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SELECTED CASE HISTORIES OF THE APPLICATION OF THE NUCLEAR REGULATORY COMMISSIONS GEOLOGIC AND SEISMIC SITING CRITERIA

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ABSTRACT

This document first presents a discussion of three generic seismic and geologic occurrences that became issues in the licensing of nuclear power plants in the central and eastern United States (CEUS). It then provides discussions of case histories of problems in the licensing activities for 32 nuclear power plant sites and a uranium mill tailings dam site during the period 1971–1990 throughout the conterminous United States dam. The central theme of the report is the application of Appendix A to 10 CFR Part 100, "Seismic and Geologic Siting Criteria for Nuclear Power Plants" to the assessment of these 33 sites. Although the regulation was successful in the licensing process during this time period, the case histories presented illustrate many of the difficulties in implementing the regulation, and the need for it to be updated and revised in keeping with advances in the geological sciences. In particular, dealing with these issues puts emphasis on the need to consider uncertainties about seismic sources, earthquake magnitudes, and ground motion in site hazard analyses. It is anticipated that describing the problems in such a manner will alert future applicants and reviewers to potential difficulties that could arise in the evaluation of seismic and geologic hazards and the licensing of nuclear facilities.

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ACKNOWLEDGEMENT

I would like to express my gratitude to Dr. Robert Rothman for his critical review of several manuscripts of this report and for his many invaluable comments, which greatly improved this document. My thanks are also extended to Dr. Andrew Murphy for his encouragement during the preparation of the report and for his support during the publishing process. Finally, I would like to acknowledge my wife, Kaye, for her help with the computer work and typing and most of all for her encouragement all through this process.

CHAPTER 1 - INTRODUCTION

1.1 Purpose of this Report

This report has been prepared to briefly document some of the siting reviews in which the "Seismic and Geologic Siting Criteria for Nuclear Power Plants," Appendix A to 10 CFR Part 100 (Ref. 1-1), was utilized in order to highlight some of the major issues encountered, and describe how these issues were resolved. The period covered is between about 1971 and 1990. It is hoped that the experiences described will help to avoid some of the pitfalls of that period and help to reduce unnecessary effort, time and expense in future licensing activities.

Although this report addresses specific issues concerning only 32 selected sites, Table 1-1 provides a list of most of the nuclear power plant sites evaluated in the United States. Also presented in the table are the geosciences regulatory issues that had to be addressed during the licensing activities for each site.

1.2 Appendix A, Seismic and Geologic Criteria for Nuclear Power Plants, and the Need for Change

1.2.1 Purpose of Appendix A

General Design Criterion 2 of Appendix A to 10 CFR Part 50 requires that Nuclear power plant structures, systems, and components important to safety be designed to withstand the effects of natural phenomena such as earthquakes and tornadoes, without loss of capability to perform their functions. Appendix A to 10 CFR Part 100, Seismic and Geologic Siting Criteria for Nuclear Power Plants, sets forth criteria pertaining to site investigations to assess the effects of earthquakes and other geological phenomena to meet the requirements of General Design Criterion 2. Appendix A presents considerations which guided the AEC/NRC in its evaluation of the suitability of the site and plant design bases considering site characteristics. It also provided guidance in what was required to provide reasonable assurance that a nuclear power plant could be constructed and operated at a proposed site without undue risk to the health and safety of the public. It was recognized at the time of preparation of Appendix A, that limitations in data and advances in the geological sciences would requite future modifications of the regulation (Ref. 1-2).

Methods and procedures in Appendix A were directed toward the following objectives: estimation of the severity of ground shaking due to earthquakes, assessment of the potential for surface faulting, evaluation of the effects of associated phenomena such as tsunamis and ground failure, and the assessment of the potential for other geological hazards such as landslides and subsidence. To accomplish these objectives, several concepts were put forth that related to the issues. They included the concepts of tectonic provinces, tectonic structures, capable faults, and specification of the Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE).

1.2.2 Tectonic Province and Tectonic Structure

A tectonic province is defined in Appendix A as "a region of the North American continent characterized by a relative consistency of the geologic structural features contained therein." This concept was developed to provide a way to estimate design basis earthquakes the cause of which could not be determined. Although seismicity is not mentioned, the AEC/NRC staff interpreted this concept to imply regions of uniform earthquake hazard. A tectonic structure was considered to be "a large-scale dislocation or distortion within the earth's crust. Its extent is measured in miles." It is used in Appendix A to ensure consideration of geologic structure that could localize earthquakes at or near the site. Appendix A requires "correlation of epicenters of locations of highest intensity of historically reported earthquakes, where possible, with tectonic structures any part of which is located within 200 miles of the site." This was interpreted to mean that epicenters that could not be reasonably correlated with structures must be assumed to have the potential to occur randomly within a tectonic province (Ref. 1-2).

The definition of tectonic province in Appendix A, with respect to the central and eastern U.S., has led to the designation of province based on classical Paleozoic (250-600 million years before the present (mybp)) geological provinces depicted on published maps such as King (1969 and 1974) (Ref. 1-3), Eardley (1962) (Ref. 1-4), and Rodgers (1970) (Ref. 1-5). These maps were not based on the distribution of seismicity. In fact, a later study, Hadley and Devine (1974) (Ref. 1-6), which was supported by the AEC and carried out by the USGS, showed very limited correlation between classical Paleozoic structure and earthquake activity. The type of assessment required by Appendix A does not adequately address the pattern, frequency, intensity of magnitude of seismicity and post-Paleozoic tectonics, particularly neotectonic (15mybp to Present) activity in a region (Ref. 1-2). These are important factors in determining tectonic provinces and earthquake ground motions for a potential nuclear power plant site. The review of several sites in which tectonic provinces and tectonic structures were major issues, such as Seabrook and Indian Point is addressed in this report (see Chapter 7).

1.2.3 Surface Faulting

The concept of capable fault was to provide a measure of the likelihood of surface rupture and/or localization of earthquakes. It consists of four fundamental elements: a single displacement within the past 35,000 years; multiple displacements within the past 500,000 years; correlation with macro-seismicity; and, to demonstrate non-capability, a structural association with structure that is geologically old. The concept is based on observations of active faults in areas of high tectonic activity such as western United States. However, in Appendix A it is meant to be applied throughout the united States including central and eastern U.S. This caused a great deal of difficulty in licensing (Ref. 1-2).

The definition of capable fault in Appendix A was created to provide some measure of surface faulting hazard. Although it was not based on the rigorous assessment of deformation activity, it was accepted as being conservative. However, the regulation does not allow for the incorporation of new and ongoing work in assessing fault hazards such as probability analyses, recurrence rates for earthquakes and fault movement, micro-earthquake data, and stress and strain measurements. The definition implies that an absolute age of last displacement is required such as by using radiometric data, etc. It has not always been possible to accomplish this and applicants and staff have had to rely on professional judgement and indirect methods such as rates of denudation, regional geological history, and geomorphology. Interpretation of data from these methods is always controversial. Additionally, it has often been difficult or impossible to determine whether or not there have been multiple displacements along a fault. Appendix A requires that a fault be considered capable if macro-seismicity, instrumentally determined with records of sufficient precision, demonstrates a direct relationship to the fault. The NRC staff regards macro-seismicity as being related to profound, deep seated tectonic activity and is considered to represent a level of seismicity that implies significant, sustained, and coherent tectonic activity representative of major deformational movement within the earth's crust (Ref. 1-2).

A fault must be considered capable according to Appendix A if it shows a structural relationship with a capable fault such that movement on one could cause movement on the other. The NRC staff interpreted this to mean either a direct physical connection, or a genetic relationship, such as being properly oriented in the same stress field as a capable fault. On the other hand, Appendix A provides that, notwithstanding, a fault can be demonstrated to be non-capable if structurally associated with other structural features that are geologically old as in the central and eastern U.S. Also, a fault can be considered non-capable if it can be shown to be related to a tectonic regime that no longer exists.

Deformation at the earth's surface can be deep seated or superficial. Deep seated deformation is considered by the NRC staff to be tectonic, and if active, capable of generating damaging earthquakes. Superficial deformation, such as those related to glaciation or deglaciation and growth faults, are unlikely to generate damaging earthquakes and are therefore considered to be non-tectonic. In the early application of Appendix A, the AEC/NRC treated growth faulting such as occurs in southeastern Texas, as tectonic faults. Difficulties in addressing these issues is illustrated by the discussions in this report regarding the Nine Mile Point, Until 2 and the Allens Creek nuclear power plant sites, respectively.

Appendix A briefly addresses the issue of designing for surface faulting near or beneath a site. This requires determining precise locations and expected amounts of displacement, which can rarely be accomplished with a high level of certainty with the current understanding of fault behavior. For this reason the time, and expense of the extensive investigations and analyses required by Appendix A to validate a site would likely cause abandonment of the site, in most cases (Ref. 1-2). However, in regard to the General Electric Rest Reactor (GETR) in central California, which is described in Chapter 5, a design basis fault displacement at the reactor site was proposed by the licensee after extensive investigations and analyses. The site was abandoned for other reasons before thorough assessment by all parties could be completed.

1.2.4 Vibratory Ground Motion

The methodology for specifying vibratory ground motion from earthquakes, in concert with the requirements of Appendix A, involves selecting an earthquake of a given size (magnitude or epicentral intensity). This activity is followed by assuming that the event occurs at a defined location relative to the site, determining an acceleration level at the site representative of this earthquake, and then specifying design ground motion corresponding to the acceleration level representative of the postulated earthquake characteristics. Designation of two earthquakes is required, SSE and OBE. The SSE is an earthquake based on an evaluation of the maximum earthquake potential of a region. The OBE is an earthquake that could reasonably be expected to affect the plant during its operating lifetime. Appendix A requires that the earthquake size be specified in terms of magnitude on the Richter scale or epicentral intensity as described on the Modified Mercalli scale. Difficulties occurred because other magnitude scales had been used in different parts of the U.S. and there are often no suitable methods available to convert to the Richter scale, and earthquakes on an intensity scale are very subjective (Ref. 1-2).

When the design earthquakes have been determined, the next step according to Appendix A, is to develop a level of ground motion from series of earthquakes postulated to occur according to various sets of conditions. In establishing the SSE it was then necessary to select earthquakes of equal size to the largest historical events associated with tectonic provinces or tectonic structures and assume that they could occur at the closest approach on these structures or within these provinces. In practice the NRC staff has interpreted Appendix A to mean that the maximum intensity earthquake in a province in which the site is located should be postulated to occur at the site, but should not be considered to be in the near field. This assumption was based on the low probability that the site would be in the near field of a random, earthquake of a postulated maximum size. It was also dependent on an extensive site vicinity investigation to identify possible earthquake sources.

Ground motion in Appendix A is represented by an acceleration level in combination with response spectra defined in Regulatory Guide 1.60 (Ref. 1-7). Appendix A requires that there be a minimum SSE acceleration of 0.1g. The ACRS has often expressed the possible need to raise this minimum level in order to provide additional conservatism and to simplify case reviews. Raising the minimum value would alleviate the necessity for future backfitting, in view of the fact that there is an ongoing trend to raise SSE acceleration levels (Ref. 1-2). Appendix A has been interpreted as requiring that response spectra acceleration be applied at foundation levels. This may mean applying acceleration at some elevation below ground surface or at some geologic stratum on which the plant is founded. A major problem in applying the response spectra below ground surface was that nearly all available recorded ground motion data were made at or near ground surface.

The OBE is defined as that earthquake that can reasonably be expected to affect the site during the operating life of the nuclear power plant, or about 40 years. This corresponds to an earthquake within a range of every 300 to 500 years. This conflicts with another requirement that the OBE be at least one half the SSE, in that the earthquake becomes one in the range of 300 to 1000 years. Appendix A also requires shutdown and inspection if ground motion is recorded that is greater than the OBE. It is not clear whether this exceedence refers to the free field OBE, the design spectra at a single frequency or several frequencies. Additionally, there is no guidance for inspection following OBE exceedence. Based on ever improving probabilistic seismic hazard analyses (PSHA's), OBE acceleration values could be at any level, including below the specified minimum value of 0.5g (one half of an SSE of 1.0g). At such low levels there is a good chance that the OBE could experience several exceedences, resulting in numerous, probably unnecessary and costly shutdowns (Ref. 1-2). The OBE was exceeded by ground motion in the high frequency end of the spectrum generated by a small magnitude event at the Summer site (see Chapter 8).

Finally, because Appendix A is a federal regulation, there is no easy or timely way to incorporate into the document new geological and seismological information and methodologies that are constantly being acquired in these rapidly developing sciences. The procedures required in Appendix A are deterministic but there is no definitive specification of degree of conservatism Neither does the regulation include a consideration of probabilistic seismic hazard analyses (Ref. 1-2).

1.3 Selected Generic Issues

There were several new findings and occurrences during the period covered by this paper that became major licensing issues because they had the potential to impact the geologic and seismic design bases of nuclear power plant sites located within the regions in which they occurred. These included: the Pacoima Dam recording of the 1971 San Fernando Valley earthquake that showed a ground motion with a peak horizontal acceleration greater than 1.0g, which contradicted the previous widely held belief that 0.5g was the maximum peak acceleration value possible from an earthquake; the geological evidence for the occurrence during the Holocene of large to great prehistoric subduction zone earthquakes in the Pacific Northwest; and the discovery of paleoliquefaction evidence of the Holocene occurrence of earthquakes up to 7.5 magnitude in the Wabash Valley of Indiana and Illinois.

An occurrence that could have developed into a major issue if it had happened during the licensing of one or more of the plant sites in New England, was the 1989 Ungava, Quebec, magnitude 6 earthquake, which was accompanied by the first documented coseismic, historic surface faulting in eastern North America.

From the generic issues that arose during this period, three have been selected for discussion in Chapter 2; the Charleston Earthquake source zone, the Meers Fault, and the 1983 New Brunswick Earthquake. These were chosen because they had the potential of affecting a large number of nuclear power plant sites, and challenged technical positions that were prevalent at the time. These three, as well as other issues, are also discussed in subsequent chapters as they relate to specific sites.

1.4 Site Cases that Illustrate Appendix A Licensing Difficulties

Chapters 3 through 8 present 32 case histories that illustrate some of the significant Appendix A-related issues that had an impact on the licensing process. There are many sites that became landmark cases as far as being characterized by specific Appendix A-related problems, among these are: the General Electric Test Reactor (GETR), where the first attempt was made to establish a design basis for surface faulting; North Anna, which was the first site in the eastern U.S. where there was litigation regarding the Appendix A criterion on surface faulting, or capable faulting; and San Onofre, the seismic design basis of which was affected by the greater-than 1.0g generated by the Feb. 9 1971, San Fernando Earthquake.

Many other examples are not addressed in this report because the author was not directly involved in them. In all of the site evaluations described herein, the author was involved at some level that ranged from early site reviews only, construction permit (CP) reviews of sites such as Washington Nuclear Power, Unit 2 (WNP-2) and Nine Mile Point Nuclear Station, Unit 2, but not in the operating license (OL) reviews, limited involvement in some sites such as Hatch Nuclear Power Plant, Unit 2 and Perry Nuclear Power Plant, Units 1 and 2, with respect to a specific problem, in Operating Licensing (OL) and post OL reviews but not in the CP reviews of sites like Diablo Canyon Nuclear Power (DCNPP), to involvement in site reviews throughout the entire licensing processes.

Table 1 presents the nuclear power plant sites in the United States and the principle problems faced by the applicants and the AEC/NRC staff during the licensing activities. The table includes both those that eventually became operating plants and those sites that were evaluated but were later deferred or abandoned for one reason or another.

1.4.1 Sites in the Pacific Northwest

I selected the sites at Hanford, Washington for discussion because they were reviewed as Appendix A was in the latter stages of being developed, or soon after its publication. Appendix A terms such as "tectonic structure" became important during these reviews. Earthquake designs that were based on tectonic structure were imposed by the AEC staff as conservative measures, even though the structures (folds) could not be demonstrated to be faulted, or to be either active or inactive. Assessment of the N-Reactor was the first case where the seismic capability of upstream dams had to be taken into account. Paleoseismicity, although that term had not been applied to the Appendix A criterion "evidence of prehistoric earthquake activity," was a big issue at Hanford in regard to the clastic dikes and certain surface deformation features. The concept of "tectonic province" was also employed for the Hanford sites even though Hanford is in the western United States. Licensing of the various sites at Hanford spanned more than two decades and provides a good look at the evolution of the regulatory process under Appendix A, from the early methods of assessment of tectonic province, tectonic structure and maximum historic earthquake to the more sophisticated methods such as fault length, area, width, slip rate versus moment magnitude, characteristic earthquake, etc.

The Pebble Springs and Trojan sites illustrate, in addition to many of the issues mentioned in the preceding paragraph, the way in which the volcanic hazard was addressed. Initially, the main issue with respect to the Washington Nuclear Power (WNP)-3 site was whether the subduction zone earthquake needed to be considered. Later, after paleoseismic studies demonstrated that large prehistoric subduction zone earthquakes had occurred, the main effort in the seismic hazard evaluation was focussed on gathering information that could be used to estimate the maximum magnitude associated with the subduction zone. The assessment of this event for the WNP-3 site was among the first, along with a similar analysis for Diablo Canyon, to employ relatively sophisticated probabilistic seismic hazard analyses (PSHA) performed for western United States sites.

1.4.2 Sites in California

The California sites illustrate the application of the "capable fault" and "zone requiring detailed faulting investigations" concepts of Appendix A. The Diablo Canyon case reviews illustrate very well the evolution of the investigation of faults from simply mapping surface geological features and outcrops, core borings, and trenching at the site, to additional investigations consisting of very detailed mapping of analogous faults at distances, and extensive onshore and offshore geophysical surveying, both shallow high resolution and deep penetrating seismic reflection profiling. Appendix A is very prescriptive in the studies to be performed to evaluate the seismic hazard for a nuclear power plant site. The regulation does not provide for probabilistic hazard estimation. However, in the late 1970s and early 1980s as the PSHA methodology was developed, nuclear power plant licensees and applicants began to use them. The first state of the art PSHA was employed for the Sequoyah site in eastern Tennessee, however that site is not discussed in this report. The first rigorous, state of the art PSHA, used for a site in the western United States was used at the Diablo Canyon site. In Regulatory Guide 1.165 (Ref. 1-8), the NRC recommends that other PSHAs for western United States sites be patterned after the Diablo Canyon PSHA. The California sites also illustrate the impact that new occurrences such as an earthquake or a new hypothesis can have on the perceived seismic hazard of a nuclear power plant sited in the western United States.

1.4.3 The Attempt to Apply Appendix A Criteria to Facilities that Were Not Commercial Power Reactors

The attempt to impose regulatory procedures to the Power Burst Facility (PBF) test reactor at the Idaho reservation (NRTS/INEL) shows the difficulties in applying the elements of Appendix A to a nuclear facility that is not a commercial power reactor. These kinds of problems occurred over an over again when the Appendix A criteria was applied in assessing uranium mill tailings dams, nuclear waste disposal or storage facilities, university test reactors, small military reactors, and other facilities of relatively low risk compared to the risk associated with large nuclear power reactors.

A discussion of the regulatory staff evaluation, using Appendix A, of a uranium mill tailings dam at the Pathfinder Mines Corporation's Lucky Mc uranium mine tailings retention system in Wyoming is also included.

1.4.4 Sites in the Central United States

The discussions of sites in the central United States illustrate the many issues that arose concerning the licensing of nuclear power plant sites in this large region. The LaSalle CP review addressed early-on, the northern extent of the New Madrid Seismic Zone (NMSZ). By requiring that the NMSZ be assumed to extend as far north as Vincennes, Indiana, based on the uncertainty of data available at that time, this plant and others to follow, were adequately designed so that the discovery fifteen years later of paleoseismic evidence for a magnitude 7+ prehistoric earthquake did not have an adverse impact on the adequacy of seismic designs in the midwest.

The licensing of Callaway addressed the impact of the NMSZ on sites at moderate distances from the zone. This review, as well as the one for Byron later on, also addressed the potential for subsidence or collapse due to solution cavities beneath the site. The evaluation of the Allens Creek site, which was withdrawn from consideration, resolved many of the issues associated with regional subsidence and growth faulting that were applied later to the South Texas Nuclear Power Plant site. The tectonic "capable fault" versus non-tectonic "capable fault" issue came to a head during this review in the consideration of growth faults, and emphasized one of the major shortcomings of Appendix A. The Byron review showed a unique method for demonstrating that a fault was not capable. The Beaver Valley review illustrated some of the problems that occurred regarding tectonic province boundaries. The Perry site is an example of the potential impact of events after the licensing review had been completed, namely an earthquake recording with ground motion at the plant, equal to or greater than the Safe Shutdown Earthquake ground motion (SSE).

1.4.5 Sites in the Eastern United States

The eastern United States is characterized by low seismicity, a short historical record, a low strain rate, and limited knowledge about seismic sources. For these reasons there is a wide range of interpretations and hypotheses about the causes of earthquakes in this region. Many of these were introduced or rejected in the licensing processes of nuclear power plant sites in the eastern U.S. Indian Point and Seabrook probably best exemplify the difficulties encountered in dealing with the uncertainties about seismic sources and ground motion. Specific issues were concerned with tectonic provinces, tectonic structures, capable faults, estimation of the maximum earthquake, where to assume that it should occur, and derivation of the SSE ground motion.

One of the main benefits to come out of these difficulties was the strong recognition of a need to develop a reliable probabilistic methodology to incorporate uncertainties about seismic sources and ground motion into the analysis along with deterministic parameters. However, it was not until the United States Geological Survey (USGS) expressed its position on the non-uniqueness of the source of the 1886 Charleston Earthquake, which is described in greater detail in the next chapter, that the development of probabilistic seismic hazard analysis (PSHA) for siting began in earnest.

The Nine Mile Point and Allen Creek sites are included in this paper because the most recent fault displacements (late Quaternary) were caused by non-tectonic phenomena. Because no distinction was made between tectonic and non-tectonic faults in Appendix A, the displacements were initially treated as capable faults. Considerable effort and cost was expended by the applicant and the NRC staff to first determine whether the faults were tectonic or non-tectonic, and then to demonstrate that these were not capable faults. Several sites such as Hope Creek, Limerick, and Summer were included to show the way in which the applicants and the staff addressed the Charleston and New Brunswick earthquake issues with respect to specific sites.

The Douglas Point site evaluation, although the site was abandoned before a construction permit was issued, illustrates how investigations of two nearby, regional-scale faults were conducted. The discussions of Summer, Limerick, and Clinch River reviews include examples of the assessments of the potential effects of human activities such as reservoir induced seismicity, quarrying, and chemical injection disposal, respectively.

1.5 Revision of the Seismic and Geologic Siting Regulation

Licensing using Appendix A has been successful in many respects and the criteria therein have served the licensing process well. However, because of advances in the sciences of geology, seismology, and geophysics, the coming of age of PSHA, and the problems described in this report, the NRC revised the nuclear power plant siting regulation. Appendix A still applies to currently operating plants, but the new regulation is to be used in siting all new plant site applications after January, 1997. In the new regulation the siting aspects are incorporated in Section 100.23, 10 CFR Part 100 (Ref. 1-9) and the engineering aspects appear in Appendix S to 10 CFR Part 50 (Ref. 1-10). The siting regulation is supported by Regulatory Guide 1.165, "Identification and Characterization of Seismic Sources and

Determination Safe Shutdown Earthquake Ground Motion" (Ref. 1-8). Sections 2.5.1, 2.5.2, and 2.5.3 of the Standard Review Plan (SRP) have been revised to be consistent with the regulation and the regulatory guide.

It is not within the scope of this report to describe the new regulatory documents or to list the reasons for revising Appendix A. Many of the reasons that made the changes necessary will be obvious while reading the following discussions of each site. The flaws in Appendix A are clearly described in SECY-300 (Ref. 1-2). One of the main changes is the requirement to specifically address uncertainties, either by a PSHA or by sensitivity studies. R.G. 1.165 describes PSHA methods that are acceptable to the regulatory staff.

TABLE 1-1

APPENDIX A AND RELATED ISSUES RELATIVE TO NUCLEAR POWER PLANT SITES

EXPLANATION OF THE SYMBOLS USED ON THE TABLE THAT REPRESENT THE ISSUES

TP - Tectonic Province Source	SI - Slope Instability
CE - Deterministic Controlling Earthquake	IS - Induced Seismicity
CF - Capable Fault	SC - Subsidence or Collapse
VH - Volcanic Hazard	S - Solutioning
FI - Foundation Instability	L - Liquefaction
T - Tsunami	TS - Tectonic Structure Source
HS - High Residual Stress	GM - Ground Motion - SSE & OBE

WESTERN UNITED STATES

PACIFIC NORTHWEST

PLANT NAME	ISSUES (IN ORDER OF IMPORTANCE)
Handford Sites - FFTF, WNP-2, 1, & 4, Skagit Hanford	CE, CF, TP, FI, VH
Pebble Springs	CF, VH, SI, TP
Washington Nuclear Project 3 & 5	CE, CF, VH, TP, GM
Trojan	CE, VH, TP, CF, SI
Skagit	CE, CF, TP, VH, TS
Power Burst Facility (PBF)	TP, CF, CE, TS

CALIFORNIA

Mendocino	CE, GM, CF, SI, T
Humboldt Bay	CE, GM, CF, TS, T
Stanislaus	CE
Diablo Canyon	CE, GM, CF, SI, T
San Joaquin	CE, GM, CF, SC, IS
Rancho Seco	TS, CE, CF
Bodega Bay	CF, CE
Malibu	CF, CE
Bolsa Island	CE
San Onofre	CE, GM, CF, T

TABLE 1-1 (cont.)

EXPLANATION OF THE SYMBOLS USED ON THE TABLE THAT REPRESENT THE ISSUES

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T - Tsunami	TS - Tectonic Structure Source
HS - High Residual Stress	GM - Ground Motion - SSE & OBE

OTHER

Palo Verde	CE, TP, CF, TS

CENTRAL AND EASTERN UNITED STATES

CENTRAL U.S.

Fort St. Vrain	CE, TS
Fort Calhoun	FI, L
Cooper	FI, L
Duane Arnold	CE, GM
Monticello	CE, GM
Prairie Island	CE, GM, FI
Kewaunee	CE, GM
Quad Cities	CE, GM
Zion	CE, GM, FI
Carroll County	CE, GM
Callaway	CE, S, TP, TS
Lacrosse	CE, FI, L
Cook	CE, GM
Bailey	CE, GM
Grand Gulf	TS, TP, CE, GM
LaSalle	CE, GM, TP, TS, SI
Byron	CE, GM, CF, S, SI, L, TP
Braidwood	CE, GM, TP
Clinton	CE, GM, TP, FI
Dresden	CE, SC, SI, CF
Greenwood	CE, FI, TP, TS
Davis-Besse	CE, GM

EXPLANATION OF THE SYMBOLS USED ON THE TABLE THAT REPRESENT THE ISSUES

TP - Tectonic Province Source	SI - Slope Instability
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HS - High Residual Stress	GM - Ground Motion - SSE & OBE

Zimmer	CE, TP, TS, FI
Palisades	FI, CE, TS, L
Big Rock Point	CE, S, TS
Marble Hill	CE, S, TS
Perry	CE, CF, TP, TS, GM, IS
Midland	CE, GM, TP, TS, SC, L
Fermi	CE, TP, TS, S
Haven	CE, TP, TS
Black Fox	CE, TP, TS, CF
Wolf Creek	CE, GM, TP, TS, CF
Commanche Peak	TP, CE, TS, CF
Allens Creek	SC, CF, FI, CE, TP, TS, SI, IS
South Texas	SC, CF, FI, SI, TS, IS
Arkansas	CE, SI, CF
River Bend	CE, SC, CF, FI, SI
Waterford	CE, SC, CF, FI, SI
Yellow Creek	CE, TP, TS
SOUTHEASTERN U.S.	
Farley	CE, TP, TS
Browns Ferry	CE, TP
Hatch	CE, TP, SI, L, FI
St. Lucie	CE, CF, S
Crystal River	S
Turkey Point	S, CE, T
Vogtle	CE, GM, CF, S, TS
Savannah River	CE, CF, TS
Oconee	CE, IS, TS, TP

TABLE 1-1 (cont.)

EXPLANATION OF THE SYMBOLS USED ON THE TABLE THAT REPRESENT THE ISSUES

TP - Tectonic Province Source	SI - Slope Instability
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CF - Capable Fault	SC - Subsidence or Collapse
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T - Tsunami	TS - Tectonic Structure Source
HS - High Residual Stress	GM - Ground Motion - SSE & OBE

Summer	CE, GM, CF, IS, SI
Watts Bar	CE, CF, S, FI, IS
Phipps Bend	CF, CE, S
Clinch RIver	CE, GM, TP, TS, CF, IS
Bellefonte	CE, TP, TS, S, CF, FI
Hartsville	CE, GM, TP, S, TS
Sequoyah	CE, GM, CF, S
Perkins	CE, TS, CF
Cherokee	CE, TS, CF
McGuire	CE, TS, CF, SI, IS
Catawba	CE, CF, TS, SI, IS
Shearon Harris	CE, TS, CF
Robinson	CE, TP, FI
North Anna	CE, CF, TS, FI, L, IS
Surry	CE, TP, TS, FI, CF

NORTHEAST

Susquehanna	TP, CE, CF
Beaver Valley	TS, SI, CE, FI, GM
Fulton	TS, CF, CE
Douglas Point	TP, TS, CF, CE, SI, L
Peach Bottom	CE, SI
Green County	CE, TP, TS
Atlantic Generating Station	CE, SI, FI, L, TS, T
Shoreham	CE, GM, TS, FI
Jamesport	CE, GM, TS, FI
Limerick	TS, CE, GM, CF
Forked River	CE, GM
Three Mile Island	CE, CF, TS

TABLE 1-1 (cont.)

EXPLANATION OF THE SYMBOLS YSED ON THE TABLE THAT REPRESENT THE ISSUES

TP - Tectonic Province Source	SI - Slope Instability
CE - Deterministic Controlling Earthquake	IS - Induced Seismicity
CF - Capaable Fault	SC - Subsidence or Collapse
CH - Volcanic Hazard	S - Solutioning
FI - Foundation Instability	L - Liquefaction
T - Tsunami	TS - Tectonic Structure Source
HS - High Residual Stress	GM - Ground Motion - SSE & OBE

Nine Mile Point	CE, TP, TS, CF, HS
Fitzpatrick	CE, TS, CF
Ginna	CE, TS, CF, GM
Hope Creek	FI, SI, L, TS, CE, GM
Salem	FI, SI, L, CE
Oyster Creek	FI, L, CE
Haddam Neck	CE, TS, CF
Pilgrim	TP, CE, GM, TS, FI, L
Seabrook	TP, CE, GM, TS, CF
Maine Yankee	CE, TP, TS, CF, GM
Millstone	CE, TP, TS, CF, GM
Yankee Rowe	CE, TP, SI, GM
Vermont Yankee	CE, TP
Indian Point	TP, CE, GM, TS, CF, S
Montague	TP, TS, CE, GM, CF
New England	TP, TS, CE, GM, CF
Calvert Cliffs	CE, TS, SI

CHAPTER 2 - GENERIC GEOLOGICAL AND SEISMOLOGICAL ISSUES

Many geologic and seismic issues with far reaching impact on the seismic hazard for nuclear power plant sites have arisen during the course of licensing over the last several decades. For example, the offshore zone of deformation, and the Pacoima Dam seismogram recording with a peak ground acceleration of 1.29g during the 1971 San Fernando Earthquake with respect to the San Onofre Nuclear Power Plant site; the discovery in 1969 of what eventually came to be called the San Gregorio-Hosgri Fault Zone just offshore from the Diablo Canyon Nuclear Power Plant site; and the discovery of ground surface displacement adjacent to the General Electric Test Reactor. Many generic seismic and geologic issues will be addressed in the case histories presented in the following chapters. In this chapter only three of the significant generic issues and the way in which the staff handled them in the licensing arena are discussed: the Charleston Earthquake, the Meers Fault, and the New Brunswick Earthquake.

2.1 CHARLESTON EARTHQUAKE

During the past several decades of licensing activities for nuclear power plant sites located within the Atlantic Seaboard (Piedmont and Coastal Plain) the controlling seismic event for estimating the SSE ground motion had been maximum Modified Mercalli Intensity (MMI) VII ground motion at the site from earthquakes with estimated magnitudes of 5.0 to 5.3. This size earthquake is based on the largest historic earthquakes that have been documented in the Piedmont, such as the 1913 Union County, SC Earthquake; and in the Coastal Plain, such as the 1872 Wilmington, DE Earthquake, which could not be associated with a causative tectonic structure. The SSE for these plants was also based on the sites being at sufficient distances from the meizoseismal area of the 1886 Charleston Earthquake that the sites would not experience ground motion greater than would normally be associated with MMI VII (Figure 2-1). However, a major issue that had to be addressed regarding each one of these sites was whether to assume that an earthquake similar in magnitude to the 1886 magnitude 7+ (MMI X) Charleston Earthquake could occur nearer to the site than the closest approach of the meizoseismal area of that earthquake.

Based on advice from the USGS and NOAA (formerly the USC & GS), the AEC/NRC adopted and retained the position that future occurrences of earthquakes of this size should be assumed to happen in the same area as the 1886 event. The bases for that position, as presented in the Summer Nuclear Power Plant Construction Permit Safety Evaluation Report (SER), include: the frequency of occurrence of historical earthquakes in the Charleston area is higher per unit area than elsewhere in the eastern United States; the event distribution within the high frequency unit shows no evidence of directional trend or predominant pattern which would suggest lateral migration of activity; the microseismic flux in the Charleston area is higher than that measured elsewhere in the eastern U.S.; and seismic refraction and aeromagnetic data suggest atypical basement structures in the Charleston area.

Recognizing the lack of definitive information regarding the structural geology in the Charleston region, and in accordance with a recommendation by the ACRS, the AEC established an inter-agency agreement with the USGS in 1973 to deploy the South Carolina seismographic network and to perform an extensive geological, seismological, and geophysical investigation in the Charleston region. Despite the comprehensive nature and detail of these investigations and the expenditure of approximately $1,000,000 per year for eight years for the USGS investigations, the source of the earthquakes was not identified. However, a vast amount of data and knowledge about the geology and tectonics of the Atlantic Coastal Plain in the Charleston, SC region were obtained.

The investigations identified tectonic features in the subsurface of the coastal plain and continental slope of South Carolina and Georgia that are also found at other locations in the Piedmont and Coastal Plain. Thus the USGS saw the necessity to modify its previous conclusion about the uniqueness of the Charleston region, to say that the occurrence of an earthquake similar to the 1886 Earthquake should be considered possible, though with a low probability, elsewhere on the Atlantic Seaboard.

As a result of the new information, numerous (approximately eleven with credibility) hypotheses about the causes of the seismicity and structural geology in the Charleston area and the surrounding region were formulated. These hypotheses

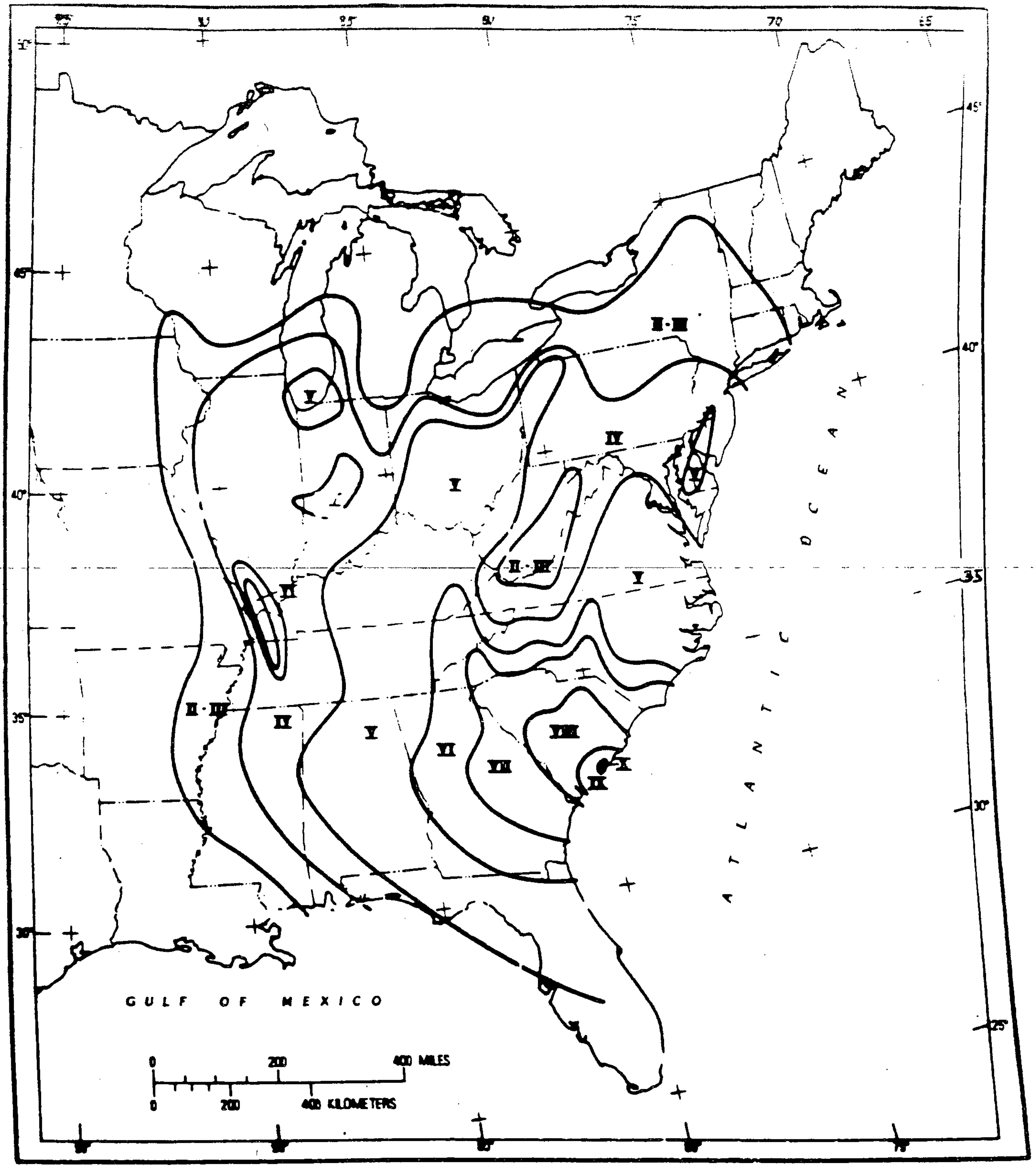


Figure 2-1. Isoseismal contours for the 1886 Charleston Earthquake. The contour lines connect sites having the same value of Modified Mercalli intensity (MMI), a numerical index of the effects of an earthquake on man, the earth's surface, and on structures (modified from Ref. 2-3).

can be grouped under one of three general hypotheses about the sources of seismicity: the source is a major decollement that underlies the Valley and Ridge, New England-Piedmont, and Coastal Plain tectonic provinces at depths between 2.5 and 9 miles; the sources are the reactivation of Paleozoic or Mesozoic high angle reverse faults; or the source is related to stress differences around the fringes of mafic/ultramafic plutons.

The NRC, acknowledging the uncertainties, but also recognizing the very low probability of an 1886 Charleston-like earthquake occurring elsewhere in the Atlantic Seaboard, concluded that its previous position was still valid. The investigations demonstrated the tectonic complexity of the Charleston region; and that complexity indicated to the staff, that the region is atypical with respect to the rest of the eastern seaboard. However, because of the remaining uncertainties about the seismic sources in the South Carolina area, and also the entire Atlantic Seaboard, the NRC developed a two-part program to investigate and evaluate the earthquake potential in the eastern United States. The first part was to conduct a probabilistic seismic hazard analysis (PSHA) to address the uncertainties in seismic sources and ground motions.

The probabilistic program was carried out by the Lawrence Livermore National Laboratories (LLNL) under contract to the NRC. At the time the LLNL began to perform a PSHA, the NRC recommended that the nuclear power industry conduct a similar PSHA of its own. The PSHA for the nuclear industry was accomplished by the Electric Power Research Institute (EPRI). The two studies resulted in the LLNL and EPRI PSHAs (Refs. 2-1 and 2-2).

The second part, a long term deterministic seismic hazard program, was the continuation of the geological, seismological, and geophysical investigations to define the seismic sources and vibratory ground motions, and in so doing reduce the number of uncertainties. The deterministic program actually began in 1973 with the deployment of the South Carolina Seismographic Network, followed by geological, geophysical, and later, paleoseismic investigations.

The 1886 Earthquake induced widespread liquefaction of soils underlying the South Carolina Coastal Plain in the Charleston area. The liquefaction evidence is in the form of sand blows, sand boils, dikes, sills, and lateral spreads. The paleoseismic studies referred to above included investigations to identify and determine the ages of liquefaction features produced by prehistoric earthquakes. These features are referred to as paleoliquefaction features.

Investigations were started in the Coastal Plain surrounding the Charleston Earthquake meizoseismal area, and four prehistoric earthquakes approximately of the same magnitude as the 1886 earthquake have been documented in the Charleston area within the last 5,000 years, with evidence for an older event. Based on radicarbon evidence, the ages of these events were approximately 600, 1,250, 3,200, and 5,150 years ago (Ref. 2-4). Evidence for an earthquake about 1,800 years ago was identified near Georgetown, SC, but not in the meizoseismal area, suggesting the presence of a second source north of Charleston (Fig. 2-2).

The investigations were expanded throughout the Coastal Plain from the Florida state line in the south into southern New Jersey in the north. Except for South Carolina and the southeastern tip of North Carolina, no paleoliquefaction features that would indicate the occurrence of a large earthquake in the Holocene (within the last 10,000 years) were identified on the Coastal Plain from north of the Georgia state line to southeastern New Jersey (Figure 2-2). The investigations were conducted in liquefaction susceptible soils similar to those that liquefied during the Charleston Earthquake. This evidence supports the staff's position that any recurrence of an earthquake like the 1886 event would most likely occur in coastal South Carolina and not elsewhere along the Atlantic Coastal Plain (Ref. 2-4).

On May 14, 1991, based on the results of the LLNL/EPRI PSHAs and the paleoliquefaction studies, the NRC published its official position on the Charleston Earthquake, SECY-91-135 (Ref. 2-5). That position is that "large 1886 Charleston-size earthquakes, greater than or equal to magnitude 6.5, are not significant contributors to the seismic hazard for nuclear plant facilities along the eastern seaboard outside the Charleston region." The staff further concluded, based on paleoliquefaction investigations throughout the Atlantic Seaboard, that for seismic design purposes, the recurrence of an earthquake of similar magnitude to that of the 1886 Charleston Earthquake should be assumed to occur in the meizoseismal area of that event.

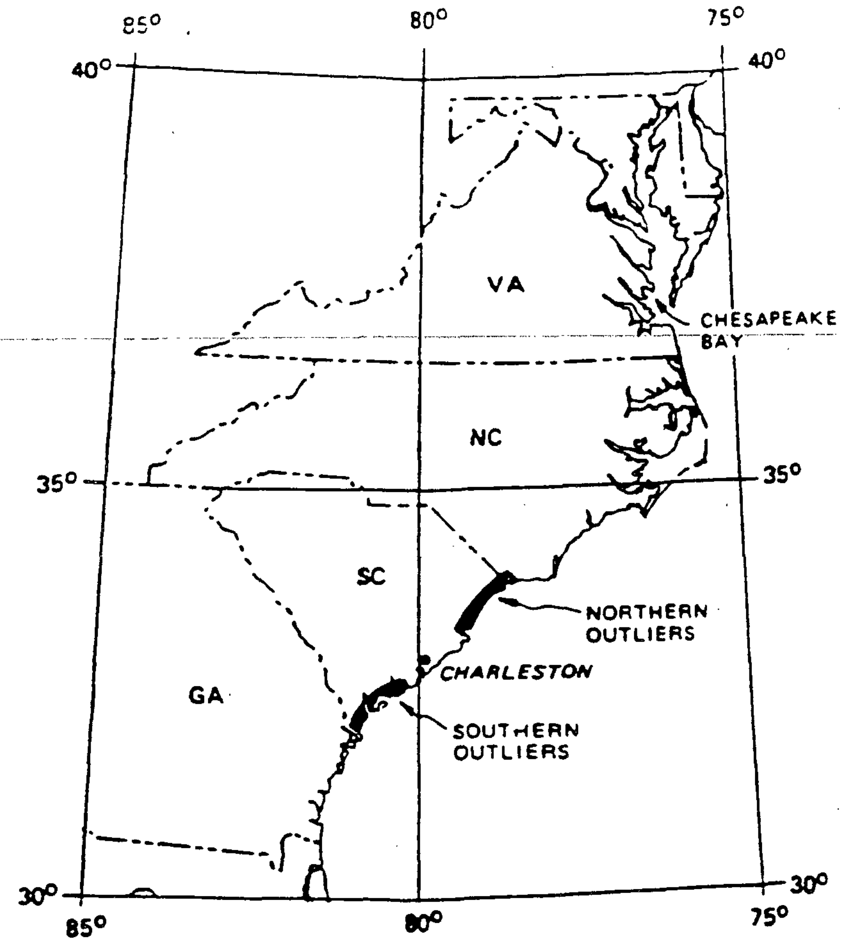


Figure 2-2. Extent of paleoliquefaction features. The coastal plain in the Charleston area contains numerous 1886 liquefaction features and paleoliquefaction features. The heavy dark lines along the coast in both directions from Charleston outlying areas where paleoliquefaction features have been mapped. Beyond these areas none were identified from the Georgia-Florida line to southeastern New Jersey (Ref. 2-4).

2.2 MEERS FAULT

The Meers Fault is part of the Frontal Wichita Fault System in southwestern Oklahoma on the northern flank of the Wichita Uplift and the southern flank of the Anadarko Basin. It is about 10 km northeast of the Wichita Mountains, and strikes N 60^0 W parallel to the general trend of the mountain front (Figure 2-3). The fault was recognized as early as 1951 (Ref. 2-6) as a large structural discontinuity between Cambrian igneous rocks in the Wichita Mountains and the lower Paleozoic sediments north of the fault in the Anadarko structural basin. The Meers Fault offsets the youngest Paleozoic rocks in the region which are about 240 million years old. It also disrupts Quaternary soils that overlie the rock, which are as young as several thousand years.

Substantial displacements occurred along the Meers Fault, which was initially named the Thomas Fault, in the middle Cambrian, the Pennsylvanian, and the Permian. Additionally, based on a scarp in Quaternary alluvium along the fault, Moody and Hill in 1956 (Ref. 2-7) suggested Quaternary activity; and Gilbert in 1983 (Ref. 2-8) suggested Quaternary activity reflected by a 26 km long scarp. Investigations were then conducted by many researchers. Two of these research programs were supported by the NRC: one conducted by Professor D.B. Slemmons of the University of Nevada Reno (Ref. 2-9), and the other by Geomatrix Consultants, Inc. (Ref. 2-10).

The NRC had become concerned about the affects that the late Holocene activity on the Meers Fault represented with respect to the assessment of seismic hazard in the central and eastern United States (CEUS). The significance was made more urgent by the fact that the fault, and this part of Oklahoma are relatively aseismic. In previous evaluations of the seismic hazard in the CEUS, it had been assumed that the temporal and spatial pattern of historic seismicity represented the probable pattern of future large magnitude earthquakes. However, the findings on the Meers Fault indicated that the historical record is too short to seismically identify a fault that may be a potential hazardous seismic source.

The Meers Fault is a capable fault, in terms of Appendix A, that is relatively aseismic, and it is interpreted to have the potential for generating a magnitude 6 or 7 earthquake. The Meers Fault is the first documented capable fault of tectonic origin in the eastern United States to significantly displace ground surface in relatively recent geologic time.

The fault trace is a well defined, N 60^0 W oriented, south-facing scarp that reaches 3 to 5 meters in height, and trends for 26 km (Figure 2-4). A more subdued surface expression may be present for an additional 11 km to the east-southeast, making its total length about 37 km. The sense of slip is controversial, but the NRC staff has accepted the interpretation that the Quaternary displacement is predominantly reverse down-to-the-south and left oblique (Refs. 2-10 and 2-11).

The research defined two displacements events on the Meers Fault within the last 3000 years that were associated with earthquakes estimated to have had magnitudes of about 7. The most recent was constrained by Geomatrix to have occurred between 1300 and 1400 years before present (BP). The earlier displacement was not well constrained with respect to time of occurrence but happened sometime between 2100 and 2900 BP.

The Criner Fault, which is located in the same fault system as the Meers Fault, but is located about 80 km to the east, was also investigated by Geomatrix because geological evidence suggested Quaternary displacement. However, based on these investigations, the most recent offset on the Criner Fault was found to have taken place before early Holocene or late Pleistocene.

2.2.1 The Impact of the Seismic Hazard Due to the Meers Fault on the Nearest Nuclear Power Plant Sites

The LLNL and EPRI PSHAs considered the earthquake potential of the Meers Fault and found that it had little impact on the seismic hazard in the CEUS. Prior to that finding the NRC had conducted a deterministic evaluation that consisted of assessing the Appendix A siting investigations that had been conducted for the four nearest nuclear power plant sites. This was to determine if a fault similar to the Meers fault could be undetected within a 50 mile radius of

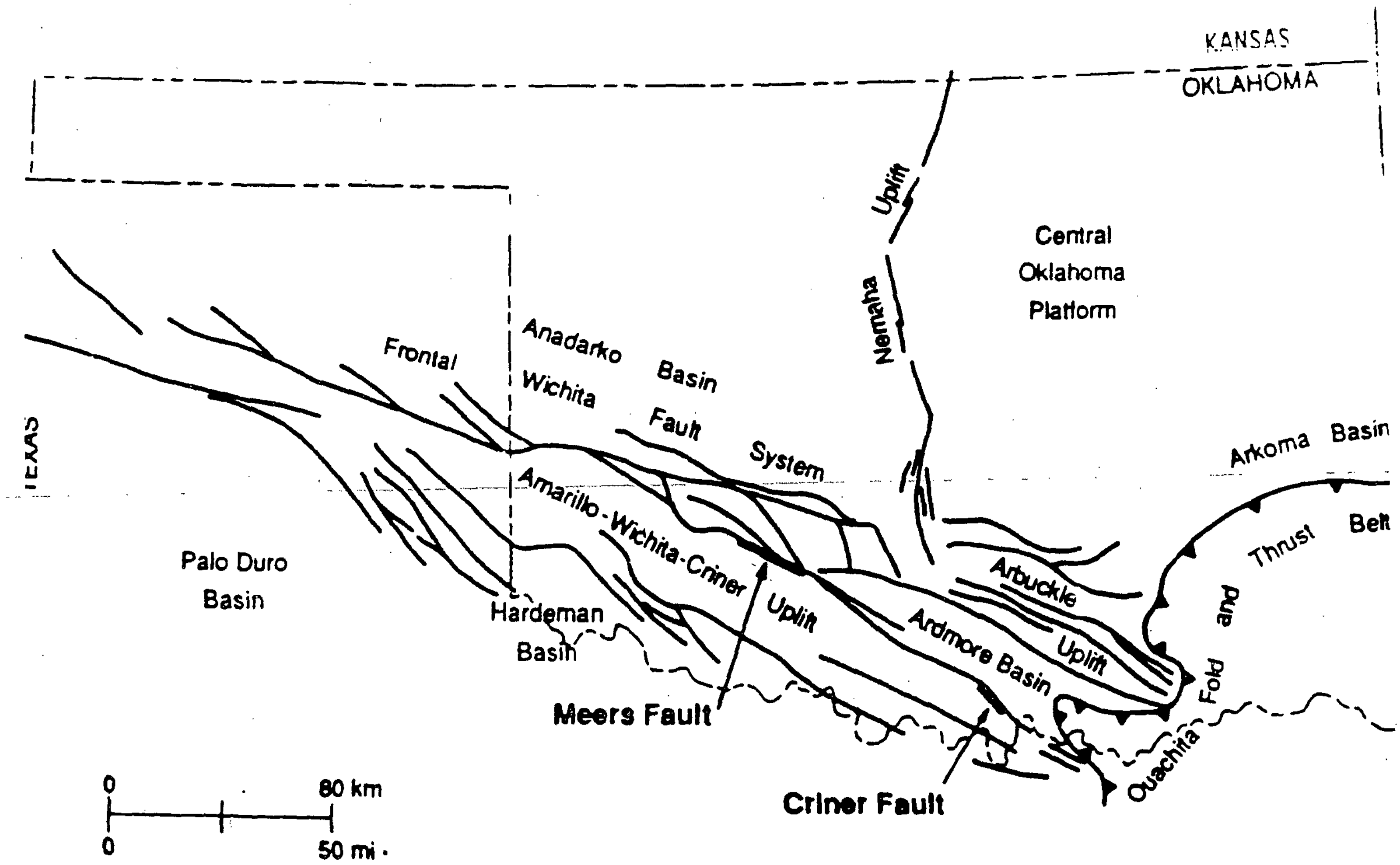


Figure 2-3. Map of the principal faults, basins, and uplifts in southern Oklahoma and the Texas Panhandle. The heavy lines show locations of the Meers and Criner fault segments having geomorphic expression that suggests Quaternary faulting (Ref. 2-10).

Figure 2-4. Topographic expression of the Meers Fault

each plant. The four plants are: the Comanche Peak Nuclear plant in northern Texas 180 miles from the Meers Fault; the proposed Black Fox Nuclear Plant site in northeastern Oklahoma 180 miles from the Meers Fault; the Wolf Creek Nuclear Power Plant site in east central Kansas 280 miles from the Meers Fault; and the Arkansas Nuclear One Power Plant site in northwestern Arkansas, about 280 miles from the Meers Fault (see Figure 6-1).

This evaluation of the Meers fault was done in 1985 using Appendix A criteria. Black Fox, Wolf Creek, and Comanche Peak licensing activities had been performed after publication of Appendix A, and Appendix A criteria were utilized by the applicants and the NRC. The licensing of the 2 units in Arkansas extended from the late 1960s to the early 1970s, generally before strict application of Appendix A, and certainly prior to its publication.

The Meers Fault is identifiable at depth using gravity, magnetic and seismic data. It is detectable by correlation of stratigraphic horizons from one boring to another, in high resolution shallow penetrating seismic reflection and refraction data, low and high angle altitude remote sensing imagery, geologic mapping and trenching. All of these techniques are widely used in satisfying the requirements of Appendix A, and wherever they are employed thoroughly and conscientiously, faults similar to the Meers Fault will be found and defined. Most of these methods are now used routinely to evaluate nuclear power plant sites and have been since the middle 1970s.

Th e Wolf Creek and Black Fox sites were investigated in the kind of detail described above within a radius of 50 miles and more. In addition, much data had been obtained during extensive hydrocarbon exploration over the past several decades in these areas and was used in the evaluation of these sites. Based on reexamination of these two sites, the NRC concluded that the presence of such an undetected structure within 50 miles is sufficiently remote that it can be disregarded.

The Comanche Peak site also lies within an area of extensive hydrocarbon exploration. It was thoroughly investigated by the applicant within a radius of 5 miles, with several traverses of detailed study extending several tens of miles outward in various directions. It is highly unlikely that a fault like the Meers Fault is present within 5 miles of the site. It is also unlikely that one exists within a 50 mile radius, however, this cannot be completely ruled out.

The Arkansas Nuclear One site, on the other hand, was investigated in the late 1960s and early 1970s, essentially before most of the techniques listed above began to be routinely used in nuclear power plant site validation. Furthermore, the Arkansas Nuclear One site is located in the transition zone between the extensively thrust faulted Ouachita Tectonic Belt to the south and the broad, open folded Arkoma Basin to the north, therefore, the geology is extremely complex. The strikes of both stratigraphic horizons and structure, and the prominent topographic features are oriented essentially east-west, making identification of a specific east-west striking fault very difficult.

There are relatively few outcrops in the area, and the region is subject to severe weathering and erosion. Apparently this area has not been as intensively explored for hydrocarbons as the three areas described above. The licensee undertook very detailed engineering type investigations in the site area, but only a cursory study of the regional geology was carried out. This consisted primarily of a literature review with little original regional investigations. Based on these factors it is possible that a Meers-like fault could be present within 50 miles of the Arkansas Nuclear One site, but not likely at the site itself.

Additional studies were not considered to be necessary for the Black Fox, Wolf Creek, or Comanche Peaks sites, but were considered to be prudent with respect to the Arkansas One site. However, after this deterministic study had been completed, the LLNL and EPRI PSHA studies were carried out, and the characteristics of the Meers Fault, including its earthquake generating capabilities and the likelihood that similar earthquakes could occur elsewhere in the central and eastern United States, were evaluated probabilistically. The analyses showed that the Meers-type faults are not a significant contributor to the seismic hazard of sites in the central and eastern United States.

2.3 NEW BRUNSWICK EARTHQUAKE

In January, 1982, an earthquake of magnitude 5 3/4 followed by a strong series of aftershocks occurred in central New Brunswick, Canada within the New England-Piedmont Tectonic Province (NEPTP). The NEPTP had been defined by the NRC staff for regulatory purposes based on Appendix A criteria. Since many sites in the Atlantic Seaboard region are located within or adjacent to the NEPTP, the issue was raised as to whether a magnitude 5 3/4 event should be the seismic design basis for these sites rather than the magnitude 5.3 to 5.5 events that had been used to characterize the seismic hazard in this tectonic province.

Prior to the occurrence of this earthquake it had not been necessary to consider subdividing the NEPTP, with the exception of the Boston-New Hampshire Seismic Zone during the Pilgrim, Seabrook, and several other licensing activities. However, to address the new issue, the staff conducted a literature study of the tectonic environments of the NEPTP and the New Brunswick earthquake regions and documented the major differences between them to support its conclusion that a New Brunswick-like earthquake should not be considered to have a potential to occur near the sites along the U.S. Atlantic Seaboard. Along with this analysis the staff considered the impact of a nearby magnitude 5.7 to 5.8 earthquake on the seismic design for sites along the U.S. Atlantic Seaboard that were then undergoing licensing reviews.

2.3.1 The differences Between the New Brunswick Epicentral Region and the NEPTP

(1) The two regions are characterized by different Paleozoic structural style and history. The New Brunswick region is characterized by strong Devonian Acadian tectonic deformation and very little late Paleozoic Alleghenian tectonic deformation. The Blue Ridge and Piedmont sections of the NEPTP were relatively undeformed by the Acadian Orogeny. However, they were strongly affected by the Late Paleozoic continental collision (Alleghenian Orogeny), during which large thrust sheets were transported westward over Precambrian crystalline (Grenvillian) basement rocks.

(2) The different Paleozoic tectonic histories of the northern and southern Appalachians have resulted in major differences in their respective crustal seismic velocity structures (Ref. 2-12). The northern Appalachian Region, within which the New Brunswick Earthquake occurred, is characterized by a crust with two well-defined layers. The upper layer appears to consist of rocks involved in the crustal shortening during the Taconic and Acadian Orogenies. The higher seismic velocities of the lower layers, indicates involvement of the oceanic crust. The southern region is relatively homogeneous indicating Grenvillian basement.

(3) The geology of the two regions is different. The New Brunswick epicenter area is within the North Pole Pluton, which is comprised of granite, granodiorite, and adamellite. These rock-types also are common in the NEPTP, but the NEPTP was greatly affected by continental rifting in the Mesozoic Era that resulted in large structural basins such as the Newark Triassic Basin. These basins, which comprise about 20% of the Piedmont are underlain by Mesozoic sedimentary rocks, such as sandstones, siltstones, and shales that have been intruded by diabase dikes and sills.

(4) The predominant structural grain of the two regions is different. In New Brunswick the structure is oriented predominantly northeast-southwest. There is also a major northeast-southwest structural orientation in the NEPTP and the Coastal Plain, but superimposed on that structure in both of these regions is a more recent northwest-southeast structural trend as shown by the axes of the Salisbury and Raritan Embayments, the New Jersey Uplift, the Cape Fear Arch, and the Southeast Georgia Embayment.

(5) Aftershock patterns following the New Brunswick main shock indicate a source consisting of conjugate fault systems that dip toward each other (Figure 2-5). There is no known comparable structure in the NEPTP. However, it should be pointed out that these structures are at depth and we only know about them because of the aftershocks.

On the basis of the above geological information derrived from the deterministic analysis, which suggests that there may be strong differences in structural style, tectonic history, stratigraphy, and local structure, the NRC staff concluded that the New Brunswick earthquake occurred in a region that may be characterized by different tectonics than those of the NEPTP.

Since the analysis described above of the New Brunswick Earthquake was performed, and after all of the sites located on the NEPTP had been licensed, two other earthquakes of equal or larger magnitudes have occurred, the 1988 Saguenay, Quebec and the 1989 Ungava, Quebec earthquakes. The latter is the first documented historic earthquake that was accompanied by surface faulting in eastern North America. Additionally, a study was conducted by the Electric Power Research Institute (EPRI) of earthquakes and their sources in stable continental regions world-wide that are analogous to eastern North America (Ref. 2-14), specifically the Atlantic Coastal Plain and the NEPTP. This study found that these regions have experienced magnitude 6 or greater earthquakes. Therefore, the staff concluded that magnitude 6 earthquakes could not be ruled out in the New England-Piedmont Tectonic Province, but that they had a very low probability.

The probabilistic programs generated as part of the program to address the Charleston Earthquake issue include consideration of the occurrence of magnitudes greater than the New Brunswick earthquake in the eastern U.S. Both the LLNL and EPRI PSHA's demonstrated that, although a large earthquake may be possible within the NEPTP and Atlantic Coastal Plain, it has a very low impact on the seismic hazard of sites located in these regions. The PSHAs also showed that the earthquakes that dominate the hazard in these regions are the events local to the plant sites with magnitudes of 5.0 to 5.5. These are the size earthquakes for which the plants at these sites are designed.

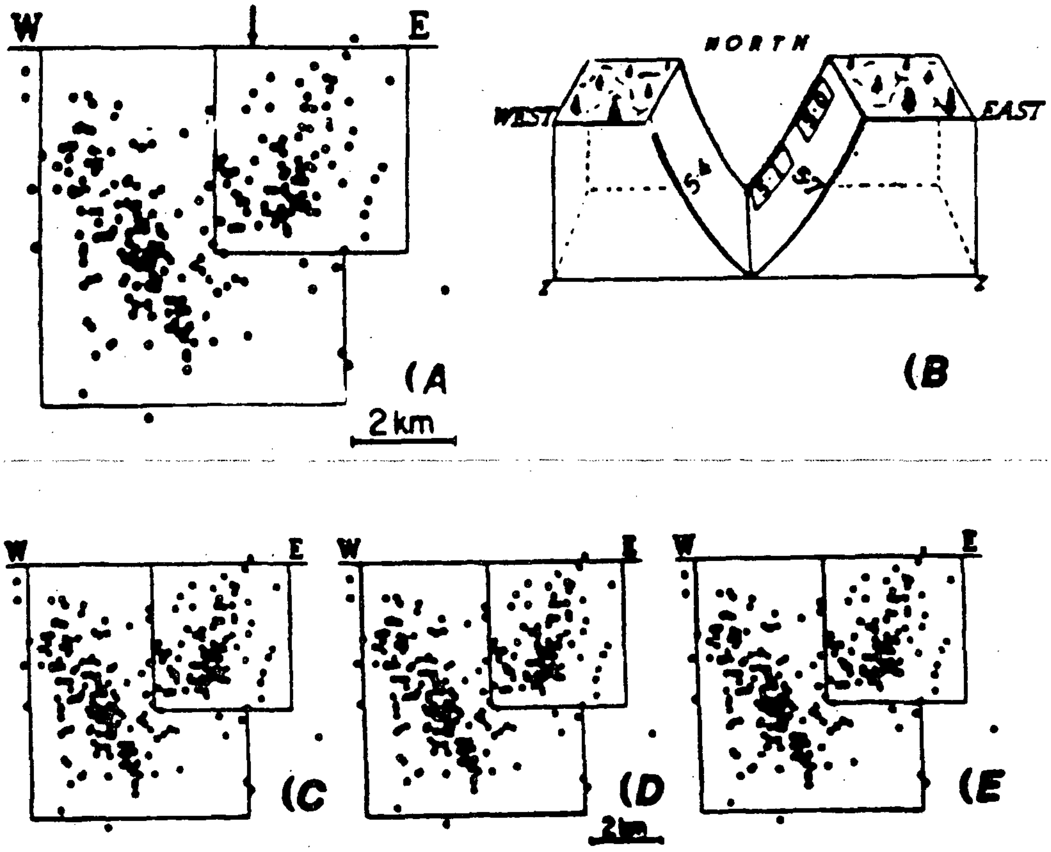


Figure 2-5. (A) East-west cross section of January and April New Brunswick aftershock hypocenters. (B) Possible Miramichi rupture planes. View is from the south looking north, and number on each plane identifies the magnitude of the earthquakes. (C, D, and E) Three alternative sets of speculative rupture planes superimposed on aftershock distribution from (A). The relative location of a bedrock crack identified after the main shock is shown by the arrow in (A). Horizontal and vertical scales are equal. (Ref. 2-13).

CHAPTER 3 - SITES IN THE PACIFIC NORTHWEST

THE HANFORD RESERVATION

The geology and tectonics of the eastern Washington state region are characterized by relatively young tectonic structures, based on seismicity and paleoseismic evidence for Quaternary fault displacement. These characteristics are typical of other regions of the western United States. The Hanford region is also characterized by low recurrence rates of activity on faults, much like the Basin and Range; and it has not been possible to relate seismicity to known seismic sources, which is similar to the central and eastern United States.

The licensing activities for several plant sites, the Fast Flux Test Facility (FFTF), the N Reactor, and Washington Nuclear Power Two (WNP-2) are described in this chapter. The regional tectonic and seismic issues are described more completely under the discussion of the FFTF site than they are for the other Hanford sites. They were first addressed in the evaluation of the FFTF site. The same issues characterized these other sites as well, but more information became available as time went on and additional investigations were conducted and the issues are presented as they were addressed for each site.

Licensing activities for WNP-1 and 4 and the Skagit Hanford site were underway during the Operating License review for WNP-2, so these sites are also briefly discussed. More than one case is addressed because the licensing of each site, although they overlapped to some extent, occurred at slightly different times and provided a progressive view of the evolution of the AEC/NRC review process during the development of Appendix A, as well as illustrating many of the major difficulties encountered in applying the regulation. Figure 3-1 shows the locations of the sites discussed in this section, and Figure 3-2 illustrates the tectonic environment of the Hanford Reservation.

3.1 FFTF (Fast Flux Test Facility)

3.1.1 Background

The site is located on the Hanford Reservation in eastern Washington, within the Pasco Basin of the Columbia Plateau Physiographic Province (Figures 3-1 and 3-2). The CP review for the FFTF was accomplished in 1970-1972, prior to publication of Appendix A, but the Appendix A criteria were used in this review (Ref. 3-1). The site was never subjected to a geosciences operating license (OL) review.

3.1.2 Tectonic Province

The Columbia Plateau Physiographic Province, which are those parts of eastern Washington and northeastern Oregon underlain by several thousand feet of late Tertiary flood basalts, was regarded as a tectonic province in this review and the reviews that followed. It was considered to be a tectonic province because of the apparent structural control of the topography and the similarity of the tectonic structures throughout the province. This is consistent with the definition of tectonic province in Appendix A (Ref. 1-1).

The style of deformation of the Columbia Plateau Tectonic Province was not known at the time of the review of the FFTF. However, based on geodetic triangulation data that indicated that the Pasco Basin was subsiding, the applicant, the Atomic Energy Commission (AEC), Office of the General Manager, compared this part of the Columbia Plateau with the Basin and Range Province to the south. Based on that comparison, the applicant selected the second largest Basin and Range earthquake (magnitude 6.7) as the design basis earthquake for the site, and assumed that an earthquake of that size could occur on the nearest and largest suspected tectonic structure, the Rattlesnake-Wallula lineament, at its closest approach to the site. The AEC Regulatory staff, based on advice from the U.S. Geological Survey (USGS) and the Coast and Geodetic Survey (USC & GS), did not agree that this region was a part of, or analogous to the Basin and Range. The regulatory staff's position was that if it was to be considered analogous to the Basin and Range, the applicant would have to assume the largest Basin and Range earthquake (magnitude 7.2) on the Rattlesnake-Wallula structure at its closest approach to the site as would be required by Appendix A.

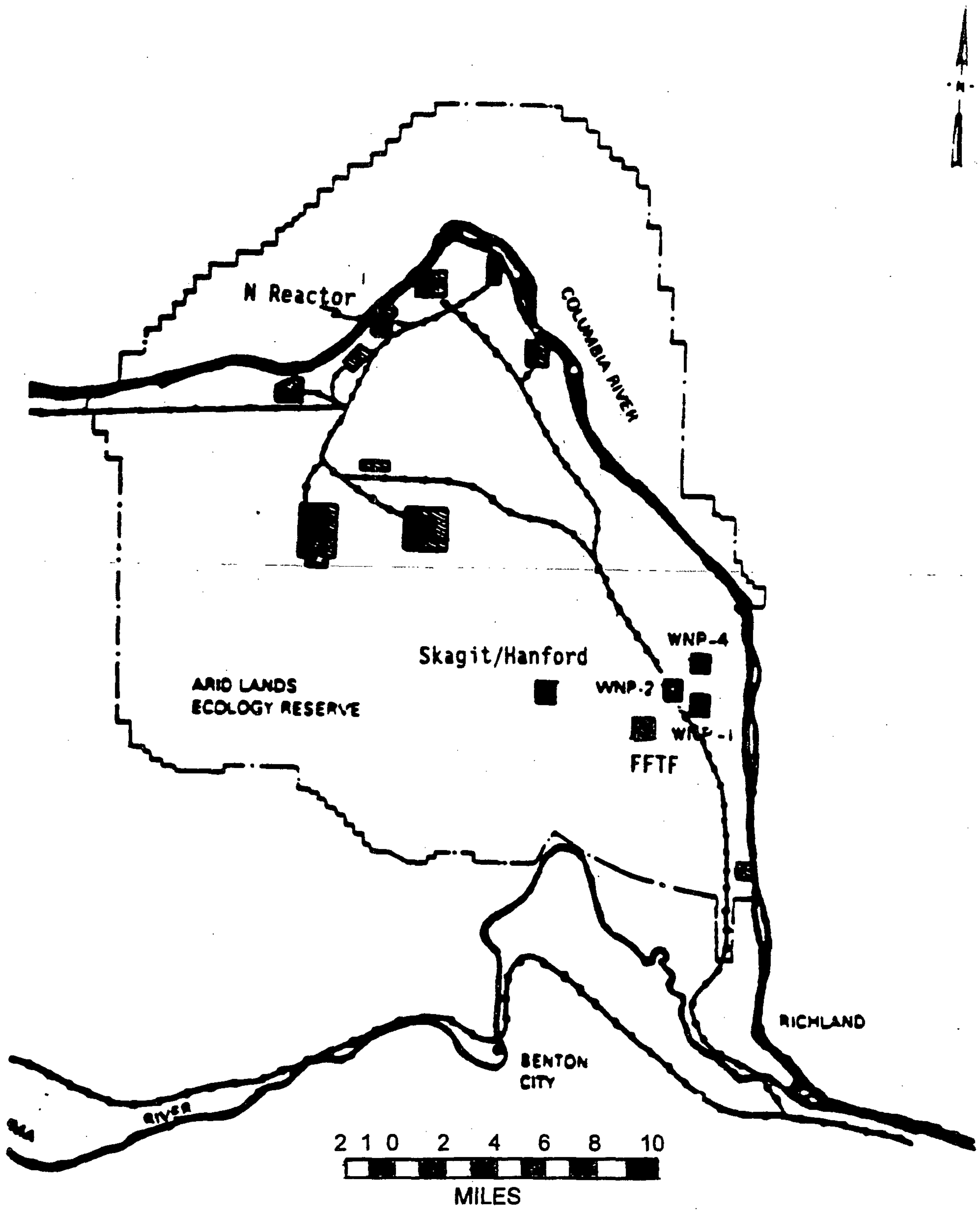


Figure 3-1 Hanford Reservation showing the locations of the FFTF, N Reactor, WNP-2, 1, and 4, and Skagit/Hanford sites (Modified from Ref. 3-7).

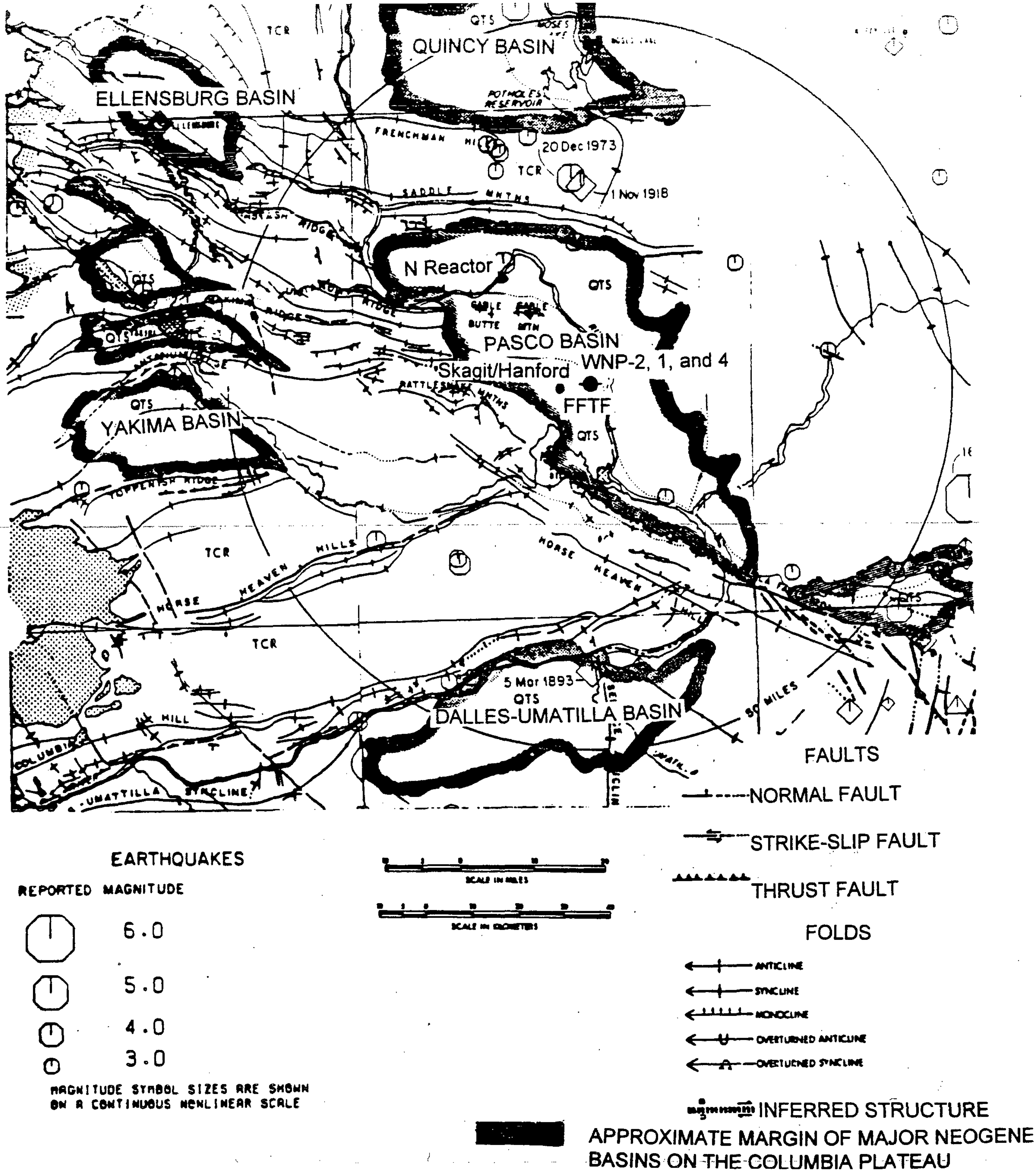


Figure 3-2 Tectonic Map of the region around the Hanford Reservation showing the locations of the FFTF, N Reactor, WNP-2, 1, and 4, and Skagit/Hanford sites (Modified from Ref. 3-7)

3.1.3 Tectonic Structure

The region surrounding the Pasco structural basin is characterized by long (many tens of miles) east-west to southeast-northwest striking folds, that are often asymmetrical to the north. Many of these folds have associated reverse or thrust faults on their asymmetrical flanks. Several of these folds such as the Yakima Anticline (expressed in the topography as Yakima Ridge) appeared to continue in more subdued form in the Pasco Basin beneath the thick glacio-fluvial deposits (Pasco Gravels) and Ringold Formation (up to 600 feet thick beneath the site) to the vicinity of the site. The issues were: the relationship between structures beneath the site to the regional structures, whether to assume the buried anticlines are faulted, and how to estimate the maximum earthquake based on the characteristics of the structures and their uncertain seismic potential.

Regional folds like the Yakima and Untanum-Gable Butte-Gable Mountain Anticlines were determined not to be continuously faulted, some of the faults were related to the asymmetricity of the folds, but the faults that were identified with the folds often cut across them, and the folds that were asymmetrical were not uniformly asymmetrical throughout their length. Because of this diversity the staff concluded that the faults were secondary to the folding and likely not potential generators of large earthquakes.

Young faulting on the north flank of Saddle Mountain and on Gable Mountain was shown by the USGS to be at least 40,000 years old (Ref. 3-2), and, therefore, the staff concluded that they were not capable. Multiple movements could not be documented. Later investigations for other sites, however, showed that these faults did meet the Appendix A criteria for capable faults (Ref. 3-3).

The Rattlesnake-Wallula structure, a northwest striking structurally controlled topographic lineament, was considered to be a major tectonic capable fault, although the Wallula Gap fault was the only positive evidence for faulting on this lineament. This structure was considered to be controlling with respect to estimating the earthquake magnitude and the SSE ground motion for this site.

3.1.4 Maximum Earthquake and Ground Motion

The Rattlesnake-Wallula structure was originally considered to be a segment of a postulated regional topographic lineament, the Olympia-Wallowa Lineament (Ref. 3-4), which extended from Olympia, Washington to the Wallowa Mountains in Oregon. An earthquake with a maximum Modified Mercalli Intensity (MMI) of VIII occurred near Olympia in 1949, and an earthquake with a maximum MMI VII occurred near the lineament at Milton, Washington-Freewater, Oregon in 1936, suggesting that it was seismogenic. The reviewers concluded, however, that there was insufficient basis to assume the existence of a single, continuous fault extending from Olympia to the Wallowa Mountains. For conservatism, however, the design basis earthquake, an event similar to the Milton-Freewater Earthquake, was increased to MMI-VIII and assumed to occur on the Rattlesnake-Wallula structure (80 miles long) about 10 miles west of the site.

The shallow local earthquakes in the Pasco Basin recorded by the USGS network such as the Wooded Island swarm (Ref. 3-5) caused a great deal of concern. There were no surface indications and no identified faults at the hypocenter depths. One hypothesis suggested that the earthquakes were related to increased irrigation by water pumped down through the Grand Coulee from Lake Roosevelt. It was finally concluded without much supporting evidence that the seismicity was related to slippage along joints and basalt bedding planes that accompanied ongoing subsidence of the Pasco Basin.

The short historic seismic record (about 100 years) was a concern also in that the largest earthquake may not have occurred within that time-frame. Search was made for geologic evidence of moderate to large earthquakes in the region. Numerous clastic dikes were mapped in the region including several in the FFTF foundation excavation. Many of these dikes at other locations were associated with polygonal patterns that were clearly apparent on air-photos. One hypothesis was that some of these structures were caused by prehistoric earthquake ground motions. Detailed investigations indicated that many of these dikes most likely were related to the severe and rapid changes in pore pressures during and following the impounding of glacial meltwaters behind ice dams and the subsequent release of those waters.

Reasonably conservative site SSE and OBE were concluded to have peak ground accelerations (pga) of 0.25g and 0.13g, respectively. The SSE is based on the possible occurrence of an MMI VIII event on the Rattlesnake-Wallula structure about 10 miles from the site and the OBE is 1/2 the SSE. The OBE pga being ½ the SSE pga became a requirement of Appendix A when it was published in 1973.

3.2 N REACTOR - WPPSS

3.2.1 Background

The plant was an operating noncommercial reactor located on the south bank of Columbia River in the northern part of the Hanford Reservation, Columbia Plateau, eastern Washington. The evaluation of this site was accomplished 1971-1972, prior to publication of Appendix A, but the criteria used were those that were later included in Appendix A.

The Washington Power Supply System (WPPSS), a public utility, planned to construct a commercial nuclear power plant at the N Reactor location and utilize some of the N Reactor facilities. The same difficulties with respect to the geology and seismology as described in the preceding section about the FFTF were addressed in this review.

3.2.2 Seismic Stability of Upstream Dams

During this review, a new problem arose that was to be addressed many times later in the licensing of other nuclear power plant sites throughout the U.S. That issue was the postulated seismic failure of an upstream dam and the consequences of that failure with respect to a nuclear power plant downstream. This issue had previously been addressed regarding the Trojan Nuclear Plant site by assuming the failure of the upstream dams would be dominated by the failure of the Grand Coulee Dam. The postulated failure mechanism in this case was a nuclear explosion at Grand Coulee Dam.

The N Reactor is situated at a low elevation relative to the Columbia River, therefore, the possibility of a seismic failure of the upstream Grand Coulee Dam had to be considered. The Bureau of Reclamation, the builder and owner of the dam, upon request by WPPSS, supplied a letter stating that the dam was designed to withstand 0.25g peak ground acceleration, but it did not provide the basis for that determination. They did furnish a report describing some of the geological investigations carried out prior to construction of the dam. At the time of the N Reactor review, the excavation for the third Power Plant at Grand Coulee was open, exposing 3 faults. The faults were in line with the eastern border fault of the Republic Graben to the north, and a fault and fold mapped in the Grand Coulee to the south. A USGS geologic map showed a splay of the southern border fault cutting Late Pleistocene deposits. Based on these observations and the lack of data supporting the non-capability of the faults, the AEC staff would not accept the stated earthquake design basis for Grand Coulee Dam as being adequate.

WPPSS then commissioned its geological consultant to perform a geological and seismological investigation (Ref. 3-6). These investigations, when completed, were also considered inadequate to support the seismic capability of the dam, and the staff concluded that the study results provided by WPPSS did not satisfy the requirements that were the basis for Appendix A, which was being prepared at that time. The WPPSS abandoned this project and began investigations at the WNP-2 site which was at an elevation above potential flooding due to the postulated failure of Grand Coulee Dam.

3.3 WASHINGTON NUCLEAR PLANT-2 (WNP-2)

3.3.1 Background

The site is located about 1 1/2 miles west of the Columbia River on the east side of the Hanford Reservation, in the structural Pasco Basin of the Columbia Plateau Tectonic Province (Figures 3-1 and 3-2). The CP review began in the early 1970s, and the licensing activities continued with the OL review through the early 1980s. Appendix A siting criteria were used throughout this period.

The same issues in geology and seismology that were addressed in the FFTF review were evaluated during the WNP-2 licensing activities, but with a greater amount of information. Three deep core borings were drilled into basalt bedrock at opposite sides of the site. These borings were logged in detail, including geophysical logging. Seismic refraction lines, using the borings as control were run between and beyond the borings to determine the continuity of the stratigraphy beneath the site. These investigations provided a much better definition of the structural geology beneath the site. No anomalous features were detected beneath the site except for an erosional channel on top of the basalt. The seismic surveys also demonstrated the horizontal continuity (unfaulted) of the Plio-Pleistocene Ringold Formation. Investigations and analyses for Units 1 and 4, which were to be located at the same site (Ref. 3-7), and later, for the Skagit Hanford site (Ref. 3-8), which was to be located several miles farther to the west, were started after construction began at WNP-2.

Since the CP evaluations of WNP-2, WNP-1, and WNP-4 which spanned the early, middle and much of the late 1970s, many advances in the fields of geology, seismology and ground motion had occurred. Additionally, extensive investigations had been accomplished by the Department of Energy (DOE), and its predecessor agencies, the AEC and ERDA, in the Hanford region for the national high level waste repository, later called the Basalt Waste Isolation Project (BWIP). New information had become available about the tectonics of the Hanford region as a result of these studies, and new structures had been identified. Additionally, new techniques for analyzing faults, earthquakes, and ground motion had been developed and used for sites such as Humboldt Bay, San Onofre, and Diablo Canyon.

Consideration of the WNP-1 and 4 sites was eventually discontinued, but the principal geological and seismological issues continued to be addressed during the OL evaluation of WNP-2 and the CP evaluation of Skagit Hanford (Ref. 3-8). These analyses and the way in which Appendix A figured into it are described in the following paragraphs.

3.3.2 Tectonic Province and Significant Historic Earthquakes

Because the lava flows in the Columbia Plateau Tectonic Province overlap adjacent provinces, the boundaries are not well defined. The largest historic earthquake that has occurred in the Columbia Plateau Tectonic Province is the 1936 maximum MMI VII Milton-Freewater Earthquake. The estimated magnitudes used in the staff's analysis were M_s = 5.75 and M_L = 6.1 (Ref. 3-9). A site specific spectral analysis was made using ground motion data from earthquakes characterized by magnitudes of about 6.1, similar subsurface conditions, and epicentral distances of less than 15.6 miles (Ref. 3-9).

The 1872 Pacific Northwest Earthquake was evaluated during the CP review of WNP-2, and also during WNP-1 and 4, and Pebble Springs licensing activities. Based on the extensive studies, WPPSS concluded and the staff and its advisors concurred, that the 1872 earthquake, which had an estimated magnitude of 7, occurred in the Cascades-Okanogen Tectonic Province. Because of the uncertainty of the southern boundary of this province beneath the overlapping basalt flows, the staff conservatively determined that an 1872-like earthquake could occur as close as 25 miles from the site and not exceed the SSE design basis of 0.25g peak horizontal ground acceleration (Ref. 3-9).

3.3.3 Tectonic Structures and Capable Faults

During the earlier reviews the AEC and NRC had concluded that faults on Gable Mountain, the nearest structure of significant size to the sites, were not capable based on USGS mapping of trenches, which indicated that the 40,000 years old soil was not offset by the faults. However, renewed investigations of these structures for the Skagit Hanford and WNP-2 sites identified new information concerning the recency of displacement on the faults.

Five faults are present on Gable Mountain: Central Fault, North Dipping Reverse Fault, South Fault, West Fault, and DB-10 Fault (Ref. 3-3). Evidence was found by consultants to the two applicants that demonstrated minor offset (0.2 in.) of glacial deposits 19,000 to 13,000 years old on the Central Fault. The West and DB-10 Faults were not analyzed in detail because they were smaller and more distant than the other two. The North Dipping Reverse and South Faults were considered capable because of their relationship to the Central Fault. The faults were secondary to folding, relatively aseismic, and exhibited low rates of deformation (long return periods for earthquakes). The staff used the rupture area and moment technique of Wyss, 1979 (Ref. 3-10), Woodward and Clyde, 1982 (Ref. 3-11) and Hanks and Kanamori, 1979 (Ref. 3-12) to derive the earthquake magnitude of 5.0(M_b). The sites are located about 10 and 6 miles from Gable Mountain.

Most of the faults on Gable Mountain are associated with two second generation folds that cross the axis of the main fold obliquely. A related en echelon fold, the Southeast Anticline, extends southeastward from the east end of the surface expression of Gable Mountain. A subsurface fault was identified on the southwest limb of this structure. However, it is truncated by undisturbed Ringold formation and therefore considered to be not capable.

The sites overlie the Cold Creek Syncline, a broad, relatively undeformed structure. The age of the Cold Creek Syncline was not known, but its southwestern flank was interpreted to be the buried northeastern limb of the Yakima Anticline, which was shown to be not-capable. About 4 miles north of the Skagit site is the north-south May Junction Monocline, a feature that dips to the east. Although it was believed to be non-capable, additional investigations were required of the Skagit applicant to demonstrate that it was not.

Numerous other regional structures, remote sensing lineaments, and local deformations, that were not identified during the WNP 1, 2, & 4 and FFTF CP reviews, were investigated and determined to be either non-capable or not tectonic structures at all, but related to Pleistocene flooding episodes or gravity slides. Regional non-capable tectonic features include Untanum Ridge, which was interpreted to be part of an ancient imbricate thrust zone of primary faulting; the Cold Creek Lineament; and a lineament on the north flank of Saddle Mountain. Non-tectonic features include clastic dikes, which were interpreted to have been formed by hydraulic injection at the bottom of the post-glacial lake that filled Pasco Basin during late Pleistocene; the Moxee Valley surface structure, which was considered to be the result of differential erosion along joints or faults; and the Wenas Valley features, which were interpreted to be gravity created structures.

3.3.4 Maximum Earthquake and SSE Ground Motion

Swarm earthquakes have long been recorded in the Pasco Basin and other parts of the Columbia Plateau, particularly at Wooded Island in the Columbia River east of Hanford. As no relation to geologic structure had been established, the staff assumed that the maximum swarm earthquake recorded (M_L 4.0-4.4), even though it was not within the Pasco Basin, could occur about 5.6 miles from the site (Ref. 3-9).

As in previous reviews the Rattlesnake-Wallula structure was concluded to be the potential source of the earthquake that dominated the seismic hazard in the site region. In the WNP-2 CP review the design basis earthquake was a maximum MMI VIII event on this structure 13 miles from the site. In the WNP-2 OL and the Skagit Hanford CP evaluations the parameters were based on: the nearest approach of the Rattlesnake-Wallula structure being about 9 miles from Skagit Hanford and 13 miles from WNP-2. Fault length analytical methods [length of surface rupture and estimated length of subsurface rupture (Ref. 3-13)], were used to determine the magnitude, assuming reverse oblique and strike slip with minor local oblique senses of displacements. The fault length assumed was 75 miles with segment lengths of 9.5 to 12.5 miles long, and the resulting maximum earthquake calculated to be Ms 6.5. Based on a slip rate that was conservatively estimated to be 22 mm/year, the resulting magnitude was 6.4. The last movement on the structure was estimated to be more than 7,000 years ago, and the fault is relatively aseismic. These factors indicate low deformation rates and long return periods for magnitude 6.0 to 6.5 earthquakes.

Based on the geological, seismological and geophysical studies and analyses, the ground motion was assumed to be a peak ground acceleration of 0.25g at the site generated by a magnitude 6.5 earthquake on the Rattlesnake-Wallula structure about 13 miles west of the WNP-2 site, and 9 miles west of the Skagit Hanford site (Ref. 3-9).

3.3.5 Volcanic Hazard

The only reasonably credible volcanic hazard for the Skagit Hanford, WNP 1, 2 and 4 sites was considered to be ashfall. Appendix A requires volcanic hazard consideration but leaves the specific types of investigations, etc. to a site by site evaluation. In addition to data from studies of ashfall from late Pleistocene and Holocene eruptions such as from Glacier Peak, Mount Mazama, and Mount St. Helens, the applicants had the benefit of data from the May 18, 1980 eruption of Mount St. Helens. The design bases derived from assuming the eruption of the closest volcano, Mount Adams, 102 miles away are: with respect to thickness, the compacted thickness of ash was estimated to be 3 in.; loose thickness for WNP 1, 2 and 4 at 20-40% compaction was estimated to be 3.6/4.2 inches; loose thickness for Skagit/Hanford at 50/60% compaction was calculated to equal 5.8/7.4 inches. The ash fall rate estimated over a 20 hour period was estimated to be 0.3/0.36 inches per hour for WNP 1, 2, and 4; and for Skagit Hanford it was estimated by the applicant to be 0.15 inches/hour. The median grain size of the ash at both sites was estimated to be 0.075 mm.

3.3.6 Seismic Stability of Foundation Materials

Stability of foundation soils under seismic loading is a major issue addressed in Appendix A. Thus, a concern was raised by the staff regarding the potential for liquefaction of sand units within the Pasco Gravels beneath foundation levels as a result of the SSE ground motion. A reevaluation was conducted and the applicant changed plans and excavated down to the very dense lower Pasco Gravel or Ringold Formation conglomerate unit and backfilled with concrete up to foundation levels.

OTHER SITES IN THE PACIFIC NORTHWEST

3.4 PEBBLE SPRINGS

3.4.1 Background

The site is located 6 Miles south of Arlington, Oregon, and the Columbia River, on the north flank of the Dalles-Umatilla basin or syncline (south flank of the Columbia Hills Anticline), of the Columbia Plateau Province (Fig. 3-3). The CP review was conducted during the middle to late 1970s after publication of Appendix A. The applicant did not apply for an Operating License.

3.4.2 Tectonic Province, Tectonic Structures, Maximum Earthquake, and SSE Ground Motion

Problems that have already been described for WNP-1, 2 and 4, Skagit, and FFTF were also major issues for Pebble Springs and much of the investigative work done by the applicant, Portland General Electric (PGE), was incorporated into the decision-making about these issues (Ref. 3-14). PGE consultants conducted an extensive regional study of the 1872 Earthquake and the resulting information contributed, along with the WPPSS data, to restricting that earthquake to the Cascades-Okanogan Tectonic Province. These geological and seismological studies were conducted along the east flank of the Cascade Mountains and the western part of the Columbia Plateau. These and other regional studies also confirmed that the site was in the Columbia Plateau Tectonic Province within the Dalles-Umatilla Structural Basin.

Trenching of the Wallula Gap Fault and mapping of Finlay Quarry (Ref. 3-15), which is located across the fault trace, provided much of the data used by the staff in assessing the earthquake potential of the Rattlesnake-Wallula Fault Zone for Skagit Hanford, WNP 1, 2, & 4, and Pebble Springs. Mapping of the Rattlesnake-Wallula Fault Zone south of Wallula Gap, revealed evidence supporting the capability of the Wallula Gap Fault and faults in the Walla Walla Basin. Using these data, PGE determined that a 50 mile segment (southern part) of the Rattlesnake-Wallula Fault Zone was capable and used a rupture length-versus-magnitude method for calculating a maximum earthquake of magnitude 5.5. However, the staff did not accept a lower value than was used during the CP evaluation of FFTF and WNP-2, which was an MMI-VIII (magnitude 6+) on the Rattlesnake-Wallula Fault Zone, assumed to occur at its closest approach to the Pebble Springs site.

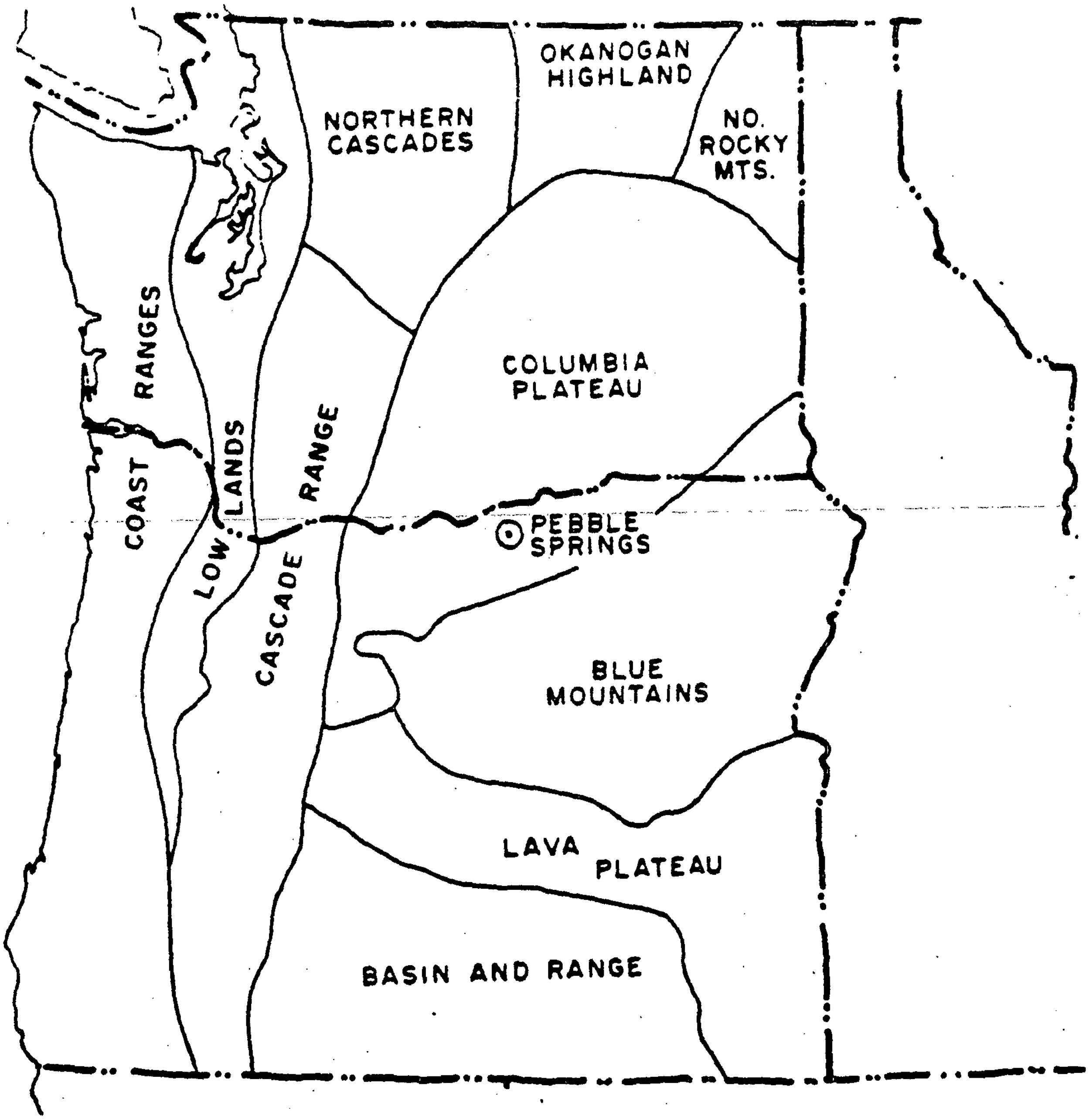


Figure 3-3. Major Physiographic Provinces of Oregon and Washington (Ref. 3-14).

Numerous clastic dikes, which cut through the Pliocene Dalles formation, filled joints in the underlying Elephant Mountain flow, and penetrated down into the Rattlesnake Ridge interbed (a member of the Ellensburg Formation), were identified in excavations at the site. Based on investigations and analyses, these features were interpreted to have been hydraulically injected downward from the bottom of a temporary post-glacial lake over the Dalles-Umatilla Basin, and not seismically induced.

Many local structures or postulated faults, such as the north-south striking Arlington-Shutler Butte Anticline and associated fault west of the site, and faults on the east-west trending Columbia Hills Anticline across the Columbia River north of the site, were investigated by trenching and mapping, and shown by crosscutting relationships and other methods to be non-capable.

3.4.3 Volcanic Hazard

Although investigations for the Pebble Springs site added greatly to the understanding of the tectonics of the Columbia Plateau region, the main contribution of the study and review was the establishment of a method to estimate the design bases for volcanic ashfall. The technique employed for this site was updated and used for the Hanford sites and the WNP-3 site. The Pebble Springs volcanic ashfall design bases were derived by a regional analysis of prehistoric ashfalls from Mount Hood (80 miles away (west), Mount St. Helens (105 miles away) and Mount Rainier (105 miles away) (Figure 3-4). These design bases included: a compacted thickness of 6 inches (based on Mount St. Helen's y/n ash thickness at Snoqualmie Pass); a rate of 1/2 in. per hour for a 20 hour period (based on 1912 Mount Katmai ashfall records); and 20%/40% compaction = 7.5/10 inches loose ash (Ref. 3-16).

3.4.4 Stability of Foundation Materials and Slopes

Other issues that were resolved included those concerned with assessing the competency of soils and rocks beneath the site including, the Rattlesnake Ridge interbed, a clinker layer, and the porous upper section of the Pomona Basalt, and the underlying massive Pomona Basalt as foundation bearing materials for seismic safety related structures. After the testing of these materials and the analysis of the results, it was concluded that the foundations of seismic safet;y related structures would be placed on massive, solid Pomona Basalt.

The site was situated on a plateau adjacent to a deep scabland coulee. The cliff next to the coulee had been retreating, by means of erosion and undercutting, toward the site during the Holocene. Past rates of erosion and undercutting of the cliff and that of other similar features in the Columbia River Valley were calculated, and it was determined, using an adequate level of conservatism, that the distance to the cliff was sufficiently far, and the rates of erosion sufficiently slow to preclude a landsliding hazard to the plant during its lifetime.

3.5 TROJAN

3.5.1 Background

The PGE Trojan Nuclear Power Plant is located in northwest Oregon on the Columbia River near Quells, Washington, east of the intersection of the Cowlitz and Columbia Rivers (Figure 3-4). The site is in the Willamette-Puget Lowland Section of the Pacific Border Physiographic Province, and structurally, it is situated within the Willamette Valley - Cowlitz trough.

The CP review was done in the late 1960s before Appendix A, but the Appendix A criteria were used in evaluating this site, particularly in assessing:
(1) a possible major fault beneath the Columbia River;
(2) the Portland Hills Fault;
(3) a fault mapped in a road cut on Interstate 5;
(4) the design basis earthquake (SSE); and
(5) the tectonic province.

During the OL review in 1973, Appendix A was published and the capable fault criteria were used to assess minor shears in the excavation.

3.5.2 Tectonic Province, Tectonic Structure, and Capable Faults

The Portland Hills Fault strikes northwest from Portland and passes 15-18 miles west of the site. The 1969 tectonic map of North America by P. King showed that a branch of the Portland Hills Fault underlies the north-south reach of the Columbia River from Portland to the site area, and up the Cowlitz River into Washington. The specific trace of this fault, if present, would pass the site either beneath the Columbia River or west of the site in the low marsh area which was formed as a glacial outwash channel during Late Pleistocene. During the CP Hearing the Atomic Safety Licensing Board (ASLB) ruled that a 3 member panel be formed of prominent geophysicists to resolve the issue. One panel member was selected by the intervenor, one by the applicant, and the third by the first 2 panel members. After it had been assembled the panel planned, supervised, and interpreted the results of geophysical investigations. Based on its analysis of the investigation results, the panel concluded that there was no strong evidence in the data for a major structure adjacent to the site (Ref. 3-17).

A normal fault was discovered in a large road cut along Interstate 5 at the Kelso Interchange. Dating was inconclusive because the Pliocene Troutdale gravels and sands, which were interpreted to truncate the fault, could not be shown to extend across both sides of the fault. The fault is 4.7 miles from the site. The last displacement along this fault, based on regional analogies, was concluded to be related to known tectonic activity during middle to upper Miocene. An element of Appendix A allows for the use of analogies in evaluating the capability of faults if absolute dating techniques are not possible or results are unreliable. This method has been used often in the central and eastern U.S. Likewise, minor shears mapped in the plant excavation, which could not be dated absolutely, were concluded to have formed as the result of adjustment to uplift that caused differential displacement along joints.

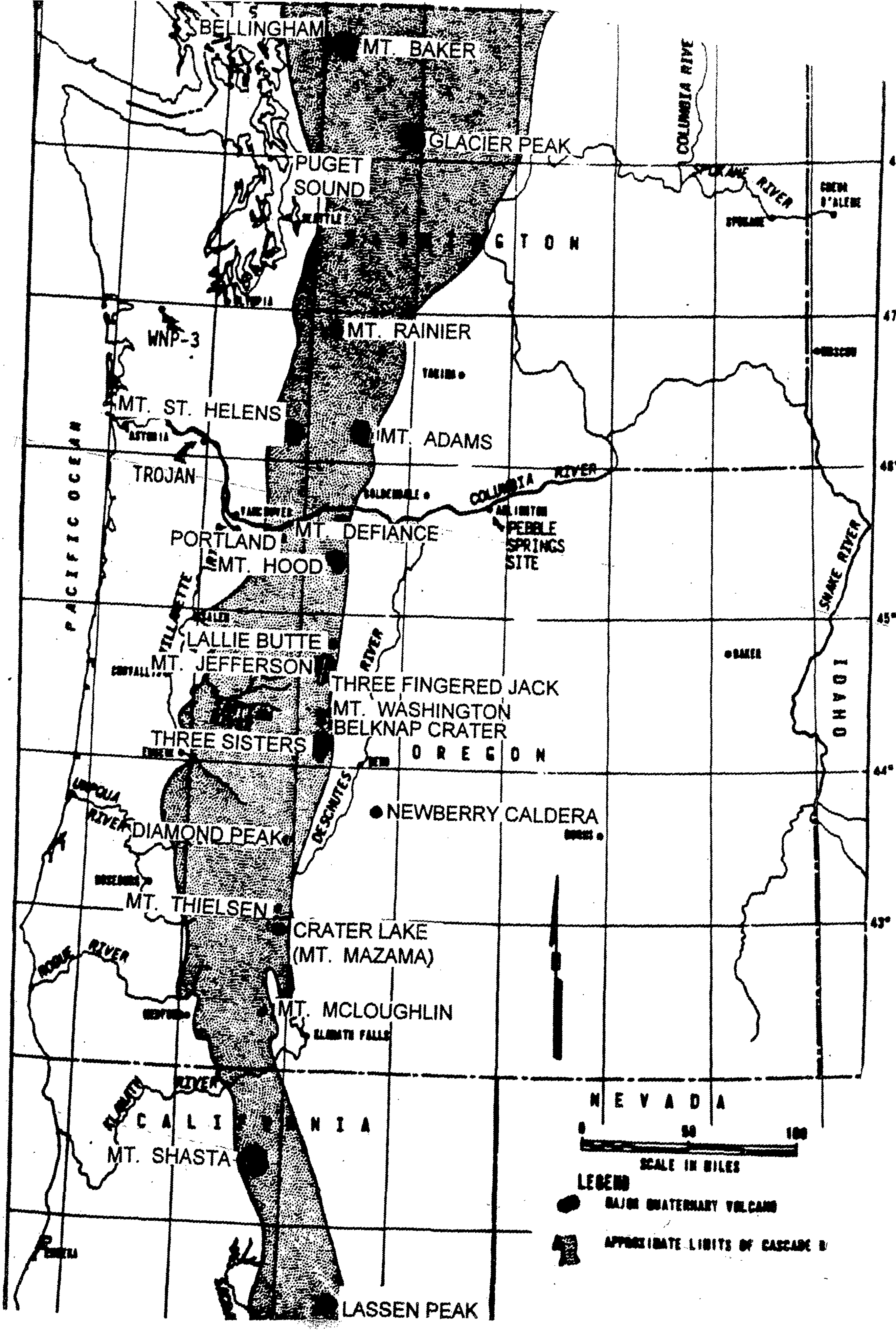
3.5.3 Maximum Earthquake and SSE Ground Motion

SSE ground motion with a peak horizontal acceleration of 0.25g for the site was based on assuming the combination of shaking from a distant MMI IX earthquake that caused MMI VII-VIII on rock at the site, and a MMI VII earthquake occurring near to site (Ref. 3-18) (Portland seismic activity translated along the postulated Columbia Hills Fault to the site).

An investigation of the seismic potential of the Cascadia Subduction Zone as described in the next section was begun to evaluate its significance to the seismic design of Trojan plant, which had been operating for several years, along with a restudy of the seismic potential of mapped and postulated faults in the site region, based on new data. However, it was discontinued after a decision was made by PGE to shut down the plant.

3.5.4 Volcanic Hazard

Trojan was the first nuclear site for which volcanic hazard issues were addressed. Lava flows, flooding, hot avalanches, mud flows (lahars), and ash fall from Mount St. Helens, about 30 miles to the east, were evaluated as to their potential hazard to the site. Ashfall was determined to be the only event that could significantly effect the site (Figure 3-4). To establish a design basis for ash fall, the ash distribution from the Mount Mazama eruptions about 7000 years ago was superimposed on Mount St. Helens. The prevailing winds are westerly most of the time, and during those few times when the wind is blowing from an easterly direction, velocities are much lower than are those of the westerly winds. On this basis, it was concluded that ashfall did not pose a severe hazard to the site, and the estimated maximum level of ashfall could be mitigated.



Major Quaternary Volcanic Centers - Oregon, Washington, and Northern ... Cascades (Ref. 3-14).

3.6 WASHINGTON NUCLEAR PLANT-3 (WNP-3)

3.6.1 Background

The WNP-3 site is in central-west Washington about 16 miles east of Aberdeen, 23 miles west of Olympia, and 2 miles south of Satsop on the south bank of the Chehalis River. The site is within the Chehalis Lowland section of the Pacific Border Physiographic Province. The reviews were conducted after publication of Appendix A and the criteria were used extensively by all parties involved in the CP and OL activities.

The nuclear units were never made operational. Construction of the two units was about 90% and 80% complete when the decision to discontinue construction was made by the utility, Washington Public Service Supply System (WPSSS).

The predominant geosciences issues concerning this site were focussed on its closeness to the Cascadia Subduction Zone and the impact that this proximity could have on the seismic hazard to the plant. Other issues were concerned with the potential hazard posed by the presence of numerous faults that were mapped in the region and site area and minor faults identified in excavations at the site.

3.6.2 Tectonic Province and Tectonic Structure

The proximity of the WNP-3 site to the Cascadia Subduction Zone (Figure 3-5) was a major concern and required careful consideration of that source as having the potential of generating large to great earthquakes. However, based on the lack of current seismicity associated with the interface, and the absence of thrust earthquakes in the historic record, it was concluded during the CP review that the subduction of the Juan de Fuca Plate beneath the North American Plate had ceased or was continuing slowly and aseismically. Therefore the earthquake that controlled the seismic hazard to the site was considered to be the largest reasonably credible earthquake associated with the Puget Basin.

Based on the seismicity of the Puget Basin, which included the 1949, magnitude 7.1 Olympia Earthquake and the 1965 magnitude 6.5 Seattle Earthquake, and the presence of a regional scale, northwest-southeast striking topographic and geophysical lineament along the western boundary of the Puget Basin, the controlling earthquake was assumed to be a magnitude 7.0 event occurring at the nearest boundary of that structure to the site. The lineament is located about 23 miles east of the site at its closest point, and the resulting SSE design basis acceleration for the site was 0.32g.

With the subduction zone earthquake thought to no longer be a concern and a conservative SSE established, the CP and early OL evaluations focussed on investigating faults in the subregion around the site and at the site, to assess their potential for generating ground motions or causing surface deformation. This was an extensive and detailed study that utilized modern techniques in geologic mapping, trenching and logging, geochronology, core borings and geophysical profiling. Strong technical bases were presented in the Safety Analyses Reports (SAR) that indicated that the faults investigated were not capable within the meaning of Appendix A.

However, during the time that the OL review was underway, evidence was recognized that supported an interpretation that the Juan de Fuca Plate was a relatively young plate that was subducting at a fairly rapid rate (3 to 4 cm per year) (Ref. 3-19). Although there was no seismic evidence of large or great thrust earthquakes in the region, this subduction zone was found to have many of the characteristics of active subduction zones around the Pacific Ocean that have generated magnitude 8 and greater earthquakes (Ref. 3-19). Therefore, the subduction zone earthquake became the major issue once again.

3.6.3 Subduction Zone Earthquake - Paleoseismic Issues

In the mid-1980s research by the USGS, partly funded by the NRC, revealed geologic evidence for large prehistoric earthquakes (Ref. 3-20). Observations following the 1960 Chilean earthquake, the 1964 Alaskan earthquake and other large to great subduction zone earthquakes indicated that sudden subsidence of up to 3 meters had occurred in a zone parallel to, and located from about 80 to 100 km from the subduction zone trench offshore. Evidence of this kind was

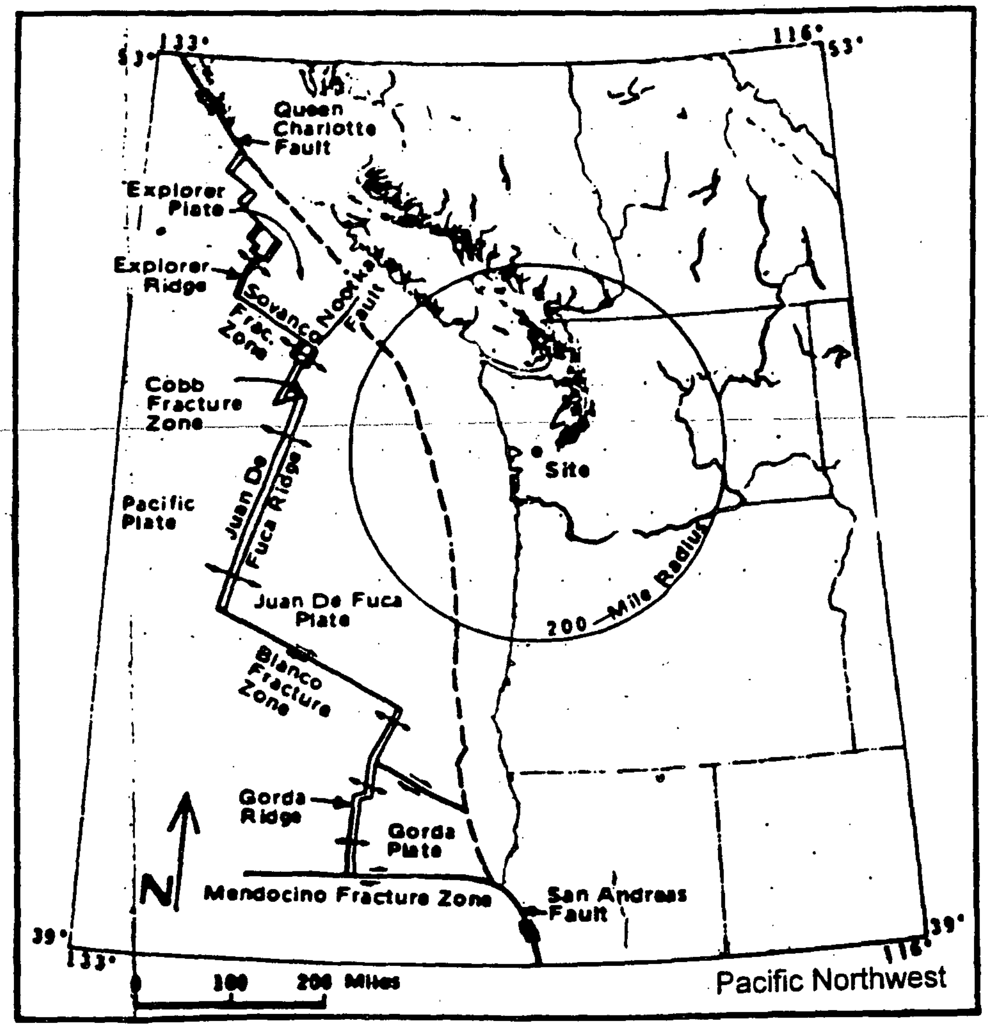


Figure 3-5 WNP-3 relative to the Cascadia Subduction Zone (Ref. 3-24).

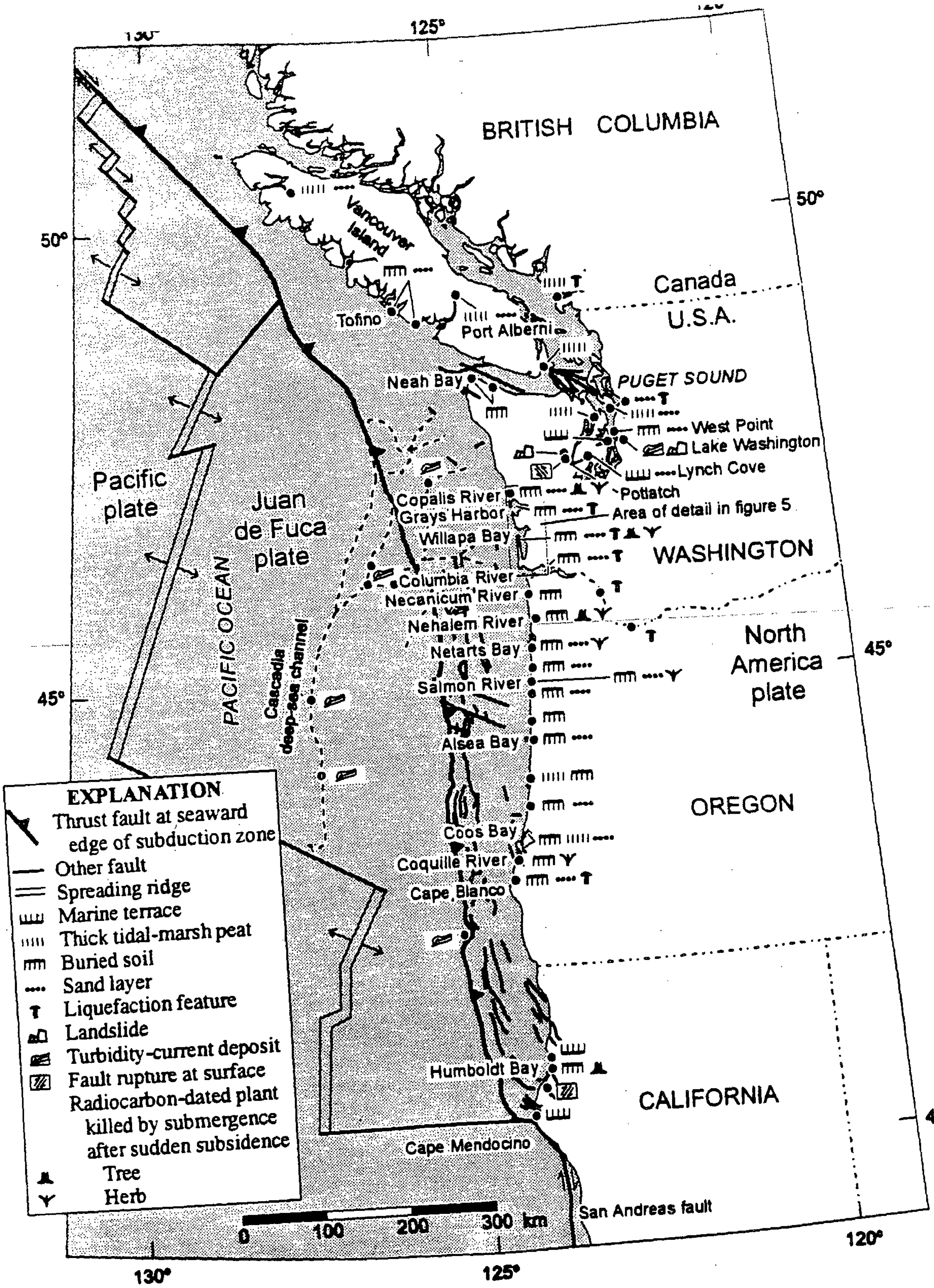


Figure 3-6 Cascadia Subduction Zone and locations along the coast from Washington to northern California where paleoseismic evidence has been identified (Ref. 3-27).

found along the coasts of Washington and Oregon, and later, northern California, indicating multiple occurrences of prehistoric subsidence events within a period that extends back several thousand years.

The evidence consisted of several cycles of alternating layers of peat and estuarian mud in the Holocene soils section near the coast. A cycle begins as peat is formed from decaying plants that grow in marshy areas near sea level. Subsidence accompanying a subduction zone earthquake occurs and the peat is dropped below sea level and becomes overlain by sediment from the new estuarian environment that was created when sea water covered the marsh areas. After the subsidence event, gradual uplift starts the next cycle. At many locations thin lamina of sand were found to overlie the peat. These occurrences are interpreted to be evidence for tsunamis following the earthquakes and associated subsidence.

The most recent event is estimated to have taken place about 300 years ago (Ref. 3-21). Dates of events were estimated by carbon 14 dating of peats and micro fossils and analyzing tree rings of Sitka Spruce and Red Cedar, which were killed during the most recent subsidence events. Paleoseismic evidence for an event, or events, about 300 years ago has been identified at coastal sites extending from northern California to central Washington (Figure 3-6).

In addition to the evidence for uplift and subsidence, paleoliquefaction features such as dikes were found on islands within the Columbia River from about 35km to 90 km from the coastline (Ref. 3-22). The event that generated these features was estimated from the data to have occurred about 300 years ago. This age is consistent with the most recent earthquake induced subsidence event as recorded in the recent stratigraphy as described above. However, the level of shaking that caused the paleoliquefaction features and their regional extent appeared to be more typical of an approximate magnitude 7 on the plate interface rather than what would be expected from a magnitude 8+ subduction zone earthquake. Also, this is the only evidence identified at this writing that demonstrates that shaking has occurred along with subsidence.

The issues in the OL evaluation then became whether the subsidence events were accompanied by aseismic slippage along the plate interface, or seismic slip accompanied by large to great earthquakes. The seismic-slip options included: earthquakes of magnitude 9+ that accompanied a rupture of the entire 900 km of the interface; several magnitude 8+ earthquakes that were associated with the rupture of 100/200 km long segments of the interface; or many magnitude 7 events related to smaller ruptures.

3.6.4 Tectonic Structure, Maximum Earthquake, and SSE Ground Motion

Evidence (geological, geophysical and seismological) was identified that supported constraining the size of rupture during a single event. This evidence included; geological and geophysical data that supported segmentation of the plate into blocks 100 to 200 km in length, and geophysical, seismological and geological evidence for a seismogenic downdip width of about 75 km (Ref. 3-23). After careful consideration of this evidence, the staff concluded that a magnitude 8¼ earthquake should be assumed to occur on the plate interface at a depth of about 30 km beneath the site, pending the results of ongoing investigations in the region. The applicant also conducted a probabilistic seismic hazard analysis, the results of which compared very well with those of the deterministic analysis.

In addition to the plate interface design basis earthquake, and based on the 1949 Puget Sound magnitude 7.1 earthquake and ongoing seismicity within the slab, the staff concluded that a magnitude 7½ earthquake should be assumed to occur within the downgoing Juan de Fuca plate.

Another issue, the magnitude of the maximum local, or random shallow earthquake was resolved by assuming the possible occurrence of a magnitude 5½ to 6 earthquake in the site vicinity. This is based on historic seismicity and geology in the site region. As there are no mapped capable faults in the site vicinity, the applicant assumed potential earthquake occurrences on faults that could be present undetected within the resolution of the methods of investigations used, for example: up to 5 meters of fault offset could be undetected during a geological reconnaissance; one meter during detailed geologic mapping; and a few centimeters during detailed mapping of trenches and outcrops.

Another criteria was the amount of cumulative slip that could escape detection given the antiquity of the geologic material present such as: 1 to 5 meters of cumulative slip in 300,000 years; 0.25 m in 75,000 years (based on detailed geologic mapping) to 1 m in 60,000 years (based on reconnaissance investigation); and 0.03 m to 0.16 m in 10,000 years (Ref. 3-24).

3.6.5 Capable Faults

The site is underlain by Cenzoic marine clastic sediments deposited on a basement of Eocene oceanic basalt. The structural geology of the site and surrounding region is characterized by large uplifts, and faults and folds related to those uplifts that were formed by regional northeast directed compression during the Tertiary period. Three of these uplifts are present within the site vicinity. The site is located on an anticline, which is the northern extension of one of these uplifts. All of these uplifts are bounded primarily on the southwest and southeast sides by high angle faults that strike north-northwest and east-northeast, respectively, with offsets ranging from several thousand feet to several hundred feet. The closest of these faults, which has an offset that exceeds 2,000 feet, is located approximately 1 mile south of the site (Ref. 3-24).

These subregional faults were investigated by means of literature search (much previous research had been carried out on the regional faults), geologic mapping, borings, trenching, and remote sensing techniques. In the absence of material that could be used for absolute age dating, the ages of last movements on the faults were estimated by establishing their relationship to Quaternary features. This was accomplished by analyzing cross-cutting relationships between faults and stratigraphic contact, relict erosion surfaces, Quaternary deposits, paleosols and weathering profiles. By determining the relative ages of these features the applicant was able to demonstrate an upper limit of displacement on these faults of at least 630,000 years before present (Ref. 3-24).

The results of this regional fault analysis were projected to the site where numerous northwest and northeast striking minor reverse faults were encountered in the excavations (Fig. 3-7.). The applicant demonstrated that these minor faults were related to the regional faults and therefore at least 630,000 years, and like the regional faults they were more likely formed by Late Tertiary northeast directed compression more than 2 million years ago (Ref 3-24).

Later studies suggested that the site area faults originated within an accretionary wedge accompanying subduction during the Tertiary when that region was closer to the trench. The faults have been rotated through time to near vertical attitudes. Since that time the trench and zone of active accretion have migrated westward to about 180 km west of the site. The area offshore, which is depicted on a regional east-west seismic reflection data, represents the easternmost limit of Quaternary fault offset related to subduction. This interpretation is based on similar characteristics in the accretionary prisms of other subduction zones and to a hypothesis by Moore and Byrne (1987) (Ref. 3-25). Moore and Byrne presented evidence that indicates that sediments accreted to the overriding plate of active subduction zones undergo stratal disruption and form a type of melange. The thickness of those disruptive zones grows with progressive deformation that propagates toward the trench in new sediments as they are added to the plate. Initial slip surfaces are abandoned and are rotated as they move away from the trench. The applicant's interpretation of the origin of the site faults is that they went through these processes many millions of years ago and have been stable for at least 630,000 years as demonstrated by the site investigations.

An issue during this review was the capability of the Wishkah River fault Zone as suggested by deformed, steeply dipping Pleistocene deposits near the fault. The concern was that a projection of this fault zone and possibly related structures extended to about 14 km from the site. After reviewing geological investigations of the fault zone by the applicant and participating in geological reconnaissance of the area, the staff concluded that the Wishkah River Fault Zone was not capable and the deformation of the Pleistocene sediment was caused by glaciation or deglaciation of the area (Ref. 3-26).

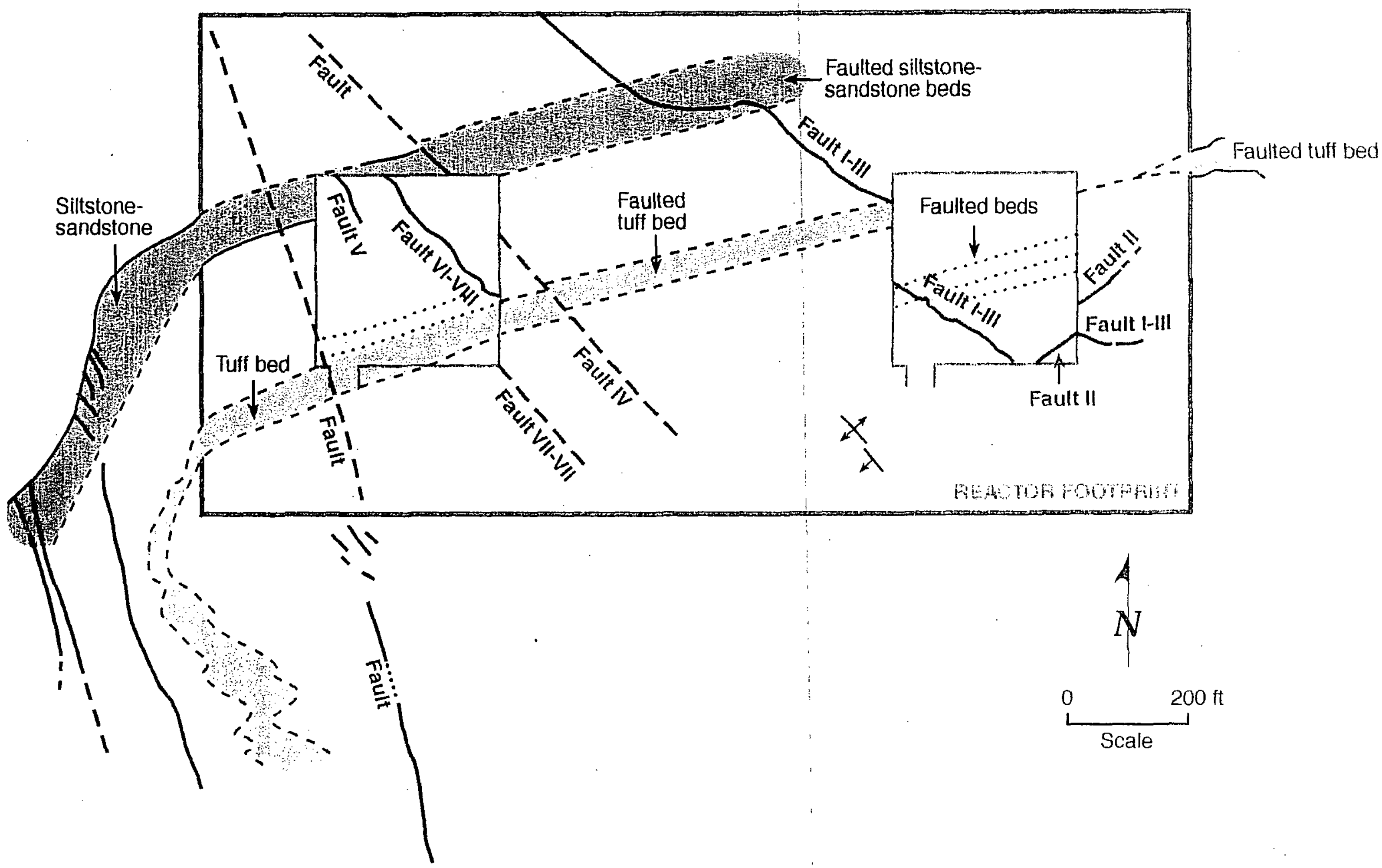


Figure 3-7 Washington Nuclear 3, Units 1 and 2. Mapped faults Through the Reactor Buildings (Ref. 3-24 and 3-28).

These and other studies conducted with respect to faults in the site vicinity, led the NRC staff to conclude that the faults were not capable faults as defined by the siting regulation, Appendix A to 10 CFR Part 100 (Ref. 3-26). There was no strong intervention regarding geosciences issues up to the time the site was abandoned. The NRC was assisted in its evaluation by the US Geological Survey and individual geological and seismological consultants. Input to the analysis was obtained by both the applicant and NRC from experts with the Geological Survey of Canada and from universities throughout the Pacific Northwest , Canada and Japan.

3.6.6 Volcanic Hazard

Volcanic hazards were assessed during the CP evaluation in much the same manner as previously described for the Hanford, Pebble Springs, and Trojan sites. Design basis quantities and rates of ashfall from the three nearest Cascade strato-volcanoes, Glacier Peak, Mount Rainier, and Mount St. Helens were determined (Figure 3-4). Following the May 18, 1980 eruption of Mount St. Helens, the volcanic hazards to the site were reassessed and the design basis for ashfall previously derived was found to be adequate.

CHAPTER 4 - SELECTED SITES IN CALIFORNIA

4.1 MENDOCINO

4.1.1 Background

The Mendocino site is located on the coast at Point Arena, California, in the northern California Coast Ranges, about 4.5 miles west of the main trace, and rift valley of the San Andreas Fault (Figure 4-1).

The site review began in 1972 prior to publication of Appendix A and continued into 1973 during preparation of the final draft and publication of the regulation. The siting criteria that were later incorporated into Appendix A were used as guidance by the applicant, Pacific Gas and Electric Company (PG&E), in the late 1960s and early 1970s for investigating this site. They were also used in the safety reviews by the staff and its advisors, the USGS and NOAA, and by the Advisory Committee on Reactor Safeguards (ACRS). Many of the individuals from the staff, the USGS, NOAA, ACRS and PG&E's consultants were involved in writing, commenting on, or revising Appendix A. Many of these scientists and engineers had been involved in the Malibu and Bodega Bay licensing activities, which provided some of the bases for assessing capable faults in Appendix A. PG&E withdrew its application for a Construction Permit on the Mendocino Plant in 1973 before the siting issues discussed below were resolved.

During these investigations and the staff's review of this site, the criteria were extremely beneficial in providing the guidance that resulted in a relatively detailed geological investigation at the immediate site. Extensive logging of trenches and core borings, surface geological mapping and detailed mapping of the sea cliffs adjacent to the site, demonstrated that there were no capable faults within the limits of these investigations. There was, however, considerable disagreement between the staff and its advisors and the applicant and its consultants about the significance of the results of those investigations to the site. The inability of exploratory techniques, particularly offshore geophysics, that were state-of-art at that time, to provide the resolution needed to base decisions about geologic and seismic hazards to the site, along with complex geology and high seismicity, were the reasons this site was abandoned. References 4-1 and 4-2 describe the main concerns of the AEC staff and its advisor, the US Geological Survey.

4.1.2 Tectonic Structure, Maximum Earthquake, and SSE Ground Motion

Although it took place prior to the publication of Appendix A, the investigation of this site was the first time that an applicant had used the technique described in Appendix A for determining the "zone requiring detailed faulting investigation," estimating a maximum earthquake associated with that zone, and estimating the distance it could occur from the site. A "control width" was determined for the San Andreas Fault Zone and used to estimate the proximity of the "zone requiring detailed faulting investigation" to the site. The formula presented in the regulation was used to calculate the maximum earthquake, a magnitude 7.5, to be associated with that control width. The maximum earthquake, or controlling earthquake, a magnitude 8.0+, based on the historic, 1906 earthquake, was assumed to occur at a distance of 4.5 miles from the site. The ground motion was then attenuated to the site, resulting in a design basis ground motion (SSE) pga of 0.5g (Ref. 4-3).

The zone boundary closest to the site that was determined in the way described above was not accepted by the staff in view of the possibility that other splays of the San Andreas Fault may exist offshore west of the site. If this were true the site would be within the San Andreas Fault Zone. The staff also adopted the position that there was insufficient data about the characteristics of ground motion in the near field to demonstrate that the applicant's analysis was conservative, and that the assumed epicenter distance of 4.5 miles from the site for the controlling earthquake may not be conservative. Using more recently developed ground motion estimates that employed regression analysis of the data base involving large near fault events, the staff would now estimate horizontal and vertical pga's over 1.0g at the site from an 8+ event on the fault.

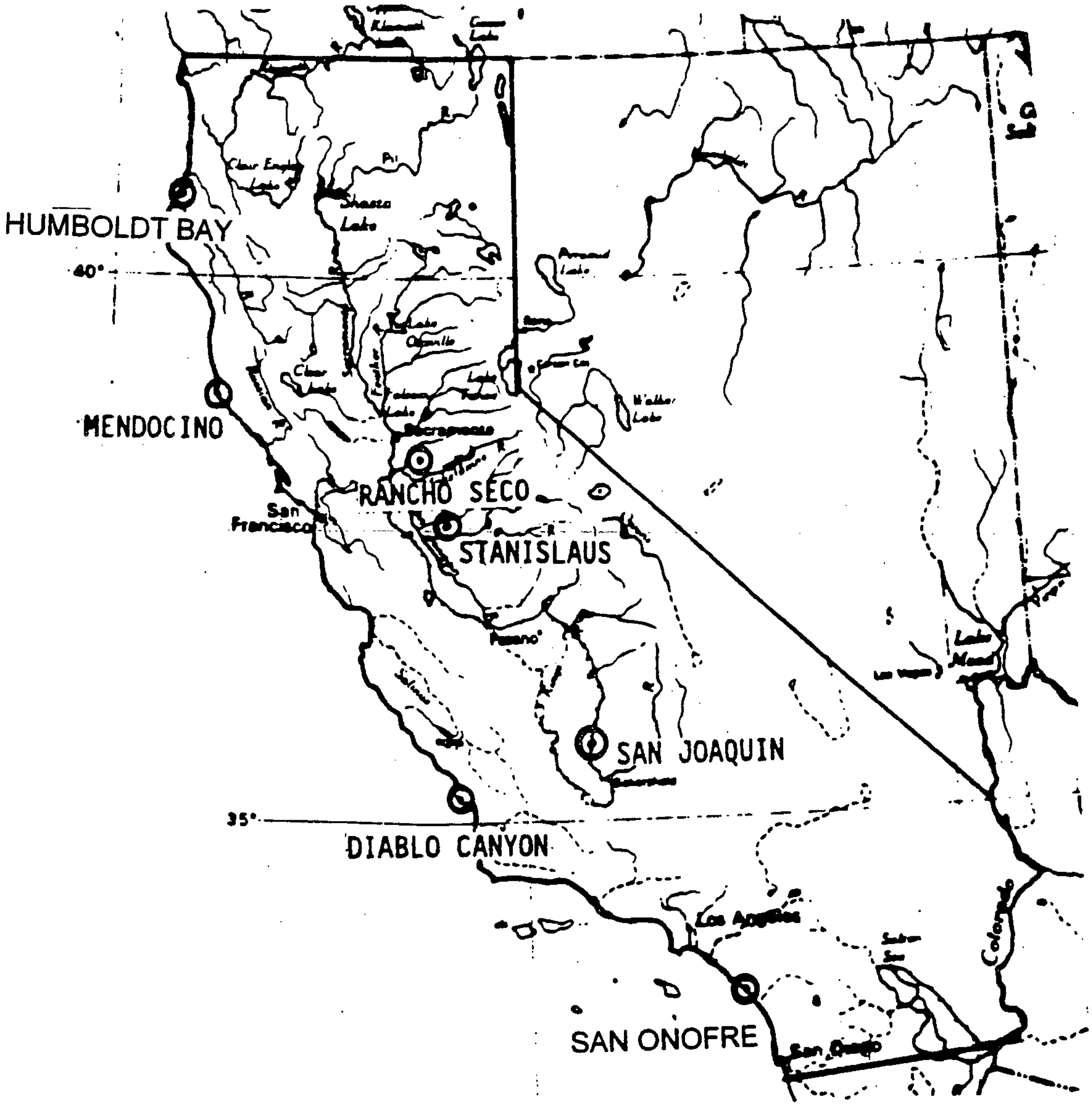


Figure 4-1 Locations of the California sites

4.1.3 Tectonic Structure and Capable Faults

The presence in the area of deformed (faulted) late Pleistocene marine terraces was not recognized by the applicant during site studies, even though long trenches were excavated across the regional grain and mapped in detail, and the sea cliffs were mapped in detail. The mapping identified several minor faults through the site, but there was substantial evidence that these faults were truncated by the marine terrace surface and overlying alluvium, indicating they were at least 105,000 years old. The post-Pleistocene faulting of the marine terraces was identified by the USGS during an airphoto analysis and a ground truth investigation by the applicant.

The applicant performed extensive seismic reflection profiling in the offshore area adjacent to the site. Anomalies were identified in the offshore seismic reflection records and were interpreted by the applicant's consultant to be erosional features, landslides, etc. An independent analysis of the same data by the USGS for the AEC resulted in an interpretation that the anomalies could also represent faults that displaced the ocean floor. Several seismic reflection lines were run across the offshore trace of the San Andreas Fault where it trends offshore north of Fort Bragg. The data from one of the lines that crossed the projected fault showed no indication of the San Andreas Fault, thus illustrating the uncertainties in the technique. It is often difficult to identify strikeslip faulting using reflection profiling.

Because the data was not definitive, faulted marine terraces were present in the site area, and the main trace of the San Andreas Fault was only 4.5 miles from the site, the staff assumed that the seismic reflection anomalies indicated the presence of young faulting offshore near the site.

4.1.4 Stability of Foundation Materials and Slopes

The potential for landslides due to erosion and undercutting of the sea cliff adjacent to the site was evaluated by the applicant and the staff. These occurrences are common in the site area, however, based on its analysis, the staff concluded that the rate of erosion of the cliff immediately west of the site and the distance of the proposed plant from the cliff (using appropriate factors of safety) precluded this being a hazard during the life of the plant.

Related phenomena occur when erosion cuts deep into the sea cliff along zones of relatively soft sedimentary rock, discontinuities, or other zones of weakness, thus forming sea caves. In many instances the ground surface subsides over these caves and can eventually collapse as undercutting continues, to form deep circular pipes that extend from the ground surface to about sea level. There was no evidence for these features in the immediate site vicinity.

4.1.5 Conclusion

Because of the proximity of the site to the San Andreas Rift Valley, the presence of deformed terraces east of the site and the suggestion in the seismic reflection data of sea floor offset west of the site, the staff could not rule out surface faulting beneath the plant site, even though minor faults exposed in the trenches and on the sea cliff did not disrupt Pleistocene terraces. Additionally, based on the lack of adequate precision of the offshore exploratory and analytical techniques available at the time, to demonstrate the absence of recent faulting in the offshore adjacent to the site, and other uncertainties; and based on the recommendation of the AEC and its advisor, the USGS (Refs. 4-1 and 4-2), the applicant withdrew its application for a construction permit.

4.2 SAN JOAQUIN

4.2.1 Background

The site is within the southern San Joaquin Valley, 33 miles northwest of Bakersfield (Figure 4-1), in the Great Valley Physiographic Province. The Great Valley trends north-northwesterly between the Sierra Nevada and Coast Ranges for about 450 miles. An early site review was conducted in the middle 1970s after publication of Appendix A, and the criteria of the rule were strongly utilized in this review. The applicant did not apply for a Construction Permit.

The principle issues during this review were: the capability and senses of displacement of mapped local faults; the maximum earthquakes in the region and site vicinity significant to the safety of the site; and the potential for subsidence and ground breakage due to the withdrawal of subsurface fluids and their effects on the site. Reference 4-4 summarizes the staff's and its advisor's, the USGS, conclusions regarding this site.

4.2.2 Tectonic Structure and Maximum Earthquake

Extensive investigations had been carried out for many years in the site region in the search for hydrocarbons, therefore, most geological structures had been mapped. The main issues concerning tectonic structures and seismic sources centered around the extent to which subsurface faults associated with the mapped tectonic structures at depth projected upward toward the ground surface, the ages of strata that truncated them, and whether the faults had significant components of strike slip movement. Extensive use was made of subsurface structural maps and stratigraphic sections, most of them proprietary data, produced by the petroleum companies and consulting firms.

The maximum earthquake to which the site may be exposed was considered to be a magnitude 8.5 comparable to the 1857 Fort Tejon Earthquake on the San Andreas Fault 52 km from the site. An SSE design basis ground motion peak ground acceleration of 0.55g along with the for Regulatory Guide 1.60 seismic design response spectra was based on that consideration. Other events evaluated were a magnitude 7.7 similar to the 1952 Kern County Earthquake on the White Wolf Fault, 84 km from the site, a magnitude 7.0 on the Pond Poso Fault 18 km from the site and a local magnitude 5.0 near the site.

4.2.3 Tectonic Structure and Capable Faults

Faults beneath the site or in the site vicinity, such as the Greeley and Semitropic faults, were concluded to be non-capable, normal faults because they were capped by strata shown to be hundreds of thousands to millions of years old. Structural relationships across these faults ruled out substantial strike slip displacement. However, the northwest striking Pond Poso fault is located about 18 km from the site and ruptures strata within the upper 10 feet of ground surface and is, therefore, capable. The Pond Poso Fault is about 60 km long.

4.2.4 Stability of Foundation Materials and Slopes

Considerable subsidence due to the withdrawal of underground fluids (primarily groundwater) has occurred several miles to the north of the site. This was accompanied by ground fissuring. This condition was expected to be allayed in the future with the import of surface water via a newly constructed canal, thus reducing groundwater withdrawal. To monitor subsidence a compaction meter, leveling network, and strain measurement networks were established at the site.

4.3 STANISLAUS SITE

4.3.1 Background

The Stanislaus Site is located in the Great Valley of California, about 25 miles east of Modesto (Figure 4-1). Stanislaus was one of several alternate sites that PG&E investigated following a regional site selection study in 1975 and 1976. The purpose of the regional study was to identify potential nuclear power plant sites away from the seismically active California coastal region, which could satisfy the Appendix A criteria and yet be located close to an adequate water supply. The AEC/NRC had encouraged this approach.

An early site review had been planned to be conducted in the same manner as that accomplished for the San Joaquin site, beginning in 1976. Before this could take place the site was withdrawn from consideration. Appendix A was used by the applicant as a guide for its investigations and by the staff during its preliminary review.

4.3.2 Pre-Early Site Evaluation

As with other sites in California the two major concerns with respect to Stanislaus were the potential for surface fault rupture at the site, and the seismic potential within the site region. The Stanislaus site was selected because it was located in a region of relatively low seismicity (for California), and it was in an area underlain at very shallow depths by a well mapped, unfaulted lithified stratigraphic unit within the Mehrton Formation of demonstrated antiquity, that is uniformly spread around the site area. The age of the Mehrton Formation exceeds the upper age limit requirement for fault movement in Appendix A. The continuity of this unit throughout the site as demonstrated by geological mapping, trenching and core borings, confirmed that there was no potential for surface faulting at this site.

The site is about 8½ miles west of the Bear Mountain Fault Zone of the Foothills Fault System. The Foothills Fault System has been relatively inactive historically but intensive investigations for Auburn Dam following the 1975 magnitude 5.7 Oroville Earthquake indicated that splays of the fault system were capable. Based on that finding the Stanislaus SSE was proposed to be 0.3g. The site was later deferred for reasons other than geology or seismology.

4.4 RANCHO SECO

4.4.1 Background

The Rancho Seco Nuclear Power Plant site is located near the eastern side of the Sacramento Valley approximately 20 miles southeast of Sacramento (Figure 4-1). The licensing reviews were conducted in the late 1960s and early 1970s, prior to publication of Appendix A, but during its preparation. This discussion concerns a reassessment of the seismic and fault displacement hazards as the result of an earthquake that occurred after the plant received an Operating License.

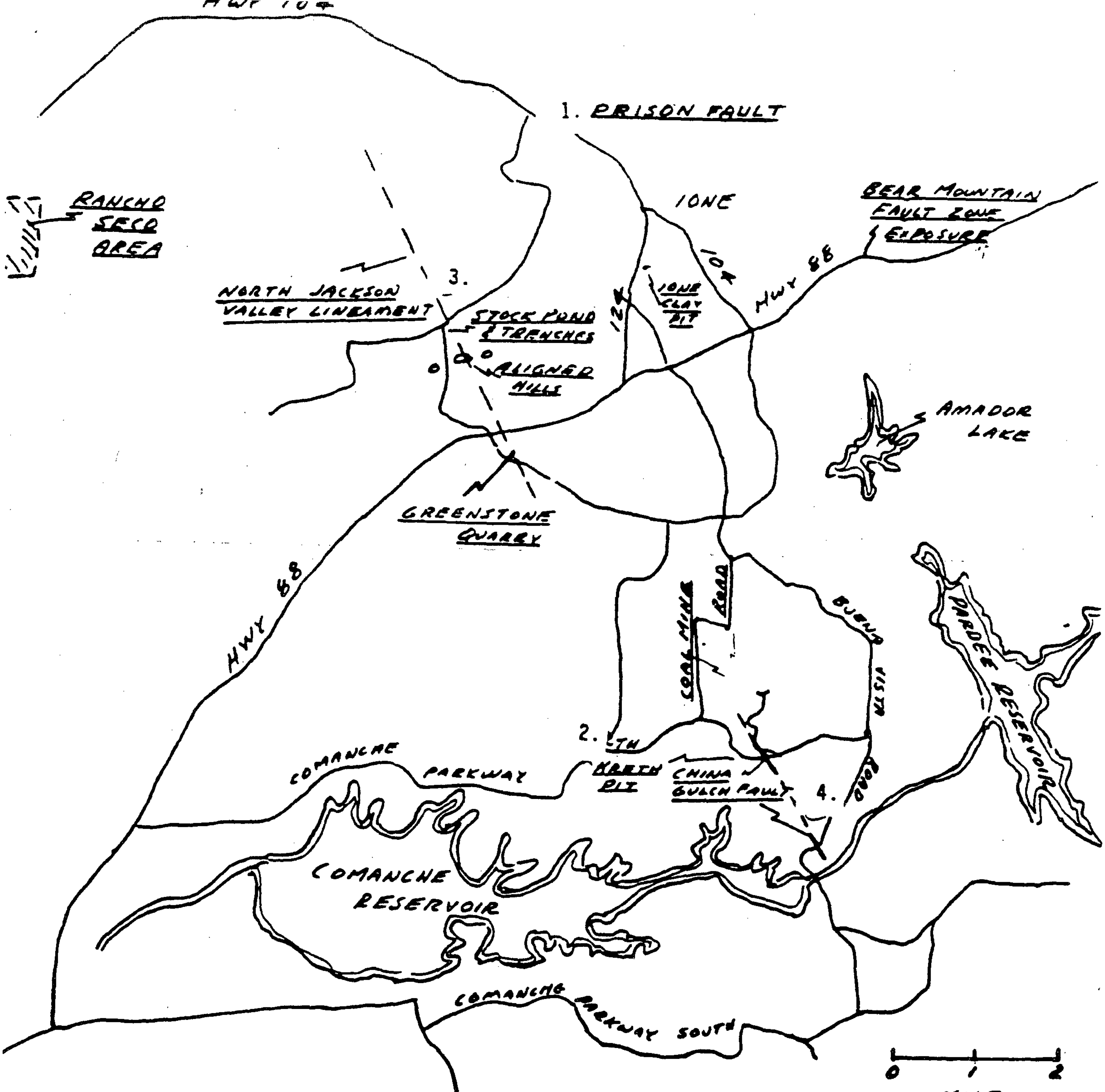
The Rancho Seco Nuclear Power Plant received its Operating License in the early 1970s. This site is an example of an operating plant where it became necessary to reassess the geology and seismology of the region around the site because of the occurrence of a significant earthquake, the 1975 Oroville magnitude 5.7 earthquake, which was accompanied by ground rupture along a branch of the Foothills Fault System (FFS). The westernmost system of faults of the FFS is the Bear Mountain Fault Zone. The location of the surface rupture is about 85 miles north of the plant. The reevaluation was considered to be necessary because the FFS extends to the south from the area of the Oroville earthquake to within about 10 miles of the Rancho Seco site at its closest known approach at the time. When Rancho Seco was licensed, the FFS was considered to be a pre-Cenozoic fault system and not likely to localize earthquakes.

4.4.2 Reevaluation of the Regional Geology and Potential Capable Faults

In 1980, the NRC, at the request of the California Division of Mines and Geology (CDMG), required the Sacramento Municipal Utility District (SMUD), the Rancho Seco Nuclear Power Plant licensee, to reassess the geology and seismology of the region around the Rancho Seco site, focussing primarily on the capability of the FFS components nearest the site, but also to consider and evaluate the possibility of capable faults closer than 10 miles.

Previous investigations by Woodward-Clyde for the Stanislaus site in 1976 had determined that one of the splays of the FFS, the Poorman Gulch Fault, had undergone multiple displacements of 100,000 year-old colluvium, and therefore was considered to be capable according to the Appendix A criteria. This particular offset is located 22 miles east of the Rancho Seco plant. Investigations during the reevaluation phase described below could not verify a tectonic offset of this colluvium in the field. SMUD consultants contended that the offsets were not tectonic, however, an analysis was performed assuming the occurrence of a magnitude 6 earthquake on the fault, and the ground motion from this event was propagated to the site. The resulting ground motion at the site was enveloped by the seismic design basis for the plant.

The revaluation-investigation was conducted within a radius of 25 miles around the site, and detailed investigations were concentrated on about 10 specific locations. The nearest faults of the FFS that had been mapped up to this time were re-investigated in detail. Only the Poorman Gulch Fault, was identified as possibly being capable. The results of these investigations were reviewed by the NRC and two field reconnaissances were conducted in 1985 and 1987 (Refs. 4-5 and 4-6).



Explanation: Numbers are the locations of suspected capable faults described in the text.

1. Prison fault.
2. Comanche Reservoir fault.
3. Jackson Valley Lineament.
4. China Gulch fault.

Figure 4-2 Area of fault investigations southeast of Rancho Seco.

As a result of these reviews, many of the earlier concerns were resolved, and narrowed down to four issues: (1) A possible fault exposed in an excavation for a new prison facility about 7 miles east of the plant; (2) an apparent deformation feature, previously mapped as a fault, 1 mile north of the Comanche Reservoir, approximately 12 miles southeast of the plant; (3) an airphoto lineament that projects from a fault exposure in a quarry toward the north-northwest to within about 4 miles from the plant; and (4) the capability of the China Gulch Fault, the exposure of which is about 13 miles southeast of the plant, and its possible extension to the north, closer to the plant site (Figure 4-2). Additional work was required regarding these features to demonstrate that they did not represent a hazard to the site greater than its seismic design.

Additional investigations that included trenching and geological mapping, geochronological studies, and interpretation of remote sensing data were carried out to resolve these issues. A report presenting the results of these studies was submitted in October, 1987 (Ref. 4-7).

Based on the findings and the technical bases for them presented in this report, the staff concluded that the feature exposed in the prison excavation was an erosion feature, a paleo-channel, and not a fault. The feature north of the Comanche Reservoir, after additional investigations, turned out to be a high angle unconformity that resembled a fault. Even if it had been a fault, it was capped by a stratum of sufficient age to preclude its capability.

The North Jackson Valley Lineament was investigated in considerable detail by mapping outcrops and quarry walls, reevaluating the trench logs, and airphoto interpretation. The lineament was found to be discontinuous and caused primarily by a break in the slope at a lithologic contact where Tertiary and Quaternary sediment to the west overlap and pinch out over Mesozoic volcanic rocks to the east.

The China Gulch Fault was also re-investigated in detail, mainly by geological mapping and several supplemental excavations. Radiometric geochronologic analysis indicated that the last displacement on the fault occurred more than 4 million years ago. Another staff field review was conducted in 1989 to examine the new findings. The NRC concluded that there was no hazard identified that would challenge the seismic design of the Rancho Seco plant or cause surface faulting at the site (Ref. 4-8).

4.5 DIABLO CANYON

4.5.1 Background

The Diablo Canyon Nuclear Power Plant is located on the coast of central California about 12 miles west of San Luis Obispo, on a broad peninsula between Estero Bay and San Luis Bay, south of Point Buchon and north of Point San Luis (Figure 4-1). The site is situated on a marine terrace on the west flank of the San Luis Mountains of the Coastal Ranges Physiographic Province.

The site is underlain at depth by Jurassic Franciscan formation basement derived from subduction of the Pacific plate beneath the North American plate in the Jurassic period. Overllying the basement are predominantly middle to late Cenozoic marine sedimentary and volcanic rocks formed during a period of transtension during the development of the San Andreas transform fault system. Bedrock directly beneath the plant is early middle Miocene Obispo formation. The stratification generally dips to the north at variable angles around the site.

Quaternary benches were cut into these and younger rocks by the ocean when sea level was at higher elevations relative to the land and are preserved as relics at various levels on the coastal landscape. Colluvial and alluvial deposits overlie these terraces. Likewise, offshore wave-cut platforms created at times when sea level was lower relative to land are also preserved. These marine terraces, especially those on shore, have been invaluable tools used during the site investigations to demonstrate an upper limit of the time of most recent displacement on faults at the site. They were particularly useful during the most recent (post-construction) Long Term Seismic Program (LTSP) investigations to estimate uplift, age of tectonic deformation, and slip rate on faults (Ref.'s 4-12 and 4-13).

Licensing related activities for the Diablo Canyon extended from about 1968 until 1991. The CP review was carried out in the late 1960s prior to publication of the siting regulation, but the preliminary version of the Appendix A criteria, particularly regarding capable faulting was used in assessing the site. The OL review was carried out after Appendix A publication and the criteria were used. The Long Term Seismic Program (LTSP) described later went far beyond Appendix A criteria. Modern investigative and analytical techniques were used including a probabilistic seismic hazard analysis. The methods used in the LTSP are examples of the application of seismic hazard investigations and analyses for western U.S. sites that are recommended in Regulatory Guide 1.165, which describes acceptable methods to fulfill the requirements of the revised seismic and geologic siting regulation, Section 100.23 to 10 CFR Part 100.

4.5.2 Major Issues During the Construction Permit (CP) Assessment and the Staff's Conclusion

The following major issues were addressed by the applicant and staff during the CP review:

1. Determination of the design earthquakes. The bases for the SSE included consideration of the following earthquakes: a great earthquake (magnitude 8+) on the San Andreas Fault - 55 miles from the site; a large earthquake (magnitude 7) on the Sur-Nacimiento Fault - 20 miles from the site; a moderate earthquake (magnitude 6.75) on the Edna Fault - 3 miles from the site, and a moderate (magnitude 6.5) on a local unknown fault, including the offshore. These analyses resulted in peak horizontal ground acceleration of 0.4 g for the SSE and 0.2g for the OBE.

2. Age of faults at the site and their significance. Several faults were mapped on the sea cliff immediately south of the plant during the initial site investigations. Mapping of exploratory trenches and later, the excavation walls for the plant showed that these faults projected to the plant area (Figs. 4-4 and 4-5). Several other small, discontinuous faults were mapped in the foundation excavations for Unit 1 and the outlet structure. Extensive geologic mapping of trenches and the sea-cliffs adjacent to the site clearly demonstrated that the faults were truncated upward by the bench created by marine erosion along the base of the overlying terrace deposits. These terrace deposits have been dated at other locations along the California coast as being 80,000 to 120,000 years old (Ref. 4-9). Although this is less than the 500,000 criteria in Appendix A for multiple movements, the faults were minor and last movements on them were concluded to be related to tectonism in the Pliocene-early Pleistocene, based on similarity to other structures in the area known to have originated during that period.

3. The possible projection to the near offshore of an east-west ocean fracture zone. USGS marine seismic reflection profiling showed that the fracture zone did not project near shore.

Major Issues During the Operating Licensing (OL) Evaluation and the Staff's Conclusions

A major fault (later named the Hosgri Fault, see Figure 4-3) that bounded the eastern side of the offshore Santa Maria Basin was mapped by oil company geologists Hoskins and Griffith (Ref. 4-10). This fault passed about 3 miles offshore from Diablo Canyon. Issues during the OL were focussed on the seismic and geologic hazards represented by this new discovery, and included:

1. Extent of the Hosgri fault. Was it joined with the San Simeon, San Gregorio to the north and Transverse Ranges faults to south forming a 400 km long major fault with a cumulative offset of more than 100 km, and capable of generating a magnitude 8+ earthquake? Based on the results of extensive investigations by the applicant and others, the staff concluded that the Hosgri Fault was a 90 mile long fault that was part of a larger system of anastomosing and en echelon faults that also included the San Gregorio and San Simeon faults. The entire system was connected but not in such a way as to rupture in its entirety during a single earthquake. Maximum strike-slip offset was concluded to be less than 20 miles in 5 million years, with some reverse dip-slip displacement.

2. Maximum earthquake for the fault. The 1927 magnitude 7.2 Lompoc Earthquake was assumed to be associated with the Hosgri Fault, although the weight of the geological, seismological, and geophysical

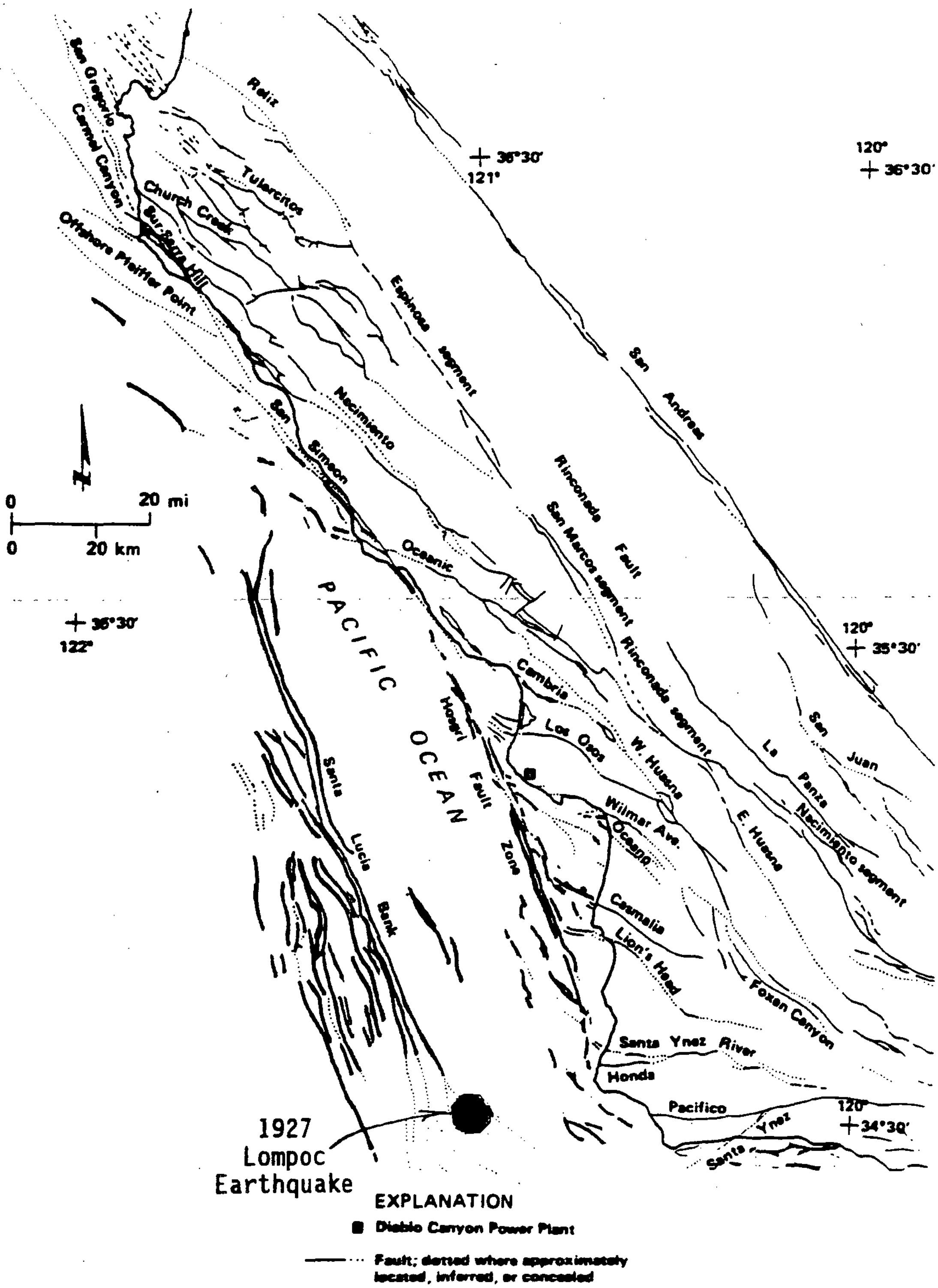


Figure 4-3 Map of faults in the south-central California coastal region illustrating the regional geologic setting of the south-central California coast (Ref. 4-12). The location of the 1927 Lompoc Earthquake as determined by PG&E is also shown.

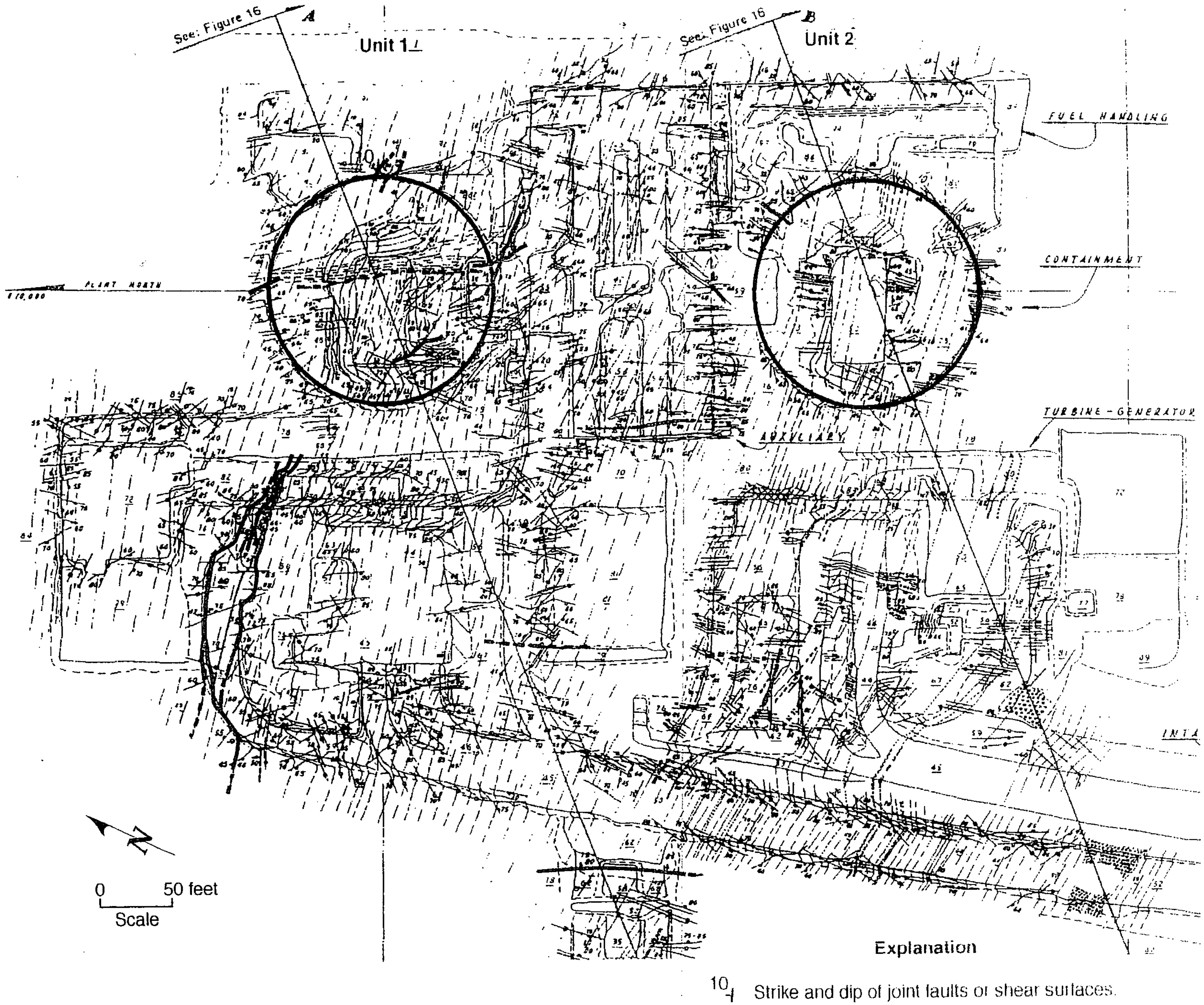


Figure 4-4 Diablo Canyon NPP reactor excavations with mapped faults and rock joints (Refs. 3-27 and 4-12).

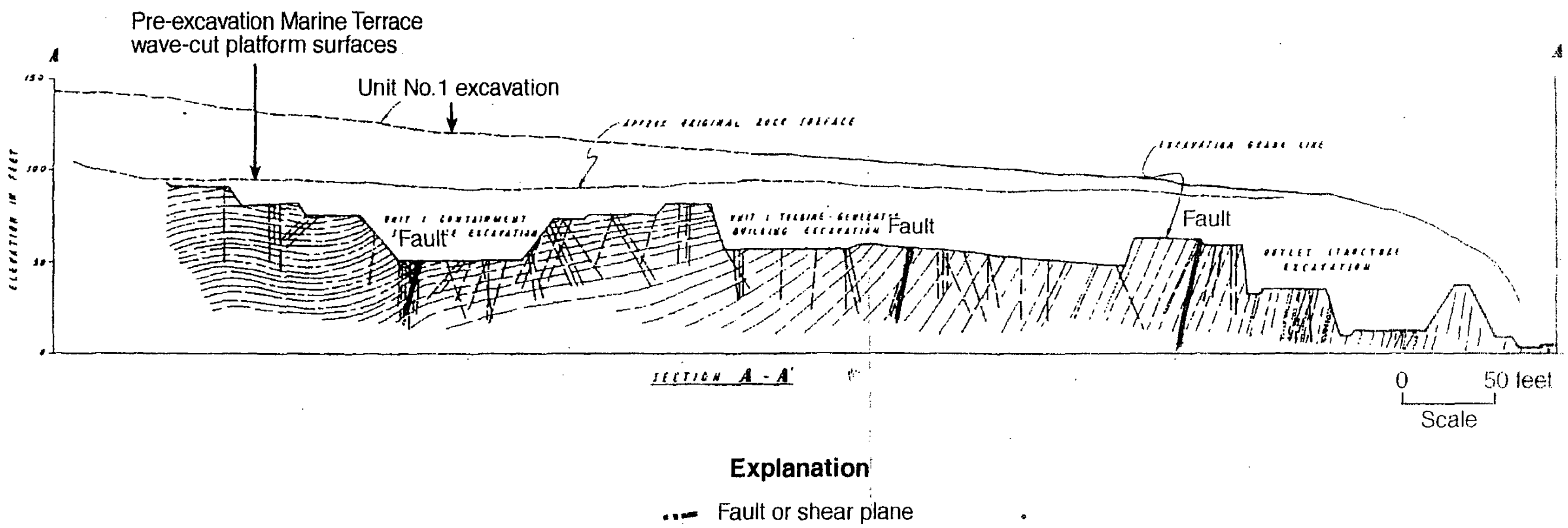


Figure 4-5 Cross Section of Diablo Canyon NPP Unit 1 Reactor Excavation (Refs. 3-27 and 4-12).

evidence supported the interpretation that this event was associated with Transverse Ranges structures. Also, the potential for high accelerations such as the high peak horizontal ground acceleration (1.25g) recorded at Pacoima Dam during the 1971 San Fernando Earthquake, had to be taken into account. Thus, a magnitude 7.5 was assumed to be possible on the Hosgri Fault, about 3 miles from the site resulting in an SSE horizontal ground motion with a peak horizontal acceleration of 0.75g, with individual spikes to 1.25g. The OBE remained 0.2g (less than ½ SSE required by Appendix A) and the staff and applicant successfully supported these values at the ALAB and Atomic Safety Licensing Appeals Board (ASLAB) Hearings.

3. Capability of the Hosgri Fault. Because the Hosgri Fault offset the sea floor, which was formed 17,000 years ago, it was concluded to be a capable fault following the criteria of Appendix A.

4.5.3 Impact of New Information on the Operating License Evaluation

In 1984, during the final stages of the OL activities, exploratory geologists, Crouch and others, published the results of their work, which led them to conclude that the Hosgri fault and other coastal faults in central and southern California were primarily reverse faults that were listric to a master decollement at about 10 km depth (Ref. 4-11). This hypothesis and supporting data raised the following issues which illustrated some of the shortcomings of Appendix A:

1. With the rolling over and flattening of the Hosgri and other faults beneath the site, are they closer to the plant than the ocean floor trace?

2. Propagation of ground motions from an earthquake on a thrust fault beneath the plant may have different characteristics than those evaluated during earlier licensing activities, which assumed that the Hosgri was predominantly a strike slip fault.

3. Evidence from the Coalinga Earthquakes demonstrated that an active fault (capable fault) can express itself during a moderate to large earthquake at or near ground surface as folding rather than surface rupture (blind fault). Seismic reflection profiles offshore indicated folding without rupture of sediment (Pliocene) above thrust faults of the Hosgri Fault Zone near Diablo Canyon. This is an issue that is not specifically addressed by Appendix A.

4.5.4 Licensing Condition to Address the Issues and the Long Term Seismic Program

Because of these concerns, the existence of considerable new information since the CP investigations, and a recommendation made by the ACRS in 1978 that the seismic design basis be reevaluated in 10 years, a condition was made a part of the OL licenses for DCNPP Unit 1in 1984. The seismic condition consisted of four parts: reevaluate the geology and seismology of the site and region; reevaluate the magnitude of the earthquake used to determine the seismic design basis; reassess the vibratory ground motions, and with that information reevaluate the site and other relevant effects such as soil structure interaction; and perform a seismic probabilistic risk assessment of the plant.

To address these issues numerous meetings were held among the PG&E and its consultants, and the NRC and its advisors. A program that was responsive to the license seismic condition was developed by PG&E and approved by the NRC in 1985. PG&E called the program the Diablo Canyon Long Term Seismic Program (LTSP), and a final report (Ref. 4-12) was to be provided in three years (1988).

The first two elements of the license seismic condition (geology and seismology, and ground motions) were addressed by detailed regional and site geological, geophysical and seismological investigations. Existing data was reviewed, including proprietary oil company data.

4.5.5 Geological, Seismological, and Geophysical Investigations

The investigations consisted of two parts, offshore studies and onshore studies. Much of the existing offshore data, primarily seismic reflection data, were reprocessed using modern processing techniques. New seismic reflection lines were run by PG&E, to fill the gaps in existing data, to resolve specific issues, and in the previously unexplored near-offshore area from Cape San Martin in the north to Pedernales Point to the south. The near-shore lines were high resolution, shallow penetrating common depth point (CDP) surveys. Three deep crust penetrating seismic reflection and refraction lines were made, two extending from the continental slope to eastern Estero Bay, and eastern San Luis Bay respectively, connecting with similar lines on shore, and the third was conducted parallel to the coastline and crossed the two east-west lines.

Bathymetric surveys were made near San Simeon Bay and in Estero Bay from Montano de Oro to Point Buchon and along the coast into San Luis Bay. Diver geologists mapped and gathered samples at certain locations such as San Simeon Bay, along the coast of the San Simeon-Pismo structural block and in San Luis Bay to trace the seaward extensions of faults mapped onshore. The USGS, as advisor to the NRC, reviewed PG&E offshore data and conducted independent analyses of the geophysical work.

The onshore investigations consisted of geologic and geomorphic mapping to identify young faults and characterize them as to their earthquake potential and potential for causing surface deformation. A valuable tool in characterizing the hazard of faults was the presence of up to 11 marine terraces of known age, ranging in age from the one currently being developed at the shoreline to one created approximately 700,000 years ago. The land has been undergoing continuous uplift during the Quaternary, so the terraces are situated from present sea level to many hundreds of feet above sea level. Fluvial terraces that had formed along streams were also mapped. These terraces served as reference points in determining uplift rates and amounts of fault offsets.

Core borings were drilled to supplement the geologic and geomorphic studies. Trenches were excavated across faults and the ages of the materials were determined for use in characterizing the faults as to their seismic potential. Geology at depth was explored by examining existing oil well logs and conducting vibroseis surveys across the San Luis Pismo Block and the onshore Santa Maria basin. These lines were tied-in with the offshore work.

Independent geological investigations supported by the NRC were conducted by the University of Nevada, Reno. These studies consisted of mapping fluvial and marine terraces, independently mapping PG&E trenches, conducting regional remote sensing analyses, mapping and analyzing the tectonics of the Casmalia Hills, Orcutt fault and other features in the Point Sal area, reviewing PG&E data, and making recommendations about the seismic potential of faults in the area. The USGS also reviewed PG&E's onshore work and provided evaluations to the NRC.

Earthquake studies were performed by PG&E that consisted of establishing a seismic network, monitoring earthquakes and analyzing data to determine hypocenter locations, focal mechanisms, and magnitudes, analysis of historical earthquakes, and performing ground motion analyses.

4.5.6 Probabilistic Seismic Hazard Analysis

A probabilistic seismic hazard analysis was also performed using the logic tree approach. Fault, earthquake, ground motion, and other characteristics were considered and weighted, based on the scientific judgement of experts. Characteristics addressed by the experts included: senses of slip on faults, downdip geometries, maximum rupture lengths (segmentation), rupture areas, depths and thicknesses of the seismogenic zone, lengths of fault, maximum and average displacements per event, and the largest historical earthquakes associated with the faults, and the techniques used for magnitude assessments were also evaluated.

4.5.7 Previously Unidentified Tectonic Structures

As the result of investigations by PG&E and the UNR, many new discoveries were made about the tectonics of the Diablo Canyon site area. These include the identification of several previously unidentified capable faults such as the Los Osos, Olson, San Luis Bay, Wilmar Avenue, Pecho and Oceano faults (Figure 4-3). The site is situated on the San Luis-Pismo structural block which is oriented west-northwest, is about 10 km wide, and bounded to the north-northeast by the Los Osos fault and to the south-southeast by the Southwest Boundary Fault Zone. Both boundaries intersect or merge with the Hosgri Fault Zone.

The Los Osos fault is a reverse fault that dips to the southwest at an angle of about 60°. The Southwest Boundary Zone is from two to eight km wide, and is comprised of a zone of reverse faults that dip steeply to the northeast, including the Olson, San Luis Bay, Wilmar Avenue, Pecho, and Oceano faults. Expected maximum earthquakes were determined for these faults, both deterministically and probabilistically, but the ground motions from these events were found to be dominated by the Hosgri earthquake ground motions. Figure 4-3 is a map of the region around the Diablo Canyon site showing significant faults and other structures, and the PG&E estimated location of the 1927 Lompoc Earthquake.

4.5.8 Seismic Potential of the Hosgri Fault Zone

Based on the results of these studies and advice from the UNR and USGS, the NRC concluded that the Hosgri Fault Zone is about 110 km long, and is part of the San Gregorio-Hosgri Fault System, which extends for more than 400 km from just west of San Francisco to Pedernales Point in the Transverse Ranges to the south. The San Gregorio-Hosgri Fault System is fundamentally a strike slip system comprised of the San Gregorio, Sur, San Simeon and Hosgri faults. Fault displacement is transferred between the San Simeon and Hosgri faults across a Quaternary pull-apart basin, the Cambria Basin, located offshore between San Simeon Bay and Estero Bay. The Hosgri Fault is slipping at the rate of 1 to 3 mm per year (Ref. 4-13).

The Hosgri fault dips to the east-northeast at an angle ranging from 60 to 90°, and there is a substantial component of vertical slip on the fault equal to about 1/3 of the horizontal slip. The deterministic maximum earthquake from the deterministic investigation is assumed to be similar in size to the 1927 magnitude 7.0 Lompoc Earthquake occurring on the closest approach of the Hosgri fault zone to the site (4.5 km). Based on the probabilistic analysis, an expected maximum earthquake of 7.2 is assumed to occur at the closest approach of the Hosgri fault zone to the site (4.5 km). This earthquake is controlling and overshadows the expected maximum events on other faults in the region.

4.5.9 Safe Shutdown Earthquake Ground Motion

Except for general agreement regarding the magnitude of the controlling earthquake (M_w - 7.2), there were disagreements among the involved groups on other issues such as sense of the slip and angle of dip on the Hosgri fault zone. However, these differences did not significantly challenge the seismic design basis for the plant. The NRC staff concluded, based on its analysis and that of its ground motion consultants, that the PG&E LTSP horizontal 50th and 84th percentile spectra are appropriate for the design evaluation above 1 Hz; however, higher ground motions should be considered at and below 1 Hz. Higher motions should also be considered for the 84th percentile vertical spectra between 1 and 10 Hz.

4.5.10 Relation to the Revised Siting Regulation

The analysis of this site is an example of the way in which deterministic and probabilistic analyses of western U.S. sites could be utilized in developing Safe Shutdown Earthquake ground motions as required by Section 100.23 to 10 CFR Part 100, and described in Regulatory Guide 1.165.

CHAPTER 5 - OTHER SITES IN THE WESTERN UNITED STATES

5.1 POWER BURST FACILITY - PBF

5.1.1 Background

The PBF is located at the Idaho National Engineering Laboratories (INEL), which was called the National Reactor Test Site (NRTS) at the time of this review (Figure 5-1). The site is in the Snake River Plain Physiographic Province in southern Idaho.

The review took place during 1971-1973, prior to the publication of Appendix A, but the criteria of the Appendix were used by the AEC Regulatory staff, the AEC Division of Reactor Development Technology (RDT), and the USGS and NOAA, advisors to the AEC Regulatory staff.

5.1.2 Tectonic Province, Maximum Earthquake, and Ground Motion

The Snake River Plain is relatively aseismic, but the Intermontane Seismic Zone, which characterizes the surrounding Basin and Range Province, is seismically active (Ref. 5-1). The issue was whether or not the Snake River Plain was somehow decoupled from the Basin and Range tectonic structures, perhaps by bounding, east-west striking faults. This hypothesis was supported by the apparent termination of Basin and Range seismicity, structure, and topography at the boundaries of the Snake River Plain. If this could be shown to be true, one would not have to assume the occurrence of the maximum credible earthquake of the Basin and Range out on the plain near the site. This was the position of the AEC RDT.

The design basis ground motion (0.25g) that AEC RDT proposed was based on the assumption that an earthquake similar to the 1959 magnitude 7.2 Hebgen Lake, Montana Earthquake could occur at the closest approach to the site of the Basin and Range Province. The regulatory staff did not agree that this approach was conservative without additional evidence to support it, because regional geological evidence suggested the continuation of Basin and Range structure beneath basalts underlying the Snake River Plain.

5.1.3 Tectonic Structures and Capable Faults

The Arco Fault and the Howe Fault, which are located northwest and north of the site respectively in the Basin and Range Province north of the Snake River Plain, were demonstrated to be capable faults. The Howe Fault had been trenched by the USGS several years before this evaluation was started (Ref. 5-2). Mapping of the trench identified not only displacement of Recent alluvium, but also evidence of multiple displacements during the Holocene. A continuation of the Howe Fault beneath the Snake River Plain was suggested by a system of rhyolite domes aligned along a projection of the fault out onto the plain closer to the site. A continuation of the Arco Fault was also suggested by a fissure expressed in young basalt flows along its southward projection.

5.1.4 AEC Regulatory Position

The review by the AEC Regulatory staff was discontinued before it had established final positions regarding these issues. However, the process points out many of the difficulties the Regulatory staff has had in applying the commercial nuclear power plant siting criteria (Ref. 1-1) to small test reactors like PBF, and to other facilities. Less stringent criteria were more appropriate because of the PBF test reactor's small size, and the fact that it would operate periodically and only a fraction of the time (a few hours at a time) compared to a commercial power reactor. However, in this case and others that followed, the decisions were left to the geoscientists, who had limited knowledge about the operating procedure of test reactors or the consequences of their failure, and thus were not qualified to authorize less stringent criteria. The geoscience reviewers had no recourse but to use Appendix A as the basis for their decisions. This problem occurred time and time again regarding the licensing of small test reactors at universities, naval reactors, uranium mill tailings dams, radioactive waste disposal sites, etc.

NATIONAL REACTOR TESTING STATION VICINITY MAP

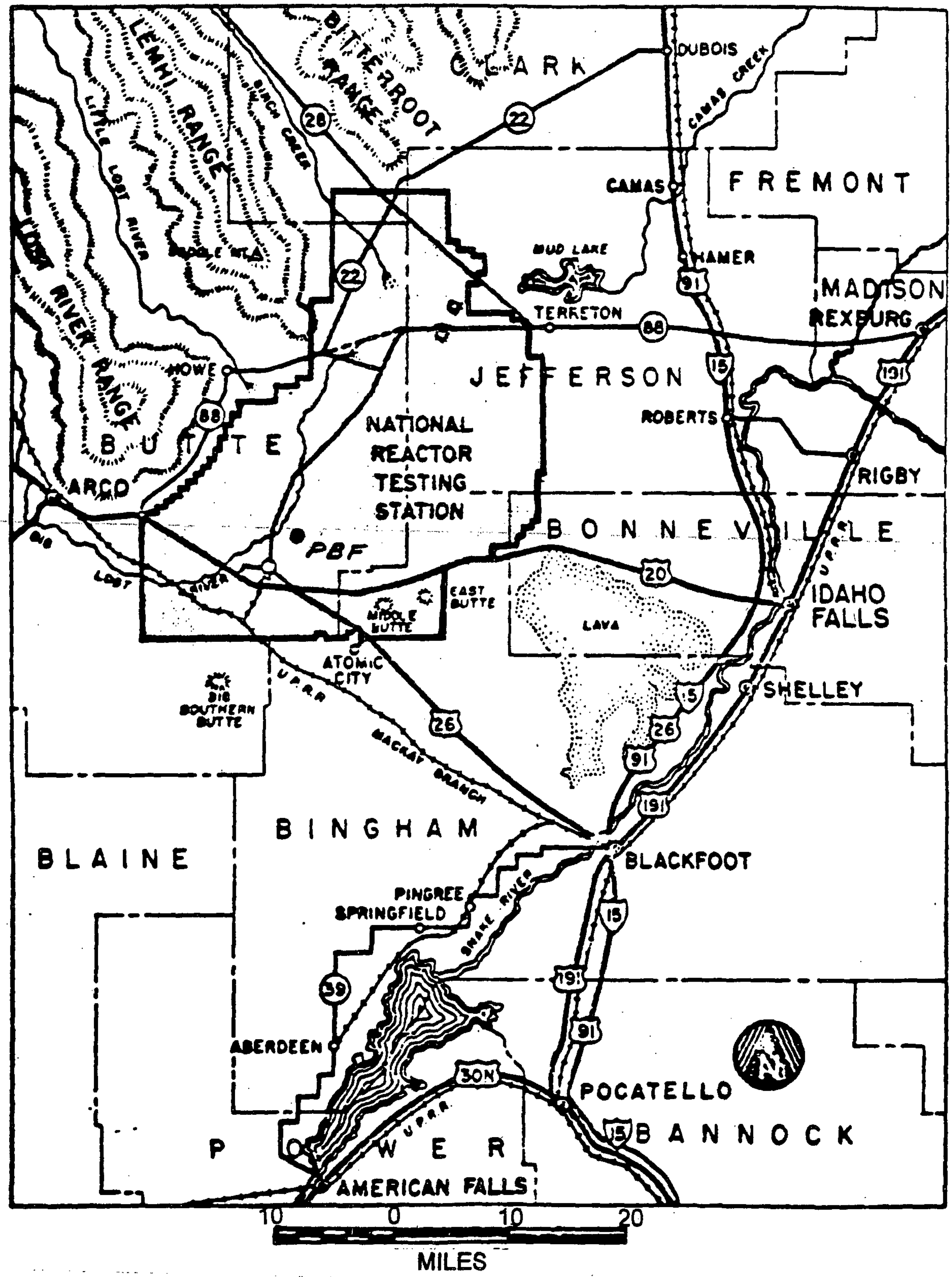


Figure 5-1 Map of the vicinity of NRTS and the Power Burst Facility (Modified from Ref. 5-1).

5.2 LUCKY MC PROJECT - URANIUM MILL TAILINGS DAM

5.2.1 Background

The Lucky Mc Project is one of many mill tailings dam sites that were reviewed by the regulatory staff using the criteria of Appendix A, due to the lack of another guideline, as a basis for licensing decisions, even though the consequences of a seismically or ground displacement initiated failure of such a facility is far less than that of a nuclear power plant.

The Lucky Mc uranium mine tailings retention system at the time of review was owned by the Pathfinder Mines Corporation, and is located in the Gas Hills mining district in Fremont County, Wyoming. It consisted of five dams, the largest and farthermost downstream of which was the subject of this evaluation.

The embankment was 1600 feet long with a maximum height of 65 feet and a top width of 30 feet. The owner proposed modifications to this dam that would raise the embankment crest by 30 feet along the centerline alignment, incorporate internal zoning to control seepage, and flattening the outer slopes. The existing structures had not been previously evaluated by the regulatory geosciences staff.

5.2.2 Tectonic Structures and Maximum Earthquake

Several tectonic structures are present near the site of the dam, including a reverse fault 650 feet east of the embankment, and a large anticline, the Dutton Anticline, with a northeast striking fault on its east flank. There was no evidence for capability of these structures, but because of the absence of datable material that was of sufficient age to support non-capability overlying them, reliance on regional associations was necessary to demonstrate their antiquity. Most of the regional structures were created by east-west compression during the Laramide Orogeny which took place during the period from late Cretaceous to early Eocene [100 million years before Present (mybp) to 45 mybp)]. Detailed investigations of the faults produced considerable quality evidence as to orientation and style, to convince the regulatory staff that the faults originated during the Laramide Orogeny. The staff required that the applicant make a commitment to geologically map the excavation in the event that any of the faults extended beneath the dam.

Large-scale faults in the region around the site, which are younger than the Laramide faults, belong to the North Granite Mountain Fault System. This fault system was formed during an extended period of crustal uplift that began during the late Cenozoic (26 mybp) and continued through the Pleistocene (2 mybp to 10,000 years ago) and maybe into recent times. The applicant, in developing the earthquake design basis for the mill site, conservatively assumed that the normal faults of the North Granite Mountain system were capable.

The result was the assumption that an earthquake on these faults could produce ground motion effects equivalent to Modified Mercalli Intensity (MMI) of IX at the site. The staff considered this evaluation to be conservative in light of the low historical seismicity of the area (the maximum historical intensity in central and western Wyoming was MMI VII) and the probability that the faults, such as the North Granite Mountain Fault System are not capable. A seismic coefficient of 0.15g used in a pseudo-static type analysis of embankment stability was considered appropriate for this site.

5.2.3 Stability of Foundation Materials and Slopes

The staff reviewed the construction records kept during the construction of the original dam and found that the low permeability fill placed in the cutoff trench beneath the embankment had not been compacted. For this reason the staff was concerned about the stability and potential settlement of the proposed dam modification. The results of investigations, laboratory tests, and settlement calculations eventually demonstrated that the trench would not affect the overall stability of the proposed dam modification.

The staff, however, to ensure stability required the removal of considerably more unsuitable soft material and debris than originally planned, and required that special measures be taken to prevent excessive seepage. The staff further required post-construction inspections on a regular basis to detect seepage and to monitor erosion on the downstream slope and toe of the embankment and its abutments.

5.2.4 Final Statement

In some respects, the evaluation of this site was not typical of an Appendix A review of a facility that is not a commercial power reactor. Potentially active faults existed adjacent to the dam, and it was prudent, even from an economic point of view, to investigate these faults in considerable detail as was done, to determine whether they represented a hazard to the dam. Therefore, it was appropriate to use the Appendix A capable fault criteria to assess the nearby faults.

Furthermore, it was overly conservative to assume that the faults of the North Granite Mountain Fault System were active, and had the capacity to generate an earthquake that could cause ground motion effects at the site equivalent to those of MMI IX. However, the staff allowed a seismic coefficient lower than would have been required if the site was for a commercial power reactor. Additionally, it was normally the policy of the staff to require a dynamic analysis of an earthen embankment dam associated with a nuclear power plant, rather than a pseudo-static analysis as was performed in this case (Appendix A allows for static evaluations with suitable justification). The decisions were made based on the judgement of the regulatory staff after carefully evaluating the available information (Ref. 5-3).

5.3 GENERAL ELECTRIC TEST REACTOR (GETR)

5.3.1 Background

The GETR received an operating license in 1959 and the license was up for renewal in 1977. The GETR had been utilized to manufacture radioisotopes for medical purposes. Because of the issuance of a USGS a geologic map (Herd, 1977), (Ref. 5-4), that showed a potentially active fault passing within a few hundred feet of the reactor, the NRC suspended operations in October, 1977, pending results of investigations and public hearings.

The author was not directly involved in this case, but decided to include a discussion of it because of its importance as being the first nuclear plant where an attempt was made to develop a design to accommodate significant surface displacement under the facility.

5.3.2 Tectonic Structures and Capable Faults

The GETR site is located in the southwestern part of the Livermore Valley, an anomalously east-west oriented valley in a region where physiographic features are generally oriented NNW-SSE. The site is bounded on the east by the right-lateral strike slip Greenville Fault; on the south by the Las Positas Fault, with postulated left-lateral strike slip motion; and on the west by the right-lateral strike slip Calaveras-Sunol fault system (Fig. 5-2). The newly mapped fault , the Verona fault, was mapped as a NNW striking thrust fault that passes through the site area, veers along a more easterly trend, and was postulated by the USGS to merge with the Las Positas fault east of the plant site. This combination would result in a fault with an estimated length of 29 km (Ref. 5-5).

Extensive investigations that included trenching, borings, mapping, geophysical surveying, aerial photograph study, etc., were conducted by the licensee to assess the proposed fault and its potential hazard. Mapping in the trenches identified shear ones with a thrust sense of displacement (Fig. 5-3). The licensee interpreted and tried to demonstrate that the shear zones were the result of a massive landslide that occurred 70,000 to 125,000years ago. Among the evidence presented for this phenomenon were amphitheater-like and headwall scarp-like features near the top of the hills east of GETR and variation of strikes and dips of bedding within the landslide.

The California Division of Mines and Geology (CDMG) participated in the review of the GETR site. It concluded that the thrust displacement could be interpreted as either tectonic offset or landslide. However, while neither interpretation could be definitively confirmed, landsliding was the preferred conclusion (Ref. 5-6).

5.3.3 NRC Regulatory Position

Based on its evaluation of the evidence, the NRC and its advisor, the USGS, concluded that Holocene soils were offset, that there is evidence for repetitive displacement, and that surface faulting beneath the reactor had to be taken into account. Based on comparison between the Verona Fault and surface displacement of the 1971, Magnitude 6.6 San Fernando Earthquake causative fault, the NRC concluded that the GETR must be able to accommodate faulting of up to 1 meter of offset, and ground motions generated by a magnitude 7.5 earthquake on the Calaveras Fault, which is 2 miles west of the site. The USGS recommended that a more conservative value of 3 meters should be imposed as an upper limit to surface faulting.

The licensee maintained that it could support a conclusion that the GETR could withstand up to 1 meter of surface displacement. However, because the investigations and several Advisory Committee for Reactor Safeguards (ACRS) Public Hearings continued over a period of more than 2 years, the users of the products formerly produced by GETR had turned to other sources. Because of this development, a decision was made by the licensee to permanently shutdown the reactor before the issue of surface faulting had been resolved.

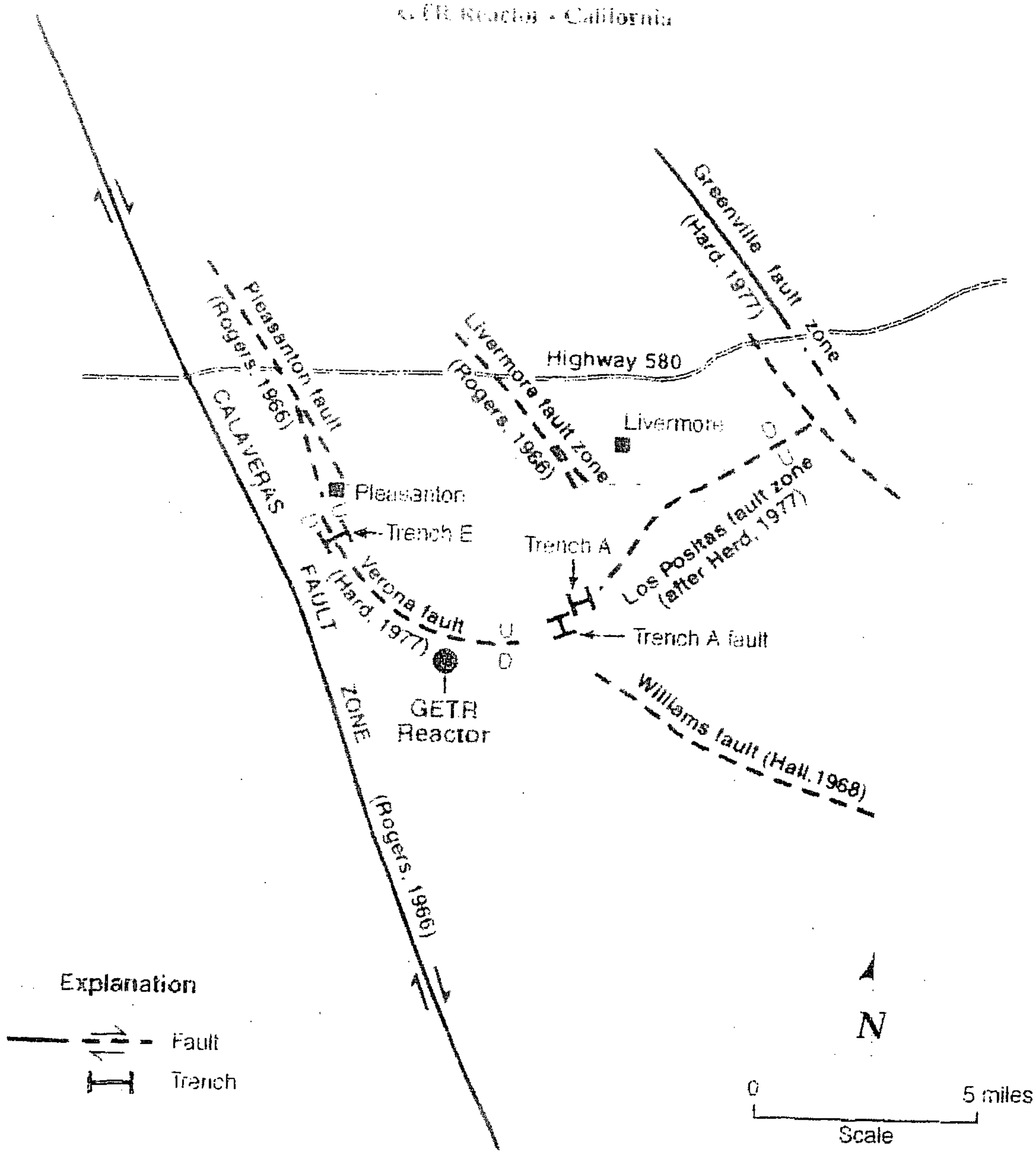


Figure 5-2. Faults mapped near the GETR site (Ref.'s 3-27 and 5-6)

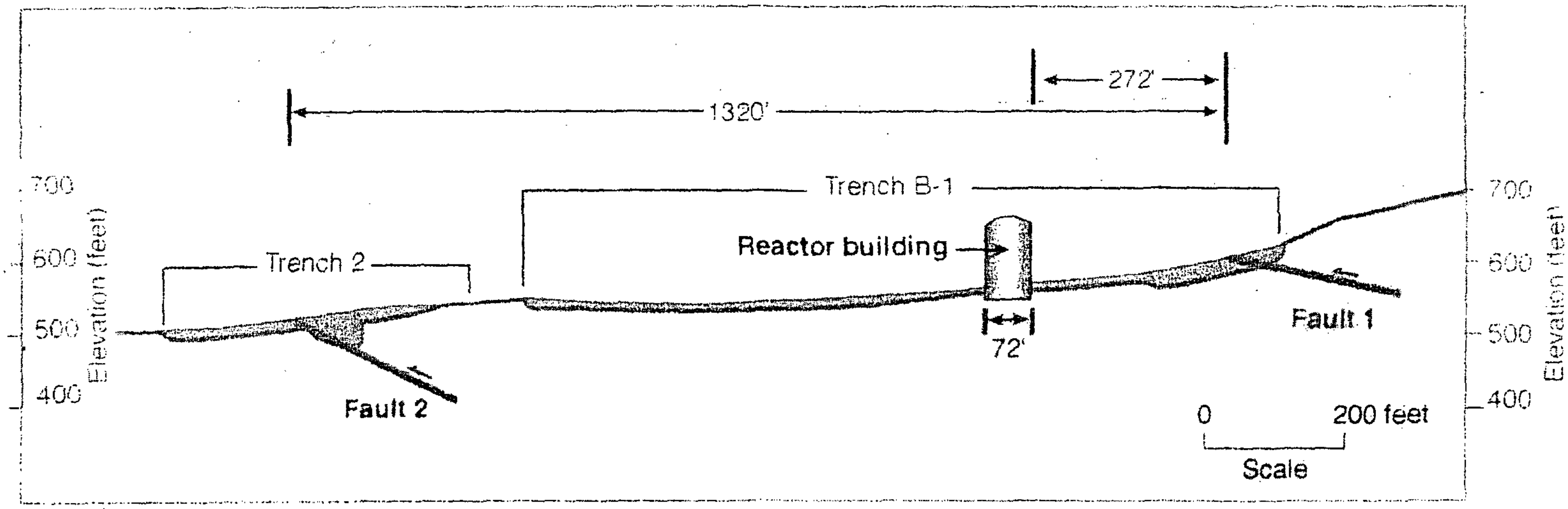


Figure 5-3. Cross section of GETR site showing position of the reactor relative to faults 1 and 2. Dips of thrusts are not known to depths indicated, but angles indicate average dips in trench exposures (Ref.'s 3-27 and 5-6).

CHAPTER 6 - SELECTED SITES IN THE CENTRAL UNITED STATES

6.1 ARKANSAS NUCLEAR ONE, UNIT 2

6.1.1 Background

The site is located in northwestern Arkansas (Figure 6-1) near Fayetteville within the Arkoma Structural Basin close to the southern boundary of the Central Stable Region Tectonic Province. Arkansas Nuclear One, Unit 2 (and Unit 1) had been licensed before publication of Appendix A, but apparently some of the thinking regarding determination of the SSE and OBE described in the rule were utilized. Arkansas 2 received its CP about the time of publication of Appendix A and the SSE and OBE concepts were used. Faults of the Arkoma Basis and Ouachita Thrust Belt were interpreted to be non-capable by using the "notwithstanding" criterion (Criterion 4) of Appendix A, relating the faults to ancient tectonic events in the absence of direct evidence for non-capability (Ref. 6-1).

6.1.2 Ultimate Heat Sink

One of the principal concerns late in the OL review (Ref. 6-2) was determining whether the combination of Dardanelle Reservoir, on the Arkansas River, and the onsite emergency cooling water pond (Figure 6-2) satisfied the intent of the then-unpublished Regulatory Guide 1.27, which was being prepared to provide guidance relative to the concept of an "ultimate heat sink." The principle goal of the proposed guide was to insure that the ultimate heat sink, whether a single facility or a composite of several facilities, was designed for the SSE ground motion and the Probable Maximum Flood (PMF), assuming their occurrence, each independently. It must also be able to withstand being simultaneously subjected to vibratory ground motion at some level and flooding at some level. The appropriate levels of each of these natural phenomena that should be assumed to happen at the same time had not been determined prior to this licensing activity.

Criteria for the simultaneous occurrence of certain levels of earthquake and flooding had to be developed for this case because Dardenelle Reservoir and Dam were designed for the PMF but not to withstand ground motion equivalent to the site SSE (0.20g) peak horizontal ground acceleration. The onsite excavated emergency cooling pond was designed to withstand the SSE but not the PMF. Based on probability studies it was decided that the Operating Basis Earthquake (OBE) and the Standard Project Flood (SPF) should be assumed to occur simultaneously, and it should be shown that the emergency cooling water supply reservoirs for the Arkansas One Unit 2 were designed to withstand these phenomena.

In compliance with these requirements, the applicant demonstrated, using Corps of Engineer's (designer, builder, and operator of the reservoir) data, that Dardenelle Dam would withstand an OBE (0.10g); and that using its own data, the emergency cooling pond onsite was capable of withstanding a Standard Project Flood. Other combinations of events that had to be considered were: (1) a PMF occurring at the same time that the site was experiencing ground motion equivalent to Uniform Building Code ground motion for this region; and (2) an SSE occurring simultaneously with a flood level less than the Standard Project Flood. These analyses provided part of the bases for Regulatory Guide 1.27, "The Ultimate Heat Sink" (Ref. 6-3).

6.1.3 Potential Seismic Sources and Capable Faults

In 1984, following the classification of the Meer's Fault in southwestern Oklahoma as a capable fault, the NRC examined the available geological and seismological data regarding the four nuclear sites that were closest to the Meer's Fault. The four sites, which were all more than 200 miles distant, were Black Fox, Oklahoma; Wolf Creek, Kansas; Comanche Peak, Texas; and Arkansas Nuclear One (Figure 6-1). The NRC concluded that there could be an unidentified fault similar to the Meers fault within a 50 mile radius of the Arkansas plant for the following reasons: (1) there are limited exposures of the underlying geology in this area, (2) the stratigraphy and structure of the area have similar easterly-westerly strikes, and (3) the investigations of the regional geology were not rigorously conducted to identify and characterize individual faults that could have an effect on the seismic design bases because it was accepted

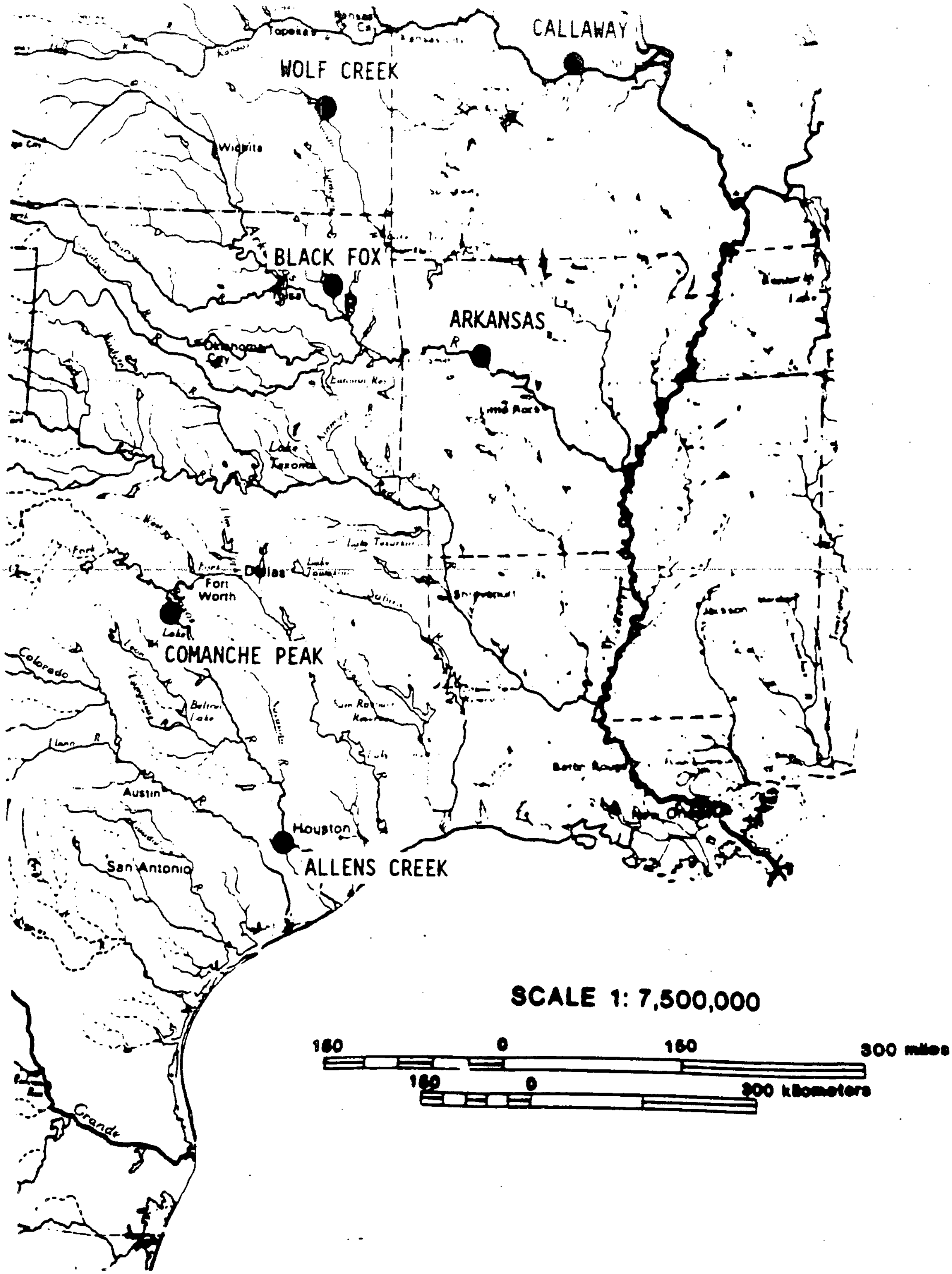


Figure 6-1 Locations of sites in the central and south-central United States that are discussed in this chapter or in Chapter 2.

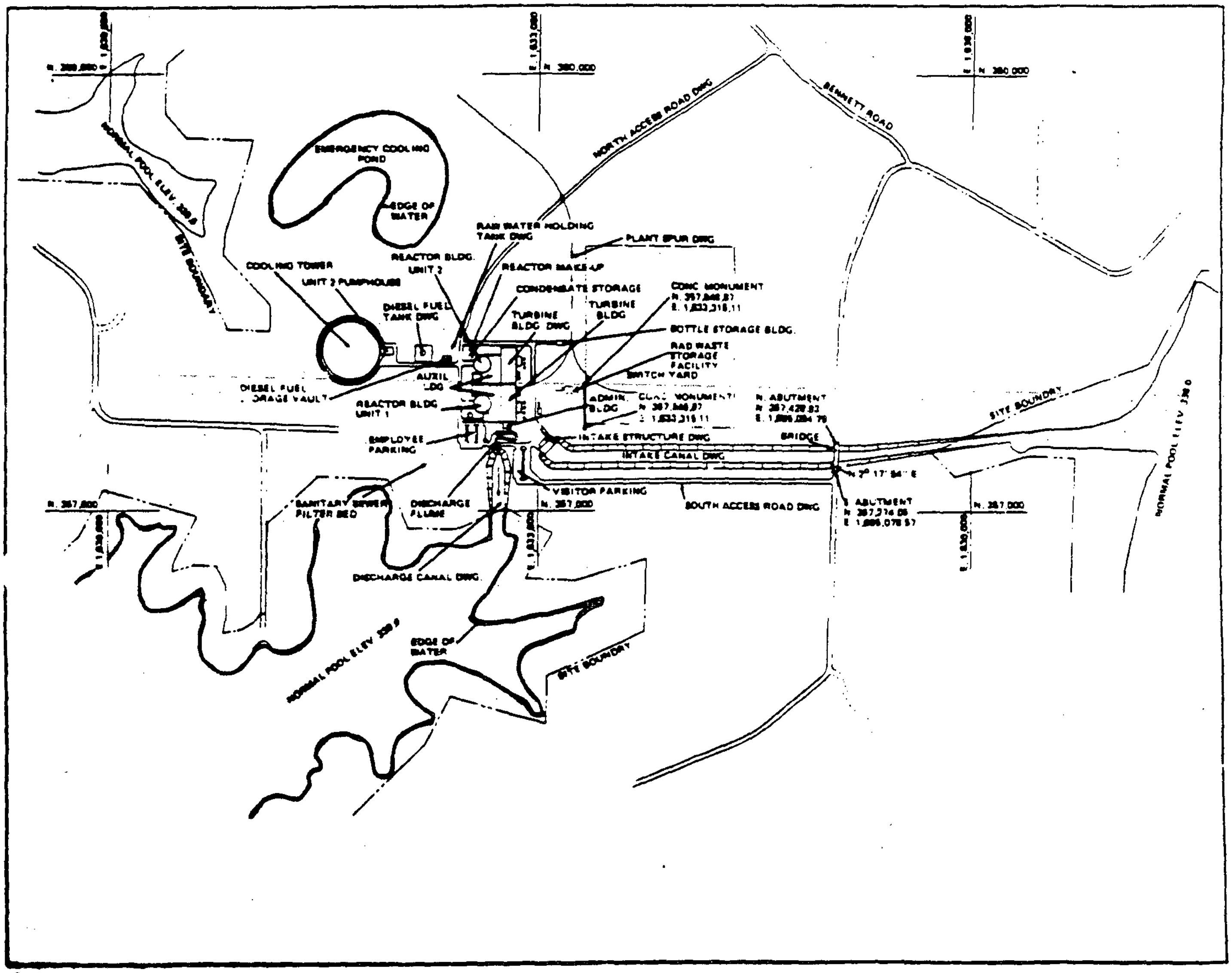


Figure 6-2 Site layout showing the location of the Emergency Cooling Pond. (Ref. 6-2).

that the structures were related to the Paleozoic deformation that created the Arkoma Basin and the Ouachita Structural Zone and, therefore, very ancient.

The LLNL and EPRI PSHAs resolved this issue by demonstrating the low probability of an occurrence of an earthquake of the size that was apparently generated by the Meers Fault in the region within which the Arkansas Nuclear One site is located.

6.2 LASALLE

6.2.1 Background

The LaSalle Nuclear Power Plant site is in north central Illinois near the town of LaSalle just south of the Illinois River. It is within the Central Stable Region Tectonic Province, on the north flank of the Illinois structural basin. Most of the CP evaluation was accomplished prior to the publication of Appendix A, but the criteria were strongly imposed during that review.

6.2.2 Tectonic Province, Tectonic Structures, Maximum Earthquake, and Ground Motion

At the time of this CP evaluation, the possibility was considered that the largest historic earthquake in the Central Stable Region Tectonic Province, the Anna, Ohio MMI VII-VIII was related to a specific, known tectonic structure. The causative structure was considered to be the zone of bifurcation toward the northwest and northeast of the Cincinnati Arch to form the Kankakee and Findlay Arches, respectively (Figure 6-3). If this were true it would not be necessary to assume that an event similar to the Anna Earthquake could occur anywhere within the Central Stable Region Tectonic Province as would be required by Appendix A. This interpretation was controversial, and the AEC staff maintained that there was insufficient data to support it, therefore the Anna Earthquake should be assumed to be possible in the site vicinity.

A major concern during the CP review was where to terminate the northern extension of the New Madrid Seismic Zone (NMSZ). In this case, based on advice from NOAA, it was decided that in order to consider the affects of the distant earthquake in estimating the earthquake design basis ground motion, the NMSZ should be assumed to extend up along the Wabash River Fault Zone to Vincennes, Indiana, or to about 200 miles from the site (Figure 6-3). This model was followed in the licensing of future nuclear power plants in the region. The decision proved to be extremely beneficial in the licensing of future plants because it likely prevented costly seismic reevaluations and backfits as a result of the identification in the late 1980s of paleoseismic evidence for large prehistoric but geologically recent earthquakes centered at Vincennes, including at least one of about magnitude 7.5.

The applicant initially proposed an SSE ground motion design peak horizontal ground acceleration of 0.15g, but was required by the AEC, based on advice from the USGS and NOAA, to upgrade this value to 0.20g, primarily because this is a deep soil site, which would amplify the ground motion. This value is considered to be appropriate for an Anna-like earthquake in the site vicinity. During the OL review the seismic design spectra for the LaSalle site, which were developed prior to Reg Guide 1.60, were reanalyzed to insure that they were as conservative as the Reg Guide spectra.

Major regional tectonic structures that trend into the site vicinity are the LaSalle Anticline and associated Oglesby Fault, and the Sandwich Fault. These structures were investigated by the applicant and concluded to be non-capable within the meaning of the then unpublished Appendix A. These conclusions were based on the lack of offset of Pleistocene glacial deposits by the faults, and by relating the most recent displacement of the faults to the known Late Paleozoic period of major deformation in the region.

6.2.3 Stability of Foundation Materials and Slopes

One of the main earth sciences (geotechnical engineering) issues during the CP review was the adequacy of the design, and later, the construction of the ultimate heat sink. The main non-category 1 cooling water reservoir consisted of a

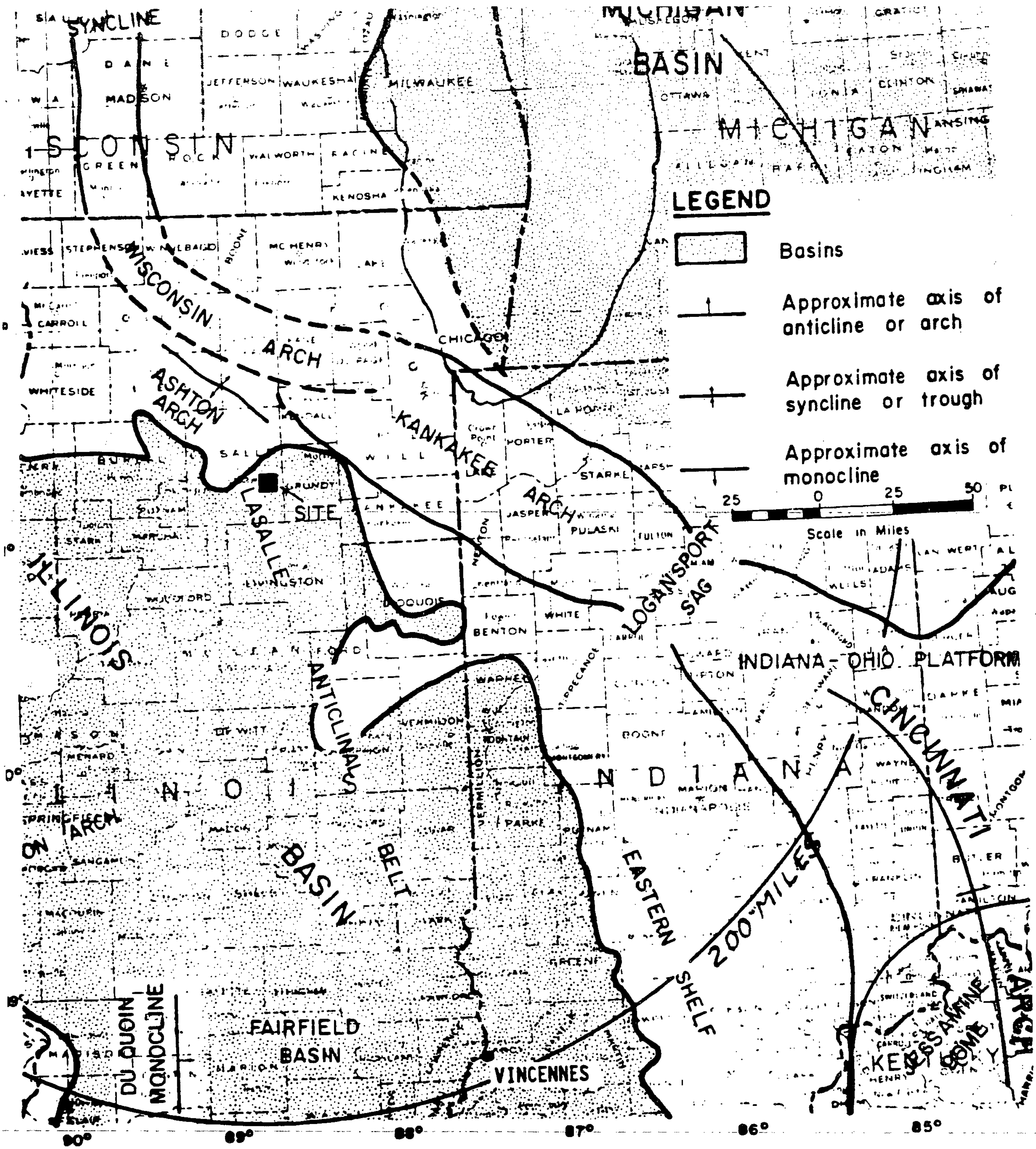


Figure 6-3 Regional Tectonic Map of North-Central United States - Basins and Arches - Paleozoic Rocks (Ref. 6-4)

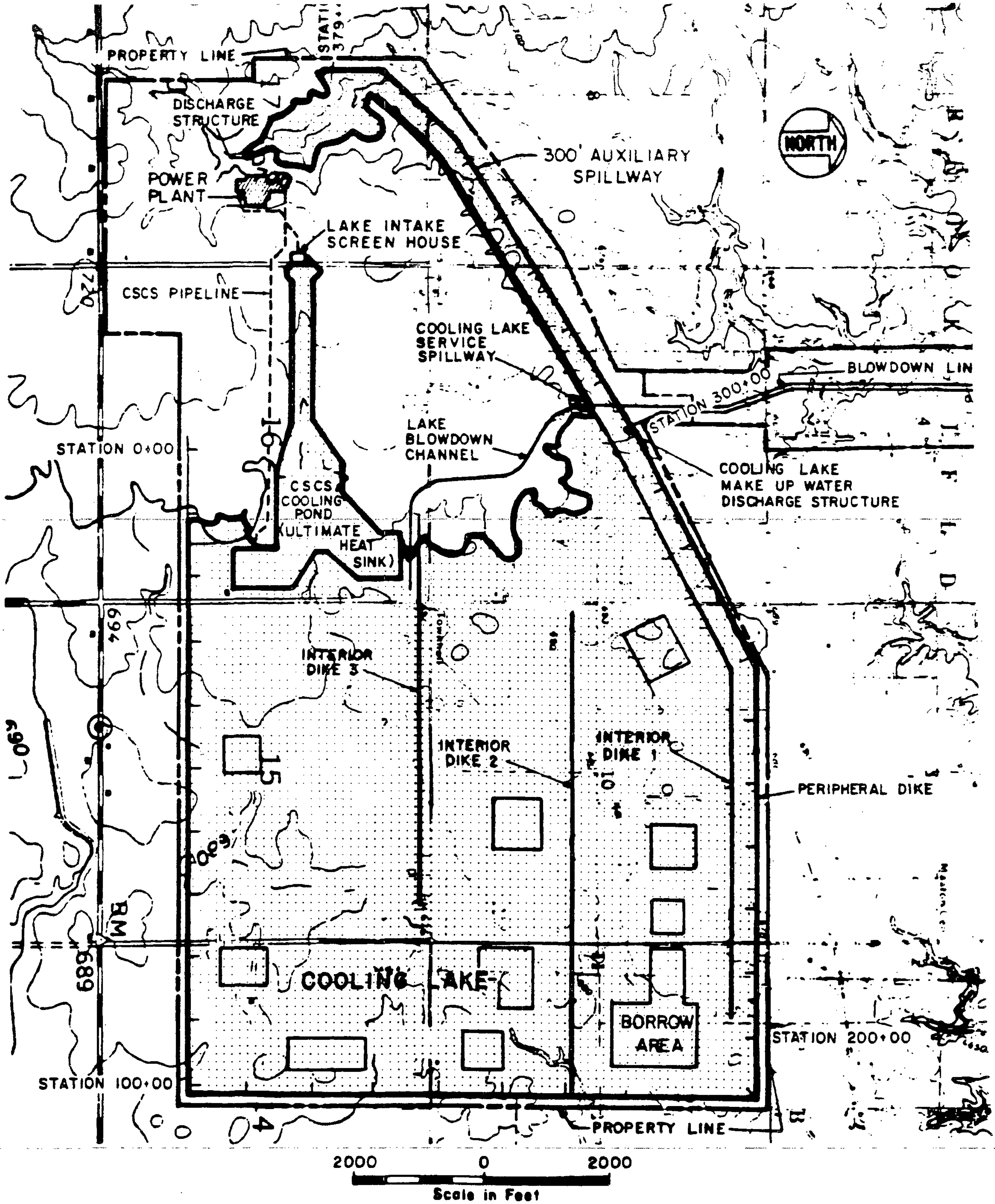


Figure 6-4 General Site Plan - Cooling Lake and Emergency Cooling Pond CSCS Cooling Pond (CSCS) (Ref. 6-4)

large artificial lake, originally designed to serve 4 nuclear units, but later reduced to 2 units. The reservoir was impounded on the high ground by using the topography and an extensive system of earthen dikes (Figure 6-4). In the event of the loss of the lake, the emergency cooling water was to be retained by the construction of a Category 1 earthen dam across one of the larger stream valleys within the lake perimeter (Figure 6-4). The dam would always be submerged beneath the larger lake unless that lake was lost. The dam had to be designed to withstand SSE ground motion and immediate sudden drawdown on the downstream side as the result of loss of the lake. It was also required to be capable of withstanding the Probable Maximum Flood (PMF) in the exposed condition.

6.3 ALLENS CREEK

6.3.1 Background

The Allens Creek site is located in southern Austin County, Texas, 45 miles west of Houston and just west of the Brazos River on the Gulf Coastal Plain. Construction Permit activities took place during 1973-1975, after publication of Appendix A. Appendix A was used extensively, particularly in the evaluation of tectonic provinces, seismic zones, and assessment of growth faults. Activities at this site ended in about 1975, and the applicant did not apply for an OL (Ref. 6-5).

6.3.2 Tectonic Province, Maximum Earthquake, and Ground Motion

The site is within the Gulf Coastal Plain Tectonic Province. King (Ref. 6-6) defines the Atlantic and Gulf Coastal Plain as Mesozoic and younger platform deposits overlying the deformed Paleozoic and older rocks of the Appalachian and Ouachita fold belts. For most of its length, the shoreward boundary is taken to be the edge of the Cretaceous and/or Tertiary deposits of the Coastal Plain where they overlap the basement. Using this broad interpretation, the relatively low seismic Gulf Coastal Plain would include the very seismic Mississippi Embayment and the relatively high seismic area that characterizes the intersection of the Ouachita Tectonic Belt and the Wichita Structural System. Considerable controversy developed among the various groups involved in the licensing procedures as to the tectonic province boundary locations.

The staff's position was that the Gulf Coastal Plain could be divided up into 3 zones relative to recent tectonic activity and seismicity: the Gulf Coast Seismic Zone, the Mississippi Embayment Seismic Zone, and the zone defined by the intersection of the Ouachita Tectonic Belt and the Wichita Structural System. The largest earthquake to have occurred in the staff's Gulf Coast Seismic Zone was the 1930 Donaldsonville, Louisiana maximum MMI-VI Earthquake, and it was considered to be the event that would generate the SSE ground motion at the site, which was estimated to be a peak horizontal ground acceleration of 0.10g. A conservative assumption was that the causative fault of the Donaldsonville Earthquake is considered to be a growth fault, and this earthquake is regarded as the upper limit for growth fault earthquakes. This model was used to license other nuclear power plant sites on the Gulf Coastal Plain. The Gulf Coast Seismic Zone was considered, in the staff's view, to be synonymous with the Gulf Coastal Plain Tectonic Province.

Another Gulf Coastal Plain earthquake, the 1891 Rusk Earthquake, was catalogued as an earthquake with a maximum MMI-VII earthquake, but its felt area was smaller than that of a typical earthquake with a maximum MMI-VI ground motion. For this reason it was reinterpreted to have been either a tornado misclassified as an earthquake, or a very shallow earthquake. The 1882 Paris, Texas Earthquake was the only other earthquake with a maximum MMI-VII event to occur on the Gulf Coastal Plain. This earthquake was concluded to be, along with other low intensity seismicity in that area, related to the zone of intersection of the Ouachita Tectonic Belt and the Wichita Structural System.

The southern extent of the Mississippi Embayment Seismic Zone (later called the New Madrid Seismic Zone) was determined during the Grand Gulf review to be the structural Monroe Uplift in the vicinity of Memphis. Thus, for the Allens Creek review the 1811-1812 New Madrid maximum MMI-XI-XII earthquakes were assumed to occur more than 400 miles away and would not challenge the seismic design of the plant if they were to recur.

6.3.3 Growth Faults and Capable Faults

There is no distinction made in Appendix A between tectonic faults and other kinds of near surface offsets. During the Allens Creek review growth faults were evaluated using Appendix A criteria for a capable fault, except that they were not considered to be generators of destructive earthquakes. Numerous growth faults have been mapped in the region around the site (Figure 6-5). Using oil company data, several growth faults were identified beneath the site. These faults were shown, using seismic reflection data, to die out in the Tertiary strata, thus being older than 2 million years and therefore not capable.

Many linear features had been identified in the site area from Landsat photography. Because many of the growth faults in the Houston area, which had undergone historic surface displacement, were expressed as linear features on Landsat imagery, the applicant was required to conduct ground truth investigations of linears in the region around the site. The linear features in the site area were determined to be cultural features such as buried pipelines and roadways, or natural features such as stratigraphic features, channel and fill structures, etc, but not faults.

Based on the study of growth faults during this review and the South Texas review, the staff recommended in SECY-300 Enclosure A (Ref. 1-2), that growth faults be considered as "hazardous faults" instead of "capable faults" because of their low seismic potential and general creep-style displacement (hours to days) as opposed to instantaneous and seismic rupture that typifies tectonic faults.

6.3.4 Subsidence

Severe subsidence accompanied by reactivation, initiation, or acceleration of displacements on growth faults due to the withdrawal of subsurface fluids, mostly groundwater, had been documented in the Houston area. Some subsidence had been measured in the site area. This was caused by the propagation outward of the Houston groundwater bowl of depression, and pumping in the site area for crop irrigation. The problem was addressed to the staff's satisfaction by the installation of observation wells to monitor changes in groundwater level, monuments and subsidence observation stations, a network of stations to measure horizontal strain which can detect potential subsidence at the site, and deep compaction measuring monuments. Construction at this site was later deferred indefinitely for reasons other than geologic or seismic.

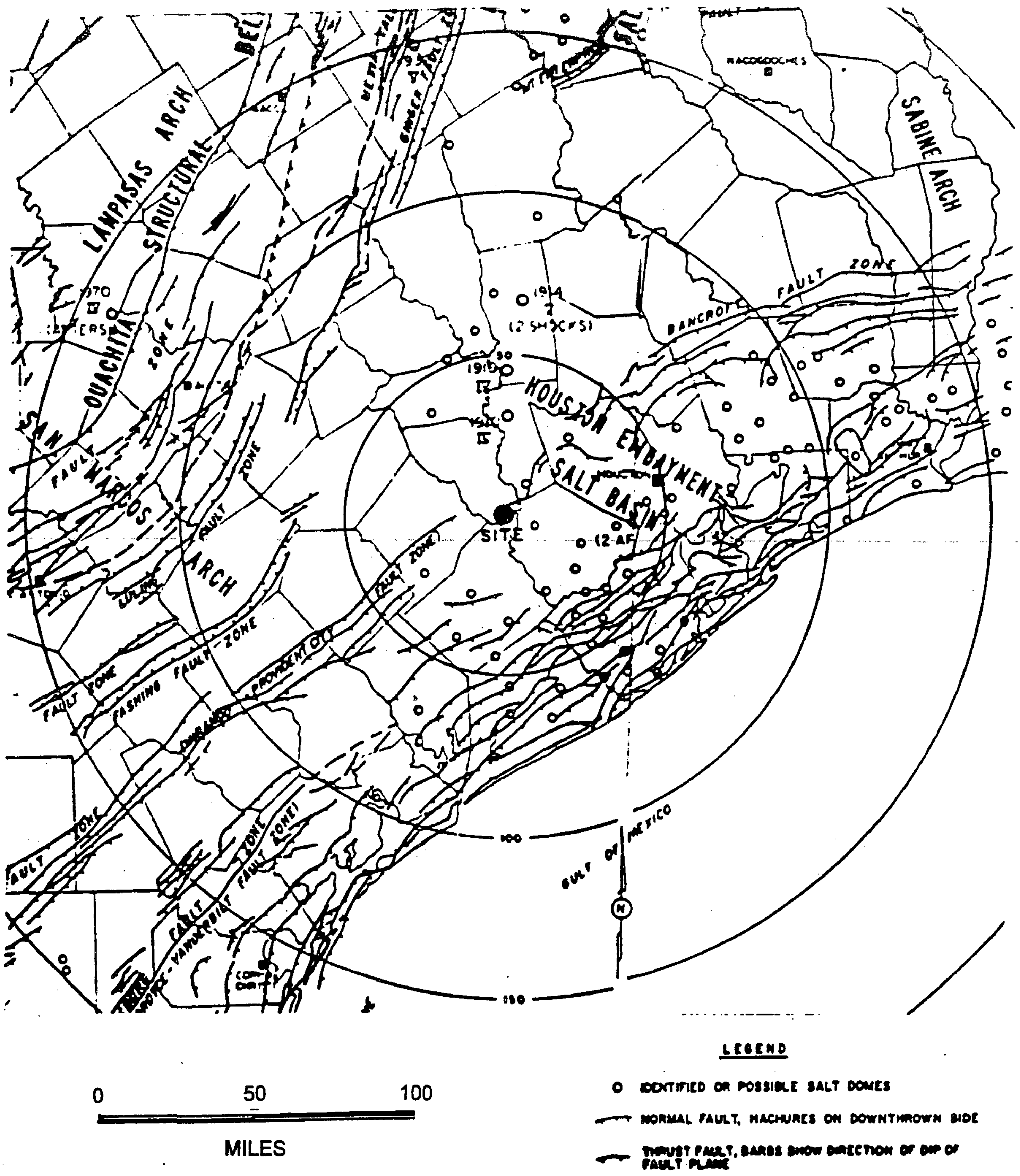


Figure 6-5 Regional Tectonic Map - most of the faults shown on the Gulf Coastal Plain are growth faults (Ref. 6-5)

6.4 BYRON

6.4.1 Background

The site is located in northern Illinois, in the Till Plains section of the Central Physiographic Province, a region of substantial glacial activity during the Pleistocene (Fig 6-6). It is situated south of the city of Rockford and just east of the Rock River. Site investigations and Construction Permit activities began in the early 1970s. The Construction Permit (CP) review of this site was well along before Appendix A was published but the criteria that were to be in the rule were used as though they were regulations. Faults were found in the excavation after publication of Appendix A, and its criteria for capable faulting were utilized.

The site is underlain by a few feet to 40 feet of Pleistocene glacial drift deposits over 2500 to 3000 feet of relatively horizontal Paleozoic sedimentary rocks on top of Precambrian basement. The upper rock unit is dolomite of the Galena Group. The dolomite had been subjected to severe solutioning activity.

6.4.2 Tectonic Province and Tectonic Structure

The site was determined to be within the Central Stable Region Tectonic Province (Figure 6-6) near the intersections of the LaSalle Anticlinal Belt and the Kankakee Arch, and the Wisconsin Dome (Figure 6-7). These regional structures were investigated, but no evidence was found that they were any younger than late Paleozoic. The 85 mile long Sandwich Fault is 7 miles south of the site, the Jannesville Fault is 40 miles north of the site, and the postulated Oglesby Fault is 25 miles south of the site (Figure 6-8). These faults do not offset Pleistocene glacial deposits and are assumed to be related to the deformation that occurred in the Late Paleozoic.

As often happens when research is ongoing in the region around nuclear power plant sites, new information was found that initially cast doubts on some earlier assumptions made. Geologic mapping by others in the region during the OL review reported evidence for post-Pleistocene offset on the Jannesville Fault. Closer examinations, however, indicated that this more recent deformation was the result of glacial activity during the late Pleistocene and not to tectonic faulting.

6.4.3 Maximum Earthquake and SSE Ground Motion

As a result of the CP evaluation, the SSE ground motion with a peak horizontal ground acceleration of 0.20g was based on the assumed occurrence of an earthquake similar in size to the 1937 Anna, Ohio event, which had a maximum MMI of VII-VIII Earthquake in the vicinity of the site (Figure 6-9). The relatively high seismicity of northern Illinois was also a factor. The largest 1811-1812 earthquakes of the NMSZ were assumed to occur as far north as Vincennes, Indiana in estimating ground motion from a large distant event.

During the CP evaluation, the applicant justified the use of an OBE that is less-than-one-half the SSE as required by Appendix A. A deconvolution technique of modeling ground motion transmission was used in determining the level of ground motions entering the plant foundations. Deconvolution of the ground motion from the surface to the foundation was a very controversial issue and later during the OL review, a reanalysis was required using state-of-the-art techniques, including a seismic margin study.

6.4.4 Capable Faults

Many small faults were investigated within 3½ miles of the site. They all were capped by undisturbed Pleistocene glacial deposits, and thus found to be non-capable using the criteria of Appendix A. The possibility of encountering faults in excavations was recognized. In July, 1975, during excavation, the utility, Commonwealth Edison, reported discovering minor faults in the excavation for the power block area. The faults generally trended in a WNW-ESE direction, and the maximum offset recorded on one to the faults was five inches strike slip and five inches vertical. The faults were truncated by glacial till but the age of that till could not be determined on site. The faults were traced out

Figure 6-6 Central Stable Region (Ref. 6-6)

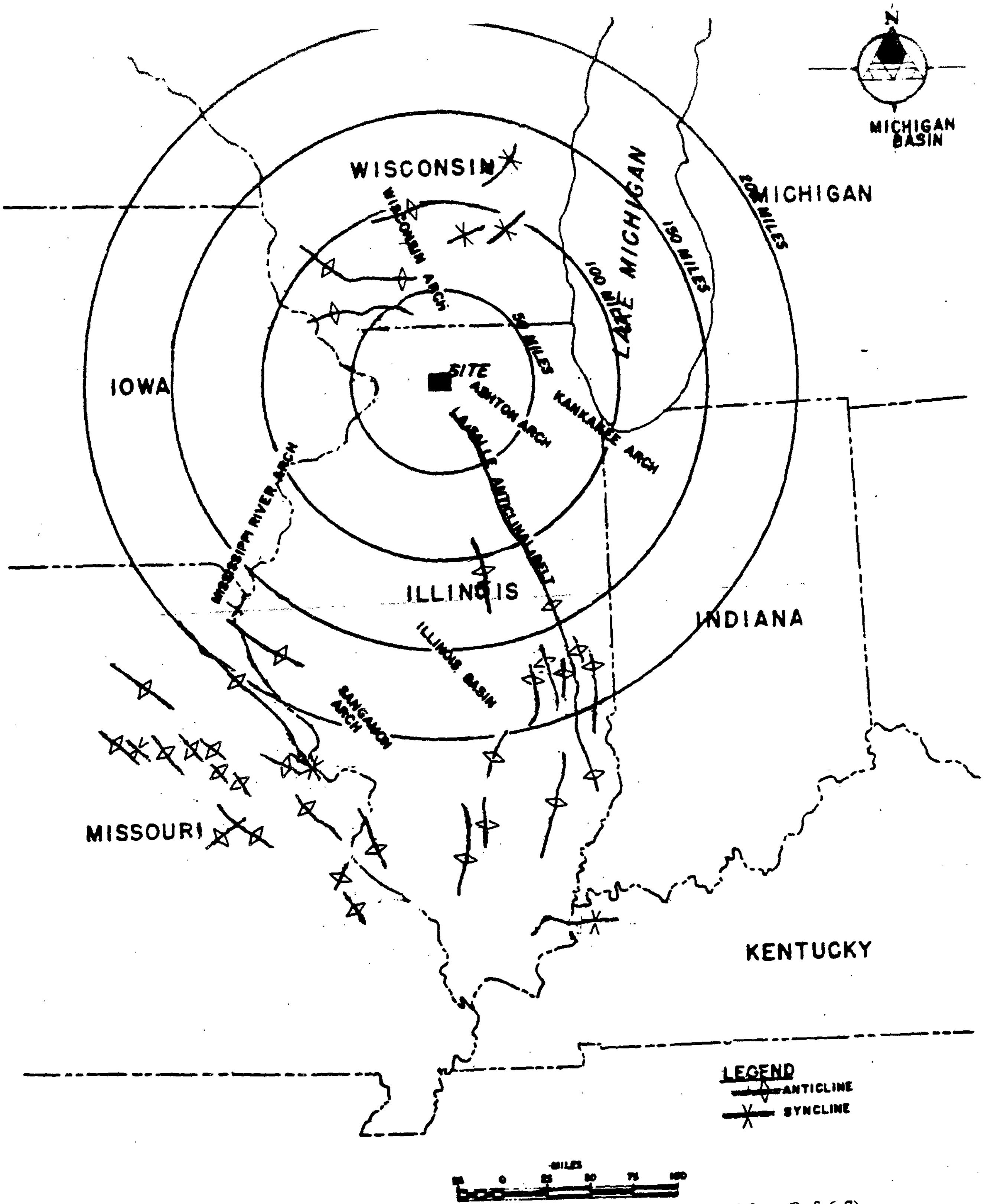


Figure 6-7 Major Folds in the region around the Byron site (Modified from Ref, 6-7)

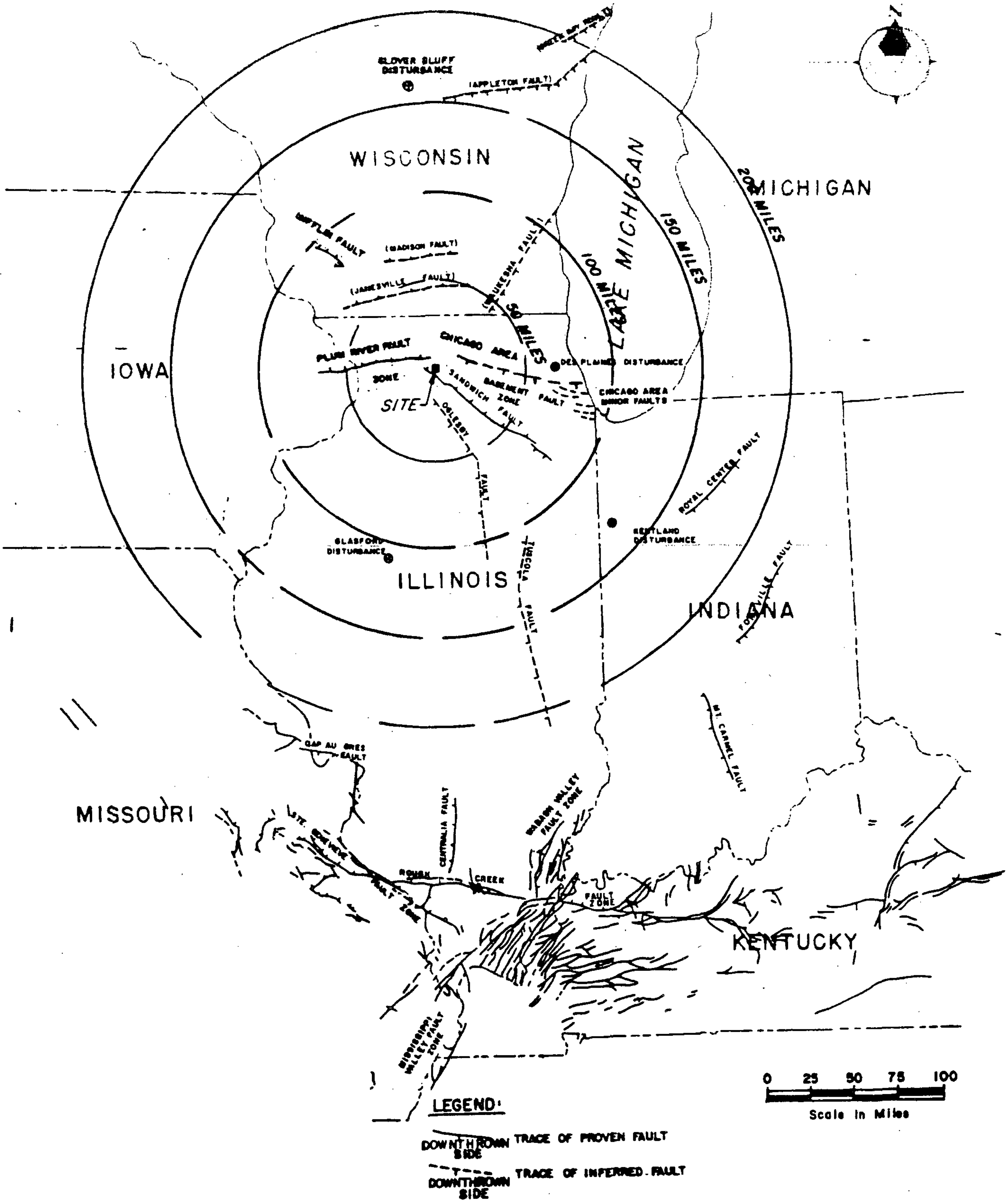


Figure 6-8 Major Faults in the region around the Byron site (Modified from Ref. 6-7)

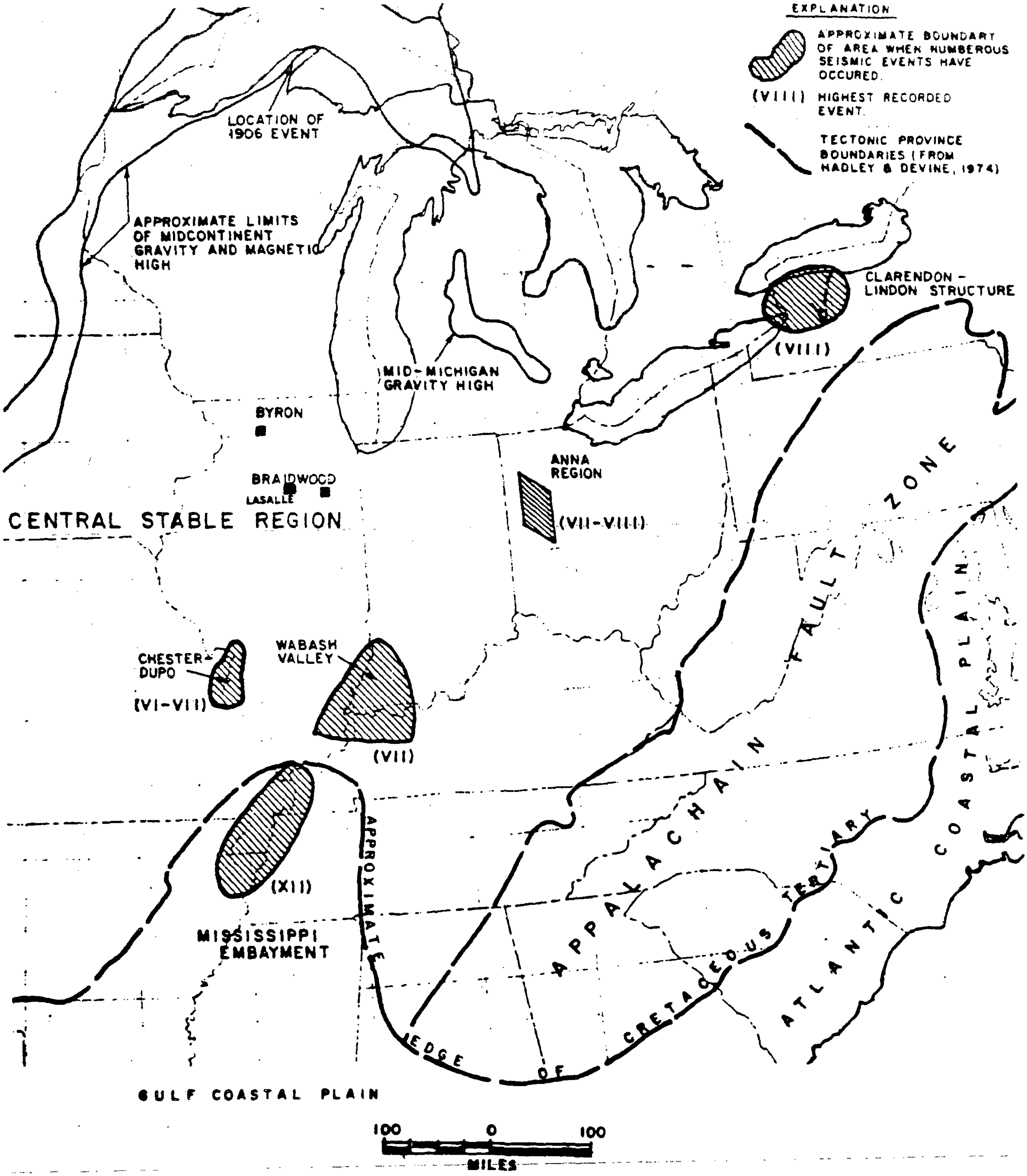


Figure 6-9 Areas of Relatively High Seismicity in the Region Around the Byron Site (Ref. 6-7)

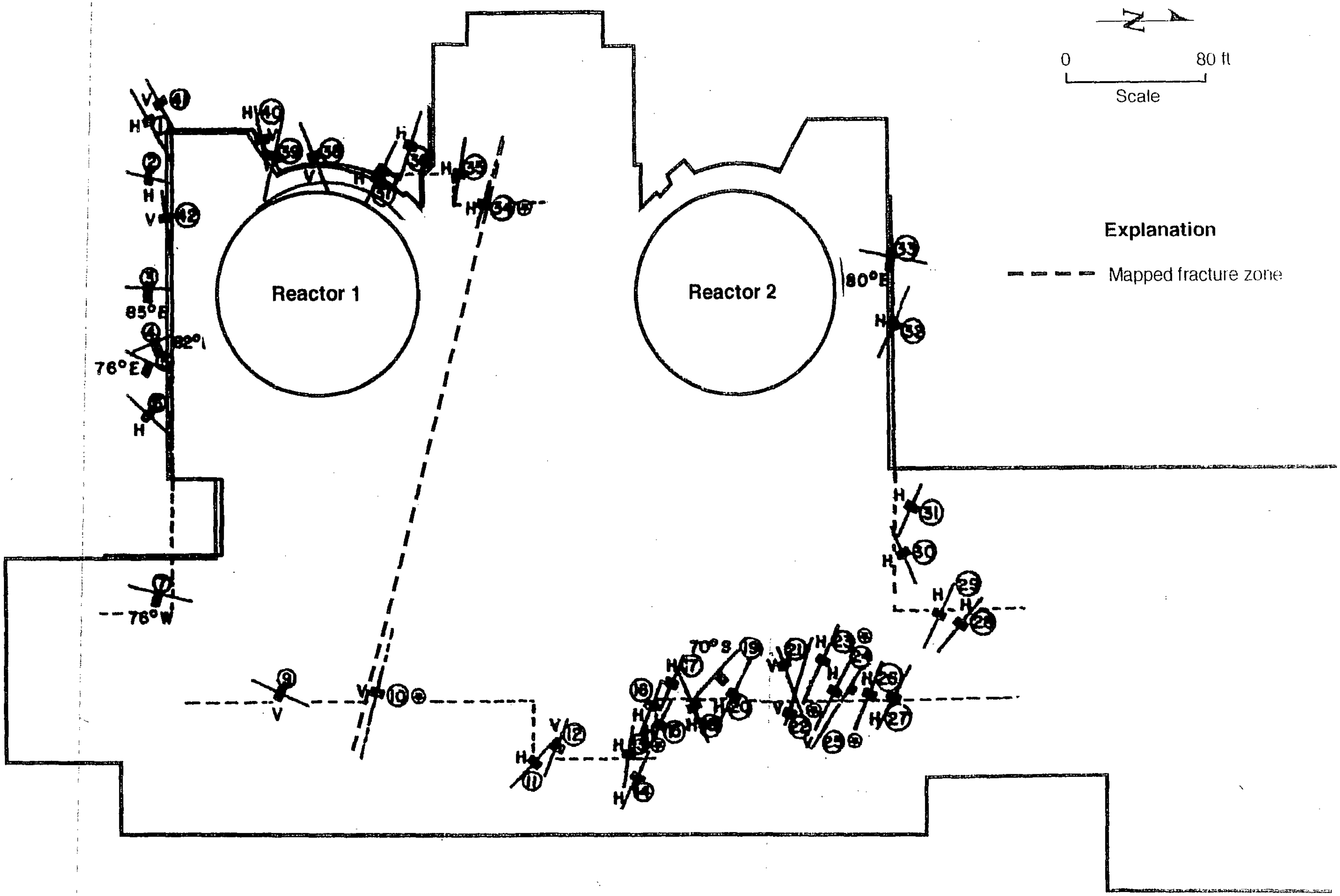


Figure 6-10 Byron NPP – Mapped faults and joints in the reactor building excavation walls (Ref.'s 3-27 and 6-7)

beyond the excavations and investigated by borings and trenches. Members of the Illinois Geological Survey, who had mapped in detail the glacial geology of the surrounding region, became involved in the analysis.

The upper limit of the time of last displacement of the faults was determined by: (1) relating their origin to the well documented regional geological history (demonstrating their similarity to other mapped faults of known age in the region, such as those of the Paleozoic Sandwich fault system); (2) interpretation of the age of unfaulted residual soil that overlay the faults; (3) comparison of unfaulted till and other glacial deposits that overlay the faults with regional outcrops, the age of which had been well documentd by the Illinois Geological Survey; and (4) by demonstrating the age of undeformed clay filling sampled from one of the faults. The upper limit of the latest faulting thus established was at least Illinoian age or 700,000 years before the present; but more likely Paleozoic age (more than 250 million years before the present).

The NRC concluded that the faults were not capable faults within the meaning of the siting criteria. The faults under the power block did not become an issue of public intervention as they did at many other sites. This was probably due to the objective involvement of the Illinois Geological Survey. The presence of the faults was addressed in considerable detail at the Atomic Safety and Licensing Board (ASLB) Public Hearing,

6.4.5 Stability of Foundation Materials and Slopes

Considerable solution by ground water activity had occurred in the Galena Dolomite beneath the site along joints, and particularly at joint intersections. The applicant mitigated this condition by injecting a grout curtain around the power block area to a depth of about 135 feet and then pressure grouting the rock within this curtain to reduce the amount of void space within the foundation bedrock. Quality assurance investigations showed that the grouting was effective.

The river screen house and pumping system was underlain by 115 feet of alluvium and glacial drift. The NRC was concerned that these soils would be prone to liquefy on being subjected to the SSE ground motions. Additional tests of material obtained from large diameter core borings and modifications in the foundation design satisfied the staff that liquefaction was not likely. In addition, the NRC required the applicant to demonstrate that the river screen house's design was adequate for the amplified SSE ground motion due to the presence of the soil under the river screen house.

6.5 CALLAWAY

6.5.1 Background

The Callaway site is in central Missouri, 110 miles west of St Louis, and about 4 miles north of the Missouri River. The site is situated in the Central Stable Region Tectonic Province on the north flank of the Ozark Dome. The site review was conducted after publication of Appendix A and the rule was used by the applicant and the NRC.

Two issues that dominated the early earth sciences reviews were: (1) the characteristics of potential ground motions at the site from the occurrence of an earthquake similar to the 1811-1812 New Madrid series of maximum MMI Intensity XI-XII earthquakes at the closest approach of the New Madrid Seismic Zone to the site, the northwest boundary of which had not been determined; and (2) the potential for solution activity (paleo or current) for causing subsidence or collapse beneath the plant site. A third major issue that developed later was the significance of numerous, mostly northwest-southeast striking faults and folds mapped in the region, and linear features identified by remote sensing studies that suggested the presence of faults.

6.5.2 Tectonic Province, Tectonic Structures, Maximum Earthquake, and Ground Motion

Although the site is within the Central Stable Region Tectonic Province, the New Madrid Seismic Zone is significant to the determination of the seismic design ground motion at the site. Investigations carried out by the applicant's consultant demonstrated to the staff's satisfaction that the northwestern boundary (closest to the site) of the Mississippi

Embayment, which was also assumed to be the boundary of the New Madrid Seismic Zone, was the Ozark Escarpment, or the convex-up bending zone of the Embayment. This location is a little more than 200 miles from the Callaway site and attenuation analyses resulted in an estimate of MMI VII-VII level of ground motion at the site, assuming an 1811-1812 size earthquake. The SSE design basis is a pga of 0.20g at the site, based on a postulated occurrence of a New Madrid-like earthquake at the closest approach of the New Madrid Seismic Zone, and on an occurrence at the site of the largest historic earthquake known to have occurred in the Central Stable Region Tectonic Province, which is the 1937 maximum MMI VII-VIII Anna, Ohio Earthquake.

Published structural geology maps of Missouri showed numerous northwest-southeast striking faults and folds (Figure 6-11). Remote sensing imagery and geophysics surveys also showed this strong northwest-southeast structural grain (Ref. 6-8). Investigations by the applicant's geological and geophysical consultants showed that those features in the site vicinity were not capable. This was demonstrated by using cross cutting relations, the lack of seismicity, their truncation by Pleistocene sediment, or by relating their origin to ancient tectonic events such as the Paleozoic uplift of the Ozark Dome.

A minor issue addressed at the CP ASLB Hearing was the reliability of defining subsurface tectonic structure by analysis of insoluble (silicate) residue collected from water well borings throughout the state, a technique developed and utilized by the Missouri Geological Survey. The staff position was that this information should be used, but its limitations must be recognized, and the results should be used in conjunction with other data such as geophysical surveying data.

6.5.3 Stability of Foundation Materials and Slopes

The issue of the potential for subsidence or collapse due to the possible presence of open karst features beneath the site was raised because the site is located within a region of known karst topography. Paleokarst features were identified in the Cotter-Jefferson City Formations beneath the site at depths between 300 and 400 feet. (These large cavities and others exposed on the cliffs above the Missouri River were filled with Ordovician rubble and sandstone (St. Peter Formation). The wide spacing between the deep exploratory borings allowed for the undetected presence of open cavities up to 100 feet wide. Because there was no other evidence for extensive post-Ordovician solutioning beneath the site and the results of an analysis that showed that an open 100 feet diameter cavern in the Cotter-Jefferson City Formations at a depth of 300 feet would not be transmitted to the bedrock at foundation levels, the staff concluded that there would be no subsidence or collapse.

6.6 BEAVER VALLEY

6.6.1 Background

The Beaver Valley Nuclear Power Plant is located at Shippingport, Pennsylvania, about 30 miles northwest of Pittsburgh (Figure 6-12), on the south bank of the Ohio River. Three reactors are located at this site. The Shippingport plant, which is not operating, is an old reactor and predates Appendix A. The licensing of Beaver Valley Unit 1 also predates publication of Appendix A but many of the geologic and seismic considerations which later became the criteria in the rule were used. Most of the Unit 2 licensing activities, including the OL review, which is the subject of this discussion, were carried out after the publication of Appendix A, therefore, its criteria were utilized entirely.

6.6.2 Tectonic Province and Maximum Earthquake

The site is in the Appalachian Plateaus Tectonic Province. The eastern boundary with the Valley and Ridge Tectonic Province, the Allegheny Front, is widely accepted as a boundary of the Appalachian Plateaus Province, however, the western boundary is controversial. After many deliberations with the utility, the staff concluded that the western boundary was the westernmost, and northern-most extent of prominent tectonic structures that could be attributed to the Appalachian Orogeny. Also used in delineating the western boundary of the Appalachian Plateaus Province is the extent to the west and north of the subsurface Salina salt horizon, which underlies the Appalachian Plateau Province.

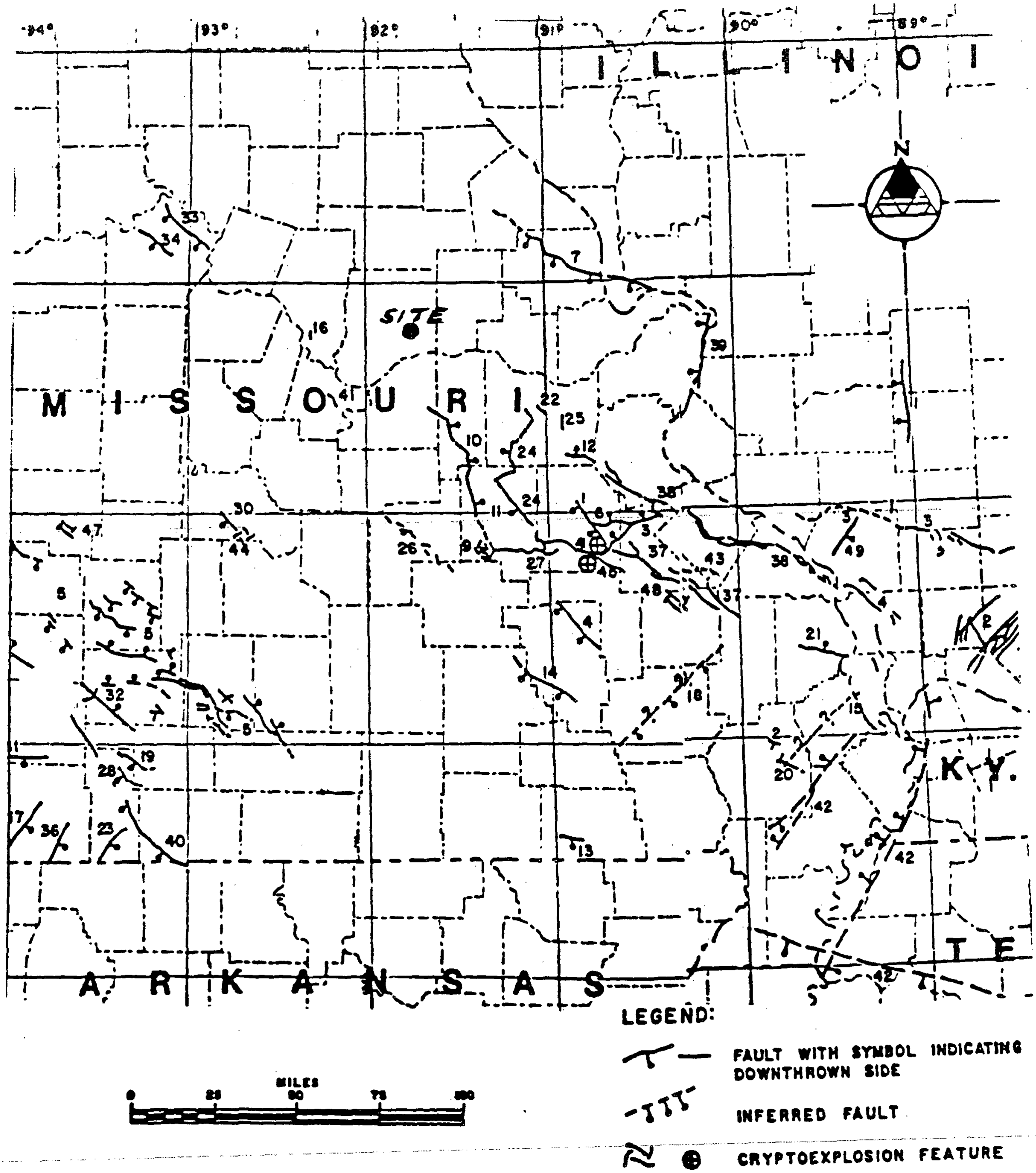


Figure 6-11 Regional Faults Around the Callaway Site (Modified from Ref. 6-8)

In its evaluation of the seismology of the Beaver Valley site and surrounding region, the NRC staff used the results of two studies that were sponsored by the NRC to provide data bases for the use of Appendix A, these are Hadley and Devine (1973) (Ref. 6-11) and Barstow and others (1981) (Ref. 6-12). The largest earthquake to occur near the western and northern boundary described above was the 1926 southern Ohio maximum MMI VI-VII Earthquake (Fig. 6-12). Although the epicenter of this event is plotted within the Central Stable Region Tectonic Province as described in previous sections, it is sufficiently close to the tectonic province boundary that the staff required that an earthquake of that size be assumed to occur anywhere in the Appalachian Plateaus Tectonic Province, including the site vicinity.

The Attica , N.Y. maximum MMI VIII earthquake was concluded to be associated with the Clarendon-Linden Fault Zone and therefore restricted to the southern extent the fault zone. The New Madrid Seismic Zone was considered but because of its distance from the site (400 miles), estimated ground motions from a recurrence of the 1811-1812 maximum MMI-XI-XII earthquakes are enveloped by the plant design response spectra.

The staff was concerned about shallow earthquakes in that they seem to exhibit high epicentral intensities when compared to their magnitudes, and high accelerations in the form of high frequency spikes of short duration. Further study indicated that high frequency spikes had low energy content and, therefore, would not be damaging to nuclear power plant structures, components, or equipment.

6.6.3 Ground Motion

The SSE ground motion was determined to be 0.125g peak horizontal ground motion, and the OBE has a peak horizontal ground acceleration of 0.07g, approximately 1/2 the SSE. The utility used a vertical response spectrum 2/3 the horizontal response spectrum at all frequencies. This was questioned by the staff on the basis that Reg Guide 1.60 shows the vertical spectrum as being the same as the horizontal spectrum at higher frequencies. The applicant conducted additional studies and showed to the staff's satisfaction, that the design vertical spectrum envelopes the site matched response spectrum.

The staff was also concerned that site subsurface conditions which consist of shallow (50 to 115 feet), alluvial, granular soil over bedrock, are similar to those known to amplify ground motions in the frequencies that are critical to Category 1 nuclear power plant structures. There is a high shear wave velocity contrast at the soil rock interface (about +620 feet mean sea level) of 1200 feet/second for the soil versus 6000 feet/second for the carbonaceous shale bedrock.

Based on the staff's recommendation the utility developed site specific response spectra using the 84th percentile of available time histories of shallow, near field earthquakes similar in magnitude to the SSE and with subsurface conditions similar to those of the site. The results had to be modified, first to accommodate the velocity contrast because the records used were not from sites with high velocity contrast like that at the site, and second to consider amplification characteristics. The applicant used the 84th percentile of the "Best Estimate" of the site specific response spectra that was developed from a consideration of Site-Matched Response Spectra and Site Dependent Response Spectra (soil response analysis), and showed that the best estimate closely matched the Beaver Valley design spectrum above 6 Hertz and is enveloped by the Beaver Valley design spectra at frequencies below 6 Hertz. This demonstrated the adequacy of the design response spectra.

6.6.4 Capable Faults

Regional geological studies found no evidence of recent movement on faults. Association of faults in the region with known ancient orogenic events similar to the method described in Appendix A was used to show that the faults were not capable.

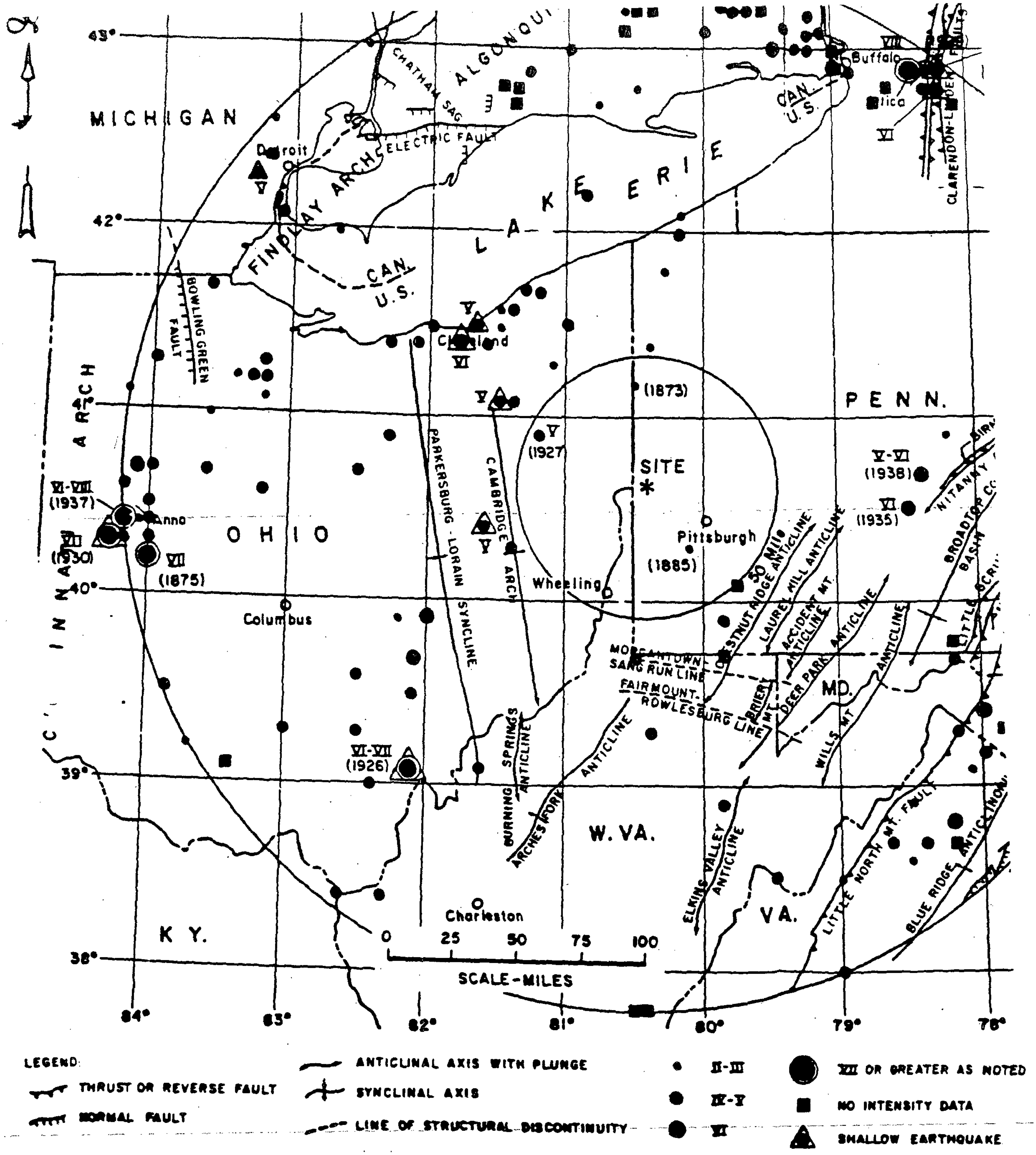


Figure 6-12 Earthquake Epicenters and Geological Structures within 200 Miles of the Beaver Valley Site (Ref, 6-11)

6.6.5 Stability of Foundation Materials and Slopes

There was an issue regarding the stability of the foundation soils under dynamic loading, which was eventually resolved. The site is in an area of extensive landsliding. Mapping of the site area and excavating for the plant, which stabilized potential slide material on the site, removed the staff's concern about the potential for rockfall or landsliding at the site.

6.7 PERRY

6.7.1 Background

The Perry Nuclear Power Plant is located on the southern shore of Lake Erie (Figure 6-13) about 20 miles northeast of Cleveland. The CP and OL reviews were carried out after publication of Appendix A in 1973, and the criteria were employed in these reviews. This section mainly addresses occurrences at about the time of issuance of the OL , a period of increased seismicity that included the January 31, 1986, magnitude 4.9 Astabula, Ohio earthquake.

6.7.2 Tectonic Province, Maximum Earthquake, and Capable Faults

The plant was designed and constructed to withstand ground motions generated by an SSE similar to the 1937 Anna, Ohio earthquake, maximum MMI VII-VIII, magnitude 5.2, the largest historic Central Stable Region Tectonic Province event occurring near the site. The plant was reevaluated after the 1982 Sharpesburg, Kentucky magnitude 5.2 earthquake. Site specific response spectra were developed and the plant design was shown to be conservative.

Faults had been found in the plant's excavations and in the seismic Category 1 intake and discharge tunnels. The faults in the excavations were shown, by their orientation, attitude, and sense of displacement to have last moved as a result of late Pleistocene glaciation. The tunnel faults could not be shown to be related to glacial activity because their orientation was not consistent with the ice movement. They were determined to not be capable by lack of seismicity, absence of offset of Lake Erie bottom, the current regional stress regime, and additional analyses that indicated that the displacements could have been the result of glacial loading and unloading.

6.7.3 Assessment of the January 31, 1986 Astabula, Ohio Earthquake and its Source

At about the time an OL was being issued to Cleveland Electric and Illuminating Co. (CEI) for Perry, an earthquake of about magnitude 4.9 occurred approximately 18 kms south of the site (Figure 6-13). Accelerations that exceeded the design ground motion were recorded at high frequencies (20 hertz and greater) within the plant. The ground motions were of very short duration and no structural damage occurred to the plant. NRC was concerned that if a similar earthquake occurred closer to the plant, or a larger event occurred, high frequency ground motions might be even greater, and the plant might be affected. Detailed analyses of structures, systems and components were carried out by the utility and by the NRC staff.

Immediately after the January 31, mainshock several portable seismic monitoring networks were set up including those of the Cleveland Electric and Illuminating Co. (CEI), the USGS, and 5 NRC contractors. Numerous aftershocks were recorded. One interpretation of the focal mechanisms and epicentral plots indicated a north-northeast trending fault plane about 1.4 kms long. Another interpretation indicated a circular or slightly oval pattern.

Geological and geophysical investigations were carried out by the applicant (Ref. 6-13), in the epicentral region. This was an attempt to identify the seismic source and to determine whether or not surface deformation had occurred (Figure 6-13). Gravity and aeromagnetic data indicated a north-northeast striking anomaly (high gravity gradient) just west of the epicentral area. Surface geological features including joints, glacial pop-ups, and minor faults were mapped in the region but these features were shown to be related to either glacial loading and unloading, or to late Paleozoic-tectonic deformation. A larger feature, consisting of severe folding and thrusting of shale bedrock and some glacial till, was mapped west of the epicentral area. The staff concluded that the last movement on this structure was related to Late Pleistocene glaciation.

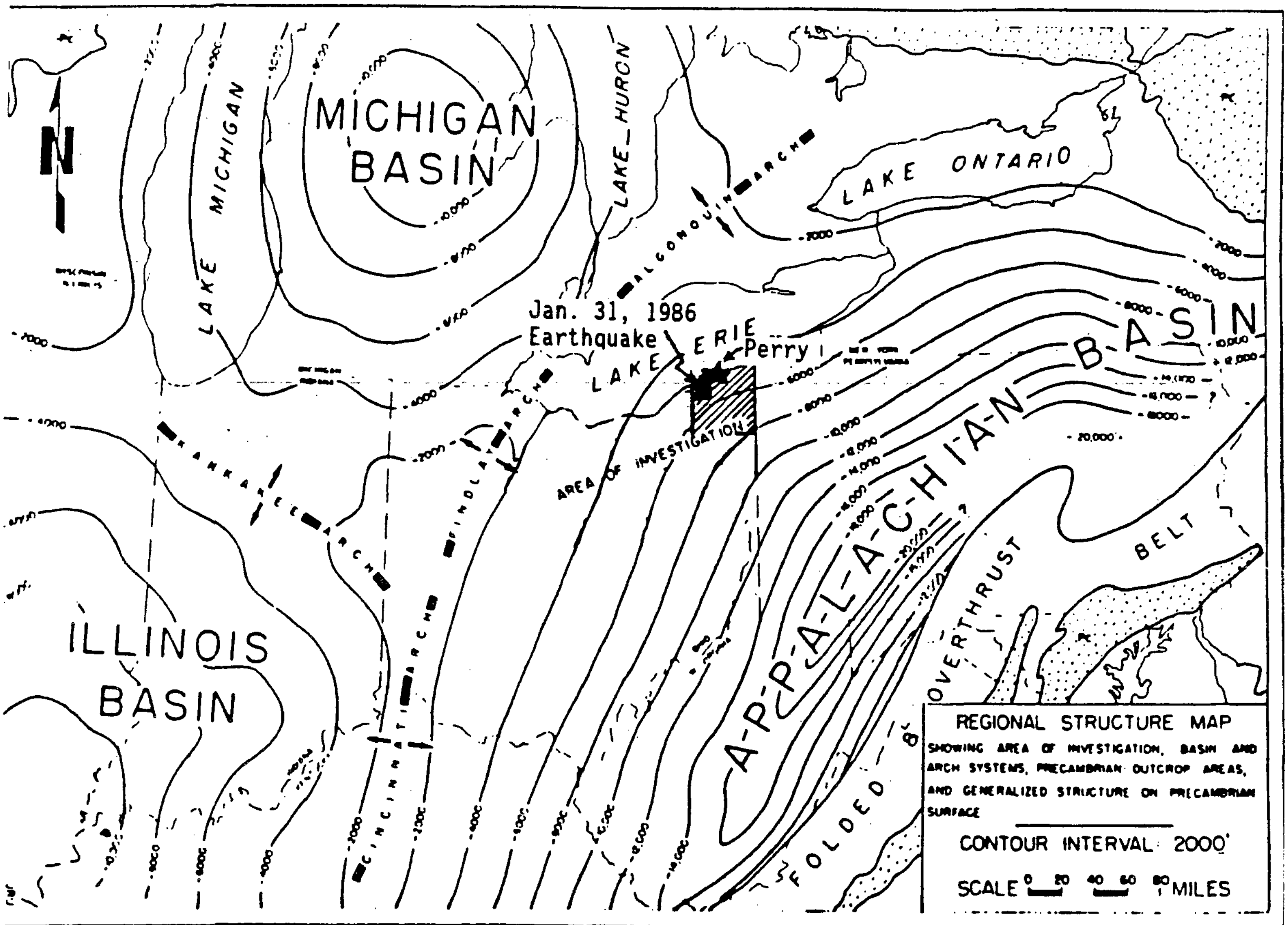


Figure 6-13 Regional structural geology map of the Perry Nuclear Power Plant (Modified from Ref. 6-13).

Two chemical waste disposal wells were located about 5 miles south-southwest of the site and north of the epicentral area. The wells extend to depths of 6,000 feet into Precambrian basement. Waste is injected at high pressures, and it was suggested that the earthquakes were induced by this activity. Investigations of these wells resulted in the conclusion that the wells are not directly related to the seismicity. This conclusion is based on the lack of seismicity in the vicinity of the wells, the occurrence of historic earthquakes in the area before the wells were installed, and the distance (12 km), and depths (2 to 9 kms) of the earthquake hypocenters with respect to the wells. In the ensuing years there have been a number of earthquakes with magnitude range of 4 to 5 in the Ohio-N.Y. border region, but none of these have resulted in strong ground motion being recorded at the plant.

The source of the seismicity was not determined, but the staff concluded, based on geological, seismological, geophysical, and engineering investigations and analyses, that the Perry seismic design basis is adequate (Ref. 6-14). Probabilistic seismic hazard analyses conducted later by the Lawrence Livermore National Laboratories (LLNL) for the NRC, and the Electric Power Research Institute (EPRI) supported the staff's conclusion that the seismic design bases are conservative.

CHAPTER 7 - SELECTED SITES IN THE NORTHEASTERN UNITED STATES

7.1 INDIAN POINT

7.1.1 Background

The Indian Point Nuclear Power complex is located near Peekskill, NY, about 30 miles north of New York City on the east bank of the Hudson River within the New England-Piedmont Tectonic Province (Fig. 7-1). There are 3 units at Indian Point and this discussion involves Unit 3. Unit 1, an older unit, had been shut down, Unit 2 was operating, and Unit 3 was well into the OL review process during the period (1974-1977), which is covered by this discussion. Unit 1 was licensed long before Appendix A was published and before the geologic and seismic principles later to become a part of the rule were being utilized. Unit 2 was licensed before Appendix A, but certain elements of the rule were used in the OL licensing activities, as they were also used in the CP review of Unit 3.

Late in the Operating License, the Citizens' Committee for the Protection of the Environment (CCPE), an intervenor, and the State Geological Survey of New York (NYGS), also an intervenor, presented testimony against the licensing of Unit 3 to the Atomic Safety and Licensing Appeals Board (ASLAB). The testimony was based on new geological and seismological data, and what they considered to be inadequate consideration of data available during the applicants' site validation study and the staff's review. The contentions fell into 3 main issues: (1) selection of a tectonic province as defined by Appendix A, (2) selection of appropriate and conservative ground motions, and (3) the capability of the Ramapo Fault.

A fourth issue was raised later by the applicants', the Consolidated Edison Company (Con Ed), and the Power Authority of New York (PASNY), as the result of a staff position requiring the expansion of an earthquake monitoring network near the plant to include the Ramapo Fault Zone. Prior to the public hearing, extensive investigations regarding the first 3 issues were carried out by the applicants, including the installation of an earthquake monitoring network.

7.1.2 Tectonic Province

The three parties to the ASLAB Hearing, which began in May 1976 with the ground motion issue, presented 3 different concepts of tectonic province. The NYGS and CCPE advocated the application of very large tectonic provinces for estimating the maximum earthquake. For example, the entire eastern U.S. was divided into an Appalachian Tectonic Province, which included the Appalachian Plateaus, Valley and Ridge, Piedmont and New England; and a Coastal Plain Tectonic Province. The NYGS wanted larger provinces on the basis that there was insufficient evidence to break them down any smaller than the two it proposed. Applying the requirements of Appendix A to the assumption that the Indian Point site is within the NYGS's Appalachian Tectonic Province, would require that a modified Mercalli Intensity (MMI) VIII earthquake, such as the 1755 Cape Ann, MA, and the 1897 Giles County, VA earthquakes be assumed to occur in the site vicinity, and then used to estimate the SSE ground motions for Indian Point.

The NRC presented testimony to support tectonic province divisions based on uniformity of geology, tectonic structures and seismicity (Figure 7-1). Eastern tectonic provinces were concluded by the staff to be: Appalachian Plateau, Southern Valley and Ridge, Northern Valley and Ridge, New England-Piedmont (including the Blue Ridge and Hudson Highlands)(see the discussion of the Seabrook site below), and the Coastal Plain. Two smaller areas within these tectonic provinces (not shown on Figure 7-1) were considered to be separate zones of unique tectonic structure and higher seismicity: the Boston-Ottawa Seismic Zone in the northeast and the Charleston Earthquake meizoseismal area in South Carolina. The Boston-Ottawa Seismic Zone was later reduced in size and redefined as the Boston-New Hampshire Zone (see the discussion of the Seabrook site below), based on new information and the reassessment of old information that indicated that the zone was not continuous through northern Vermont. The ASLAB was critical of the NRC for not publishing a map that presented its tectonic province concept to accompany Appendix A.

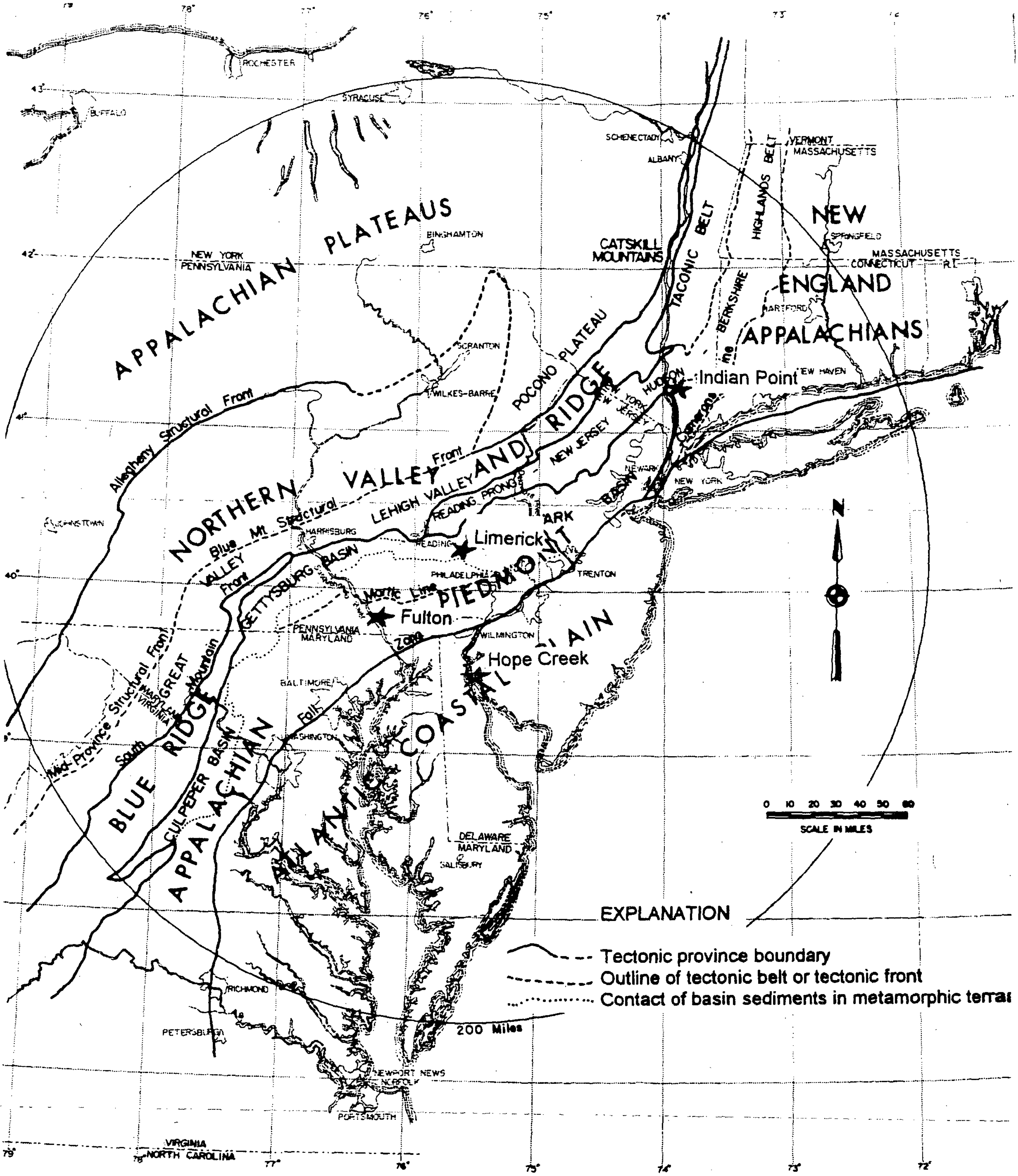


Figure 7-1 Tectonic Provinces in the northeastern United States (Modified from Ref. 7-1)

The applicants had divided the eastern U.S. into numerous small tectonic provinces based on types of rocks, ages, and relations to known tectonic events. This interpretation would put the site at the northern end of the Conestoga Province, which is a narrow belt of Ordovician carbonate metamorphic rocks that extends from northern Maryland to southeastern New York. In its decision the majority of the ASLAB accepted this concept, while the minority accepted the staff's.

7.1.3 Ground Motions

The staff and applicants supported the conservatism of the SSE, which is based on the potential occurrence of an MMI-VII in the site vicinity and 0.15g peak horizontal acceleration ground motion at the site. Using their tectonic province model, the NYGS and the CCPE supported an MMI VIII in the site vicinity and 0.25g peak horizontal acceleration ground motion at the site. The ASLAB accepted the staff and applicants analysis.

7.1.4 Capability of the Ramapo Fault

Extensive geological investigations were performed over a period of several years by Dames and Moore and Dr. N. Ratcliffe, each working independently. No evidence was found to support capability of the Ramapo Fault Zone. However, several lines of evidence were found, such as results of the geochronological analyses of faults within the Ramapo Fault System, and other geological evidence that were used to relate the origin of the Ramapo Fault to known ancient tectonic events. These findings indicated that the most recent movement of faults within this system occurred during the Mesozoic Era, thus satisfying the "time of last displacement" and "notwithstanding" criteria of Appendix A.

There was evidence that suggested that seismicity may be related to the Ramapo Fault Zone, including several historical MMI VII earthquakes of uncertain location, instrumentally recorded microearthquakes, and at least 2 magnitude 3 events, the focal solutions of which suggested motions consistent with the last documented displacement on the Ramapo Fault. As with the staff's position on the tectonic province issue, the ASLAB was critical of the NRC for not clearly defining "macroseismicity" as the term was used in the Appendix A definition of capable fault. It directed the staff witnesses to write their consensus opinion of what "macroseismicity" meant as described in Appendix A.

The applicants' position was that the Ramapo Fault was not a capable fault. The NYGS concluded that there was not sufficient evidence to rule out capability. The CCPE's position was that the Ramapo Fault Zone was capable based on the seismic evidence. The staff's position with respect to seismicity was that there may be tectonic stress being released along faults of the Ramapo system as along the other countless faults in the region. There is no greater level of seismicity in the vicinity of the Ramapo Fault Zone than in adjacent sections of the New England-Piedmont Tectonic Province. The majority of the ASLAB concluded that the Ramapo Fault was not a capable fault. The minority agreed with the NYGS that there was not enough evidence to support non-capability.

7.1.5 Expansion of the Seismic Network

The staff concluded that, even though the Ramapo Fault zone was not capable, stress was likely being released along its fault members, as it was throughout the region. It would therefore be prudent not only to continue monitoring seismicity, but to upgrade the capability of the existing network. This position had been recommended by the staff as a condition to the operating license. The staff's position was supported by the CCPE and the NYGS. The applicant appealed the condition. The ASLAB majority supported Con Ed on the grounds that the Ramapo was not capable, therefore, the expanded network would be a research project and not for site safety. The Board minority agreed with the staff.

The issues of tectonic province and maximum earthquake raised concerning this site and other northeastern sites, along with the later Charleston and New Brunswick issues, were major contributors to the staff's recognition of the need for the siting regulation to allow, or even require probabilistic seismic hazard analyses to address the large uncertainties regarding potential seismic sources, earthquake upper-limit magnitudes, and ground-motion estimates.

7.2 FULTON

7.2.1 Background

The site is located in Lancaster County, Pennsylvania, in the Piedmont Upland portion of the Piedmont Physiographic Province about 20 miles northwest of the Fall Zone (Figure 7-1). The site is situated on the east side of Conowingo Pond, a reservoir impoundment of the Susquehanna River. It is on the east side of the Susquehanna Gorge about 300 feet above the pond level on high ground that slopes very steeply down to the river (Fig. 7-2).

The Fulton site is across the river and downstream from the Peachbottom Nuclear Plant site, which received its Construction Permit (CP) before Appendix A was published. Operating License (OL) activities for Peachbottom were nearly complete when Appendix A was published, therefore, the regional geological and seismological review was accomplished before the elements of Appendix A were put into effect. Of the two sites, the most comprehensive geological and seismological investigations carried out to resolve the issues raised by the Appendix A criteria that apply to this region and site area, were conducted during the Fulton validation studies. The Fulton site was among the first group of sites to fall under the jurisdiction of the newly published siting regulation; and, along with the Summit site in Delaware, were the first proposed sites for gas cooled power reactors since the licensing of Fort St. Vrain. The review took place from late 1973 until 1976, when licensing efforts for this site were discontinued. The applicant withdrew the application for reasons other than geology, seismology or foundation stability.

7.2.2 Tectonic Province and Tectonic Structures

The site is in the New England-Piedmont Tectonic Province (Figure 7-1). Numerous major faults occur in the region around the site. Most of these faults have been studied for many years, and based on their nature, as described by the scientists who have studied them, can be related to major tectonic events that occurred in the Paleozoic or Mesozoic Eras. The applicant demonstrated this through an extensive literature review supported by regional field reconnaissances, and some focussed geological mapping.

7.2.3 Capable Faults

The most challenging issues were concerned with evaluating and characterizing faults and shears identified in the bedrock within the site area as to their potential for localizing earthquakes and causing surface deformation at the site. The site is located above an ENE-WSW striking, tightly folded, Paleozoic syncline, which is bounded on its north side by a major fault structure. The structures are known as the Peachbottom fold and fault. The fault is located 1,000 feet north of the proposed reactor complex. Drilling and trenching at the site revealed the presence of numerous shear zones.

Investigations were conducted to characterize the major fault to the north and the shear zones that crossed the site. As often happens with respect to evaluating faults in the eastern United States, obtaining absolute age dates for the most recent displacements was extremely difficult. In its attempt to accomplish this, the applicant performed geophysical surveys, detailed geologic mapping in the area around the site, including the excellent exposure adjacent to the Pennsylvania Central railroad along the eastern wall of the Susquehanna Gorge, and mapping of trenches excavated across the fault and shear zones (Ref. 7-2) (Figure 7-2). Potassium argon age dating of gouge material taken from the faults and rock petrofabric studies were carried out. Core borings were drilled to explore the faults at depth, especially the Peachbottom Fault, and to correlate the origin of these features with known regional tectonic episodes. The ages, plus the shear and tensional characteristics determined from these activities suggested that the deformations were related to Appalachian compression followed by tension in the Mesozoic Era.

The results of the investigations were not conclusive as to the ages of the faults and shear zones, and there were many uncertainties in the methods employed. There was also strong intervention by local geologists, professors from the

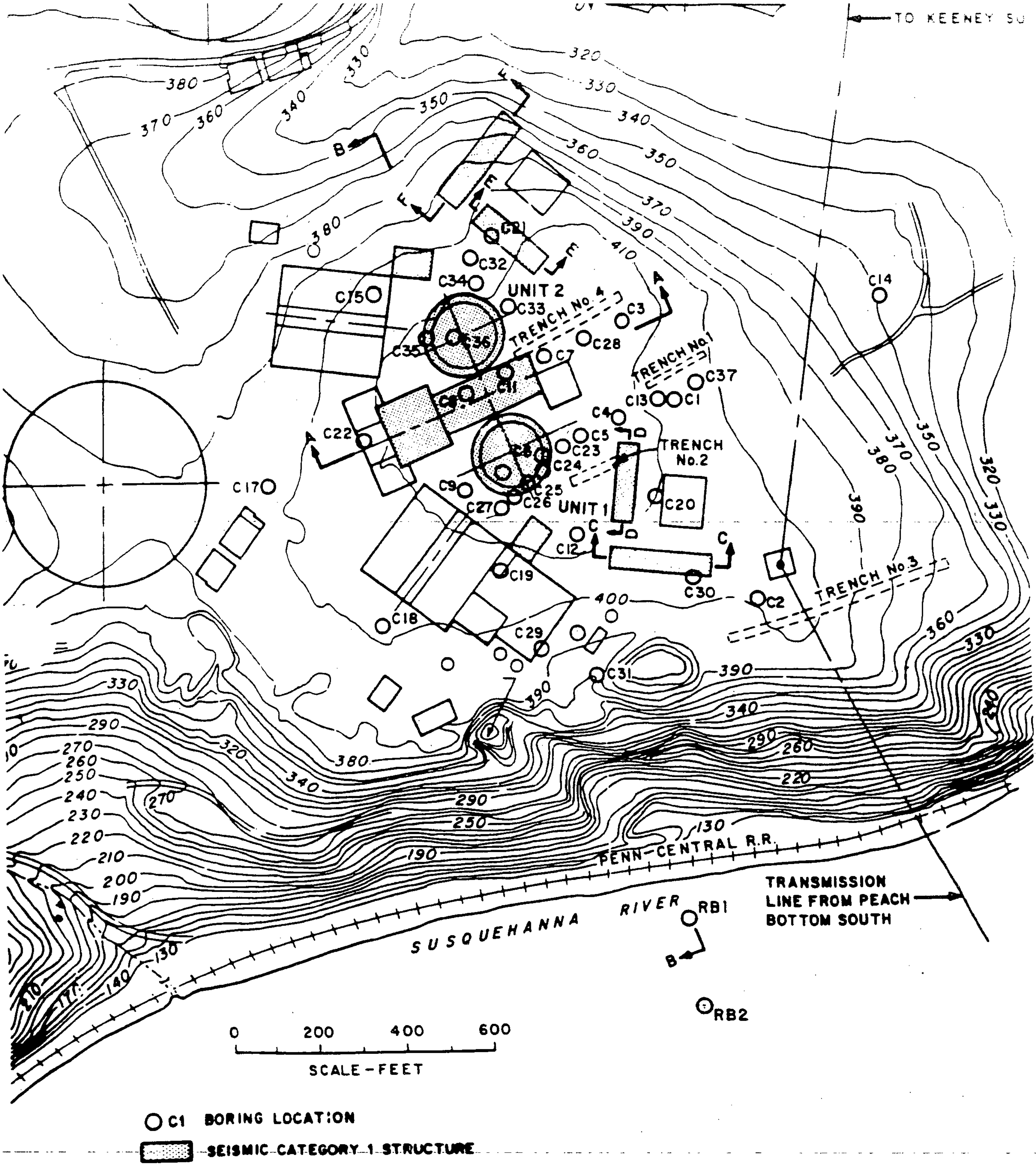


Figure 7-2 Fulton site plot plan showing topography and boring and trench locations (Modified from Ref. 7-2).

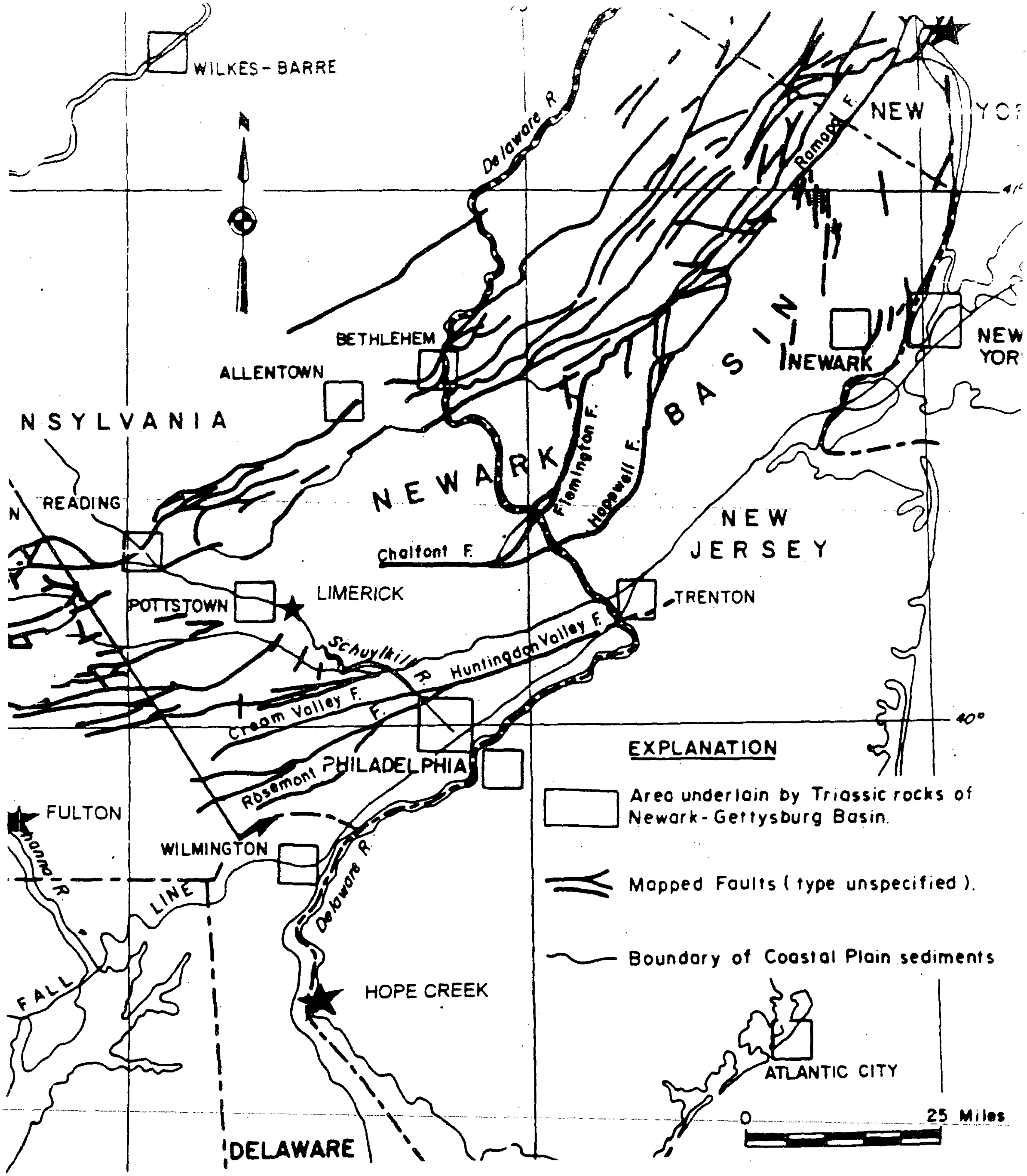


Figure 7-3 Geologic Structure in the Vicinity of the Newark-Gettysburg Mesozoic Basins 9 (Modified from Ref. 7-1).

Franklin and Marshall College in Lancaster. To assist in resolving the issues, a panel of three renowned experts in Piedmont geology was assembled by the applicant at the recommendation of the staff. The panel members were Drs. Carlyle Gray, former State Geologist, Alfred Hendron, Professor at the University of Illinois, and Donald Wise, Professor at the University of Massachusetts.

Additional investigations were conducted because of the need to reduce uncertainties, and also in response to the panel's recommendations. The additional investigations consisted of magnetic and gravity surveys, borings, trenches, geomorphic studies, radiometric dating, geochronological studies, including rates of weathering, geological mapping, rock petrofabric analysis, and soil and rock mineralogical studies.

Based on the review of the results of these investigations, numerous geological reconnaissances of the region and site, and the conclusions and recommendations of the expert panel, the AEC staff concluded that there was no potential for fault displacement at the site or for the localization of earthquakes in the site vicinity.

7.2.4 Stability of Foundation Materials and Slopes

Another important issue was the adequacy of the weathered bedrock to support the plant structures. The uppermost rock unit at the site is the Peachbottom slate. Relatively unweathered Peachbottom slate is a competent foundation material and lies at depths ranging from 45 to 75 feet. The rock becomes more severally weathered toward the surface with shear wave velocities ranging from 2500 to 1800 feet per second. The applicant agreed to excavate all severely weathered rock, including that which penetrates fractures at depth, and backfill with concrete. Where severe weathering extends along joints, schistocity, etc., below the base of the foundations, this material was to be excavated to a depth 1 and ½ times the width of the zone and replaced with concrete. This removed the staff's concern regarding the competence of the foundation rock to support the major structures of the plant.

7.3 SEABROOK

7.3.1 Background

The Seabrook site is located near the northern boundary of the town of Seabrook in Rockingham County, southeastern New Hampshire. The Construction Permit evaluation began in the early 1970s at about the time of the publication of Appendix A, and continued with the OL application evaluation into the early 1980s. The Appendix A criteria were used extensively in the review process with respect to tectonic province, ground motion, and capable fault issues. As previously described in the discussion of the Indian Point site OL review, these three topics, as they relate to Appendix A criteria were also major issues in the Seabrook CP ASLAB Public Hearings. The ASLAB was comprised of the same three members who presided at the Indian Point 3 Hearing. The ASLAB findings were presented at the same time, and in the same document for both Indian Point and Seabrook.

The post CP review of faults in the excavation was conducted in the mid and late 1970s and the geosciences OL review was carried out in the late 1970s and early 1980s. The requirements of Appendix A were closely adhered to during this review by both the applicant and the NRC staff.

7.3.2 Tectonic Province

During the CP review the staff recognized the New England Tectonic Province as the site's tectonic province. Also at this time, based on seismicity and geological information available at the time, the staff concluded that the New England Tectonic Province could be further subdivided. The staff recognized within the New England Tectonic Province a seismic, and possible structural (rift) zone that extended from Cape Ann, Massachusetts through the White Mountain Plutonic Belt, New Hampshire, Monteregian Hills, Quebec, and the Ottawa-Bonnechere Graben in Ontario, called the Boston-Ottawa Seismic Zone. The staff also recognized the possibility that this postulated rift zone could extend offshore to the southeast and include the Kelvin Seamounts.

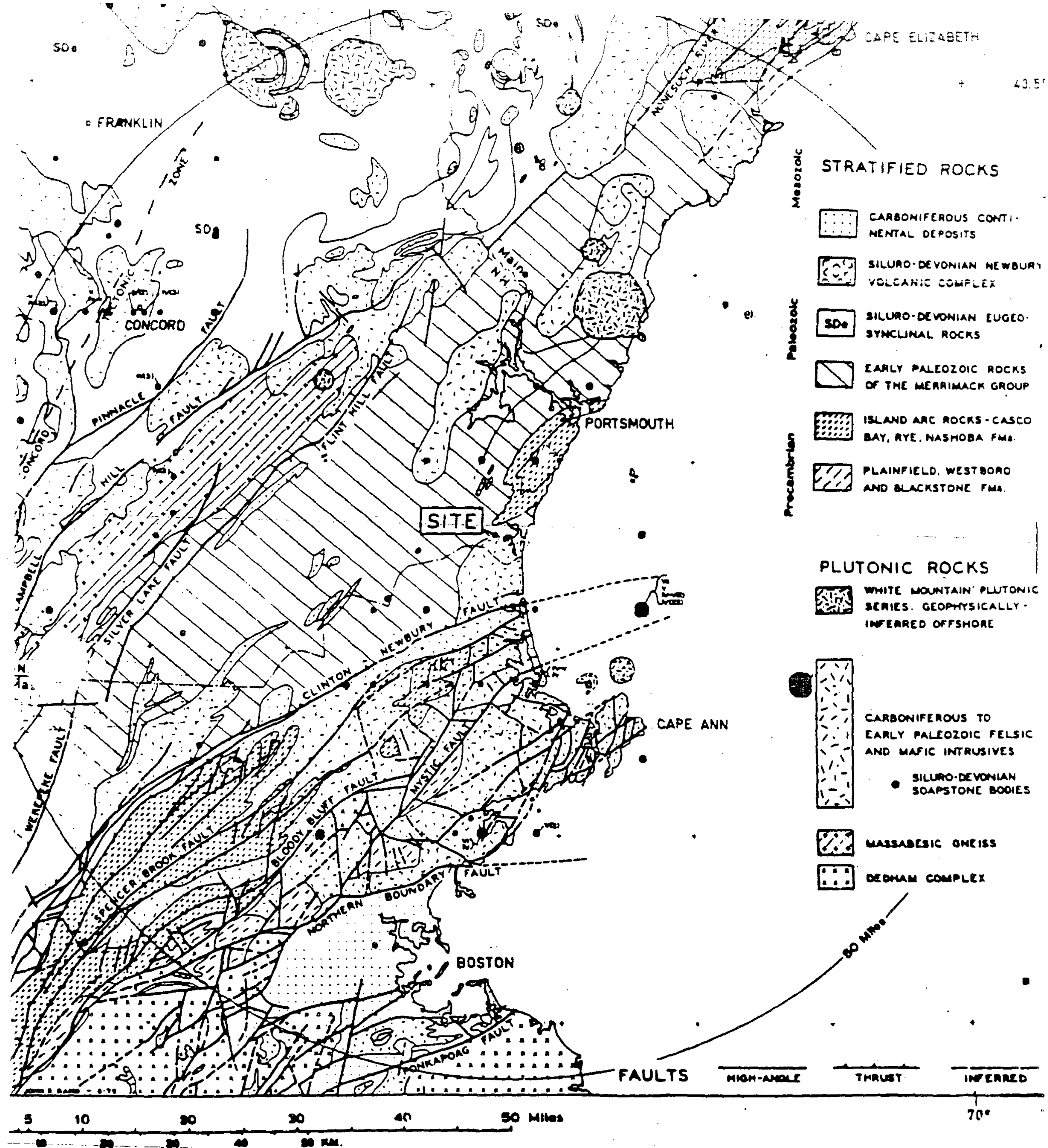


Figure 7-4 Tectonic and Epicenter Map of the Seabrook site vicinity (Modified from Ref. 7-7).

At the ASLAB hearing, the intervenor's (Concerned Citizens for the Protection of the Environment-CCPE) seismology witness disagreed with the staff and maintained that the eastern U.S. should not be subdivided into tectonic provinces. He further concluded that, because of the uncertainties regarding seismic sources in this region, it should be assumed that the largest historic earthquake (MMI X+) could occur anywhere in that region.

The applicant's position was that earthquakes in the site region were generated by faults tangential to Mesozoic alkaline plutons, such as those comprising the White Mountains and located offshore of Cape Ann. As in the Indian Point Hearing, the majority of the ASLAB agreed with the applicant's interpretation.

Prior to the OL review, based on its evaluation of numerous sites on the Atlantic Seaboard and the similarity of the seismicity in New England with that in the Blue Ridge and Piedmont provinces, the staff had enlarged the New England Tectonic Province to include these latter two areas, and referred to this broad region as the New England-Piedmont Tectonic Province. Likewise, as a result of new information and its evaluation of the Pilgrim site, the ongoing reviews of Indian Point 3 and Seabrook sites, and the analyses of the proposed sites of Montague 1 and 2, and New England 1 and 2, the staff concluded that the so-called Boston-Ottawa Seismic Zone was not a continuous entity. It did, however, recognize that a segment of it, extending from northeastern Massachusetts through the White Mountain plutonic complex into Quebec, was characterized by higher seismicity and different geology than the rest of New England. The staff concluded that there was a spatial relationship between this seismicity and the north-south elongated group of White Mountain intrusives, which contains the youngest significant, major tectonic deformation features in New England. The staff referred to this area as the New Hampshire-Cape Ann Seismic Zone (later changed to the Boston-New Hampshire Seismic Zone) within the New England-Piedmont Tectonic Province.

7.3.3 Tectonic Structures

The nearest major tectonic structural zone to the site (7 miles south) is the Clinton Newbury-Bloody Bluff Fault System (Figure 7-4). Although previous investigators such as Dennen in 1979 and 1980 (Refs. 7-3 and 7-4), and Schride in 1971 (Ref. 7-5) had concluded that the fault system was either Acadian or Permian, Appendix A requires that such structures be investigated in the field. The applicant investigated the northernmost fault of this system, the Scotland Road Fault, a north-over-south thrust fault, in considerable detail, and found it to be at least 240 million years old.

An occurrence that typifies hazard analyses of many critical facility sites located in areas of complex geology and tectonics is that research by others (universities, government agencies, and commercial consulting firms) is continuous. Faults and their levels of activity are often postulated, based on information that is sufficient to suggest the presence of a fault and its degree of activity, but inadequate to either prove its existence or demonstrate its age of most recent displacement. Such is the case concerning a large fault postulated by Novotny in 1963 (Ref.7-6), which was mapped about 1.5 miles north of the Seabrook site. To meet the requirements of Appendix A, an investigation was conducted by the applicant. This work did not identify the fault. Since there was no evidence that the postulated fault offset the boundary of the Newburyport Pluton, it was concluded that if a fault existed, it was at least 330 million years old. Such investigations are necessary, but require considerable effort and expense, and often cause substantial delays in the licensing process.

7.3.4 Capable Faulting

Mapping of the walls and floor of the excavation at the Seabrook site identified more than 60 faults (Figure 7.5). Bedrock at the site consists of two main lithologies: Ordovician to Devonian metasediments consisting of quartzite, schist, slate, and phyllite; and gneisioid quartz diorite of a pluton that intruded the metasediments during the Acadian Orogeny in the Devonian period. The site area is crossed by mafic dikes that range in thickness from one inch to 20 feet and are spaced from 30 to 300 feet apart. The dikes generally strike northeast and dip at high angles to the northeast and southwest. Most of the dikes were discontinous in exposure, short, and formed en echelon, left stepping patterns. Radiometric dating indicted that the dikes were emplaced during two periods: Early Triassic and Upper Paleozoic.

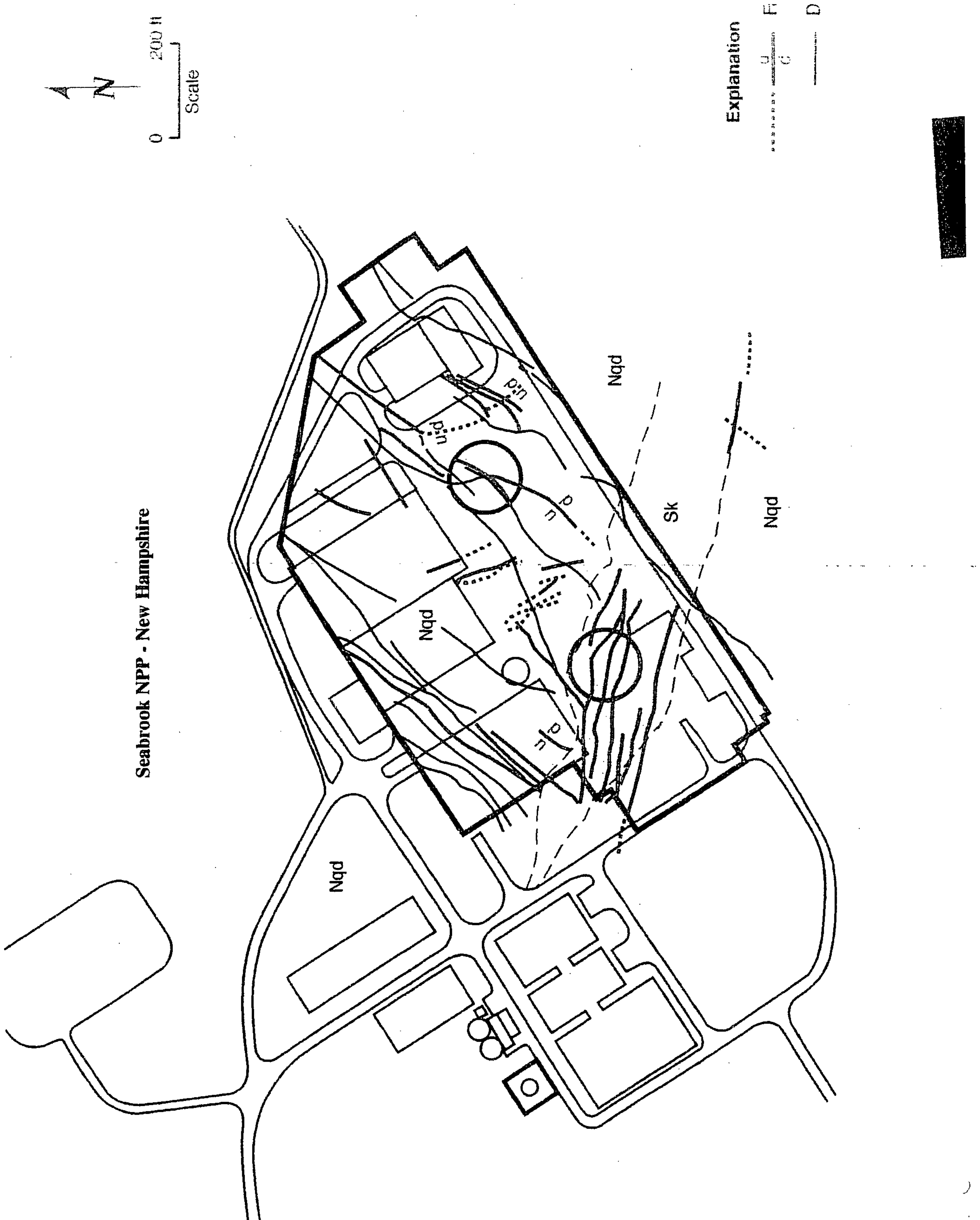


Figure 7-5 Seabrook Station – mapped faults and dikes through the reactor complex (Ref.'s 3-27 and 7-7).

Quaternary glaciation stripped away most of the weathered soil and rock that developed during the Cenoizic and left various thicknesses of till, glacial outwash, and marine clay and silts overlying the bedrock. Recent deposits of beach sands and gravels and peat are also present.

Numerous faults had been mapped at the site and in the region around the site during the early investigations so that it was expected that faults would be encountered in the excavations. As in past practice, detailed mapping of all excavations was required by the NRC. Sixty one minor faults were mapped in the excavations for the plant. The faults were not through going in that, with one exception, at least one end of each fault terminated within the excavation, and many were of limited vertical extent. They appeared to be controlled by pre-existing joints or foliation planes. Displacements ranged from a few inches to several feet, and sense of displacement was generally normal.

The applicant categorized all the faults in the excavation into seven sets based on orientations, attitudes, sense of displacements, physical characteristics, and lithologic relationships. The applicant demonstrated by cross- cutting relationships among the faults and the numerous Mesozoic diabase dikes cutting through the site bedrock exposed in the excavation, and the results of a radiometric age dating program (mainly potassium argon), that some of the faults were related to the Acadian Orogeny (400 million years ago), and others to early Triassic rifting and dike emplacement (about 200 million years ago). Additional evidence of fault antiquity was documented by mapping unfaulted Pleistocene sediment s overlying the faults.

In addition to excavation for the plant, two safety-related, 22 feet in diameter tunnels for circulating cooling water were constructed from the plant pumping structure to the intake and discharge structures several miles offshore. The tunnels were 16,000 and 1,7000 feet long, respectively. Prior to lining with three feet thick concrete, these tunnels were also geologically mapped in detail. The tunnel alignments were located along the contact between the diorite of the pluton and the metasedimentary quartzite and mica schist, so these types of rocks form the tunnel walls. Numerous diabase dikes were also encountered. More than 100 faults were identified and mapped in the tunnels. Some radiometric dating was accomplished, but the time of last displacement of the tunnel faults was mainly obtained by demonstrating a relationship to tectonic events that created the faults analyzed in the plant's excavations and to other faults mapped throughout the region. The NRC concluded that the faults in the excavations were not capable faults as defined by Appendix A.

7.3.5 Stability of Foundations

Weathering along joints and faults penetrated to depths well below the foundation. The applicant removed this material and backfilled with 3,000 psi concrete.

7.3.6 New Brunswick Earthquake

The possible affects of an occurrence near the site of an earthquake similar to the January, 1982, magnitude 5.7 to 5.8 New Brunswick Earthquake on the Seabrook plant were assessed. The results showed that the plant, which is designed to accommodate ground motions from a nearby magnitude 6 event and , therefore, would not be adversely affected by the nearby occurrence of an earthquake similar to the New Brunswick event.

7.4 HOPE CREEK

7.4.1 Background

The Hope Creek Nuclear Power Plant site is located on Artificial Island on the eastern shore of the Delaware River in the Coastal Plain Tectonic Province approximately 18 miles southeast of the Fall Zone. The Fall Zone is the boundary between the Coastal Plain and the New England-Piedmont Tectonic Provinces (Figure 7-1). The Hope Creek licensing activities took place from the middle1970s into the middle 1980s, and the Appendix A criteria were used throughout.

The Hope Creek Nuclear Plant is adjacent to the Salem Nuclear Plant, which went through the licensing process prior to the publication of Appendix A. However, the concepts of tectonic provinces, tectonic structures, and maximum earthquake were used for Salem. This evaluation resulted in an SSE peak horizontal ground acceleration of 0.20g based on the postulated occurrence near the site of a maximum MMI VII earthquake similar to the 1871 Wilmington and considering the 1927 Asbury Park earthquakes, and amplification due to the soil foundation of the plant.

The Charleston Earthquake and New Brunswick Earthquake issues were discussed in Chapter 2. Because these two issues were significant to the seismic evaluation of Hope Creek, they are briefly discussed in the next two sections as they apply to the site.

7.4.2 Charleston Earthquake

Based on extensive investigations in the Charleston, South Carolina region, in 1983, the USGS revised its previous position that the 1886, MMI X Charleston Earthquake is associated with a unique seismic source near Charleston. Its revised position is that the source is not unique and such an event is possible, although with a low probability, in other parts of the Atlantic Seaboard.

Numerous hypotheses were developed as a result of the geological, seismological, and geophysical investigations at Charleston. These hypotheses are described in Chapter 2. In the Hope Creek review the staff concluded that, due to the speculative nature of these hypotheses, and the fact that the staff had decided to continue to support its long term deterministic investigation program, which began in 1973 with the deployment of the South Carolina seismographic network, followed by the USGS geological and geophysical program. Another reason for this conclusion was that the staff was also preparing to initiate, as part of the Charleston Plan, a probabilistic seismic hazard analysis program, which would address all of the uncertainties. In view of these occurrences and based on the available evidence, the staff concluded that there was no need to alter its previous position that the Charleston Earthquake is associated with tectonic structure peculiar to the meizoseismal area of that earthquake, and should not be assumed to occur any closer to the site for seismic design purposes.

7.4.3 New Brunswick Earthquake

The magnitude 5.7 to 5.8 earthquake that occurred in January, 1982, in terrane similar to terrane that characterizes parts of the New England-Piedmont Tectonic Province, which is located 18 miles from the site, caused concern with respect to the Hope Creek site.

Using data developed by Canadian Agencies and from investigations sponsored by New England utilities, the staff documented the tectonic, structural, seismicity, and geological differences between the epicentral area and the site area. Such differences include: (1) differences in Paleozoic structural style and tectonic history, (2) the site is located in an area of substantial Mesozoic rifting, but the New Brunswick Earthquake epicentral area lies considerably west of this zone of rifting, (3) the New Brunswick Epicenter is within Devonian plutonic rock while Hope Creek is on Coastal Plain sedimentary soils and rocks, (4) the New Brunswick Epicenter is located in the northern extension of the New England fold and thrust belt, which is the result of Acadian deformation of early to middle Paleozoic. The Hope Creek site is underlain by tectonic structure that originated as a result of the Alleghenian Orogeny in the late Paleozoic, (5) the tectonic structure of the New Brunswick earthquake area is oriented predominantly northeast-southwest. The structural grain at Hope Creek is also northeast-southwest, but superimposed on that structure is a later northwest-southeast orientation, as shown by axes of the Salisbury and Raritan Embayments and the New Jersey Uplift, and (6) aftershock sequences of the New Brunswick Earthquake suggest structural control, a pair of conjugate faults that dip into one another. No structural control has been identified for the seismicity around Hope Creek, but it seems to be clustered around the Fall Zone.

The staff concluded that it is unlikely that an earthquake the size of the New Brunswick event would occur in the site area, but if it did it would most likely occur at the Fall Zone based on the historic seismicity. The staff concluded that such a happening would not impact the seismic design bases of the Hope Creek site.

The staff conclusion described above was later confirmed by the results of a study conducted by the Electric Power Research Institute (EPRI), which is described in Chapter 2, of earthquakes and their sources in stable continental regions world-wide, where magnitude 6 earthquakes have occurred. These sources in stable continental regions throughout the globe are analogous to many of those in eastern North America. The conclusion was further confirmed by the occurrence of the 1988 Saguenay, Quebec and the 1989 Ungava, Quebec earthquakes, which occurred in this region. All of these events supported the staff's conclusion that magnitude 6 earthquakes could not be ruled out in the New England-Piedmont Tectonic Province, but would have a very low probability of occurring in the vicinity of the Hope Creek site.

The LLNL and EPRI probabilistic seismic hazard analyses (PSHA) of the central and eastern United States demonstrated that, although a moderate to large earthquake is possible in the vicinity of the Hope Creek site, the probability of such an occurrence is so small that it has a very low impact on the seismic hazard of this site. The PSHAs also showed that the earthquake that dominates the hazard near the site is the local magnitude 5.3 to 5.5 event, such as the 1972 Wilmington and 1927 Asbury Park Earthquakes for which the Hope Creek Plant is designed.

7.4.4 Tectonic Structures and Capable Faults

Regional faults were investigated primarily by reviews of documents containing the results from other investigations, and by regional-type geological reconnaissances. The analysis found the following significant faults to be geologically ancient and noncapable using Appendix A criteria: (1) the postulated eastern U.S. major decollement, (2) the postulated Cornwall-Kelvin Wrench Fault, (3) the Martic Line of thrust faulting, (4) the Hunting Valley-Cream Valley Fault, (5) the border faults and interior faults of the Newark-Gettysburg Mesozoic Basin, particularly the Ramapo Fault Zone, and (6) the Hopewell and Flemington faults (Figure 7-3).

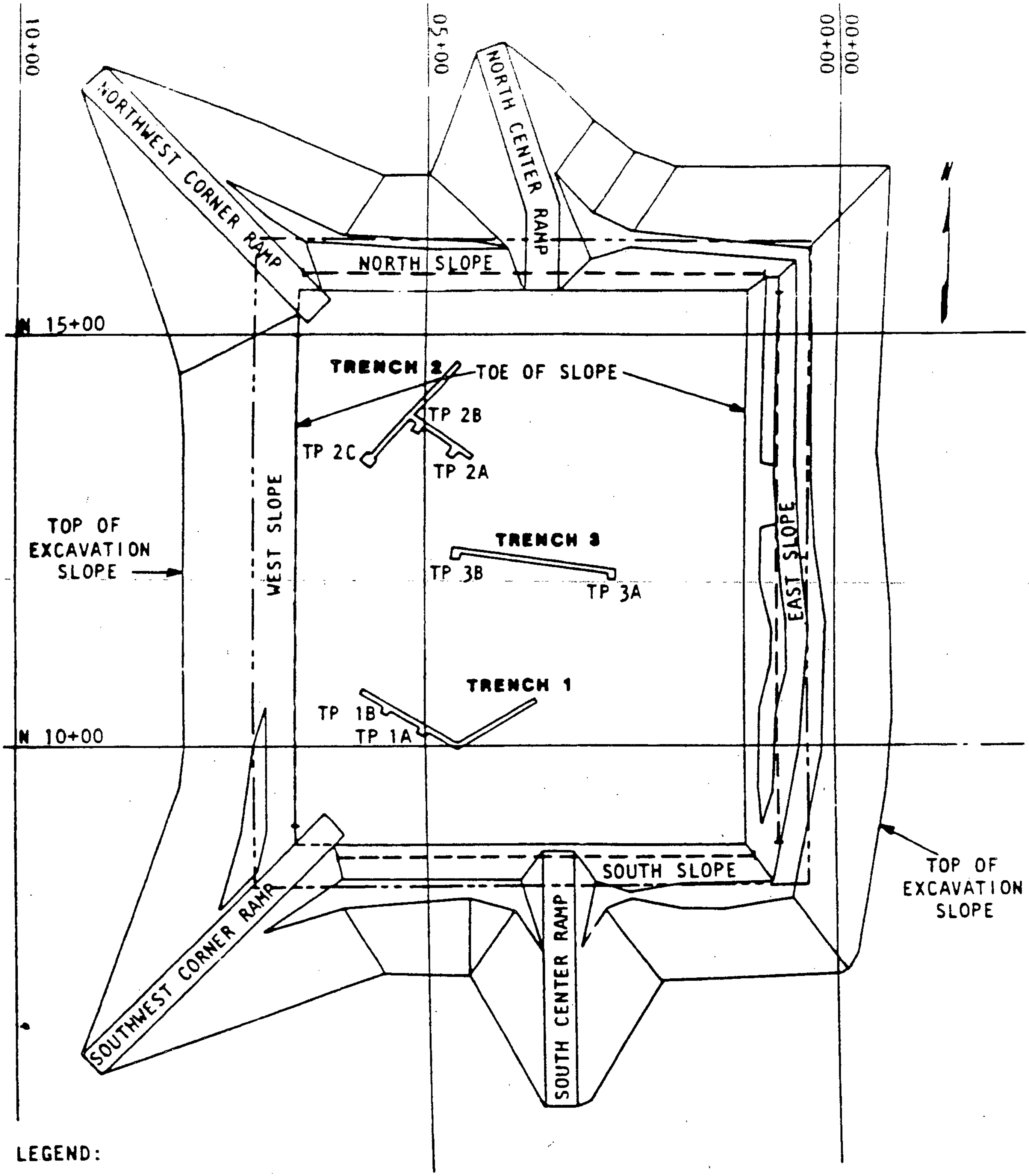
During the past 30 plus years, numerous post-Mesozoic faults have been identified in the Coastal Plain and Piedmont: the Augusta, Brandywine, Stafford, Helena Banks, and Cooke faults to name a few. The staff has evaluated these and other post-Mesozoic faults during the reviews of other Coastal Plain and Piedmont nuclear power plant sites, including the Hope Creek site, and found that none of them are younger than two million years.

The closest relatively young faults to the site are part of a group of faults at the Fall Zone about 18 miles northwest of the site. These faults were shown not to displace the upper Cretaceous Merchantville Formation as a result of the CP assessment of the Summit site in Delaware. The Delaware Geological Survey postulated several faults from Landsat imagery. The lineaments were also investigated by the applicant's consultant, which found no evidence that would suggest that the features were capable faults.

A consultant working on the northern Fall Zone as part of the New England Seismic Study sponsored by the NRC, postulated that historic and instrumentally recorded earthquakes formed linear patterns, and these linears represented faults in the basement rocks. As the different lines of evidence were not consistent, and too few earthquakes were in the database, the staff concluded that existence of young faulting at the locations designated by this researcher was not demonstrated.

7.4.5 Stability of Foundation Materials and Slope Stability

Penetration blow counts in borings during site investigations were variable and some counts were relatively low, and core recovery was poor. Based on these characteristics, the staff questioned the adequacy of the foundation material, the Vincentown sandstone, to support the plant, particularly when being subjected to SSE ground motion. The applicant was, therefore, required to dewater and excavate down to elevation -59 msl, perform in-situ tests in trenches and test



LEGEND:

TP 3B — EXPLORATORY TRENCHES AND ADJACENT TEST PITS EXCAVATED FOR GEOTECHNICAL EXAMINATION

LOCATION OF EXCAVATION SLOPE PROFILES

LIMIT OF AREA INCLUDED IN STRUCTURAL CONTOUR MAPS

Figure 7-6 Plot Plan of the Main Excavation for the Hope Creek Nuclear Generating Station (Modified from Ref. 7-8).

pits in the bottom of the excavation, and perform laboratory tests on undisturbed samples (Figure 7-6). Also because of the remote possibility of faults in the soil and rock beneath the plant, the applicant was required to geologically map the walls and floor of the excavation.

The staff concluded that the Vincentown Formation was mostly composed of weakly cemented sand and silt, and although it contained discontinuous pockets of loose sand, differential settlement resulting from earthquake ground motions could be mitigated by the size and thickness of the concrete slabs and other provisions in the design. There was no evidence of faulting in the excavation walls or base.

7.5 NINE MILE POINT

7.5.1 Background

The Nine Mile Point, Units 1 and 2 are located adjacent to the Fitzpatrick Nuclear Power Plant on the southern shore of Lake Ontario near Oswego, New York. Unit 1 was licensed and began operating before Appendix A became part of the rules. It is unclear to what extent the criteria in Appendix A were utilized in the licensing activities of Unit 1. The CP evaluation for Unit 2 was carried out in 1972 and 1973 during the finalizing of Appendix A, and the criteria were utilized. During the OL activities, from the late 1970s to the middle 1980s, the criteria for determining the capability of faults were used extensively (Ref. 7-9 and 7-10). The reason for this long time span was to evaluate the potential hazard posed by faults discovered at the site and in the surrounding area during excavations for plant structures.

The site is underlain by thin layers of peat, sand, lakebed deposits on top of about 10 meters of glacial till. These strata were dated by the Carbon 14 method as ranging in age from 12,600 to 10,000 years before present and thus provided a good upper limit control. Beneath the surficial soils are about 670 meters of Paleozoic sedimentary strata consisting of carbonates, sandstones, and siltstones. The uppermost units are sandstones of the Oswego and Pulaski formations. A most useful tool for the analysis of faults was the cross-cutting relationships between the faults and the nearly horizontal strata.

7.5.2 Tectonic Province, Tectonic Structures, Maximum Earthquake, and Ground Motion

A major issue during the CP review was the adequacy of the proposed SSE. The SSE was based on the postulated occurrence of a maximum MMI-VII earthquake (maximum earthquake in the site's tectonic province) assumed to occur near this bedrock site, and resulting in the generation of peak horizontal ground accelerations of 0.15g. The 1929 maximum MMI VIII Attica Earthquake was assumed by the staff and its seismological advisors, the National Oceanic and Atmospheric Administration (NOAA) to be associated with the north-south striking Clarendon-Linden Fault, located about 60 miles west of the site. An article by Woollard, published in 1968 (Ref. 7-11) postulated a continuation of the New Madrid structural zone and seismicity from southern Illinois, across Indiana and Ohio, across Lake Erie, through Lake Ontario, and up the St. Lawrence River. Such a structure would pass beneath Lake Ontario north of the site.

The staff concluded that there was no major continuous tectonic structure from New Madrid to the St. Lawrence River based on various previous investigations which revealed that a more northerly structural grain characterized the region through which this postulated structure would pass. This structural grain is reflected by the Cincinnati Arch, the Grenville Front, the Clarendon-Linden Fault, the Frontenac Arch, and the southern extension of the Gloucester Fault across the St. Lawrence River. Additionally, seismicity patterns do not indicate a regional northeast trending tectonic structure along the postulated zone. The peak horizontal ground acceleration SSE of 0.15g was accepted by AEC and its NOAA advisors.

Nine Mile Point NPP- New York

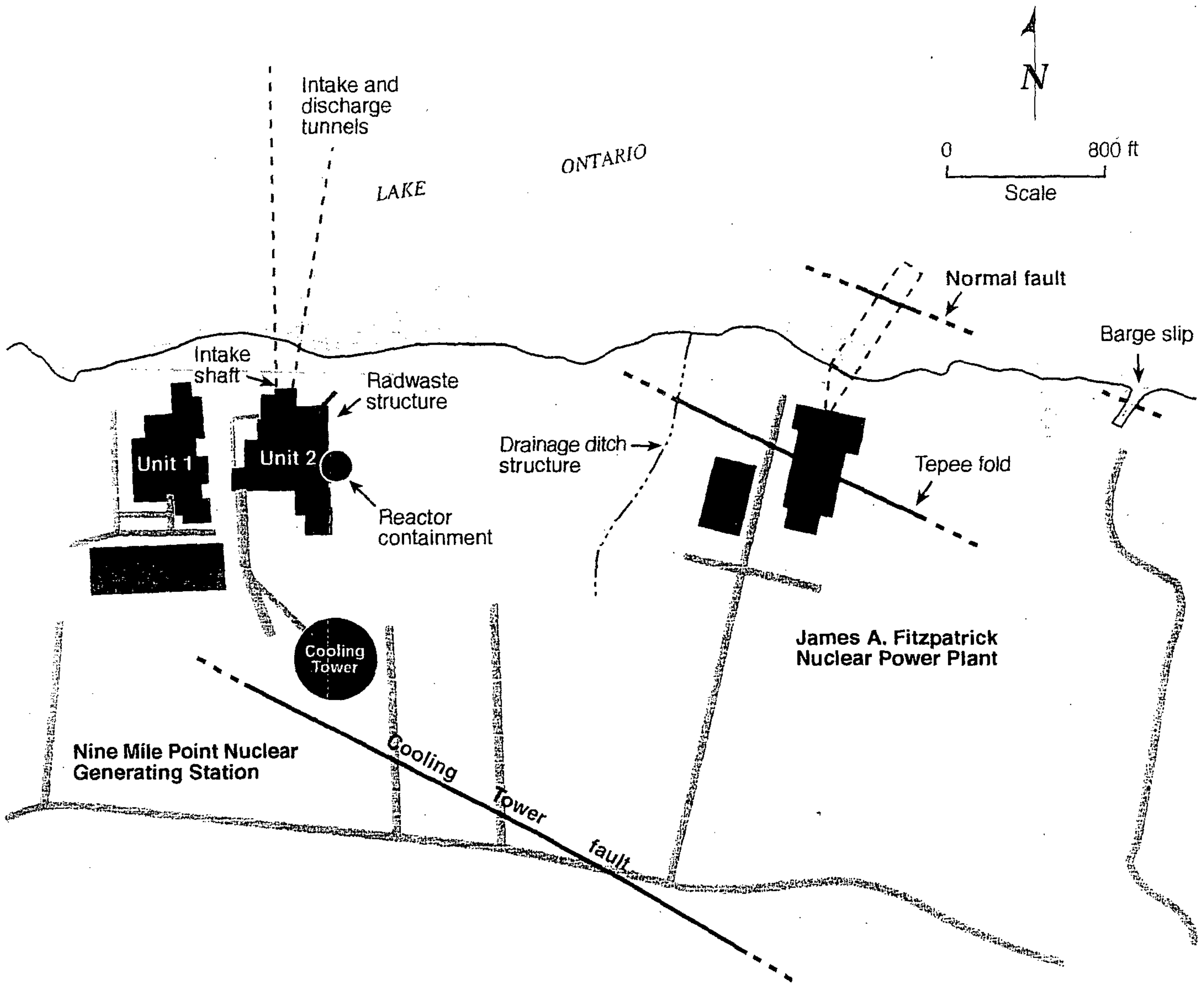


Figure 7-7 General layout of the Nine Mile Point Nuclear Station, Unit 2 (Modified from Ref. 7-9, Ref. 3-27)

7.5.3 Capable Faults

During the OL evaluation several faults were encountered at the Nine Mile 2 site and in the surrounding area. While excavating for the non-safety related cooling tower foundation, a reverse fault was discovered that offset post-glacial (Holocene) soils by a fraction of an inch to several inches (Figure 7-7). The fault (Cooling Tower Fault) displaced underlying bedrock several feet. The strike of the fault was west-northwest and dip steeply northeast. The fault appeared to die out to the west-northwest. The amount of reverse offset also decreased from more than 3 feet at the surface of bedrock to 0 at a depth of about 200 feet. The fault was interpreted to have been formed as a normal fault in the Late Paleozoic, underwent strikeslip displacement during the Mesozoic, and experienced reverse movement in the late Quaternary as the result of glacial activity. Pleistocene displacement caused buckling (teepee folding) at the surface of bedrock.

A feature similar to the Cooling Tower Fault (same strike and dip) was identified northeast of Unit 2 exposed in a drainage ditch (Drainage Ditch Fault) near the shoreline of Lake Ontario (Figure 7-7). This fault also offset Holocene deposits and was concluded to be a continuation of a fault and teepee fold with 1½ feet displacement that had been discovered in the rock excavation for the Fitzpatrick Nuclear Plant adjacent to Nine Mile Point. The Drainage Ditch Fault also extended to the west and cut across the Nine Mile Point 2 intake and discharge tunnels. It was anticipated that displacements would occur along this fault in the future due to the high stresses in the bedrock. Future offsets were estimated and accommodated for in the design of the tunnels. The estimates were based on findings of the site investigations of the Holocene displacements recorded in the geology and on strain measurements in test excavations.

A third fault had been mapped during the Fitzpatrick OL review. This fault had the same strike as the two faults to the south, but dipped steeply to the south instead of to the north. Investigations of the Fitzpatrick site demonstrated that this fault was truncated by lodgement till deposited during the last glacial advance (Woodfordian), or about 13,000 years ago. This fault could be traced west-northwestward across the Fitzpatrick barge slip and was called the Barge Slip Fault (Figure 7-7).

Low angle thrust faults and folds were mapped in the power block excavation. These faults were exposed in bedrock but contained glacial lakebed sediment within the fault. Detailed analysis of the conditions and comparison with the late Quaternary geological history led to the conclusion that the soil had been forced into the fault zone from above and subsequently deformed by the forces described in the following paragraph.

After several years of geological, geophysical, and rock mechanics investigations, the applicant, the Niagra Mohawk Power Corp., demonstrated that the most recent displacements along the faults and folds mapped in the site area were not the result of deep-seated tectonic activity. The displacements were determined to be the result of a combination of: (1) glacial loading and unloading; (2) substantial post glacial changes of groundwater pore pressure caused by impoundment of glacial lakes and their sudden drawdown; and (3) naturally high in-situ stresses in the site bedrock. The latter was illustrated by offsets in core borings along bedding planes and by the closing in, or inward movement of all excavation walls within hours after excavation. The movements ranged from fractions of an inch to several inches, and stabilized within a few days. This phenomenon is relatively common in New York State. The walls and floors of structures were designed to accommodate rock movements by cutting a rock slot and backfilling it with crushable material to take up differential displacement along joints, faults, or bedding planes.

The conclusion that the most recent movement on the faults was not caused by deep seated tectonic stresses is important because the time of that displacement is well within the limit of 35,000 years provided in Appendix A for a "capable fault." The NRC concluded that the faults did not constitute a hazard to the structures of the plant that were designed for minor rock displacements, nor did they have the capacity to generate damaging ground motions (Ref.7-9).

The licensing activity at this site illustrated, more than any other, one major problem in the application of Appendix A. These young faults, the last movements of which, satisfied the Appendix A criteria for classifying them as capable faults, were not capable faults in the true meaning of the criteria because the most recent displacements on them were related to non-tectonic natural phenomena. The faults also were concluded not to have the capacity for generating damaging earthquake ground motions.

7.6 LIMERICK

7.6.1 Background

The site is located two miles southeast of Pottstown, Pennsylvania. It is within the Newark-Gettysburg Triassic Basin in the New England-Piedmont Tectonic Province (Figure 7-1). The CP site review activities took place in the early 1970s and the OL application was reviewed in the late 1970s and early 1980s.

The site is characterized by rolling, broad ridges with elevations that range from +200 to +300 feet msl. The ridges are dissected by the Schuylkill river and its tributaries. The ridges are oriented generally east–west, controlled by the strike of the more erosion-resistant rocks, diabase, sandstone, and argillite, which cap the ridges. Major joint trends control the drainage channels. Two prominent trends of vertical joints are present in the rock at the site. The first ranges in strike from N20 to 50W degrees, and the second ranges from N50 to 60 degrees W. Bedrock beneath the site consists predominantly of interbedded, interfingered, and gradational reddish brown siltstone, sandstone, and shale of the late Triassic Brunswick lithofacies, which in the region is several thousand feet thick (Ref. 7-1).

The Charleston Earthquake and New Brunswick Earthquake issues, and their potential impact on the seismic design of the Limerick site are briefly described in the next sections. These issues were discussed earlier in this chapter with respect to the Hope Creek Nuclear Power Plant site. They are described in greater detail in Chapter 2.

7.6.2 Charleston Earthquake

The staff's position during the CP review regarding the potential future occurrences of earthquakes similar in size to the 1886 maximum MMI X, Magnitude 7+ Charleston Earthquake with respect to the Limerick site was the same as for other sites licensed during the same time frame. The position was that for establishing the seismic design bases, the recurrence of a Charleston-like earthquake should be assumed to be confined within the 1886 meizoseismal area, and the resulting ground motions attenuated to the site. That position was reaffirmed during the OL review.

Whether there was sufficient bases to continue to support that position became a major issue during the OL review because of the results of an extensive investigative effort funded by the NRC and carried out by the USGS. The findings from these investigations were the bases for a modification of the former position of the USGS that recognized the uniqueness of Charleston tectonics. The position was modified to acknowledge the possibility that a Charleston-like earthquake could occur in other parts of the Atlantic Seaboard.

The results of these investigations spawned a number of hypotheses regarding the source of the seismicity around Charleston, South Carolina. As described in greater detail in Chapter 2 and the discussion of the Summer site in Chapter 8, nearly all of these hypotheses can be grouped into three general categories: decollement, reactivation of high angle reverse faults, or the concentration of stresses at the boundaries of mafic or ultramafic plutons.

The high angle reverse fault theory was especially significant to the Limerick site because it is located within a Mesozoic Basin, which are bounded and transected by high angle faults. Numerous high angle faults were identified in the site area. They were investigated in considerable detail and demonstrated to be noncapable.

The staff evaluated the available information and concluded that the hypotheses were highly speculative, and not founded on a strong enough basis to assume translating a Charleston-like earthquake to the Limerick site for purposes of design. However, the staff acknowledged that there were substantial unknowns regarding the sources of the Charleston Earthquake and eastern seismicity.

The LLNL and EPRI PSHAs that resulted from the Charleston Plan, demonstrated that a Charleston-like earthquake is not a significant contributor to the seismic hazard of the Limerick site. Furthermore, the deterministic program of the Charleston Plan has produced strong evidence that supports the uniqueness of the Charleston seismic source.

7.6.3 New Brunswick Earthquake

The review of the Limerick site, like that of the Hope Creek site, was impacted by the January, 1982 magnitude 5.7 to 5.8 New Brunswick Earthquake and its long series of aftershocks. The earthquake occurred in central New Brunswick, Canada within a projection into the region of the New England-Piedmont Tectonic Province. Since the Limerick site is located in that tectonic province, the issue was raised in accordance with Appendix A as to whether that magnitude event should be the seismic design basis for the Limerick plant rather than the magnitude 5.3 that had up to this time characterized this province.

The staff documented the major differences between the two regions, as was accomplished during the Hope Creek evaluation, to support its conclusion that the New Brunswick Earthquake should not be assumed to occur at the Limerick site. Along with this analysis, the staff considered the impact of a nearby magnitude 5.7 to 5.8 earthquake on the Limerick site.

The staff concluded that the two regions are different in that they are characterized by different Paleozoic structural styles and histories. The different Paleozoic tectonic histories of the northern and southern Appalachians have resulted in major differences in their respective crustal seismic velocity structures (Ref. 2-12). The bedrock of the two areas is different in that the New Brunswick epicenter area is underlain by igneous rocks and the Limerick site is located in the Newark Triassic Basin, which is underlain by Mesozoic sedimentary rock that have been intruded by diabase dikes and sills. The youngest predominant structural grain of the two regions is different. Finally, the aftershock patterns following the New Brunswick mainshock indicate a source consisting of conjugate fault systems that dip toward each other, and there is no known comparable structure in the Limerick region.

On the basis of the above geological information, which suggests that there may be strong differences in structural style, tectonic history, stratigraphy, and local structure, the NRC staff concluded that the New Brunswick earthquake occurred in a region that may be characterized by different tectonics than that of the Limerick site.

Based on the occurrence of the magnitude 5.8 1988 Saguenay and the magnitude 6 1989 Ungava earthquakes, and the study conducted by the Electric Power Research Institute (EPRI) of earthquakes and their sources in stable continental regions world-wide that are analogous to eastern North America, the staff concluded that magnitude 6 earthquakes could not be ruled out in the New England-Piedmont Tectonic Province, but would have a very low probability.

The LLNL and EPRI PSHAs, conducted as a part of the resolution of the Charleston earthquake issue, include consideration of the occurrence of magnitudes 5.5 to 6.0+ earthquakes in the eastern U.S. Both of these PSHA's demonstrated that, although a moderate to large earthquake is possible at the Limerick site, it has a very low impact on the seismic hazard of this site. The PSHA's also showed that the earthquake that dominates the hazard is the local magnitude 5.3 to 5.5 event, such as the 1872 Wilmington and 1927 Asbury Park Earthquakes for which the Limerick Plant is designed.

7.6.4 Tectonic Structures and Capable Faults

Numerous faults were evaluated by the staff to determine if there were capable faults in the site region, site vicinity, site area, or at the site (Figure 7-3). The following are the faults examined and a summary of the staff's assessment of them:

(1) The Appalachian decollement has been extensively investigated in the field along thrust fault outcrops in the Appalachian Mountains to identify the source of seismicity in that region, but no evidence of recent fault activity has been found.

(2) The Cornwall-Kelvin wrench fault is a hypothetical structure, but if it exists it could not be younger than 345 million years, based on its relationship to mid-late Paleozoic tectonics.

(3) The Martic Line of thrust faulting (Figure 7-1) is characterized by Mesozoic dikes that cross faults of this system without offset.

(4) The Huntingdon Valley-Cream Valley Fault System (Figure 7-3) is a northeast striking fault system about 15 miles south of the site. It does not offset Cretaceous strata where it crosses into the Coastal Plain.

(5) Several faults have been mapped in the Piedmont Uplands the closest of which is about 9 miles south of the site (Figure 7-3). They are truncated by the Triassic border fault.

(6) The Ramapo Fault System is more than 100 miles northeast of the site (Figure 7-3). It has been investigated extensively over the years and no evidence for capability has been found. See the discussion of this fault system in the first section of this chapter concerning its significance to the Indian Point site.

(7) The Hopewell and Flemington faults (Fig. 7-3), which merge and become the Furlong and Chalfont Fault Zone farther west, approach to within about 9 miles northeast of the site. The faults displace Triassic rocks and are interpreted to be at least Jurassic in age, but their is no evidence that they have moved since that time.

(8) Numerous post-Mesozoic faults have been mapped within the region during the past 30 to 35 years of this writing, such as those identified by the Delaware Geological Survey and described in the Hope Creek discussion in this chapter, the Stafford Fault Zone, the Cooke Fault, Helena Banks Fault, the Augusta Fault, etc. These and other faults have been evaluated by the staff in the reviews of many nuclear power plant sites, including the Limerick site. The preponderance of evidence indicates that none of them have experienced displacement in the last two million years.

(9) Three moderately large faults were identified within two miles of the site and investigated in detail by the applicant. The closest to the site is located 1300 feet west of the site and is called the Sanatoga fault. It strikes N 20 to 30 degrees E, dips vertically, and has 290 feet of down-to-the-east displacement. It has been intruded by the Downingtown diabase dike of Mesozoic age. Another fault, the Brooke Evans fault, is located 2800 feet south of the plant. It strikes N 50 degrees E and has a measured 350 feet of vertical displacement with the south side down. A third fault, the Linfield Fault, is a zone comprised of five near-vertical faults and is located about 2 miles southeast of the site. Strikes of the zone range from N 40 to 50 degrees E, and offsets range from one to 20 feet (Ref. 7-12).

7.6.4.1 Faults Identified in the Category One Excavations

In 1974, during excavation for the plant structures, three zones of fracturing were mapped (Figure 7-8). The first zone extended from the south edge of the Unit 1 excavation toward the northeast, where it consisted of a broad zone with fractures 20 feet apart, separating blocks of hard, unfractured rock. These fractures converged to form a zone from two to seven feet wide, which continued on through the control structure and turbine building. No offset was found along this zone. The second zone began in the southeast corner of the Unit 2 excavation and strikes N 30 degrees E. It has a vertical dip, is one inch wide, and had 8 to 10 inches of down-to-the-southeast displacement. The third zone was mapped in the Unit 2 turbine area with a northeast-southwest strike and an apparent vertical offset of two feet. It is up to four inches thick. Several northeast-southwest striking clay seams with evidence of minor shearing were also identified in the excavation.

Later, during excavation for the spray pond, offsets were found on several near-vertical joints and branches. One of the larger of these extends from the west end of the pond in a N20 degrees E direction for more than 100 feet and has one inch offset, with the east side down. Another one strikes E-W from the west slope of the pond and extends for 600 feet. It exhibits two inches of displacement with the south side down. On the eastern slope of the pond, an E-W fault was mapped with two to three inches of apparent left lateral offset.

Analyses of the time of last movements on these faults consisted of: radiometric age dating, fluid-inclusion analysis of unsheared quartz crystals in the fault zones, paleosol and geomorphic studies of high level terraces, and analysis of undisturbed soil overlying the Downingtown dike complex. Those individual faults that could not be dated in an absolute manner, were shown to be genetically related to those faults that could, and therefore, were interpreted to be the same age. Based on these studies the last displacements on the faults was concluded to have occurred more than 500,000 years before present, but more likely 150 million years ago. As part of the studies, a panel of three experts in Appalachian geology was assembled to review the investigation program and the results. The panel concurred with the conclusions (Ref. 7-12). The NRC, on reviewing the results of the investigations concluded that the site faults were not capable faults within the meaning of Appendix A (Ref. 7-12).

7.6.4.2 Treatment of fracture Zones and Clay Seams in the Main Power Block Area

The three fracture zones described above were treated according to the following criteria. Soft and excessively fractured material in the zones under footings were excavated to depth below foundation grade that is at least equal to the width of the undesirable material at foundation grade. Slopes were cut so that the excavation became narrower downward. The excavations were extended laterally beyond the edges of the footings crossing the fracture zones. The excavations were backfilled with concrete. This dental treatment was designed to replace the compressible material under the footings with a wedge of concrete that transfers vertical loads laterally to the adjacent sound rock on each side of the zone, to confine this adjacent rock, and to reduce unit loads by extending the bearing area beyond the edges of the walls and columns (Ref. 7-12).

Clay seams, except for those under column footings were examined to determine the thickness of soft, compressible material in the seams at their intersections with the foundation grade. Only those seams that contained compressible material ¼ inch or more thick were treated. Under the wall footings, treatment consisted of removing the compressible material in the seam and the rock above it, to provide a minimum of three feet of sound rock between the bottom of the footing and the seam. The material removed was replaced with concrete. Where isolated column footings did not span the intersections of clay seams with the base of the foundation, the clay seams and all rock above it were removed under the column footing and replaced with concrete so that all of the footing is founded on solid material (Ref. 7-12).

7.6.4.3 Foundation Preparation for the Limerick Spray Pond

The spray pond is an excavation with bottom grade of +239, a length of 1000 feet E-W, a width of 400 feet (N-S, and depth of 11 feet (water depth). Soil and weathered rock were removed and spoiled or stockpiled. In the northwest corner, where the excavation was extended below elevation +239 to remove deep weathered rock, the grade was reestablished by backfilling with concrete. The bottom and slopes were then lined with a two-foot thickness of a soil-bentonite mixture. Slopes in the natural material were cut at one horizontal to one vertical in unweathered rock, two horizontal to one vertical in weathered rock, and four horizontal to one vertical in soil (Ref. 7-12).

The pond was excavated into siltstone, sandstone and shale of the Brunswick and Locatong lithofacies of Triassic age. The bedding strikes North 70 degrees East. The spacing between joints varied from a few inches to several feet. A jointed, thin bedded and relatively soft rock allowed most of the excavation to be done by ripping and shoveling with pans and dozers. Blasting was required to excavate for the intake-discharge structure.

Excavation began at the west end of the pond and proceeded toward the east where the rock surface was higher. The rock was stratigraphically lower in that direction and harder rock was closer to the surface; therefore, some blasting was required. The third fault in the pond excavation that is described above was believed to have been caused by the blasting, as it was truncated by bedding at depth (Ref. 7-12).

The in-situ spray pond soils graded from clayey silt derived from weathered siltstone, sandstone and shale, to unweathered bedrock to depths below +239 feet in the northwest quadrant of the pond. Results of laboratory tests indicated the weathered coil can be classified as CL to ML with an average of 71% by weight passing the #200 sieve. Results of cyclic triaxial laboratory tests indicated a shear strength sufficient to provide a minimum factor of safety against liquefaction of 1.9 for the spray pond soils. The plastic nature (average PI = 17) further supported the conclusion that the soil could be considered not susceptible to liquefaction under earthquake loading associated with an SSE 0.15g. Results of slope stability analysis for the spray pond presented in the FSAR indicated that the in-situ soil will remain stable on a 4:1 slope under static and seismic loading conditions using a conservative soil strength of 0 = 33.5 degrees obtained from laboratory testing. In addition, the finished slopes are covered by a 24 inch soil and soil-bentonite liner which is protected by a 12 inch maximum gravel layer covered by an 18 inch layer of 500 pound maximum riprap (Ref. 7-12).

7.6.5 Effects of Ground Motions Generated by Blasting at a Nearby Quarry

During the OL review an intervenor group, Air and Water Pollution Patrol, presented its concerns about the possible detrimental effects of ground motions, generated by blasting in a quarry, located about 2000 feet from the plant on local faults, and on concrete at the plant, both green and cured. These concerns were assessed by the USGS, advisor to the NRC. The USGS concluded that ground motions (maximum particle velocity) from the blasts are one-fifth of that allowed by the Pennsylvania State Blasting Code Criteria for safe ground motion.

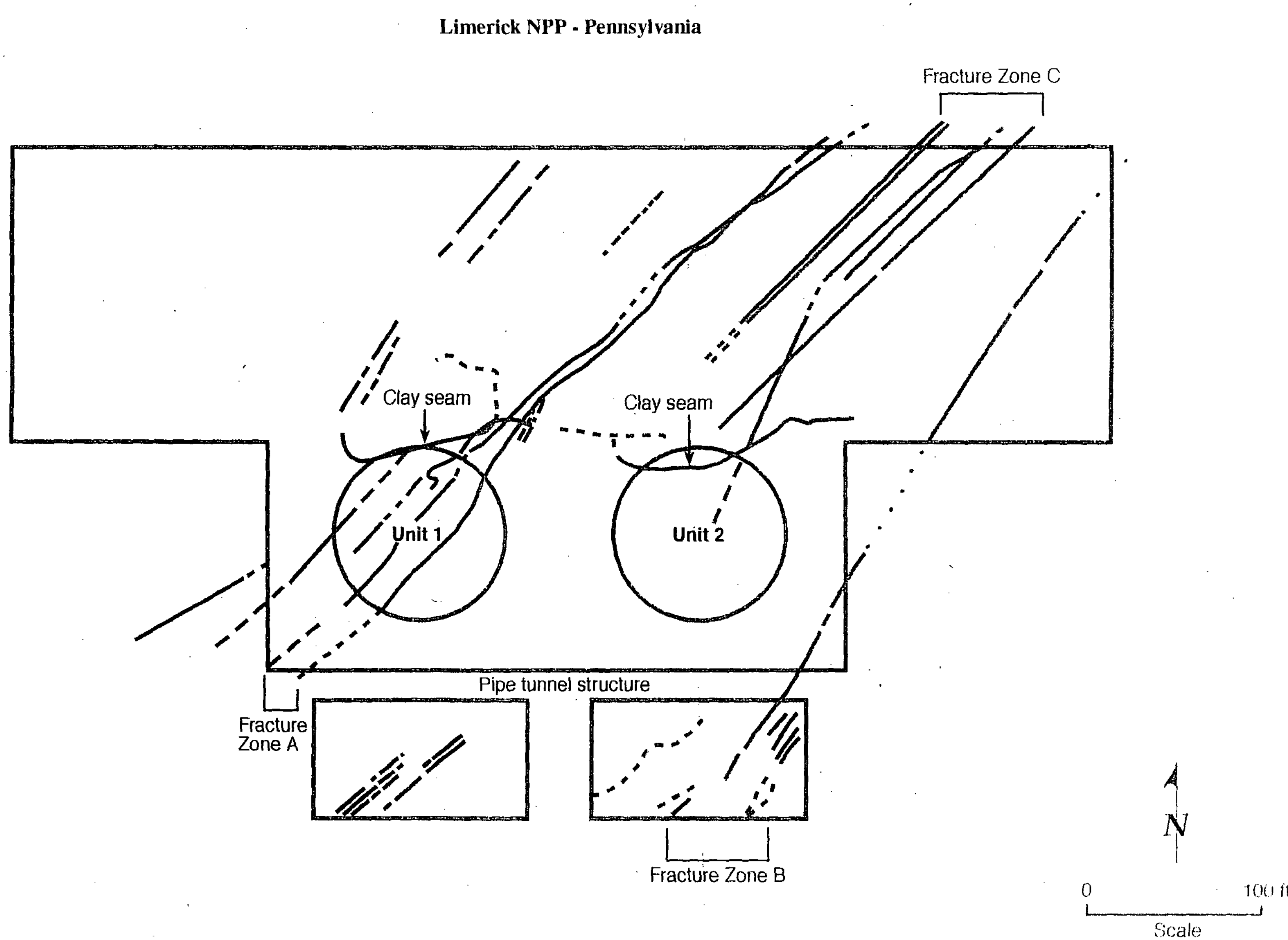


Figure 7-8 Limerick NPP reactor complex mapped faults and fractures (Ref.'s 3-27 and 7-12).

CHAPTER 8 - SELECTED SITES IN THE SOUTHEASTERN UNITED STATES

8.1 MCGUIRE

8.1.1 Background

The site is located on the southern Piedmont about seventeen miles north of Charlotte, North Carolina (Figure 8-1). The CP application review began in 1972, more than a year before the publication of Appendix A. However, the proposed criteria of Appendix were followed. For example significant nearby structures such as the Kings Mountain belt were investigated in considerable detail in compliance with the criteria for the definition of potential earthquake generating tectonic structures.

8.1.2 Tectonic Province and Maximum Earthquake

Between the CP and OL reviews for this site, largely due to the Indian Point and Seabrook site evaluations described in Chapter 7, the staff came to consider the southern Piedmont to be a part of the New England-Piedmont Tectonic Province. Therefore, in keeping with the Appendix A tectonic province-maximum earthquake criteria, the earthquake design basis is based on the postulated occurrence in the site vicinity of the largest historic earthquake to occur in that province; that is, one similar in magnitude to the 1913 maximum MMI VII, Union County Earthquake.

A recurrence of an earthquake like the 1886, MMI X Charleston earthquake was assumed to be possible only in the meizoseismal area of this event. At the end of the CP review, the staff had concluded, based on the advice of its advisors, the USGS and NOAA, that the Charleston Earthquake was associated with structure that controlled the deepest part of the Southeast Georgia Embayment. These and other conclusions are summarized in Ref. 8-1, the 1971 CP SER (Ref. 8-2) and the 1978 OL SER (Ref. 8-3).

While the OL evaluation was underway, a series of events occurred that illustrated the impact that a new hypothesis can have on licensing activities for a nuclear power plant site. An organization called the Carolina Environmental Study Group raised a concern during the McGuire proceedings regarding the probability of a major earthquake occurring in eastern North Carolina that could generate high accelerations at the site. The allegation was based on a 1975 report by three University of North Carolina professors (Ref. 8-4), who interpreted tide, groundwater, and geodetic data from the Southport area to indicate rapid changes in land elevation and groundwater behavior. These anomalous conditions were interpreted to be possible precursors of a major earthquake.

The Carolina power and Light Company, owner of the Brunswick Nuclear Plant, deployed a highly sensitive seismic network for about 22 months in the Southport area and installed a permanent tide gage station. No seismicity was recorded and the past measurements that showed short term land elevation changes were found to be inconclusive. Based primarily on the more than 200 mile distance of the McGuire site from Southport, the lack of microseismicity, and the low level of historic seismicity, the staff concluded that the Southport issue had no impact on the seismic design basis of the McGuire Nuclear Power Plant.

8.1.3 Tectonic Structure and Capable Faults

Geological investigations of the Kings Mountain Belt, located about 12.5 miles west of the site, were among the early efforts in the eastern seaboard to determine whether or not a nearby tectonic structure should be considered as a seismic hazard. Minor faults that cut across the belt were shown to be the latest tectonic events to affect the belt. These faults were dated by the potassium argon dating technique and found to be about 200 million years old. Other significant structures investigated and demonstrated, in the same manner, to be geologically ancient were the Gold Hill Fault, 27 miles east of the site, the Stony Ridge Fault, 45 miles north of the site, and the Brevard zone, 50 miles northwest of the site.

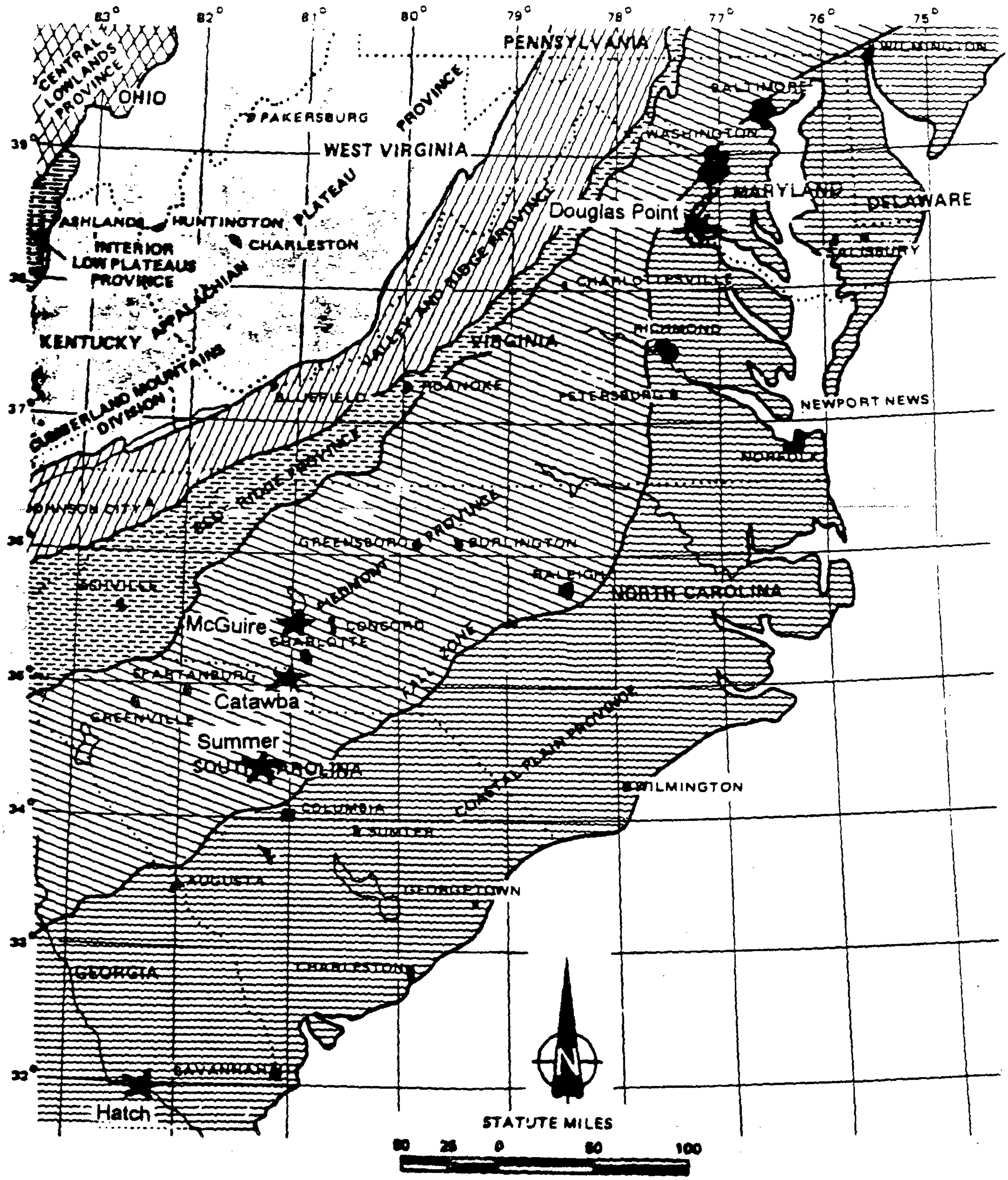


Figure 8-1 Physiographic Provinces of the southeastern United States showing site locations (Modified from Ref. 8-1).

A shear zone was identified at a depth of 45 feet beneath the proposed plant from exploratory core boring data. It was investigated by drilling a wide diameter boring to allow access for mapping, analysis, and sampling to determine the approximate age of shearing using the potassium argon radiogenic dating method. A geochronological analysis was also performed on a diabase dike that truncated the fault. This analysis showed that the dike was emplaced during the Mesozoic Era, postdating displacement on the fault, therefore, the fault is not a capable fault.

8.1.3 Stability of Foundation Materials and Slopes

A pseudo-static analysis had been performed during the seismic design of the Nuclear Service Water Pond (NSWP) Dam, and that analysis was provided to the staff during the CP review. Because the factors of safety for each condition were relatively high the staff concurred with the design. By the time of the OL review, however, the state-of-the-art in dam design began to emphasize the importance of performing true dynamic analyses. Thus the utility was required to perform a dynamic finite element analysis of the NSWP Dam. The results showed that the dam would remain stable under SSE ground motions.

8.1.4 Ultimate Heat Sink

Early in the CP review, with the publication of Regulatory Guide 1.27, it became necessary for each nuclear site to have an ultimate heat sink able to withstand both the probable maximum flood and the maximum credible earthquake ground motion (SSE) for that site. The McGuire site, like the Arkansas, Unit 2 site, was to have two reservoirs; one, the Nuclear Service Water Pond (NSWP) was designed to withstand the SSE, but not the PMF. The other, Lake Norman and its dam, Cowans Ford Dam, were designed for the PMF but not the SSE. According to the staff's interpretation at that time of the Ultimate Heat Sink Regulatory Guide, the NSWP Dam should be designed for a simultaneous occurrence of an SSE and a lower level flood, the Standard Project Flood (SPF); and the Cowans Ford Dam should have the capacity to withstand the simultaneous occurrences of a PMF and sustain an earthquake peak ground acceleration of 0.1g.

The utility demonstrated to the satisfaction of the staff that the flooding criteria were met regarding the two dams and the seismic requirement were met with respect to the NSWP Dam, but there was insufficient data on the in-situ soil comprising the embankment to demonstrate that Cowans Ford could withstand a simultaneous PMF and ground motion up to a peak ground acceleration of 0.1g, with the weakness being the earthquake. The dam was relatively old, and most of the exploration, design, and construction records were not available. However, an expert panel of highly regarded soils engineers and geologists had reviewed the design and construction and vouched for its integrity under seismic peak ground acceleration of 0.1g or less. The staff concluded that the duel reservoir complex met the ultimate heat sink guidelines based on its review of the few remaining exploratory boring logs that were available, the design parameters, and the evaluation of the panel of experts.

8.2 V.C. SUMMER

8.2.1 Background

The Summer Nuclear Power Plant site is approximately 30 miles north of Columbia, South Carolina on the southern Piedmont Physiographic Province, 25 miles northeast of the Fall Zone (Figure 8-1). The CP application review, which occurred from 1972 through 1975, spanned the time that Appendix A was published, and the fault and ground motion criteria of the rule were used in the licensing of this plant. The OL application review took place from 1979 through 1983 and the elements of Appendix A regarding tectonic structures and tectonic provinces, capable faulting, and vibratory ground motions were used to a considerable extent (Ref. 8-5).

8.2.2 Tectonic Province, Tectonic Structures, Maximum Earthquake, and SSE Ground Motion

The Summer site is located within the New England-Piedmont Tectonic Province. The design basis earthquake was based on the 1913 maximum MMI VII Union County Earthquake, and the SSE ground motion from that event in the site vicinity was estimated to be a horizontal peak ground acceleration of 0.15g on rock and 0.25g for structures founded on soil (Ref. 8-5). During the CP review a major issue was whether to assume that an event similar to the 1886 MMI X Charleston Earthquake could occur closer to the site than the meizoseismal area of that earthquake. Based on advice from the USGS and NOAA, the AEC concluded that future occurrences of this earthquake should be assumed to occur in the same area as the 1886 event for the following reasons: the frequency of occurrence of historical earthquakes is higher per unit area than elsewhere in the eastern U.S.; the event distribution within the high frequency unit shows no evidence of directional trend or predominant pattern which would suggest lateral migration of activity; the microseismic flux in the Charleston area is higher than that measured elsewhere in the eastern U.S.; and seismic refraction and aeromagnetic data suggest atypical basement structures in the Charleston area.

8.2.3 Charleston Earthquake

Recognizing the lack of definitive information regarding the structural geology in the Charleston region, and in accordance with a recommendation by the ACRS, the AEC contracted the USGS to perform an extensive geological, seismological, and geophysical investigation in the Charleston region. As a result of these investigations, the source of the earthquakes was not identified, but numerous hypotheses about the causes of the seismicity were formulated. As stated in the previous chapter, nearly all of these hypotheses can be grouped under one of three general sources of seismicity: decollement, reactivation of Paleozoic or Mesozoic high angle reverse faults, or the concentration of stresses at the boundaries of mafic or ultramafic plutons.

The investigations performed by the USGS identified tectonic features in the subsurface that are found at other locations on the Piedmont and Coastal Plain. Based on these findings, the USGS modified its previous conclusion about the uniqueness of the Charleston region, to say that the occurrence of an earthquake similar to the 1886 Earthquake should be considered possible, though with a low probability, elsewhere on the Atlantic Seaboard.

The NRC concluded, however, that the bases for its previous conclusion were still valid, and the investigations demonstrated the tectonic complexity of the Charleston region; and that complexity indicated that the region is atypical with respect to the rest of the Eastern Seaboard. In an effort to explore ways to resolve the remaining uncertainties the NRC devised a two part program, which is described in Chapter 2, to investigate the earthquake potential of the eastern U.S.: a probabilistic seismic hazard analysis (PSHA) to address the uncertainties in seismic sources and ground motions, and a deterministic program, which consisted of a continuation of geological, seismological, and geophysical investigations to define the seismic sources and vibratory ground motions. The former resulted in the LLNL and EPRI PSHA's, and the latter, provided further confirmation (paleoseismic data) that the Charleston meizoseismal region has been seismically unique during the Holocene. The deterministic investigations showed that although there have been repeated occurrences of earthquakes similar to the 1886 event in the meizoseismal area in the last 3,000 years, there had been no evidence found at that time for events of this size elsewhere in the eastern seaboard.

8.2.4 Capable Faults

After the Construction Permit had been issued and excavations for the reactor complex structures were being dug, on November 26, 1973, the applicant reported encountering numerous faults in the bedrock underlying the site (Figure 8-2). The AEC (now NRC) required the utility to halt construction and conduct mapping and analyses of the faults to determine the ages of last displacements. The applicant conducted detailed microscopic study and isotopic dating (principally potassium argon) of undisturbed post-faulting minerals (mainly zeolites) present in some of the filled shear zones . the AEC-NRC conducted an independent analysis of the faults using consultants from the University of California, Berkeley, Professors R. Hay and G. Curtis. A minimum age of the faults that could be demonstrated from both studies was 45 million years before present (8-5).

The faults could be categorized into specific groups based on strike, dip, and the nature of the material within the faults (gouge). Therefore, after determining the age range for each fault category (or group), it was then only necessary to determine which category that faults encountered later, as excavation progressed, belonged in, based on these characteristics, to show that they were not capable.

On October 29, 1975, the applicant reported discovery of new faults in excavations for seismic category 1dams, which were part of the emergency cooling pond. Again NRC ordered construction halted in the area until it could be determined whether the faults represented a potential hazard. Similar fault characterization studies to those conducted in the reactor complex were carried out for the dam excavation faults. Based on the results, the NRC concluded that the newly discovered faults belonged to the same set as encountered beneath the reactor complex and were, therefore, more than 45 million years old (8-5).

Forty five million years is the minimum age that could be demonstrated by the potassium argon dating of unsheared zeolites in the fault zones. Along with the radiometric dating, relating the origin of the faults in the excavations to documented tectonic events in the site region that occurred throughout the Paleozoic Era, was an important basis for the NRC staff's conclusion. Therefore, the age of last displacement on these faults was considered more likely to be more than 200 million years ago occurring during the Appalachian Orogeny. The NRC concluded that the faults were not capable faults as defined by the siting regulation.

There was no strong intervention regarding the faults under the power block at the Summer site, although their discovery occurred shortly after discovery of faults beneath the containments at North Anna Nuclear Power Plants in Virginia, and while that strongly contested hearing was underway. The reason for the absence of intervention was likely because the utility was forthright in reporting the faults and the utility and NRC immediately began conducting analyses of them using state-of-the-art techniques at the time. There was, however, strong intervention regarding the issues of reservoir induced seismicity and probability of an earthquake similar to the 1886 M 7.5 Charleston Earthquake occurring near the site.

During the OL application review a previously unknown fault, the Wateree Creek Fault, south of the site was identified. Projection of the fault to the north would cause the fault to pass beneath the proposed reservoir, Lake Monticello. Initially, although there was no conclusive evidence that the fault extended to the site, topographic evidence caused the staff to conclude that the fault did cross the site.

Core borings and groundwater flow tests conducted later to investigate the causes of the seismicity induced by impoundment of the lake, described in the next section, indicated the presence of a zone of highly fractured rock along the strike projection of the Warteree Creek Fault into the area. Several microearthquake swarms were identified with focal depths that would fall near the projection of an east dipping Wateree Creek Fault. Analysis of this information caused the staff to conclude that the fault extended northward from its mapped location to just west of Lake Monticello. However, based on the geological evidence for the non-capability of the fault, the absence of historic seismicity in the vicinity of the fault, and the fact that the seismicity did not grow along the trace or downdip of the fault and eventually faded out, the staff concluded that the Wateree Creek did not pose a hazard to the plant.

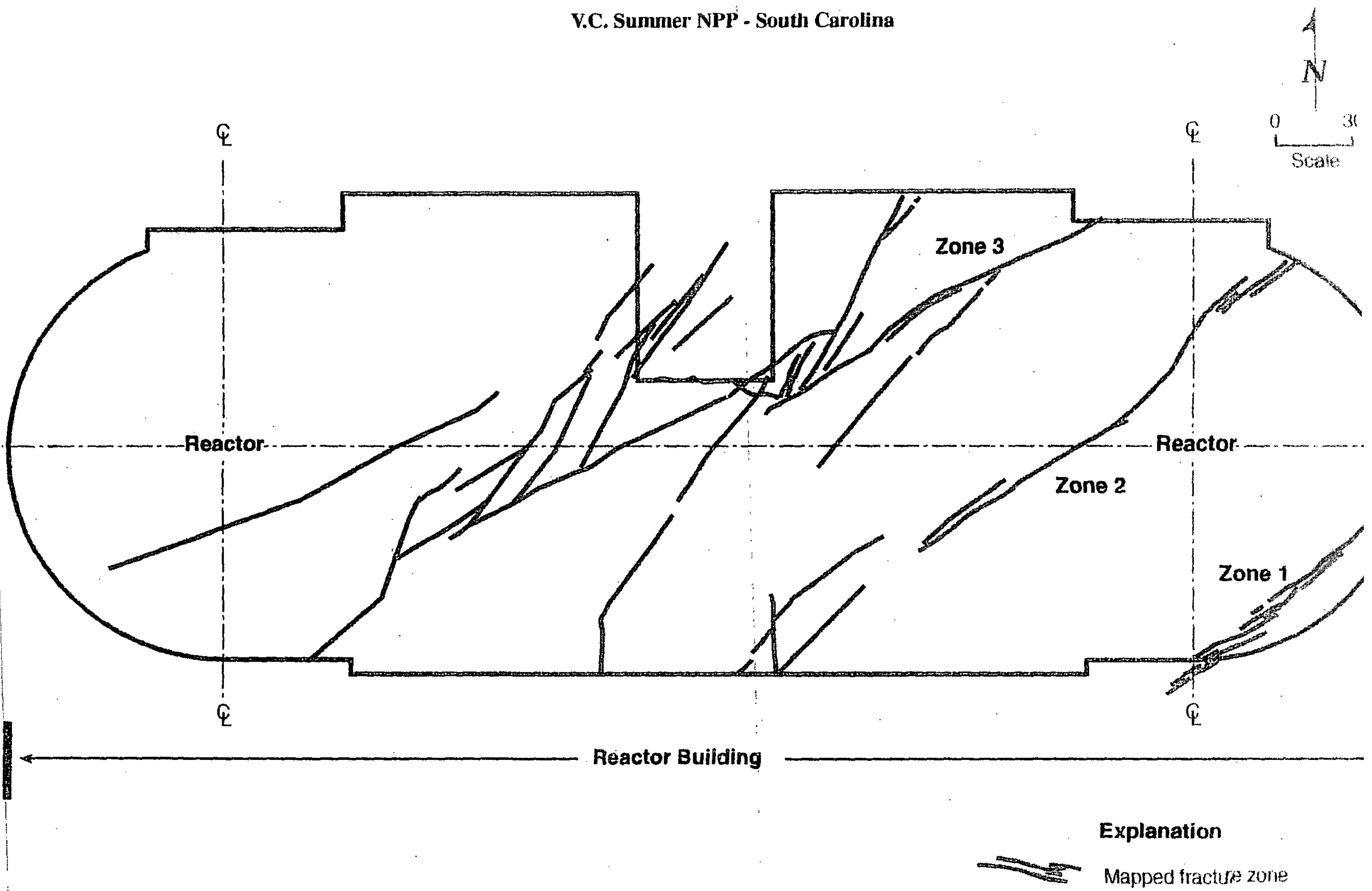


Figure 8-2 V.C. Summer NPP – map of fracture zones across the reactor complex excavation (Ref.'s 3-27 and 8-6).

8.2.5 Reservoir Induced Seismicity

In order to store water for a pumped storage facility, provide cooling water for the plant, and provide makeup water for emergency cooling, the applicant planned to create a large reservoir (Montecello Reservoir) next to the plant. A smaller seismic category 1 emergency cooling water pond was to be constructed adjacent to the plant and Monticello Reservoir. A major issue during the CP review was the dynamic stability of the service water dams comprising the emergency cooling water pond impoundment. The concern was for the dams' stability during the design basis earthquake and/or during sudden drawdown conditions in the event of the loss of Monticello Reservoir. By means of dynamic analyses the applicant was able to demonstrate the stability of the dams during an earthquake, but agreed to perform seepage tests during the impoundment of Monticello Reservoir.

The staff had concluded during the CP review that filling Monticello Reservoir wouldn't adversely affect the faults in the excavations or faults in the surrounding area. However, because of its concern that impounding the reservoir could induce seismicity, the staff required that a seismographic network be deployed six months prior to impoundment and that microearthquakes be monitored. The initial requirement was that monitoring should continue for one year after impoundment, but because of the increased seismicity, the network was operational for many years after filling. A four station network was deployed in December, 1977. A USGS seismograph located three miles east-southeast of the site had recorded about one local event every six days from 1973-1977. The USGS installed a strong motion accelerometer in the abutment of an existing dam in the site area (Fairfield Dam) in February, 1978 and a six station network in the reservoir area in May, 1978.

Reservoir filling began in December, 1977 and reached full pond by February 1978. While filling of the reservoir proceeded, seismicity increased during the last week of December, 1977, and began to spread. Seismicity began to occur in five distinct clusters, and most of the spreading took place during the first six months. Ninety percent of the spreading occurred during the first year following impoundment. Peak activity occurred during February and March, 1978 after completion of filling. The seismicity decreased after March, 1978 except for brief swarms between August and December, 1978, a swarm in October, 1979, and a final swarm in July, 1980. The maximum event, a magnitude 2.8 occurred on August 27, 1978, generating a peak acceleration that briefly equaled the plant SSE (0.25 for structures founded on soil) at high frequencies. The ground motion was recorded on an instrument founded on soil. Because the peak ground motion occurred at high frequency and short duration, there was no structural damage.

Most of the events, based on focal mechanism solutions, had predominantly thrust mechanisms and were at depths shallower than one km; there were some between one and two km; and a few between two and four km. Events between one and two kilometers showed a component of strike slip. The predominant orientations of nodal planes were north-south and northwest-southeast.

Based on stress and pore pressure analyses conducted in two deep borings (1100 and 1203 meters) drilled at the reservoir by the USGS, the staff concluded that in the upper 300 meters, high horizontal stress conditions along with increased pore pressures caused failure along preexisting planes of weakness that were already near failure, thus causing the seismicity.

Following detailed analyses by the staff and its consultant, Los Alamos National Laboratory, and the applicant, of the available information on the site reservoir induced seismicity and data regarding other reservoir seismicity throughout the Piedmont, the staff concluded that: (1) the limited spatial and temporal extent of the seismicity suggested that the induced seismicity was a minor, shallow, local adjustment and the reservoir would not induce a large tectonic earthquake; (2) the reservoir would not impact faults beneath or in the area around the plant; (3) the design basis reservoir induced event occurring near the site will have no impact on the SSE, but will likely produce low energy, short duration, high frequency (greater than 10 Hz) non-damaging ground motion that may exceed the SSE (0.15g on rock and 0.25g on soil) at high frequencies; (4) the microearthquake monitoring network should remain in operation at least until the end of 1982 (the network was shutdown at the end of 1985 when background seismicity returned to pre-impoundment levels), and (5) for design purposes, the maximum RIS earthquake should be magnitude (M_L) 4.5 (Ref. 8-5).

8.3 DOUGLAS POINT

8.3.1 Background

The site is located in Charles County, Maryland, on the shore of the Potomac River, within the Atlantic Coastal Plain Physiographic Province. It is about 5 kilometers east of the Fall Zone (Figure 8-1), the physiographic boundary between the Coastal Plain and the Piedmont. The site is within the Coastal Plain Tectonic Province, and is situated above the western flank of the Salisbury Basin, a northwest-southeast trending downwarp in the basement and overlying sediments. This structural basin is centered in the vicinity of the Chesapeake Bay near Salisbury, Maryland.

The staff review began in 1973 and extended into the late 1970s. Appendix A criteria were major guidelines in the applicant's investigations, and the staff's review of the results of those investigations. The seismic design basis was based on the assumed occurrence in the site vicinity of an earthquake with a maximum MMI VII, similar to the 1872 Wilmington, Delaware Earthquake.

Two seismic issues were raised during the review of this site because of the presence within the site's region of regional-scale faults, the Stafford Fault Zone and the Brandywine Fault Zone. These fault zones were characterized by preliminary geological evidence that suggested that they could be capable faults as described in Appendix A. The issues were: (1) the potential for an earthquake to occur on either of these faults that was larger than the one used as the basis for the site SSE; and (2) the potential for surface displacement at the site from such a nearby event. Other issues that arose later were the potential for seismically induced liquefaction and slope failure, but only the earthquake and fault issues will be discussed.

Litigation regarding faults discovered in excavations at the North Anna site in Virginia, which was going on concurrently with the Douglas Point review, further intensified these issues. All issues were eventually resolved, but the license application was withdrawn for other reasons.

8.3.2 Tectonic Structures and Capable Faults

The Stafford Fault Zone, strikes in a northeasterly direction, approximately parallel and adjacent to the Fall Zone, and is located about 5 kilometers west of Douglas Point at its closest approach (Fig. 8-3). It is described by Mixon and Newell (Refs. 8-6 and 8-7) as being approximately 56 kilometers in known length and consisting of four en echelon northeast trending structures. The structures include three northwest dipping, high angle reverse faults (Fall Hill, Hazel Run, and Dumfries faults) and a complex of southeast dipping monoclines and a fault collectively known as the Brooke structure. Displacements of the Cretaceous [135-65 million years before present (mybp)] units along the faults range from 15 to 43 meters at its base. Displacements of younger stratigraphic units decrease upward in the stratigraphic section to less than one meter at the base of the Upland Gravel Unit. The youngest units observed in the area (e.g. colluvium and Pleistocene terrace deposits overlying the Dumfries Fault) are not offset.

The Brandywine Fault Zone is parallel to the Stafford Fault Zone and is located about 25 kilometers northeast of the site (Figure 8-3). This fault zone was defined during an investigation for a potential subsurface storage of natural gas by Washington Gas Light (Ref. 8-8). After extensive investigations of the fault zone by Washington Gas Light, and later by the applicant, it was determined that the zone is composed of two faults, the northeastern one called the Cheltenham Fault and the southwestern one designated the Danville Fault. The Danville Fault is a reverse fault with more than 76 meters of offset at both the top of the crystalline basement and the top of the lower Cretaceous Arundel Formation. It is upthrown to the east, and dips with progressively less steepness and amount of displacement toward the surface. The Cheltenham Fault is characterized by about 30 meters of throw at the top of the Arundel Formation.

Regional geologic considerations indicate that the Stafford Fault Zone aligns with a lineament formed by the northeast trending segments of the Potomac, Susquehanna, and the Delaware estuaries. According to Mixon and Newell (Ref. 8-7) this is a possible suggestion of deformation in latest Tertiary (11-2 mybp) or Quaternary (2 mybp-Present) time.

Similarities between the Brandywine and Stafford fault zones suggest that the two structures may be tectonically related (Refs. 8-6 and 8-7), and it is likely that both the Brandywine and Stafford fault zones experienced movements during the same tectonic events. Mixon and Newell (Ref. 8-7) suggest that the two fault systems apparently define a 25 kilometer-wide block of Coastal Plain sediments which has been depressed relative to blocks on either side. Most of the deformation along both systems appears to have occurred during the Cretaceous and again in post-middle Eocene to pre-middle Miocene (40-15 mybp) time.

Some late Tertiary (11-2 mybp) movement is suggested along the Brandywine Fault Zone by slight flexuring across the anticlinal structure near Danville, Md. (Refs. 8-8 and 8-9), and by minor offsets of the Upland Gravels near Brandywine. Likewise, late Tertiary or early Pleistocene (2-1 mybp) movement along the Stafford Fault Zone can be inferred by possible offsets of the base of the Upland Gravels mapped by Dames and Moore in 1976 (Ref. 8-10), and noted in a USGS review letter (Ref. 8-11).

The presence of linears, sharp turns in the Potomac and Rappahanock Rivers, and the Richmond Triassic Basin along a southern projection of the Brandywine Fault Zone may also reflect a geologic relationship between these structures. Additionally, Triassic rocks have been encountered in deep borings along the trend, suggesting the presence of a major structure extending from at least Prince Georges County, Md. to the Richmond Triassic Basin. A similar relationship can be inferred by the alignment of the Stafford Fault zone, Neuschel's lineament, and the Farmville Triassic Basin.

8.3.3 AEC/NRC Evaluation of the Stafford and Brandywine Fault Zones

Based on its review of the geologic information available on the Stafford Fault Zone and several geological reconnaissances in the field, the staff concluded that the geologic evidence did not support an interpretation of a single movement on the Stafford Fault Zone in the last 35,000 years nor multiple movements during the last 500,000 years. Therefore, one zone was not a capable fault within the criteria of Appendix A. This conclusion was based on the following:

(1) The level of seismicity in the vicinity of the Stafford Fault Zone is lower than in the surrounding area, which includes the southern Appalachian and central Virginia seismic zones, and no correlation between the fault zone and historic seismicity could be seen.

(2) The amount of recurrent movement along the Stafford Fault Zone has decreased through time. For example, between the beginning of the Cretaceous [136 million years before present (mybp)] and the beginning of the Miocene (26 mybp) approximately 40 meters of fault offset took place. Since the beginning of the Miocene (25 mybp), possibly 12 to 46 centimeters of local movement has occurred as suggested by offset of the Upland Gravels, which overlie the Miocene Calvert Formation.

(3) A 46 centimeter offset of the base of the Upland Gravels that was discussed in the Douglas Point Preliminary Safety Analysis Report (PSAR) (Ref. 8-9) may be a local feature. Although evidence of the original feature was destroyed by active use of the borrow pit where it had been mapped, other apparent offsets in the same area can be better explained as being caused by depositional and erosional processes.

(4) A trench excavated across the projection of the Hazel Run Fault, about 1.5 kilometers south of the Hazel Run Creek exposure of the fault, showed that the Calvert Formation of early and middle Miocene age (25-15 mybp) was not disturbed. In addition, a line of borings drilled in the same area, showed that the base of the Calvert Formation was not offset within the resolution of a few feet. This finding further supported decreasing displacement since the Cretaceous.

(5) Trenches excavated by the applicant across the Fall Hill Fault seemed to indicate that the base of the Upland Gravels truncated the fault, however, the relationship was not entirely clear. A possible 2.5 centimeter offset at the base of the Upland Gravels at another exposure could be interpreted as either a fault offset or an erosional feature.

(6) The ages of unfaulted soils (colluvium and terrace deposits) overlying the Dumfries Fault, the western and northern-most segment of the Stafford Fault Zone, are not definitively determined. However, the elevations at which they lay, the

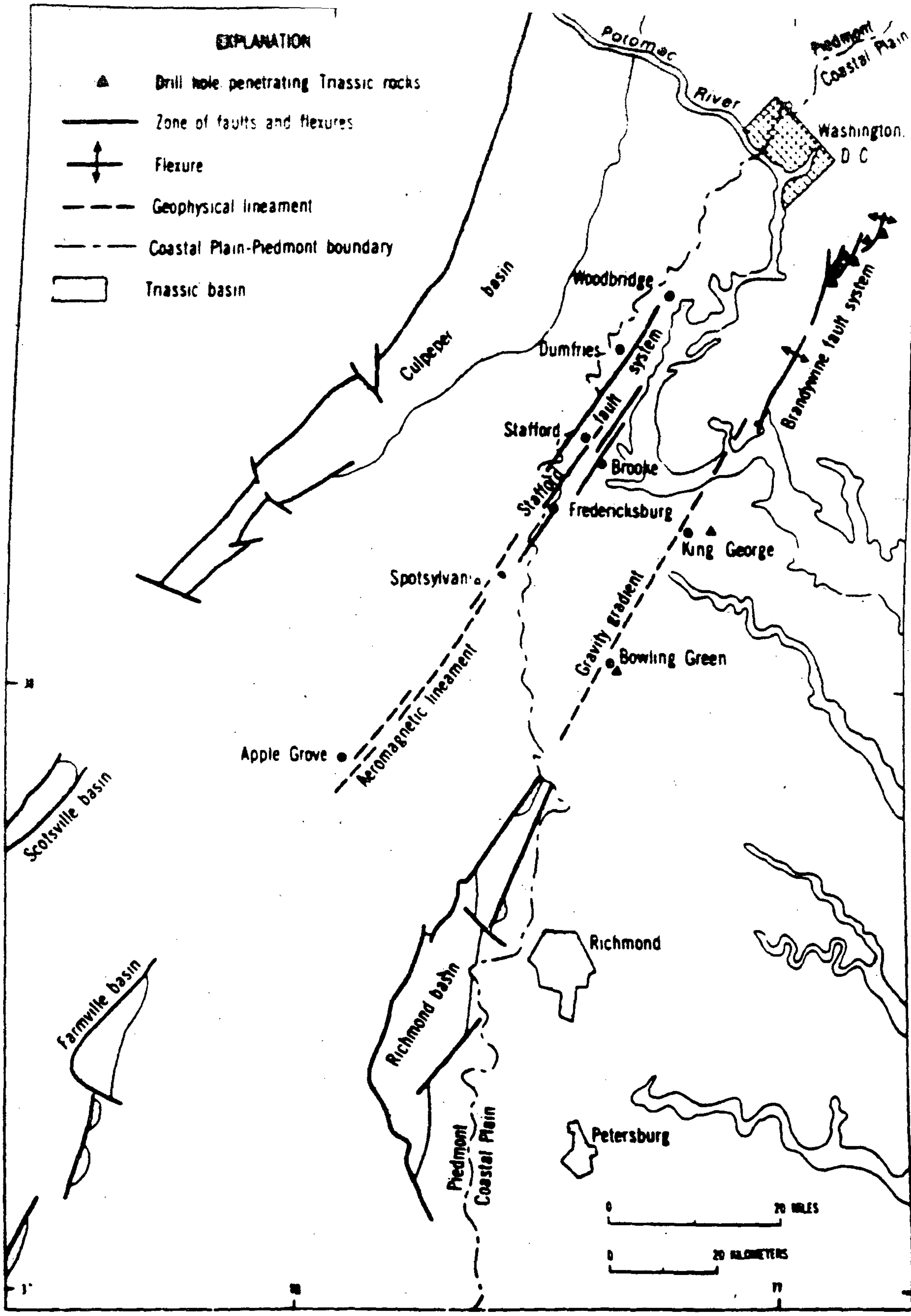


Figure 8-3 Stafford and Brandywine Fault Systems (Ref. 8-6)

similarity to other soils of known antiquity in the region, and the degree of weathering, indicated that they are ancient.

(7) The Brooke Structure, which is the eastern-most component of the Stafford Fault Zone, appears to have been inactive at least since the middle Miocene. An unconformity is present at the top of the Eocene Aquia Formation. An undated clay unit, which was deposited on this unconformity prior to deposition of the Miocene Calvert Formation, appears at the same elevation on both sides of the structure, indicating that little or no offset had taken place since that time.

No one element of the above data unambiguously determined a definitive age of the most recent movement of the Stafford Fault Zone. Taken in total, however, the available geological and seismological information supported the conclusion that the Stafford Fault Zone is not capable.

To determine whether the Brandywine Fault Zone is capable and if it extended closer to the site, the applicant undertook an investigation program that included field geological mapping, airphoto interpretation, trenching, core borings and seismic reflection profiling. The data obtained by these investigations indicated that there was no structural reflection of basement faults into post lower Tertiary (40 mybp) formations.

Subsequent to the completion of the staff's CP review, Dr. F. Jacobeen, who discovered the Brandywine Fault Zone, reported to the staff, the existence of several geological anomalies in the Brandywine area, which he believed were suggestive of recent movement along the Brandywine Fault Zone. The anomalies included 2 to 4 inches of reverse, down to the west offsets of Brandywine gravels in a gravel pit near Danville, a photolinear at Wicomico Creek, and cracked masonry in walls and footings of the Crestview Elementary School that lies adjacent to an airphoto lineament. The lineament is equivalent to a northeast projection of the Brandywine Fault Zone.

The staff evaluated Dr. Jacobeen's report through several meetings with him, an airphoto study, and two field reconnaissances, the last of which was attended by Dr. Jacobeen. Based on that review, the staff concluded that the new information since the CP review did not alter its conclusion that the site is suitable from a geological and seismological point of view. This conclusion was based on the following evidence, although inconclusive when taken separately, when considered in total is supportive of non-capability of the Brandywine Fault Zone.

(1) The airphoto linears could have many causes. In the eastern U.S. photolinears had not been shown to reflect recent tectonic movement on faults, and photolinears are present where there are no faults. The staff concluded that the linear commensurate with a northward projection of the Brandywine Fault Zone is the result of a concentration of seepage and erosion along the deeply buried fault and not due to recent tectonic movement.

(2) The 1973 investigation by the applicant south of Danville, Md. demonstrated that there had been no detectable movement of the Danville Fault segment since deposition of the middle Miocene Calvert Formation (16-11 mybp).

(3) The cracked masonry at the Crestview School was considered to be more likely related to differential consolidation of foundation fill relative to in-situ Coastal Plain sediments. The foundations of the structure were supported by both materials. This is a common occurrence in the region.

(4) The offsets in the gravel pit could be best explained by slumping or landsliding, however, it can also reflect minor tectonic adjustment on the Brandywine Fault Zone during the time of deposition of the Upland Gravels. In 1978, Newell and others (Ref. 8-12) interpreted the Upland Gravels as being a fluvial facies of the Yorktown Formation, which they date as lower and middle (?) Pliocene in age (7-3 mybp). From this it can be interpreted that up to several inches of displacement occurred within that time frame. The staff concluded that because this displacement could be best explained by a non-tectonic origin, was ancient, minor (less than 4 inches), and apparently localized, it was not a hazard to the Douglas Point site.

(5) The staff concluded that the Stafford Fault Zone was not capable, and that the Brandywine and Stafford fault zones are tectonically related. Therefore, evidence for the antiquity of the Stafford Fault Zone would tend to support the inactivity of the Brandywine Fault Zone.

(6) Seismicity in the vicinity of the Brandywine Fault zone is low and not atypical to that of the surrounding Coastal Plain and Piedmont regions.

Based on the weight of the available geological and seismological information, it was the staff's position that the Stafford and Brandywine fault zones were not capable.

8.4 HATCH 2

8.4.1 Background

The Hatch Nuclear Power Plant is located 75 miles west of Savannah, Georgia near the south bank of the Altamaha River (Figure 8-1). The construction permit review for Unit 2 was done between 1970 and 1972 during the final period of development of Appendix A, but prior to its publication in 1973. The concepts of Appendix A with respect to tectonic provinces, tectonic structures and capable faults were used by the AEC staff in reviewing this site.

Charleston, SC seismicity, including the 1886 maximum MMI X Earthquake was assumed to be localized along the deepest part of the southeast Georgia Embayment, south of the Cape Fear Arch, and 150 miles from the site. The SSE peak horizontal ground acceleration of 0.15g is based on assuming the occurrence at the site of the maximum historic earthquake that had occurred on the southern Coastal Plain and recurrence of the Charleston Earthquake at Charleston. The OBE of 0.08g peak horizontal acceleration is based on the earthquake disturbance likely to occur within the lifetime of the plant. No capable faults were identified in the site region.

One of the main problems for the staff during the OL review was obtaining assurance that soils with low standard penetration testing blow counts obtained during tests in the excavation area, would not liquefy on being subjected to SSE or even lower ground motions. Based on comparison of Unit 2 borings with borings and settlement records acquired for Unit 1, most of the loose soil was determined to be the result of unloading following excavation that re-consolidated after reloading with the plant structures.

Several seams of loose sand were also identified beneath the seismic safety related stack after construction. Although the stack was founded on piles, the staff was concerned that lateral shear forces exerted on the piles as a result of seismically induced liquefaction of these layers would damage the stack foundation. Additional sampling and state-of-the-art analyses demonstrated to the staff and its consultants, Drs. Newmark, Hall, and Hendron, that there were adequate factors of safety against liquefaction of these layers at the depths they were encountered.

8.5 CATAWBA

8.5.1 Background

The site is located in York County in north-central South Carolina, approximately 20 miles south of Charlotte, NC (Figure 8-1), on a peninsula in Lake Wylie, a reservoir created by construction of a dam across the Catawba River in 1904. The site is located within the southern Piedmont Physiographic Province (Figure 8-1). Tectonically the site is located in the southern section of the New-England-Piedmont Tectonic Province.

The CP review began in 1972 and ended with publication of the SER in 1973. Post CP evaluation of faults took place when the geological mapping of excavations for the plant and dam's foundations identified numerous faults beneath the site. The OL review ended in 1983 with the preparation of the SER (Ref. 8-13), except for some confirmatory items with respect to the amplification of ground motions through soils underlying the site. Appendix A was published after the CP SER had been completed, but the criteria regarding capable faults, tectonic structures, tectonic provinces, SSE, and OBE were used throughout both the CP and OL review (Ref. 8-13).

8.5.2 Tectonic Province and Maximum Earthquake

Because the site lies within the southern part of the New England-Piedmont Tectonic Province, the seismic design is based on the postulated occurrence of the maximum MMI VII, 1913 Union County Earthquake near the site. The resulting SSE peak horizontal ground acceleration is 0.15g. Any earthquake similar to the 1886 Charleston Earthquake was assumed to occur at the same epicentral location as the 1886 event and no nearer to the site, based on the reasons described in previous sections.

Shortly after the OL review had been completed the geological, seismological, and geophysical investigations in the Charleston area were carried out, and analyses of the findings by the geoscience community resulted in several alternate hypotheses about the sources of the seismicity in that region. These hypotheses are described in the previous section concerning the Summer OL licensing activities. As a result of these findings and the 1983 modification by the USGS of its position regarding the regional transferability (although at a low probability) of the Charleston seismicity, the staff required the applicant to assess the hypotheses as they might impact the Catawba seismic design bases just as it was done for the sites described earlier.

The NRC concluded, after reviewing the applicant's assessment, that the bases for its previous conclusion were still valid. In the staff's view, the investigations demonstrated the tectonic complexity of the Charleston region; and that complexity supports the atypicality of the region with respect to most of the rest of the eastern seaboard. As described in previous chapters, the staff and industry responses to the multitude of uncertainties remaining, resulted in the LLNL and EPRI PSHAs. The staff also continued its deterministic geological, seismological, and geophysical investigations that have been underway since the early 1970s, to define the seismic sources and vibratory ground motions. These studies have provided further confirmation (paleoliquefaction evidence) that the Charleston meizoseismal region has been seismically unique during the Holocene.

During the OL review there was also some concern among the staff that an earthquake similar to the January, 1982, magnitude 5.7 New Brunswick could occur near the site. The hazard posed by the possible widespread occurrence of this kind of earthquake was assessed with respect to many nuclear power plant sites on the eastern seaboard, some of which were described in the preceding chapters. Regarding the Catawba site, the staff concluded that there is sufficient geological and seismological evidence suggesting control of the New Brunswick seismicity by sources that are not present in the southern Piedmont to conclude that the New Brunswick Earthquake should not be used as the design basis earthquake.

8.5.3 Capable Faults

During preliminary trenching operations that were part of the site investigations prior to application for a CP, a fault with a nearly horizontal dip was identified that offset weathered pegmatite dikes within the saprolite that overlay weathered adamellite bedrock. There was no material available with which to date the most recent offset on the fault. Because of the brittle deformation characteristics of the fault and the offset dikes, the faulting was interpreted to have taken place when the saprolite was hard rock. An upper limit of time of last displacement was calculated using published weathering and erosion rates (Ref. 8-13) to determine how long ago the saprolite had been hard, unweathered rock. The calculated age was at least 300,000 years ago, but, based on regional relationships, was estimated to be more than 136 million years ago. As expected, other sub-horizontal faults like this were found in the construction excavations. Cross-cutting relationships with other faults and intrusives in the excavations helped to better define the ages of last offset.

Construction began in 1973. In September, 1975, during excavation for the power block complex, and later as excavation progressed, more than 22 brecciated fault zones were encountered. The utility was required to map in detail and determine the ages of last displacements on these faults. The fault zones appeared in plan view as fractures or networks of anastomozing clay-filled fractures along which displacement of pegmatite dikes had occurred. The zones were healed, tight and essentially continuous with the country rock. The faults occurred in sets with strikes ranging from N-S, NNE, to NW, and dips ranging from high angle to vertical. Magnitudes of displacement varied on the faults but the maximum offset of 23 feet of net slip occurred on one of the zones. Width of the zones ranged from a fraction of an inch to several feet, (Ref. 8-15).

Several lines of investigations of these features were conducted: fault dating based on petrographic thin section analysis, hydrothermal mineral assemblage and radiometric (potassium argon) age-dating, site and regional geologic history, and soil and saprolite considerations.

The minimum age of last displacement on the faults that could be demonstrated, based on radiometric dating of unsheared veinlets and crystals of prehnite and laumontite that cut across the faults, was 86 plus or minus 30 million years before present (mybp). Based on comparison of the site faults with regional tectonic history the minimum age of last displacement was estimated to be 136 million years.

Based on the applicant's analysis, a sequence of hydrothermal mineralization followed the most recent faulting. Laumontite-calcite veinlets are the youngest major assemblage of this sequence. The pressure-temperature conditions under which this assemblage would have been stable would require burial to a depth of about 15,000 feet. The utility estimated that it would require several hundred thousand to several million years of weathering, erosion and uplift to bring these features to near ground surface using accepted weathering and erosion rates.

Soil and saprolite studies of the weathered adamellite supported the conclusion that no movement had occurred on the faults during the time required to produce observed weathering. The saprolitization rate of rock similar to that at the site was calculated to proceed at 22k to 77k years per meter. The site rock has been saprolitized to depths ranging from 40 to 120 feet. Using these rates, existing depths of saprolite would require at least 660k years to develop.

In addition to the above analyses, and at the NRC's recommendation, the applicant during the process organized a panel of three independent experts in Appalachian Piedmont geology to follow the investigations, review the results of the studies and provide an analysis. The experts concluded that the faults were ancient and did not represent a potential hazard to the site (Ref. 8-13).

There was no strong public intervention regarding the fault issue. As in the Summer case described above, this was probably due to the thoroughness and open nature of the investigations, and also to the remoteness of the site. After reviewing all of the data and the independent panel's final report, the NRC staff concluded that the faults were not "capable faults" as defined by Appendix A, (Ref.'s 13 and 14).

8.5.4 Stability of Foundation Materials and Slopes

Major plant structures were to be founded on relatively unweathered, sound adamellite bedrock, therefore, no special foundation treatment was required due to the presence of the relatively narrow, healed and tightly filled faults.

A source of emergency cooling water was to be provided by constructing a safety related (category 1) dam across a valley which previously had been a flooded arm of Lake Wylie. A finite element analysis showed that the dam would be stable on being subject to SSE ground motion. To validate input into the finite element and other stability analyses (such as sudden drawdown in the event of the loss of Lake Wylie) the applicant monitored the slopes of the dam for seepage or indications of failure for several months after the pond had been flooded. No unusual or unexpected seepage was reported.

8.6 CLINCH RIVER

8.6.1 Background

The Clinch River site is on a peninsula formed by sharp meanders of the Clinch River immediately west of the Oak Ridge National Laboratory Reservation, Tennessee. The site is within the Southern Valley and Ridge Tectonic Province (Ref. 8-16).

Interest in this site as a location for a nuclear facility occurred twice, once for a proposed TVA nuclear power plant in the early 1970s; and the second as a site for a demonstration liquid metal fast breeder reactor in the middle and late 1970s and the early 1980s. This site application was eventually withdrawn for reasons other than geosciences issues.

During the initial CP review four major issues significant to the requirements of Appendix A were identified:

1. The appropriate SSE for the site, which is located in the Eastern Tennessee Seismic Zone, of the Southern Valley and Ridge Tectonic Province, a relatively high seismic area in the southeastern United States;

2. The capability of faults in the site vicinity;

3. The potential for solution cavities in foundation bedrock that could lead to the potential for subsidence or collapse beneath the plant structures; and

4. The possibility of earthquakes induced by the injection of deep well waste on the Oak Ridge Reservation four miles east of the site.

The staff developed tentative conclusions regarding these issues which resulted in the site being considered acceptable from geological, seismological, and geotechnical standpoints, but the licensing process was delayed.

During the late 1970s and continuing through the early 1980s the licensing process was reinstated, but this time as the site of the Clinch River Breeder reactor. The staff reevaluated the site with respect to the four issues listed above based on the considerable new information that had been developed since it had first assessed the site. Two sub-issues of Issue 1 were added: the significance of new data regarding the sources of eastern seismicity, particularly about the 1886 Charleston Earthquake; and the significance of the results of work accomplished by Bollinger and Wheeler (Ref. 8-17) regarding the epicenter of the 1897 Giles County, maximun MMI VIII, Magnitude 5.8 Earthquake, which is the controlling event within the Southern Valley and Ridge Tectonic Province.

8.6.2 Tectonic Province, Tectonic Structure, and the Adequacy of the SSE

The new information that had the greatest potential of affecting the staff's conclusion on the adequacy of the SSE were the results of the NRC-USGS supported geological, geophysical, and seismological in the Charleston, SC area. As described in the discussion of the Charleston Issue in Chapter 2, numerous hypotheses were developed regarding the source of the 1886 Earthquake from this new information, and the USGS concluded that the occurrence of a similar event was possible, although with a low probability, in other parts of the eastern U.S. The hypothesis that most affected the Clinch River site was the decollement hypothesis. This theory held that the southeastern U.S. is underlain at a depth of four to thirteen kilometers by a major detachment surface that was active, and the Charleston Earthquake and much of the rest of eastern seismicity is associated with it.

The staff's position on how it proposed to handle the Charleston Earthquake issue was also described in the Chapter 2 discussion. Briefly it involves the idea that there is no immediate problem, and the hazard represented by this event and eastern seismicity in general, would be addressed by a probabilistic study and a deterministic study. These hazard studies would also address the Giles County earthquake issue.

If the Decollement Hypothesis was true the low angle faults of the Valley and Ridge that are listric to the decollement, such as the Copper Creek Fault, which lies 3,000 ft. southeast of the site, and the White Oak Fault, which lies 1.7 miles to the northwest, would also be potentially active. The staff's review of the available information resulted in the following findings concerning the activity of the Valley and Ridge faults (Ref. 8-18):

(1) Extensive field research conducted in the region with the intent of finding evidence for recent displacement along these faults to explain current seismicity found no such evidence;

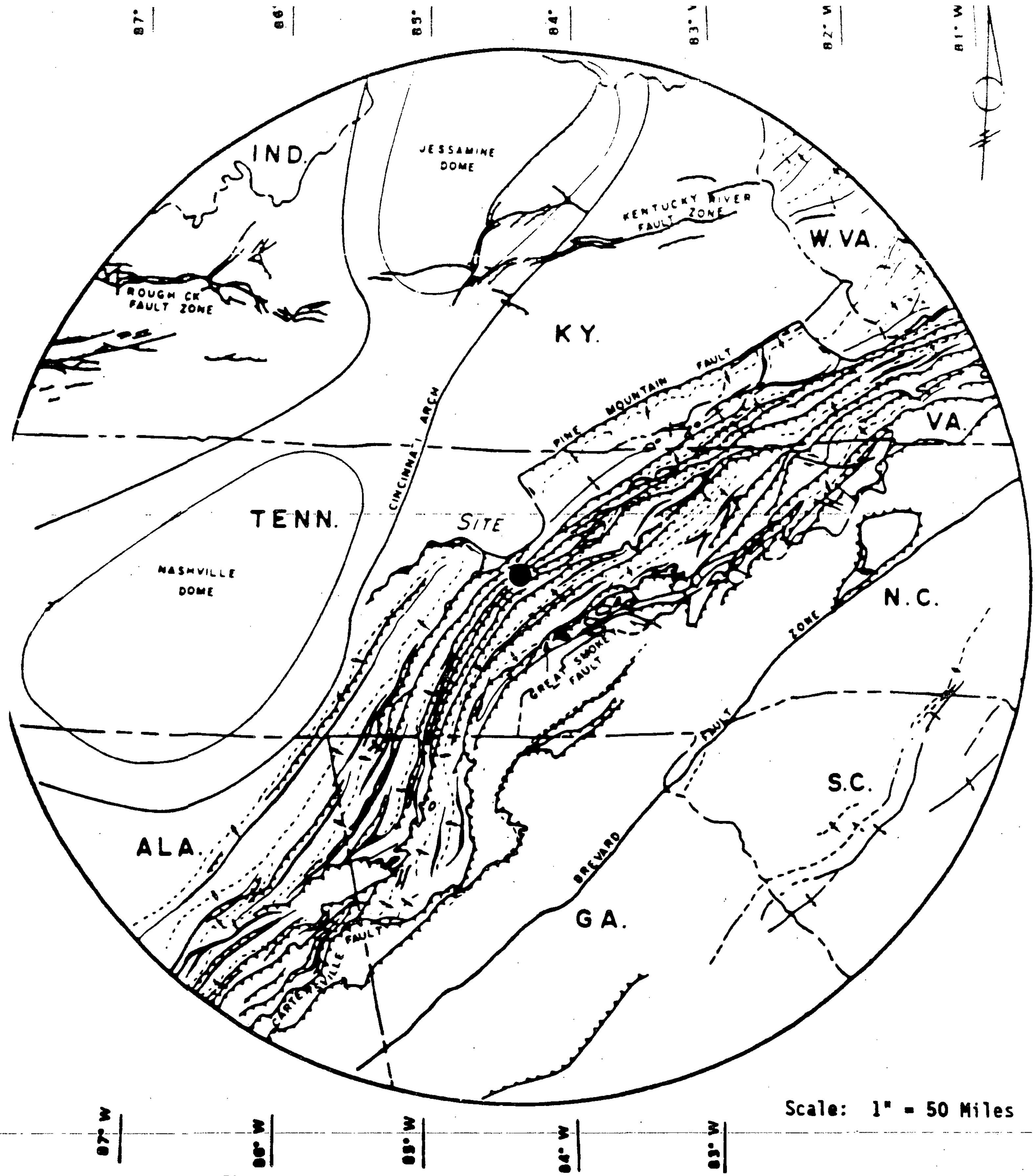


Figure 8-4 Tectonic Map of Eastern Tennessee (Modified from Ref. 8-14).

(2) Triassic dikes mapped in Virginia penetrate Valley and Ridge structures without being offset (Ref. 8-19);

(3) Coastal Plain deposits in Alabama, where they overlie Valley and Ridge structures, are not deformed (Ref. 8-20);

(4) In studies related to the evaluation of the Phipps Bend and Watts Bar nuclear power plant sites (Refs. 8-21 and 8-22), where subsidiary faults of the major faults have been mapped in relation to overlying ancient terrace deposits, those terraces have not been offset; and

(5) Radiometric age dating of gouge taken from the Copper Creek Fault indicate an age of at least 280 mybp (Ref. 8-18).

Bollinger's work regarding seismicity in the Giles County Seismic Zone led him to conclude that those earthquakes were occurring on a structure, the postulated dimensions of which were such that it had the capability of generating a magnitude 7 earthquake (Ref. 8-17). The significance of this to Clinch River is that being in the same tectonic province as Giles County, it raises concerns over the potential for a magnitude 7 near the site. Based on its review of the available information, the staff concluded that the evidence of the postulated seismogenic source is tentative subject to interpretation and it would have been premature to adopt Bollinger's interpretation. Additionally, investigations were still underway and the probabilistic and deterministic studies regarding central and eastern U.S. seismicity described above will also address the Valley and Ridge seismic hazard.

Therefore, based on all of the above considerations, the staff concluded that the SSE design basis with a peak horizontal acceleration of 0.25g was adequate.

8.6.3 Capable Faults

Samples of the gouge taken from the Copper Creek Fault were radiometrically dated and found to be at least 280 million years old. The minor faults, shear zones, and folds found in the site area could not be dated absolutely because of the absence of datable material. However, because of their orientations and other similarities to the Copper Creek Fault, they were associated with the tectonic episode that generated the last displacement on that fault, which was the Appalachian Orogeny of the late Paleozoic Era.

Although the staff's position was that the site faults did not represent a hazard to the plant, it recommended that the applicant geologically map the high level terraces found on and around the site, to determine whether they had been tectonically deformed, and their approximate age.

8.6.4 Potential for Subsidence or Collapse

The staff concluded that there was no potential for subsidence or collapse due to solutioning of carbonate bedrock beneath the site, thus satisfying the foundation stability criterion of Appendix A. The decision was based on the following:

(1) The foundation bedrock of the site, which is the upper strata of Unit A of the Chickamauga Formation, is predominantly a siltstone and not prone to solutioning;

(2) The high percent of core recovery and high Rock Quality Designation of rock samples obtained from the 129 closely spaced core borings demonstrated the tightness of the bedrock and absence of solution features beneath the foundation level of the rock;

(3) In-hole geophysics, in-hole seismic, cross-hole seismic, and surface seismic refraction surveys demonstrated the competency of the foundation rock; and

(4) A test grouting program with low grout takes, and core borings drilled after the test grouting demonstrated that the rock contained few voids.

8.6.5 Potential Effects of Man's Activities

In accordance with the Appendix A criterion concerned with the effects of man's activities, the staff conducted an analysis of the injection well records, stratigraphy, structural geology, and the local seismicity, and concluded that the future injection of wastes into the ground would not affect the seismic hazard of the plant because it will be confined to a specific stratigraphic zone with a very limited range of injection pressures. The zone is well above the Copper Creek Fault at that location, and separated from it by relatively impervious zones (Ref. 8-18).

CHAPTER 9 CONCLUSION

9.1 The New Regulatory Documents

The geosciences issues that occurred over the past approximately three decades, many of which are described in the preceding chapters, motivated the preparation of a new siting regulation and a new regulatory guide. In addition to these documents, sections of the Standard Review Plan (SRP), Chapter 2.5, NUREG-0800, that deal with the staff's evaluation of the geological and seismological aspects of siting nuclear power plants, have been updated and revised. The new regulation is titled "Geologic and Seismic Siting Factors," 10 CFR Part 100, Section 100.23 (Ref. 1-9). The title of the new siting guide, which describes a methodology that is acceptable to the staff to fulfill the requirements of Section 100.23, is "Identification and Characterization of Seismic and Determination of Safe Shutdown Earthquake Ground Motion," Regulatory Guide 1.165 (Ref. 1-8). The revised SRP sections are: 2.5.1 - "Geologic and Seismic Information," 2.5.2 - "Vibratory Ground Motion," and 2.5.3 - "Surface Faulting."

In addition to a revision of the siting portions of the regulation, the engineering elements of the rule are now in 10 CFR Part 50 as a new Appendix S (Ref. 1-10). Acceptable methods to satisfy the requirements of Appendix S are described in new Regulatory Guides 1.12, 1.166, and 1.167. Both the siting and engineering criteria of the old siting regulation, Appendix A (Ref. 1-1), still apply to currently operating nuclear power plants, but the new regulation will be required for any future commercial nuclear power plant sites.

9.2 Major Shortcoming of Appendix A and the Need to Address Uncertainties

The major shortcomings of Appendix A have been discussed in Chapter 1. The most significant and far-reaching shortcoming of Appendix A was the lack of an explicit recognition or requirement to include in the seismic hazard analysis, a consideration of uncertainties such as are inherent in the identification and characterization of seismic sources, estimation of maximum magnitudes, and analyses of ground motions. The new regulation, Part 100.23, includes such a recognition of the use of both probabilistic and deterministic evaluations.
The new regulatory guide, R.G. 1.165, describes an acceptable methodology by which this consideration of uncertainties may be carried out.

The methodology specified in Appendix A to estimate the seismic hazard is a deterministic procedure, and although Appendix A did not preclude a probabilistic seismic hazard analysis it did not require that uncertainties be addressed. Therefore, in many of the licensing review cases, these unquantified uncertainties led to time-consuming and costly deadlocks because each party involved advocated different, but equally credible hypotheses with respect to tectonic provinces, maximum earthquakes, surface rupture, etc., that were based essentially on the same data (see discussions about Indian Point and Seabrook in Chapter 7). It soon became apparent that serious consideration of uncertainties must be a strong part of the hazard analyses.

The need for a revision was most strongly realized relative to the Charleston Earthquake Issue described in Chapter 2. This issue not only had an impact on the way we regarded the seismic potential of the region around the 1886 earthquake meizoseismal zone, but also our conception of the seismic potential of the entire Atlantic Seaboard. Appendix A proved to be inadequate to deal with this and other seismic issues in the central and eastern United States (CEUS) because of the prescriptive manner in which it states the seismic siting criteria and the large uncertainties associated with seismic sources, maximum potential earthquakes, and ground motion parameters that characterize these regions (Chapters 1, 2, and 8).

9.3 Benefits of the New Regulatory Documents

9.3.1 Generic Issues

Deterministic investigations (paleoliquefaction studies in particular) related to the 1886 Charleston Earthquake, both in South Carolina and elsewhere along the Atlantic Seaboard, support the staff's position that has been used in licensing since the late 1960s. That position is that the seismogenic source (or sources) is unique to coastal South Carolina. The basis for that support is paleoliquefaction evidence for the Charleston Earthquake and for at least five prehistoric earthquakes in coastal South Carolina during the last several thousand years (Ref.'s 9-1 and 9-2), and the absence of such evidence elsewhere on the Atlantic Coastal Plain (Ref. 9-3). PSHAs (LLNL and EPRI) also demonstrate that the occurrence of an 1886 Charleston-like earthquake elsewhere on the eastern seaboard is very unlikely.

The Meers Fault, based on paleoseismic evidence, generated at least two estimated magnitude 7 earthquakes, one about 1300 years ago and the other approximately 3,000 years ago. The geologic evidence also suggests that prior to 3,000 years ago there was a hiatus of large events that lasted many tens of thousand years. PSHAs as described in R.G. 1.165 provide a methodology for dealing with this kind of situation.

The occurrences of the1982 New Brunswick, the 1988 Saguenay, and the 1989 Ungava earthquakes in eastern North America, and the mounting evidence from around the world, more and more indicate that magnitude 6 earthquakes occur in stable continent regions such as the central and eastern U.S. more frequently than had previously been considered. However, the recurrence rate of such events in stable continental regions still is extremely low. PSHAs support their occurrence in the stable continental regions, but show that they have no, or very little impact on the risk of well designed and constructed to critical facilities.

9.3.1 Central and Eastern United States (CEUS)

The most significant change in the siting regulation is the addition of an explicit requirement that uncertainties be addressed, either by probability seismic hazard analyses or sensitivity studies. The probabilistic seismic hazard analysis (PSHA) methodologies and databases developed by the Lawrence Livermore National Laboratories (LLNL) (Ref. 2-1) and the Electric Power Research Institute (EPRI) (Ref. 2-2) are recommended by the NRC staff to be used by future applicants in the CEUS to address uncertainties. The appropriate seismic hazard probability to be used in siting future nuclear power plants was developed using the probability of exceeding the seismic design bases of the more recently designed nuclear power plants. This was not meant to be an absolute value, but rather a value relative to the existing plants obtained using the same PSHA. These PSHAs are to be updated periodically, about every ten years, but the regulatory guide provides guidance on the way in which significant new findings such as a previously unknown seismic source, or occurrences such as an earthquake or surface faulting events are to be incorporated into the analysis.

9.3.2 Western U.S. Sites

Large uncertainties also characterize the western U.S., such as the seismic potential of the Cascadia Subduction Zone, the potential hazard posed by volcanoes as described in Chapter 3, and the potential hazards represented by displacements on faults, maximum earthquakes, and ground motions as described in Chapter 4.

The PSHAs described in R.G. 1.165 and in Chapters 3 and 4 with respect to the WNP-3 and Diablo Canyon sites, respectively, have strong application in the evaluation of western sites. A PSHA based on a strong deterministic database and appropriate consideration of uncertainties conducted by consultants to the WNP-3 applicant provided a rational means to deal with potential subduction zone earthquakes. For Diablo Canyon a PSHA confirmed the deterministically derived controlling earthquake on the Hosgri Fault, and demonstrated that the hazard represented by smaller, closer-in, low slip rate faults would be enveloped by the Hosgri earthquake and thus not impact the seismic design basis. A PSHA was not used in the assessment of volcanic hazard for nuclear power plants, but could have strong application in any future evaluations of potential sites in the Pacific Northwest, northern and east-central California, or Basin and Range regions.

For the western U.S. the regulatory guide recommends that PSHAs also be carried out, but since there is no equivalent database like that for the CEUS, these analyses will have to be accomplished on a site by site basis. Examples of the way in which western sites may be analyzed probabilistically are presented in References 3-24 and 4-12.

9.3.3 Removal of the Requirement for a Deterministic Seismic Hazard Analysis in the New Regulatory Documents

Along with the new requirement to consider uncertainties, is the removal from the siting regulation of the explicit requirement to perform a deterministic seismic hazard analysis. Appendix A essentially requires that a deterministic seismic hazard analysis be performed. That is, it requires the determination of the maximum earthquake that is controlling in estimating the safe shutdown earthquake ground motion (SSE), based on historic seismicity and regional investigations; and estimation of its distance from the site (closest approach of the causative structure or tectonic province to the site).

The removal of the requirement for a deterministic seismic hazard analysis does not mean that the requirement to perform a deterministic investigation of the site and region does not have to be carried out. On the contrary, the requirements for geological, seismological, geophysical, and geotechnical investigations remain the same, or are even more stringent because of the advent of new methodologies.

In regard to the use of PSHAs in the estimation of seismic hazard of nuclear power plant sites, the author is concerned that: (1) investigators, analysts, and reviewers will be lulled into a false sense of security that all potential hazards have been enveloped in the hazard curves; (2) because of this sense of security, regional and site investigations are reduced in scope and detail; (3) those investigations that are carried out will be accomplished simply to confirm the PSHA data base instead of actively searching for sources of potential hazard; and (4) research in the geosciences to reduce the uncertainties in seismic sources, ground motion generation and propagation, and site specific characteristics will be considered to be of less importance than it has in the past.

9.3.4 Tectonic Province, Tectonic Structure, and Capable Fault

Many of the issues described in this report were brought about by ambiguities of Appendix A terms such as tectonic province, tectonic structure, and capable fault. Changes were made in the regulation and amplified in Regulatory Guide 1.165 in an attempt to reduce such ambiguities in the future. Tectonic province, seismotectonic province, and tectonic structure are combined into either of two subdivisions of seismic source: seismogenic source or capable tectonic source. A seismogenic source is a seismic source that has the potential to generate earthquakes but will not directly cause surface deformation. A capable tectonic source has the potential to generate earthquakes and cause surface deformation.

Capable tectonic source replaces the term capable fault for future plant sites. The changes in name and definition were made to emphasize the earthquake generating capacity of the fault, the potential to cause surface deformation, and to specifically point out the need to identify and evaluate the surface and near surface effects of blind faults even though there is no surface rupture by the causative fault.

Applying the capable fault criterion of Appendix A to sites in California meant conducting investigations and analyses for surface rupture potential. This was insufficient, as demonstrated by the occurrences of the 1989 Loma Prieta, 1992 Petrolia, and 1994 Northridge earthquakes during which the causative faults did not rupture ground surface (blind faults). The new regulatory documents strongly promote the consideration of these kinds of faults and ways to evaluate them. The new definition, capable tectonic source, provides earthquake criteria for fault activity. An issue during the Indian Point licensing with respect to the Ramapo Fault arose as a direct result of the ambiguity in Appendix A capable fault criteria as to what are the earthquake indicators of fault capability in the absence of geologic evidence (Chapter 7).

9.3.5 Tectonic Versus Non-tectonic Faulting

Another major issue on a number of the nuclear power plant sites in the northeastern and north-central U.S. was how to handle young surface rupture that met the Appendix A criteria for being capable faults but were more than likely created or reactivated by other phenomena such as glaciation or deglaciation (see the discussion of Nine Mile Point in Chapter 6). Similar problems were encountered in karst terrane and in the Gulf coast region (see Chapter 6 - Allens Creek). Thus R.G. 1.165 emphasizes the importance of making a distinction between faults with a tectonic origin and those created or reactivated by other, nontectonic phenomena.

A research project that was designed to support of R.G. 1.165 was completed in 1998. Its purpose was to develop criteria by which faults of various origins can be identified and characterized as to the hazard they represent. This research is summarized in NUREG/CR-5503, "Techniques for Identifying Faults and Determining their Origins" by Geomatrix Consultants, Inc. and William Lettis & Associates, Inc. (Ref. 9-4).

9.3.6 Geochronology of Faults

A major problem, as demonstrated by the discussions in Chapters 7 and 8 has to do with determining the age of most recent displacements on faults. R.G. 1.165 recommends state-of-the-art methods to date fault displacements. These recommendations are based on a geochronology research project conducted between 1993 and 1997. This project included activities such as a literature search, interviews of geochronology and paleoseismology experts, a workshop, field and laboratory validations of new methods, and preparation of a report that describes the methods, theories behind each procedure, their applications, resolutions and accuracies of each method, and uses in paleoseismic analyses. The research was published in March, 1998 as NUREG/CR-5562, "Dating and Earthquakes: Review of Quaternary Geochronology and Its Application to Paleoseismology," by William Lettis and Associates, Inc. (Ref. 9-5). It was also published in, *"Quaternary Geochronology, Methods and Applications," American Geophysical Union shelf reference* 4, edited by Stratton J.N., J.M. Sowers, and W.R. Lettis (Ref. 9-6).

9.4 Future Licensing of Nuclear Power Plant Sites

The problems encountered and their resolutions through the years of licensing have resulted in the new licensing documents, the revised regulation, supporting guides and SRP sections. One of the principal strengths of the new licensing documents, due to the concise general regulation and detailed regulatory guide, is that they can be more easily modified than Appendix A to accommodate advances in the geosciences through time. The NRC staff anticipates that these documents will help to insure that future licensing of nuclear power plant sites will not be plagued with the issues described in Chapters 1 through 8 of this report; or that they will provide a means to more efficiently and rationally resolve these issues as they arise without the extensive litigation and excessive delays that occurred during the licensing of the sites discussed in this report, and the numerous other plant sites that were not included in this report.

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