INTRODUCTION

This field trip guide presents the results of reconnaissance and detailed geologic studies in the vicinity of the Palo Verde Nuclear Generating Station (PVNGS), south-central Arizona. These studies were directly related to the investigation and licensing requirements for PVNGS and have provided much new geologic information on the western Phoenix Basin area. In addition to the geologic descriptions, we have provided a travel log and a series of appendices giving the background of the site selection process, synopsis of Nuclear Regulatory Commission (NRC) siting criteria, seismology of Arizona, and a summary of new geologic information resulting from the Palo Verde studies.

ACKNOWLEDGEMENTS

The authors express their thanks to the Arizona Nuclear Power Project and Arizona Public Service for permitting this field trip. Preparation for this field trip guide was supported financially by Fugro, Incorporated.

Text portions of this paper have been largely abstracted or paraphrased from two publications: The PVNGS Preliminary Safety Analysis Report (ANPP, 1974) and an article in FIELDNOTES from the Arizona Bureau of Mines (Scott and Moore, 1976). In addition, supplemental data were obtained from the files and the library of Fugro, Inc.

SUMMARY

The Palo Verde Nuclear Generating Station site is approximately 40 miles west of Phoenix and is situated within the Basin and Range physiographic and structural province of southwestern Arizona. The geology within a 25 mile radius of the site (site vicinity) is characterized by mountain ranges which are relatively short, irregular and stand sharply above broad, alluvial-filled basins. The rocks of these mountains vary from deformed crystalline rocks of Pre-cambrian age to volcanic and sedimentary rocks of middle-Tertiary age. Alluvium and volcanic rocks in the broad basins range from Miocene to Holocene in age, based on potassium-argon age dates of basalt interbeds.

The geology of the site area (5 mile radius) consists of 1) Precambrian metamorphic and granitic rocks, 2) Miocene volcanic and interbedded sedimentary rocks and 3) basin sedimentary deposits on the order of 400-600 feet thick and consisting of lithified fanglomerate, un lithified fan, alluvial, and lacustrine deposits with basalt interbeds. The dominant structure of the site is homoclinal folding of the volcanic bedrock dipping 15° to 23° to the southwest. The overlying basin sediments are flat-lying and undeformed. Only one northwest-trending fault, displacing the volcanic bedrock, has been observed within a 5 mile radius of the site. This fault does not displace Miocene fanglomerate.

The Palo Verde Clay, a lithologically and geophysically distinctive lacustrine member of the basin sediments, underlies and is older than the base of the Arlington basalt flow (2.0 million years—based on potassium-argon age dates supported by paleomagnetic analysis). The Palo Verde Clay can be continuously traced in borings across the site and at least 5 miles southeast of the site. Consistent correlations of the Palo Verde Clay indicate no faulting within the site for more than 2.8 million years.

Main groundwater levels at the site, based on regional water contours and actual water level measurements, range from approximately 200 to 270 feet below ground surface.
A perched water zone exists in the power plant area with depth to water ranging from 15 feet to 100 feet below ground surface.

GEOTECHNICAL INVESTIGATION OF PALO VERDE

The site-specific geotechnical investigation (for the PSAR) at Palo Verde required approximately one year to complete after confirmation that the site was feasible. The activities included:

• reconnaissance and detailed geologic mapping of a 25 mile radius and 5 mile radius around the site;
• over 9 miles of seismic refraction geophysical surveys;
• reconnaissance and detailed gravity and magnetic geophysical surveys covering a 10 mile radius around the site;
• 2,000 feet of exploratory backhoe trenches;
• drilling of over 200 exploratory borings to depths ranging from 50 to 721 feet (in total about 10 miles of borings were drilled for geologic and foundation engineering analysis);
• high-resolution downhole geophysical logging of nearly all exploratory borings for stratigraphic correlation;
• potassium-argon age dating of 34 rock samples;
• analysis of approximately 550 samples of basin sediments for paleomagnetic polarity;
• static and dynamic engineering tests on core and drive samples;
• detailed groundwater analysis;
• complete research of all pertinent geologic, seismologic, and hydrologic data.

In addition, there were seven other specialists or consultants from the University of Arizona and Arizona State...
University who consulted on specific aspects of the project, such as geohydrology, stratigraphy, structural geology, petrology, clay mineralogy, palynology and geophysics.

GEOLOGY OF THE PALO VERDE SITE

The Palo Verde Nuclear Generating Station is located within a broad valley surrounded by the Palo Verde Hills, an intermittent series of low hills having a maximum relief of about 250 feet. The valley floor slopes very gently towards the Gila River about 10 miles to the south. The area studied in detail for this investigation is included within a 5 mile radius of the site. Geologic reconnaissance studies involved an even larger area (about a 25 mile radius).

The rocks of the Palo Verde Hills can be divided into three groups: 1) Precambrian metamorphic and granitic basement rocks, 2) Miocene volcanic and interbedded sedimentary rocks, and 3) Miocene to Holocene basin sediments consisting of alluvial fan, lacustrine, and basin fill deposits (STOP 1, fig. 8), with local interbeds of volcanic rocks (figs. 1, 2, and 3).

The crystalline basement rocks are not exposed at the ground surface in the site area but they have been encountered at a depth of several hundred feet in a number of exploratory borings. The buried granitic surface is unconformable and undulatory with a general slope toward the northeast (fig. 3).

Miocene volcanic rocks, which unconformably overlie the crystalline basement rocks, are exposed in the Palo Verde Hills. These rocks represent massive flows, plugs, dikes and flow breccia with scattered, discontinuous interbeds of tuff and tuffaceous sandstone. The rocks of flow origin range in composition from hornblende andesite,
Figure 2. Stratigraphic chart of the site area.
which is relatively rare, to pyroxene andesite, basalt, and basanite. The pyroclastic rocks consist of welded hornblende biotite tuff. Whole-rock potassium-argon ages on basalt samples from seven localities range from 17.9 to 19.9 million years old. The many basalt dikes and plugs indicate numerous local sources for the volcanic rocks throughout the area (fig. 2).

Lithified and un lithified sediments overlying the basement and volcanic rocks cover the site and contain up to six distinctive stratigraphic units. These sediments are nearly horizontal and have an average thickness of approximately 320 feet with a variation of thickness in the site area of approximately 100 feet. The stratigraphic units within this alluvial sequence extend across the Palo Verde site and are generally continuous for at least 5 miles beyond the site boundaries towards the northeast and southeast (figs. 3 and 4).

At the base of the basin sediments is a Tertiary fanglomerate which contains rounded to angular clasts predominantly of andesite and basalt set in a well-cemented matrix of sand, silt, and occasionally, tuffaceous sand. The fanglomerate is exposed along the lower slopes of the Palo Verde Hills and unconformably overlies the volcanic bedrock. The fanglomerate has been traced into the subsurface where it commonly fills bedrock depressions and is absent on buried bedrock highs. A basalt interbed within the fanglomerate has been dated by potassium-argon techniques at 16.7 million years old, indicating a middle Miocene age.

Near the top of the basin sediment stratigraphic section another series of potassium-argon age dates was obtained from the Arlington and Gillespie basalt flows. The Arlington and Gillespie basalt flows are well exposed at the ground surface and clearly overlie basin fill sediments and Gila River terraces along old U. S. 80 (STOPS 2 and 3). A mean age of about 2 million years was obtained from seven samples of the Arlington basalt flow and about 3 million years for the Gillespie flow.

The stratigraphic and age correlation between the basin sediments at the site and those underlying the Arlington basalt flow 5 miles southeast was accomplished by tracing a distinctive clay stratum, named the Palo Verde Clay for this study, in relatively closely spaced borings. This clay unit is a lacustrine or lake deposit, about 200 feet below the ground surface, that averages between 80 to 100 feet thick and has a known maximum thickness of at least 136 feet. The Palo Verde Clay displays a remarkably distinctive signature in borehole geophysical logs, particularly those logs measuring natural gamma radiation. In addition, the clay was recognizable in lithologic cores because of its characteristic reddish-brown color and high clay content which contrasted to the coarser units stratigraphically above and below. Because the upper surface of the Palo Verde Clay represented a broad lake bottom, the correlations are nearly horizontal and show remarkable stratigraphic and structural continuity for the entire five miles between the site and the Arlington basalt flow. To assure that the clay was stratigraphically below the basalt, two borings were made through the Arlington flow into the Palo Verde Clay, thereby confirming that the clay was older than 2 million years. To further refine the age of the clay, a paleomagnetic analysis was made on 550 samples of the alluvial sediments from the site to the Arlington basalt. Results showed two prominent and continuous magnetic reversals which may correspond to worldwide reversals conservatively estimated to be 2.4 and 2.8 million years.

The presence, extent, and continuity of the Palo Verde Clay are of great significance to the Palo Verde site for several reasons:
1. The clay continuously underlies the site and the site area to at least 5 miles southeast and northeast (fig. 5).
2. The clay is relatively old (estimated at least 2.7 million
years on the upper surface) and is not deformed or faulted, indicating long term geologic stability of the area.

The only structural folding and faulting observed in the site area have been restricted to the Miocene volcanic rocks in the Palo Verde Hills. (STOP 4). Stratification within the Miocene volcanic bedrock sequence is indistinct but detailed geologic mapping has shown that the dominant structure of the Palo Verde Hills area is a homocline with the volcanic flow-bedding striking approximately N.40°W. and dipping 15° to 23° southwest.

Attitudes and areal extents indicate the volcanic sequence to be nearly 6,500 feet thick across the site area. Detailed mapping and trenching revealed no faulting except at one locality in the Palo Verde Hills, about 3 miles west of the site. This fault displaces Miocene volcanic rocks, trends northwest, and is approximately 2,000 feet long. The fault was traced in closely spaced backhoe trenches to a point where it is overlain by Tertiary fanglomerate. Since the fanglomerate was not displaced and was of Miocene age (16.7 million years based on a basalt interbed), the fault was pre-fanglomerate in age and not considered a safety hazard by NRC criteria.

**CONTINUING GEOLOGIC ACTIVITIES**

As the basin sediments are exposed by construction activities at Palo Verde, detailed geologic inspections are made of all excavations to satisfy NRC seismic safety criteria. The trenches and other excavations form an extensive network of exposures that are invaluable for subsurface geologic analysis. At least one wall of all pertinent exposures is photographed as a permanent record and geologic contacts with descriptions are logged at scales of ten feet to the inch. The purpose of such detailed inspections and logging is to give site geology in as much detail as possible:

- establish and document the actual subsurface conditions at the site;
- confirm that design considerations made during earlier investigations still are appropriate for the site conditions.
- insure that the public health and safety will not be jeopardized due to geologic processes affecting plant integrity.

Periodically, representatives of the NRC, U. S. Geological Survey and Arizona Bureau of Geology and
Mineral Technology make detailed inspections of these excavations and check the critical components of the detailed mapping. All logs and other pertinent information will be assembled into a final report at the conclusion of grading. This data will be submitted as a part of Final Safety Analysis Report to the NRC, which, upon approval of the document, will issue the license to operate PVNGS.

REFERENCES CITED


ROAD LOG

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Start at Broadway Road and Maricopa Freeway

Bridge over Salt River. The Salt River drainage basin comprises an area of 13,730 square miles and drains portions of the Sierra Ancha and Mogollon Rim on the north, the White Mountains on the east and the Superstition and South Mountains on the south. The average annual stream flow is about 350,000 acre-feet with a maximum flow recorded of 45,000 cubic feet per second (cfs).

The South Mountains to the southwest expose Precambrian granite gneisses, schists, phyllites, and quartzite. The metamorphics are locally intruded by late Mesozoic granitics.

19th Avenue off-ramp and Maricopa Freeway

Buckeye Road (Highway 80) and Black Canyon Freeway
On the south is a very good view of the Sierra Estrella Mountains, a northwest-trending range with a maximum relief of about 3,500 feet. The rock types exposed are similar to those exposed in the South Mountains. Bridge over Agua Fria River. This southerly flowing tributary to the Gila River drains an area of about 2,000 square miles. Most of the runoff from the Hieroglyphic Mountains is retained by Lake Pleasant dam about 35 miles upstream of the mouth. The yearly average runoff is 1,100 cfs with a maximum recorded streamflow of 4,700 cfs. To the north are the White Tank Mountains and the Caterpillar Tractor Company proving grounds. Gneissic rocks consisting of foliated granite and hornfelsic rocks intruded locally with pegmatitic veins make up the White Tank Mountains. Town of Buckeye. To the south, a view of the subdued terrain of the Buckeye Hills, an east-west trending complex of Precambrian gneiss, hornfels, mica schist (the mica is mined commercially by the Buckeye Mica Company,) granite, quartz monzonite, and quartz diorite. These rocks are intruded by late Mesozoic granitics. Mining and exploration for rare earth, uranium, gold, silver, and copper has occurred sporadically in this area. Highway 80 and Olgelsby Road Bridge over the Gila River. This river provides drainage for a large portion of Arizona and New Mexico, encompassing approximately 50,000 square miles. This area includes most of the Central Highlands Province and the Basin and Range Lowlands Province. Prior to construction of runoff control and irrigation diversion the greatest known flood discharge in this area was 250,000 cfs (1891). The greatest flood flow since construction was 45,800 cfs in 1941. STOP 1. Overview of Gila River flood plain area with subdued knobs of Tertiary volcanics which protrude through the basin fill sediment (Power and Robins Buttes). The Buckeye Hills area is to the south, the Arlington basalt flow in the west middle distance, and the Palo Verde Hills and Saddle Mountain on the western horizon (fig. 7). Road cuts in late Mesozoic granitics of the Buckeye Hills. 1.5 39.6 2.5 42.1
3.5 12.2
9.2 21.4
4.0 25.4
10.9 36.3
1.8 38.1
122
drilling and geophysical surveys, the site was abandoned for more favorable sites at Gillespie Dam and Palo Verde. The Maricopa Mountains are predominantly Precambrian granitics with localized pegmatitic intrusions.

Towards the west is a good view of the Gillespie basalt flow. The Gillespie basalt forms a small flow along the west side of the Gila River in the vicinity of Gillespie Dam. It overlies portions of old alluvial fan deposits, old river terrace deposits, older alkali basalt, and granitic basement rock. The flow is dark gray to black and very dense with few vesicles except for occasional scoriaceous zones; it is slightly fractured and locally has columnar jointing. Petrographically, the unit is an olivine basalt, with olivine phenocrysts in a groundmass of matted plagioclase with intergranular calcic augite and opaque minerals. The basalt is 15–30 feet thick at its periphery and its surface is intensely calichified. The basalt is actually a composite of several flows and three or four flow fronts have been identified on the upper surface. Pillow lavas exposed in the northeast side of the basalt suggest that it flowed into the Gila River as it covered the old ‘‘40-foot’’ flood plain.

Ten radiometric dates have been obtained from the basalt. They range from 4.2 ± 0.4 million years for a sample near the bottom edge of the basalt to 1.3 ± 0.4 million years for a sample taken near the vent. Five of the dates fall between 3.3–3.5 million years and the average of all dates is 3.3 million years.

To the north can be seen typical examples of debris flows common to the volcanic terrain in this area. The underlying rock consists of several flows of dark gray alkalic basalt with abundant augitic phenocrysts. It dips about 10° to 30° to the west. Based on K-argon dating, it ranges in age from 19.1 ± 0.9 to 19.6 ± 0.4 million years.

Bridge over the Gila River; Gillespie Dam is to the north; the El Paso Natural Gas pipeline is to the south.

STOP 2. Borrow cut exposing Gila River gravel and sediments overlain by the Gillespie basalt flow. The sediments in this exposure are remnants of paired river terraces which border the modern flood plain and stand 40 to 80 feet above the modern channel. The deposit consists of material ranging from silty, fine sand to cobbles. Many of the clasts are well rounded and consist of distinctive rocks such as quartzite, rhyolite and metadiabase whose provenance is many miles upstream (fig. 8).

The deposits 80 feet above the present river channel represent the upper level of a major fluvial aggradation. These high terrace deposits are poorly preserved and strongly calichified. Old pediment-alluvial fan systems along the east side of the Gila Bend Mountains were graded to and interfingered with these deposits as they accumulated. Fine-grained basin-fill deposits overlie and/or interfinger with Gila River deposits at
Figure 8. View of borrow pit cut exposing Gila River gravels (GR) overlain by the Gillespie basalt flow (Gbf).

Figure 9. View of road cut exposing basin fill sediments (BF) which are overlain by the Arlington basalt flow (Abt).

STOP 3. Road cut exposing basin fill sediments overlain by the Arlington basalt flow. The flow, K-argon dated at 1.2 to 3.2 million years, unconformably overlies sands and silt sediments that have been traced continuously to the northwest where they underlie the plant site. A good paleosol has been recognized in this cut. Note the alteration zone at the contact between the flow and sediments (fig. 9).

On the east the gently undulating topography defines river terrace and overbank deposits of the Hassayampa River.

Old Highway 80 and Salome Highway

Salome Highway and Elliot-Ward Roads

On the north the southern site boundary of PVNGS.

Ward (Elliot Rd.) and Wintersburg Road

STOP 4. Road cut exposing Tertiary volcanic flow sequence (K-argon age of about 14 million years) and interbedded sequence of water-laid tuffs and sand. About six distinctive flows can be differentiated at this the 80-foot level. This suggests that at least the upper part of the basin-fill sequence in the western end of the Phoenix Basin (including the Palo Verde site area) accumulated after the Gila River entered the area.
exposure as a result of alteration at contacts and the both massive and vesicular nature of the rock. Some of these flows were probably extruded into a body of water as evidenced by the glassy texture in portions of the exposure. The flows and sediments are striking to the northwest and dip to the south at about 45° to 55° (fig. 10).

STOP 5. Main entrance, PVNGS.

RETURN LOG

0.0 0.0 Main gate
2.3 2.3 Wintersburg Road and Salome Highway
4.0 6.3 Baseline-Salome Highway Intersection
1.5 7.8 On the north and south is the Hassayampa River flood plain. Terrace and overbank deposits are quite extensive above the active channel. The Hassayampa River uncontrolled drainage area is about 2,000 square miles and drains portions of the Vulture and Bradshaw Mountains to the north. The yearly average discharge is 3,070 cfs with a maximum recorded streamflow of 6,500 cfs.
6.8 14.6 Baseline and Olgelsby Roads
   Return to ASU via Highway 80 and Freeway

APPENDICES

BACKGROUND OF THE SITE SELECTION PROCESS; SCREENING THE REGIONAL SITE SELECTION PROCESS; SYNOPSIS OF THE NRC SITING CRITERIA; SEISMICITY OF ARIZONA; SUMMARY OF NEW GEOLOGIC INFORMATION RESULTING FROM PVNGS STUDIES.

BACKGROUND OF THE SITE SELECTION PROCESS

Experience has shown that the most effective way of identifying the best of a number of nuclear power plant sites is the systematic examination of a large region. This method provides the greatest effectiveness and flexibility in selecting optimum sites relative to all criteria critical to safety. This type of regional approach was utilized in the Palo Verde site selection and involved a screening, in distinct phases, of the entire state of Arizona. Each phase reduced the area under consideration using selected geologic, hydrologic, environmental and land-use criteria.

The first phase consisted of regional studies which divided the state in terms of seismotectonic characteristics based on selected geologic and seismologic criteria such as: physiographic provinces, natural geologic and structural provinces, complexity of geologic structure, distribution of Tertiary and Quaternary volcanic rocks, major tectonic lineaments, distribution of Quaternary faults, and distribution of historic and instrumented earthquake epicenters (fig. 11). In general, this regional screening showed that the most seismically active and geologically complex parts of Arizona for nuclear siting were 1) in the Southwest corner of the state, near Yuma, which is within the influence of the
Figure 11. Generalized tectonic map of Arizona.
active San Andreas fault zone, and 2) a broad band coinciding roughly with the central mountains or Transition Zone, which extends diagonally across the state from near the Grand Canyon to Bisbee. In addition to identifying the most restrictive area for siting, the regional study rated all the major areas in the state in terms of potential for satisfying the stringent NRC criteria. The most satisfactory areas for demonstrating a suitable site were in the region west of Phoenix and a limited area on the Colorado Plateau. Since land access and availability were severely restricted on the Colorado Plateau, the area west of Phoenix was selected for the more detailed Phase II and III investigations, and eleven candidate valleys were identified for the second study phase.

Phase II of the screening studies evaluated and ranked the eleven candidate valleys using geotechnical and environmental criteria. Of prime consideration were 1) presence of sufficient quantities of water for plant operation, 2) absence of Quaternary faults or lineaments which might be considered capable of generating earthquakes and/or ground displacements, 3) presence of suitable topographic and foundation conditions, 4) presence of stratigraphic units of Quaternary or late Tertiary age at or near ground surface which would be useful in evaluating the long term geologic stability of the site and site area. In geologically complex regions such as the western United States, the Quaternary (most recent) stratigraphy becomes critically important to any effort to document conclusively that a site has been tectonically stable for a considerable length of time. Phase II investigations relied on extensive literature search, aerial reconnaissance, studies of satellite imagery and aerial photography, and consultation with experts in local geology. At the conclusion of this phase, three basic candidate valleys were identified with 28 potential siting areas divided among them.

Phase III screening reduced the three valleys and 28 candidate site areas to a number of top-rated site areas for further consideration. The prime objective was to have enough potential sites to identify a prime and alternate site having a high likelihood of satisfying the NRC criteria. The geologic criteria used in the Phase III screening were similar to Phase II, however, the ranking criteria were quantified in more detail based on extensive literature search, detailed air photo analysis, ground and aerial reconnaissance, and analysis of all available subsurface and water well data. The ability to age-date the late Tertiary and Quaternary stratigraphic units at the site areas was also an important consideration at this phase.

A limited amount of surface and subsurface exploration was performed in the highest-rated candidate sites in order to confirm the suitable geotechnical characteristics. Typical investigations included: reconnaissance geologic mapping on specially flown low level stereo aerial photographs; seismic refraction and gravity surveys; several borings to 500 feet with samples for geologic and engineering analysis; age-dating of subsurface materials (when possible); backhoe trenches across lineations or faults. As a result of these limited confirmatory investigations, several sites were removed from further consideration; however, it also became apparent that the Palo Verde site had superior geologic characteristics to satisfy the NRC siting criteria.

SEISMICITY

Historic seismicity in Arizona has been moderate in a few parts of the State and almost nonexistent in other parts (fig. 12). Of the recorded epicenters within the State, the three largest have been between magnitude 5.0 and 5.9 and were in the north central part of Arizona between Flagstaff and the north state line. More epicenters have been located for earthquakes less than magnitude 5.0 and these smaller earthquakes form loose concentrations along the Central Mountains Province, trending diagonally northwest across the State, and at the southwest corner near Yuma. The most notable of strong earthquakes felt in Arizona, but originating outside the State, occurred in 1887 in Sonora, Mexico. The estimated magnitude was 8 and shaking was felt as far north as Prescott and as far south as Mexico City—a radius of about 400 miles from the assumed epicenter. Surface ruptures were reported for 35 miles along north-trending faults on the east and west sides of the Sierra Teras Mountains. The rupturing reportedly had a maximum vertical displacement of 26 feet and extended to within 10 miles of the Arizona border.

In terms of the Safe Shutdown Earthquake, the maximum level of earthquake shaking was postulated from the 1887 Sonora earthquake (magnitude 8) relocated at a distance of 72 miles from the Palo Verde site. This conservative estimation was based on a hypothetical relocation of the epicenter from Sonora, Mexico about 250 miles northwest along major fault and mountain systems in the Transition zone province. The closest approach of mapped Quaternary faults in the Transition zone are east of Phoenix and about 72 miles east of the site. This relocated earthquake is larger than any historical event occurring within Arizona and is a conservative representation of the maximum level of shaking that the plant might experience within its design life.

SYNOPSIS OF THE NRC SITING CRITERIA

The NRC has developed specific geologic and seismologic siting criteria which require, in general terms:
1) Establishment of the maximum level of earthquake shaking that might conceivably be experienced by the plant;
2) Determination of the potential for surface faulting within 5 miles of the site;
Figure 12. Earthquake epicenter map of Arizona and adjacent areas.
3) Effect of shaking or loading on the performance of foundation soils;
4) Impact of other geologic hazards at the site (subsidence, fissuring, collapse, etc.)

The maximum level of earthquake shaking that could conceivably be expected at the site is called the Safe Shutdown Earthquake (SSE). This is the level of shaking used to design the critical components of the plant. Under SSE conditions, the plant is designed to shut down operation without an accident if such shaking occurred. The SSE is a maximum credible seismic event that is conservatively determined after a complete study is made of the seismology, structural geology and tectonics of a 200-mile radius of the site.

The NRC criteria requires that the potential for surface faulting be precluded within a 5-mile radius of the site. To accomplish this, any faults within a 5-mile radius must be demonstrated to:

- a) have not moved once within the last 35,000 years, or
- b) have no multiple movements within the last 500,000 years, or
- c) have no logical connection to a fault beyond the 5-mile radius which might be considered capable of movement
- d) have no demonstration of active seismicity.

As a result, it becomes highly important that a potential nuclear site has consistent Quaternary stratigraphy relatively close to ground surface to determine minimum age on faults within the 5-mile radius and, in some cases, even beyond.

A comprehensive analysis of the foundation soils is required by the NRC for Preliminary Safety Analysis Studies to preclude differential settlements, excessive consolidation, liquefaction during the Safe Shutdown Earthquake, or any other foundation phenomena that might endanger the integrity of the plant. The foundation studies also include such considerations as subsidence due to decreases in groundwater level, differential settlements or collapse of soils, and the effects of man-made hazards such as mining or withdrawal of oil. Besides immediate impacts of such conditions, all of these investigations must also consider possible long-term changes over the projected 40-year life of the plant.

SUMMARY OF NEW GEOLOGIC INFORMATION RESULTING FROM PVNGS STUDIES

GENERAL GEOLOGY
- Detailed geologic mapping of the Palo Verde Hills, Gillespie Dam area; southcentral Gila Bend Mountains; southcentral Vulture Mountains; and Rainbow Valley north of the Maricopa Mountains.
- Petrographic analysis of early and pre-Tertiary igneous and metamorphic rock; late Tertiary and early Quaternary volcanics and volcanic-derived sediments within the study area.
- Refinement of the seismo-tectonic character of southern Arizona.
- Refinement of the late Tertiary and Quaternary geologic history of the western portion of the Phoenix basin.
- Definition of small desert basin depositional history and stratigraphy.
- Reevaluation of the geothermal characteristics of the Palo Verde Hills region.

GEOPHYSICS
- Detailed seismic information and reflection surveys within a 25 mile radius of PVNGS.
- Reconnaissance and detailed gravity and magnetic surveys near Gillespie Dam, Vulture Mountain and PVNGS.

AGE DATING
- Redefinition of volcanic rock ages in the vicinity of PVNGS using K-argon method. Rock making up the Palo Verde Hills, previously identified as being Quaternary age, was K-argon dated in excess of 13 million years b.p.
- Absolute ages of the Gillespie and Arlington basalt flows were established as being 3.4 to 1.4 million years b.p.
- Paleomagnetic analysis of several hundred samples of basin sediments in the vicinity of PVNGS; because of this analysis supported by the radiometric dates, we know that the Palo Verde basin fill is older than 0.7 million years.

GEOMORPHOLOGY
- Geomorphological studies were performed to differentiate alluvial deposits southwest of the Gillespie flow and establish their age relative to the Gillespie basalt.
- Geomorphic analysis of terrace levels on the Gila River from Hassayampa south to Gila Bend. The study was accomplished through the use of leveling surveys on terrace benches and showed no evidence of deformation or displacement of the 40 foot terrace across the prominent Gila River lineament.

GROUNDWATER
- Identification, modeling, and analysis of a significant perched water zone in the Palo Verde site area. The zone apparently developed as a result of the infiltration of irrigation waters and the retarding of its downward migration by the Palo Verde Clay acting as an aquitard.

ENGINEERING
- Detailed engineering analysis of desert basin sediments to establish their potential for liquefying under seismic loads.
- Refinement of available subsidence data relative to salt bodies and massive groundwater withdrawal.

Specific details concerning the items listed may be obtained by consulting the references cited.