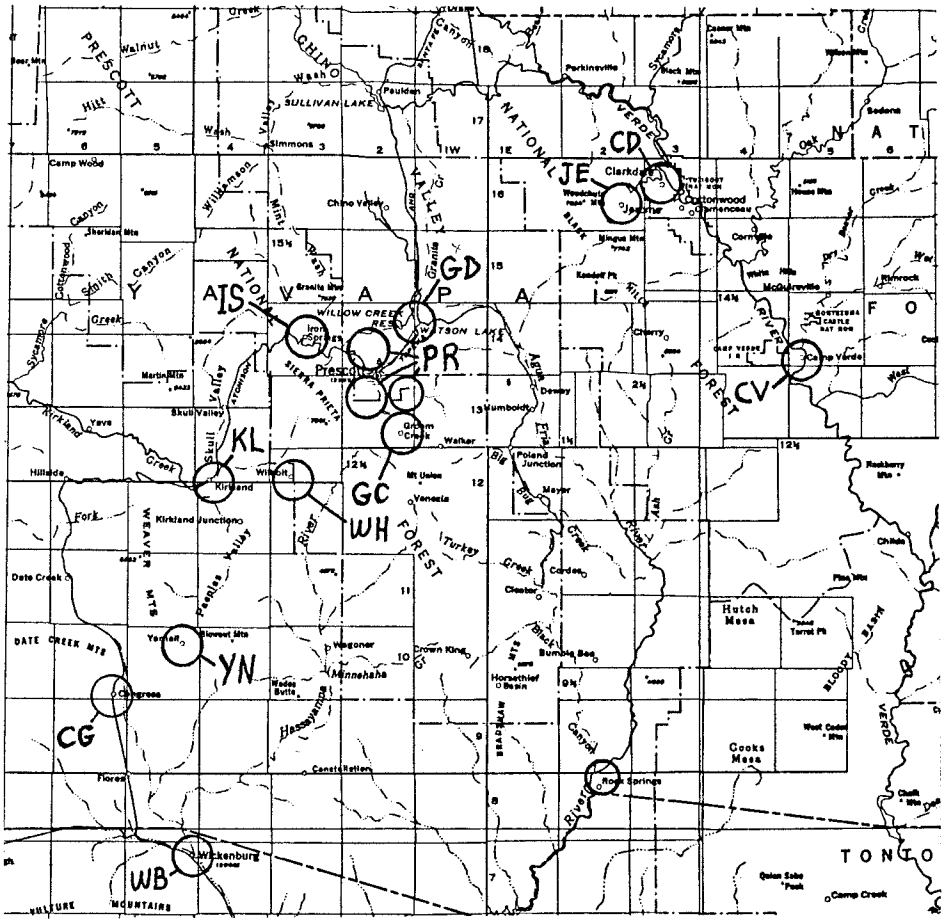
R.L. Grasty, J.E. Glynn, and J.A. Grant, 1985, The Analysis of multichannel airborne gamma ray spectra: Geophysics, 50, 2611-2650.

S. Briener, J.T. Lindon, and R.J. Kalenbach, 1976, Gamma ray measurements and data reduction considerations for airborne radiometric surveys: International symposium on exploration of uranium ore deposits: Vienna, Austria, paper #34.

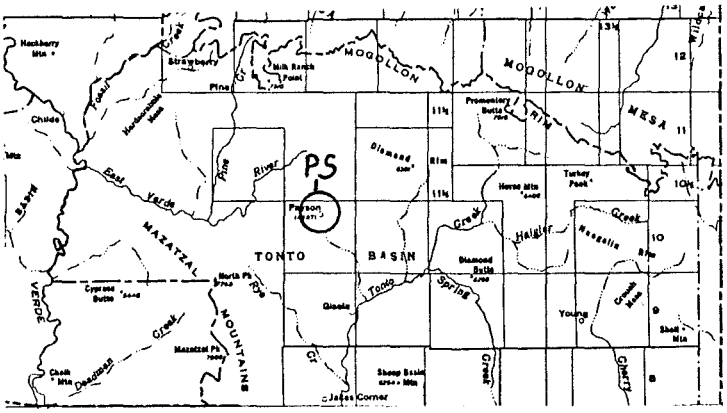
GeoMetrics, 1977, Survey guidelines for using a portable gamma ray spectrometer in uranium exploration: GeoMetrics, Sunnyvale, California, Technical report number 13, 1-12.

L. Lovborg and E. Mose, 1987, Counting statistics in radioelement assaying with a portable spectrometer: Geophysics, 50, 2611-2650.y

Scintrex Ltd., 1979, GAD-6 four channel stabilized gamma ray spectrometer operation manual: Scintrex Ltd., Ontario, Canada.



CAMP VERDE - PRESCOTT - WICKENBURG AREA



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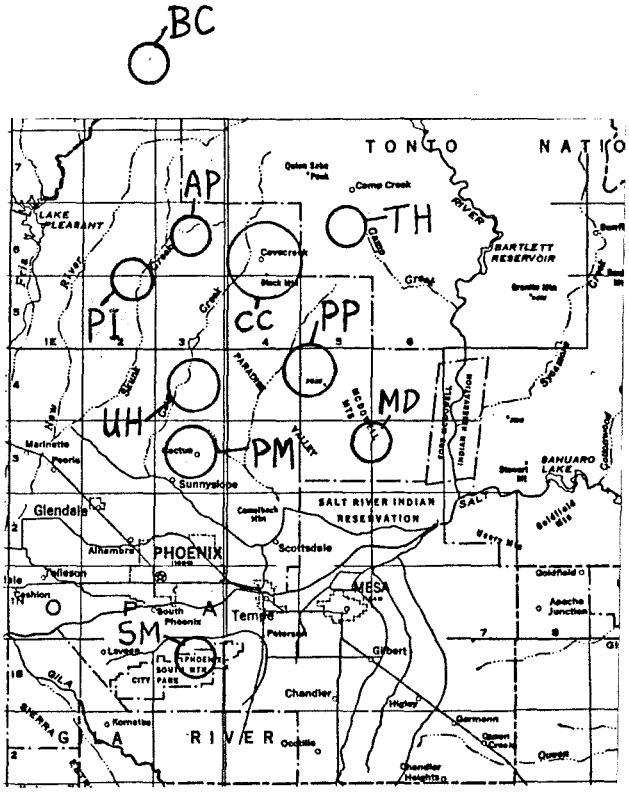

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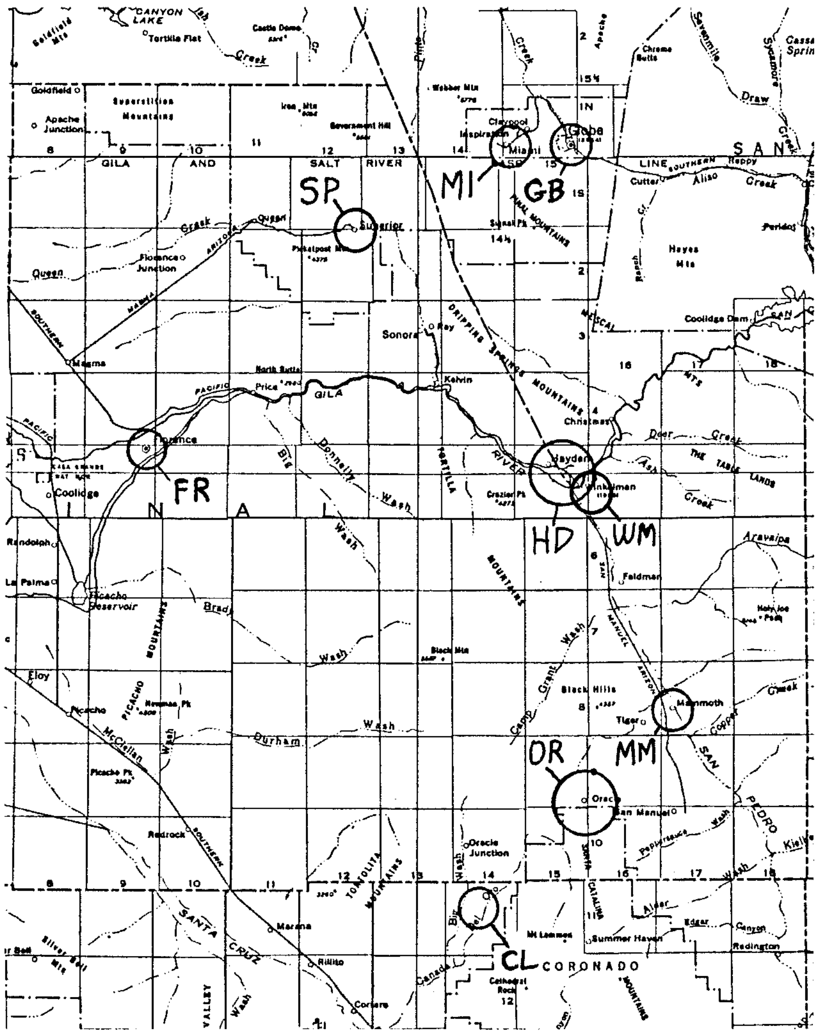

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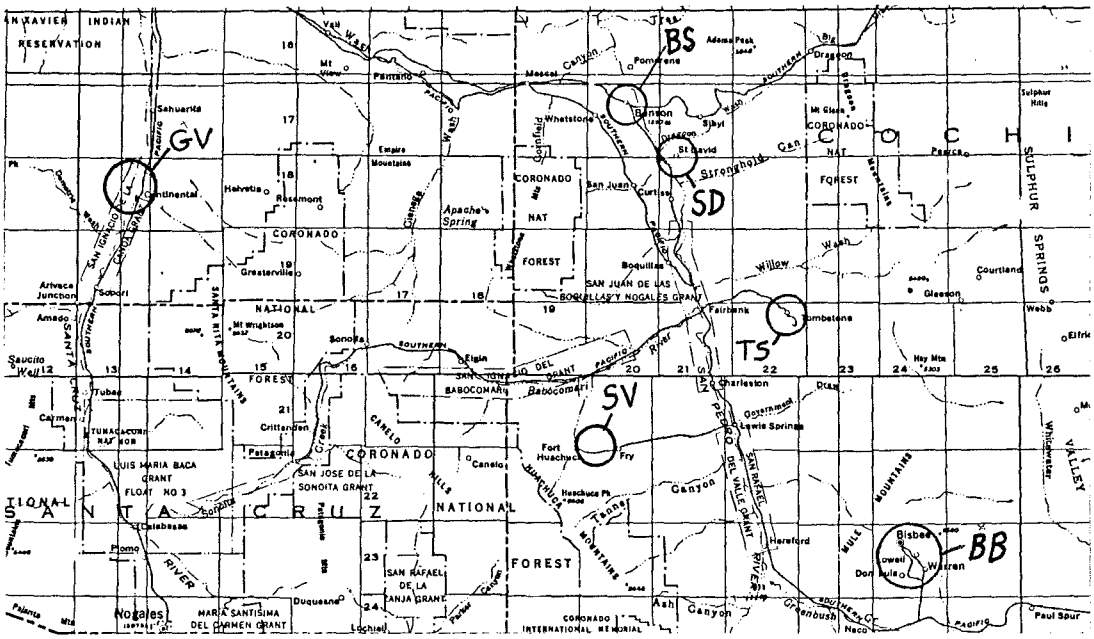

SOUTHEAST ARIZONA

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40

FIGURE 1

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
AP-01	SE New River, Apache Peak	Altered granitic rock, faulted, silicified.	1.1	1.1	15.3	3.4	10.0	1.8	2.9
AP-02	SE New River, Apache Peak	Basin fill.	1.3	1.1	16.7	3.9	9.7	2.0	2.5

FIGURE 2

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
BB-01	Bisbee, Locklin Ave	Basin fill.	1.3	1.2	25.2	3.8	10.9	3.0	2.9
BB-02	Bisbee, Moon Canyon and Sunset Ave	Shale.	1.5	1.8	37.6	4.6	16.5	4.5	3.6
BB-03	Bisbee, Sunset Ave and Adams Ave	Granite.	2.2	2.0	53.1	6.7	18.2	6.3	2.7
BB-04	Bisbee, Art Ave	Granite	1.7	1.6	44.9	5.1	14.6	5.4	2.9
BB-05	Bisbee, Sawles Ave	Decomposed granite.	1.7	1.5	32.3	5.1	14.2	3.9	2.8
BB-06	Warren, Arizona and Briggs Ave.	Schist.	1.2	3.2	27.0	3.6	29.0	3.2	8.1
BB-07	Warren, 30th and 16th Terrace	Limestone.	1.2	0.3	2.9	3.5	3.2	0.4	0.9

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 3

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	eTh	K	ppm eRa	eTh	% K	Th/U
BC-01	Black Canyon, Rock Springs exit and I-17	Marl.	2.5	1.9	36.1	7.6	17.3	4.3	2.3
BC-02	Black Canyon, K Mine Rd. and Black Canyon Highway, dirt lot.	Pediment gravels.	1.2	1.0	12.7	3.5	9.4	1.5	2.7
BC-03	Black Canyon, Oasis Dr. and Westridge	Pediment gravels.	0.7	1.0	14.0	2.1	9.0	1.7	4.3
BC-04	Black Canyon, Black Canyon Highway and I-17.	Marl.	2.2	1.7	34.2	6.7	15.9	4.1	2.4

FIGURE 4

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	eTh	K	ppm eRa	eTh	% K	Th/U
BS-01	Benson, 4th St and Prickly Pear	Basin fill.	1.8	1.3	23.7	5.4	11.6	2.8	2.1
BS-02	Benson, Pearl and Huachuca	Basin fill.	1.4	1.4	27.6	4.1	12.9	3.3	3.1
BS-03	Benson, Comstock and County	Basin fill	1.6	1.2	30.2	4.9	11.1	3.6	2.3
BS-04	Benson, 8th and Patagonia	Basin fill.	1.8	1.1	33.2	5.4	10.0	4.0	1.9

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 5

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
CC-01	Cave Creek, Black Mtn., Blue Ridge Pl.	Schist.	1.1	1.2	27.0	3.2	10.9	3.2	3.4
CC-02	Cave Creek, Black Mtn., Sunset Tr. and Surry Dr.	Schist.	1.3	1.3	27.1	3.8	12.2	3.2	3.2
CC-03	Cave Creek, Black Mtn., Sentinel Rock Rd.	Schist.	1.4	1.3	25.9	4.0	11.7	3.1	2.9
CC-04	Cave Creek, Black Mtn., Lanquid Ln. and Chino Ln.	Schist.	1.1	0.8	17.0	3.3	7.5	2.0	2.3
CC-05	Cave Creek, Black Mtn., Whileaway Rd and Stagecoach Pass.	Decomposed granite.	1.4	2.0	38.8	4.1	18.8	4.6	4.6
CC-06	Cave Creek, Black Mtn., Meander Way and Stagecoach Pass.	Granite and decomposed granite.	1.3	1.5	37.3	3.8	13.5	4.5	3.6
CC-07	Cave Creek, Black Mtn., Carefree Dr. and Piedra Grande.	Basin fill.	1.3	1.9	33.4	3.9	17.5	4.0	4.5
CC-08	Cave Creek, Black Mtn., Carefree and Skyline	Decomposed granite.	1.6	2.0	35.8	4.7	18.2	4.3	3.9

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 5 (cont.)

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
CC-09	Cave Creek, Willow Springs, Echo Canyon Dr.	Marl.	8.8	0.7	4.4	26.4	6.9	0.5	0.3
CC-09a	Cave Creek, Willow Springs area, Echo Canyon, Sierra Vista	Marl.	12.0	0.8	2.7	35.9	7.2	0.3	0.2
CC-09b	Cave Creek, Willow Springs, powerline rd.	Marl.	7.9	0.6	1.1	23.5	5.4	0.1	0.2
CC-09c	Cave Creek, Willow Springs, powerline road.	Marl.	3.1	0.4	2.6	9.2	3.5	0.3	0.4

FIGURE 6

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
CD-01	Clarkdale	Colluvium.	0.6	0.8	14.2	1.9	7.7	1.7	4.1

FIGURE 7

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
CG-01	Congress	Basin fill.	1.5	1.7	32.4	4.6	15.4	3.9	3.3
CG-02	Congress	Basin fill.	1.4	1.5	34.5	4.2	14.1	4.1	3.4

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 8

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
CL-01	Catalina, Grahn Street.	Basin fill.	1.2	1.8	27.9	3.6	16.6	3.3	4.6
CL-02	Catalina, Magoo and Columbus	Basin fill.	1.5	2.9	30.9	4.6	26.6	3.7	5.8
CL-03	Catalina, Bronco Ln and Pinto	Basin fill.	1.2	2.7	29.8	3.5	24.6	3.6	7.0

FIGURE 9

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
CV-01	Camp Verde.	Marl.	23.1	1.1	0.0	69.3	10.2	0.0	0.1
CV-01a	Camp Verde.	Marl.	27.1	0.9	0.0	81.2	8.6	0.0	0.1
CV-01b	Camp Verde.	Marl.	4.5	0.5	4.5	13.5	4.8	0.5	0.4
CV-01c	Camp Verde.	Marl.	9.8	1.0	7.4	29.3	8.8	0.9	0.3
CV-02	Camp Verde, 3rd and Head St.	Pediment gravels.	1.1	0.6	7.0	3.4	5.1	0.8	1.5

FIGURE 10

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
FR-01	Florence, Ruggles and Pinal Parkway	Basin fill.	1.1	1.2	25.6	3.2	11.2	3.1	3.5

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 11

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	eTh	K	ppm eRa	eTh	% K	Th/U
GB-01	Globe, Silver and Santee	Basin fill.	0.6	0.8	22.3	1.8	7.6	2.7	4.2

FIGURE 12

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	eTh	K	ppm eRa	eTh	% K	Th/U
GC-01	Prescott, Groom Creek, Spur Lane	Granite and decomposed granite	1.1	0.9	18.9	3.2	8.1	2.3	2.5
GC-01a	Prescott, Groom Creek, Spur Lane	Decomposed granite.	1.0	0.9	18.8	3.0	8.2	2.3	2.7
GC-02	Prescott, Groom Creek.	Granite.	1.2	1.1	21.8	3.7	10.4	2.6	2.8
GC-03	Prescott, Groom Creek, Groom Creek canyon road.	Schist.	1.6	1.2	23.2	4.7	11.2	2.8	2.4

FIGURE 13

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	eTh	K	ppm eRa	eTh	% K	Th/U
GD-01	Prescott, Granite Dells.	Decomposed granite.	1.1	0.9	21.4	3.2	8.6	2.6	2.7
GD-02	Prescott, Granite Dells.	Decomposed granite.	1.6	1.0	21.8	4.9	8.8	2.6	1.8
GD-03	Prescott, Granite Dells.	Granite.	4.4	4.3	36.6	13.2	39.2	4.4	3.0

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 13 (cont.)

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
GD-03a	Prescott, Granite Dells.	Granite.	6.3	4.2	30.3	19.0	38.9	3.6	2.0
GD-04	Prescott, Granite Dells.	Granite.	7.1	4.0	31.0	21.2	36.6	3.7	1.7
GD-05	Prescott, Granite Dells.	Granite.	6.2	3.8	30.9	18.7	34.5	3.7	1.8
GD-06	Prescott, Granite Dells.	Granite and decomposed granite.	3.7	3.5	29.6	11.1	32.0	3.5	2.9
GD-07	Prescott, Granite Dells.	Decomposed granite.	1.9	1.4	24.9	5.7	12.6	3.0	2.2
GD-08	Prescott, Granite Dells.	Granite.	3.8	4.3	34.5	11.5	39.6	4.1	3.4
GD-09	Prescott, Granite Dells.	Granite.	8.7	4.0	34.5	26.0	36.7	4.1	1.4
GD-10	Prescott, Granite Dells.	Granite.	5.8	1.9	24.4	17.5	17.2	2.9	1.0

FIGURE 14

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
GV-01	Green Valley, Duval Mine Rd.	Basin fill.	1.3	1.5	32.3	3.8	14.0	3.9	3.7
GV-02	Green Valley, Aliso Drive.	Basin fill.	1.1	1.5	33.9	3.4	13.5	4.1	4.0
GV-03	Green Valley, El Nopal.	Basin fill.	1.4	1.9	29.6	4.2	17.6	3.5	4.2
GV-04	Green Valley, Paseo del Chino	Basin fill.	1.6	1.5	30.6	4.9	13.8	3.7	2.8

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 14 (cont.)

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
GV-05	Green Valley, Avenida Cipres.	Basin fill.	1.2	1.6	32.0	3.5	15.0	3.8	4.3
GV-06	Green Valley, Paseo Quinte and Apeo	Basin fill.	0.9	1.6	34.6	2.8	14.8	4.1	5.3
GV-07	Green Valley, Los Topacios and Camino del Monte	Basin fill.	1.3	1.4	36.7	3.8	12.8	4.4	3.4
GV-08	Green Valley, Paseo del Canto.	Basin fill.	1.3	1.4	37.5	3.9	13.1	4.5	3.4
GV-09	Green Valley, Abrego and Cont.	Basin fill.	1.4	1.2	35.8	4.3	10.8	4.3	2.5
GV-10	Green Valley, Abrego and Los Arcos	Basin fill.	1.3	1.3	32.1	3.9	12.0	3.8	3.1
GV-11	Green Valley, Abrego and Paseo del Verde.	Basin fill.	1.4	1.4	28.8	4.2	13.1	3.4	3.1

FIGURE 15

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
HD-01	Hayden, 4th and Ray	Basin fill.	0.9	0.9	26.3	2.7	8.3	3.1	3.1

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 16

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
IS-01	Prescott, Iron Springs Rd.	Granite.	1.9	1.6	35.6	5.6	14.2	4.2	2.5
IS-01a	Prescott, Iron Springs Road	Granite.	1.3	2.0	41.6	3.9	18.7	5.0	4.8
IS-01b	Prescott, Iron Springs Road	Granite.	1.9	3.6	43.7	5.6	32.6	5.2	5.8

FIGURE 17

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
JE-01	Jerome	Colluvium.	0.7	0.7	13.8	2.1	6.3	1.6	3.0

FIGURE 18

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
KL-01	Kirkland.	Rhyolite.	3.4	2.0	40.0	10.3	18.7	4.8	1.8
KL-01a	Kirkland	Rhyolite.	2.8	1.7	32.8	8.3	15.7	3.9	0.0
KL-02	Kirkland.	Rhyolite.	3.3	2.0	33.4	9.8	18.4	4.0	1.9
KL-03	Kirkland.	Basin fill.	0.8	0.8	22.3	2.4	7.0	2.7	2.9

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 19

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	eTh	K	ppm eRa	eTh	% K	Th/U
MD-01	McDowell Mtns., Shea Blvd. and Mayo Clinic	Basin fill.	1.4	1.3	30.8	4.2	11.5	3.7	2.7
MD-02	McDowell Mtns., 3N 5E SE1/4 13	Granite.	1.8	1.7	38.0	5.5	16.0	4.5	2.9
MD-03	McDowell Mtns., 3N 6E NW1/4 18	Granite.	1.4	1.6	32.8	4.3	14.5	3.9	3.4
MD-04	McDowell Mtns., 3N 5E SE1/4 24	Basin fill.	1.1	1.1	25.2	3.3	10.1	3.0	3.1
MD-05	McDowell Mtns., 3N 6E C 30.	Basalt.	0.8	0.7	14.3	2.3	6.2	1.7	2.7

FIGURE 20

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	eTh	K	ppm eRa	eTh	% K	Th/U
MI-01	Miami	Schist.	2.3	1.8	28.5	6.9	16.9	3.4	2.4
MI-02	Miami, Wentworth and Woodrow	Pediment gravel.	0.8	1.2	21.8	2.3	10.8	2.6	4.7
MI-03	Miami	Schist.	1.8	1.7	34.3	5.5	15.4	4.1	2.8
MI-04	Miami, Laurel Ave and Live Oak	Schist	2.3	1.7	46.3	7.0	15.5	5.5	2.2

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 21

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
MM-01	Mammoth	Basin fill.	1.3	2.0	33.4	4.0	18.2	4.0	4.5

FIGURE 22

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
OR-01	Oracle	Granite.	0.9	2.0	29.5	2.6	18.5	3.5	7.1
OR-02	Oracle	Decomposed granite	1.5	2.0	36.0	4.6	18.7	4.3	4.1
OR-03	Oracle	Basin fill.	1.0	1.7	31.6	2.9	15.4	3.8	5.3
OR-04	Oracle	Basin fill.	1.2	2.0	33.3	3.6	18.5	4.0	5.1

FIGURE 23

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
PI-01	Pioneer, Pioneer Interchange, I-17.	Colluvium.	1.0	1.2	24.0	2.9	11.0	2.9	3.8
PI-02	Pioneer	Marl.	1.1	0.8	13.4	3.4	7.7	1.6	2.3
PI-02a	Pioneer	Marl.	0.8	0.4	4.2	2.4	3.7	0.5	1.5
PI-03	Pioneer	Colluvium.	1.4	0.9	30.3	4.2	8.5	3.6	2.0

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 24

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
PM-01	Phoenix Mtns., N. 16th Pl., dead end, dirt lot.	Schist and basalt.	1.4	1.4	12.5	4.3	12.6	1.5	2.9
PM-01a	Phoenix Mtns., N. 16th Place, dead end.	Basaltic andesite.	2.3	3.3	18.8	7.0	29.8	2.3	4.3
PM-01b	Phoenix Mtns., N. 16th Place, dead end.	Basaltic andesite.	2.1	2.6	19.1	6.2	23.9	2.3	3.9
PM-02	Phoenix Mtns., N. 16th St.	Basaltic andesite cobbles.	2.7	3.8	22.4	8.1	34.7	2.7	4.3
PM-03	Phoenix Mtns., N. 16th St.	Basaltic andesite.	4.0	6.8	35.3	12.0	62.5	4.2	5.2
PM-03a	Phoenix Mtns., N. 16th Place.	Basaltic andesite.	5.7	9.8	50.5	17.0	89.9	6.0	5.3
PM-03b	Phoenix Mtns., N. 16th Street.	Basaltic andesite.	5.2	10.4	54.5	15.6	95.3	6.5	6.1
PM-04	Phoenix Mtns., E. Sierra.	Basaltic andesite.	4.8	6.3	32.3	14.5	57.7	3.9	4.0
PM-05	Phoenix Mtns., Mtn. View, dead end.	Schist.	1.0	0.6	14.5	3.0	5.3	1.7	1.8
PM-06	Phoenix Mtns., E. Hatcher Dr., dead end.	Schist.	1.0	0.6	9.4	3.0	5.7	1.1	1.9
PM-07	Phoenix Mtns., N. 3rd St.	Colluvium.	1.0	0.9	12.3	3.1	8.3	1.5	2.7
PM-08	Phoenix Mtns., Roberts Rd.	Fanglomerate.	1.4	1.1	20.6	4.2	9.9	2.5	2.4

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 24 (cont.)

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
PM-09	Phoenix Mtns., Lookout Mtn, SE corner.	Fanglomerate.	1.2	0.9	15.1	3.7	8.3	1.8	2.2
PM-10	Pheonix Mtns., E. Karen St. dead end.	Fanglomerate.	1.1	1.0	20.4	3.4	9.5	2.4	2.8

FIGURE 25

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
PP-01	Pinnacle Peak, Jomax Rd, dead end.	Decomposed granite.	1.6	1.3	19.9	4.7	11.9	2.4	2.5
PP-02	Pinnacle Peak, Jomax Rd and Pima Rd.	Decomposed granite.	1.3	1.0	23.0	3.9	9.0	2.7	2.3
PP-03	Pinnacle Peak, Windy Walk Dr. and Happy Valley Rd.	Granite and decomposed granite, small lot.	1.6	1.8	39.2	4.6	16.5	4.7	3.6
PP-04	Pinnacle Peak, Candlewood cul-de-sac.	Granite and decomposed granite.	1.4	1.5	38.5	4.3	13.5	4.6	3.1
PP-05	Pinnacle Peak, 109th St. and Jomax Rd., dirt road.	Granite and decomposed granite	2.1	1.5	31.1	6.2	13.3	3.7	2.1
PP-06	Pinnacle Peak, Quartz Rock Rd. cul-de-sac and Windy Walk Dr.	Granite and decomposed granite.	1.7	1.3	30.8	5.2	12.3	3.7	2.4

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 25

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
PP-07	Pinnacle Peak, Desert Willow Dr. and Yearling Dr.	Granite and decomposed granite.	1.2	1.3	32.3	3.5	12.2	3.9	3.5
PP-08	Pinnacle Peak, Golf Club Dr., dirt road.	Decomposed granite.	1.6	1.2	24.7	4.8	11.0	3.0	2.3
PP-09	Pinnacle Peak, Falcon Circle cul-de-sac and Apache Plume Dr.	Granite and decomposed granite.	1.7	1.5	26.9	5.2	14.1	3.2	2.7
PP-10	Pinnacle Peak, Hayden Rd. and Via de Luna Dr.	Basin fill and decomposed granite.	1.5	1.4	25.9	4.4	13.2	3.1	3.0
PP-11	McDowell Mtns. prospect, 4N 5E SE1/4 20.	Schist.	1.2	1.1	21.9	3.7	9.7	2.6	2.6
PP-12	McDowell Mtns. 4N 5E SE1/4 18	Basin fill and decomposed granite.	1.2	1.1	27.8	3.7	10.4	3.3	2.8

FIGURE 26,27,28

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
PR-01	Prescott, Oak Knolls Village.	Granite.	0.9	1.8	30.4	2.6	16.4	3.6	6.3
PR-02	Prescott, Juniper Heights	Colluvium.	0.7	0.6	17.0	2.2	5.9	2.0	2.7
PR-03	Prescott, Pebble Hill Ln and Paul Dr.	Granite.	0.9	0.8	22.9	2.6	7.4	2.7	2.8

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 26,27,28 (cont.)

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
PR-04	Prescott, Forbing Park, Estrella Rd.	Granite.	1.0	0.7	21.9	3.0	6.6	2.6	2.2
PR-05	Prescott, Geneva and Willow Creek Road.	Basalt.	3.4	4.9	38.1	10.1	44.6	4.6	4.4
PR-05a	Prescott, Geneva and Willow Creek Road.	Basalt.	2.7	4.0	32.3	8.1	36.2	3.9	4.5
PR-06	Prescott, Willow Creek Rd.	Basalt.	3.3	2.9	27.4	9.9	26.6	3.3	2.7

FIGURE 29

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
PS-01	Payson, N. Sherwood and Beeline Highway	Granite.	2.0	1.8	40.9	6.0	16.4	4.9	2.7
PS-01a	Payson, N. Sherwood and Beeline Highway	Decomposed granite.	1.2	1.5	41.4	3.6	14.1	5.0	3.9
PS-01b	Payson, N. Sherwood and Beeline Highway	Granite.	2.1	2.0	41.2	6.4	18.2	4.9	0.0
PS-02	Payson	Decomposed granite.	0.6	1.3	40.0	1.7	11.6	4.8	6.8

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 29 (cont.)

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
PS-03	Payson	Granite.	1.7	1.6	41.4	5.2	14.6	4.9	2.8
PS-03a	Payson	Decomposed granite.	1.1	1.8	39.9	3.4	16.4	4.8	4.8

FIGURE 30

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
SD-01	St. David, Miller Lane	Basin fill.	1.5	1.7	25.0	4.6	15.3	3.0	3.3
SD-02	St. David, Miller Lane	Basin fill.	0.8	1.4	27.4	2.4	12.5	3.3	5.2

FIGURE 31

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
SM-01	Phoenix, South Mtns.	Granodiorite, chloritic and fractured.	1.2	0.7	25.1	3.5	6.1	3.0	1.7
SM-02	Phoenix, South Mtns, 24th and Baseline	Granodiorite, unaltered.	0.6	0.6	38.2	1.9	5.2	4.6	2.7
SM-03	Phoenix, South Mtns.	Gneiss.	0.7	1.3	32.1	2.1	12.0	3.8	5.7

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 32

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
SP-01	Superior, Stone and East	Basin fill.	0.7	0.7	14.0	2.0	6.8	1.7	3.4
SP-02	Superior	Decomposed granite.	0.6	1.0	19.5	1.9	9.5	2.3	5.0
SP-03	Superior, Lobb and Porphyry	Basin fill.	0.5	0.8	14.5	1.6	7.0	1.7	4.4

FIGURE 33

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
SV-01	Sierra Vista, Camino del Norte and Foothills Drive	Basin fill.	1.2	1.8	34.3	3.6	16.4	4.1	4.6
SV-02	Sierra Vista, Between Ft Hill and 90/92 intersection	Basin fill.	1.1	2.1	38.5	3.3	19.2	4.6	5.8
SV-03	Sierra Vista, Morman Ave	Basin fill.	1.0	2.0	30.9	3.0	18.7	3.7	6.2
SV-04	Sierra Vista, Taylor and Garden	Basin fill.	1.3	1.5	28.1	3.8	13.5	3.4	3.6

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 34

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	eTh	K	ppm eRa	eTh	% K	Th/U
TH-01	Cave Creek, Tonto Hills, La Plata Rd and Cave Creek Highway	Decomposed granite.	2.2	2.4	28.0	6.5	22.1	3.3	3.4
TH-02	Cave Creek, Tonto Hills, Hohokam Lane	Decomposed granite.	1.9	2.2	28.6	5.7	19.9	3.4	3.5

FIGURE 35

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	eTh	K	ppm eRa	eTh	% K	Th/U
TS-01	Tombstone, Toughnut and Sumner	Limestone.	1.1	0.7	10.7	3.2	6.4	1.3	2.0
TS-02	Tombstone, Allen and 12th	Limestone.	1.2	0.6	8.1	3.5	5.3	1.0	1.5
TS-03	Tombstone, Skyline Drive	Shale	4.5	1.7	31.6	13.5	15.6	3.8	1.2
TS-03a	Tombstone, Skyline Drive	Shale	1.4	1.7	29.7	4.2	15.2	3.5	3.6
TS-04	Tombstone, Skyline Drive	Shale.	3.0	1.3	21.2	9.1	12.3	2.5	1.4

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 36

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
UH-01	Union Hills, Buffalo Ridge, 22nd St., rd cut.	Granite.	1.6	0.8	17.7	4.7	7.4	2.1	1.6
UH-02	Union Hills, Buffalo Ridge.	Granite.	2.0	1.6	28.6	6.0	14.9	3.4	2.5
UH-03	Union Hills, 16th St. and Beardsley Rd.	Granite.	1.6	1.2	24.8	4.9	11.1	3.0	2.3
UH-04	Union Hills, 16th St. and Beardsley Rd.	Granite	1.3	0.9	16.7	3.9	8.0	2.0	2.0

FIGURE 37

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
WB-01	Wickenburg, N. Tegner and Cavaness Av.	Basin fill.	1.5	1.2	28.1	4.5	11.0	3.4	2.4
WB-02	Wickenburg	Rhyolite.	1.0	2.5	49.7	2.9	22.7	5.9	7.8
WB-02a	Wickenburg	Rhyolite	1.6	1.0	21.1	4.9	9.3	2.5	1.9
WB-02b	Wickenburg	Sandstone.	1.7	1.7	36.2	5.2	15.2	4.3	2.9

FIGURE 38

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
WH-01	Wilhoit.	Granite.	0.8	1.0	22.4	2.3	8.7	2.7	3.8

TABLE 1 - SAMPLE DESCRIPTIONS
FOR STATIONS PLOTTED IN FIGS. 1-40 (CONT.)

FIGURE 39

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
WM-01	Winkleman, 4th and Thorne	Basin fill.	0.6	1.3	23.6	1.7	11.5	2.8	6.8

FIGURE 40

LOC #	AREA, LOCATION	DESCRIPTION	pCi/g eRa	pCi/g eTh	pCi/g K	ppm eRa	ppm eTh	% K	Th/U
YN-01	Yarnell, Oak Way and Shrine Rd.	Granite.	2.7	2.6	36.8	8.0	23.9	4.4	3.0
YN-01a	Yarnell, Oak Way and Shrine Rd.	Basin fill.	1.7	1.8	30.1	5.2	16.1	3.6	3.1
YN-02	Yarnell, Broadway and Happy	Basin fill.	1.5	1.3	29.8	4.4	12.0	3.6	2.7
YN-03	Yarnell	Granite.	2.4	2.4	33.9	7.1	21.8	4.1	3.1
YN-04	Yarnell	Granite.	1.5	2.4	42.5	4.6	21.7	5.1	4.7

CCT-1

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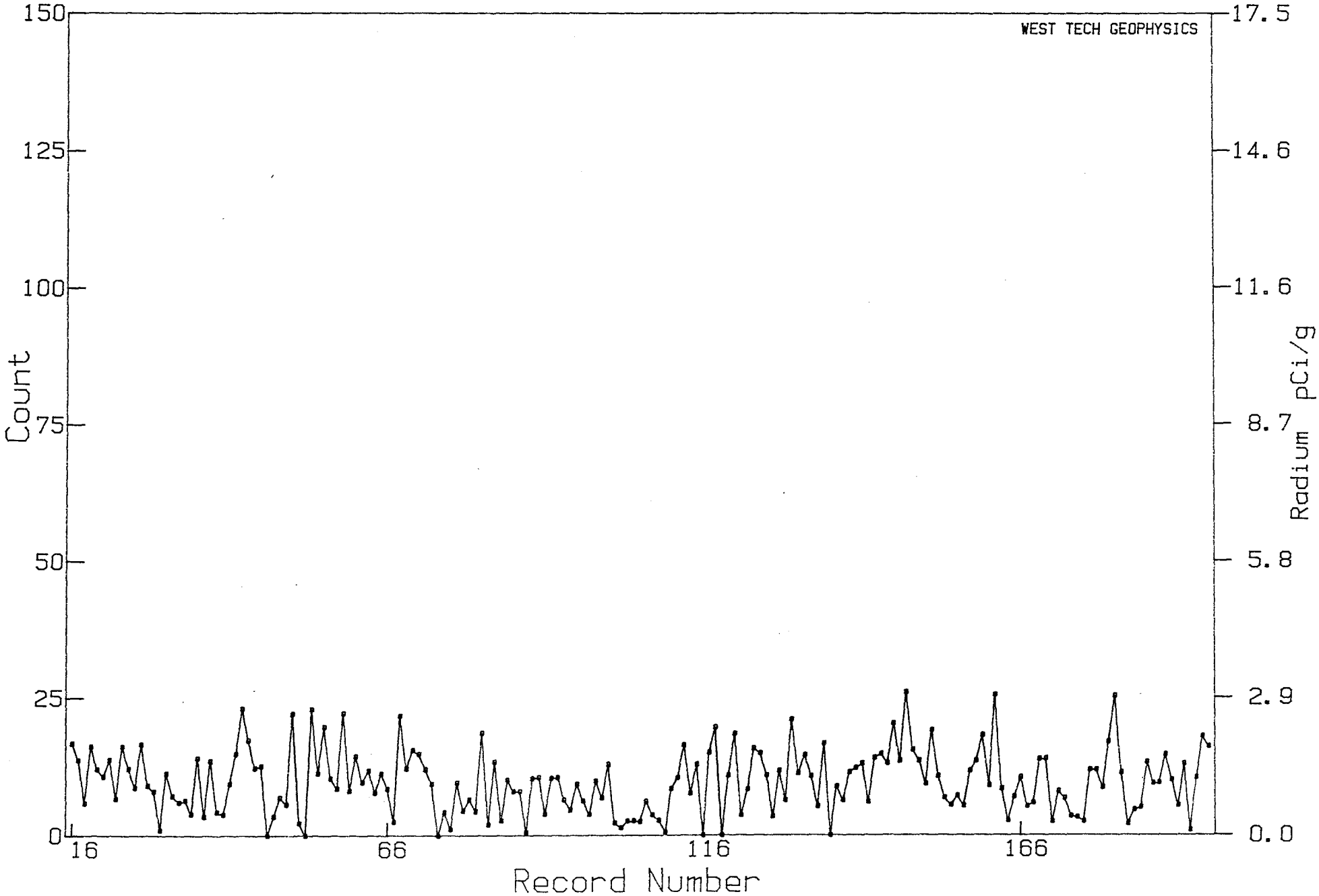

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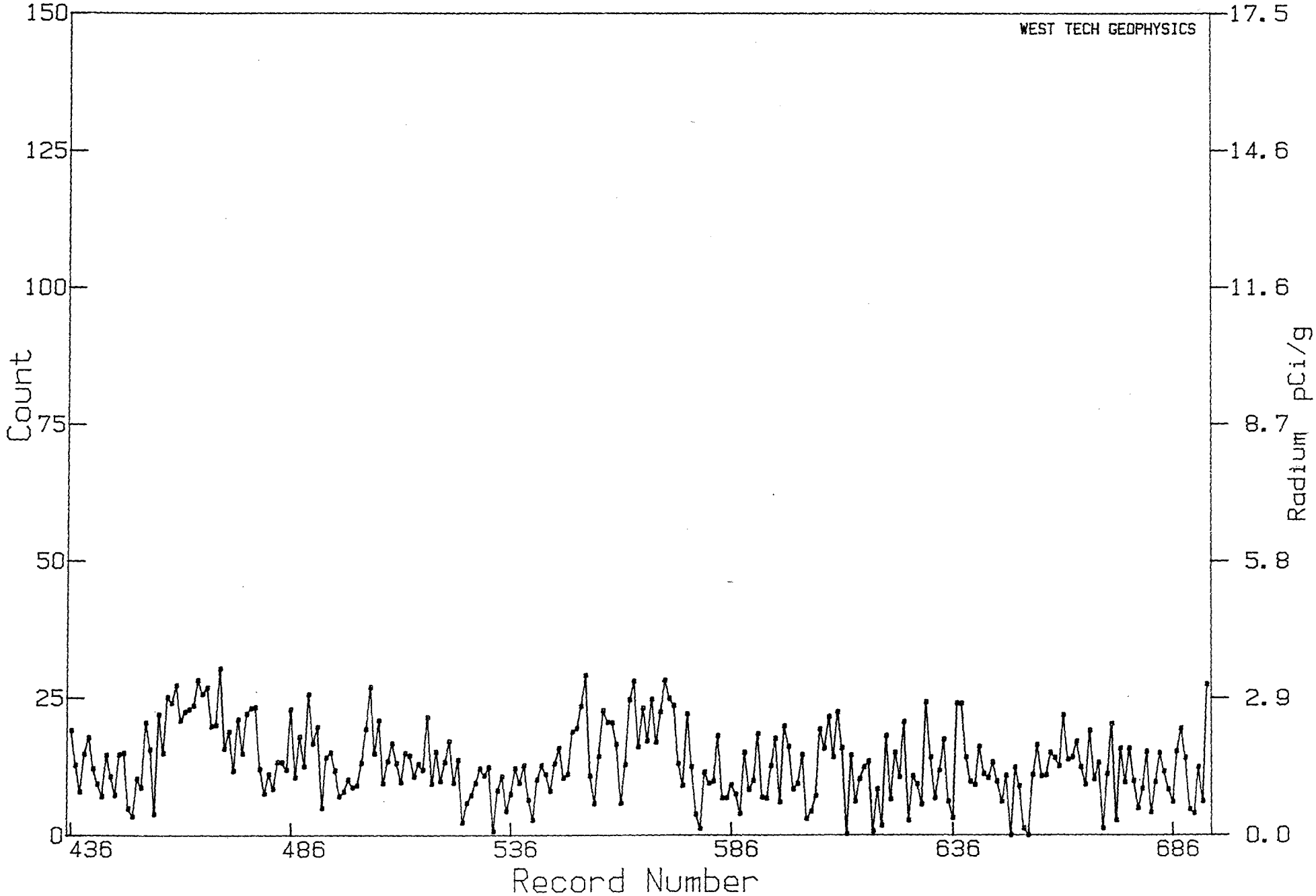
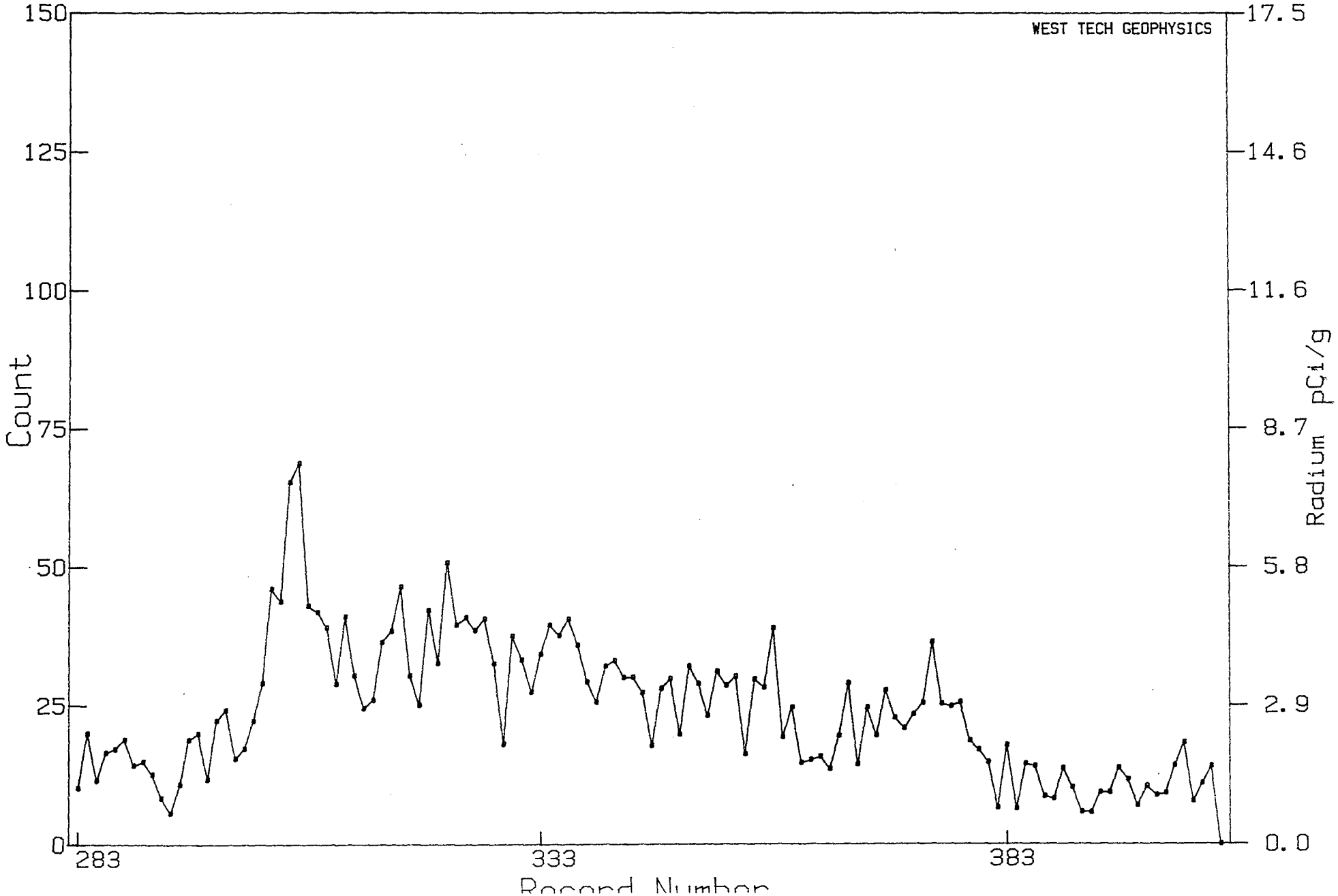


CCT-3

Profile: 43-44. Channel: Radium. Gamma Ray Spectrometer Survey.

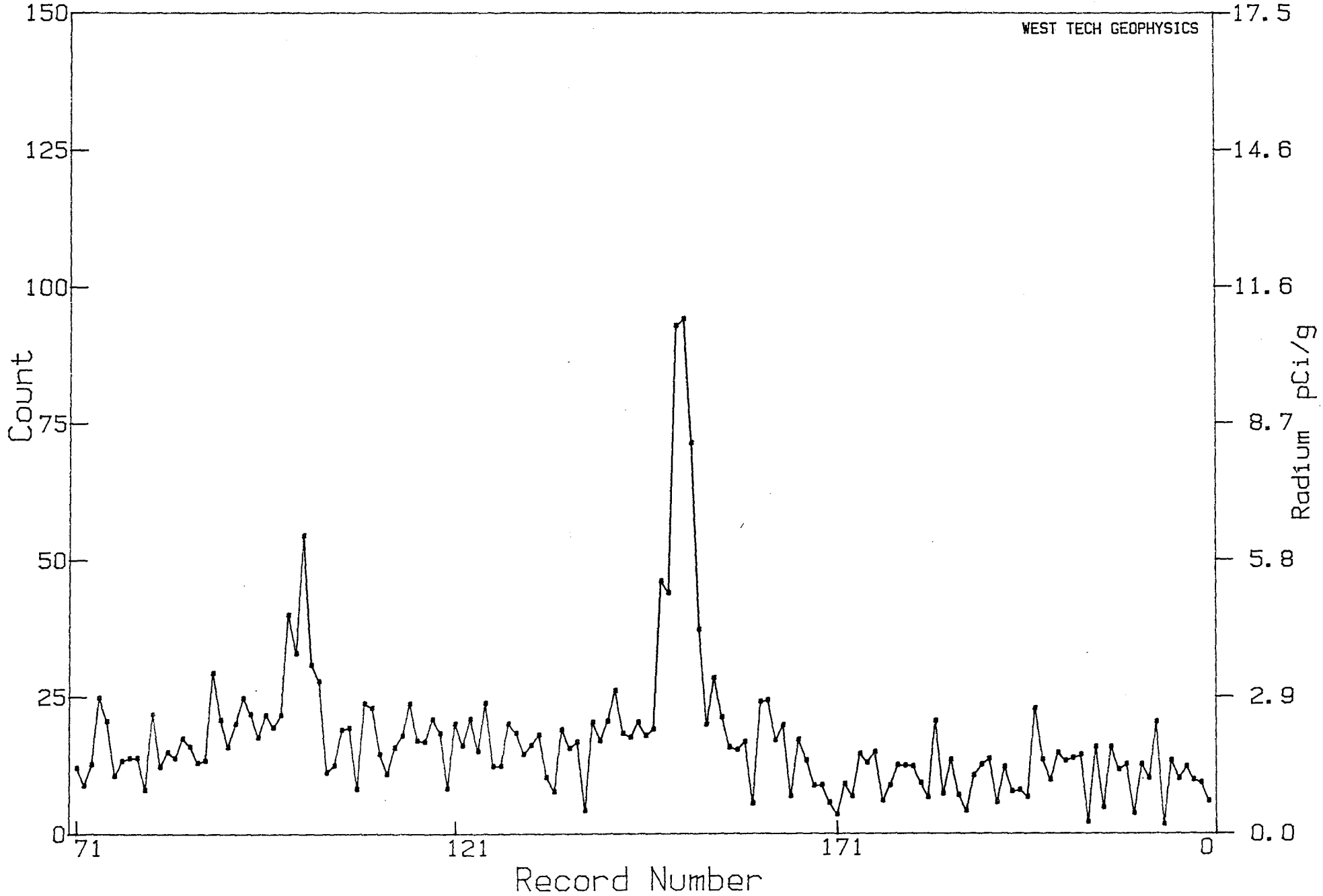
File: CVCRK4B.EDT. Count Time: 1 sec.. Cave Creek.



CCT-4

Profile: 50-50B. Channel: Radium. Gamma Ray Spectrometer Survey.

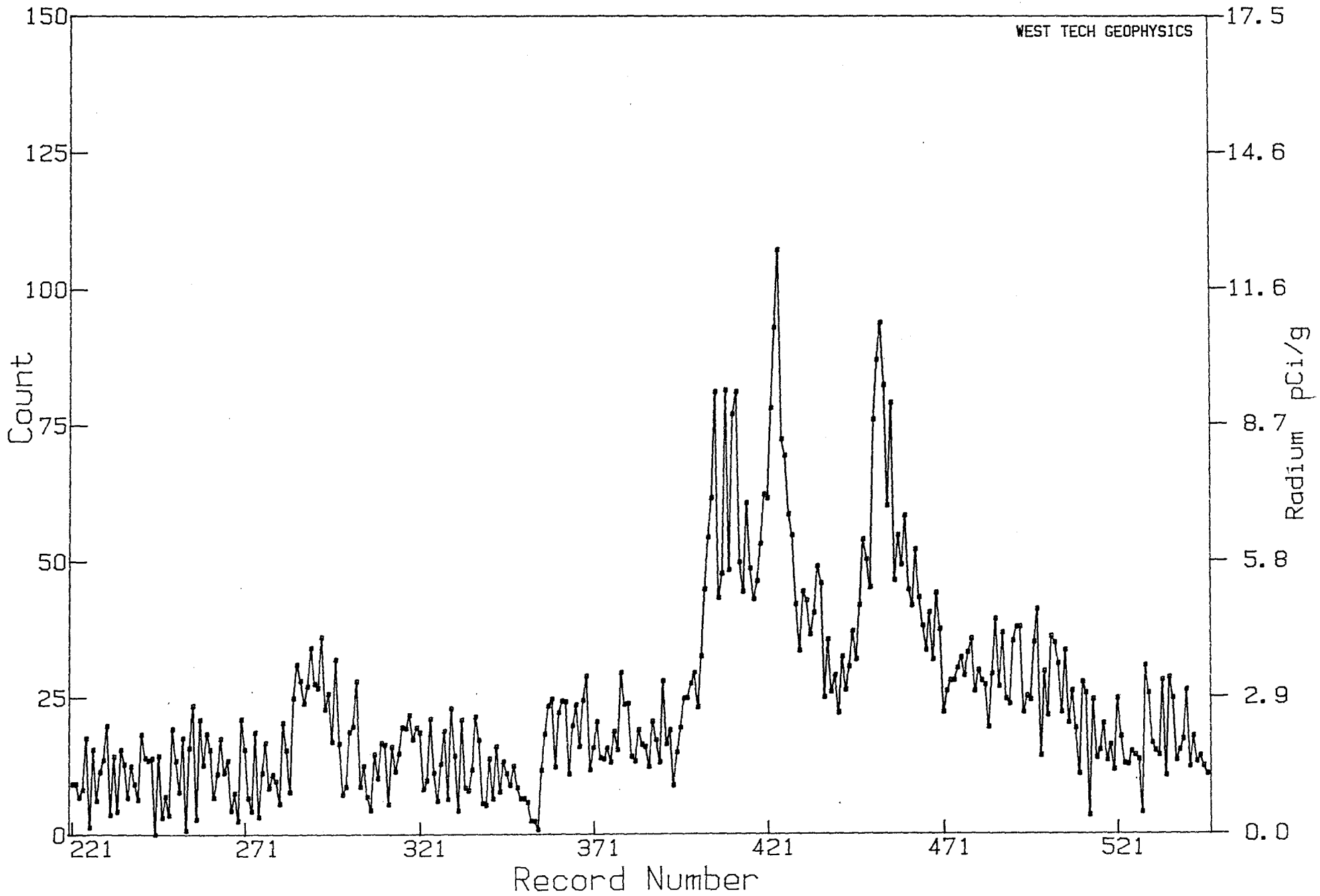
File: CVCRK5.EDT. Count Time: 1 sec.. Cave Creek Fleming Sprgs. & Sierra Vist



CCT-5

Profile: 50B-50C. Channel: Radium. Gamma Ray Spectrometer Survey.

File: CVCRK5.EDT. Count Time: 1 sec.. Cave Creek Fleming Springs east side.

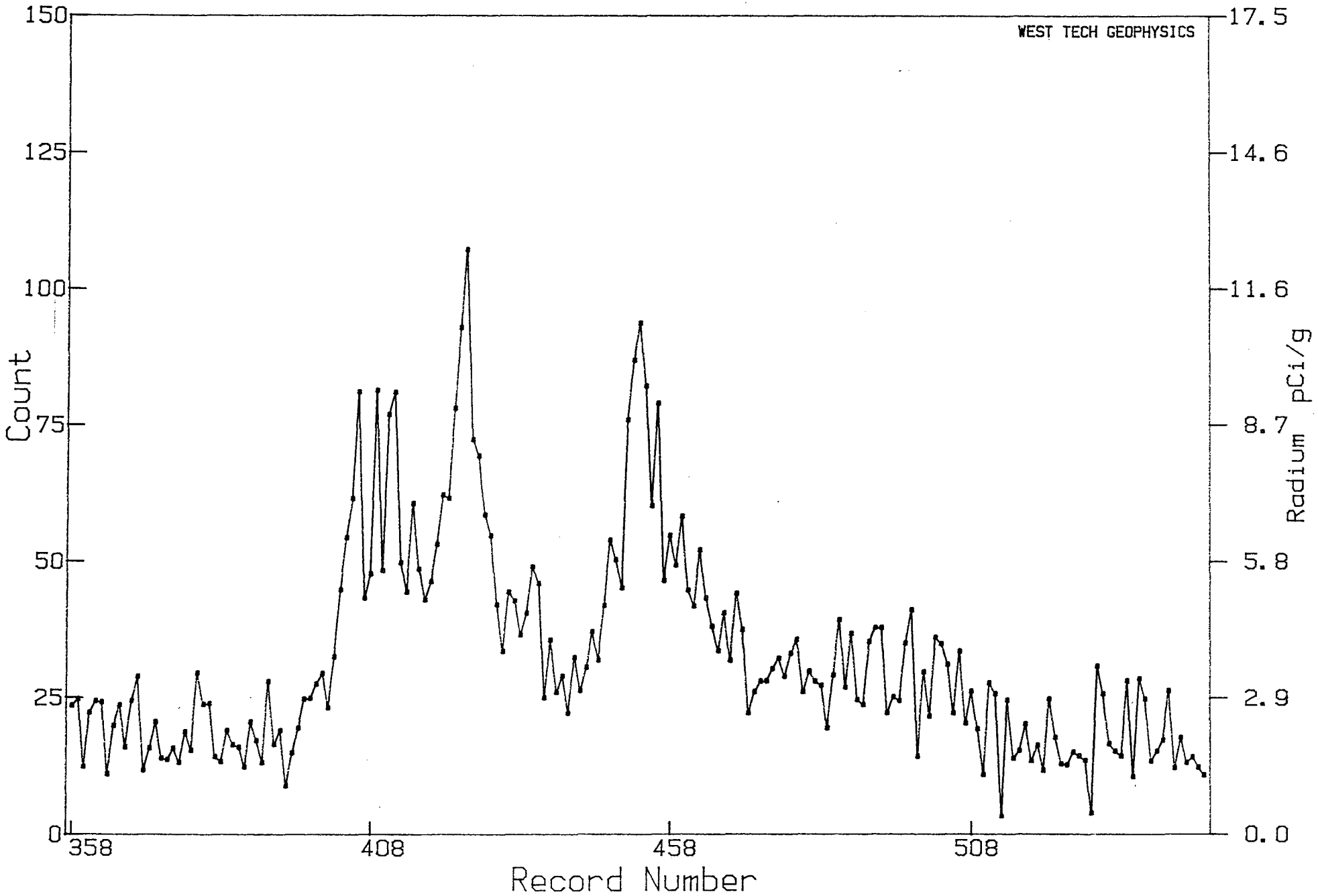


CCT-6

Profile: 51-51A.
File: CVCRK5.EDT.

Channel: Radium.
Count Time: 1 sec..

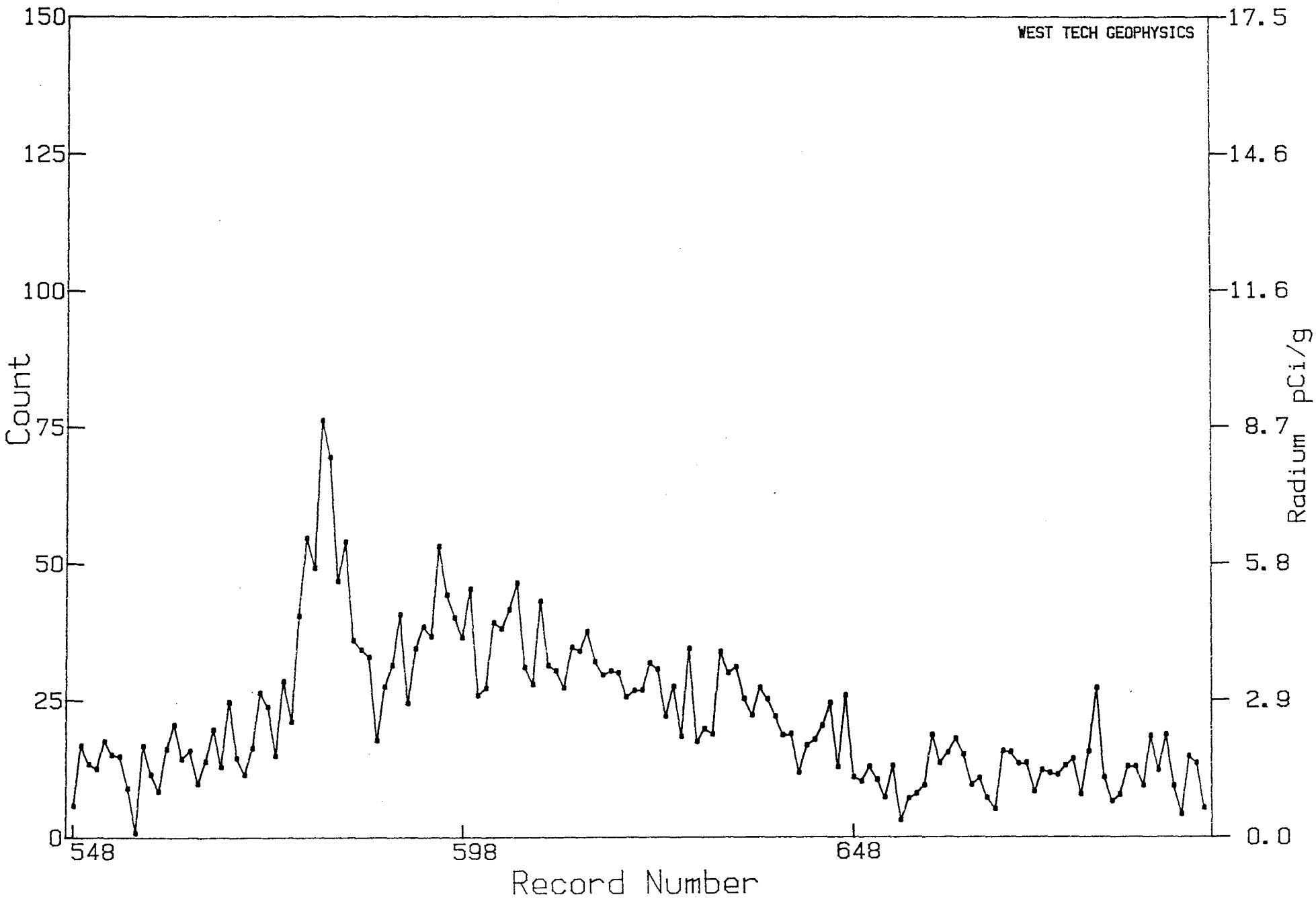
Gamma Ray Spectrometer Survey.
Cave Creek powerline road.



CCT-7

Profile: 52-52A. Channel: Radium. Gamma Ray Spectrometer Survey.

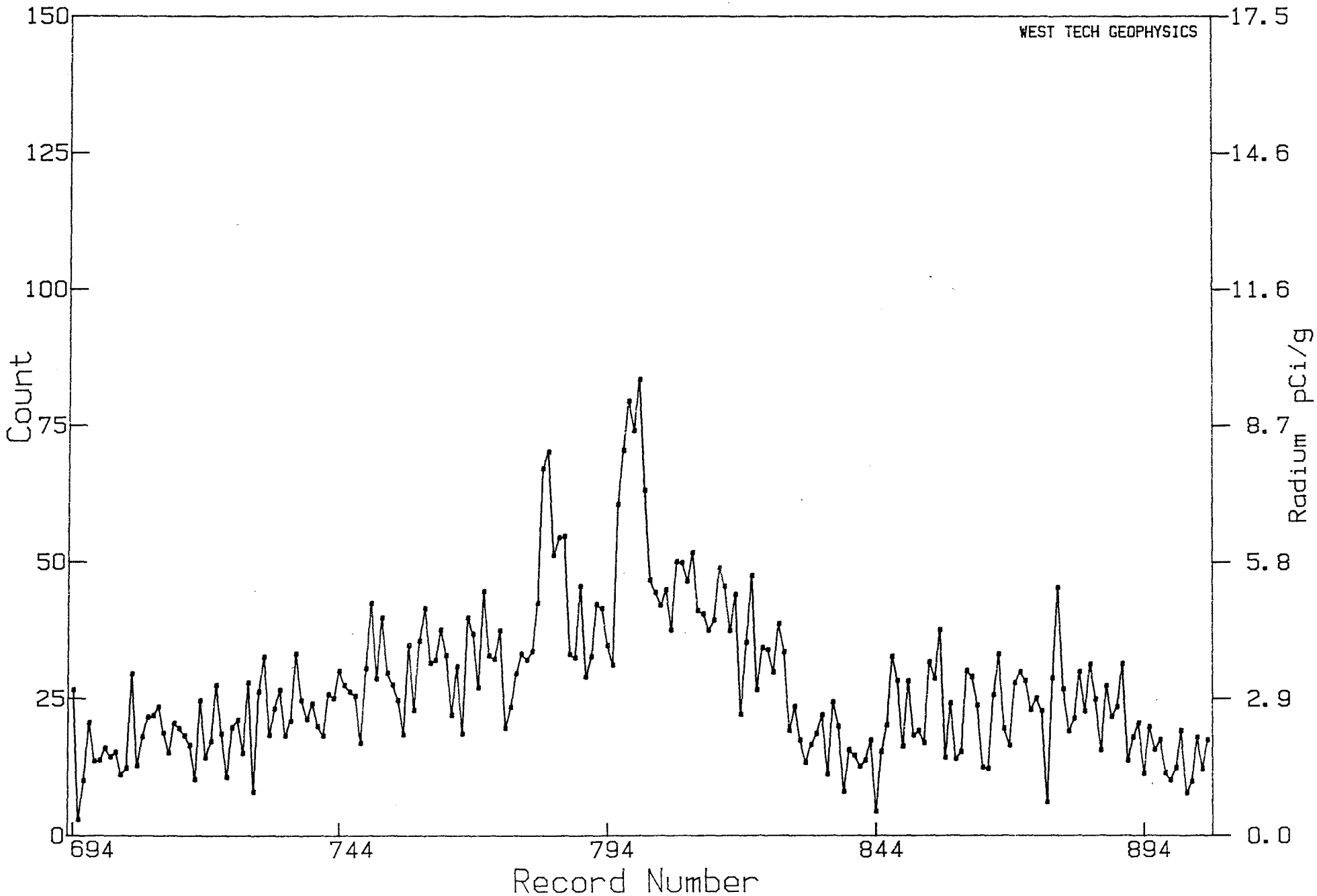
File: CVCRK5.EDT. Count Time: 1 sec.. Cave Creek.



CCT-8

Profile: 53-53A. Channel: Radium. Gamma Ray Spectrometer Survey.

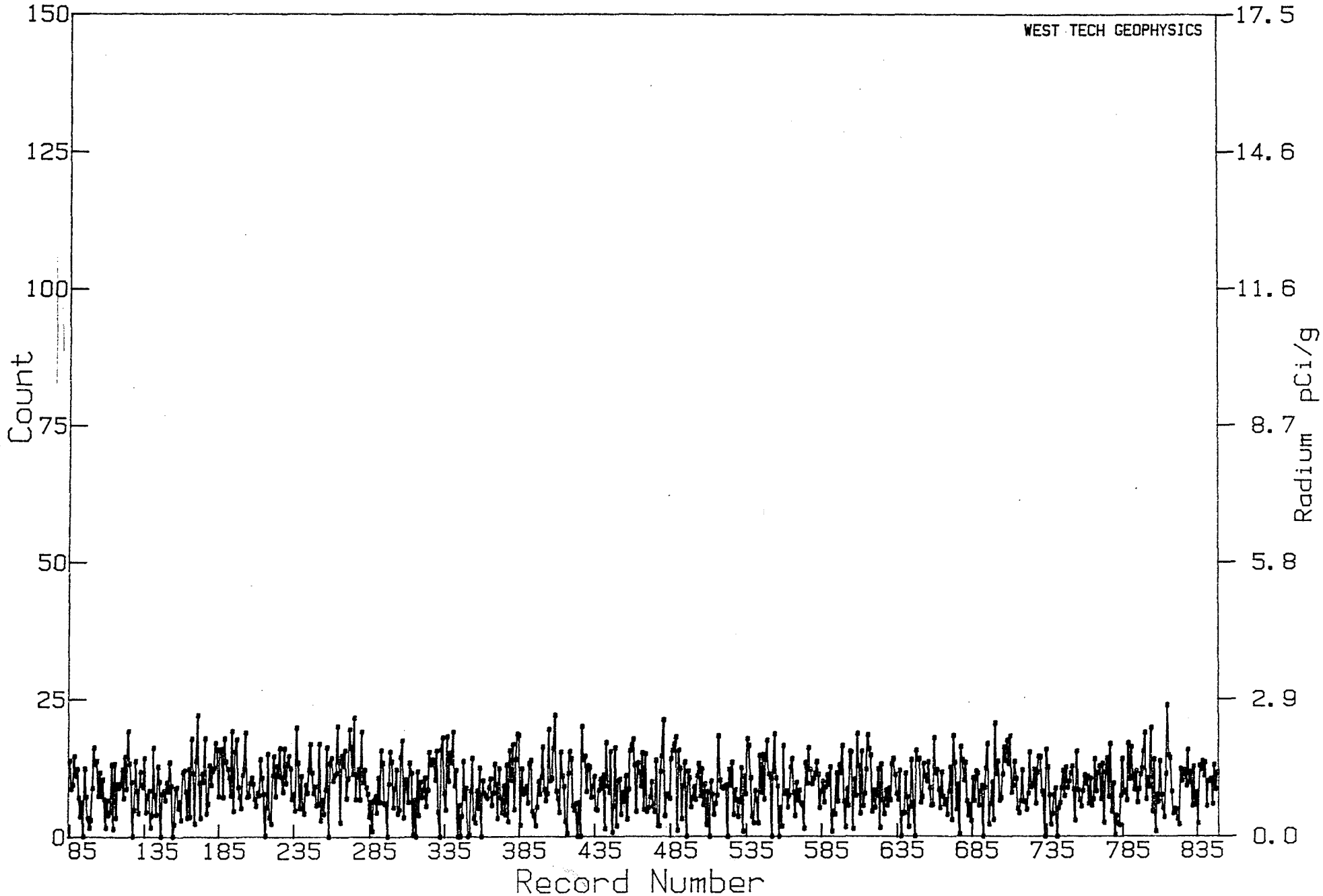
File: CVCRK5.EDT. Count Time: 1 sec.. Cave Creek Sierra Vista Rd..



GCT-1

Profile: 99-99A. Channel: Radium. Gamma Ray Spectrometer Survey.

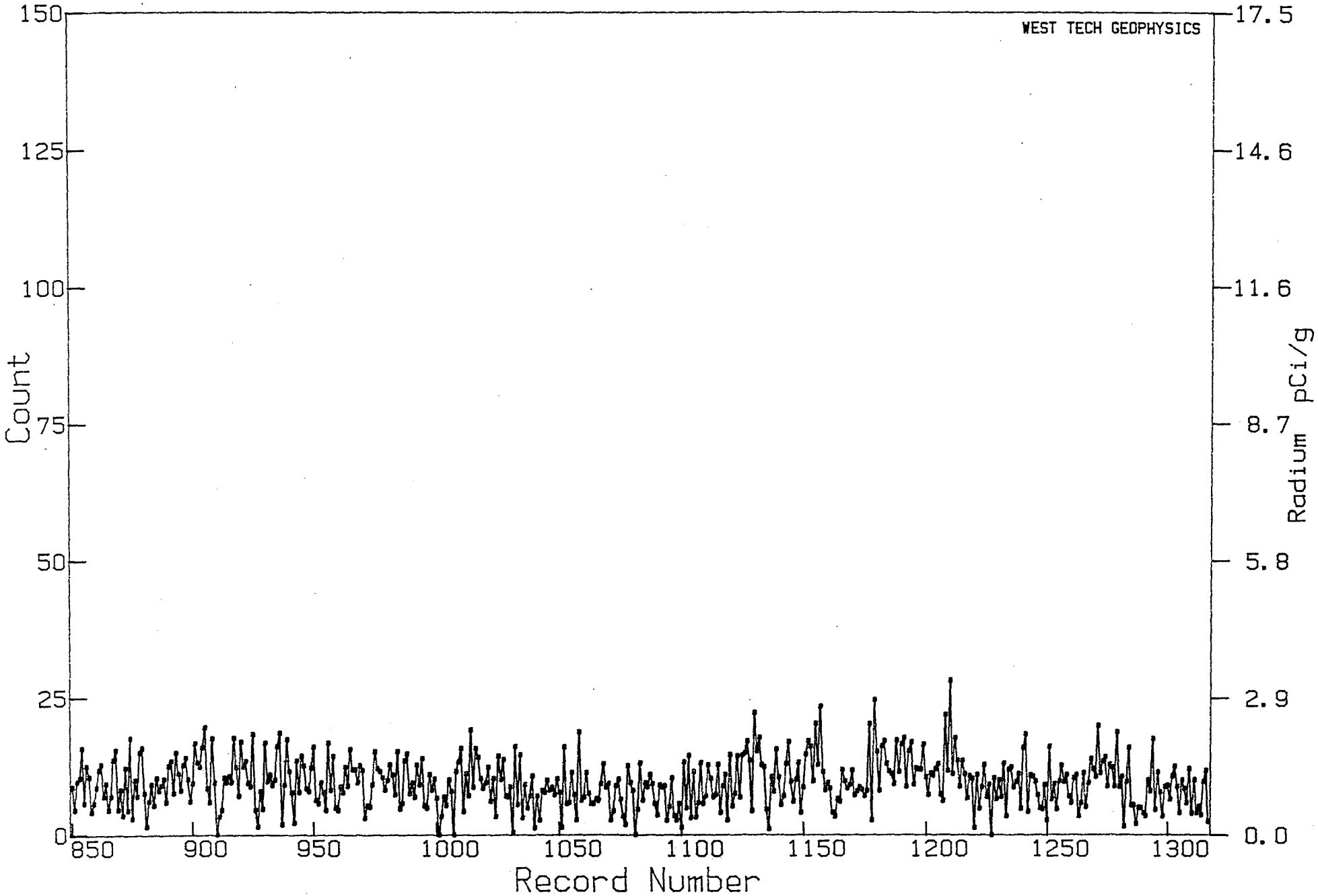
File: PRESCT2.EDT. Count Time: 1 sec.. Groom Creek.



GCT-2

Profile: 100-100A. Channel: Radium. Gamma Ray Spectrometer Survey.

File: PRESCT2.EDT. Count Time: 1 sec.. Groom Creek.

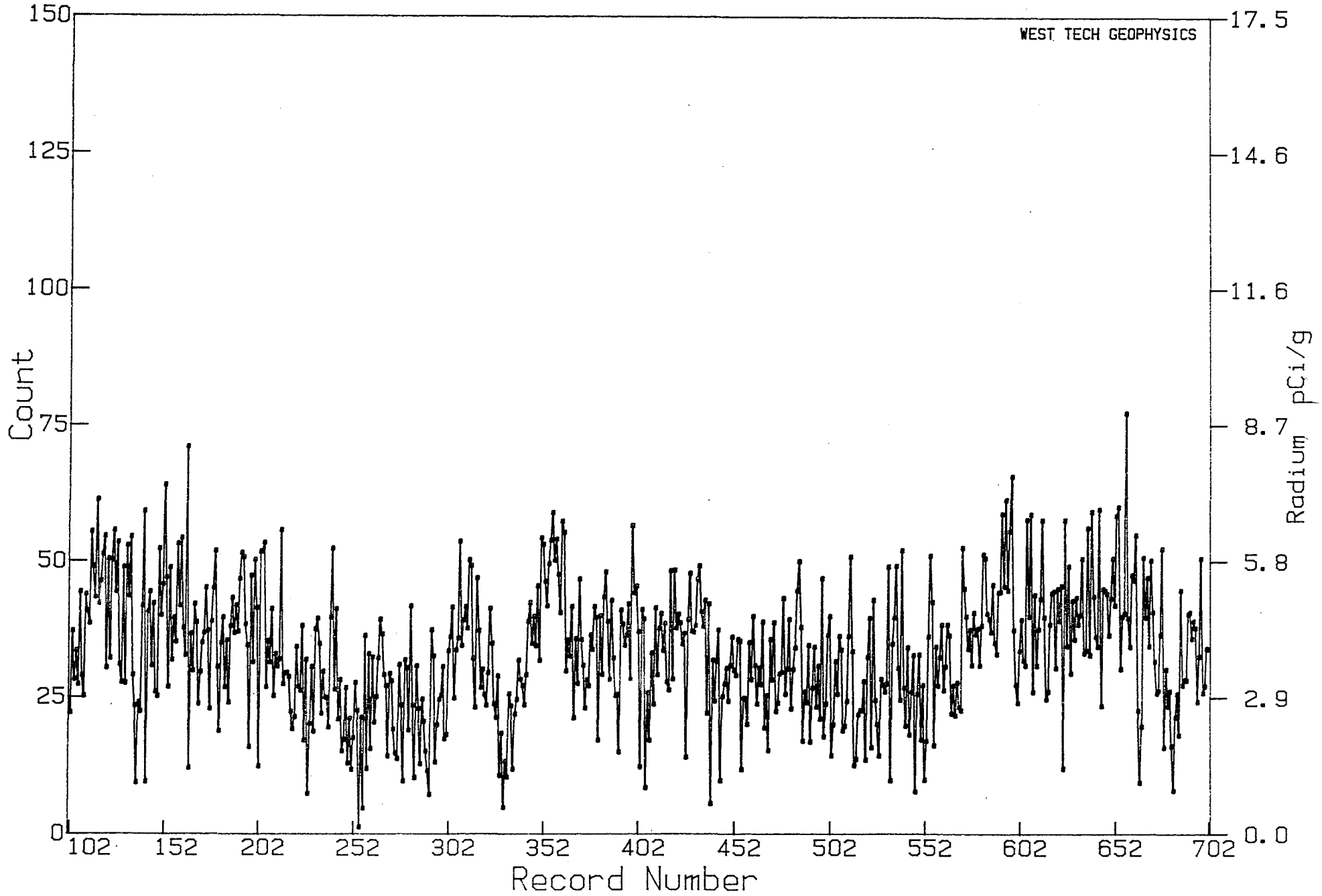


GDT-1

Profile: 84-84A.
File: PRESCT1.EDT.

Channel: Radium.
Count Time: 1 sec..

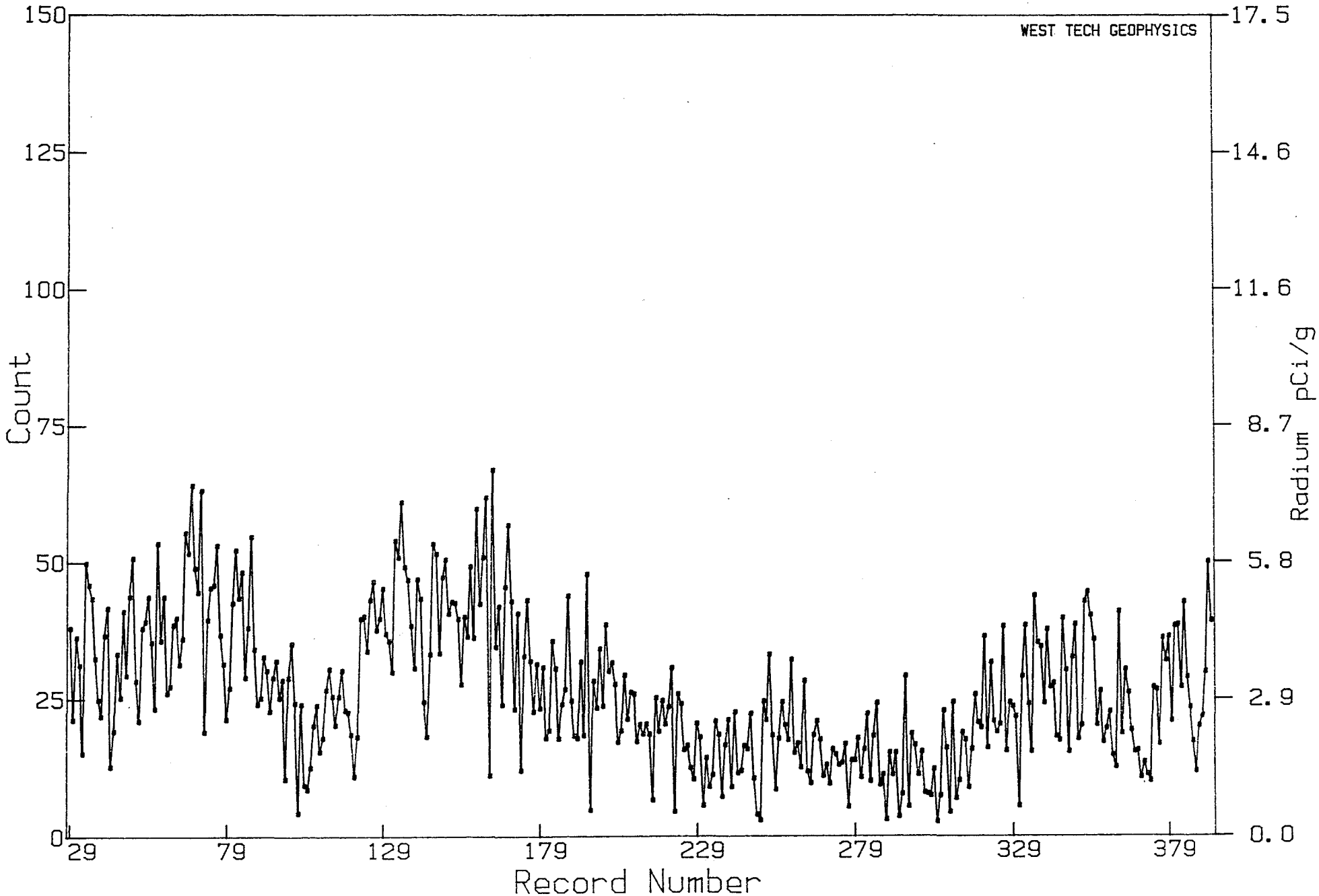
Gamma Ray Spectrometer Survey.
Prescott Granite Dells.



GDT-2

Profile: 84A-84B. Channel: Radium. Gamma Ray Spectrometer Survey.

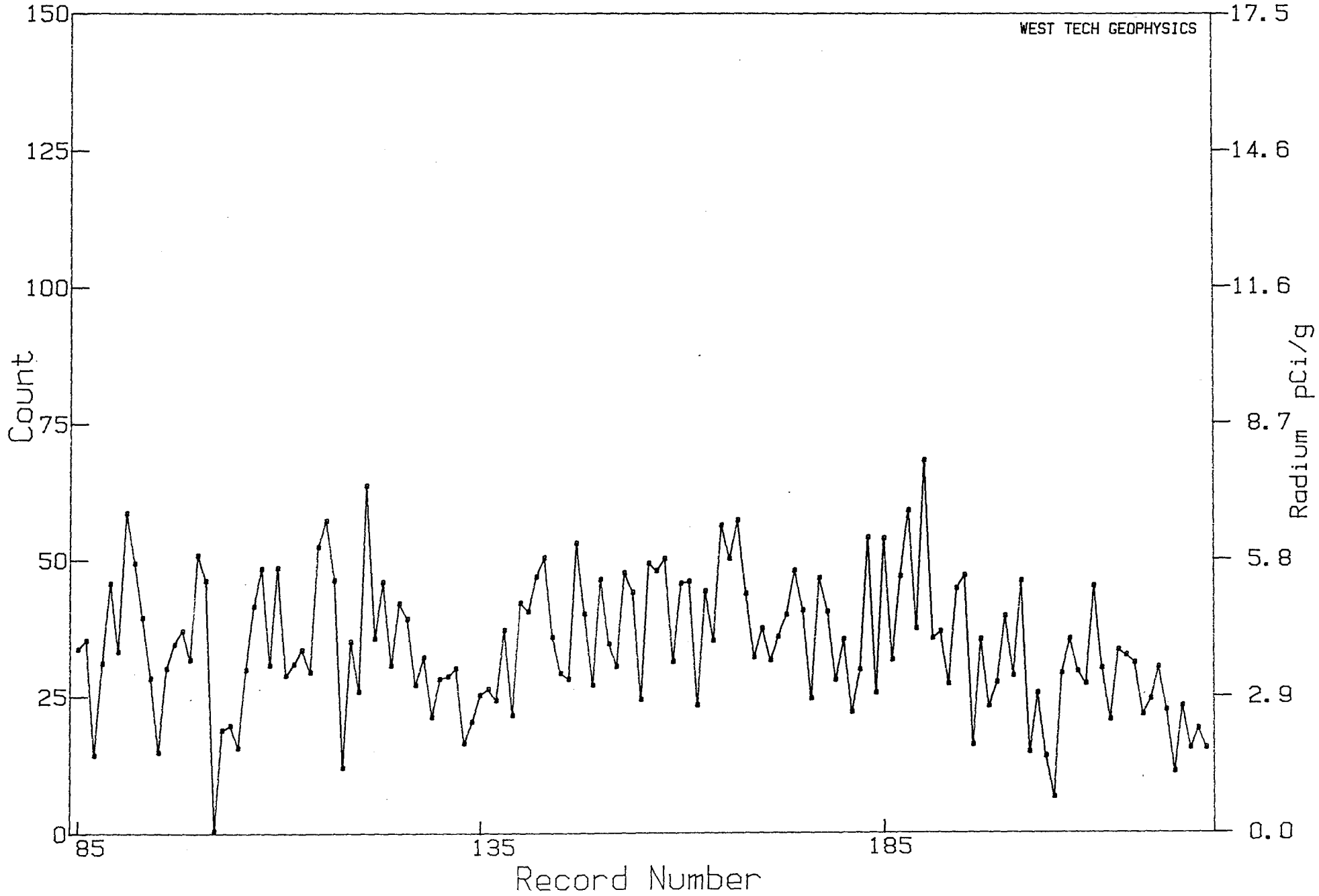
File: PRESCT1B.EDT. Count Time: 1 sec.. Prescott Granite Dells.



PMT-1

Profile: 20-21. Channel: Radium. Gamma Ray Spectrometer Survey.

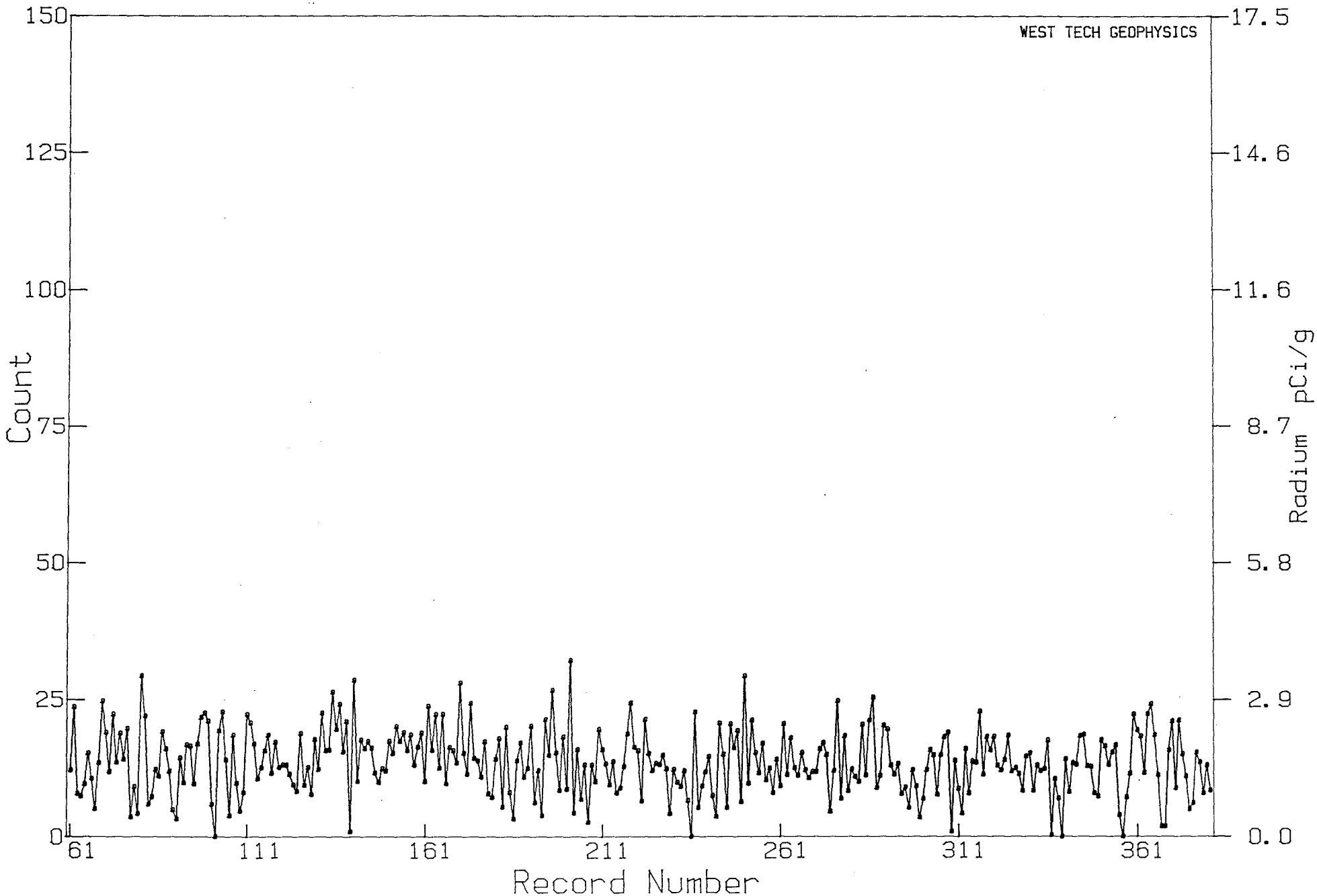
File: CVCRK3.EDT. Count Time: 1 sec.. Phoenix Mts. Saddle to Mt. base.



PPT-1

Profile: 1-2. Channel: Radium. Gamma Ray Spectrometer Survey.

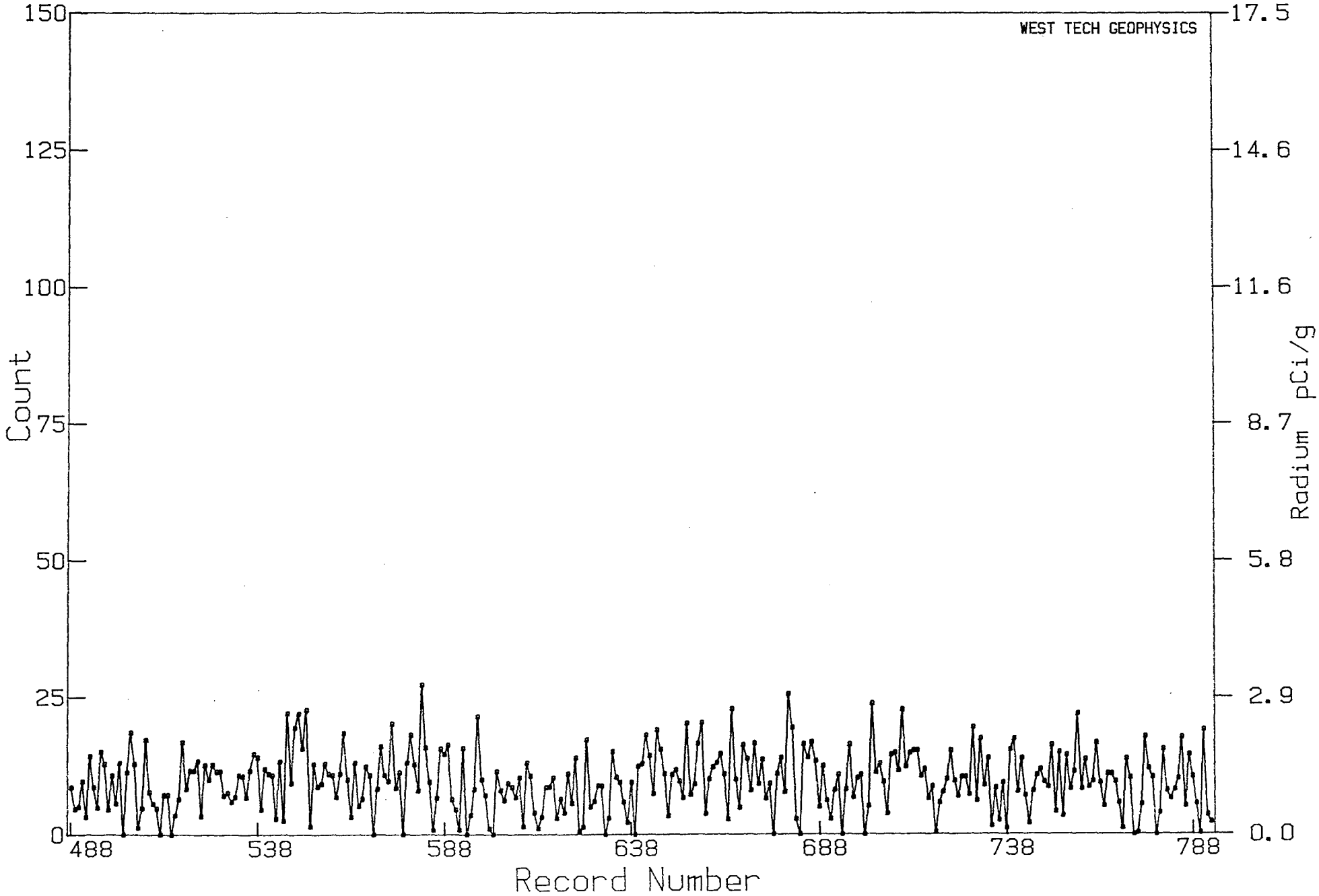
File: CVCRK2.EDT. Count Time: 1 sec.. Jomax East to West.



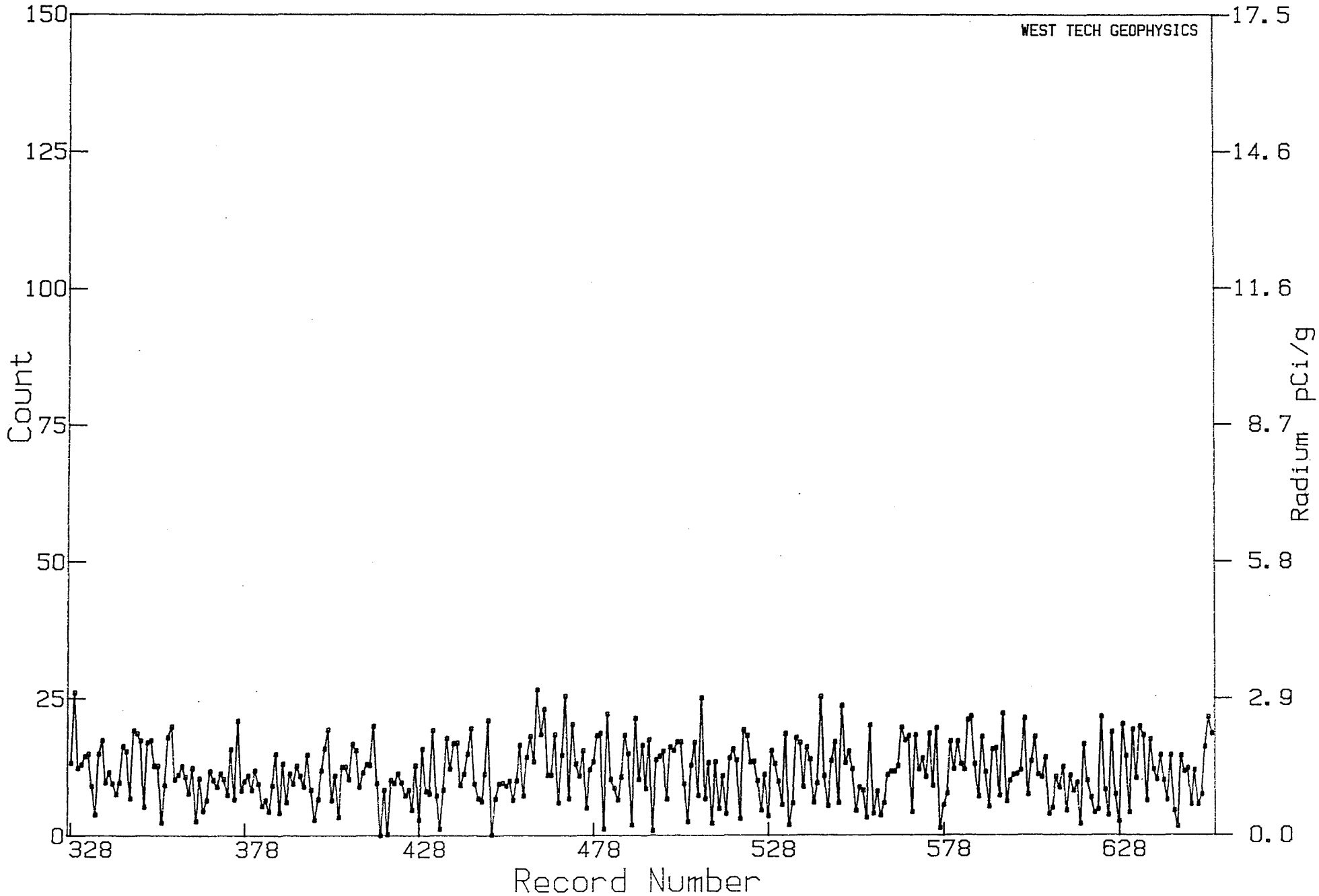
PPT-2

Profile: 11-12. Channel: Radium. Gamma Ray Spectrometer Survey.

File: CVCRK2.EDT. Count Time: 1 sec.. Pinnacle Peak Mt. base to pavement.



UHT-1
Profile: 32-33. Channel: Radium. Gamma Ray Spectrometer Survey.
File: CVCRK3.EDT. Count Time: 1 sec.. Turkey Track Pit N. 16th St..



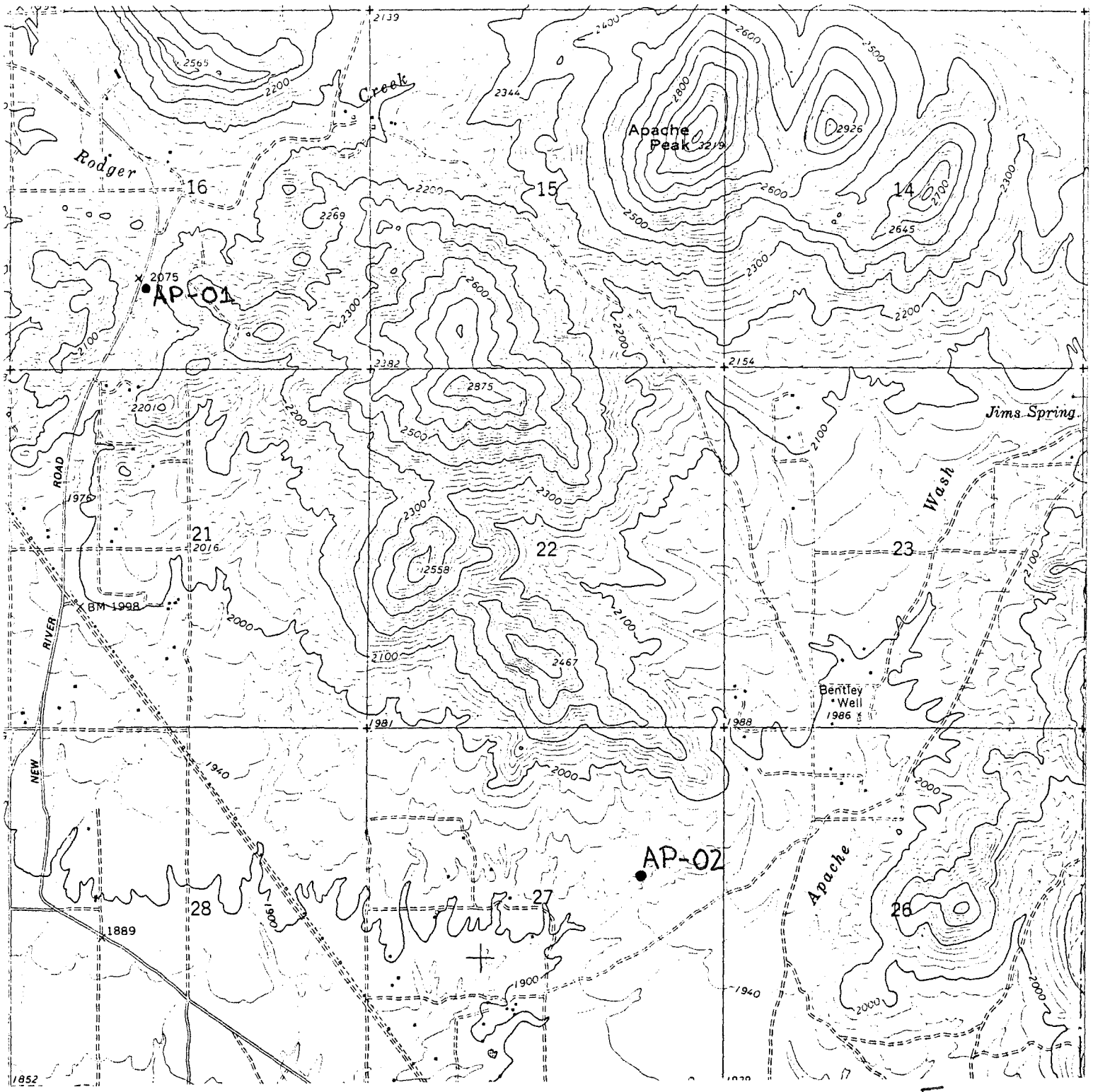
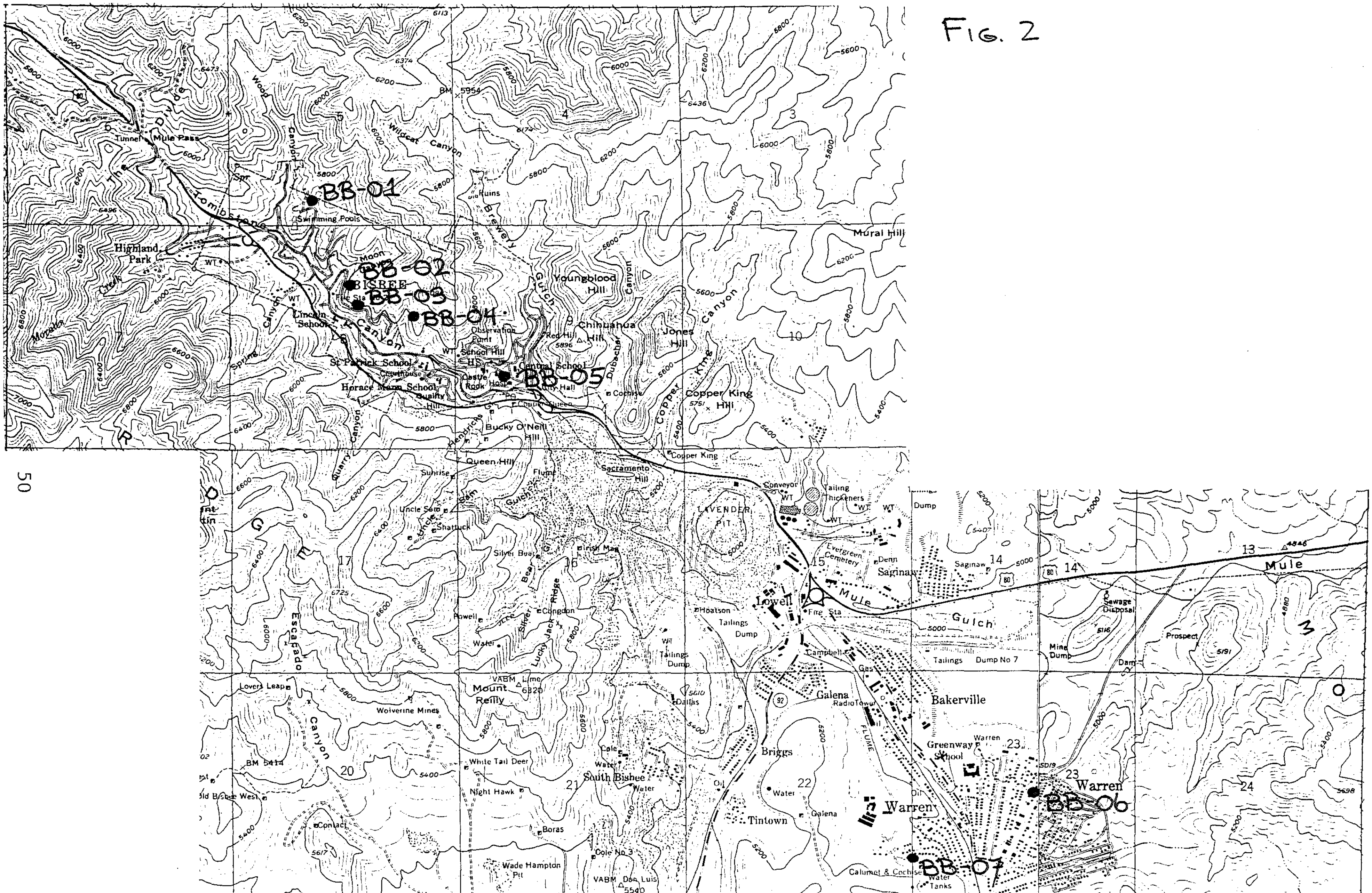

Rodger
Creek
Apache
Peak
2219
2926
2645
2344
2565
2269
2875
2558
2467
2075
AP-01
AP-02
16
15
14
21
22
23
26
27
28
2139
2382
2154
2016
1976
1998
1981
1988
1986
1889
1852
BM 1998
ROAD
RIVER
NEW
Jims Spring
Wash
Apache
Bentley
Well

FIG. 1

FIG. 2



BB-01
BB-02
BB-03
BB-04
BB-05
BB-06
BB-07
BISBEE
Tombstone
Mule Pass
Tunnel
Swimming Pools
Highland Park
Wood Canyon
Wildcat Canyon
Brewery Gulch
Youngblood Hill
Chihuahua Hill
Jones Hill
Copper King Canyon
Copper King Hill
Mural Hill
Moon
Fire Sta
Lincoln School
St Patrick School
Horace Mann School
Courthouse
Quality Hill
Observation Point
School Hill
Central School
Castle Rock
Hosp
City Hall
Copper Queen
Red Hill
Cochise
Bucky O'Neill Hill
Queen Hill
Sacramento Hill
Copper King
Conveyor
Tailing Thickeners
Dump
Lavender Pit
Evergreen Cemetery
Denn
Saginaw
Lowell
Fire Sta
Mule Gulch
Sewage Disposal
Prospect
Mine Dump
Dam
Tailings Dump No 7
Campbell
Hoatson
Tailings Dump
Galena
Radio Tower
Bakerville
Greenway School
Warren
Briggs
Tintown
Calumet & Cochise
Water Tanks
Flume
Sunrise
Uncle Sam
Shattuck
Silver Bear
Irish Mag
Congdon
Powell
Lucky Jack Ridge
Escabrosa
Escalado Canyon
Lovers Leap
Wolverine Mines
Mount Reilly
VABM Lime 6820
BM 5414
White Tail Deer
Night Hawk
South Bisbee
Cole
Cole No 3
Boras
Contact
Old Bisbee West
Wade Hampton Pit
VABM Don Luis 5540
Dallas
Mule
Spring Canyon
Moranda Creek
Quarry Canyon
Hendricks Gulch
Dubacher Canyon

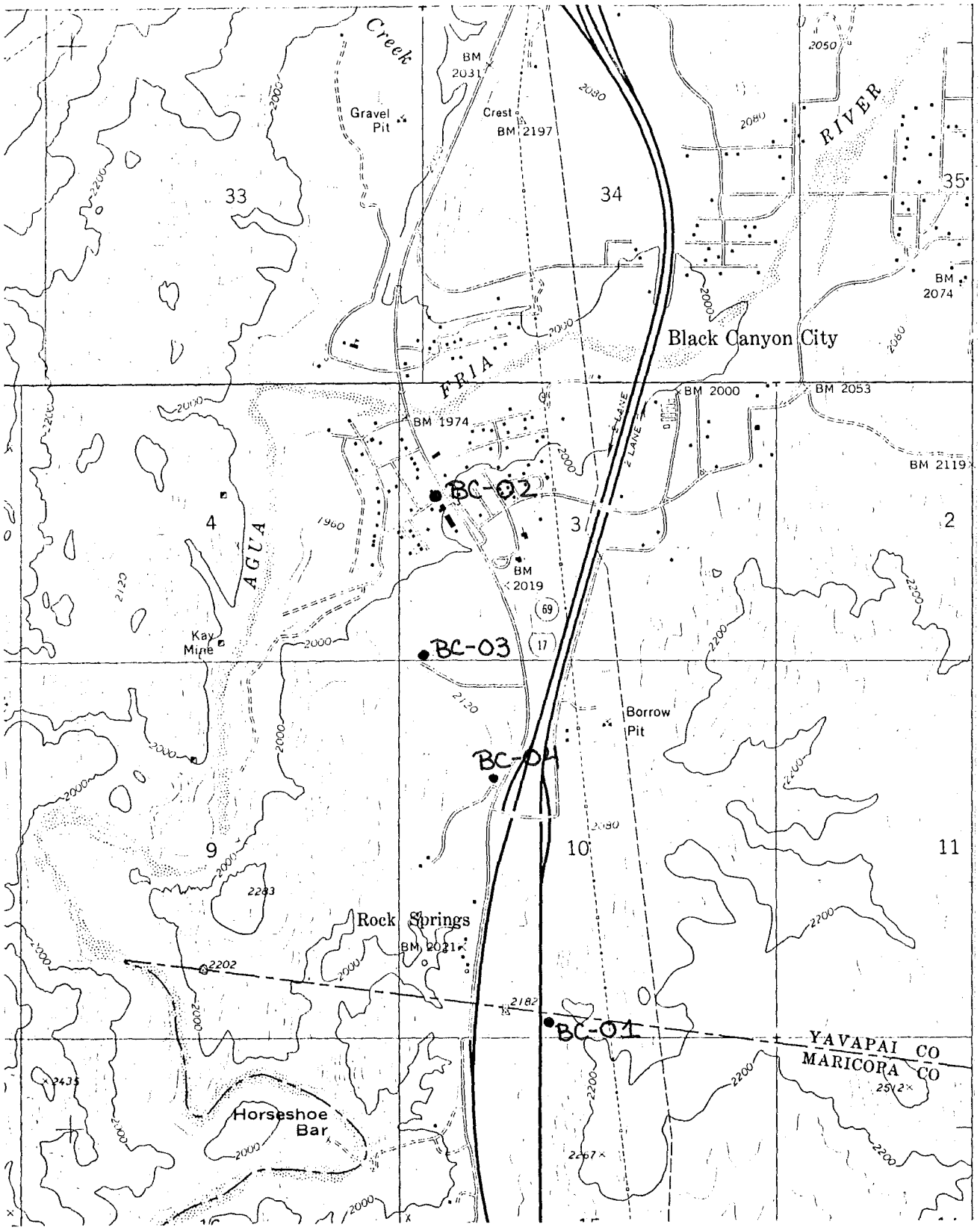

Creek
BM 2031
Gravel Pit
Crest
BM 2197
33
34
35
RIVER
BM 2074
Black Canyon City
FRIA
BM 2000
BM 2053
BM 1974
BC-02
BM 2119
4
3
2
AGUA
BM 2019
Kay Mine
BC-03
Borrow Pit
BC-04
9
10
11
Rock Springs
BM 2021
BC-01
YAVAPAI CO
MARICOPA CO
Horseshoe Bar

FIG. 3

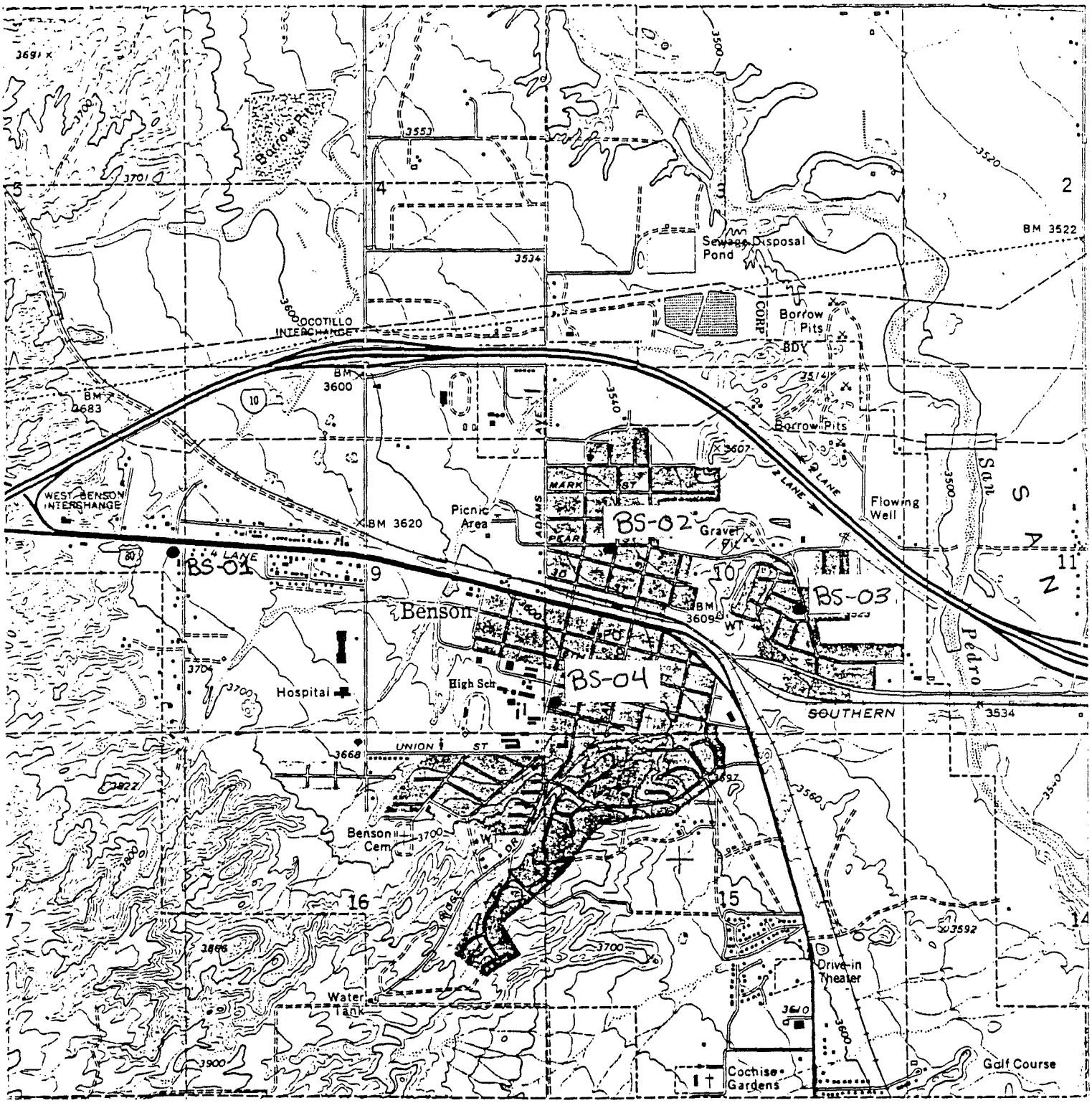

Sewage Disposal Pond
Borrow Pits
COCOTILLO INTERCHANGE
BM 3600
BM 3683
BM 3522
WEST BENSON INTERCHANGE
BM 3620
Picnic Area
BS-01
BS-02
BS-03
BS-04
Benson
Gravel Pit
Flowing Well
San Pedro
Hospital
High Sch
SOUTHERN
UNION ST
Benson Cem
Water Tank
Drive-in Theater
Cochise Gardens
Golf Course
BM 3609
WT

FIG. 4

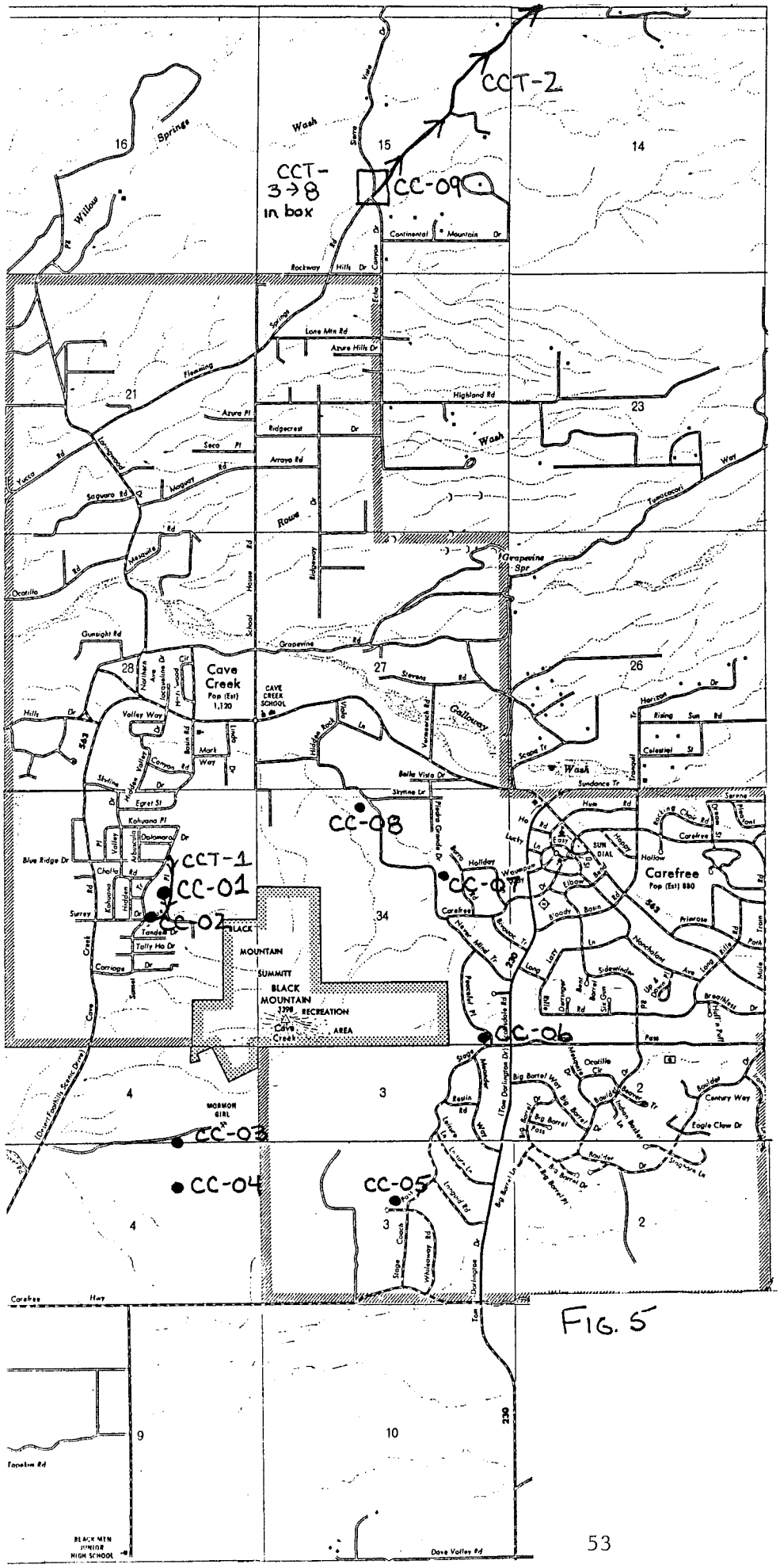

CCT-2
CCT-3→8 in box
CC-09
CC-08
CCT-1
CC-01
CC-02
CC-07
CC-06
CC-03
CC-04
CC-05
Cave Creek
Pop (Est) 1,120
Carefree
Pop (Est) 880
BLACK MOUNTAIN SUMMIT
BLACK MOUNTAIN RECREATION AREA
MORMON GIRL
Continental Mountain Dr
Rockway Hills Dr
Lone Mtn Rd
Azure Hills Dr
Highland Rd
Ridgecrest Dr
Arroya Rd
Grapevine Rd
Gunsight Rd
Valley Way
Stevens Rd
Galloway
Rising Sun Rd
Carefree Hwy
Dove Valley Rd
Tonto Darlington Dr
Big Barrel Way
Eagle Claw Dr
Century Way
Tapaloma Rd
BLACK MTN JUNIOR HIGH SCHOOL

FIG. 5

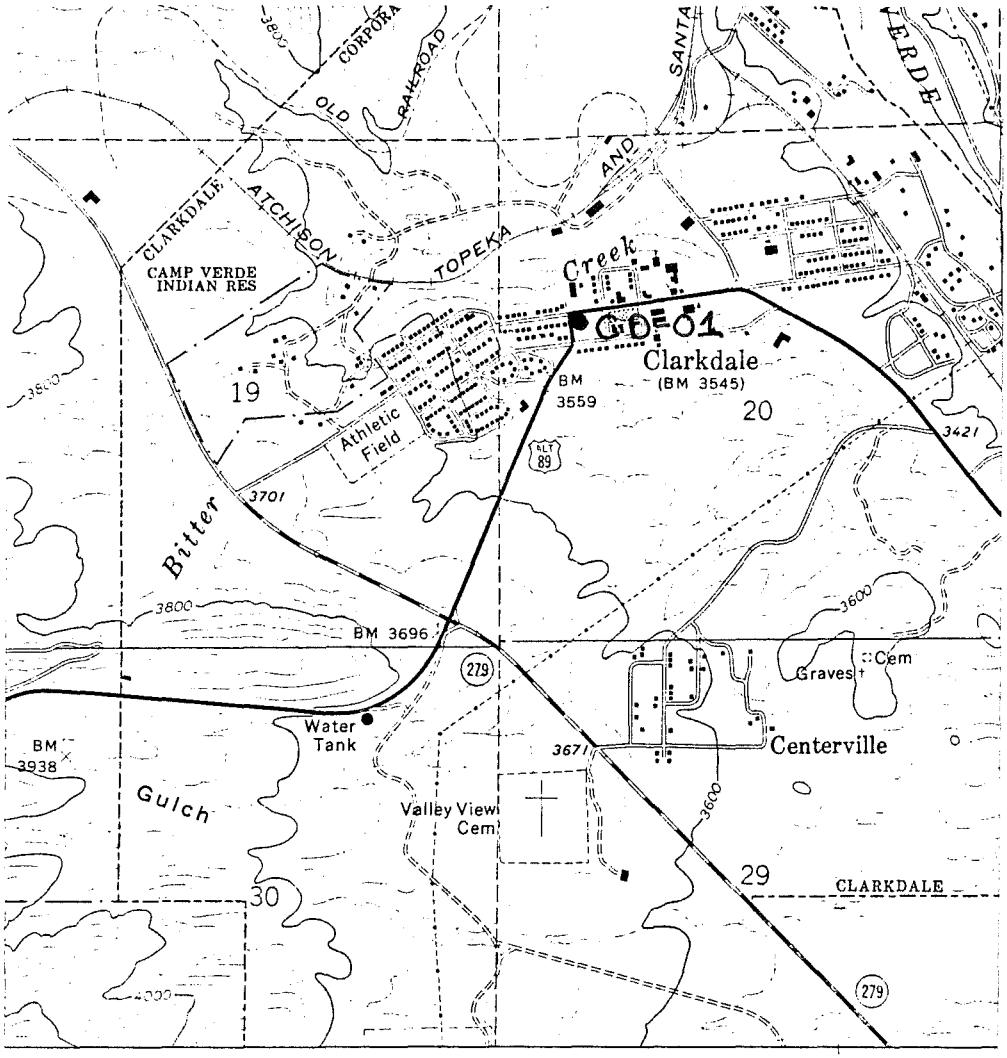

CORPORA
OLD
RAILROAD
SANTA
FERDE
AND
CLARKDALE
ATCHISON
TOPEKA
CAMP VERDE
INDIAN RES
Creek
GD-01
Clarkdale
(BM 3545)
BM
3559
20
19
Athletic
Field
ALT
89
3421
3701
Bitter
3800
3600
BM 3696
279
Graves
Cem
Water
Tank
BM
3938
3671
Centerville
Gulch
Valley View
Cem
29
CLARKDALE
30
4000

FIG. 6

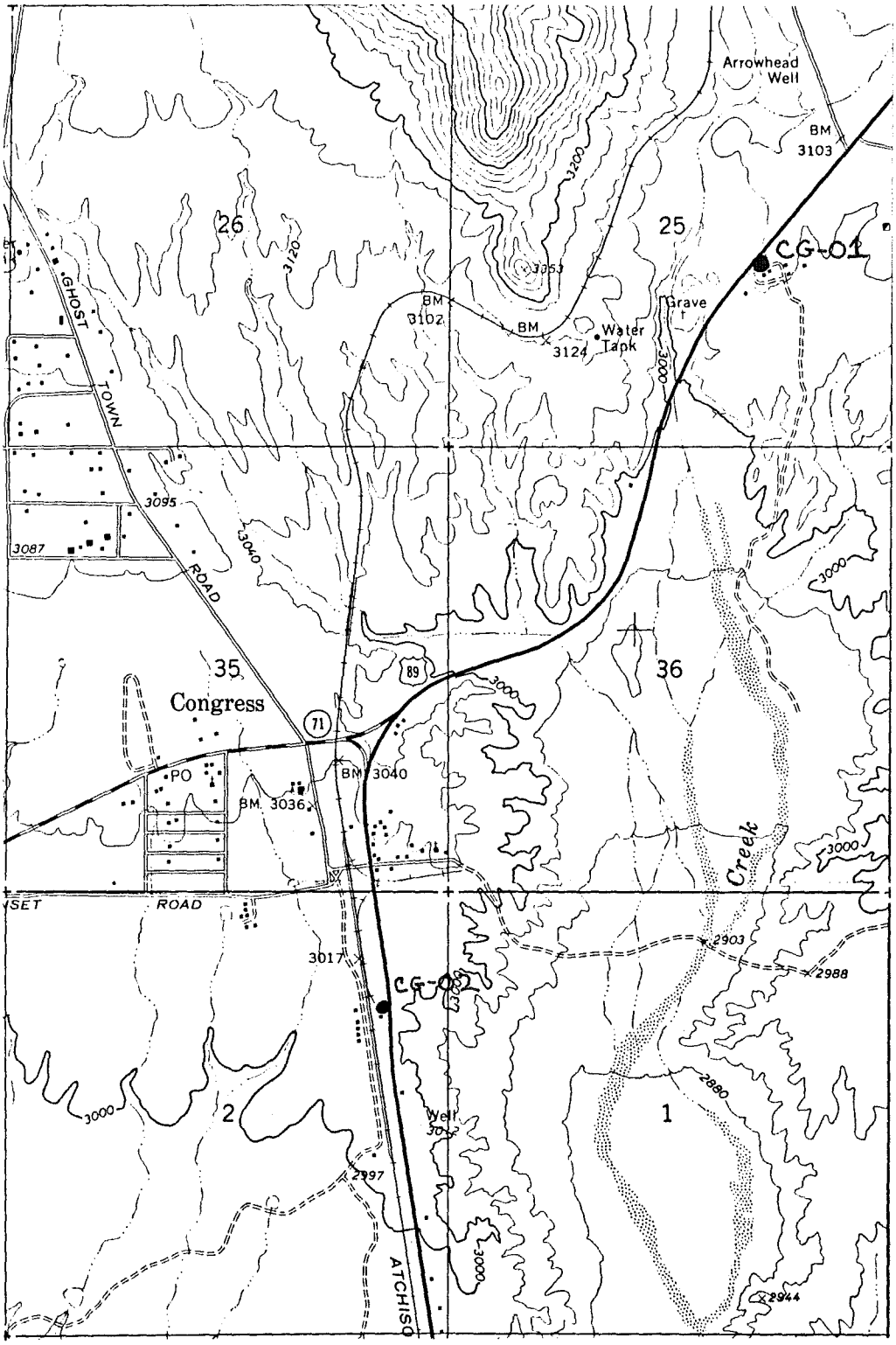

Arrowhead Well
BM 3103
26
25
CG-01
3120
3200
3353
BM 3102
BM 3124
Water Tank
Grave
3000
GHOST TOWN ROAD
3095
3087
3040
3000
35
36
Congress
89
71
3000
PO
BM 3040
BM 3036
Creek
3000
ROAD
2903
2988
3017
CG-02
3000
2
1
2890
Well
2997
3000
ATCHISO
2944

FIG. 7

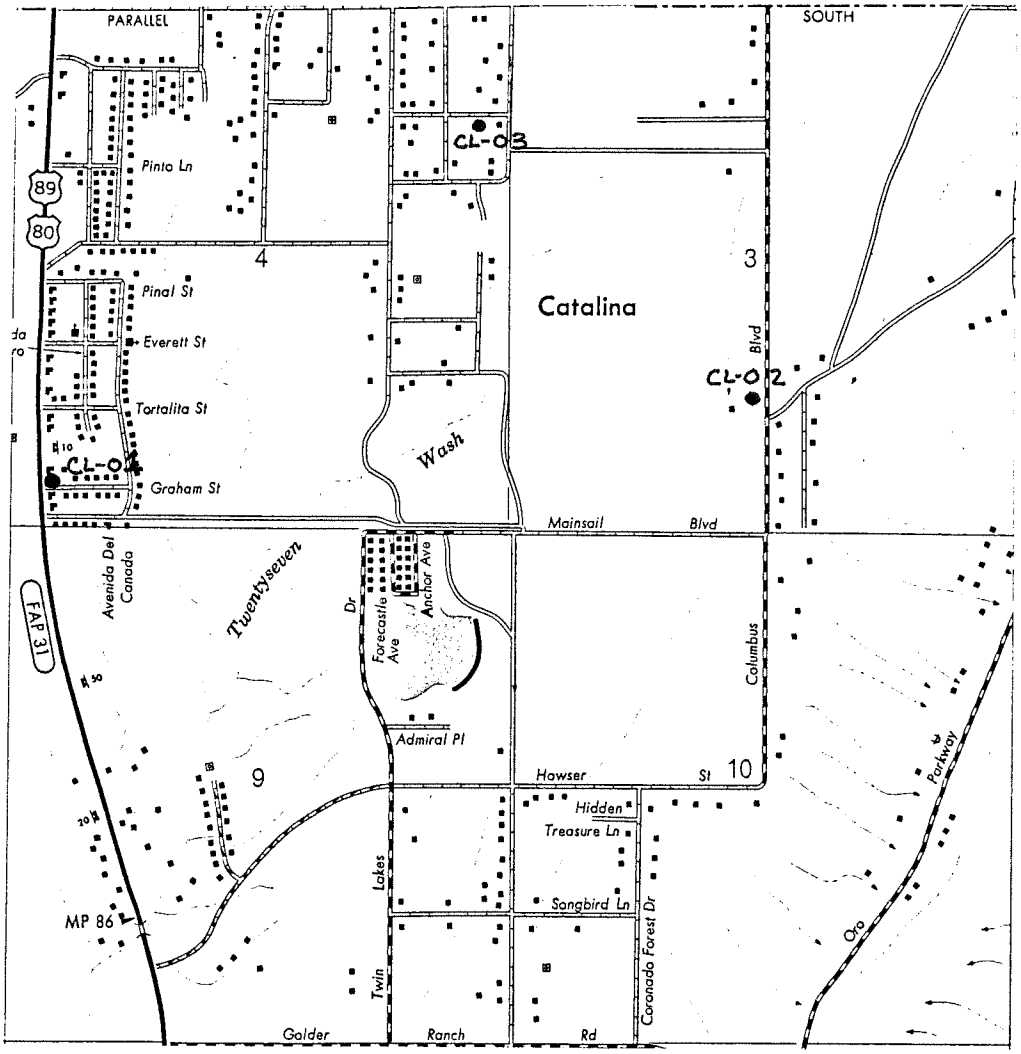

PARALLEL
SOUTH
Pinto Ln
89
80
4
3
Catalina
Pinal St
Everett St
Tortalita St
Graham St
CL-03
CL-02
CL-01
Wash
Blvd
Mainsail
Blvd
Avenida Del Canada
Twentyseven
Dr
Forecastle Ave
Anchor Ave
FAP 31
Columbus
Admiral Pl
9
Howser
St
10
Hidden
Treasure Ln
Lakes
Songbird Ln
MP 86
Twin
Coronado Forest Dr
Oro
Parkway
Golder
Ranch
Rd

FIG. 8

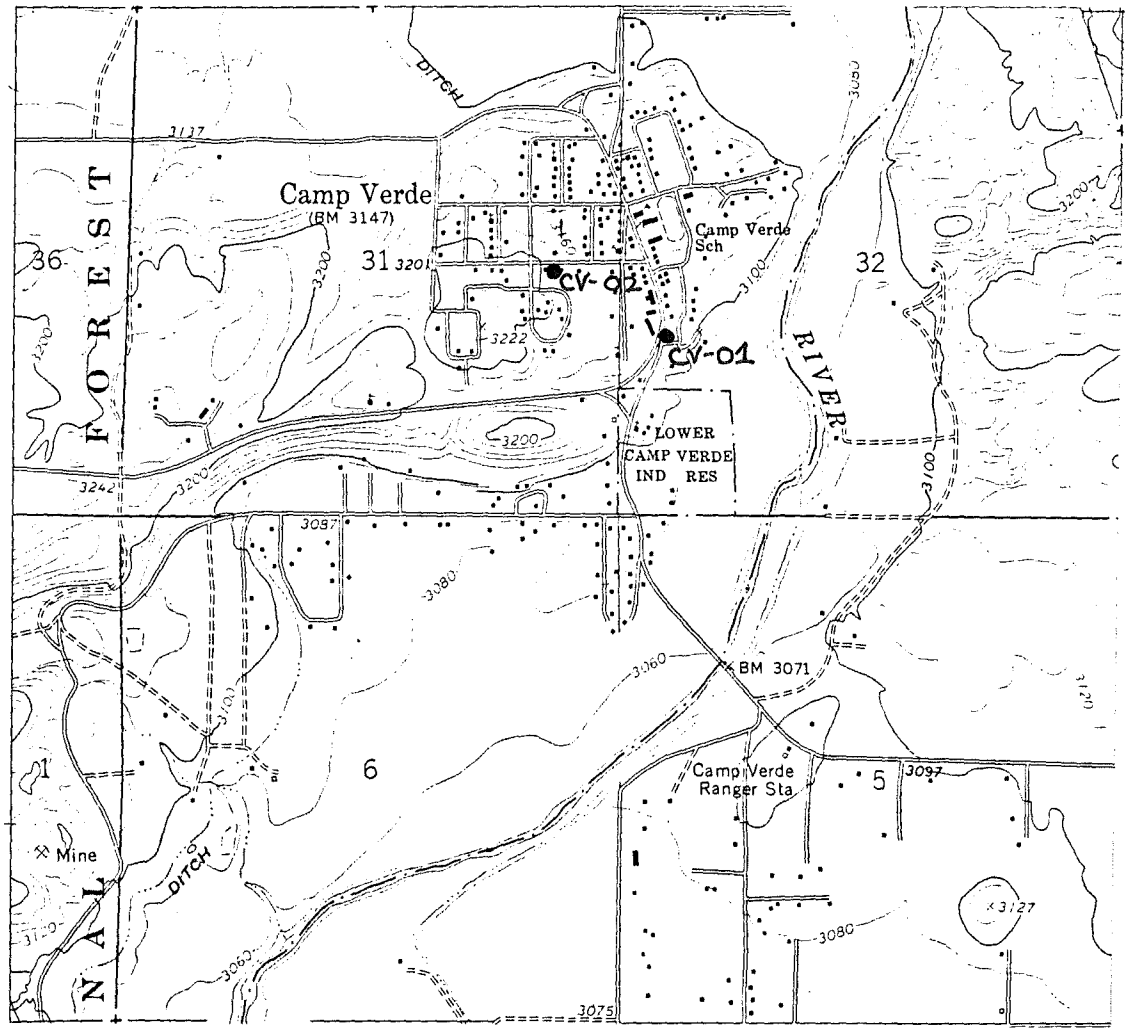

Camp Verde
(BM 3147)
Camp Verde Sch
CV-02
CV-01
LOWER CAMP VERDE IND RES
RIVER
BM 3071
Camp Verde Ranger Sta
Mine
DITCH
NAL FOREST
36
31
32
6
5
1
3137
3201
3222
3200
3242
3097
3080
3060
3100
3120
3075
3127

Fig. 9

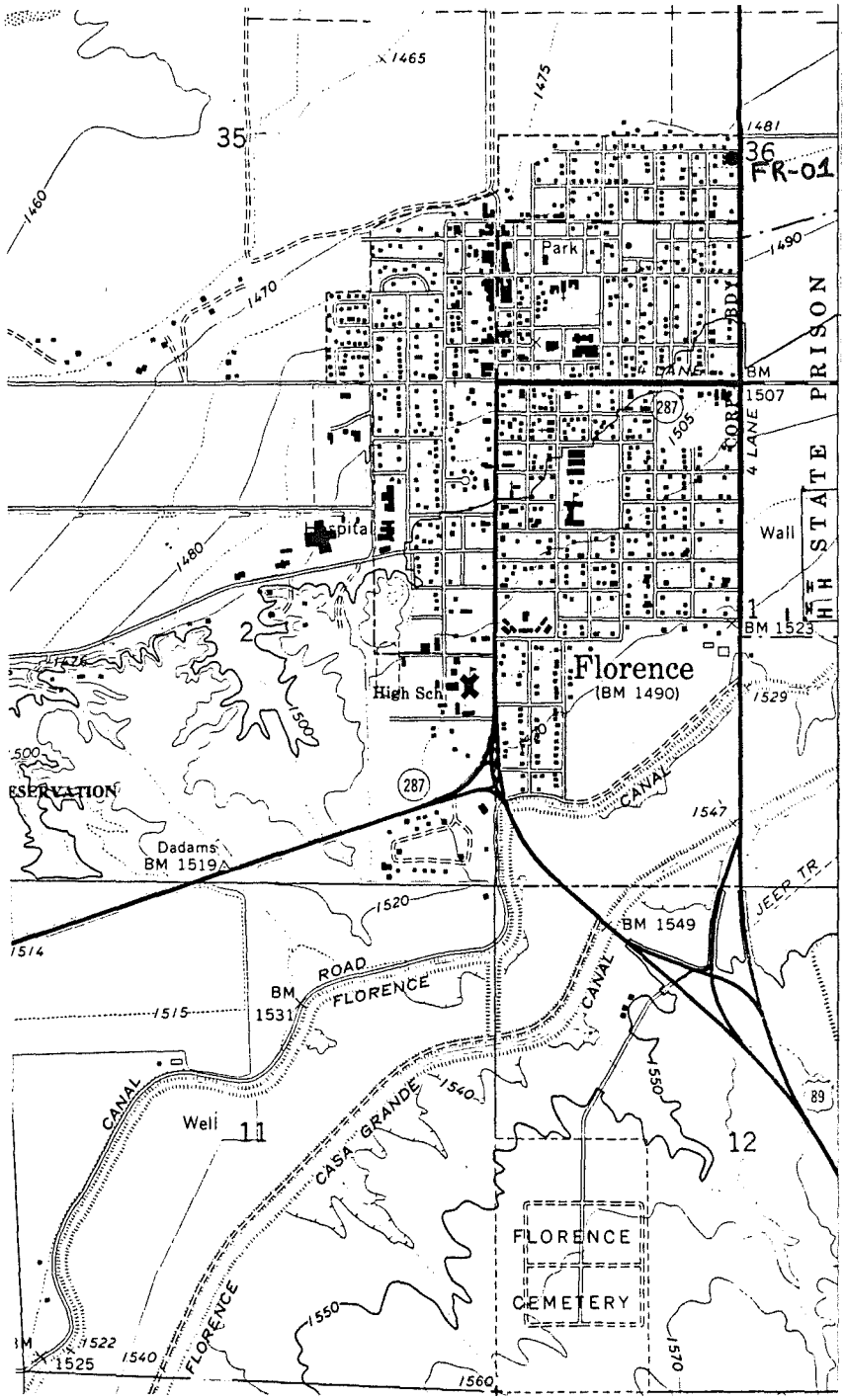
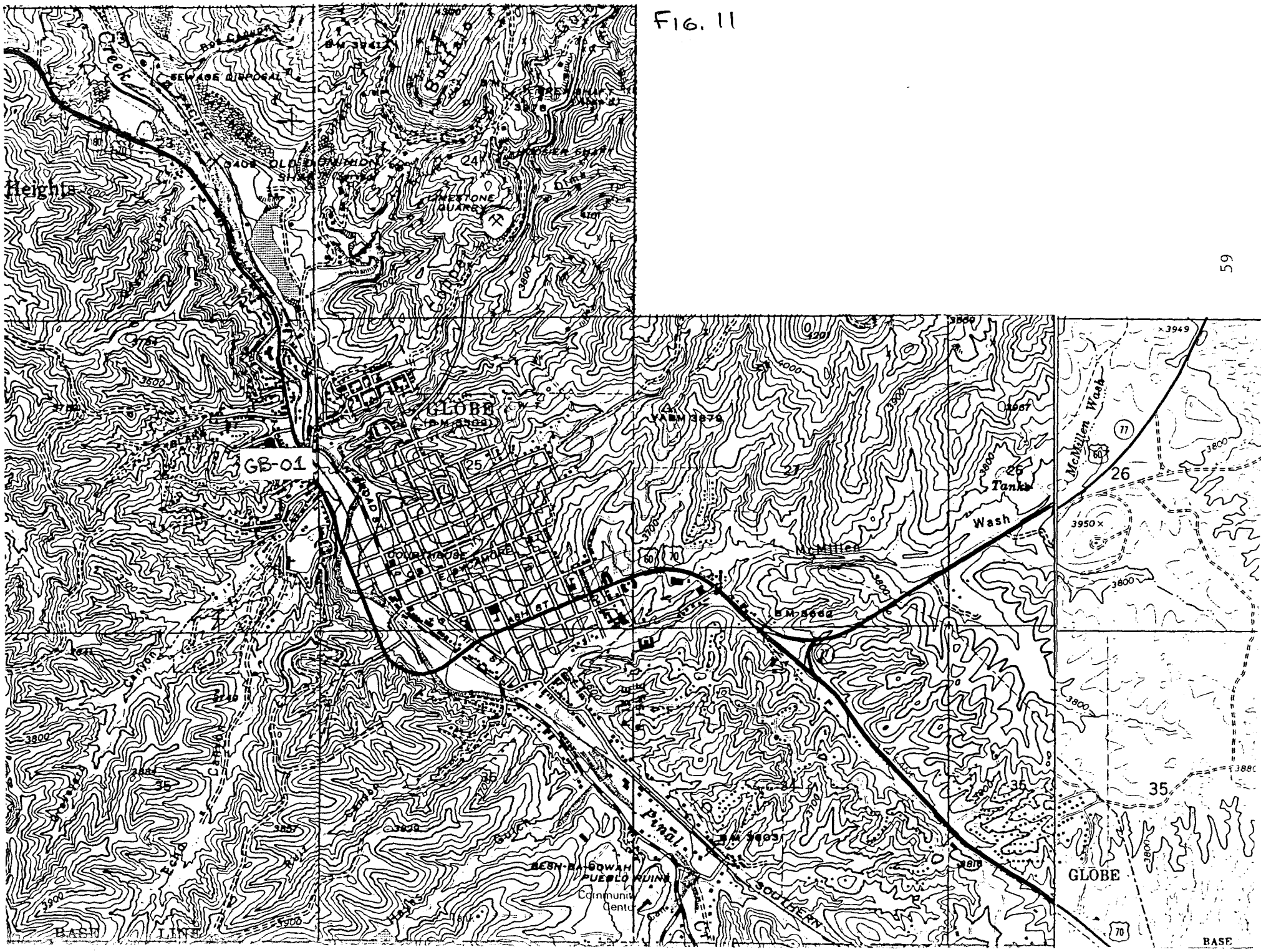

FR-01
35
36
1
2
11
12
Park
Hospital
High Sch
Florence
(BM 1490)
BM 1523
BM 1507
BM 1549
BM 1531
Dadams
BM 1519
Well
Wall
STATE PRISON
4 LANE
CORP BDY
FLORENCE CANAL
CASA GRANDE CANAL
FLORENCE ROAD
JEEP TR
FLORENCE CEMETERY
287
89
1465
1475
1481
1460
1470
1490
1480
1500
1505
1529
1547
1520
1514
1515
1540
1550
1560
1570
1522
1525

FIG. 10

FIG. 11


GB-01
GLOBE
Heights
Creek
Buffalo
Canyon
Pinal
Wash
McMillen
Tanks
BESH-BA-GOWAH PUEBLO RUINS
SOUTHERN
BASE LINE
BASE
GLOBE

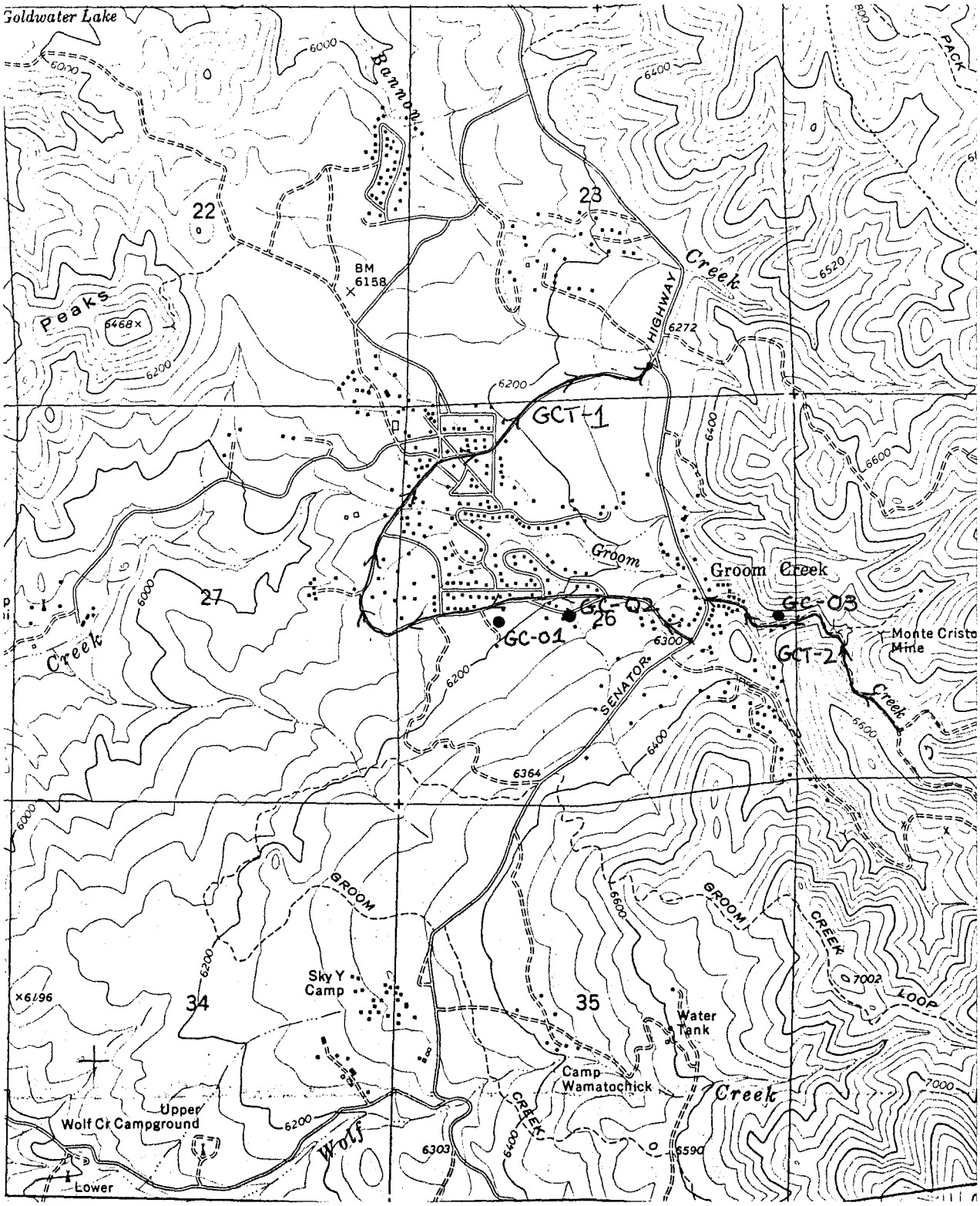

Goldwater Lake
Bannon
Creek
22
23
BM
6158
Peaks
6468
HIGHWAY
6272
GCT-1
Groom
Groom Creek
GC-03
GC-02
26
GC-01
27
Monte Cristo
Mine
GCT-2
Creek
SENATOR
6364
GROOM
CREEK
LOOP
7002
34
35
Sky Y
Camp
Water
Tank
Camp
Wamatochick
Creek
Upper
Wolf Cr Campground
Wolf
6303
6590
Lower
PACK

FIG. 12

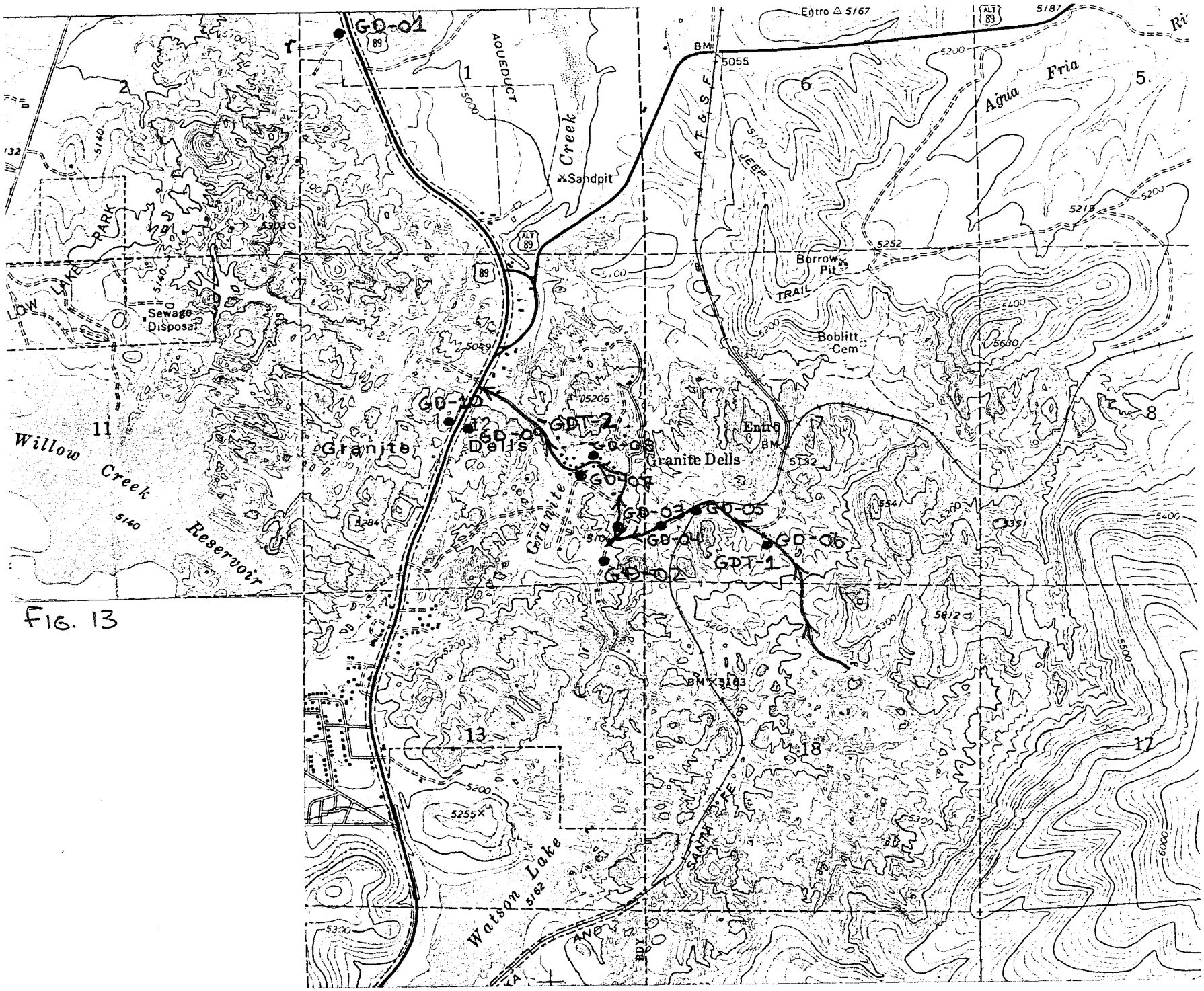

GD-01
GD-10
GD-12
GDT-2
GD-08
GD-07
GD-03
GD-05
GD-04
GD-06
GDT-1
GD-02
Granite Dells
Granite Dells
Sandpit
Sewage Disposal
Borrow Pit
Boblitt Cem
Willow Creek Reservoir
Watson Lake
Agua Fria
Granite Creek
AQUEDUCT
JEEP TRAIL
A T & S F
SANTA FE
LOW LAKE PARK
Entro △ 5167
5055
5252
5218
5206
5132
5541
5612
5163
5255
5162
5284
5140
5200
5300
5400
5600
5000
6000
1
2
5
6
7
8
11
12
13
17
18

FIG. 13

FIG. 14

U S MILITARY RESERVATION
GV-01
GV-02
GV-03
GV-04
GV-05
GV-06
GV-07
GV-08
GV-09
GV-10
GV-11
DUVAL MINE ROAD
Gravel Pit
BM 2838
Well
Santa Cruz
DRIVE
2 LANE
BM 2849
Golf Course
GREEN VALLEY
SAN IGNACIO
LA CAÑADA
Borrow Pit
Hosp
ESPERANZA DRIVE
Res
CONTINENTAL
Green Valley
ROAD
ABREGO
CRUZ
VALLEY
LA CANOA
Gaging Station
BM 2858
BM 2865
CONTINENTAL INTERCHANGE
LA River
Continent

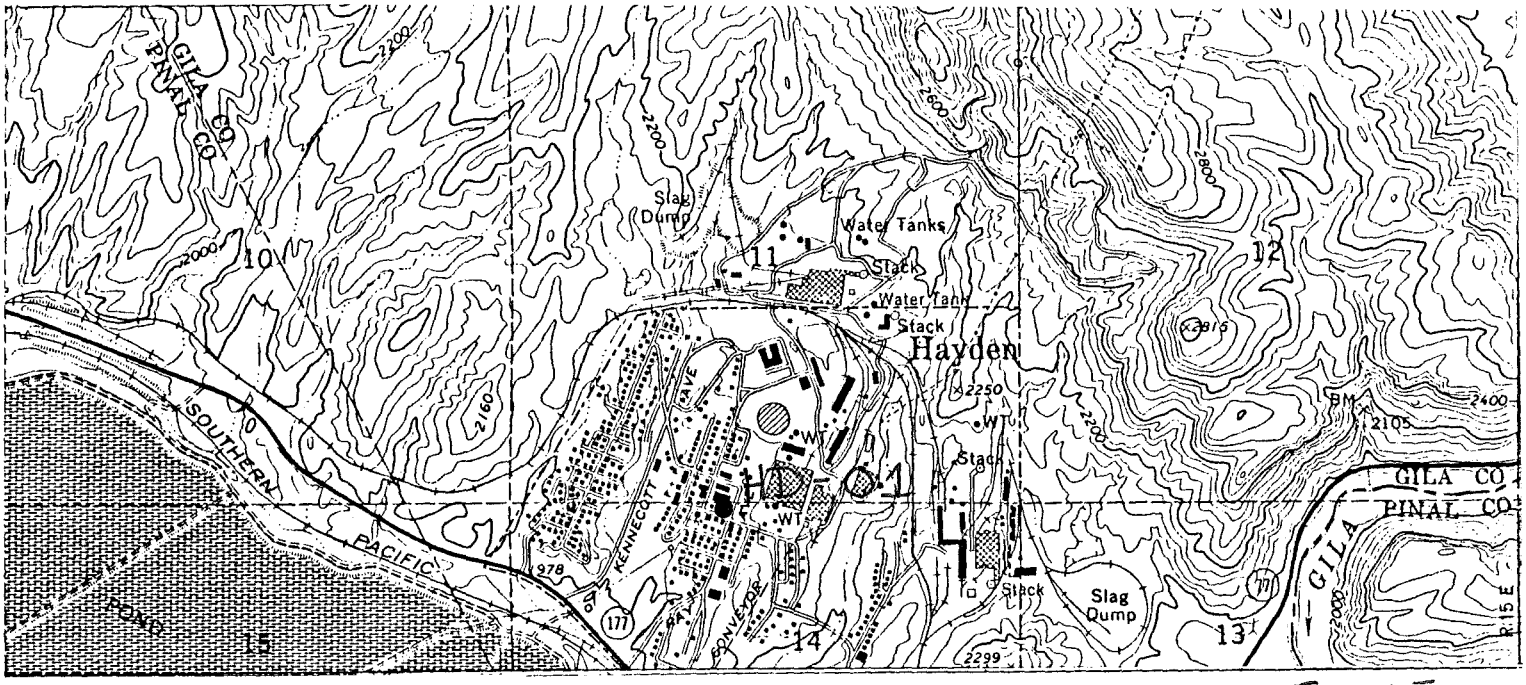

GILA CO
PINAL CO
Slag Dump
Water Tanks
Stack
Water Tank
Stack
Hayden
10
11
12
13
14
15
2200
2800
2000
2160
2250
2105
2400
2299
978
177
SOUTHERN
PACIFIC
POND
KENNECOTT
AVE
CONVEYOR
Stack
Slag Dump
GILA CO
PINAL CO
GILA
R15E

FIG. 15

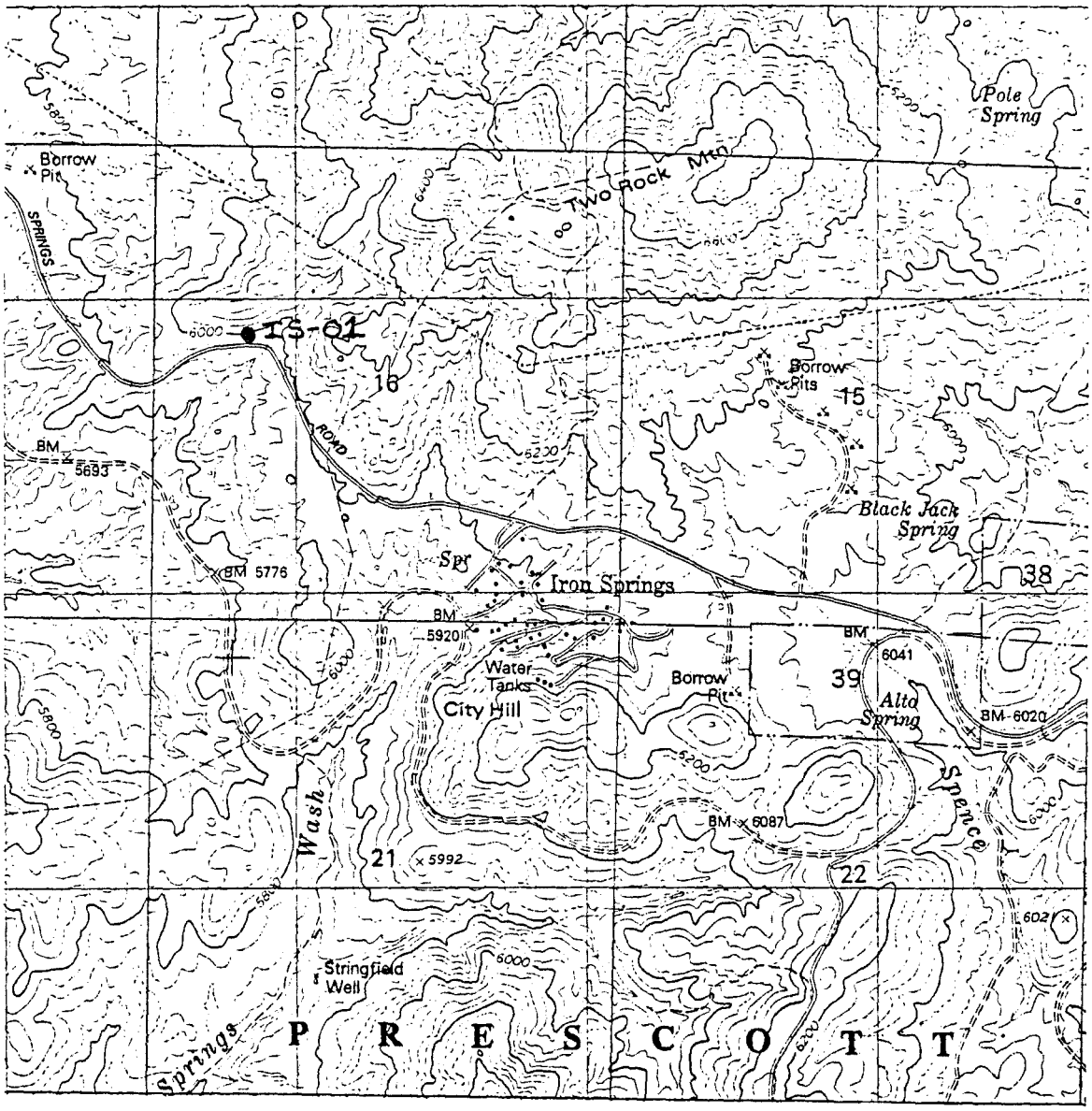

Pole Spring
Borrow Pit
SPRINGS
Two Rock Mtn
IS-01
16
Borrow Pits
15
BM 5693
ROAD
Black Jack Spring
BM 5776
Spr
Iron Springs
38
BM 5920
BM 6041
Water Tanks
Borrow Pit
39
City Hill
Alta Spring
BM 6020
Wash
BM 6087
Spence
21
5992
22
Stringfield Well
Springs
P R E S C O T T

Fig. 16

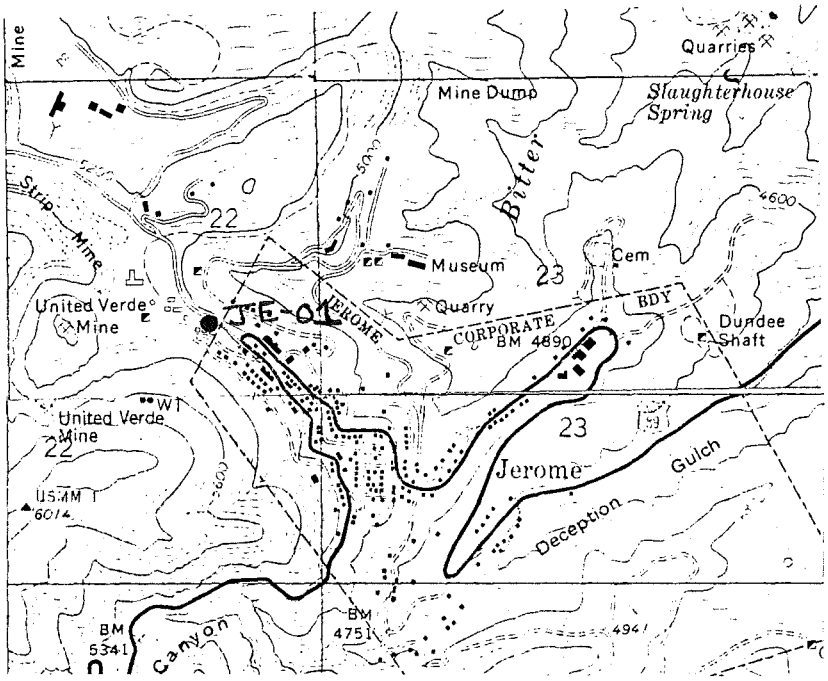

Mine
Quarries
Mine Dump
Slaughterhouse Spring
Butler
Strip Mine
22
Museum
23
Cem
4600
United Verde Mine
JE-01
JEROME
Quarry
CORPORATE BDY
BM 4890
Dundee Shaft
United Verde Mine
22
23
Jerome
Gulch
Deception
USGM 6014
BM 5341
Canyon
BM 4751
4941

FIG. 17

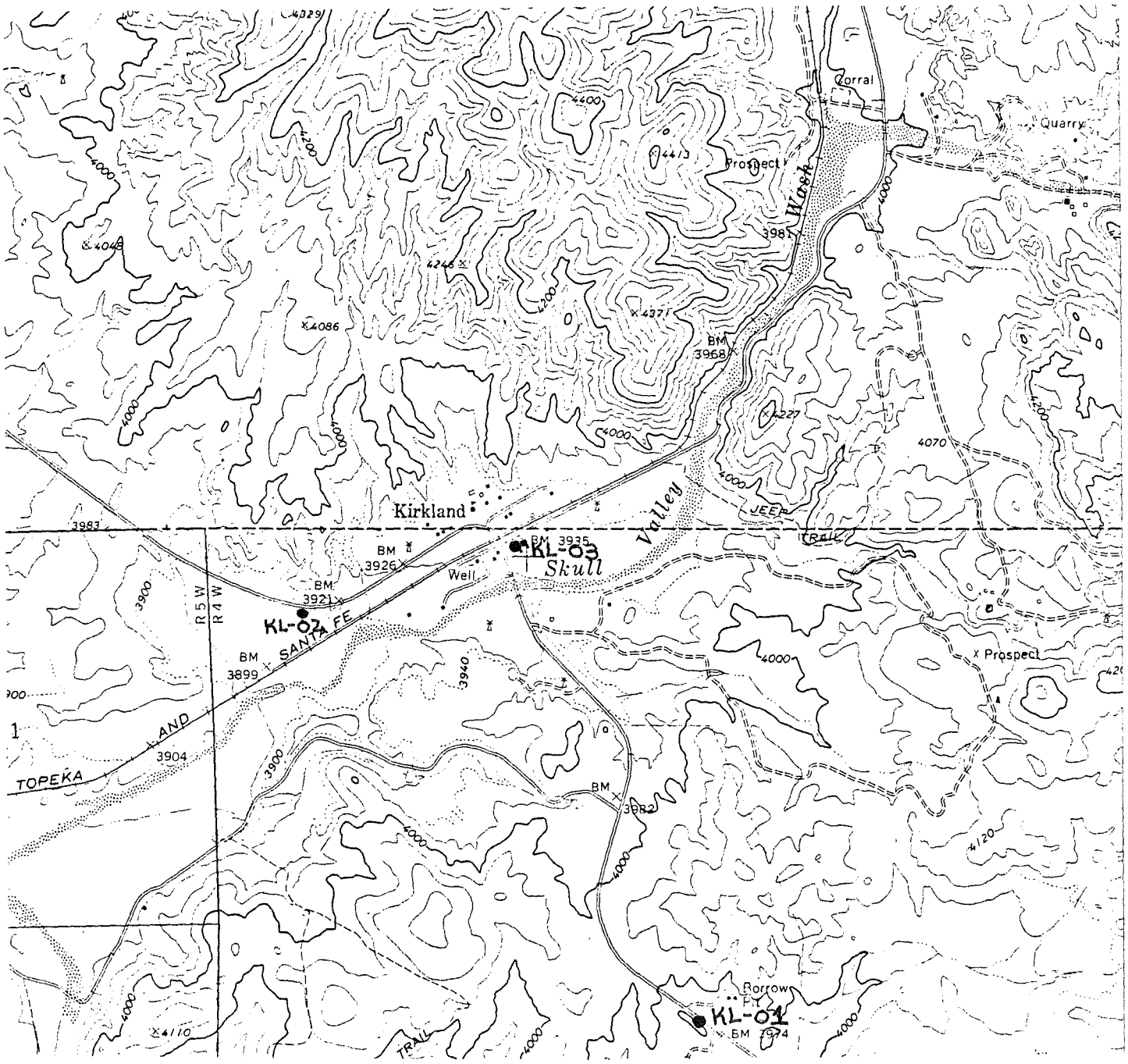
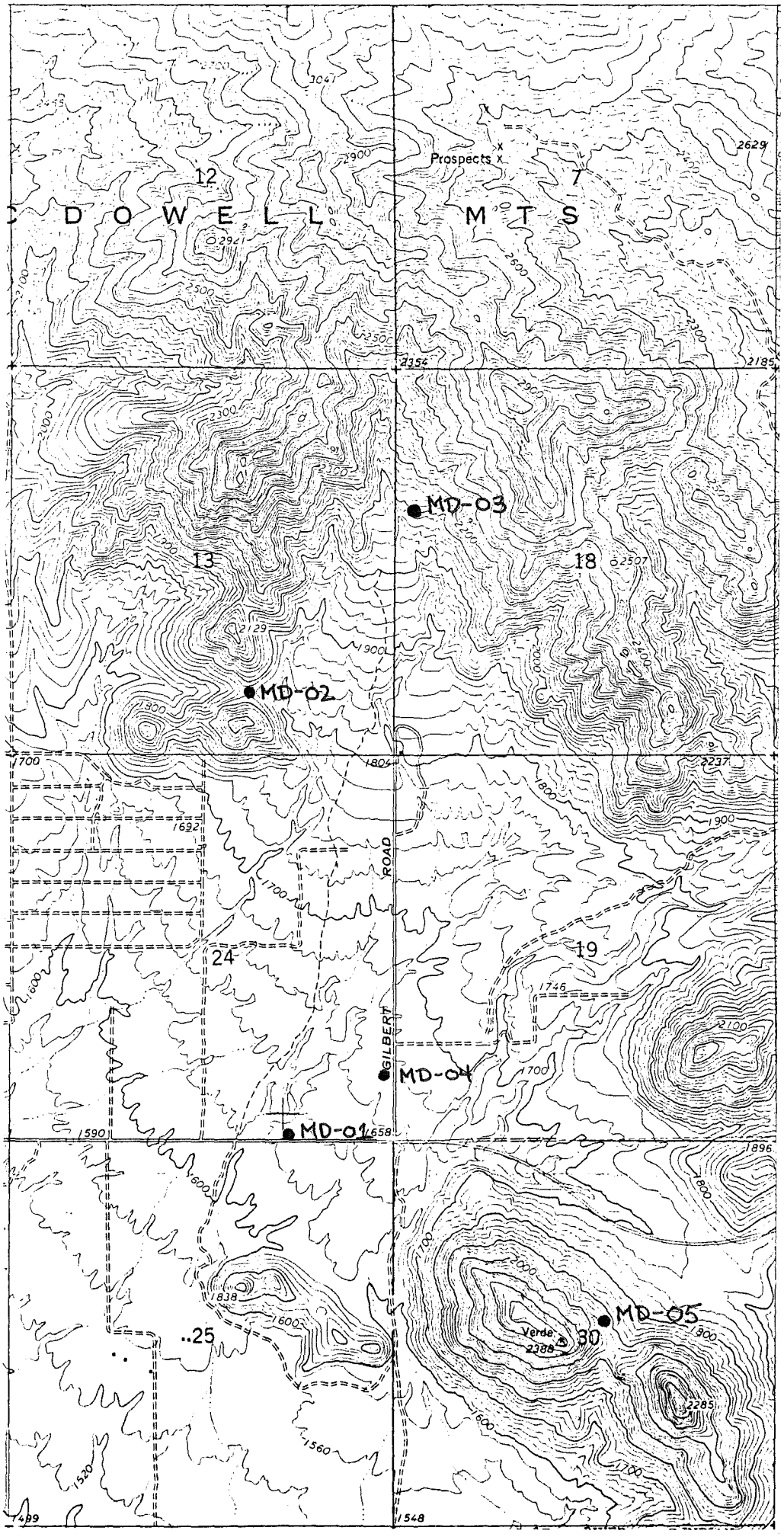

Corral
Quarry
Prospect
Wash
Kirkland
Valley
Skull
KL-03
KL-02
KL-01
Well
JEEP
TRAIL
Prospect
Borrow Pit
BM 3968
BM 3935
BM 3926
BM 3921
BM 3899
BM 3982
BM 1974
R 5 W
R 4 W
SANTA FE
TOPEKA AND
4329
4413
4048
4246
4086
4371
4227
4070
4110
4120
3983
3981
3904
3900
3940

FIG. 18

FIG. 19


DOWELL MTS
Prospects
12
7
13
18
19
24
25
30
MD-01
MD-02
MD-03
MD-04
MD-05
GILBERT ROAD
Verde

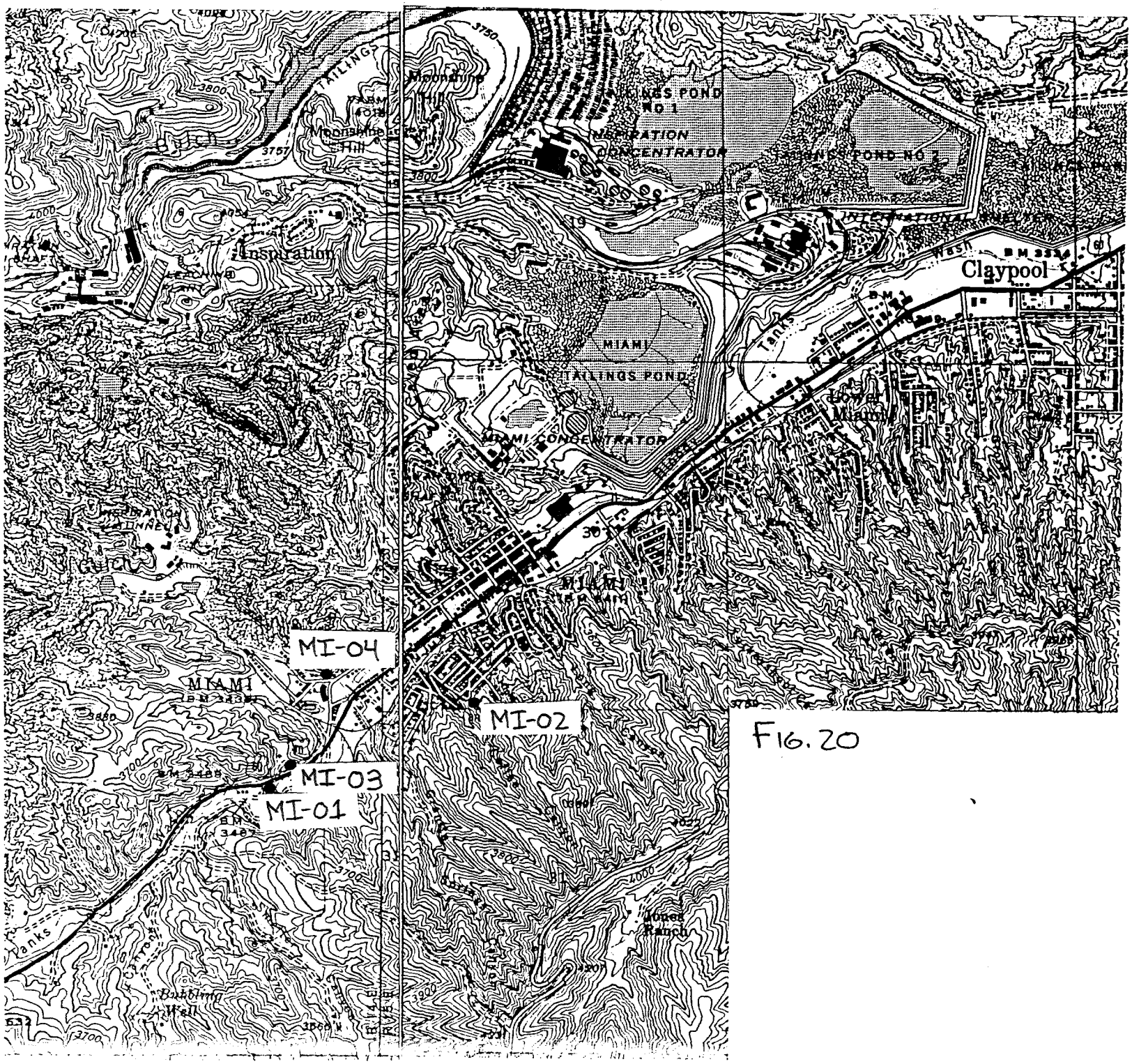

MI-04
MI-03
MI-01
MI-02
Moonshine Hill
Inspiration
TAILINGS POND NO 1
INSPIRATION CONCENTRATOR
TAILINGS POND NO 2
MIAMI TAILINGS POND
MIAMI CONCENTRATOR
Claypool
Lower Miami
MIAMI
Jones Ranch
Bubbling Well
Tanks

FIG. 20

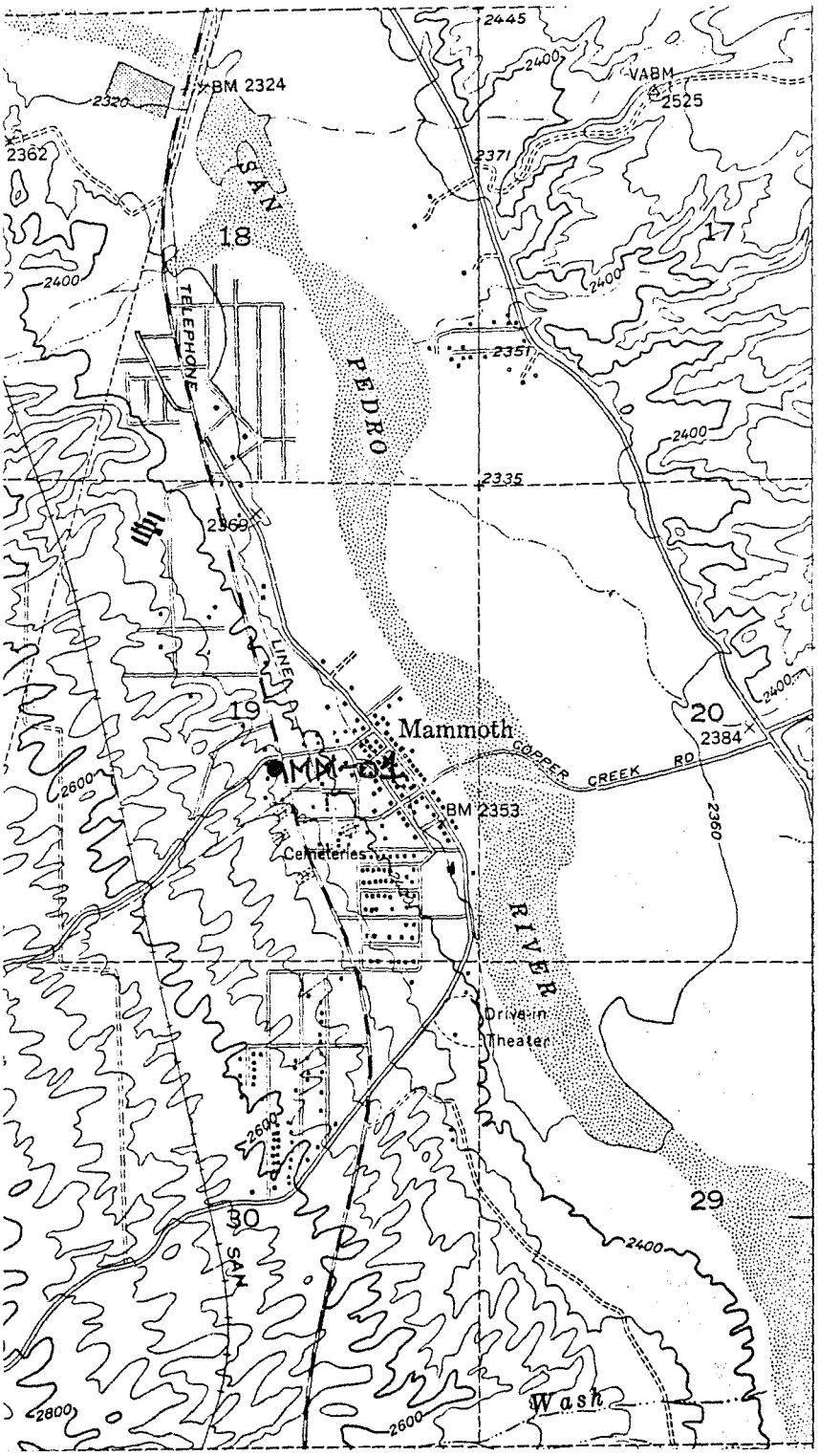

2445
2400
VABM
2525
BM 2324
2320
2362
2371
SAN
18
17
2400
TELEPHONE
2351
PEDRO
2400
2335
2369
LINE
19
Mammoth
20
2384
COPPER CREEK RD
2400
2600
MM-04
BM 2353
2360
Cemeteries
RIVER
Drive-in
Theater
2600
29
30
2400
SAN
Wash
2800
2600

Fig. 21

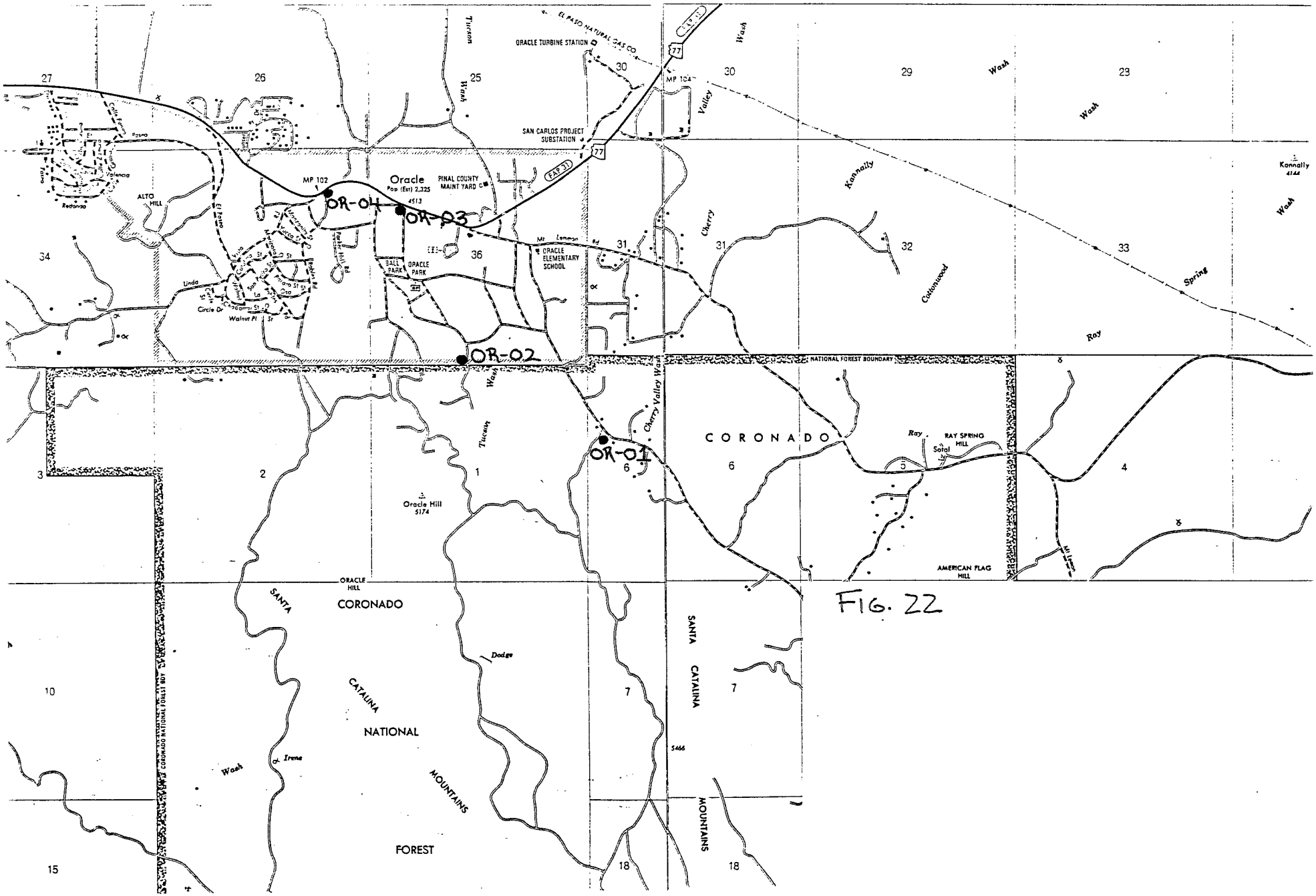

EL PASO NATURAL GAS CO
ORACLE TURBINE STATION
SAN CARLOS PROJECT SUBSTATION
MP 102
MP 104
Oracle
Pop (Est) 2,325
4513
PINAL COUNTY MAINT YARD
ALTO HILL
OR-04
OR-03
OR-02
OR-01
ORACLE ELEMENTARY SCHOOL
BALL PARK
ORACLE PARK
Mt Lemmon Rd
Linda
Circle Dr
Walnut Pl
Tucson Wash
Cherry Valley Wash
Kannally Wash
Cottonwood Wash
Ray Spring Wash
Kannally
4144
NATIONAL FOREST BOUNDARY
CORONADO
Ray
RAY SPRING HILL
Sotol
AMERICAN FLAG HILL
Oracle Hill
5174
ORACLE HILL
SANTA CATALINA MOUNTAINS
CORONADO NATIONAL FOREST
Dodge
Irene Wash
5466
27
26
25
30
29
23
34
36
31
32
33
3
2
1
6
5
4
10
7
15
18

FIG. 22

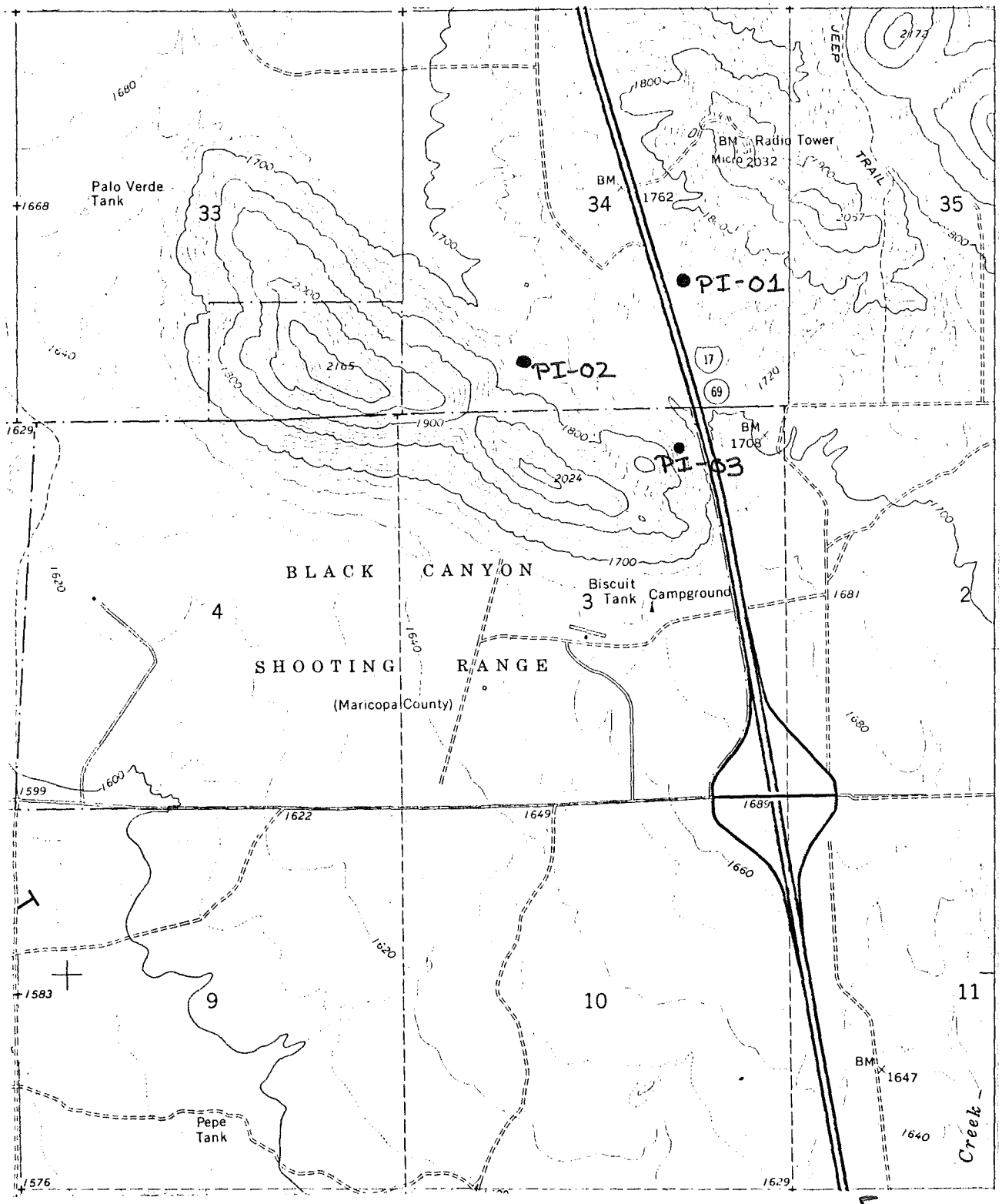
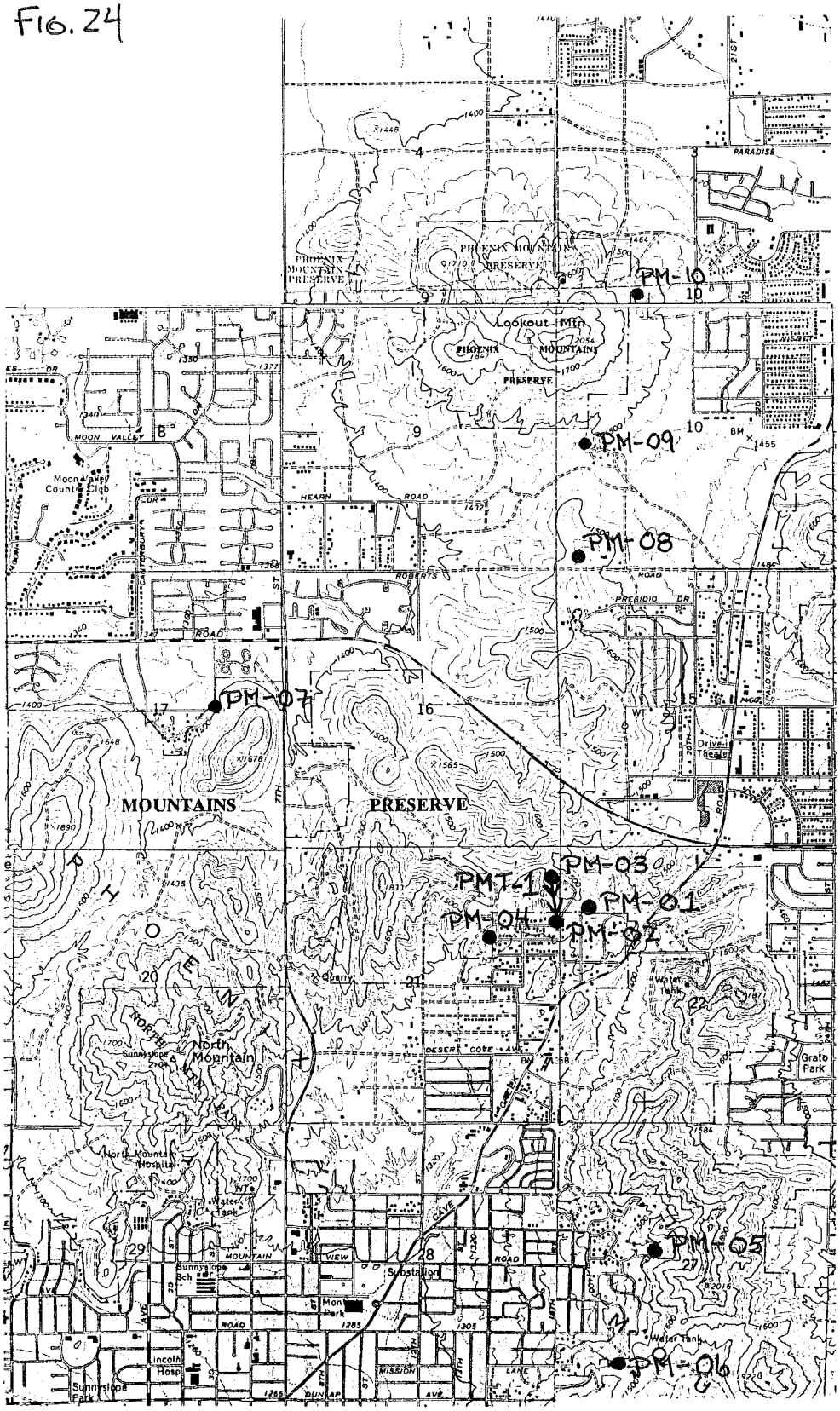

Palo Verde Tank
33
34
35
BM 1762
BM Radio Tower Micro 2032
JEEP TRAIL
PI-01
PI-02
PI-03
17
69
BM 1708
BLACK CANYON
SHOOTING RANGE
(Maricopa County)
Biscuit Tank
Campground
3
4
2
9
10
11
BM 1647
Pepe Tank
Creek

FIG. 23

FIG. 24


PM-10
PM-09
PM-08
PM-07
PM-03
PMT-1
PM-01
PM-04
PM-02
PM-05
PM-06
Lookout Mtn
PHOENIX MOUNTAINS PRESERVE
MOUNTAINS
PRESERVE
PHOENIX
North Mountain
Grato Park
Sunnyslope Park
Lincoln Hosp
Moon Valley Country Club
Drive-in Theater
Water Tank
Substation
PARADISE
MOON VALLEY
HEARN ROAD
ROBERTS ROAD
PRESIDIO DR
DESERT COVE AVE
MOUNTAIN VIEW ROAD
MISSION LANE
DUNLAP AVE

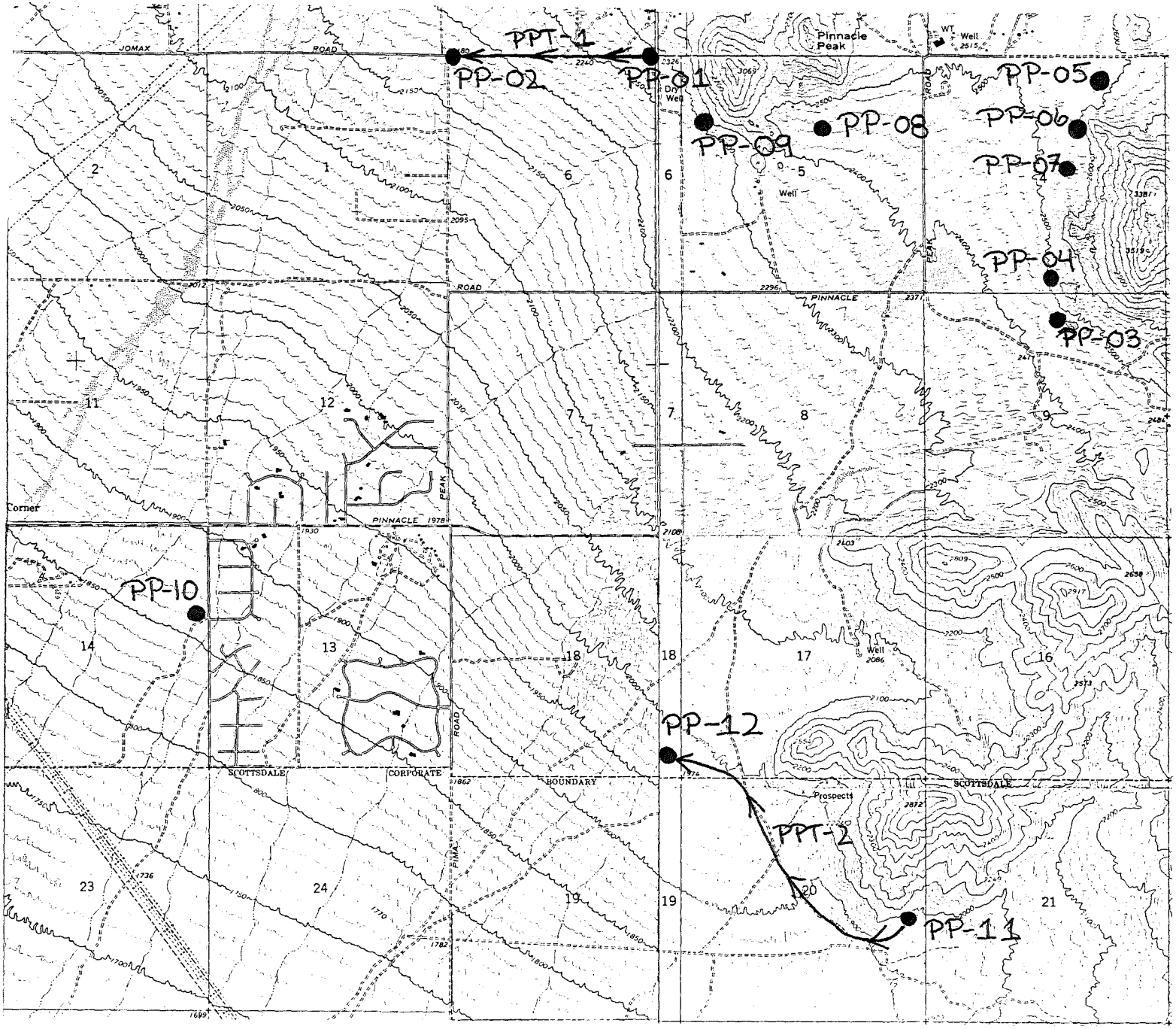

PPT-1
PP-02
PP-01
PP-05
PP-06
PP-08
PP-09
PP-07
PP-04
PP-03
PP-10
PP-12
PPT-2
PP-11
Pinnacle Peak
JOMAX ROAD
PINNACLE PEAK ROAD
PINNACLE PEAK
SCOTTSDALE
CORPORATE
BOUNDARY
PIMA ROAD
Corner
Well
Prospects

FIG. 25

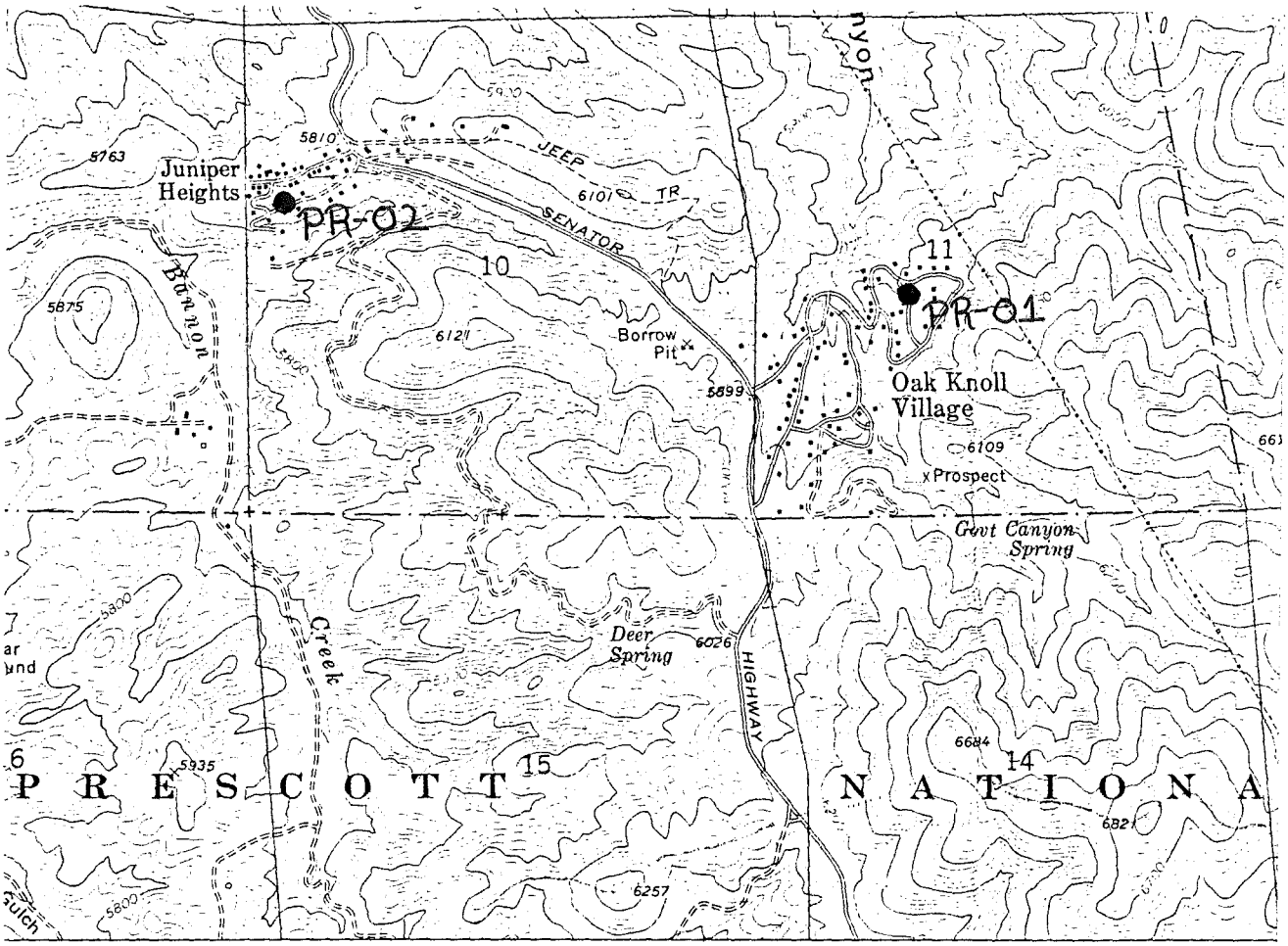

Juniper Heights
PR-02
PR-01
Oak Knoll Village
JEEP TR
SENATOR
Borrow Pit
Prospect
Govt Canyon Spring
Deer Spring
HIGHWAY
Creek
Canyon
10
11
15
14
5763
5810
5875
6121
5899
6109
6026
6644
6257
5935
PRESCOTT NATIONA

FIG. 26

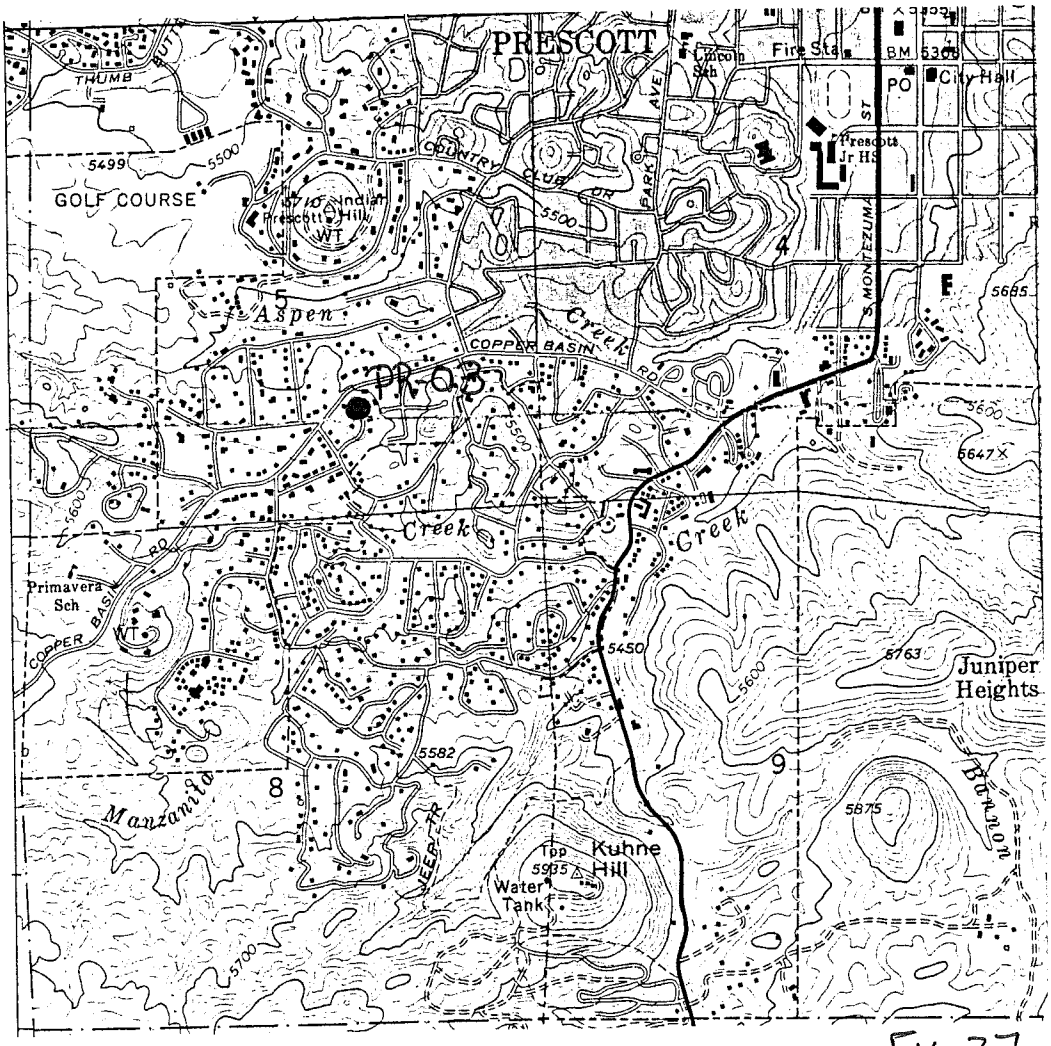

PRESCOTT
Lincoln Sch
Fire Sta
BM 5305
PO
City Hall
Prescott Jr HS
THUMB BUTT
5499
5500
GOLF COURSE
COUNTRY CLUB DR
PARK AVE
Indian Hill
Prescott
WT
5500
4
S MONTEZUMA ST
5685
5
Aspen
Creek
COPPER BASIN RD
PR-QB
5500
5600
5647
5600
Creek
Creek
Primavera Sch
COPPER BASIN RD
WT
5450
5763
Juniper Heights
5600
5582
9
8
Manzanita
DEER TR
Top 5935
Kuhne Hill
Water Tank
5875
Barron
5700

Fig. 27

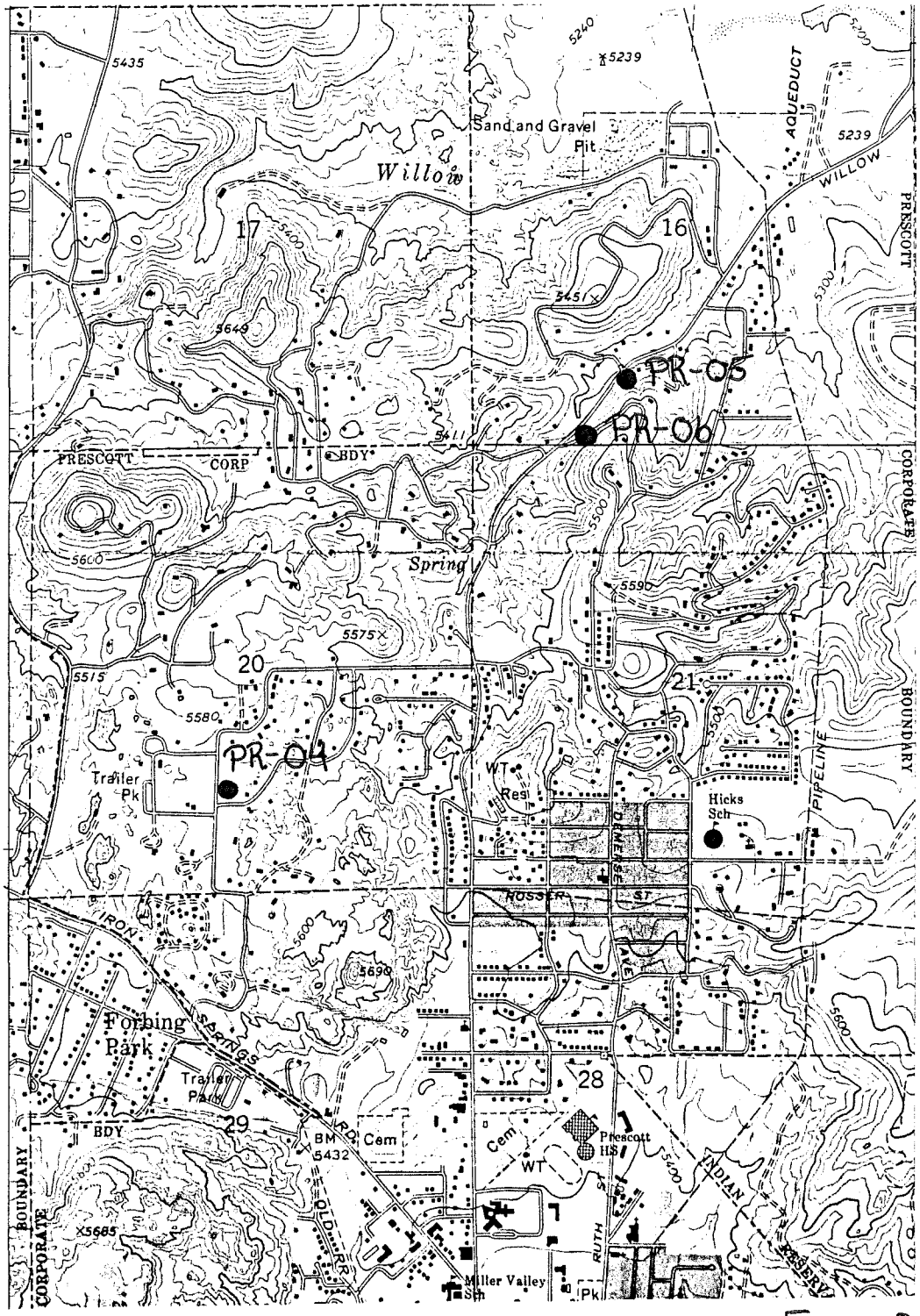
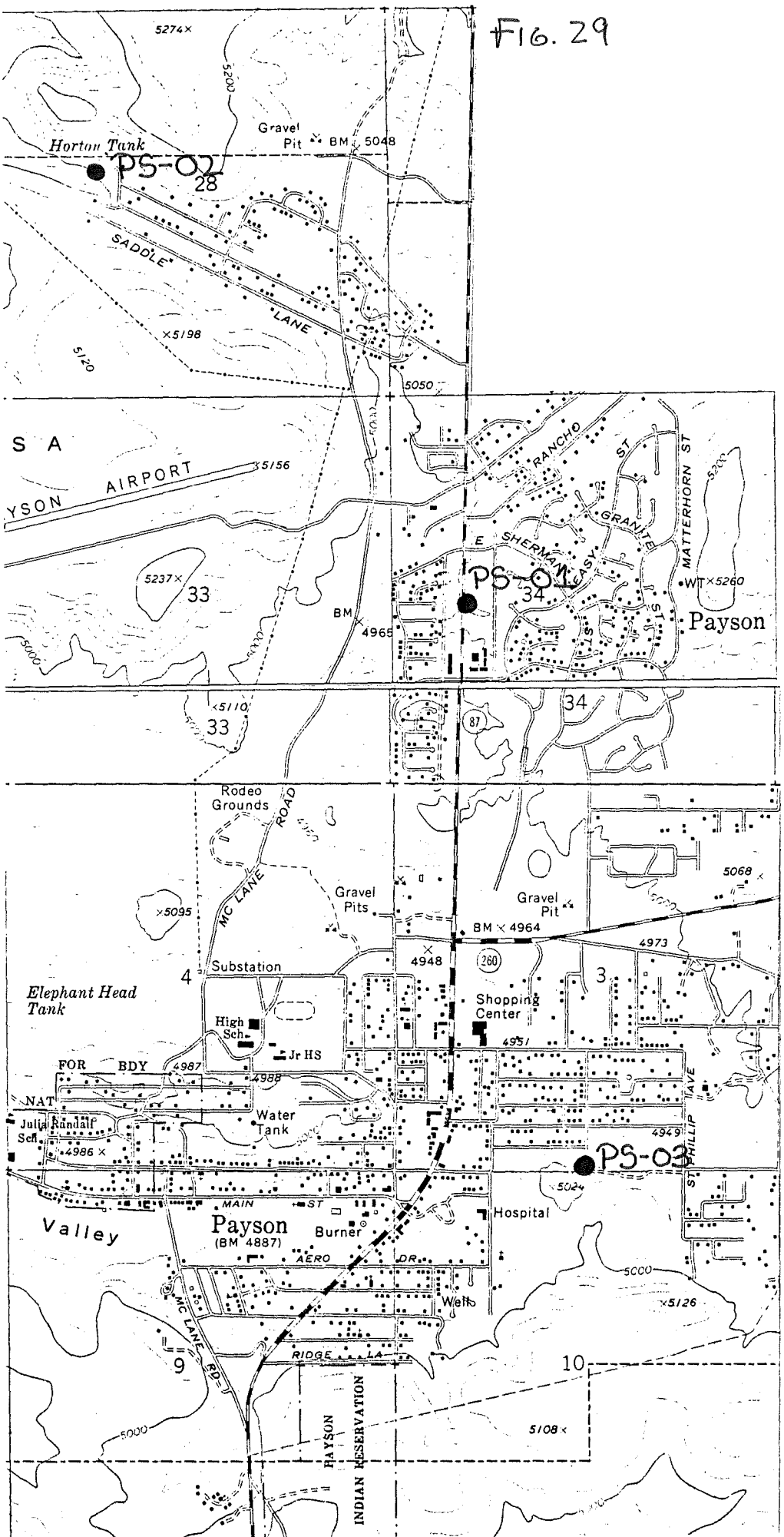

Sand and Gravel Pit
Willow
AQUEDUCT
WILLOW
PRESCOTT
CORPORATE
BOUNDARY
PIPELINE
PR-05
PR-06
PR-04
PRESCOTT
CORP
BDY
Spring
17
16
20
21
28
29
Trailer Pk
WT
Res
Hicks Sch
HOSSER
ST
DREW
AVE
IRON
SPRINGS
Forbing Park
Trailer Park
BM 5432
Cem
Prescott HS
INDIAN
RUTH
OLD
RD
Miller Valley Sch
Pk
5435
5239
5240
5649
5451
5411
5600
5575
5590
5515
5580
5690
5685
5400
5500

FIG. 28

FIG. 29


Horton Tank
PS-02
28
Gravel Pit
BM 5048
SADDLE LANE
5274
5200
5198
5120
5050
S A
YSON AIRPORT
5156
5237
33
BM 4965
RANCHO
ST
GRANITE
MATTERHORN ST
E SHERMAN
EASY
ST
PS-01
34
WT 5260
Payson
5110
33
87
34
Rodeo Grounds
ROAD
MC LANE
Gravel Pits
Gravel Pit
5068
5095
BM 4964
4973
4948
260
4
Substation
3
Elephant Head Tank
Shopping Center
High Sch
Jr HS
4951
FOR BDY
4987
4988
NAT
Water Tank
Julia Randalf Sch
4986
4949
PS-03
5024
MAIN ST
Hospital
Valley
Payson
(BM 4887)
Burner
AERO DR
5000
Wells
5126
MC LANE RD
RIDGE LA
9
10
5000
5108
PAYSON INDIAN RESERVATION

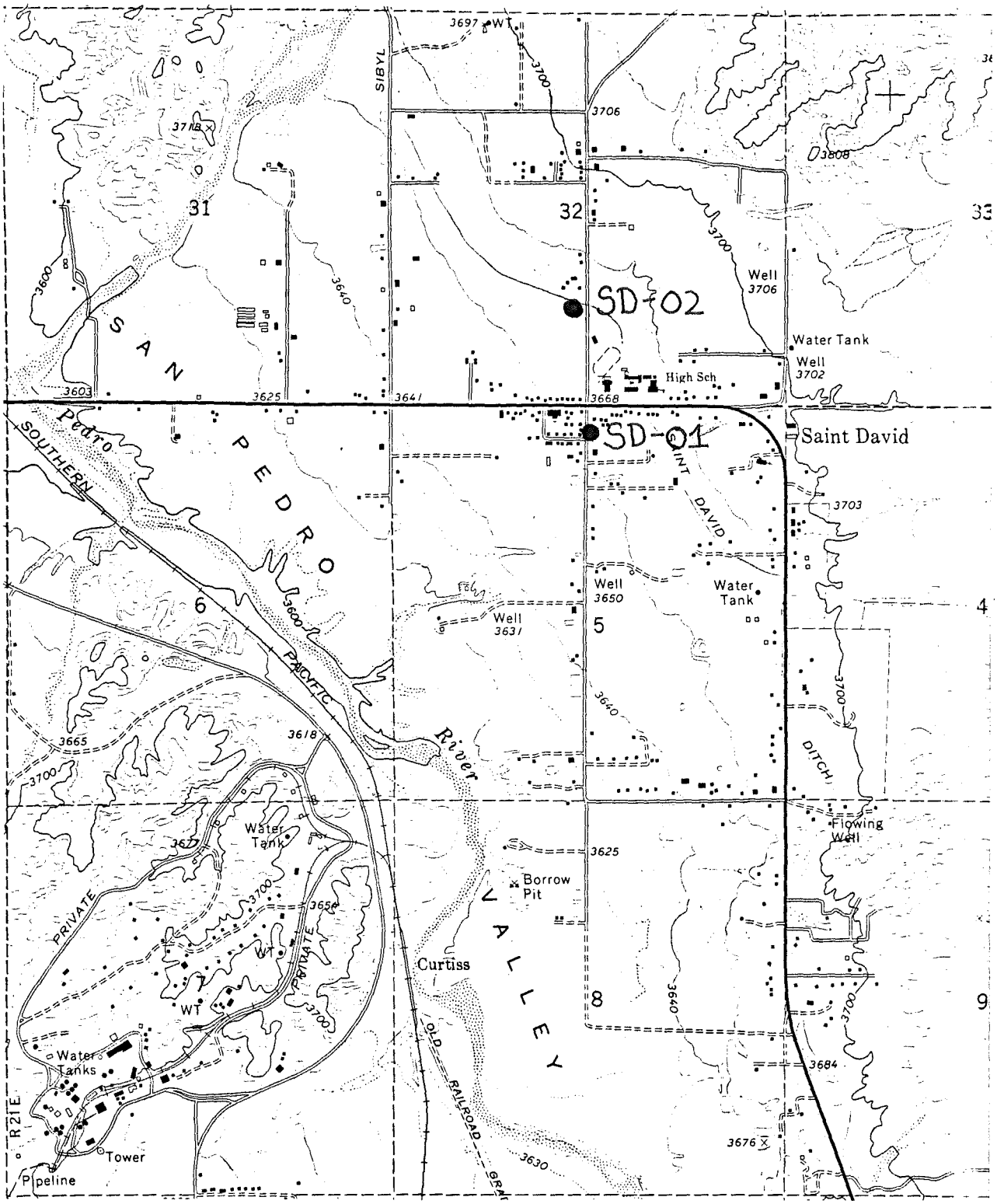

SD-02
SD-01
Saint David
SAN PEDRO
Pedro
River
SOUTHERN PACIFIC
SIBYL
SAINT DAVID
DITCH
VALLEY
Curtiss
OLD RAILROAD GRADE
PRIVATE
Water Tank
Well 3706
Well 3702
High Sch
Well 3650
Well 3631
Borrow Pit
Flowing Well
Water Tanks
Tower
Pipeline
R21E
31
32
33
6
5
4
8
9
3697 WT
3706
3808
3718
3600
3640
3603
3625
3641
3668
3703
3665
3618
3700
3627
3656
3684
3676
3630

FIG. 30

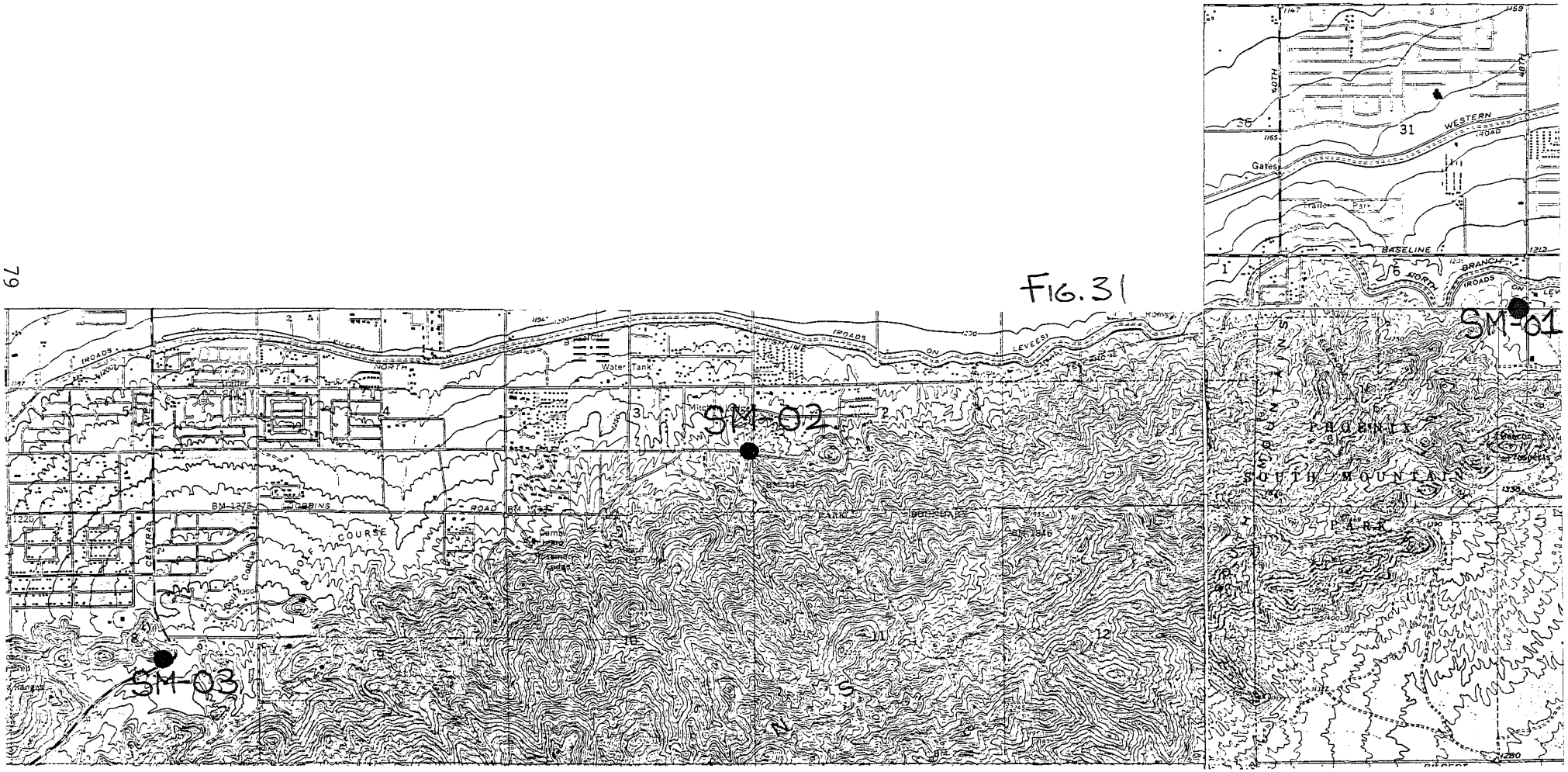

SM-01
SM-02
SM-03
WESTERN
ROAD
BASELINE
NORTH
BRANCH
ROADS
ON
LEVEES
Gates
Trailer
Park
Water Tank
GOLF COURSE
CENTRAL
PHOENIX
SOUTH MOUNTAIN
PARK

FIG. 31

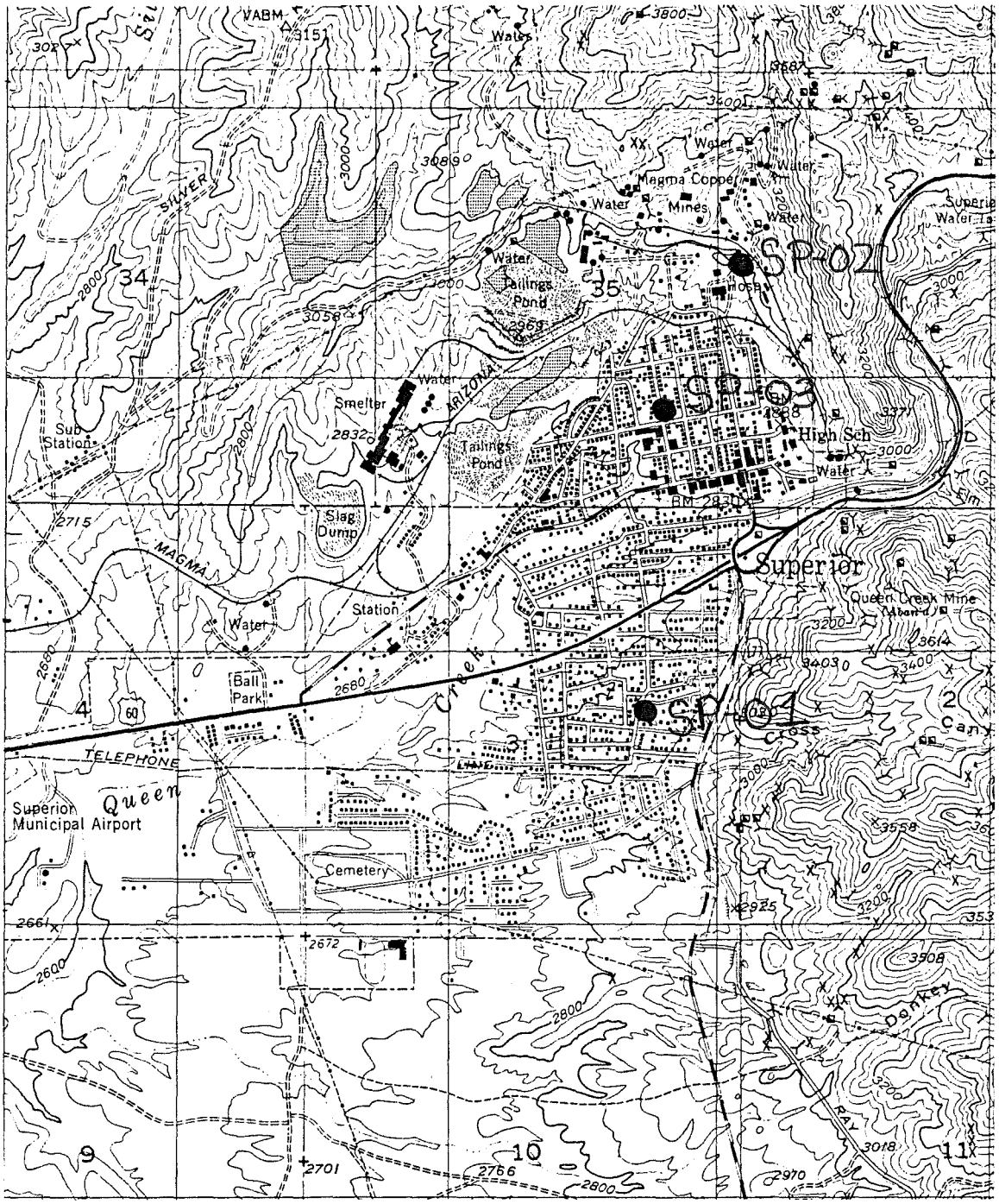

VABM
Water
Magma Copper
Mines
Superior
Water Ta
SP-02
Tailings Pond
35
34
SILVER
Smelter
ARIZONA
SP-03
High Sch
Sub Station
Slag Dump
MAGMA
Station
Superior
Queen Creek Mine
(Aband)
Ball Park
TELEPHONE
SP-01
Cross
Superior Municipal Airport
Queen
Cemetery
Donkey
4
9
10
11
2

FIG. 32

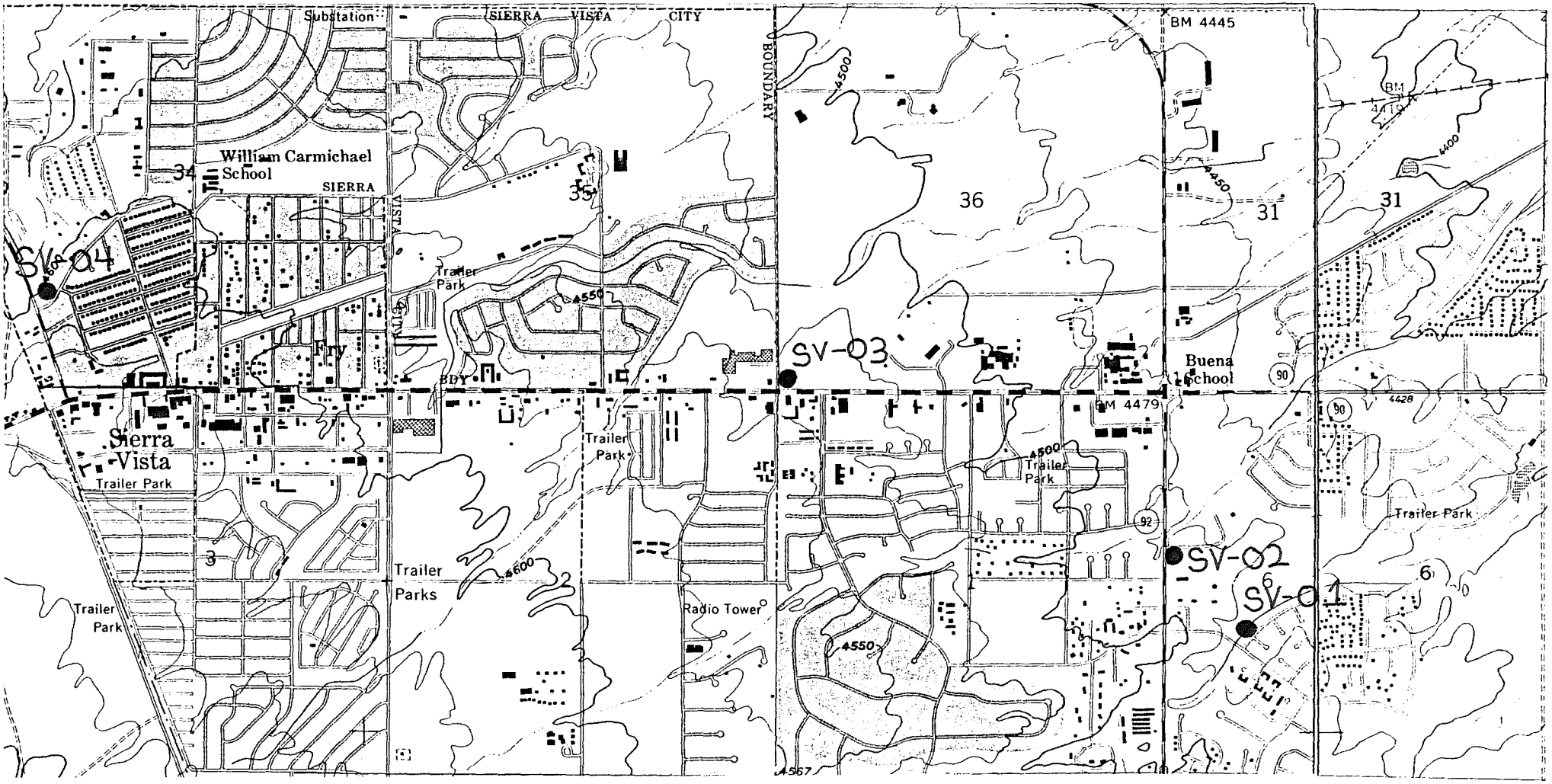

Substation
SIERRA VISTA CITY
BOUNDARY
BM 4445
William Carmichael School
SIERRA
VISTA
34
35
36
31
SV-04
Trailer Park
4550
Fry
SV-03
Buena School
90
BM 4479
Sierra Vista
Trailer Park
4500
Trailer Park
92
SV-02
SV-01
3
Trailer Parks
4600
Radio Tower
Trailer Park
4550
4567
4400
4450
4428
6

FIG. 33

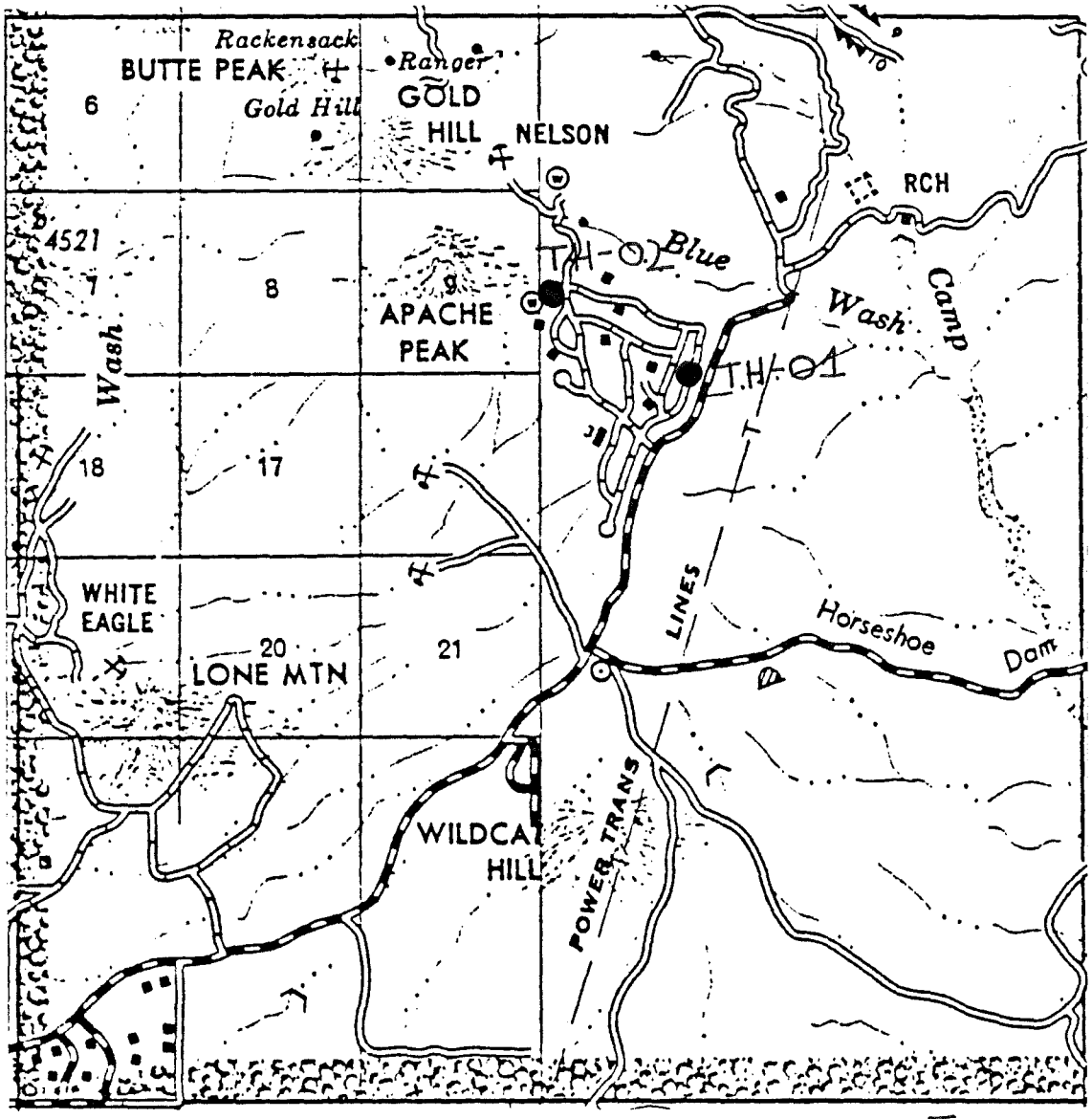

Rackensack
BUTTE PEAK
Ranger
Gold Hill
GOLD
HILL
NELSON
RCH
6
4521
7
8
9
APACHE
PEAK
Blue
Wash
Camp
Wash
TH-01
TH-02
18
17
WHITE
EAGLE
20
LONE MTN
21
LINES
Horseshoe
Dam
WILDCAT
HILL
POWER TRANS

FIG. 34

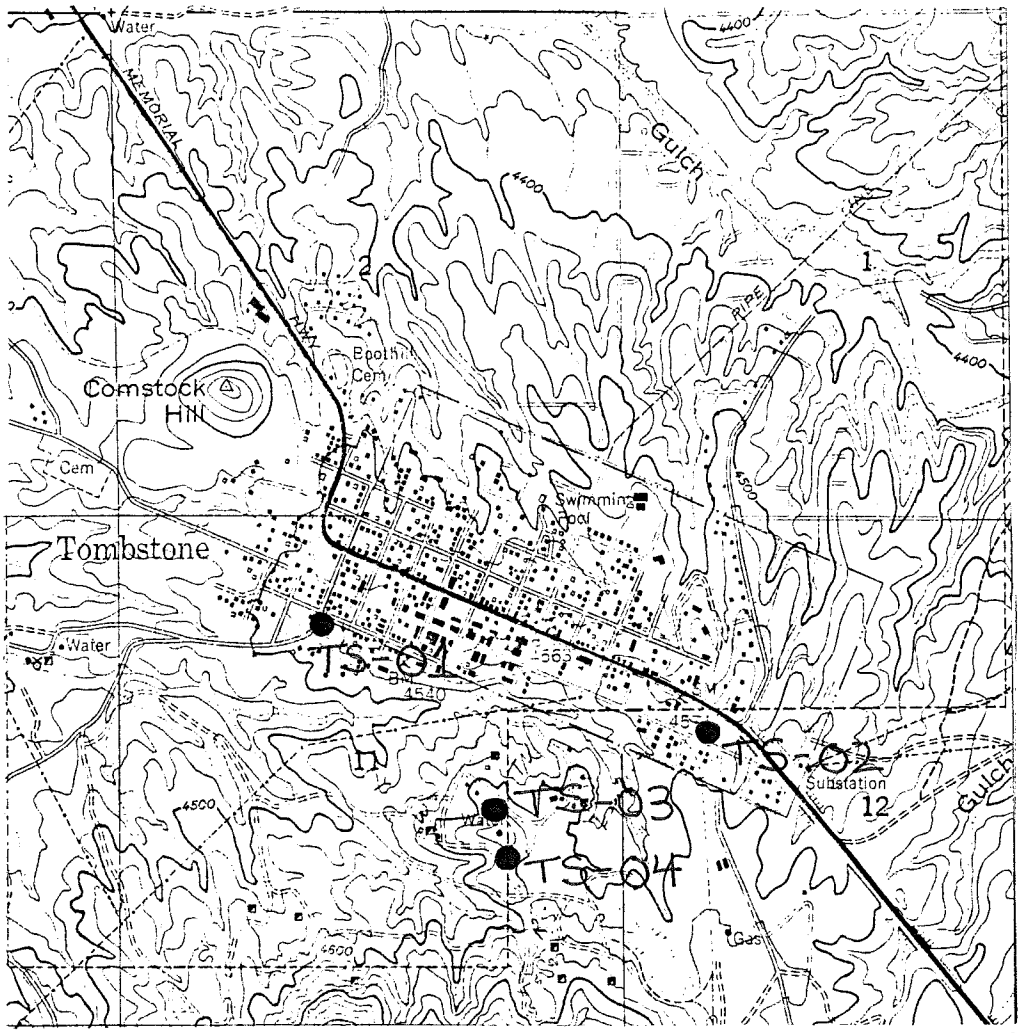
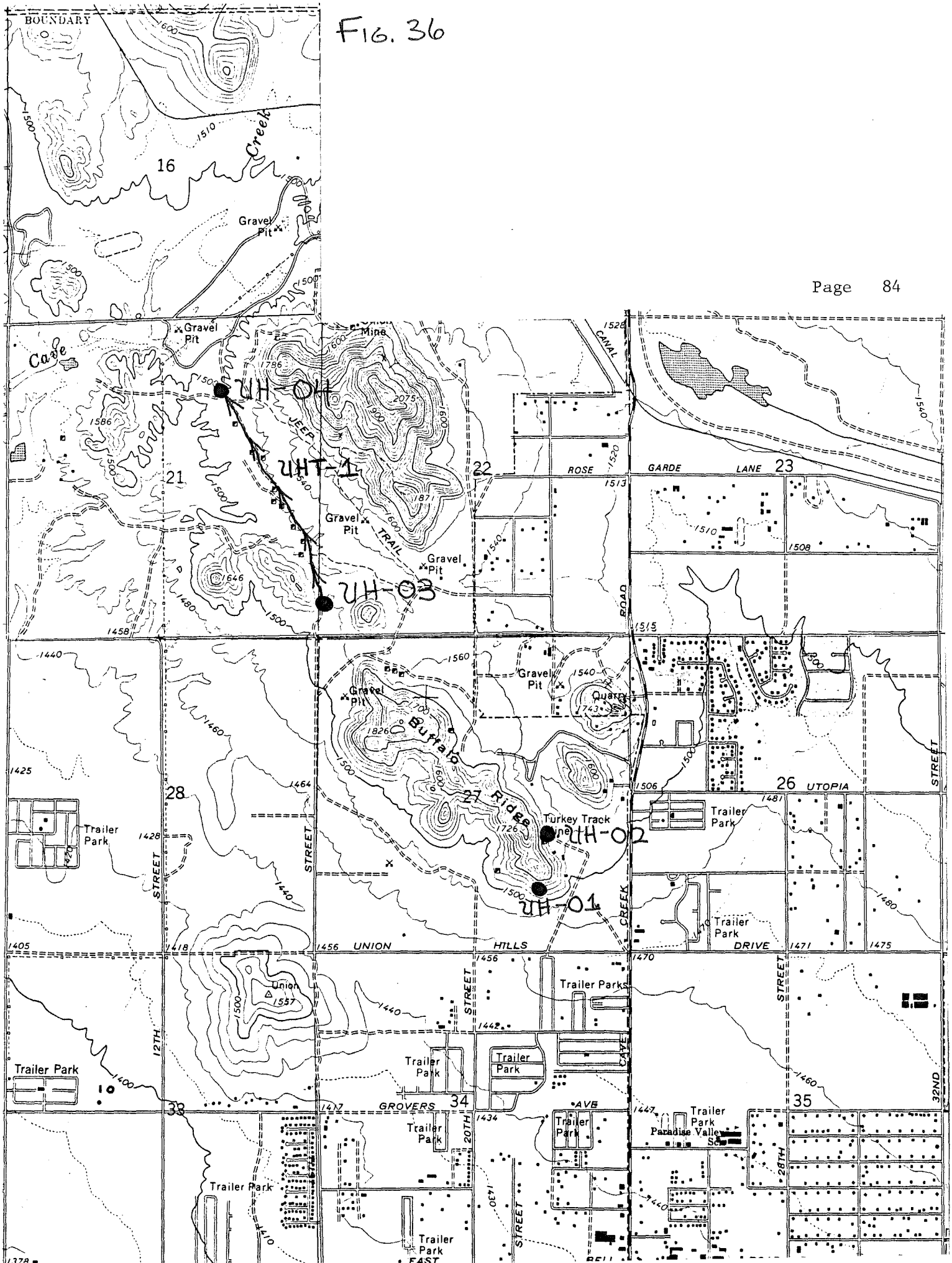

Water
MEMORIAL
Gulch
4400
Comstock Hill
Cem
Tombstone
Swimming Pool
Water
TS-01
TS-02
TS-03
TS-04
Substation
12
Gulch
Gas
4500

FIG. 35

FIG. 36


BOUNDARY
Creek
16
Gravel Pit
Gravel Pit
Mine
Cave
UH-04
JEEP
UHT-1
21
22
ROSE
GARDE
LANE
23
CANAL
Gravel Pit
TRAIL
Gravel Pit
UH-03
ROAD
Gravel Pit
Gravel Pit
Quarry
Buffalo
Ridge
Turkey Track Mine
UH-02
UH-01
26
UTOPIA
STREET
Trailer Park
28
STREET
STREET
Trailer Park
Trailer Park
CREEK
Trailer Park
UNION
HILLS
DRIVE
Union
Trailer Parks
STREET
STREET
12TH
Trailer Park
Trailer Park
Trailer Park
CAVE
33
GROVERS
34
AVE
Trailer Park
Trailer Park
Trailer Park
Paradise Valley Sch
35
32ND
20TH
28TH
Trailer Park
STREET
Trailer Park EAST
BELL

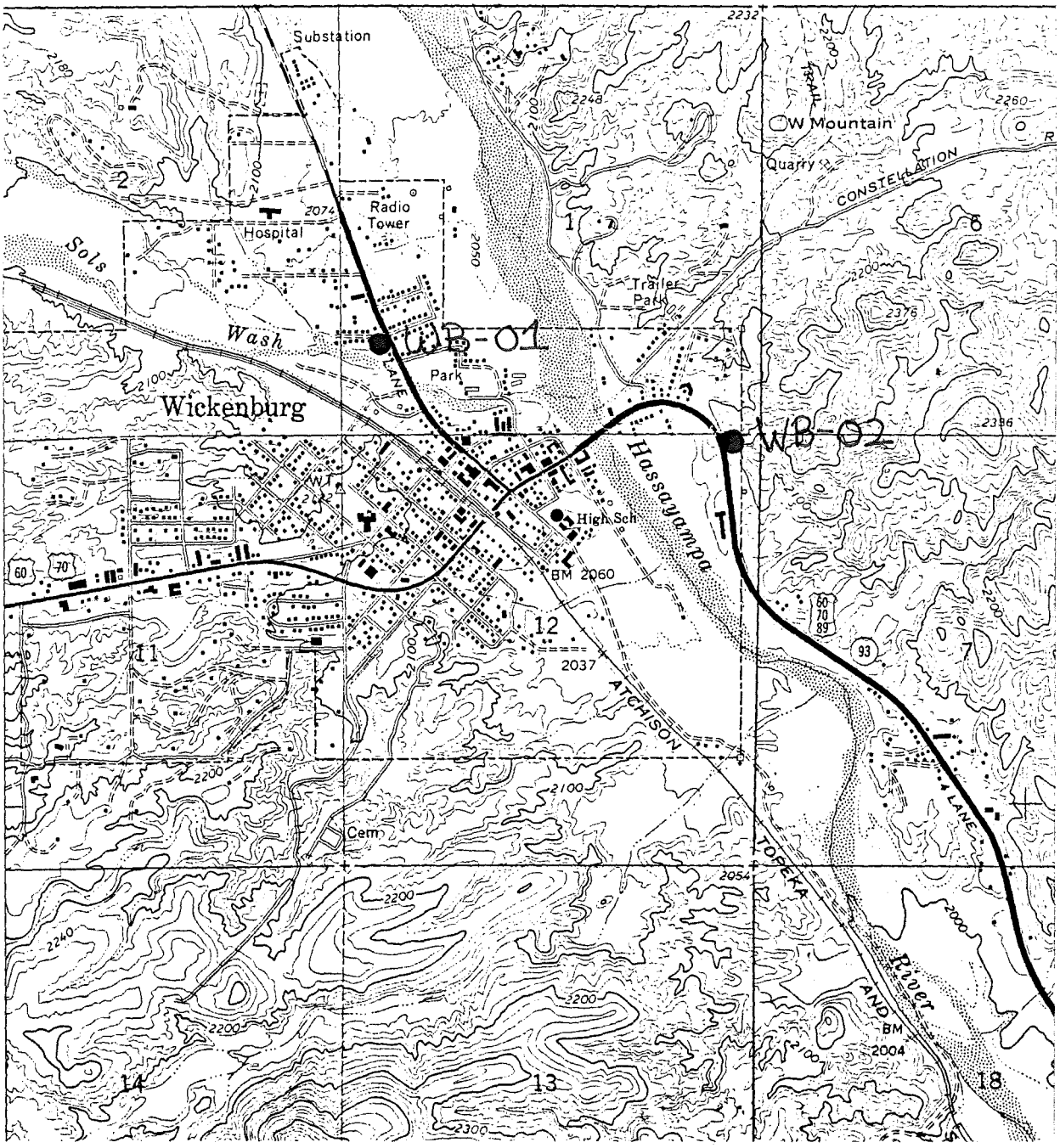

Substation
Radio Tower
Hospital
Sols Wash
Wickenburg
Park
WB-01
WB-02
Trailer Park
W Mountain
Quarry
CONSTELLATION
Hassayampa
High Sch
BM 2060
ATCHISON
TOPEKA
AND
River
BM 2004
Cem
LANE
2232
2248
2260
2074
2050
2376
2386
2037
2054
2004
1
2
6
7
11
12
13
14
18
60
70
93

FIG. 37

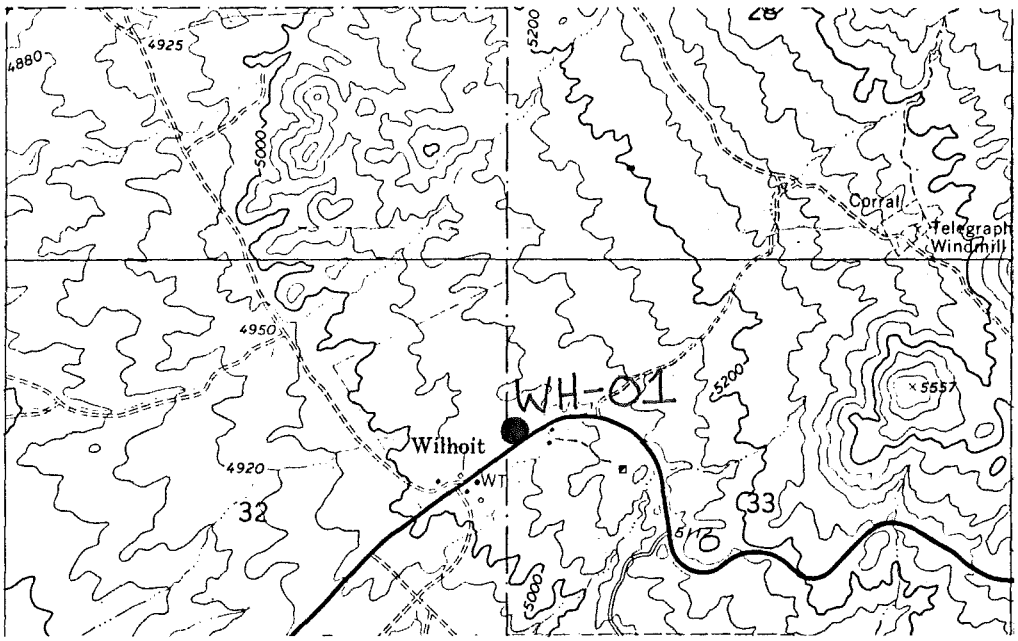

4880
4925
5000
5200
28
Corral
Telegraph
Windmill
4950
WH-01
5200
5557
Wilhoit
WT
4920
32
33
5000

FIG. 38

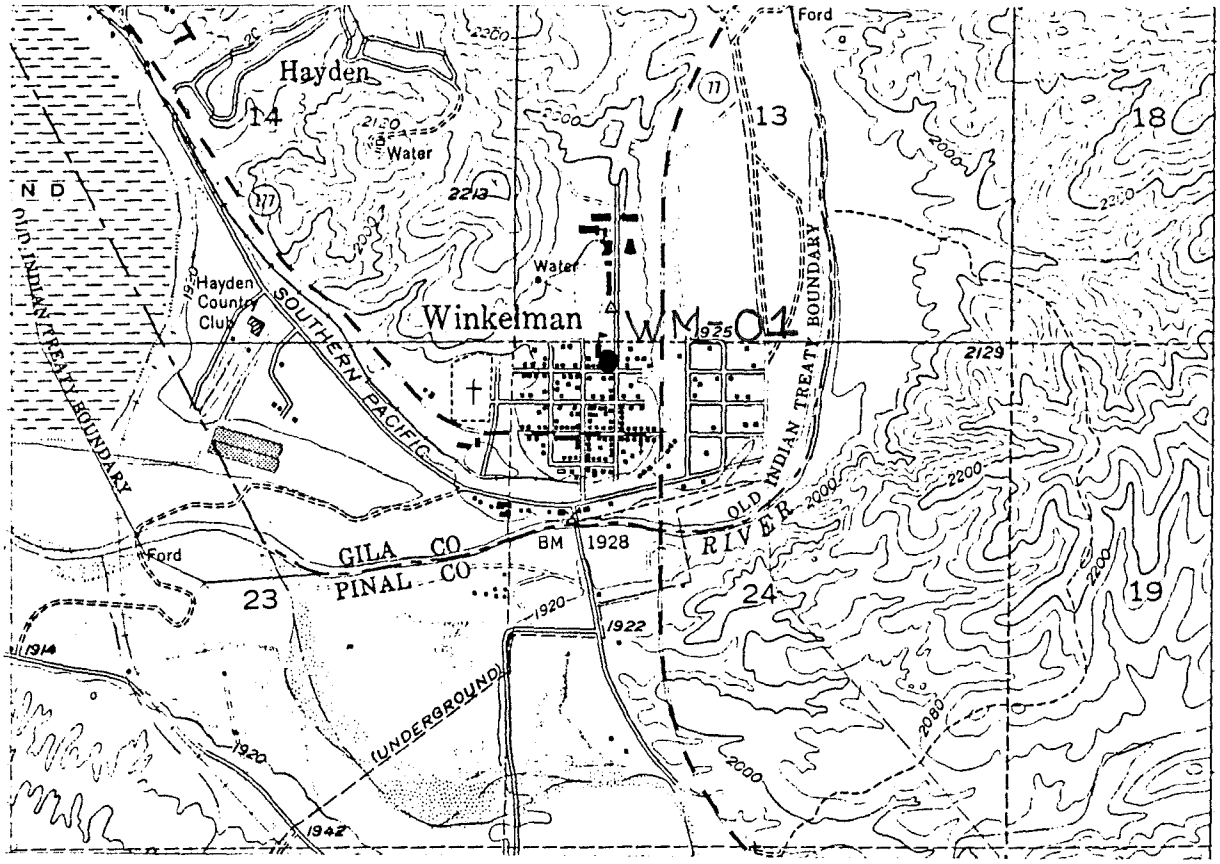

Hayden
14
13
18
Water
Ford
Hayden Country Club
SOUTHERN PACIFIC
Winkelman
WM-01
OLD INDIAN TREATY BOUNDARY
RIVER
GILA CO
PINAL CO
BM 1928
23
24
19
UNDERGROUND
2129
2213
1920
1922
1914
1942
2000
2200
2080

FIG. 39

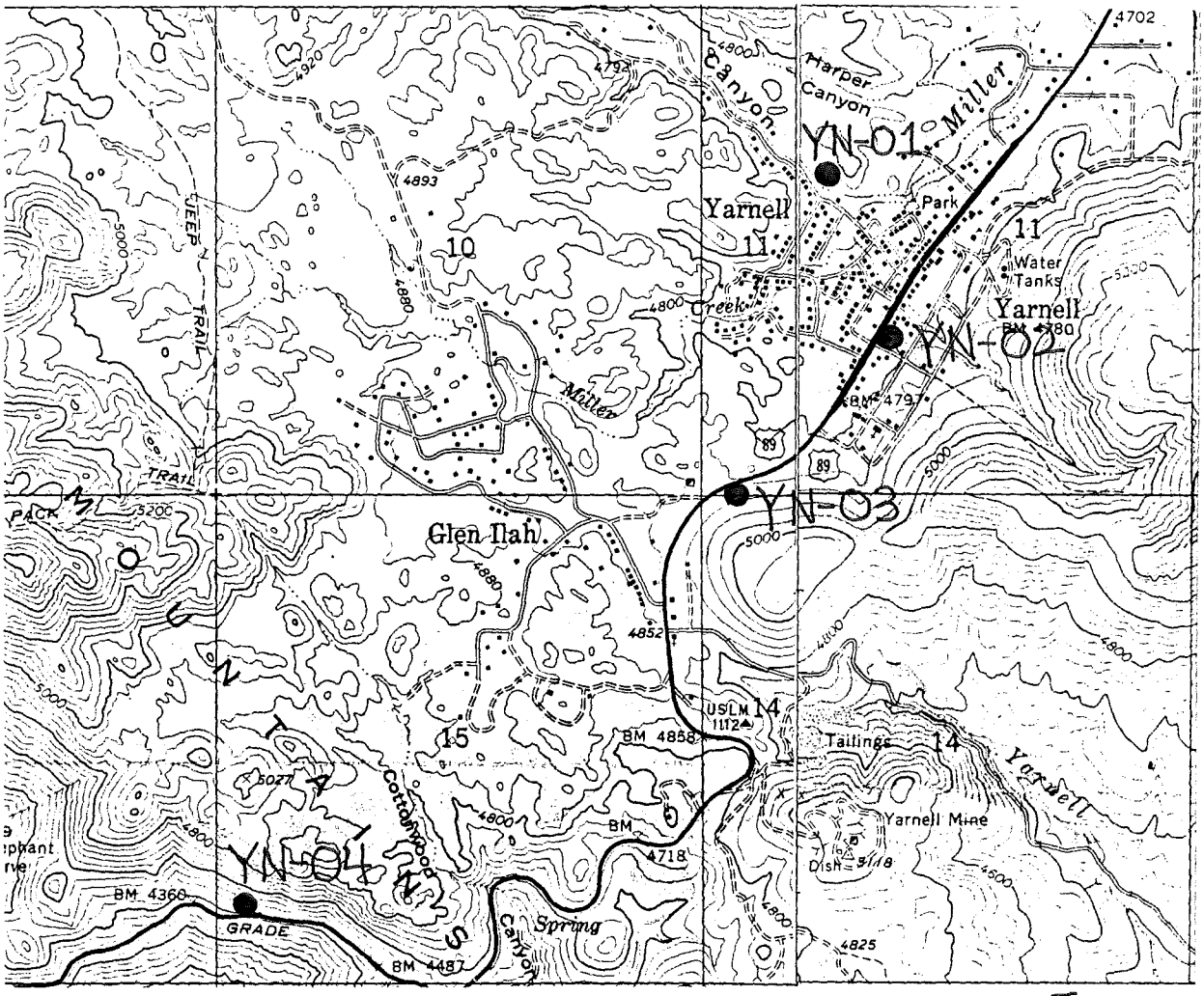
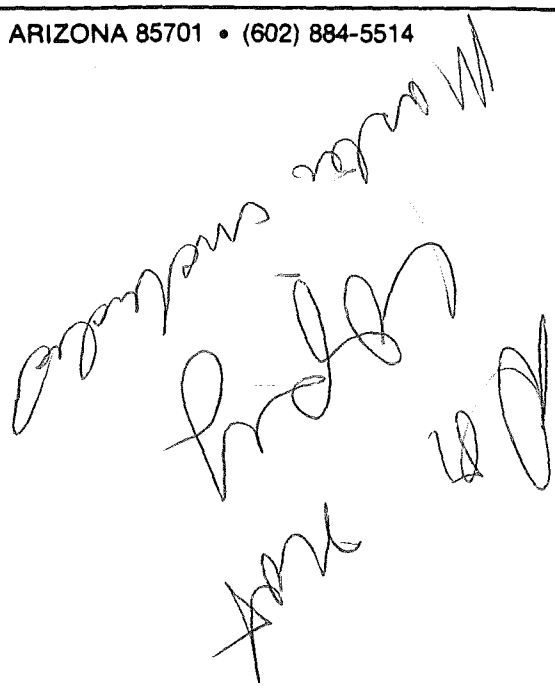

YN-01
YN-02
YN-03
YN-04
Harper Canyon
Miller
Yarnell
Park
Water Tanks
Yarnell
BM 4780
BM 4797
Creek
Miller
Glen Ilah
Tailings
Yarnell Mine
Yarnell
Cottonwood Canyon
Spring
Canyon
BM 4858
BM 4718
BM 4360
BM 4487
GRADE
JEEP TRAIL
PACK TRAIL
USLM 1112
Dish
4702
4893
4852
4825
5000
5200
5077
4800
4880
4900
4920
4792
89

FIG. 40

• TUCSON, ARIZONA 85701 • (602) 884-5514



RECONNAISSANCE GAMMA-RAY SPECTROMETER SURVEY OF RADON-DECAY PRODUCTS IN SELECTED POPULATED AREAS OF ARIZONA

Dudley F. Emer — Reynolds Electric and Engineering Co., P.O. Box 98521, Las Vegas, NV 89193

Jonathan D. Shenk, Jon E. Spencer — Arizona Geological Survey, 845 N. Park Ave., Tucson, AZ 85719

ARIZONA GEOLOGICAL SURVEY

OPEN-FILE REPORT 88-12

1988

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Location of study areas (Figures).....9
Spot location measurements.....13
Strip-chart records (Figures).....33
Spot locations (Figures).....49

This report is preliminary and has not been edited or reviewed for conformity with Arizona Geological Survey standards

DUDLEY F. EMER
Geophysicist
Operational Research Projects
Radioactive Waste Management
Environmental Sciences Department

Reynolds Electrical & Engineering Co., Inc.

M/S 738
P.O. Box 98521
Las Vegas, Nevada 89193-8521

702-295-7808 FTS 295-7808

AN EG&G COMPANY

INTRODUCTION

The objective of this survey was to characterize, in terms of their uranium content, random and selected rock units that are either known or suspected to have a potential for radon gas generation, and are located in populated areas. This survey was not designed to find and delineate all source rocks that meet this criteria, rather only examine in general terms the range of uranium content of selected rock types found through out the state. Due to budget limits the survey was limited to several major population centers and surrounding rural towns. No detailed examination of any one particular rock type was attempted. The values reported only reflect the uranium content as found at some convenient location and should not be construed as to represent the highest or lowest or average value for that rock type in that area.

Variations in the uranium content of any particular rock type depend strongly on the chemistry of the rock at the time the uranium was emplaced as well as the chemical history of the rock and its environment through time. For an example, in the Granite Dells located in Prescott Arizona, the uranium content varies from below detectable limits to 39.7 ppm (13.2 pCi/g) with an average value of 8.8 ppm (2.9 pCi/g) as determined by a detailed survey of 146 grid stations (Proctor 1987). The survey conducted for this report obtained 10 stations and three continuous profiles along roads within the Dells. These stations show an average uranium content of 13.8 ppm (4.6 pCi/g) with a low of 3.2 ppm (1.1 pCi/g) and a high of 21.2 ppm (7.1 pCi/g). The enrichment in uranium and thorium in localized areas occurred at the time of crystallization of the late stage magma. The subsequent removal of uranium is due to weathering and leaching of uranium by infiltrating ground water. In general this can be seen in the lower measured uranium content of decomposed granite and soils compared to the uranium content of relatively fresh granites as noted in the geologic descriptions in this report. It is therefore important to distinguish between the depletion of uranium by weathering (oxidation) as opposed to a naturally low

uranium content of the rock unit at the time of formation. It should also be borne in mind that this radiometric survey represents only the uranium and thorium content of the material located at the surface and assumes that their daughter nuclides are in secular equilibrium. Clearly for oxidizing conditions this assumption may not be valid and the uranium content may increase with depth. Consequently, radon gas from such sources may still present a problem to structures built on these areas even though the measured equivalent uranium values appear low.

The uranium decay series produces 14 major daughter nuclides including radon-222 and bismuth-214. Because uranium itself does not produce a suitable gamma ray peak for detection the gamma ray from the bismuth-214 daughter at 1.764 Mev is used instead. Consequently the amount of uranium present, as measured by bismuth-214 is only correct if the deposit is in secular equilibrium, that is, none of the chemically different daughter nuclides have been selectively removed from the deposit geochemically. It is interesting to note that radium, one of the daughters of uranium, produces radon-222 gas which has a half life of 3.6 days. Radon decays through a series of short lived daughter products to bismuth-214. The decay of bismuth-214 to polonium-214 emits the gamma ray of 1.764 Mev which is used to measure the amount of bismuth-214 (and therefore uranium) present, but also and more accurately reflects the amount of radium and radon-222 present as well. For the purposes of this report it is assumed that the uranium decay series is in equilibrium and therefore the activity of any one daughter product implies the same activity (in picocuries not ppm) for all the other daughters and their names may be freely exchanged. ie; uranium and radium.

The thorium decay series has 11 daughter nuclides and is almost always found in equilibrium. The gamma ray peak at 2.615 Mev due to thallium-208 is used to identify the amount of thorium present. The thorium decay series like the uranium series decays through radium and produces radon gas as the radioisotope radon-220 (sometimes called thoron gas) which has a half life of 55 seconds. Because of the short half life, which limits mobility, thoron gas is usually not as prevalent a problem as radon-222.

The reported values in this survey are radiometrically determined assuming equilibrium and are reported as equivalent radium, uranium, or thorium (eRa, eU, eTh). In situ radiometric measurements tend to

indicate higher concentrations than laboratory methods due to source conditions, inhomogeneous distributions, disequilibrium, and the ambient radiation field (Marutzky 1986).

METHODOLOGY

For this survey two survey instruments were used; a portable McPhar model 44 Gamma Ray Spectrometer using a 3in. x 3in. thallium activated sodium iodide crystal and a jeep mounted Scintrex GAD-6 Gamma Ray Spectrometer using three thallium activated sodium iodide crystals of approximately 5 liters total volume. Both of these instruments measure 4 energy channels simultaneously. The specifications for each instrument and channel are detailed below:

Channel 1	Total Count - Measures changes in gamma radiation in the range 0.15 - 2.77 Mev for the GAD-6 and all energies greater than 0.4 Mev for the McPhar 44. This channel provides the most sensitivity to overall changes in gamma radiation. It will also detect man-made gamma radiation sources (cesium-137, cobalt-60, etc.) within its energy band.
Channel 2	Potassium - Measures the potassium-40 peak located at 1.461 Mev. The GAD-6 window extends between 1.380 to 1.560 Mev while the McPhar 44 extends between 1.66 to 1.86 Mev.
Channel 3	Uranium - Measures the bismuth-214 peak located at 1.764 Mev. The GAD-6 counting window extends between 1.660 to 1.900 Mev while the McPhar 44 extends between 1.66 to 1.86 Mev.
Channel 4	Thorium - Measures the thallium-208 peak located at 2.615 Mev. The counting window of the GAD-6 extends between 2.440 to 2.770 Mev while the McPhar 44 extends between 2.42 to 2.82 Mev.

These spectrometers while having a high sensitivity, will respond only to very near surfaces radiation sources due to the attenuation

effects of various materials on gamma radiation. For example, about 3 feet of water or 1.5 feet of rock will almost completely shield out any uranium or thorium radiation present. Therefore the survey requires either near surface mineralization in outcrop or as weathered in place soils, or upwardly migrating radon gas depositing daughter products in the very near surface material to be effective.

The spectrometers used on this survey were calibrated for background, potassium, uranium, and thorium at the United States Department of Energy's Walker Field calibration facility, located in Grand Junction, Colorado on September 1-2, 1987. U.S. Environmental Protection Agency and Department of Energy <u>In Situ Gamma Ray Measurement Protocol</u> (GJ/TMC-06 UC-70A) were adhered to in the operation and reporting of this radiometric survey. A daily calibrate was performed prior to field operations to insure the instrument was in calibration and operating correctly. Periodic calibrations were performed through out the day to insure the instruments had minimal drift due to temperature changes. Base station checks were obtained periodically to monitor instrument drift. With the exception of a large temperature change that required recalibration in Prescott, no operational problems were encountered.

Daily calibrations for the McPhar 44 spectrometer are straight forward and used the characteristic 660 kev photopeak of a cesium-137 source to align the spectrometer's calibration window to the sodium iodide crystal. The calibration of the custom designed GAD-6 system requires that each of the three sodium iodide crystals must be gain matched to each other and the spectrometer's pulse height analyzer. This calibration is accomplished by using the 2.625 Mev photopeak of a thorium oxide calibration source in a fixed geometry with detector #1 and adjusting the gain of the spectrometer's pulse height analyzer to shift the 2.615 Mev photopeak from the detector into the calibration window. Once the thorium peak from detector #1 is properly aligned in the calibration window the respective energy peaks representing potassium, uranium, and thorium will fall into their preset windows within the spectrometer. When the pulse height analyzer has been calibrated to detector #1 (the standard) detector #1 is turned off and the thorium oxide source is used to calibrate detector #2. The gain of detector #2 is then adjusted to shift its thorium peak to match that of detector #1. Detector #3 is calibrated in a similar manner which results in the thorium peak

from each detector properly aligned for the pulse height analyzer and each channel centered in the pulse height analyzer.

The spectral data collected on this survey have been corrected for compton scattering of the higher energy gamma rays. Compton stripping corrections are necessary to remove the effects of the interferences between the spectra of each of the radionuclides of interest. This interference is due to the compton continuum and superposition of multiple spectra. The compton continuum occurs when a high energy gamma ray, say for example from thorium at 2.615 Mev, is not completely captured by the sodium iodide crystal and leaves only a portion of its energy in the crystal with the remaining portion passing through as a lower energy gamma ray. The portion of the energy expended within the crystal is seen as a lower energy photon and is counted on a lower energy channel, say for example the uranium channel at 1.76 Mev. Clearly this photon is not due to uranium and the uranium channel must be corrected for the count rate due to thorium. This correction is called compton stripping. For series equilibrium the equivalent uranium (radium) can be determined by:

$$eRa = k2 \; [\; C(U) - a \; C(Th) \;]$$

where eRa = equivalent radium in picocuries/gram (pCi/g)
k2 = proportionality constant (pCi/g / counts/sec)
a = compton stripping coefficient for Thorium on Uranium
C(U) = count rate - background in the uranium channel
C(Th)= count rate - background in the thorium channel

For Thorium, which has no significant natural interference, equivalent thorium is determined by:

$$eTh = k3 \; [\; C(Th) \;]$$

where eTh = equivalent thorium in picocuries/gram (pCi/g)
k3 = proportionality constant (pCi/g / counts/sec)
C(Th) = count rate - background in the thorium channel

The compton stripping coefficients and proportionality constants were determined at the Department of Energy's Calibration facility in Grand Junction, Colorado by taking measurements of the individual count rates produced in all channels by a known source of thorium,

radium and potassium in series equilibrium.

General data discussion

For remedial action work at uranium mill tailings and industrial sites the EPA has set a standard (CFR 10 192.12a) for clean up of 5 picocuries/gram (pCi/g) Ra-226 above background levels in the first 15 cm. of soil below the surface, averaged over an area of 100 sq. meters. However, there is no standard that specifies acceptable natural background levels. Background levels vary considerably depending on rock type, mineralization and weathering history. In general, igneous rocks have a higher uranium content than sedimentary rocks. In this radiometric reconnaissance of Arizona it was found that precambrian granites range from 0.7 pCi/g to 13 pCi/g eRa-226 (2 to 39 ppm eRa-226) and typically average between 1.2 and 1.5 pCi/g eRa-226 (3.6 to 4.5 ppm). Volcanic rocks range from about 1.0 to about 3.8 pCi/g eRa-226 (2.9 to 11.4 ppm) with an average of about 1.3 pCi/g (3.9 ppm). Sedimentary rocks in Arizona are generally low (1.1 pCi/g) with the exception of some black shales and limestone lake beds. These limestone lake beds are generally marly or silty and typically exhibit an eRa-226 content in excess of 2 pCi/g where as a normal limestone would average about 0.7 pCi/g (2 ppm) eRa-226. These limestones can exceed 27 pCi/g (81 ppm) eRa-226 in some parts of the state. Black shales are also known for their higher than average uranium content and average approximately 2.7 pCi/g eRa.

The activity of basin fill material depends on the source rock and its weathering history. Typical ranges for alluvial fill in southern Arizona range from 0.5 pCi/g to 1.8 pCi/g (1.5 to 5.4 ppm) eRa-226 with an average of 1.3 pCi/g (3.9 ppm).

In general, material containing over 2.0 pCi/g eRa-226 should be considered elevated while values in excess of 3 pCi/g may be considered mineralized. As mentioned previously the EPA requires clean up at its remedial action sites (mill tailings) to 5 pCi/g above background. Any amount of radium, through radioactive decay, will produce radon gas which can build up in the soil. The amount of radon gas in a residential structure depends primarily on how well the structure is coupled to the soil gas rather than how high the radium or radon content of the soil is. Therefore no direct relationship between soil radium (radon) content and a residential

structure's radon gas content can be drawn with out determining the degree of coupling between the structure and the soil gas present. However, for a given coupling coefficient between the soil gas and the structure (entry ability of soil gas through cracks and pipes) any increase in the soil radium content will also increase the radon gas content within the structure itself from diffusion or advection due to the increased concentration gradient. Elevated radon levels have been found in residences with average and below average soil radium content due to excellent coupling with the ground and a low air exchange rate of the residence.

Dudley F. Emer
Geophysicist

References

P. D. Proctor, K. S. Fleck, and A. N. Shanin, 1987, Radiometric and petrochemical characteristics of the Dells granite, Yavapai county, Arizona: State of Arizona Bureau of geology and Mineral Technology, Open File Report 87-8.

Y. Onishi, R.J. Serne, E.M. Arnold, C.E. Cowan, F.L. Thompson, 1980, Critical review: radionuclide transport, sediment transport, and water quality mathematical modeling; and radionuclide adsorption/desorption mechanisms:NUREG/CR-1322 PNL-2901 RE, Pacific Northwest Laboratory, Richland Washington.

S.J. Marutzky, H.L. Fleischhauer, P.R. Engelder, 1986, Comparison of in-situ and laboratory measurement methods for radium-226 in soils:GJH/TMC-24, UC-70A; U.S. Dept. of Energy, Technical Measurements Center, Grand Junction, Colorado.

S.J. Marutzky, W.D. Steele, B.N. Key, K. Kosanle, 1984, Surface gamma ray measurement protocol:GJ/TMC-06, UC-70A, U.S. Dept of Energy, Bendix Field Engineering Corporation, Grand Junction, Colorado.

R.L. Rock and R.T. Beckman, 1979, Radiation monitoring U.S. Dept. of Labor, Mine Safety & Health Administration.

R.L. Grasty, J.E. Glynn, and J.A. Grant, 1985, The Analysis of multichannel airborne gamma ray spectra: Geophysics, 50, 2611-2650.

S. Briener, J.T. Lindon, and R.J. Kalenbach, 1976, Gamma ray measurements and data reduction considerations for airborne radiometric surveys: International symposium on exploration of uranium ore deposits: Vienna, Austria, paper #34.

GeoMetrics, 1977, Survey guidelines for using a portable gamma ray spectrometer in uranium exploration: GeoMetrics, Sunnyvale, California, Technical report number 13, 1-12.

L. Lovborg and E. Mose, 1987, Counting statistics in radioelement assaying with a portable spectrometer: Geophysics, 50, 2611-2650.y

Scintrex Ltd., 1979, GAD-6 four channel stabilized gamma ray spectrometer operation manual: Scintrex Ltd., Ontario, Canada.