San Juan Basin Action Plan

GEOLOGIC SETTING TECHNICAL REPORT

for the
Environmental Impact Statement on Public Service Company of New Mexico's Proposed New Mexico Generating Station and Possible New Town

United States
Department
of the Interior

Bureau of Land Management
New Mexico State Office
Santa Fe, New Mexico

October 1982

Report 7 of 22

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
NEW MEXICO STATE OFFICE
P.O. BOX 1449
SANTA FE, NEW MEXICO 87501

IN REPLY REFER TO
NM30840EIS
1792.73(934A)

October 1982

Dear Interested Citizen:

Attached is one of twenty-two technical reports developed as a basis for writing the Environmental Impact Statement on Public Service Company of New Mexico's Proposed New Mexico Generating Station and Possible New Town (NMGS EIS). (A list of the technical reports is attached.)

These technical reports provide detailed information on the existing environment, methods used for the impact analysis, and related data supportive of the analysis and conclusions presented in the EIS. These reports should be retained for use with the Draft and Final EIS and other documents related to BLM's San Juan Basin Action Plan (SJBAP).

The Draft NMGS EIS will be filed with the Environmental Protection Agency and released for public review on November 30, 1982. Comments on the Draft EIS will be due by close of business February 7, 1983, at the BLM New Mexico State Office. Because of the large volume of material presented in the technical reports, the BLM is distributing these reports in advance of the Draft EIS to provide sufficient time for public review. The technical reports will be available for public review at the places indicated on the attached list. Copies will also be available from the BLM New Mexico State Office, U.S. Post Office and Federal Building, Santa Fe, for a copy fee.

Informational public meetings are scheduled for December 1982 to provide a public forum to clarify questions and concerns about the SJBAP proposals and the related environmental documents, which will all have been issued by that time. The meetings are scheduled as follows:

- December 14, Civic Center, Farmington, 3 to 9 PM
- December 14, Convention Center, Albuquerque, 3 to 9 PM
- December 15, Chapter House, Crownpoint, 3 to 9 PM
- December 16, Holiday Inn, Gallup, 3 to 9 PM
- December 16, Kachina Lodge, Taos, 3 to 9 PM

In addition, formal public hearings will be held in January 1983 to solicit public comments on the SJBAP Proposals. These meetings are scheduled as follows:

- January 10, Chapter House, Crownpoint, beginning at 1:00 PM
- January 12, Civic Center, Farmington, beginning at 9:00 AM
- January 14 (and 15th if necessary because of the number of registrants), Four Seasons Motor Lodge, Albuquerque, I-40 and Carlisle Blvd., beginning at 9:00 AM (each day)

Questions on the public meetings, hearings, and the technical reports themselves should be directed to:

Leslie M. Cone
NMGS Project Manager
BLM, New Mexico State Office
P.O. Box 1449
Santa Fe, NM 87501
(505) 988-6184 FTS 476-6184

Sincerely yours,

Charles W. Luscher
State Director, New Mexico

<u>List of Technical Reports</u>

1. Purpose and Need
2. Project Description
3. Alternatives to the Project
4. Site Alternatives
5. Permit Reconnaissance
6. Air Quality
7. Geologic Setting
8. Mineral Resources
9. Paleontology
10. Soils, Prime and Unique Farmlands
11. Hydrology
12. Water Quality
13. Vegetation
14. Wildlife and Aquatic Biology
15. Threatened and Endangered Species
16. Cultural Resources
17. Visual Resources
18. Recreation Resources
19. Wilderness Values
20. Transportation
21. Social and Economic Conditions
22. Land Use Controls and Constraints

Availability of Technical Reports for Public Review

Individual copies of the technical reports can be obtained for a copy fee. Inquiries should be directed to:

Bureau of Land Management, New Mexico State Office
Title Records and Public Assistance Section (943B)
U.S. Post Office and Federal Building
P.O. Box 1449
Santa Fe, NM 87501
(505) 988-6107 FTS 476-6107

Copies of the reports are available for public review at the locations listed below. [Formal and informal cooperating agencies are denoted by an asterisk (*).]

BUREAU OF LAND MANAGEMENT OFFICES

New Mexico State Office

NMGS Project Staff (934A)
Room 122, Federal Building
Cathedral Place
P.O. Box 1449
Santa Fe, NM 87501
(505) 988-6184 FTS 476-6184

San Juan Energy Projects Staff (911)
Room 129, Federal Building
Cathedral Place
P.O. Box 1449
Santa Fe, NM 87501
(505) 988-6226 FTS 476-6226

Public Affairs Staff (912)
Room 2016
U.S. Post Office and Federal Building
P.O. Box 1449
Santa Fe, NM 87501
(505) 988-6316 FTS 476-6316

Division of Resources(930)
509 Camino de los Marquez, Suite 3
P.O. Box 1449
Santa Fe, NM 87501
(505) 988-6212 FTS 476-6212

Albuquerque District Office
3550 Pan American Freeway NE
P.O. Box 6770
Albuquerque, NM 87107
(505) 766-2455 FTS 474-2455

Farmington Resource Area Headquarters
900 La Plata Road
P.O. Box 568
Farmington, NM 87401
(505) 325-3581

Taos Resource Area Office
Montevideo Plaza
P.O. Box 1045
Taos, NM 87571
(505) 758-8851

Socorro District Office
198 Neel Avenue
P.O. Box 1219
Socorro, NM 87801
(505) 835-0412 FTS 476-6280

Las Cruces District Office
1705 N. Valley Drive
P.O. Box 1420
Las Cruces, NM 88001
(505) 524-8551 FTS 571-8312

Roswell District Office
1717 W. Second Street
P.O. Box 1397
Roswell, NM 88201
(505) 622-7670 FTS 476-9251

Carlsbad Resource Area Headquarters
114 S. Halagueno Street
P.O. Box 506
Carlsbad, NM 88220
(505) 887-6544

USDI, Bureau of Land Management
Division of Rights-of-Way (330)
18th and C Streets, NW
Washington, D.C. 20240
(202) 343-5441 FTS 343-5441

USDI, Bureau of Land Management
Denver Service Center (D-460)
Technical Publications Library
Denver Federal Center, Bldg. 50
Denver, CO 80225
(303) 234-2368 FTS 234-2368

NEW MEXICO STATE AGENCIES

New Mexico State Environmental Improvement Division*
725 St. Michaels Drive
P.O. Box 968
Santa Fe, NM 87503
(505) 827-5217, ext. 2416

New Mexico Energy and Minerals Department*
525 Camino de los Marquez
P.O. Box 2770
Santa Fe, NM 87503
(505) 827-3326

New Mexico Historic Preservation Bureau*
State Historic Preservation Officer
505 Don Gasper Avenue
Santa Fe, NM 87503
(505) 827-2108

New Mexico Natural Resource Department*
Villagra Building
Santa Fe, NM 87503
(505) 827-5531

New Mexico Public Service Commission*
Bataan Memorial Building
Santa Fe, NM 827-3361
(505) 827-3361

New Mexico State Engineer's Office*
Bataan Memorial Building
Santa Fe, NM 87503
(505) 827-2423

New Mexico State Planning Office*
505 Don Gaspar Avenue
Santa Fe, NM 87503
(505) 827-5191

OTHER ORGANIZATIONS

Public Service Company of New Mexico
Alvarado Square
P.O. Box 2268
Albuquerque, NM 87158
(505) 848-2700

Woodward-Clyde Consultants, Inc.
3 Embarcadero Center, Suite 700
San Francisco, California 94111
(415) 956-7070

PUBLIC AND UNIVERSITY LIBRARIES

Reading copies of the NMGS EIS and associated technical reports will be available at the following public and university libraries:

State and Public Libraries

Albuquerque Public Library
501 Copper Avenue NW
Albuquerque, NM 87102

Aztec Public Library
201 W. Chaco
Aztec, NM 87401

Crownpoint Community Library
c/o Lioness Club, P.O. Box 731
Crownpoint, NM 87313

Cuba Public Library
Box 5, La Jara
Cuba, NM 87027

Farmington Public Library
302 N. Orchard
Farmington, NM 87401

Gallup Public Library
115 W. Hill Avenue
Gallup, NM 87301

Mother Whiteside Memorial Library (Public)
525 W. High Street
P.O. Box 96
Grants, NM 87020

New Mexico State Library
325 Don Gaspar Avenue
Santa Fe, NM 87503

OTHER DEPARTMENT OF THE INTERIOR AGENCIES

Bureau of Indian Affairs*
Albuquerque Area Office
123 4th Street
P.O. Box 2088
Albuquerque, NM 87198
(505) 766-3374 FTS 474-3374

Bureau of Indian Affairs*
Eastern Navajo Agency
P.O. Box 328
Crownpoint, NM 87313
(505) 786-5228

Bureau of Indian Affairs*
Navajo Area Office
Box M - Mail Code 305
Window Rock, AZ 86515
(602) 871-5151 FTS 479-5314

Bureau of Reclamation*
Upper Colorado Regional Office
125 S. State Street
P.O. Box 11568
Salt Lake City, UT 84147
(801) 524-5463 FTS 588-5463

Minerals Management Service*
South Central Region
505 Marquette Avenue NW, Suite 815
Albuquerque, NM 87102
(505) 766-1173 FTS 474-1173

Minerals Management Service*
Resource Evaluation Office
411 N. Auburn
Farmington, NM 87401
(505) 327-7397 FTS 572-6254

National Park Service*
Southwest Regional Office
1100 Old Santa Fe Trail
Santa Fe, NM 87501
(505) 988-6375 FTS 476-6375

National Park Service*
Environmental Coordination Office
Pinon Building, 1220 St. Francis Drive
P.O. Box 728
Santa Fe, NM 87501
(505) 988-6681 FTS 476-6681

U.S. Fish and Wildlife Service*
Field Supervisor, Ecological Services
3530 Pan American Highway, Suite C
Albuquerque, NM 87107
(505) 766-3966 FTS 479-3966

U.S. Geological Survey (WRD)*
505 Marquette Avenue, Room 720
Albuquerque, NM 87101
(505) 766-2810 FTS 474-2817

OTHER FEDERAL AGENCIES AND ORGANIZATIONS

Environmental Protection Agency*
Region VI
1201 Elm Street
Dallas, TX 75270
(214) 767-2716 FTS 729-2716

Navajo Tribe*
c/o Division of Resources
P.O. Box 308
Window Rock, AZ 86515
(602) 871-6592

Pueblo of Zia*
General Delivery
San Ysidro, NM 87053
(505) 867-3304

Soil Conservation Service*
424 N. Mesa Verde
Aztec, NM 87410
(505) 334-9437

U.S. Corps of Engineers*
P.O. Box 1580
Albuquerque, NM 87103
(505) 766-2657 FTS 474-2657

USDA, Forest Service*
717 Gold Avenue
Albuquerque, NM 87102
(505) 474-1676 FTS 474-1676

USDA, Forest Service*
District Ranger
Mt. Taylor Ranger District
201 Roosevelt Avenue
Grants, NM 87020
(505) 287-8833

Harwood Foundation Library
(Public)
25 LeDoux
P.O. Box 766
Taos, NM 87571

University/College Libraries

University of New Mexico
General Library
Albuquerque, NM 87131

Navajo Community College Library
Shiprock Branch
P.O. Box 580
Shiprock, AZ 87420

Northern New Mexico Community College
P.O. Box 250
Espanola, NM 87532

New Mexico State University
San Juan Campus
4601 College Blvd.
Farmington, NM 87401

University of New Mexico, Gallup Campus
Learning Resources Center
200 College Road
Gallup, NM 87301

New Mexico State University/Grants
1500 Third Street
Grants, NM 87020

New Mexico Highlands University
Donnelly Library
National Avenue
Las Vegas, NM 87701

College of Santa Fe
Fogelson Memorial Library
St. Michaels Drive
Santa Fe, NM 87501

GEOLOGIC SETTING TECHNICAL REPORT

for the

Environmental Impact Statement on Public Service Company of New Mexico's Proposed New Mexico Generating Station and Possible New Town

Prepared by

Woodward-Clyde Consultants

for the

U.S. Department of the Interior
Bureau of Land Management

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MAPS AND FIGURE

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NEW MEXICO GENERATING STATION

1.0

INTRODUCTION

BACKGROUND

Included in the recent Council on Environmental Quality Regulations (1979) are several important objectives to reduce excessive paperwork in the preparation of environmental impact statements (EISs):

- Discuss only briefly issues other than significant ones.
- Emphasize the portions of the EIS that are useful to decision makers and the public and reduce emphasis on background material.
- Prepare analytic rather than encyclopedic EISs.

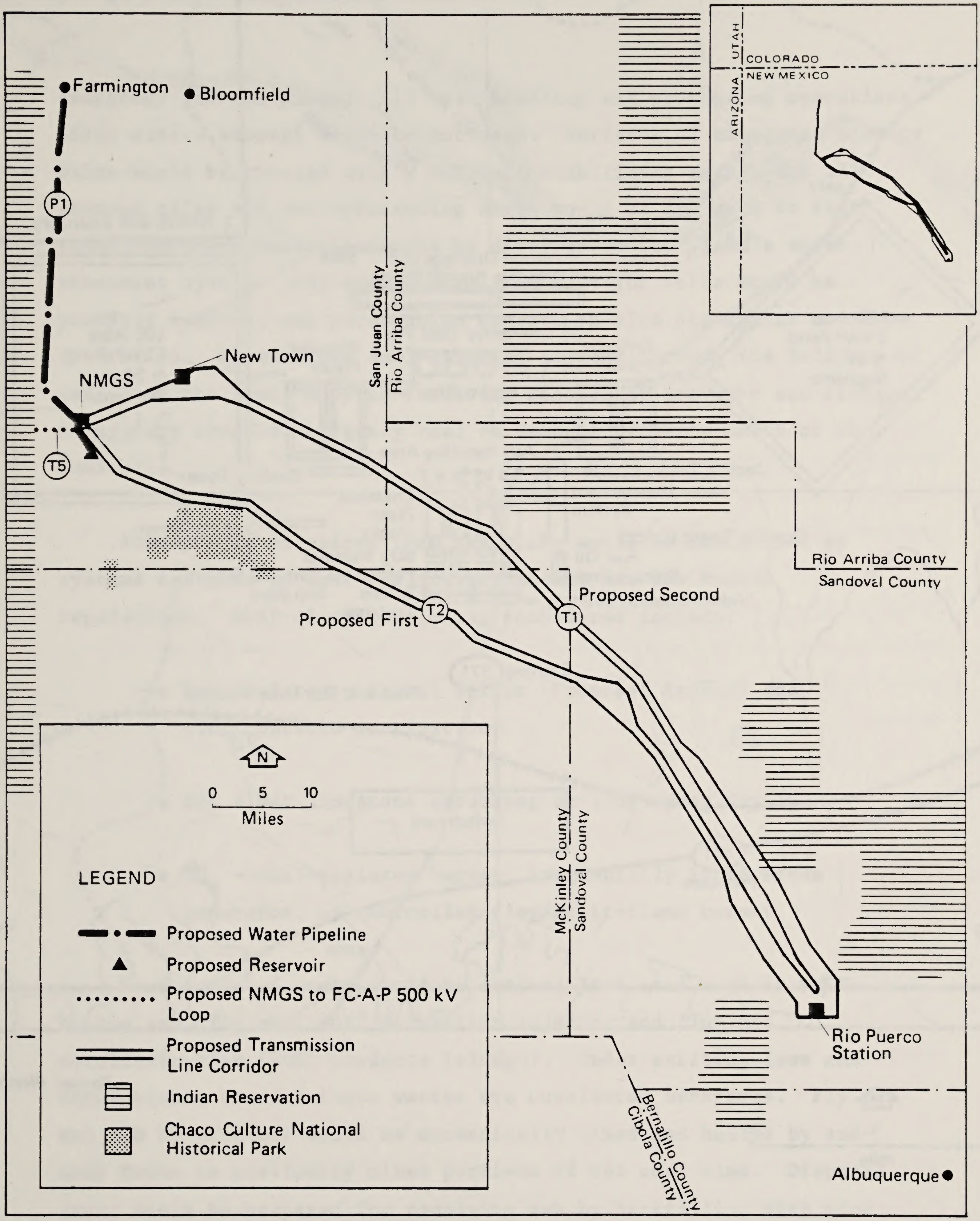
In order to accomplish these objectives and still provide the depth and background required for an analytic impact statement, this technical report has been prepared for the New Mexico Generating Station (NMGS) project. In this report, impacts that were not identified as significant but which are still considered important by the public or technical specialists are analyzed. Background material is provided for those issues and impacts that were considered necessary for the comparison of alternatives. Impacts that were not identified as significant or important by the public and by technical preparers are summarized, and reasons for their elimination from detailed analysis are discussed.

SUMMARY DESCRIPTION OF PROJECT COMPONENTS

Public Service Company of New Mexico (PNM) proposes to construct a 2000-megawatt (MW) coal-fired electric generation plant approximately 35 miles south of Farmington, New Mexico, in San Juan County (Map 1-1). The proposed NMGS, at ultimate development, would have four 500-MW generating units. Each generating unit would include a turbine generator area, coal pulverizer area, boiler area, particulate removal system, SO_2 removal system, and chimney stack. The proposed arrangement of these and other power plant components is shown in Figure 1-1. For the environmental analysis, it was assumed that commercial operation of the first 500-MW unit would begin in 1990 and that other units would start operating during the 1990s.

Coal for NMGS would be acquired through long-term contracts with Sunbelt Mining and Arch Minerals (Proposed Action) or other producers in the San Juan Basin (alternative coal supply). Coal acquired from a joint venture of Sunbelt and Arch Minerals would be supplied from surface mines (referred to as the Bisti mine in this analysis) in the immediate vicinity of the proposed plant site. Coal acquired from other producers in the San Juan Basin would be hauled from mines located as much as 30 miles from the proposed plant site. Coal required for NMGS would average 7.5 million tons per year, or a total of 300 million tons over the 40-year project life.

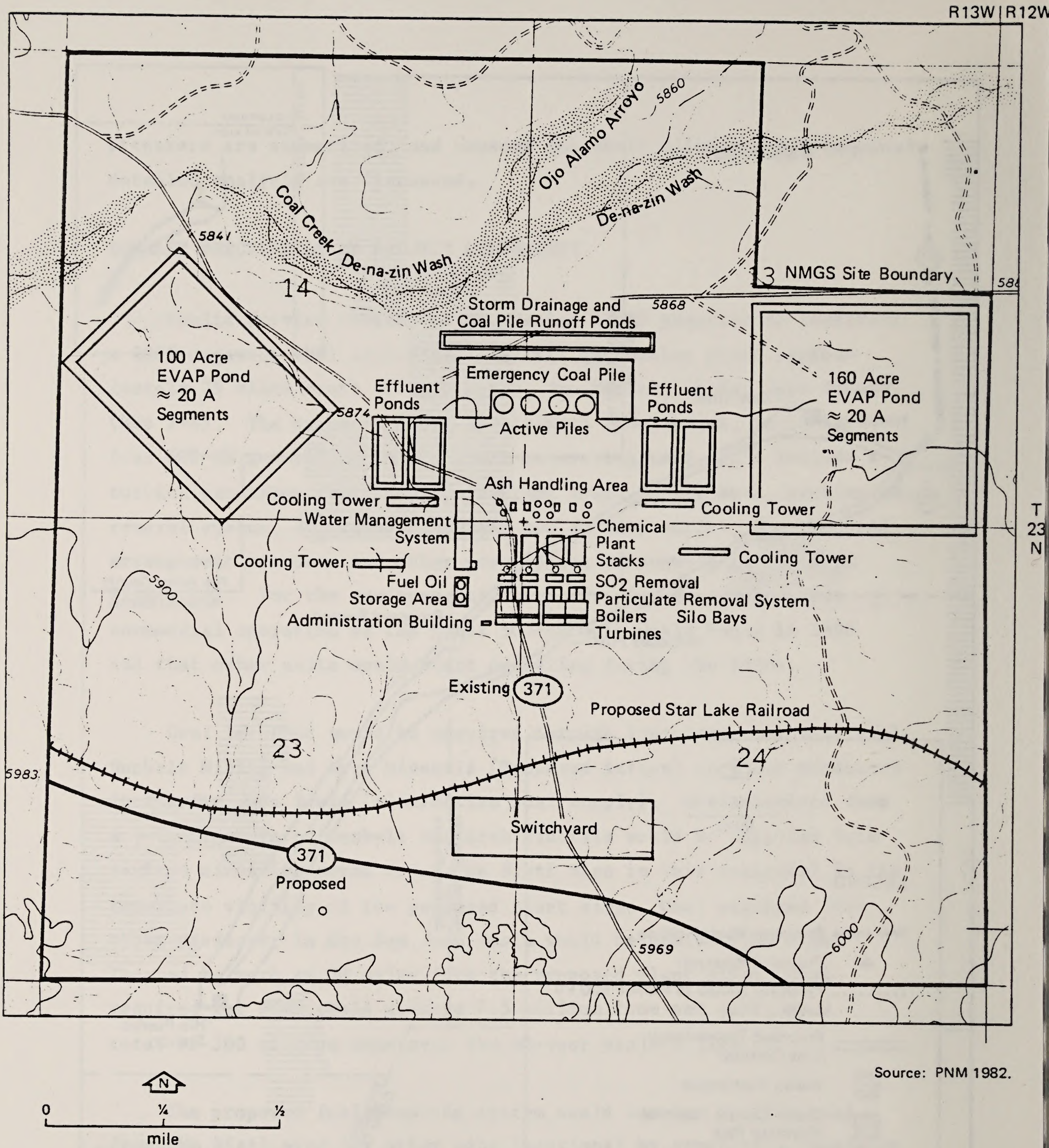
The proposed fuel-handling system would involve hauling coal from the Bisti mine (or other mine locations) by truck to a receiving facility located adjacent to the NMGS site. Coal would then be transferred via conveyor belt from the receiving station to active or



Note: For more information, see the location maps in Appendix G of the EIS.

Source: BLM 1982.

Map 1-1. GENERAL LOCATION OF PROPOSED ACTION



Source: PNM 1982.

Figure 1-1. STATION LAYOUT

emergency storage piles. All coal-handling and processing operations after active storage would be enclosed. Surfaces of emergency storage piles would be treated with a nontoxic stabilizing agent, and all storage piles and coal-processing areas would be designed so that runoff from precipitation would be diverted to the plant's water treatment system. Any coal spills from conveyor belts would be promptly removed, and percolation beneath on-site stockpiles would be controlled. Alternative fuel-handling systems include the delivery of coal from the Bisti mine to receiving station by conveyor and storage of primary crushed emergency coal on Sunbelt property north of the NMGS site.

Atmospheric emissions from the plant would be controlled by systems designed to meet applicable federal and New Mexico regulations. Control systems being considered include:

- Particulates - fabric filter (Proposed Action) and electrostatic precipitator
- SO_2 - wet limestone scrubbing or lime spray drying
- NO_x - dual-register burner, tangentially fired steam generator, or controlled-flow/split-flame burner

Four types of waste would be derived from coal used in NMGS: bottom ash, fly ash, coal pulverizer rejects, and flue gas desulfurization (FGD) products (sludge). Under existing laws and regulations, none of these wastes are considered hazardous. Fly ash and FGD by-products would be mechanically mixed and hauled by end-dump truck to previously mined portions of the coal mine. Disposal areas would be prepared for receiving ash by backfilling with mine overburden. Ash would then be dumped and spread in layers over the mine overburden. After the ash was placed and spread, it would be covered with layers of overburden and surface soil or topsoil and then a vegetative cover would be established. Bottom ash and pulverizer rejects would be collected for disposal in dewatering bins and then hauled by end-dump trucks for disposal into previously mined portions of the coal mine. Procedures for disposal would be the same as for fly ash.

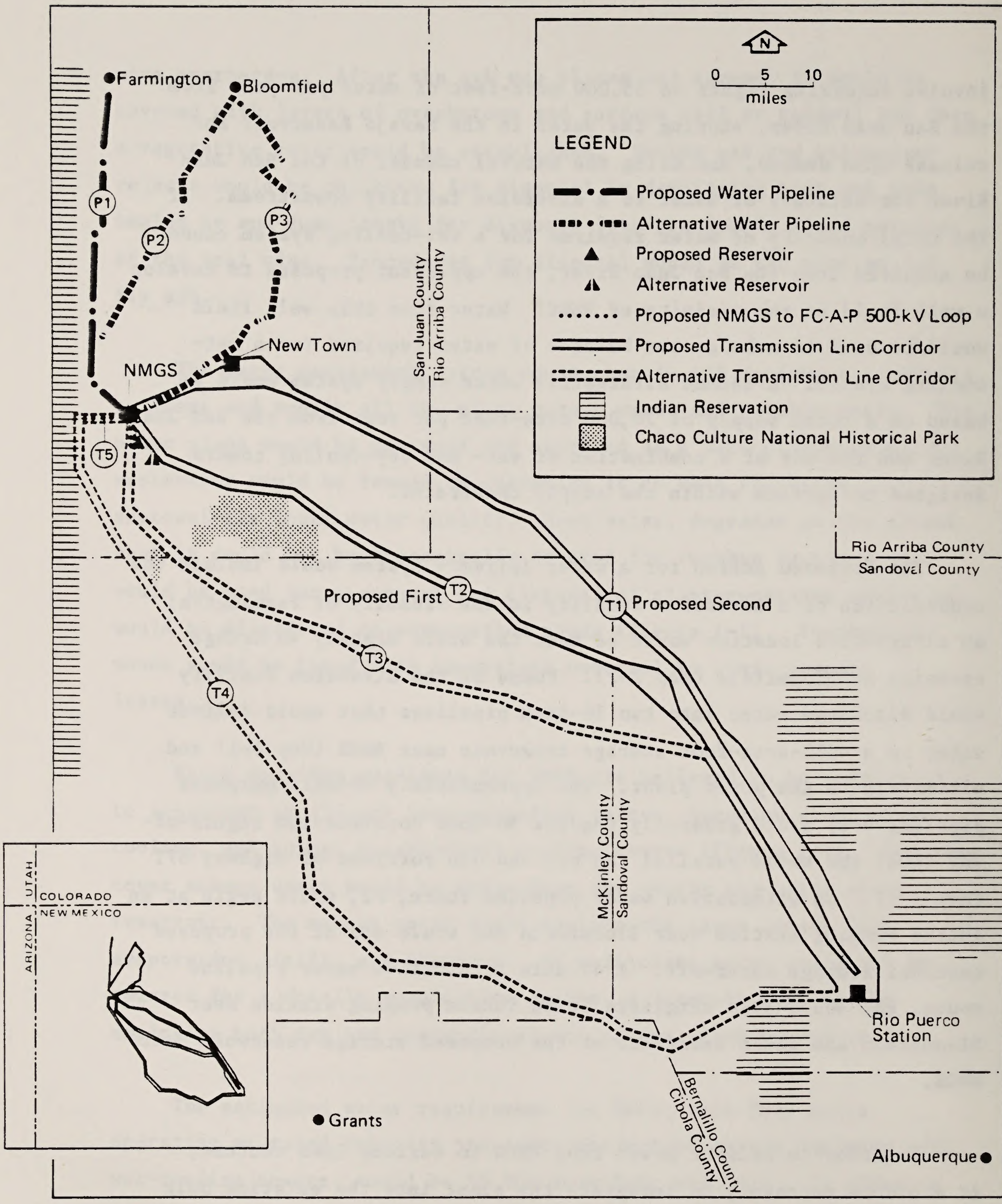
The water management system would contain all equipment necessary to treat and supply all the plant makeup water and potable water. The power plant would be designed and operated as a zero-discharge plant; wastewater would be reused by cascading it to uses requiring successively lower water quality. Used water, degraded to the extent that it could not be economically treated for further in-plant use, would be used for transport and disposal of plant-generated wastes or would be discharged to evaporation ponds (Figure 1-1). Evaporation ponds would be lined with impervious material to limit seepage losses.

Water supplies available for NMGS are believed to be sufficient to construct an all-wet heat-rejection system, based on evaporative cooling, and to use forced-draft cooling towers (Figure 1-1). Cooling-tower makeup water would be drawn from the nearby raw-water storage reservoir. The makeup water would replace the tower losses from evaporation, drift, and blowdown. If sufficient water could not be secured for a totally evaporative system, a water-cooling system employing both dry and conventional wet towers might be required.

The estimated water requirement for NMGS, with four units operating at rated capacity and a heat-rejection system equipped with wet-cooling towers, would be 35,000 acre-feet per year. In order to supply this quantity of water to NMGS, the Proposed Action would involve acquiring rights to 35,000 acre-feet of water per year from the San Juan River, storing the water in the Navajo Reservoir for release upon demand, and using the natural channel of the San Juan River for delivery of water to a diversion facility downstream. If the total quantity of water required for a wet-cooling system cannot be acquired from the San Juan River, the applicant proposes to develop a well field in the vicinity of NMGS. Water from this well field would be used to make up the balance of water required for a wet-cooling system. A second alternative water supply system would be based on a total supply of 20,000 acre-feet per year from the San Juan River and the use of a combination of wet- and dry-cooling towers designed to perform within the supply constraint.

The Proposed Action for a water delivery system would include the construction of a diversion facility in the vicinity of Farmington; an alternative location would be near the State Highway 44 bridge crossing at Bloomfield (Map 1-2). Pumps at the diversion facility would discharge water into two 36-inch pipelines that would deliver water to a 4000-acre-foot storage reservoir near NMGS (Map 1-1) and ultimately to the power plant. The approximately 40-mile proposed pipeline (P1) would generally require 90-foot construction rights-of-way (ROW) and would parallel the new and old portions of Highway 371 (Map 1-1). An alternative water pipeline route, P2, would begin at an intake pumping station near Bloomfield and would end at the proposed terminal storage reservoir. A 49-mile alternative water pipeline route, P3, would also originate at an intake pumping station near Bloomfield and would terminate at the proposed storage reservoir near NMGS.

In order to deliver power from NMGS to various load centers, it would be necessary to integrate the plant into the existing bulk



Note: For more information, see the location maps in Appendix G of the EIS.

Source: BLM 1982.

Map 1-2. GENERAL LOCATION OF ALTERNATIVES INCLUDING THE PROPOSED ACTION transmission systems of PNM and neighboring utilities. Thus the proposed transmission system would consist of a 500-kilovolt (kV) loop linking NMGS with PNM's approved 500-kV Four Corners-Ambrosia-Pajarito (FC-A-P) line, located approximately 5 miles west of NMGS, and two 500-kV lines linking NMGS with the Albuquerque distribution and load center at the proposed Rio Puerco Station (Map 1-1). The NMGS-Albuquerque system would be installed in phases: the 500-kV loop in 1990 with commencement of commercial operation of Unit 1, the first 500-kV line with Unit 2 in 1993, and the second 500-kV line with Unit 4 in 1998.

Four routes are considered technically and economically feasible for construction of the 500-kV transmission system. Route T2 is proposed for the first 500-kV line and route T1 is proposed for the second 500-kV line; routes T3 and T4 are alternatives to the Proposed Action. The total distance traversed would be similar for the two proposed and two alternative corridors: 101 miles (T2), 107 miles (T1), 105 miles (T3), and 126 miles (T4). With the exception of tower sites, the proposed 200-foot ROW could support other compatible land uses, such as grazing. PNM would keep the transmission line ROW closed and would patrol the line by helicopter each month. Lands disturbed by heavy equipment and temporary access roads would be restored to their original condition.

Table 1-1 displays construction work force estimates over time. Construction employment for station facilities would reach peaks of 1515 employees in 1987 and 1530 employees in 1992. Operations employment at station facilities would increase steadily, from 30 employees in 1989 to 900 employees in 1999 when all four units are expected to be on-line.

Table 1-1. NMGS CONSTRUCTION AND OPERATION EMPLOYMENT

			NMGS												
			Construction					Operation							
Year	Intake Pipeline and Reservoir	500-kV Transmission Line	Unit 1	Unit 2	Unit 3	Unit 4	Total	Unit 1	Unit 2	Unit 3	Unit 4	Total	Total Employment	Annual Change
1985	—	—	85	—	—	—	85	—	—	—	—	—	85	+85
1986	—	—	800	—	—	—	800	—	—	—	—	—	800	+715
1987	115	—	1515	—	—	—	1630	—	—	—	—	—	1630	+830
1988	295	104	1180	30	—	—	1505	—	—	—	—	—	1505	-125
1989	—	—	360	450	—	—	914	30	—	—	—	30	944	-560
1990	—	—	100	940	40	—	1080	200	—	—	—	200	1280	+336
1991	—	—	—	750	570	—	1320	250	—	—	—	250	1570	+290
1992	—	—	—	270	1260	—	1530	250	24	—	—	274	1804	+234
1993	—	—	—	105	955	30	1090	250	160	—	—	410	1500	-304
1994	—	78	—	—	325	435	838	250	200	30	—	480	1318	-182
1995	—	—	—	—	90	940	1030	250	200	200	—	650	1680	+362
1996	—	—	—	—	—	775	775	250	200	250	—	700	1475	-205
1997	—	—	—	—	—	255	255	250	200	250	24	724	979	-496
1998	—	—	—	—	—	95	95	250	200	250	160	860	955	-24
1999	—	—	—	—	—	—	0	250	200	250	200	900	900	-55

Source: PNM 1980, unpublished data.

According to PNM (unpublished data, 1980), estimated construction employment skill requirements would be as follows:

Skill	Percent of Total Construction Work Force
Boilermakers	9.4
Pipefitters	14.2
Electricians	14.4
Carpenters	5.6
Ironworkers	10.0
Operators	10.0
Laborers	9.0
Teamsters	4.1
Cement masons	0.8
Millwrights	3.3
Insulators	4.0
Sheetmetal workers	1.1
Painters	1.2
Others	0.5
Supervision	12.4

The above estimates are averaged for construction of all four units.

SAN JUAN BASIN ACTION PLAN OVERVIEW AND RELATIONSHIP OF THE NMGS EIS TO ACTIONS INCLUDED IN THE PLAN

The proposed site for the NMGS is located in the San Juan Basin of northwestern New Mexico. The Bureau of Land Management (BLM) is responsible for the management of much of the land and mineral resources in this area, and currently has six separate but interrelated proposals under consideration within the basin. In order to respond to these, the BLM has developed a San Juan Basin Action Plan (SJBAP). This plan provides for the organizational arrangements whereby the environmental analyses and decision making can be implemented in a timely and efficient manner. The plan describes the process for preparation of three site-specific EISs (including the NMGS EIS) and three Environmental Assessments (EAs):

- Coal Preference Right Lease Applications (EA)
- San Juan River Regional Coal Leasing (EIS)
- Wilderness Study Areas (WSAs) (EIS)
- New Mexico Generating Station (EIS)
- Ute Mountain Land Exchange (EA)
- Bisti Coal Lease Exchange (EA)

In addition to these documents, the action plan provides for the preparation of a Cumulative Overview (CO). The CO is intended to focus on the cumulative impacts that would result from the proposed actions analyzed in the EISs and EAs listed above and therefore to facilitate public review and decision making. As a result of this organization, the impact analysis in the NMGS EIS and technical background reports concentrates on the impacts expected to result from the specific NMGS components proposed. The cumulative impacts expected to result from the proposed NMGS, in addition to the cumulative impacts of other proposals to be developed in the same time period, are described in the CO.

BASELINE CONDITIONS ASSUMED FOR THE NMGS TECHNICAL REPORT IMPACT ANALYSES

The site-specific impact analysis for this technical report was based on the affected environment and available resources that would be existing at the time of construction and operation of the NMGS facility. Since construction at the NMGS facility would not begin until 1985, certain assumptions regarding project development in the San Juan Basin were necessary. Two levels of project development were considered, along with criteria for each, in developing a status for the various non-SJBAP actions proposed for the San Juan Basin area.

- Baseline 1 - The projects considered in this level of development are those that have approval and are to be built or under construction in 1985. This level represents the projected existing environment without the proposals included in the SJBAP.

- Baseline 2 - The projects considered in this level are in some phase of the application stage. In this level, Baseline 1 projects are added to any projects in Baseline 2 along with any revision in resource production or uses (e.g., coal).

Where differences in Baselines 1 and 2 affect the results of impact analyses, discussion is provided. If no differences are identified, it should be assumed that consideration of the two different baselines did not alter the impact analyses.

A complete list of projects and comprehensive location maps for Baselines 1 and 2 are provided in Appendix C of the NMGS EIS.

ORGANIZATION OF THE REPORT

Section 2.0 of this technical report describes the assumptions and methodological approach used in the assessment of potential impacts of the Proposed Action on the affected environment. In addition, Section 2.0 contains a definition of the study area and identification of data sources.

Section 3.0, Affected Environment, contains baseline data on existing conditions in the study area, as well as projections of future conditions without the Proposed Action. Information on historical trends is presented where it is useful in providing a basis for predicting most likely future trends. The description of projected future trends takes into consideration the changes in the environment that are expected to occur as a result of the projects identified in Baseline 1. This provides a reasonable estimate of the future existing environment against which the potential impacts of the Proposed Action and alternatives can be assessed.

Section 4.0 describes the potential effects of implementing the Proposed Action and alternatives. Impacts identified are measured against indicators of significance in order to estimate the importance of the impact to the affected human environment. (Potential impacts associated with alternatives to the Proposed Action are compared in Section 9.0.)

In Section 5.0, mitigation measures are suggested. These measures would help to alleviate the potentially significant adverse impacts or enhance the beneficial impacts identified in the Section 4.0 analysis. Those potentially adverse impacts for which no appropriate mitigation measures have been suggested are discussed in Section 6.0 as "unavoidable adverse impacts."

GEOLOGIC SETTING

The proposed New Mexico Generating Station and most of the related project features would be located within a structural geologic feature known as the San Juan Basin. The sedimentary accumulation within this basin is as much as 15,000 feet thick. The basin is surrounded by uplands created by tectonic warping or volcanic activity. As a result of tectonic, volcanic, and erosional processes, the elevation difference between the center of the basin and the rim is as much as 3400 feet. Badland topography with steep-sided buttes and mesas has been produced by water erosion, and dune fields produced by wind action cover parts of the area. The San Juan Basin is noted for its seismic stability, but it is bounded on the south and east by belts of somewhat greater seismic activity. Those project features crossing the eastern boundary of the basin would be subjected to a potential for surface fault rupture.

This report is directed toward describing the potential geologic and seismic hazards that might be found in the various geologic environments. The regional geologic information that is necessary to an understanding of the geologic hazards assessment has been thoroughly described in reports prepared by PNM; PNM's description of the geologic setting is presented verbatim in Appendix A of this report. Some additional site-specific information is presented in the text, and various original data sources are cited for the benefit of those who may want more information on the geology of the region. For the purposes of this report, the project region is defined as the aggregate of the areas underlying or immediately adjacent to the individual project components.

2.0
FRAMEWORK FOR ANALYSIS

2.1 GEOGRAPHIC AREA OF INFLUENCE

Direct Impacts

The geographic area of influence for direct impacts is made up of the actual areas to be occupied by the individual project components, and of contiguous areas for a distance of 1/4 mile.

Indirect Impacts

The geographic area of influence for indirect impacts would include the entire Four Corners area, as the limestone source for the project probably will be somewhere within that broad region. As the source has not been selected, no analysis has been performed. However, it is anticipated that the geologic issues would be slope stability and accelerated erosion.

2.2 INDICATORS OF IMPACT SIGNIFICANCE

The following conditions were considered to be indicators of impact significance:

1. Disturbance or destruction of unique geologic features.

2. Disturbance or destruction of locations of unusual value for the purpose of scientific study and interpretation.

3. Geologic conditions potentially damaging to project components and not susceptible to mitigation by means of customary engineering design procedures.

2.3 METHODS FOR DATA COLLECTION

Data Collection Procedures

The data collection steps that were followed are enumerated below:

1. Information in WCC's files on the PNM site selection study was reviewed.

2. Geologic map indices were consulted.

3. A GEOREF search was run.

4. The U.S. Geological Survey library card catalogue listings for New Mexico were checked.

5. Publications pertinent to the project area were obtained from various sources and were studied.

6. An aerial and ground reconnaissance of the project area was performed.

Verification Methods

The information gained through the steps listed above was verified and supplemented by means of contacts with federal and state agencies and institutions, including the following:

1. Bureau of Land Management - Albuquerque, Santa Fe, and Farmington

2. Bureau of Mines and Mineral Resources, Socorro

3. State Department of Highways, Santa Fe

4. University of New Mexico, Albuquerque

Identification of Data Gaps and Means of Resolution

Data gaps were identified by means of WCC's internal review process and though BLM review of the preliminary draft report. The gaps thus identified were resolved by further literature review and additional agency contacts.

2.4 INTERRELATIONSHIPS

Interrelationships of geologic conditions with other environmental disciplines were examined by means of direct communications with other technical discipline leaders, both individually and in group meetings. During one such meeting, the following interrelationships with geology were suggested:

1. Emissions

   Coal beds, if not promptly covered following exposure by excavation, may ignite spontaneously, producing gaseous combustion products.

2. Minerals

   Excavation for the project features may enhance opportunities for collection of mineral specimens.

3.0
AFFECTED ENVIRONMENT

3.1 OVERVIEW

Most of the proposed project would be located within the San Juan Basin, which is a structural depression underlain by Tertiary, Cretaceous, and older sedimentary rocks. A thin veneer of Late Quaternary deposits covers the bedrock units over much of the area. Volcanic necks and potentially active faults border the basin on the east. The surface of the San Juan Basin has been strongly eroded, creating badlands, buttes, mesas, and dissected plateaus. The interior of the San Juan Basin is relatively inactive tectonically, but may be subject to the effects of relatively distant earthquakes that could cause local bedrock accelerations up to about 0.2g.

Landslide blocks border many of the buttes, mesas, and plateaus, and deposits of baked shale produced by spontaneous combustion of coal are widespread. Soils with a variety of engineering defects are present in the general region, and may be encountered at some of the site locations.

3.2 TOPOGRAPHY

Regional Topography

The topography of the region has been well described in a paper by Gutierrez (1976), from which the following narrative is taken. The

San Juan Basin is one of the several large basins that are interspersed between the ranges of the Rocky Mountains. The basin comprises about 25,000 square miles of the eastern section of the Colorado Plateau, containing portions of the Navajo and Datil subdivisions of the plateau as described by Fenneman (1931).

The boundaries of the basin consist of three structural categories (Kelley 1950, 1951)--uplifts, structural platforms, and monoclines--that define the basin as a geographic entity. To the north and northwest, the basin is bounded by igneous intrusions such as the San Juan, Ute, and La Plata mountains of Colorado and Utah. To the northeast it is bounded by broad structural arches and the clearly defined Nacimiento uplift. To the southeast and south it is bounded by a structural rise and the Zuni uplift. To the west, the Defiance uplift and monocline separate the basin from the rest of the Colorado Plateau. The central portion is the floor of the basin, characterized by a gently dipping land surface and little regional topographic relief.

The major regional topographical features of the basin are controlled by geologic structures of the basin or isolated remnants of volcanic activity. Three large monoclines in the basin comprise the major topographical features within the basin. They are reflected as long hills rising above the surrounding landscape with a gently rising limb on one side and a steeply dipping limb on the opposite side. A classic example of this topography is the Hogback monocline west of Farmington. The best example of topography created by remnants of volcanic activity is Shiprock, an old volcanic plug with radial dikes leading to it. Mt. Taylor also represents an abandoned volcanic cone and associated uplift. The structural platforms bounding the basin on the southeast and northwest sides are characterized by a pronounced slope dipping towards the central basin and some surface expressions of small anticlines as hills paralleling the structural contour of the basin. The central basin, lacking any pronounced regional topographic relief, is generally a gently dipping to flat surface, broken only by the development of drainage patterns.

In addition to the major regional topographic features of the basin, the most ubiquitous local expressions of topography result from the differential erosion and drainage development of perennial and ephemeral streams throughout the basin. Important controls affecting this development are slope and lithology. Generally, in areas where sediment is coarse grained, flat, broad sandy washes tend to predominate; whereas in areas where the sediment supply is very fine grained, more deeply incised arroyos and even badland-type topography result.

The San Juan Basin is drained by two major watersheds separated by the continental divide: the San Juan River Basin, flowing northwest to the Colorado, and the Rio Puerco Basin, flowing southeast to the Rio Grande. Most of the study area is drained by perennial and ephemeral tributaries to the San Juan. The perennial streams in the basin include the Los Piños, Animas, La Plata, Navajo, Piedra, and San Juan rivers. The major ephemeral drainages are the Chaco River, Rio Puerco, La Jara Creek, Gobernador Canyon, Canon Largo, and their tributaries. Badland topography created by water erosion of fine-grained sedimentary rocks gives parts of the basin a very distinctive look, often characterized by abrupt relief and lack of vegetation. The best examples of this type of topography can be found in the Bisti Badlands and in Kutz Canyon near Bloomfield. Near areas where lava has been erupted, flat-topped mesas are often developed. These features are often very distinctive, comprised of red-brown sedimentary rocks capped by a relatively thin layer of black basalt, often having vertical or steeply sloping sides.

To summarize the topography of the study area: the large-scale regional features, such as monoclines, mountains, etc., occur around the periphery of the basin and are controlled by geologic structures; more localized relief, resulting from erosion and growth of drainages, varies in degree of development but is present throughout the entire basin.

Site-Specific Topography

The proposed NMGS plant site is situated within the southwestern part of the San Juan Basin. When viewed from a regional scale, this part of the basin is a nearly featureless, gently dipping land surface. The site-specific view of the topography encountered in the NMGS project area reveals a more complex topographic setting characterized by mesas and canyon lands. The following is a detailed description of the topography encountered by the routes of the water pipelines and transmission line corridors. The areas of potential slope instability are summarized in tabular form on Table 3-1.

Water Pipeline P1. Water pipeline route P1 traverses 37 miles, from near Farmington to the NMGS plant site, with 39.7 miles of pipe. The proposed pipeline route is nearly a straight line that runs north to south.

P1 begins along the San Juan River at proposed water intake station No. 4. An 1100-foot-long tunnel is proposed to bring the pipeline up from river level, approximately 5210 feet above sea level, to the top of the mesa, at an elevation of 5680 feet, a rise of 470 feet through a nearly vertical face.

The next 4500 feet extends from the end of the tunnel to Highway 371 and trends N25°E over the mesa top, rising 260 feet from the edge of the mesa to the center.

Table 3-1. AREAS OF POTENTIAL SLOPE INSTABILITY TRAVERSED BY NMGS WATER PIPELINES AND TRANSMISSION LINE CORRIDORS

Water Supply System			Transmission Lines			
P1	P2	P3	T1	T2	T3	T4
MP 3 Head Canyon tributary	MP 3-6: Badlands	MP 15-16: Kutz Canyon rim	MP 23: Kimbeto Wash	MP 0-1 Badlands	MP 3-5: Chaco River tributary canyons	MP 0-7: De-na-zin Wash
	MP 13-15: Cedar and Gallegos Canyons	MP 34-35: De-na-zin Wash rim	MP 28: Betonnie Tsosie Wash	MP 4-10: Tributaries to Chaco River	MP 49: Edge of Chaco Mesa	MP 10-12: Chaco River Canyon
			MP 31-33: Escavada Wash	MP 55-60: Base of Torreon Wash Canyon	MP 55: Edge of Chaco Mesa	MP 13-16: Badlands
			MP 37: Canada Alemita	MP 60-61: Base of Black Mountain	MP 58-63: Edge of Chaco Mesa	MP 62-85: Base of San Mateo Mesa
			MP 40-41: Canada Alamos	MP 68: San Luis Mesa	MP 72: Torreon Wash	MP 85-86: Mesa Chivato
			MP 45-46 & 48-49: Canada Corrales	MP 74-75: Rio Puerco River	MP 73: Arroyo Piedra	MP 92: Base of Cerro Chivato
			MP 76: Rio Puerco Valley	MP 77: Base of Cabezon Peak	MP 73-76: Steep canyons in northern edge San Luis Mesa	MP 105: Agua Salada
				MP 80-85: Base of Mesa Prieta	MP 80-85: Base of Mesa Prieta	MP 107-111: Mesa Cocina and Canada de los Alamos
				MP 91-93: Collier Draw	MP 91-93: Collier Draw	MP 114: Unnamed mesa
						MP 116: Rio Puerco
						MP 122: San Felipe Mesa
						MP 126: Unnamed mesa

Note: MP = milepost along pipeline or transmission line route.

The route of P1 is then coincident with Highway 371 for the next 1280 feet, between mile markers 1 and 3.5. This section of the route traverses the gently undulating mesa top. Just south of mile 3 the route passes over a steep-walled tributary canyon of Head Canyon for a distance of 500 feet.

From mile 3.5 the proposed pipeline route leaves the course of Highway 371 and trends S5°W to mile 14.9, traversing the very gently undulating mesa top.

At mile 14.9 the pipeline route jogs approximately 1 mile to the west, skirting the edge of the mesa. The mesa edge in this location is characterized by badlands topography, which borders the Bisti oil field. The jog in the route enables the pipeline to continue along the top of the gently sloping Moncisco Mesa. The pipeline route follows the mesa down onto the flat plain occupied by the Navajo Indian reservation. The pipeline is approximately 1 mile east of the reservation boundary. The slope of this plain is no more than 1 degree.

At mile 29.6, P1 is joined by proposed pipeline route P2 and they continue south on this flat plain. Mile 3.1 marks a change in direction as the pipeline route bends around to a southeasterly course through the NMGS plant site, toward the proposed water reservoir site. The pipeline remains on very flat ground until mile 35. Mile 35 marks the descent into the De-na-zin Wash. The slope into the wash is very gentle, approximately 4 degrees, and is approximately 1 mile in length from top to stream bed. The pipeline goes up the south side of the wash over a slightly steeper slope, climbing 400 feet over a distance of 4000 feet, approximately 6 degrees. This route is over alluvial fans and skirts the edge of badlands-type topography present just to the south of the pipeline route. The proposed pipeline traverses several alluvial fans rising in elevation no more than 80 feet until reaching the end of the pipeline at the proposed water reservoir site at Dog Eye Pond.

Water Pipeline P2. Water pipeline route P2 is 42.2 miles long and runs from near Bloomfield in a southwesterly direction to its junction and subsequent coincidence with the P1 route.

Pipeline alternative P2 begins in the San Juan River, just south of Bloomfield, at an alternative water intake station. The first mile of P2 traverses river terraces of both the San Juan River proper and Kutz Canyon. The terraces are generally flat with a slight 3 degree dip toward the river.

From mile 2.6 to 5.7 the pipeline proceeds through an area of extensive badlands topography. While the overall slope of the area is very gentle (approximately 2 degrees), it is highly dissected and the topography is irregular. One major canyon, Horn Canyon, is crossed by the pipeline at mile 5. The Canyon is 1500 feet wide and 120 feet deep at the crossing.

Beginning at mile 5.7 the pipeline obliquely crosses a north-to-northwest-facing 15 degree slope. The trend of the pipeline is to the southwest, and remains level, losing only 150 feet of elevation in 5.5. miles (approximately 0.3 degree).

Gallegos Canyon, and its tributary, Cedar Canyon, are crossed by the pipeline route from mile 13.3 to 15. Cedar Canyon is encountered first; it is 1200 feet wide and 120 feet deep. On the northern, gently sloping back of Gallegos Canyon, the pipeline jogs 2 miles to the west, from mile 14 to 16. From mile 14 to 15 the pipeline climbs up the steep southern bank of Gallegos Canyon.

From mile 16, the pipeline continues with a southwest trend across the Bisti oil field, passes 1 mile to the west of Black Hill across a gently undulating surface, remaining between approximately 5900 and 6200 feet above sea level. P2 joins P1 at mile 32.5 and follows the same course from that point until its termination at the proposed water reservoir site, Dog Eye Pond.

Water Pipeline P3. Water pipeline route P3 is 48.5 miles long, beginning near the town of Bloomfield and running a jagged but generally southwest-trending course to its termination point at the proposed water reservoir site, Dog Eye Pond.

Pipeline alternative P3 begins as a branch of P2, approximately 1 mile south of P2's origin at the San Juan River. P3 branches out and trends approximately southeast, running midline on the top of the mesa that separates Kutz and Armenta canyons. The mesa top is level, dipping only 1 degree.

At mile 9 the pipeline jogs 2 miles southwest to the bottom of the East Fork of Kutz Canyon, mile 11. The slope down into the canyon is gentle and the pipeline drops from 6200 feet at mile 9 to 5920 feet at the canyon bottom, mile 11.

The pipeline continues on its southeast trend from mile 11 to mile 16, on top of the mesa that forms the southwest rim of the East Fork of Kutz Canyon. Mile 16 marks an abrupt change in topography as the pipeline follows the mesa up to and over the rim of a large table-land plateau that has a gently undulating slope, dipping 1 degree to the west. The pipeline trends southwest, oblique to the dip of the plateau, until mile 20.3 where the pipeline jogs to the southeast for 1 mile, coincident with State Highway 44. At mile 21.3 the pipeline turns and runs directly south, traversing broad hills and ravines, varying in elevation no more than 60 feet above or below 6600 feet above sea level. An exception to this occurs at mile 25, where the pipeline route crosses Gallegos Canyon. It is a broad gentle slope into and out of the canyon, but it drops 140 feet from the plateau elevation to the canyon bottom.

The pipeline continues on a southerly course to mile 28.2, where it turns abruptly to the southwest, through a 2-mile section of the Bisti oil field. This section of the Bisti oil field dips 1 degree to the north. The pipeline route climbs up to the mesa that forms the southern boundary of the Bisti oil field and, further to the west, from mile 32 to 35, the southern rim of the De-na-zin Wash watershed. The mesa dips toward the southwest with a gentle 1 degree slope. The pipeline route continues on top of this mesa until mile 37, where the mesa widens and becomes Split Lip Flats. This section of the route has a gradual but constant loss in elevation from 6700 feet at mile 33 to 6100 feet at mile 40, a slope of less than 1 degree.

The pipeline continues its gradual elevation loss through Split Lip Flats until mile 44.8 where the line turns sharply to the south-southwest, passing just to the east of Tanner Lake, up a broad northward-dipping alluvial fan slope to the proposed water reservoir site, Dog Eye Pond.

<u>Transmission Line Corridor T1</u>. The proposed second transmission line corridor, T1, originates at the NMGS and runs on a generally southeasterly course to the Rio Puerco station, a total of 105 miles. It is the most northerly of the proposed transmission line corridors.

The T1 corridor is approximately 6000 feet wide at its origination point at the NMGS, and it starts off with a northeasterly trend over Split Lip Flats, encompassing Tanner Lake. T1 follows

Split Lip Flats, a gentle, less than 1 degree, west-dipping slope to mile 9, where the corridor begins to widen to its maximum width of 16,000 feet just to the east of the new town site. Split Lip Flats steepen slightly at their eastern terminus to a slope of 2 degrees; this slope angle is encountered from mile 9 to 12. At mile 12 the topography changes from an even slope to a broad, gently undulating plateau.

At mile 14 the corridor changes orientation such that it is trending southeast and has narrowed down to its original 6000-foot width. From mile 14 the corridor obliquely traverses a series of mesas and washes. The mesas are flat-topped, with 100-200 feet of relief from the creek bottoms. The major washes that are crossed are the Kimbeto Wash at 23 miles, the Betonnie Tsosie Wash at 28 miles, the Escavada Wash at 33 miles, the Cañada Alemita Wash at 37 miles, the Cañada Alamos at 40-41, and Cañada Corrales at 45-46 miles. This course involves a gradual climb in elevation such that at mile 50 it crosses the continental divide, an elevation of 6840 feet above sea level.

The eastern side of the continental divide in this locality is less steep than the western side. From mile 50 to 60 the corridor keeps to low passages such as Encino Wash, and avoids the mesas such as Ojo Encino Mesa and Eagle Mesa. From mile 60 to 76 the corridor route encounters topography similar to that on the western continental divide, that of mesas and intervening washes with a gradual decrease in elevation as the corridor heads towards the south. The washes are wider, with very gentle slopes. The mesas are dissected to a greater degree than on the western side of the continental divide.

At mile 76 the corridor T1 begins to descend into the valley of the Rio Puerco. The descent begins over the precipitous, vertical face of the San Luis Mesa. The vertical slope is 100 feet high; below that, the slope levels and gradually leads down to the river. Running down the center of the corridor (which is 1000 feet wide at this point) is a tributary to the Rio Puerco, Arroyo Balcon. The maximum elevation of San Luis Mesa is 6540 feet above sea level, the elevation of the river is 6160, and the distance from top to bottom is approximately 1 mile.

The southeastern side of the Rio Puerco Valley rises only 140 feet from the river as a low flat slope up to a long, low flat-topped ridge. The corridor runs over this ridge and straddles the Alamo Arroyo valley to the southeast as it goes into Ojo Del Espiritu Santo.

Miles 85 to 90 transect a partially dissected pediment surface; the overall topographic expression for the most part is gentle undulation. An abrupt change in topographic expression begins at mile 90. There are mesas with vertical upper slopes and badlands-type topography along the lower slopes with relief from mesa top to canyon bottom of 300 feet. This steep-sided mesa topography is present until mile 95, when the gently undulating, partially dissected pediment surface is once more encountered, and continues to the termination point at Rio Puerco station.

<u>Transmission Line Corridor T2</u>. The proposed first transmission line corridor, T2, originates at the NMGS and runs for 102 miles to the Rio Puerco station.

Transmission line corridor T2 starts out at the NMGS plant site in a small section (less than 1 mile) of badlands topography. Once past the badlands, the corridor trends obliquely across a partially dissected pediment surface. Occasional deeper drainages with steep sides are crossed, such as the Ah-shi-sle-pah Wash at mile 10. Large drainages with very broad, gently sloping sides are also present along the corridor route, such as Escavada Wash at mile 14, Kimbeto Wash at mile 16, and Bentonnie Tsosie Wash at mile 17.

Gradually the corridor for the transmission line climbs in elevation, and at mile 45 it crosses the continental divide. The topography on the eastern side of the divide is very similar to that of the western side: a gently undulating, partially dissected pediment surface with a gradual but consistent loss of elevation toward the southeast.

At mile 55 a change in topography is encountered. The transmission line corridor straddles the Torreon Wash; the boundaries of the corridor run near the rims of the steep-sided mesas to the north and south of the wash. Mile 60 marks the deflection of the Torreon Wash to the south by Black Mountain; the corridor boundaries widen to take advantage of the low valleys to the north and south of Black Mountain. From Black Mountain south to mile 68, the transmission line corridor transects a low-lying, partially dissected pediment, some incipient badlands topography, and wide, broad, shallow river canyons.

At mile 68 the transmission corridor begins to climb onto San Luis Mesa. The western edge of the mesa is a broad gradual slope up alluvial fan surfaces. The corridor goes over the generally flat top of the San Luis Mesa and down the steep eastern edge into the Rio Puerco River valley at mile 74.

The eastern side of the Rio Puerco River valley is a broad, gentle slope up to a long, low, flat-topped hill. The eastern side of the hill is the boundary of the extremely dissected watershed of the

Ojo del Espiritu Santo. The corridor stays within this watershed along the base of the high mesas, such as Cabezon Peak and Mesa Prieta. Low-lying, broad, gently undulating topography of partially dissected pediment surfaces--with occasional deeper steep-sided canyons such as Collier Draw, mile 91--is predominant from mile 90 to the corridor termination at the Rio Puerco station.

Transmission Line Corridor T3. Transmission line corridor alternative T3 originates at the NMGS and runs southeasterly en route to the Rio Puerco station, its termination point, approximately 107 miles.

Transmission line corridor 3 runs directly south of the NMGS for a distance of 7 miles over a mesa with steep river canyons, the tributaries to the Chaco River at mileposts 3, 4, 5, and 6. The route crosses the Tsaya Canyon tributary to the Chaco River at mile 6 and crosses the Chaco River itself at mile 7.

At mile 9 the corridor turns and takes on a southeasterly trend. The eastern boundary of the corridor is in Juans Lake at this point. The topography of this section is one of small flat mesas (approximately one-half mile across) dotted between wide, flat, intermittent stream valleys. The corridor crosses Rock Point Valley at mile 12 and Kim-me-ni-oli Valley at mile 14. The route is just south of the Chaco Culture National Historical Park beginning at mile 16. The topography remains much the same: broad, flat, intermittent stream valleys with interspersed small mesa remnants with a very gradual increase in elevation from 6100 feet at mile 10 to 6500 feet at mile 30, a slope of 0.2 degree.

The corridor crosses the continental divide at mile 46, but the character of the topography does not change and the slope is just as gentle, dipping to the east. The northern boundary of the corridor skirts the base of the near vertical southern edge of Chaco Mesa at MP 49, 55, and 58 to 63. The southeast trend of the corridor takes it south of the Chaco Mesa, to remain on the very flat, low-lying topography of the broad gentle valleys. Steep-sided Torreon Wash is crossed by the corridor at MP 72; and its tributary, Arroyo Piedra, is crossed at MP 73. The corridor trends obliquely across steep-sided tributary canyons to the Arroyo Piedra as it approaches the top of the San Luis Mesa from MP 73-76. The relief encountered in the steep tributary canyons is as much as 300 feet.

Mile 76 marks the confluence of T3 with T2. Their courses are coincident from this point to their termination point at the Rio Puerco station.

Transmission Line Corridor T4. Transmission line corridor alternative T4 is the most southerly of the transmission line corridor routes; it runs 127 miles from the NMGS to the Rio Puerco station.

T4 runs directly west from its origination point at NMGS for a distance of almost 6 miles. It generally follows the course of the De-na-zin Wash, a steep-sided, flat-bottomed valley with mesas rising 200 feet to either side.

At mile 5.8 the route of the corridor turns and goes directly to the south for a distance of 6.4 miles. The topography of this south-trending section is varied. Beginning at the De-na-zin Wash MP 7, the corridor runs up the mesa that forms its southern embankment, which is a gentle slope on the south side of the wash. It then runs over the top and down the southern side of this mesa, into the Chaco River, a wide, flat valley with gentle banks at this locality, MP 9.

To the south of the Chaco River is a section of well-developed badlands topography.

Mile 12.2 marks the change in bearing of the corridor route from south to southeast, but it continues in badlands topography to mile 16. Mile 16 begins a topographic setting vastly different from the previous badlands section.

This topographic section is characterized by very wide, flat valleys with intermittent streams, with occasional small mesas or erosional remnants rising above this essentially flat plain. This plain has a very gentle slope (less than 0.5 degree) that dips to the west as the corridor heads to the continental divide.

On the eastern side of the continental divide, MP 55, the topography is much the same as on the western side. The corridor trends directly south, starting at the continental divide to MP 62, where the southeast trend is continued. This deviation in the general southeast trend is taken to direct the corridor south of the very steep and high San Mateo Mesa. The corridor transects the alluvial fans off the San Mateo Mesa, some of which are quite steep sided, with 300 feet of relief from the top of the fan surfaces to the bottom of the intervening streams from MP 62 to 85.

Once past the San Mateo Mesa at approximately mile 85, the corridor climbs atop the moderate slopes and flat top of the Mesa Chivato. The mesa top is studded with occasional steep erosional remnants, such as Cerro Chivato at mile 92.

From this point (Mesa Chivato) to the end of this line, the corridor route obliquely transects a series of relatively north-northwest-trending mesas and intervening steep-sided, wide flat-bottomed valleys such as Agua Salada at MP 105, Mesa Cocina at MP 108, Rio Puerco at MP 116, and San Felipe Mesa at MP 122. Other steep but unnamed topographic features are encountered at MP 114 and 126. The corridor terminates at the Rio Puerco Station at MP 127.

3.3 REGIONAL GEOLOGY

Previous Investigations

The proposed sites of NMGS and most of the related facilities are located within the San Juan Basin. The bedrock geology of the region is described by numerous investigators, including Baltz (1962), Baltz et al. (1966), Burgener (1953), Fassett and Hinds (1971), Gregory (1917, 1938), and O'Sullivan et al. (1972). In addition, compendia of the geology of the region are presented in a series of guidebooks prepared by the New Mexico Geological Society (1950, 1951, 1968, 1977), the National Association of Geology Teachers (1970), and the Four Corners Geological Society (1973). The geologic units that crop out around the margins of the San Juan Basin or are present at depth within it are described in detail by Bauer (1916), Reeside (1924), Baars and Knight (1957), Baars and Stevenson (1977), Armstrong and Mamet (1977), Jentgen (1977), Parker (1961), Green and Pierson (1977), Harshbarger et al. (1957), and O'Sullivan (1977). The regional geology is well summarized in environmental statements prepared for the NMGS project (PNM 1980), for the El Paso coal gasification project (U.S. Bureau of Reclamation 1977), and for the Star Lake-Bisti regional coal project (U.S. Bureau of Land Management, undated).

The windblown deposits that form a thin veneer over the bedrock in much of the portion of the project area that lies within the San Juan Basin are described in great detail by Schultz (1980) and Wells (1981). These deposits are also described by Hack (1941) and by Cooley et al. (1969). The geology of the alluvial deposits of the

Chaco River, which is the major stream in the project region, is exhaustively examined by Love (1980). The distribution of surficial deposits over much of the project area is delineated by Hunt (1978).

The power transmission lines would extend across the southeastern margin of the San Juan Basin and into the Albuquerque Basin. The geology of the Albuquerque Basin is summarized by Kelley (1977). Dane and Bachman (1957) present a map showing the regional geologic relationships throughout the project area, and major parts of the project area are shown on geologic maps prepared by Hackman and Olson (1977), Hunt and Dane (1954), and O'Sullivan and Beikman (1963). A series of large-scale geologic maps published by the U.S. Geological Survey (USGS) show the geology in the vicinity of some of the project features, including:

- Water Pipeline P1--O'Sullivan, Scott, and Heller (1979b)
- Water Pipeline P2--Scott, O'Sullivan, and Mytton (1979)
- Transmission Route T2--O'Sullivan, Scott, and Weide (1979; Weide and others (1979a,b); Scott, Mytton, and Schneider (1980)
- Transmission Route T1--Schneider and others (1979); Scott, Mytton, and Schneider (1980); Scott, Schneider, and Mytton (1980)
- Transmission Route T3--O'Sullivan, Scott, and Weide (1979)
- Transmission Route T4--Moench and others (1965); Santos (1966); Santos and Thaden (1966)

The geology of the Rio Puerco Station site area is shown on a map presented in New Mexico Bureau of Mines and Mineral Resources Memoir 33 (Kelley 1977). A generalized depiction of the geology of the region to be traversed by the proposed project is presented on Map 3-1.

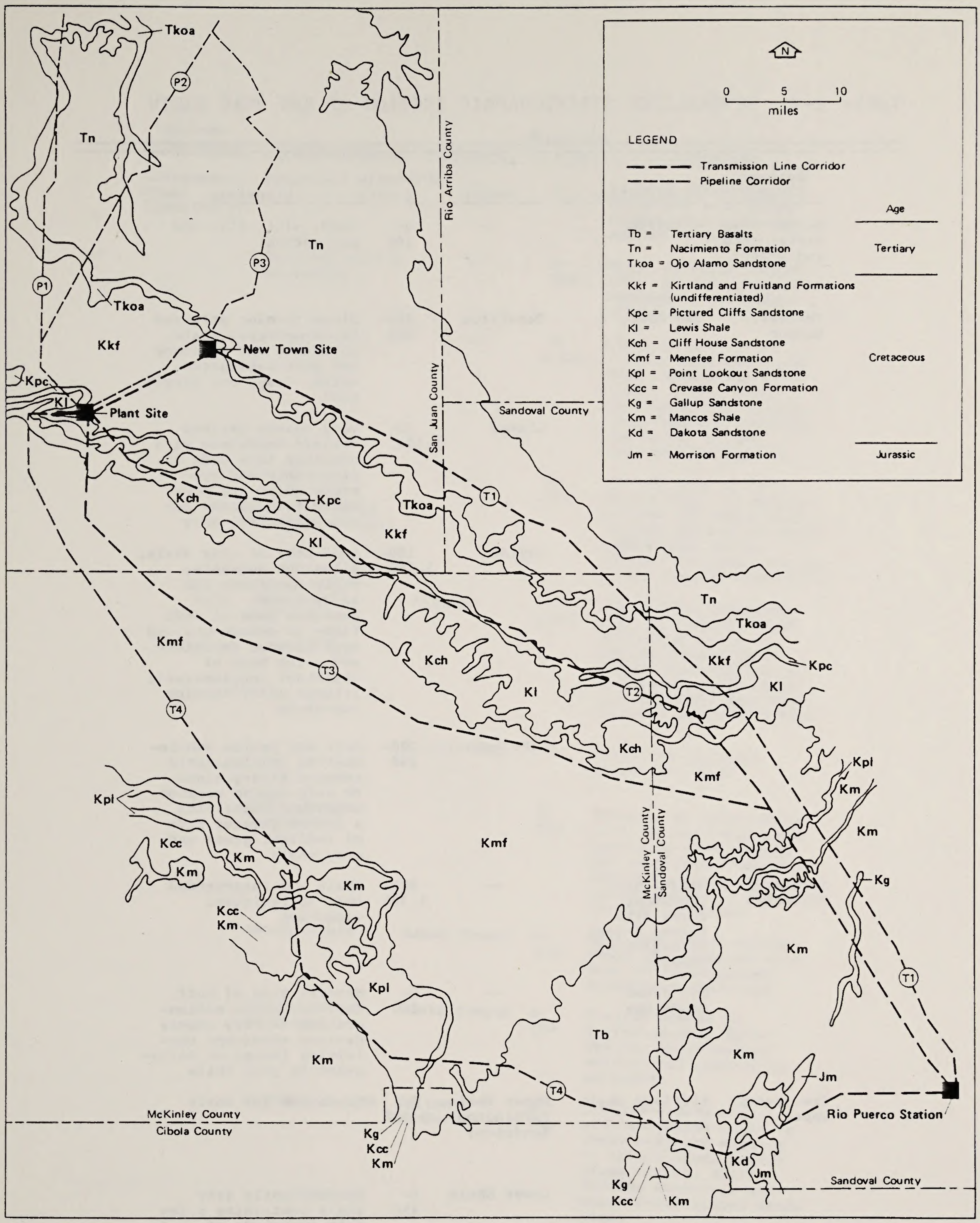
SUMMARY OF REGIONAL GEOLOGY

Most of the proposed project would lie within the San Juan Basin, a structural depression believed to have been formed in Laramide time (about 40 million years ago). The San Juan Basin is bounded on the west, north, and east by the Hogback monocline and on the south by the Chaco slope. The near-surface bedrock units within the project region are principally of Cretaceous and Tertiary age. However, older geologic units are exposed in the Chaco slope area. A shallow veneer of late Quaternary deposits covers the bedrock over much of the San Juan Basin. Geologically recent faults are believed to be absent from the San Juan Basin. However, faults of late Cenozoic, and possibly late Quaternary, age are present along the southeastern margin of the basin. These are associated with the Rio Puerco fault belt, which forms part of the western edge of the seismically active Rio Grande rift zone. The stratigraphic relationships of the rock units in the project area are indicated on Table 3-2. The principal landforms in the project region are dune fields, badlands, and dissected plateaus, with a series of volcanic necks being present in the Rio Puerco fault belt. The southerly transmission routes, especially route T4, would cross relatively rugged terrain at the margin of the San Juan Basin.

MAJOR GEOLOGIC UNITS IN PROJECT AREA

<u>Menefee Formation</u>

The Menefee Formation is exposed around the confluence of Chaco and De-na-zin washes. This unit represents the middle nonmarine unit



Modified after Dane and Bachman, 1965: Geologic Map of New Mexico

Map 3-1. GEOLOGY OF THE STUDY AREA

Table 3-2. GENERALIZED STRATIGRAPHIC SECTION OF SAN JUAN BASIN

System/ Series	Formation	Member	Thickness (feet)	Lithology
Quaternary/ Pleistocene and Recent	Alluvium	--	0-100	Sand, silt, clay and some gravel
Tertiary/ Eocene	San Jose	Tapicitos	200-500	Slope forming pale-red to maroon clay shale, siltstone and mudstone and some variegated white, gray, and purple beds
		Llaves	20-1,300	Very coarse grained arkosic sandstone with numerous thin beds of clay shale and mudstone which are predominately maroon but also green and gray
		Regina	100-1,600	Soft beds of clay shale, siltstone mudstone, shaly sandstone and sandy shale. Also numerous beds of soft fine- to coarse-grained argillaceous sandstone, and a few beds of resistant conglomeratic arkosic cliff-forming sandstone
		Cuba Mesa	200-250	Buff and yellow pebble-bearing conglomeratic arkosic fine-grained to very coarse grained sandstone containing a few lenticular beds of reddish, green and gray shale
Tertiary/ Paleocene	Nacimiento (Includes rocks also termed Animas Formation by others)	--	500-1,300	Shale and interbedded soft to resistant sandstone
	Ojo Alamo Sandstone	--	0-250	Several beds of buff, tan, and brown medium-grained to very coarse grained sandstone containing lenses of olive-green to gray shale
Cretaceous/ Upper	Kirtland Shale	Upper Shale, Farmington Sandstone	0-1,500	Sandstone and shale
		Lower Shale	0-450	Predominantly gray shale containing a few thin interbeds of sandstone and siltstone

System/ Series	Formation	Member	Thickness (feet)	Lithology
Cretaceous/ Upper (continued)	Fruitland	--	0-500	Paludal carbonaceous shale and coal interbedded with siltstone and sandstone
	Pictured Cliffs Sandstone	-	0-400	Thin- to thick-bedded, fine- to medium-grained sandstone, siltstone, and shale
	Lewis Shale	--	0-2,400	Light to dark-gray fissile clay shale and some interbedded siltstone, fine-grained sandstone, and modular concretionary limestone, containing marine invertebrate deposits
	Cliff House Sandstone (including La Ventana Tongue)	--	0-800	Tan and gray cross-bedded fine- to medium-grained sandstone with varying amounts of interbedded gray shale. Locally includes tongues of the Menefee Formation
	Menefee	Allison	0-2,000	Interbedded yellowish-gray to grayish-orange lenticular fine- to medium-grained sandstone, dusty-yellow to olive-gray sandy shale and mudstone, dark-gray to black shale, and coal
		Cleary Coal	--	Dark gray to black shale, and coal
	Point Lookout Sandstone	--	0-300	Grayish- to pale-orange fine- to medium-grained generally even-bedded, but in places cross-bedded, moderately well-sorted quartzose cliff-forming sandstone
	Mancos Shale	Satan Tongue	0-300	Dark gray sandy marine shale and numerous thin beds of fine-grained calcareous sandstone
	Point Lookout Sandstone	Hosta Tongue	0-130	Grayish-orange to yellowish-gray fine-grained thick-bedded well-sorted calcareous sandstone
	Crevasse Canyon	Dalton Sandstone	0-150	Grayish-orange and grayish-yellow fine- to medium-grained massive to thin-bedded, partly cross bedded, cliff-forming sandstone and minor intercalated sandy shale
		El Vado Sandstone	0-100	Thinly interbedded siltstone and very fine grained sandstone and shale

System/ Series	Formation	Member	Thickness (feet)	Lithology
Cretaceous/ Upper (continued)	Mancos Shale	Mulatto Tongue	0-500	Thinly interbedded shale, siltstone and very fine grained, ripple-bedded sandstone
	Gallup Sandstone (including basal Niobrara Sandstones)	--	0-300	Light-gray, buff, and pale-red very fine to very coarse grained sandstone and thin to thick beds of shale
	Mancos Shale	Juana Lopez (Sanostee) Sandstone	50-100	Thinly interbedded calcarenite, very fine grained arenaceous sandstone and shale
		Semilla Sandstone	0-70	Very fine grained to fine grained and medium grained sandstone
		Greenhorn Limestone	40-70	Calcareous shale and thin beds of argillaceous limestone
		Graneros Shale	60-300	
	Dakota Sandstone	--	50-200	Yellowish-buff to gray, massive quartz sandstone with local beds and lenses of conglomerate and coal
Cretaceous/ Lower	Burro Canyon	--	0-200	Conglomerate and sandstone with thin red and green shale and mudstone lenses
Jurassic/ Upper	Morrison	Brushy Basin Shale and Jackpile Sandstone	0-300	Pale-red-orange and greenish-gray claystone and buff to rusty tan, medium to fine grained sandstone
		Westwater Canyon	0-350	White to red very fine to coarse-grained partly conglomeratic sandstone
		Recapture	180-300	Light reddish brown, calcareous fine- to very fine grained sandstones and calcareous, arenaceous dark brown claystones
		Salt Wash	10-60	Light yellow to grayish white fine- to very fine-grained sandstones, interbedded with gray to black shales and arenaceous gray limestone beds
	Cow Springs and Bluff Sandstones	--	0-350	Well-sorted, fine- to medium grained quartzose sandstone

System/ Series	Formation	Member	Thickness (feet)	Lithology
Jurassic/ Upper (continued)	Summerville	--	20-100	Massive to planar bedded sandy siltstone and fine-grained sandstone
	Todilto Limestone	--	10-100	Interbedded gray to brownish-gray, calcareous shale and limestone
	Entrada Sandstone	--	100-250	Reddish-orange, fine- to medium-grained, well-sorted quartzose sandstone beds
Jurassic/ Lower	Carmel	--	0-300	Red, silty sandstone
Triassic/ Upper	Wingate Sandstone	Rock Point and Lukachukai	0-900	Flat bedded dark-red calcareous siltstone. Reddish-brown to orange, fine to medium grained, cross bedded sandstone
	Chinle	Owl Rock	0-200	Pink and red shale mottled light greenish gray. Shale is silty and calcareous
		Petrified Forest	0-300	Variegated blue, gray, red, brown and purple fluviatile mudstone and siltstone. Sonsela sandstone bed within member is light-yellowish-gray cross bedded tuffaceous sandstone containing conglomerate lenses and interbedded siltstone and shale
		Monitor Butte	0-300	Red mudstones and siltstones intermixed with lighter colored sandstones and conglomerates
		Shinarump	0-200	Very light gray, light tan and brown coarse-grained sandstone, conglomerate and minor mudstone beds
Triassic/ Lower	Moenkopi	--	0-350	Reddish-brown siltstone with minor amounts of fine-grained sandstone
Permian/ Lower	San Andres Limestone	--	0-300	Redbeds and thin dolomite beds. Locally a bluish-gray limestone or light-gray to yellowish-buff sandstone or sandy limestone
	Glorieta Sandstone	--	0-250	Well sorted, very fine to medium-grained, orange-pink to whitish, quartz sandstone
	Yeso	--	0-500	Dolomites along with thin beds of gypsum
	De Chelly Sandstone	--	0-600	Orange-red, fine-grained sandstone
	Abo or Lower Cutler	--	400-2,000	Arkosic redbeds

Sources: Cooley and others, 1969

Cooper and John, 1968

of the Mesaverde Group. It is composed of carbonaceous shales, coals, fluvial sandstones, and floodplain shales (Molenaar 1977). Thickness ranges from about 2000 feet on the south side of the Chaco slope to a pinchout on the north flank of the basin. Some of the upper portions of the Menefee near the ancient Cliff House Sandstone shoreline are coal-bearing.

Cliff House Sandstone

The Cliff House is a thick (0-800 feet), transgressive, strand-line sandstone. This unit represents fairly long, still stands of the beach line between the marine Lewis Shale and the continental Menefee Formation; in many places it conformably contacts both these units. In the NMGS area, the La Ventana Tongue of the Cliff House Sandstone produces some natural gas.

Lewis Shale

The Lewis Shale is found on the western margins of the proposed NMGS plant site. This unit was named by Cross, Spencer, and Purington (1899) from a type of exposure near Fort Lewis in Colorado. The Lewis Shale is the youngest marine shale in the basin and is characterized by marine shell fragments, including gastropods and ammonites (Marshall and Breed 1974). The dark shale contains scattered interbeds of marine sandstone, calcareous silty concretions with veins of anhedral barite, and bentonite beds. The Lewis Shale is easily eroded into badlands that are frequently covered with euhedral gypsum crystals and crusts of soluble salts. Along the Chaco River, the Lewis Shale has been redeposited as slopes or terraces with low gradients.

Pictured Cliffs Sandstone

The Pictured Cliffs Sandstone was defined by Holmes in 1877 from outcrops north of the San Juan River and west of Fruitland. The name was chosen because of numerous petroglyphs that decorated the type location. This sandstone forms the vertical cliffs on the western side of the proposed plant site. Lithologically, the Pictured Cliffs can be divided into two units: an upper massive sandstone and a lower shaley unit that grades into the Lewis Shale. The sandstone beds are medium- to fine-grained, well sorted, and composed of 8 percent quartzes, 13 percent feldspars, and 4 percent coal fragments (Burgener 1953). Cement averages 60 percent carbonate, 30 percent clay, and 10 percent silica, with less than 1 percent iron oxide.

Fruitland and Kirtland Formations

The Fruitland and Kirtland formations were defined by Bauer (1916) and named for the towns of Fruitland and Kirtland. The Fruitland Formation is the coal-bearing portion and consequently is the major geologic feature within the coal lease to the north. The Fruitland-Kirtland contact follows the northern boundary of the SMC lease but is gradational and arbitrary. The Fruitland is commonly defined by the limit of the uppermost coal deposits. On the basis of flora and fauna, however, the two formations are quite similar. Further work is needed to accurately distinguish the conformable contact in surface expression (Marshall and Breed 1974).

The Fruitland is lithologically more complex than the Kirtland; it includes 300 to 350 feet of interbedded sandstone, siltstone, shale, clays, carbonaceous shale, carbonaceous siltstone, coal, and thin limestone beds composed entirely of brackish-water pelecypod shells. All beds within the Fruitland are discontinuous and pinch out laterally. Sandstones are composed mostly of well-rounded, fine- to medium-grained quartz with some biotite, ferromagnesian minerals, and include angular to subangular chert, rock fragments, and white feldspar grains (Baltz 1967). Calcite is the most abundant cement, but iron-cemented sandstone beds occur locally.

Commonly, a sequence of thin coal seams overlain by fine laminated clays and sandstone is encountered in the Fruitland. Careful observation reveals burrow structures from the sandstone into the underlying clay. This sequence is typical of a swampy delta in a marginal marine environment. The Fruitland often weathers to a badland condition, and in some areas it is marked by low hills of baked shale that has been fired to a porcelainlike material by spontaneous oxidation of underlying coals.

The Kirtland Shale is divided into two or three units and varies considerably in thickness throughout the San Juan Basin. The lower and upper shales are often divided by a sandstone layer that is medium- to fine-grained and averages 21 percent quartz, up to 5 percent chert, 45 percent feldspars, 9 percent biotite, and 20 percent clay minerals with traces of muscovite, chlorite, heavy minerals, limonite, and hematite (Dilworth 1960). The upper unit of the Kirtland is thin or missing in some areas but is conformable with the overlying Ojo Alamo where the contact can be traced (O'Sullivan et al. 1972).

Ojo Alamo Sandstone

The Ojo Alamo Sandstone crops out in a 1- to 3-mile-wide belt to the southwest of the proposed project area. The Paleocene Ojo Alamo Sandstone is the oldest Cenozoic unit in the area (Baltz et al. 1966). The lower contact is a disconformity that separates Upper Cretaceous and Lower Tertiary rocks in the southern two-thirds of the San Juan Basin.

The Ojo Alamo Sandstone consists principally of angular, arkosic, medium- to coarse-grained sandstone. The distinctive basal unit of the formation also contains clay balls from 1 to 4 inches in diameter, silicified logs up to 40 feet in length, and thin lenses of olive-green to gray shale and sandy shale.

The basal Ojo Alamo is cross-bedded, and erosional scour and depositional channel fill are present on the eroded surface of the Kirtland Formation. The base of the Ojo Alamo Sandstone contains shale blocks representing bank collapse from the Kirtland Formation. The Ojo Alamo Sandstone contains much reworked sand and shale from the underlying units (Baltz et al. 1966). The upper contact is gradational, and sandstones intertongue with red and green shales and claystones of the overlying Nacimiento Formation.

Nacimiento Formation

The Nacimiento Formation is of Paleocene age (Baltz 1967). The lower contact of the Nacimiento Formation is gradational with the underlying Ojo Alamo Sandstone. The upper contact is an angular unconformity with the overlying San Jose Formation, which rests in channels cut in the upper part of the Nacimiento Formation (Baltz 1967).

The Nacimiento Formation consists of claystone, sandy shale, lignitic shale, siltstone, and soft lenticular sandstone. Thin, prominent ledges of resistant argillaceous sandstone are occasionally present. These ledge-forming sandstones are present in the upper third of the formation. Sediments of the middle and upper parts of the formation are well sorted and more evenly bedded than those in the lower part.

The outcrop of the Nacimiento Formation forms low cuestas, benches, and rounded hills. The lithology and fauna of the formation suggest a terrestrial origin. The lenticular sandstones of the formation are stream channel deposits, and the clay and siltstone are flood basin, alluvial fan, and ephemeral lake deposits.

San Jose Formation

The San Jose Formation is of Eocene age and rests unconformably on the Nacimiento Formation. Baltz (1967) divides the San Jose Formation into four members: the Tapicitos, the Llaves, the Regina, and the basal Cuba Mesa. The four members of the San Jose Formation have not been mapped as individual stragigraphic units in the published literature on the project area.

The Tapicitos member consists of maroon and variegated shales and claystones, and lenticular sandstone. The Llaves member is composed of massive beds of resistant arkosic, conglomeritic sandstone. The Regina member consists of soft beds of claystone, siltstone, mudstone, and shaley sandstone. The upper Regina intertongues with the overlying Llaves member. The Cuba Mesa member consists of conglomeritic, arkosic sandstone containing lenticular red, green, and gray shale. The upper third of the member intertongues with the overlying shaley Regina member. Sandstones of the Cuba Mesa member are coarse to very coarse, and most grains are angular to subangular. Pebbles of quartzite, quartz, granite, and chert are common.

The sandstone members of the San Jose Formation cap mesas and buttes and form benches; the shaley members form slopes and valleys. Erosion of the units has produced a varied and rugged topography.

Quaternary Deposits

The Quaternary deposits in the project region consist mainly of riverine quartz sand transported by various washes and dune sand transported across the area by wind activity. The local upper, flat erosional surfaces are characterized by stabilized longitudinal sand dunes that trend to the northeast. Bedding patterns of ancient sand dunes in the Miocene Chuska Sandstone reveal a consistent southwesterly wind pattern (Wright 1956). As shown by Hack (1941) and

Cooley et al. (1969), dune patterns across the entire Navajo Reservation trend from southwest to northeast. Arrested dunes and older features such as parallel drainages controlled by longitudinal dunes indicate that eolian activity has been consistent though intermittent since Miocene times. The constant wind direction is responsible for the formation of linear dunes characterized by some vegetal stabilization and migrating blowout patterns. Both Hack (1941) and Cooley et al. (1969) date the major longitudinal dune fields of the Navajo country as recent and late Pleistocene in age, and they are not considered in further detail here.

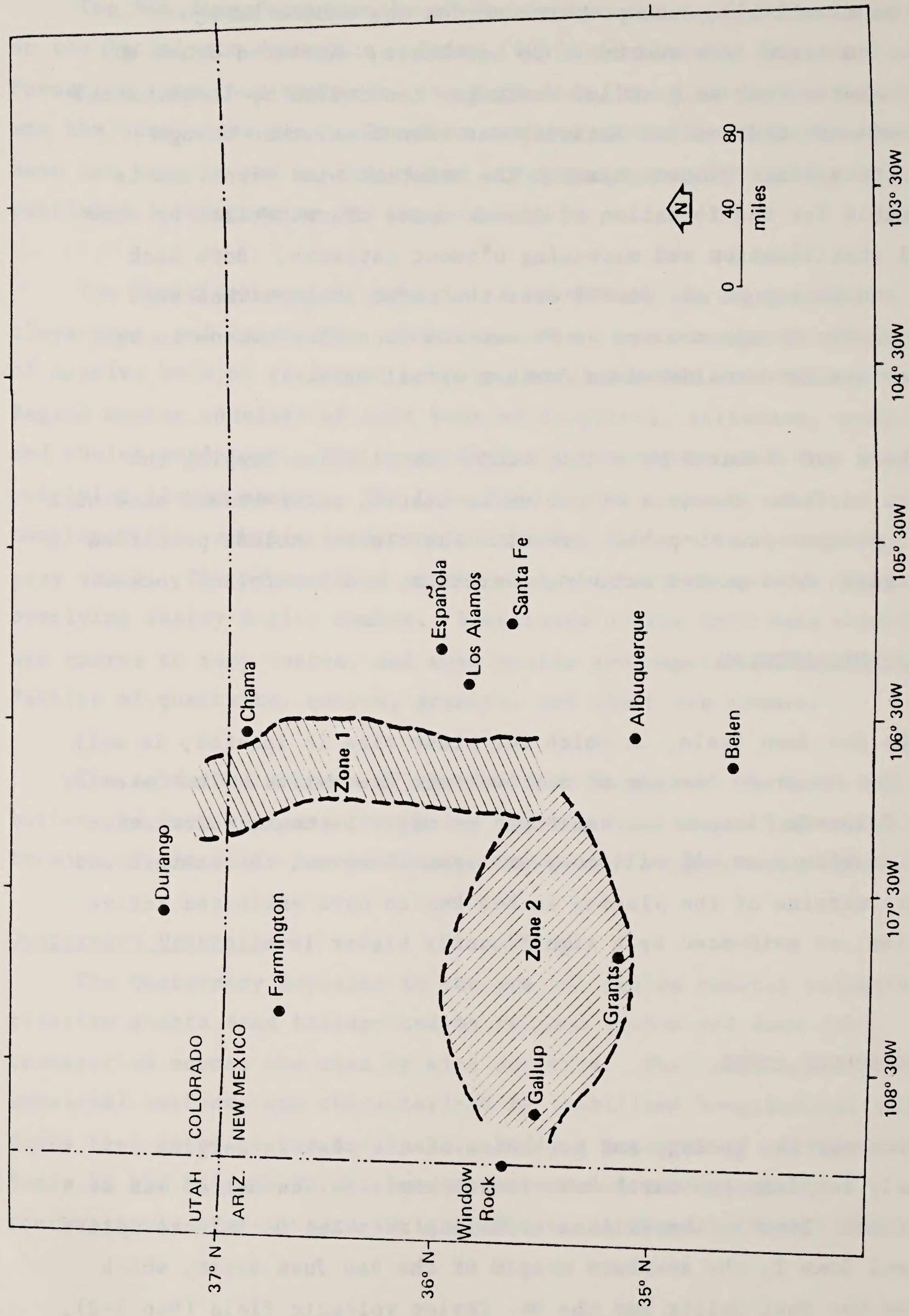
Where not obscured by eolian sand, the alluvium capping the pediment surfaces consists of medium to coarse, cross-bedded sand with about 5 percent pea to pebble gravel. The clasts include petrified wood, agate, transported caliche, quartzite, and hornfelsic rocks.

3.4 SEISMIC SETTING

The San Juan Basin, in which the plant site is located, is well within the Colorado Plateau of northwestern New Mexico. The interior of the Colorado Plateau has exhibited no major tectonic deformation since Laramide time, 40 million years ago. However, the eastern and southern margins of the plateau in New Mexico have exhibited active tectonism, as evidenced by a significantly higher level of seismicity.

SEISMIC SOURCE ZONES

Although the geology and tectonics of the plateau margins are extremely complex, two earthquake source zones in New Mexico can be identified: Zone 1, the Gallina-Archuleta arch and Nacimiento uplift zone; and Zone 2, the southern margin of the San Juan Basin, which includes the Zuni uplift and the Mt. Taylor volcanic field (Map 3-2).



Map 3-2. SEISMIC SOURCE ZONES

Seismicity in zone 1 may be associated with major north-south faults known from surface and subsurface data (Sanford et al. 1981). A fault plane solution of the January 23, 1966, Dulce earthquake (M_L 4.3, the most damaging earthquake in New Mexico since instrumental data became available in 1962)* exhibits north-northwest trending slip planes with east-northeast to west-southwest extension (Hermann et al. 1980). The latter is characteristic of the tectonic stress direction for the Rio Grande rift and thus suggests that the influence of the rift extends this far west. Whether zone 1 is capable of producing large-magnitude earthquakes (M_L 7-7.5)--as is evidenced by late Quaternary and Holocene fault scarps in the adjacent Rio Grande rift--is not known at this time.

Zone 2 is a diffuse zone of seismicity that extends across the southeastern margins of the Colorado Plateau and that may actually consist of several elements. The Jemez lineament, which is manifested by the Mt. Taylor volcanic center, appears to play a major role in the seismicity of the southern margin of the San Juan Basin (Sanford et al. 1981).

Another epicentral trend north of Grants, New Mexico, may be another distinct source zone and may represent the transition from the Zuni uplift to the basin. It has been suggested that the north-northwest trending buried faults of Late Pennsylvanian-Early Permian age may be responsible for this observed seismicity (Sanford et al. 1981). The largest event known to have occurred during the period of instrumental data (1962 to the present) in this zone measured M_L 4.6 (January 5, 1976). However, its focal depth is estimated to be 30 to 40 km, and so the relationship between it and surficial features is unclear (Sanford et al. 1979). A preliminary fault plane solution of

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*M_L = local magnitude

this event suggests east-west compression and north-south extension (shear deformation) (Sanford et al. 1978), characteristic of the tectonic stress direction for the interior of the Colorado Plateau (Wong and Simon 1981).

With the exception of the north-northwest trending seismicity previously mentioned, no seismic source zones are known within the New Mexico portion of the Colorado Plateau, based on the historical seismicity record. Seismicity within the interior of the Colorado Plateau, including Utah, Arizona, and Colorado, is generally diffuse, small magnitude, and low level (Wong and Simon 1981). However, because of the generally poor seismographic coverage that has existed in northwestern New Mexico, and the poor historical record, any assessments of seismicity in that region must be treated cautiously. The largest event during the instrumental period and within the New Mexico portion of the plateau interior was less than M_L 3.0.

MAXIMUM EARTHQUAKES AND RECURRENCE

Estimating the maximum probable earthquake and its recurrence or the maximum credible earthquake (MCE) for the seismic source zones is extremely difficult because the historical seismicity record for northwestern New Mexico is short and incomplete. Only two earthquakes are reported to have occurred between 1849 and 1962 in northwestern New Mexico; undoubtedly, the low number of reports reflects the low population density--there were simply too few people for personal reports to be an accurate measure. The seismicity record became more complete with the installation of seismographs in 1962.

In 1969 the U.S. Coast and Geodetic Survey published a seismic risk map of the United States (Algermissen 1969) that classified areas by the amount of expected earthquake damage. Much of northwestern New

Mexico was classified as Zone 2, in which moderate damage could be expected. In 1976 the U.S. Geological Survey published another seismic risk map (Algermissen and Perkins 1976), depicting expected maximum values of horizontal ground acceleration caused by earthquakes in a 50-year period. Northwestern New Mexico was below the 0.04g contour, so hazards from earthquake-generated ground motions were not expected to be significant.

Sanford (1978) attempted to estimate the maximum intensities or magnitudes for 50- and 100-year periods based on the preinstrumental and instrumental seismicity records for northwestern New Mexico. Maximum accelerations were estimated from Richter's (1958) intensity-acceleration relationship. Ideally, these values should be determined for specific seismic source zones. Since the historical record is too inadequate to allow this, the data from the Colorado Plateau and the Rio Grande rift in northwestern New Mexico (two very distinct tectonic regimes) were used together in the recurrence calculations. Based on felt shocks, the results were as follows:

Time Period	Maximum Intensity/ Magnitude	Maximum Acceleration
50 years	MM VII	0.07g
100 years	MM VII-VIII	0.10g

From the instrumental data:

50 years	M_L 4.9 (MM VI)	0.03g
100 years	M_L 5.2 (MM VI-VIII)	0.05g

Maximum Modified Mercalli intensities were estimated from M_L values employing the relationship proposed by Bath (1973).

Examination of the acceleration values determined by Sanford suggests that the intensity-acceleration relationship used to arrive at these values is providing accelerations that are too low. Employing the relationships of Neumann (1954) and Trifunac and Brady (1975) for intensities, we would suggest the following revisions in the maximum accelerations:

Based on felt data:		Neumann	Trifunac & Brady
50 years	MM VII	0.13g	0.13g
100 years	MM VII-VIII	0.19g	0.19g
From the instrumental data:			
50 years	M_L 4.9 (MM VI)	0.07g	0.07g
100 years	M_L 5.2 (MM VI-VII)	0.09g	0.09g

Although Neumann's values are supposed to be valid for distances up to 25 miles, they are exactly the same as values determined using the Trifunac and Brady relationship for maximum horizontal accelerations with no implied distance dependence.

Also, because Sanford combined the seismicity data from the tectonically stable Colorado Plateau interior with the relatively tectonically active plateau margins, the maximum intensities and magnitudes determined by Sanford for the 50- and 100-year periods are probably too high and thus quite conservative.

The above results differ significantly, and determining which approach is valid is not possible at this time. The conservative approach would be to use the values based on the felt reports and assume they are valid at the plant site (rather than attenuating the maximum intensities and accelerations from source to site). Although the use of recurrence curves is controversial, especially in light of such a poor historical data base, it is a method available at this time to estimate the size of the maximum probable earthquake and its effects on the site, given the present data base.

An alternative and certainly less rigorous approach is to estimate the maximum credible earthquake and corresponding maximum accelerations by simply assuming that an M_L 7.5 earthquake (similar to postulated events within the Rio Grande rift) could occur on the Nacimiento uplift approximately 100 km east of the plant site. The maximum accelerations at the plant site would be between 0.05g and 0.10g (Schnabel and Seed 1973), similar to the values determined by Sanford (1978).

In summary, several varying approaches have been described that attempt to assess the seismic hazard in northwestern New Mexico. All are more or less based on a historical seismicity record that is short, relative to the time frame of geologic changes, and incomplete. A more rigorous and applicable (relevant to the structure involved) study would be prudent in order to apply any of the above assessments for seismic design evaluation.

4.0

ENVIRONMENTAL CONSEQUENCES

4.1 POTENTIAL GEOLOGIC HAZARDS

A number of potential geologic hazards were identified, as is hereinafter described; the specific hazards and the project components that they might affect are indicated on Table 4-1. None of these potential hazards was identified as being so severe as to defy mitigation. Suggested mitigation measures are mentioned briefly below and are described more fully in Section 5.0

Landslides

Portions of the project region are occupied by relatively steep-sided buttes or mesas. The tops of these physiographic features typically consist of a hard, jointed sandstone cap rock. The cap rock is commonly underlain by an interbedded sequence of sandstone and shale. Water penetrating the more open joints in the cap rock contributes to weathering of the underlying softer rock. As the weathering process progresses, the cap rock tends to become undermined. Joint-bounded blocks then topple or slide from the margin of the butte or mesa. This process presents a potential hazard to facilities constructed on the slopes or tops of buttes or mesas. This hazard can be mitigated by sloping back the tops of the mesas along the pipeline routes, by placing pipelines in tunnels below the expected zone of failure, and by placing transmission line towers an individually determined safe distance back from the lips of buttes or

Table 4-1. PROJECT COMPONENTS EXPOSED TO POTENTIAL GEOLOGIC HAZARDS

	PROJECT COMPONENT											
Potential Hazard	P1	P2	P3	NMGS	R1	R2	T1	T2	T3	T4	T5	Rio Puerco Substation
Landslides			Low				High			High		
Spontaneous combustion	Low	Low	Low	Low			Low	Low	Low	High	Low	
Soluble soils				Low	Low	Low						
Expansive soils				High	Low	Low						Low
Collapsing soils				Low	Low	Low						
Accelerated erosion	Low	Low	High	Low								
Piping				Low	Low	Low				Low		
Mine subsidence										Low		
Seismic shaking	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High
Seismically induced ground failure	Low	Low	Low							Low		
Surface fault rupture							Low	Low	Low	Low		Low

Note: "Low" indicates some potential may exist; "high" indicates that a relatively high potential appears to exist.

mesas. Slumping of banks of steep-sided washes might also pose a potential hazard to structures. The locations of possible concern are indicated on Table 4-1 and Table 3-1.

Spontaneous Combustion

Coal sometimes ignites spontaneously and burns on exposure to the atmosphere, baking or fusing the overlying rock. Fires thus started can continue to burn underground for many years, extending back hundreds or thousands of feet from the outcrop, and can bring about eventual surface collapse (Dunrud and Osterwald 1980). A strong pipeline might have sufficient tensile strength to survive such a collapse, but collapse under a transmission tower could put the power lines out of service. The actual amount of collapse would be dependent upon the thickness of the coal bed involved in the fire; coal beds up to 32 feet thick are present in the area.

Bauer and Reeside (1921) observed a burning coal bed near the proposed NMGS site, in the southwest corner of Section 23. At the time of their visit in September 1915, they noted that "gases were issuing from crevices over the outcrop, and many slumps of the overlying beds had taken place recently." The Draft Technical Report on Cultural Resources refers to coal fires in White Rock, a major mesa and badlands formation just south of Chaco Wash, documenting an Indian legend about the fires that created the present topography. According to this account, there is a "place where steam comes out" somewhere on the southwest slope of this mesa.

Baked shale and other materials produced by this process are present at the proposed plant site and at many other locations in the project region, and coal beds crop out at the surface at the plant site and at various locations along the transmission line routes. Therefore it can be inferred that there may be a potential hazard due to spontaneous combustion of coal. This potential probably would be restricted principally to the areas in which the pipeline and transmission line routes would cross strippable coal deposits. These areas are listed below:

P-1	MP 33 to plant site
P-2	MP 34 to plant site
P-3	MP 38.5 to 42.5
	MP 44 to reservoir
T-1	MP 2 to 6.5
	MP 55 to 61
	MP 78.5 to 80
T-2	MP 0 to 1
T-3	MP 0 to 1
	MP 2 to 5
T-4	MP 0 to 1 ?
	MP 7 to 10 (White Rock)

As mentioned previously, a coal fire is burning in the White Rock area; therefore route T4 in this area would be examined with special care.

Soluble Soils

Gypsum crystals were observed on the ground surface at the proposed NMGS site. Dissolution of gypsum is hypothesized to have been the cause of differential settlement of shallow foundations at the Four Corners Power Plant; chemical alteration of clays has also been hypothesized by Hinkle and Yen (1982). The results of testing performed by Sergent, Hauskins and Beckwith (1978) indicate that there is much less gypsum at the proposed NMGS site than at the Four Corners site, but that the possibility of dissolution of that mineral at the former site cannot be ruled out. However, the potential for settlement as the result of such dissolution quite likely could be reduced by extending the foundation below the near-surface weathered zone in which veins of gypsum are most likely to occur. Settlement at the Four Corners Plant eventually was stopped by means of lime-cement grouting (Hinkle and Yen 1982).

Expansive Soils

The Fruitland Formation, which is exposed at the site, is made up principally of interbedded sandstone and shale (Fassett and Hinds 1971). The shale is reported to contain expansive clay (Love 1981). Buildings erected astride the contact between expansive and nonexpansive rocks and soils, or entirely on expansive soils, may be subject to minor structural damage; this may include cracking of walls and deformation of door openings (Bennett 1981). The available mitigation measures include erecting the structure on an engineered fill, chemically treating the clay, and extending the foundation below the zone of seasonal moisture change.

Collapsing Soils

Sergent et al. (1978) report that the silty sand surface soils at the proposed NMGS site have a slight potential for collapse. This phenomenon occurs when highly porous soils are wetted sufficiently to cause their constituent mineral particles to assume a denser packing. This process can cause severe damage to structures. The potential for such damage can be mitigated by prewetting the soil or by extending the structure foundations to a noncollapsible material.

Accelerated Erosion

Construction of buildings and paved areas reduce the area available for infiltration of rain. Uncontrolled runoff from buildings and paved areas may have a potential for creating gullies in highly erodible soils such as those downslope from the proposed NMGS site. A common means of mitigating such a potential hazard is to construct a collector drain and discharge system. Disturbance of the dune deposits in the region may also provide a potential for accelerated erosion; reseeding is the usual mitigation measure. Pipeline trenches crossing steep slopes diagonally may form preferred channels for erosion.

Piping

Internal erosion (or piping) may be an important factor in gully formation within the project region. It typically consists of "flushing out" particles of silt or fine sand and the development of subterranean conduits as water moves through the soil. This process is described by Heede (1971). Wells (1981) reports development of pipes up to 5 meters in diameter in shale bedrock. Evidence that the piping process is at work was seen at a gully at the plant site during the investigation for the proposed project.

Fletcher et al. (1954) point out that the existence of a high hydraulic head is an important requisite to the development of piping. The proposed reservoir may provide this hydraulic head. Therefore the permeability of the soils and bedrock within the reservoir area(s) should be carefully studied to ascertain whether they are susceptible to piping. If the potential for piping is found, it can be mitigated by lining the reservoir(s).

Mine Subsidence

Collapse of underground openings, such as mines, can pose a hazard to structures on the surface. This is a major problem in areas where underground coal mining has been, or is being, done. As a result, there is a very large body of literature pertaining to this phenomenon. Voight (1970) provides a good overview of the state of the art of mine subsidence engineering, and presents a relatively comprehensive bibliography on the subject.

Although the problems related to ground surface subsidence are best known, and have been most thoroughly studied in coal mining areas, subsidence can occur in any area where minerals are extracted from underground mines in relatively weak rock. Johnson (1963) describes an example of subsidence in the Marquez uranium mine, in Sec. 23, T13N, R9W, about 28 miles northwest of Grants, New Mexico. The ore body was 180 to 270 feet deep, and averaged 8 to 9 feet thick. The subsidence amounted to between 4 and 4.5 feet.

Structures at the margins of a subsidence area such as that above the Marquez mine could be subjected to tilting when subsidence takes place. Therefore, there may be cause for concern wherever underground mines are present. The most likely areas where this might be a problem for the proposed project are restricted to proposed transmission route T4, at the following locations: MP 35 (Nose Rock No. 1 mine), MP 70-72 (uranium prospects), and MP 102 to 106 (uranium prospects).

4.2 POTENTIAL SEISMIC HAZARDS

Potentially Active Faults

The proposed Rio Puerco Station and nearby transmission lines and towers would be located within the Rio Puerco fault zone. This zone consists of a broad band of northeast-trending en echelon normal faults that are believed to be related to the late Cenozoic development of the Rio Grande rift (Woodward and Callender 1977). The structural relief across the zone is down to the east, and amounts to about 3000 feet; it is implied that some geologically recent deformation or displacement has occurred (Slack and Campbell 1976). Howard et al. (1978) indicate that some of the faults within the zone are of Quaternary or late Quaternary age, but the map scale is too small to allow the specific faults to be identified. Thus, for preliminary planning purposes, it is suggested that the faults in the immediate vicinity of the proposed Rio Puerco Station be treated as being active. It is recognized, however, that site-specific studies may demonstrate either that no faults are present or that those faults which are present are not active.

The individual fault traces nearest the proposed Rio Puerco Station are the Sand Hill, Garcia, and Tenorio faults. The Sand Hill fault is a prominent, north-trending feature that displaces pediment remnants. The Garcia fault also is implied to be a prominent feature, possibly forming the western boundary of the Rio Grande rift zone. The Garcia fault zone is reported to be the most disturbed zone of the basin margin; the Tenorio fault is inferred to be part of the Garcia fault zone (Kelley 1977). These faults may be significant to the proposed project because of the potential for surface fault displacement or damaging earthquakes. Surface fault displacement can disrupt or collapse overlying buildings or transmission towers. Other types of earthquake damage might include toppling of inadequately secured transformers or equipment.

<u>Seismically Induced Ground Failure</u>

Unconsolidated granular deposits beneath the water table can undergo a transient but complete loss of shear strength (liquefaction) as a result of high pore pressures created by strong ground motion during earthquakes. Where this condition extends to or near to the surface, foundation failure can occur in overlying structures. Therefore it would appear prudent to perform subsurface studies at the sites of the proposed intake structures to ascertain whether the unconsolidated granular sediments at those locations are susceptible to liquefaction within the range of seismic acceleration that might reasonably be expected to occur within the design life of the facility. If a potential for liquefaction proves to exist, it probably could be mitigated through the use of piles extending to a nonliquefiable layer. The possibility of liquefaction of alluvial soils in the Rio Puerco region also should be examined if transmission towers cannot be founded on bedrock.

Ground shaking during earthquakes can also trigger landslides in marginally stable areas, such as the rims of mesas and buttes. Such areas would also be of potential concern during static (nonearthquake) conditions, as discussed above in the section on landslides.

Strong Ground Shaking

Most of the project components, including the proposed NMGS, would be located in a zone of relatively low seismicity. Therefore, it appears unlikely that those features which lie within the San Juan Basin would be subjected to accelerations in excess of 0.2 g. However, due to its position within the Rio Puerco fault zone and its relative proximity to the Rio Grande rift zone, the proposed Rio Puerco Station could be subjected to somewhat greater accelerations. If a maximum earthquake of magnitude 7.5 were to occur at the northern end of the most active portion of the Rio Grande rift zone, the relationships published by Schnabel and Seed (1973) would indicate that the maximum acceleration at the Rio Puerco Station might be as high as 0.4 g. Failure to incorporate appropriate seismic criteria in the station design might lead to toppling of transformers and to structural damage at the station site. Inadequately anchored towers might topple or lean.

5.0

MITIGATION

5.1 MITIGATION OF IMPACTS ON THE ENVIRONMENT

Spontaneous Combustion of Coal

Coal would be exposed during excavation for construction of the NMGS, and may be exposed during excavation for any of the proposed pipeline alternatives. In order to reduce the likelihood of spontaneous combustion, this freshly exposed coal should be covered with clayey soil as soon as possible following completion of the excavation. At the plant site it may prove feasible to entirely remove the coal.

Accelerated Erosion

Accelerated erosion of slopes can be avoided by use of tunnels and shafts, or by excavating trenches directly down steep slopes rather than across them. In some cases, installation of interceptor drains upslope from freshly excavated surfaces is appropriate. As discussed in the Technical Report on Soils, replanting of disturbed areas is a widely accepted means of reducing the likelihood of accelerated erosion.

5.2 MITIGATION OF EFFECTS OF THE GEOLOGIC ENVIRONMENT ON THE PROJECT

Landslides

The best approach for mitigation of landslides depends upon the type of construction that is planned. Installation of pipelines in tunnels and shafts, such as is planned for route P1, is a particularly effective way to avoid a landslide hazard. Laying back the slope to a stable configuration is another technically satisfactory approach for pipeline construction, and one that has an economic advantage over tunneling in most cases. However, some persons not concerned either with costs or with the safety of the construction workers involved may object to this approach on aesthetic grounds. Mitigation of the landslide potential along the transmission line routes is best accomplished by placing the towers an individually determined safe distance back from the edge of the butte or mesa. This distance would be determined on the basis of the thickness and the joint spacing of the cap rock and of the configuration and characteristics of the geologic unit making up the slope below the cap rock. Observation of the size of previous landslide masses in the vicinity can provide a basis for judgment as to what constitutes a safe setback from the edge.

Spontaneous Combustion

Preexisting coal fires may present a hazard to construction workers and to project components underlain by coal beds. This hazard probably would be the greatest where the outcrop of the shallowest coal bed is within one mile up-dip from the project feature. The first step in mitigation of this hazard would be to locate the coal fires. In some cases, this is a simple matter of observing where smoke or steam are venting to the surface. This condition reportedly exists in the White Rock area, south of the Chaco River, so it might affect the routing of T4. In general, it is possible to identify the presence of burning coal beds by looking for bare spots when the area is thinly blanketed with snow. If the reconnaissance cannot be done when snow is on the ground, a thermal infrared survey might prove useful. This approach probably would have the greatest chance of success if carried out during the predawn hours when solar heating effects would be at a minimum.

The best mitigation measure for identified active coal fires is avoidance. Attempts to extinguish coal fires with water tend to be counter-productive, and smothering may not be possible because sufficient air may continue to reach the fire through fissures in the overburden. Therefore, if the active burn area cannot be avoided, the best approach is to remove the burning coal by excavation.

Soluble Soils

Coarsely crystalline gypsum with a relatively high potential for dissolving tends to be confined to strongly weathered or decomposed shale adjacent to the ground surface. The problems that might be caused by the presence of such soils is best avoided either by removing these soils prior to construction or by extending the structure foundations entirely through them. Mitigation by chemical treatment or grouting following construction can be successful, but should be reserved for contingency use in case problems develop in spite of implementation of the other approaches mentioned above.

Expansive Soils

Problems caused by expansive soils typically are the result of shrinking and swelling due to changes in moisture content. Therefore, it may be possible to mitigate the potential for such problems by maintaining a constant level of moisture or by extending the foundation below the zone of seasonal moisture change. In some cases, chemical treatment of the swelling clay with lime may inhibit expansion. The most positive mitigation measure is to over-excavate the expansive soil, replacing it with an engineered fill prior to construction.

Collapsing Soils

Consolidation of collapsing soils can be accomplished in many cases by erecting a dike and flooding the surface within the dike perimeter. Depending upon the thickness of the zone of collapsible soil, it may be possible to extend the structure foundations to a noncollapsible material having an adequate bearing capacity. Other mitigation methods include repeatedly dropping heavy weights on the construction area, or compaction grouting. The most appropriate approach for any given site is best determined by a geotechnical engineer following subsurface investigations and laboratory testing.

Piping

The surface soils at the reservoir sites should be tested to ascertain whether a potential for piping exists. If such a potential does prove to exist and it is not feasible to remove the unsuitable soils, the reservoir should be lined. Clay linings, in general, are more reliable than synthetic materials for this purpose. However, other considerations include availability of suitable material, and consequences of failure.

Mine Subsidence

The most reliable means of reducing the likelihood of ground surface subsidence over a mined area is to backfill the mine. This can be accomplished by injecting a slurry of Portland cement and pulverized fuel ash or fly ash under high pressure. If it is possible to enter the mine, it is preferable to construct a bulkhead at either end of the portion of the mine that is to be filled.

5.3 MITIGATION OF SEISMIC HAZARDS

Potentially Active Faults

The best mitigation measure potential hazard of surface fault rupture during the life of a project is to avoid the fault trace. In the case of linear structure, such as transmission lines, tower footings should be kept off fault traces and sufficient slack should be allowed in the section of wires above the fault that the anticipated movement could be accommodated. Construction of buildings astride active faults is not recommended when alternative construction sites can be found. However, if the likelihood of rupture is low (but not nil), a degree of protection can be provided by placing a thick (perhaps 5 ft) blanket of sand across the site prior to erecting the structure. The objective of this approach is to allow shearing to occur in the sand, while limiting the likelihood of shearing in the building. This approach should not be attempted without the advice of a structural engineer having extensive experience with earthquake effects and seismic design. Application of this approach would also require a knowledge of the type and amount of fault displacement that might occur. Regardless of the approach used, a knowledge of the location of active fault traces is essential. As regional geologic maps probably never indicate the location of active faults with the degree of accuracy needed for siting structures, a site-specific fault investigation should be undertaken for the proposed Rio Puerco Station.

<u>Seismically Induced Ground Failure</u>

The potential for liquefaction of saturated granular sediments is commonly ascertained by standard penetration tests in the field and grain size analyses in the laboratory, followed by comparison of the results with correlation charts for the expected earthquake acceleration.

If liquefaction appears possible, the mitigation options include the following:

1) Avoidance

2) Densification of the soil
   (a) grouting
   (b) vibroflotation
   (c) compaction

3) Extending foundations to good bearing layer

Choice of the appropriate option must be based both upon site-specific subsurface data and upon project economics.

Landsliding is another common form of seismically induced ground failure. The mitigation methods for seismically induced landslides are the same as those for gravity-induced landslides so they will not be described again here.

Strong Ground Shaking

The potential adverse effects of strong ground shaking can be mitigated by appropriate structural design. For some structures, this may require that a dynamic analysis be performed. Transmission towers would not only have to be sufficiently strong and flexible to withstand the vibrations, but would have to be anchored so as not to topple.

6.0

UNAVOIDABLE ADVERSE IMPACTS

There would be no unavoidable adverse impacts if studies and design provisions are instituted. However, the consequences of failure to mitigate are potentially severe. Coal fires once started, are extremely difficult and expensive to extinguish and the consequences of surface fault rupture can include loss of life when structural collapse occurs.

7.0
RELATIONSHIP BETWEEN SHORT-TERM USE OF THE ENVIRONMENT AND LONG-TERM PRODUCTIVITY

There would be no effect on long-term productivity.

8.0 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

If proper construction and design methods are followed there would be no irreversible and irretrievable commitment of resources. However, large coal reserves could be lost if spontaneous combustion occurs.

9.0

COMPARISON OF ALTERNATIVES

Impacts to geologic resources for each of the project component alternatives are compared in Table 9-1.

Table 9-1. GEOLOGIC CONSIDERATIONS FOR COMPARISON OF ALTERNATIVES

Project Component	Impact Summary
Water Pipelines	
P1	Shortest distance disturbed.
P2	Slope stability problems in Gallegos Canyon.
P3	Possible erosion and slope stability problems in Kutz Canyon; greatest distance disturbed.
Transmission Routes	
T2	Minimum disturbed length; minimum exposure to coal burns and erosion.
T3	Minimal exposure to coal burns; least topographic relief.
T1	Possible coal burns; slope stability problems due to mining.
T4	Most rugged topography; greatest distance disturbed.
Reservoirs	
R2	Side hill location presents design problems.
R1	Underlying coal beds may promote leakage.

POSSIBLE NEW TOWN

Table 3-1. [illegible]

[illegible]	[illegible]
[illegible]	
[illegible]	Surface disturbance [illegible].
[illegible]	Slope stability problems in [illegible].
[illegible]	Possible erosion and slope stability problems in [illegible].
[illegible]	
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	
[illegible]	[illegible]
[illegible]	[illegible]

1.0
AFFECTED ENVIRONMENT

The area in which a possible new town could be located lies on the upper part of the Naashoibito Member of the Kirtland Formation and the lower part of the Ojo Alamo Sandstone. The entire area is covered by a thin layer of surficial Quaternary alluvium (underlain to a large extent by bedrock). Topography is flat to gently rolling, with ridges and badlands on the northern half of the new town site. No potential geologic or seismic hazards are known in the area.

2.0

ENVIRONMENTAL CONSEQUENCES

No impacts to unique or scientifically important geologic formations would be expected to result from a possible new town. No potential geologic or seismic hazards would be expected.

APPENDIX A

WESTERN AREA SURVEY: GEOLOGIC DATA*

* Taken verbatim from Loose (1978)

PHYSIOGRAPHY/GEOLOGY

The study area for the Western Area Survey lies almost entirely within the San Juan Basin, (shown on the Physiography and Geology maps), which is in the Navajo and Datil physiographic sections of the Colorado Plateaus Province (Fenneman 1931). Geologic deposits within the basin range from Cambrian (600 million years old) to Recent in age and are as much as 15,000 feet thick (Fassett and Hinds 1971). In the southern margins of the study area some Precambrian granitic rocks are exposed which may be well over 600 million years old.

Within the study area, geology and physiography are closely related to each other through processes of crustal deformation (tectonic activity) and differential resistance to erosion. The basin is surrounded by uplands built on monoclinal warps with additional intrusive or extrusive volcanic activity. These volcanic areas are often more resistant to erosion than the softer shales, siltstones and sandstones of the lower central basin, which are being eroded and may still be slowly subsiding at the same time. As a result, forces of tectonics and erosion have produced elevational differences of as much as 3,400 feet between the center and the rim of the San Juan Basin.

Since the Western Area Survey encompasses such a large area, it would not be within the scope of this report to discuss in detail all the geological formations within the study area boundaries. Only the following Generalized Stratigraphic Sequence will be used. The units in the table represent geologic deposition which can be widely correlated over much of the basin and do not take into account local tongues or small discontinuous units.

Structure

The San Juan Basin is an asymmetric structural feature with a northwest trending axis. There is a steep dip into the basin in the northwestern, northern and eastern areas and a rather gentle and even dip in the southwestern and southern parts (Fassett and Hinds 1971). The San Juan Basin structure map shows these formations. By the late stages of the Laramide orogeny (late Cretaceous mountain-building phase), most of the uplifts which formed the basin rim had been initiated. This is reflected in lake bed deposits of the Nacimiento Formation which indicate a closed basin prior to deposition of the San Jose Formation. The basin is bounded on the north by the Hogback Monocline and the San Juan Uplift (in Colorado). The rim on the east is formed by the Nacimiento Uplift, the Brazos Uplift and the Jemez Mountains Caldera. The Zuni Uplift and the Chaco Slope form the southern margin of the basin; the Defiance Uplift and Four Corners Platform complete the basin rim on the northwest (Fassett and Hinds 1971).

Geologic History

Precambrian rocks in the Zuni Mountains have been described by Fitzsimmons (1967) as mainly granitic in composition, with minor exposures of chlorite schist and quartzite. In a few places along the Defiance Uplift, granite, gray and purple quartzites, and low grade metamorphic rocks can be found which may be of Precambrian age.

The geology of the region between Precambrian and Cretaceous times is characterized by many cycles of marine and continental sedimentation which can be interpreted in diverse ways. Intensive exploration of economic deposits from late Cretaceous times, however, has allowed a more accurate interpretation of their depositional sequences. Almost all workers in the area agree that a series of three basin-wide cycles of transgression and regression by an epicontinental sea in late Cretaceous time resulted in the deposition of the Dakota Group, the Mancos Shale, coal-bearing sequences of the Mesa Verde Group, and the dark marine Lewis Shale. These deposits rest uncomformably on a truncated late Jurassic surface.

The marine Pictured Cliffs Sandstone of the Mesa Verde Group represents the final regression, which was frequently interrupted by minor transgressive episodes. This resulted in vertical buildup and inter-

era	period	stratigraphic unit	thickness (feet)	physical properties (economic uses)
CENOZOIC	Quarternary	alluvium	0-100±	unconsolidated silt, sand, and gravel covering the floodplain of modern streams (sand and gravel; placer gold)
		lake deposits	50±	clay, shale, and sand covering old lake bottom
	Quarternary –Tertiary	terrace and piedmont deposits	up to 300	unconsolidated sand, gravel, and cobble to boulder conglomerate in terraces and alluvial fan deposits (sand and gravel; placer gold)
		basalt	up to 1,500	basaltic and basaltic andesite lava flows and interbedded scoriaceous pyroclastic deposits (crushed stone, scoria)
		Santa Fe Group	10,000±	poorly cemented gray, red, and tan clay, silt, sand and pebble beds; includes minor ash beds (sand and gravel)
	Tertiary	intrusives		stocks, dikes, and sills; generally basaltic in composition
		San Jose Formation	1,200±	banded white, gray, green, yellow, and purple clays, sandy clays and siltstones, narrow channeled sandstones locally; some petrified wood near base
		Nacimiento Formation	up to 800	brown and gray sandstones, greenish and gray shale, with local thin seams of impure coal
		Ojo Alamo Sandstone	up to 400	interbedded sandstone, conglomeratic sandstone, and shale, ranging from light brown to rusty brown, with petrified wood and pebbles of silicic and igneous composition
MESOZOIC	Cretaceous	Kirtland Shale	up to 800	gray shales, siltstones, laterally discontinuous sandstone, and a colorful upper unit with purple, green, white, and gray shales; some channel deposits of quartz and jasper conglomerate in an iron oxide matrix (some gas and oil)
		Fruitland Formation	0 to 500	interbedded sandstone, siltstone, shale, carbonaceous shale, carbonaceous sandstone, siltstone, thin limestone beds, with color ranges similar to that of the overlying Kirtland Shale (coal)
		Pictured Cliffs Sandstone	up to 400	white, yellow-gray, and brownish laminated sandstones, some interbedded sandstones and shales below the massive upper unit (some gas)
		Lewis Shale	up to 2,400	light to dark gray and black shale interbedded with light brown sandstone, sandy to silty limestone, calcareous concretions, and bentonite
		Mesaverde Group	up to 2,900	buff and gray sandstone with interbedded gray to black shale; coal beds of mineable thickness locally (coal, oil, and gas, minor uranium)
		Mancos Shale	1,500-1,800	mostly black shale, with local sandstone and siltstone; coal beds in the upper part and near the base (minor coal)
		Dakota Formation	5-250	buff, medium-grained, quartz sandstone; may be conglomeratic; dark-gray, fissile, calcareous shale at base
	Jurassic	Morrison Formation	400-750	mostly variegated shale and mudstone; sandstone and conglomerate beds prominent in lower and middle part; some limestone (uranium)
		San Rafael and Glen Canyon groups	up to 2,000	massive gypsum with laminated, locally petroliferous, limestone at base; locally has a sandstone at top, some variegated sandstone, massive light-red to buff, cross-bedded quartz sandstone (gypsum)
	Triassic	Chinle Formation	1,500-2,000	tan to maroon mudstone and lenticular sandstone; variegated in lower part (brick clay)
PALEOZOIC	Permian	San Andres Formation	0-190	limestone and buff to tan sandstone
		Glorieta Sandstone	0-150	white to light-gray medium-grained sandstone; commonly cross-bedded
		Yeso Formation	320-550	brown to maroon medium-grained sandstone; includes gray limestone in upper part of unit; local gypsum beds (brick clay locally)
		Abo Formation	700-950	orange to red medium-grained sandstone; some lenses of light gray limestone and sandstone, and black shale (brick clay locally)
	Pennsylvanian	Pennsylvanian rocks		in subsurface only in northwestern New Mexico (some oil or gas near Rattlesnake and Ute domes)
	Mississippian	Mississippian rocks		in subsurface only in northwestern New Mexico
PRECAMBRIAN		Metamorphic and igneous rocks		mostly granite and granitic; quartzite, greenstone, chlorite schist, and mica gneiss locally abundant (stone, fluorite, metal deposits)

tonguing with the overlying Fruitland Formation. The Pictured Cliffs Sandstone is a littoral deposit, while the overlying Fruitland and Kirtland Formations represent landward swamp and floodplain environments. The beach lines of the Pictured Cliffs Sandstone run from northwest to southeast, with deep water to the northeast and swamp and floodplain conditions to the southwest. Eventually the Pictured Cliffs Sea retreated from the San Juan Basin and probably laid down the regressive Trinidad Sandstone of northeastern New Mexico. As the sea regressed, sediment-laden streams flowed northeast from a highland area and aggraded the floodplain through which they emptied into the Pictured Cliffs Sea. Evidence for this sequence of events lies in the fact that the Pictured Cliffs Sandstone becomes progressively younger from southwest to northeast across the San Juan Basin (Baltz 1967).

After deposition of the Kirtland Formation the study area was tilted to the northwest. A basin-wide cycle of erosion began and as much as 2,100 feet of sediments were removed. Fassett and Hinds (1971) interpret this to indicate that the pre-Ojo Alamo Sandstone surface was a relatively flat peneplain. Source material for the conglomerates in the Ojo Alamo probably came from west of the present basin. A decrease in pebble size from west to east within the Ojo Alamo substantiates this interpretation. Baltz, Ash, and Anderson (1966) assigned the uppermost Ojo Alamo conglomerates to the Tertiary and renamed lower units which were placed in the Kirtland Formation. Their work was based on faunal, floral and geological relationships with the overlying Nacimiento Formation.

Although the Paleocene Nacimiento Formation is deposited on top of the Ojo Alamo, there is frequent intertonguing which represents migrations of depositional facies and allows a conformable contact in some places. Another erosional cycle followed between the Nacimiento and the Eocene San Jose Formation (Simpson 1950). As the San Jose was being deposited, the basin continued to form and ultimately acquired its present configuration.

Events following the Eocene are characterized by regional erosional cycles and units of local deposition. Due to the relatively short duration of middle and late Tertiary ages and to limited dating techniques, regional correlations of erosional events are very difficult. This situation is reflected in the proliferation of names for Tertiary surfaces and lack of widespread age correlations.

Cenozoic erosional surfaces in the San Juan Basin are related to the entrenchment of the ancestral Colorado River system, which may have appeared as early as the Miocene. These surfaces can be correlated to the present river level or to a widespread mid-Tertiary peneplaination first recognized by Dutton in 1882 and referred to as the "great denudation". In 1901, Davis called the same ancient surface the "plateau cycle" and called all subsequent events the "canyon cycle". The recent work of Cooley, Harshbarger, Akers and Hardt (1969) has largely substantiated the general interpretations of the earlier workers. Tertiary erosional development can be divided into four major cycles: the Valencia cycle of Miocene age, the Hopi Buttes-Zuni cycle of Pliocene age, the Black Point cycle of late Pliocene age and the Wupatki cycle of probably middle and late Pleistocene age. The major cycles may relate to tectonic events while minor perturbations can be correlated to climatic fluctuations in the Pleistocene (Stokes 1973).

Little work has been done in correlating specific quaternary erosional surfaces in the study area (Love 1977). Lag gravels on Pleistocene terraces include reworked materials from Mesozoic and Cenozoic sedimentary rocks, and Tertiary igneous rocks from the surrounding upland areas. These igneous materials may be useful in dating some erosional events. For instance, Chuskan basalt cobbles found on the west side of the lower Chaco River are not present on the east side, except on very low Pleistocene terraces below Pena Blanca/Sanostee Wash. This differential distribution of material on the east and west sides of the present Chaco River indicates that the Chaco was entrenched before the intrusion of the Beautiful Mountain or Washington Pass basalts (which are Miocene in age according to Akers, Shorty and Stevens 1971).

Many of the erosional surfaces of the San Juan Basin are characterized by various kinds of dune activity, the largest overall pattern being longitudinal sand dunes which trend to the northeast. Bedding patterns of ancient sand dunes in the Miocene Chuska Sandstone reveal a consistent southwesterly wind pattern (Wright 1956). As shown by Hack (1941) and Cooley et al. (1969), dune patterns across the entire

Navajo Reservation trend from southwest to northeast. Arrested dunes and older features such as parallel drainages controlled by longitudinal dunes indicate that aeolian activity, though intermittent, has been consistent in direction since Miocene times. The constant wind direction is responsible for the formation of linear dunes characterized by some vegetal stabilization and migrating blowout patterns. Both Hack (1941) and Cooley et al. (1969) date the major longitudinal dune fields of the Navajo Reservation as late Pleistocene and Recent.

Present Land Forms

Chuska Mountains

The Chuskas (Navajo for white spruce) extend along the western boundary of the study area from Tohatchi north of Gallup to Red Rock Valley in Arizona. These mountains are entirely within the Navajo Reservation and are considered a sacred area by the Navajos. These mountains represent the eastern edge of the Defiance Uplift as defined by the Defiance Monocline, a longitudinal buckling of the earth's crust. Elevations in the Chuskas range from 6,500 to 9,800 feet.

The Chuskas consist of eastward dipping Mesozoic sediments along a monoclinal warp capped by Miocene sandstones and volcanic flows. The Chuska Sandstone is a cross-bedded white to gray sandstone with a carbonate or opaline cement and may represent an ancient dune field (Wright 1956). In many places this sandstone has collapsed, giving rise to the numerous small lakes found on top of the Chuska Mountains. In addition to the sandstone, basalt-like flows and sills of an unusual volcanic rock called melatrachyte (Fitzsimmons 1973) cap much of the area around Washington Pass and Beautiful Mountain.

Triassic and Jurassic rocks of the Glen Canyon and San Rafael groups are exposed on the western side of the mountains and form the exceptional red cliffs that can be seen east of the highway between Window Rock and Lukachukai, Arizona. Intruding through these rocks are the remnants of many volcanic events: necks, dikes, lava flows and layers of volcanic ash.

On the east side, the Chuska flanks are covered by spectacular layers of landslide debris composed of angular blocks of Chuska Sandstone and volcanic rock (Blagbrough 1967). The debris forms ridges and troughs parallel to the main escarpment between elevations of 8,400 feet and 7,600 feet.

Chuska Valley

Between the Chuska Mountains on the west and the Chaco River on the east lies the Chuska Valley (Warren 1967). This is a wide, open lowland about 60 miles long and 20 miles wide, trending north to south from the San Juan River to Mesa de los Lobos. The area is characterized by generally north or northeast trending drainages, including Captain Tom, Deadmans, Naschitti, Pena Blanca/Sanostee and Theodore washes, which empty into the Chaco River. On the north end of the valley, the Little Shiprock and Shiprock washes drain directly into the San Juan River. Elevations in the valley average around 5,500 feet.

The Chuska Valley lowlands are more of a slope than a true valley. They are separated from the Chaco River by a long, dissected ridge of mesas, buttes and cuestas formed in the Cliffhouse Sandstone. Many of the minor drainages are perennial at their headwaters on the Chuska flanks but soon disappear in alluvial flats on the dry valley floor. Valley bottoms are often characterized by vertical-walled, headward-cutting arroyos.

Probably the most outstanding features of the Chuska Valley are the numerous peaks and radiating dikes. The best example is Ship Rock at the northern end of the valley, which rises some 1,700 feet above the surrounding plain. Similar though less spectacular peaks include Ford Butte, Bennett Peak, Barber Peak and Mitten Rock. All these peaks are part of the Pliocene Navajo volcanic field and can be classed as a breccia or tuff breccia (frozen rock froth which includes fragments of rock known as xenoliths). These fragments often come from several thousand feet below the surface, making up as much as one-third of some volcanic necks in the Navajo physiographic section (Fitzsimmons 1973).

Four Corners Platform and San Juan Slope

The Four Corners Platform occupies the northwestern corner of the study area and is bounded by the Hogback Monocline on the east and the Carrizo Mountains and Ute Mountain on the west. This feature is a relatively flat, wide and low divide between the Chuskas and the San Juan Uplift in Colorado. The main structural features include singly and doubly plunging anticlines distributed in an irregular fashion.

Geological units of the platform include upper Cretaceous members of the Mesa Verde Group and the Mancos Shale, which dip eastward into the central basin. South of the San Juan River along Shiprock and Red washes, banded shale units have been eroded into extensive badlands.

For the purposes of this report, the portion of the study area east of the Four Corners Platform and north of the San Juan River will be called the San Juan Slope. This includes the country between the San Juan Uplift in Colorado and the San Juan River in New Mexico. The slope is drained by the Mancos, La Plata, Animas, Los Pinos and San Juan rivers. The topography is one of mesas and canyons, forming mainly in sandstone units of the Mesa Verde Group and Tertiary Nacimiento and San Jose formations. All the geological units in this area dip generally to the southeast and are strongly deformed along the ridge forming the Hogback Monocline. Elevations range from 6,500 feet at the Colorado-New Mexico border to 4,900 feet at the San Juan River.

Chaco Plateau

As defined by Warren (1967), the Chaco Plateau includes the portion of the central San Juan Basin north and east of the Chaco River, south of the San Juan River and west of Canon Largo. The term was first used by Gregory in 1916 to designate a geographic province. In this area, southern tributaries of the San Juan, including Ojo Amarillo, Gallegos, Kutz and Largo canyons have dissected high mesa and plateau surfaces. Valley flats with alluvial soils exist in the bottoms of many of the tributary canyons and some badland topography has developed along major drainages. These badlands are especially striking in the Nacimiento Formation along Kutz Canyon and in the Fruitland and Kirtland shales near the abandoned Bisti Trading Post.

Wide shallow drainages such as Chinde, Cottonwood, Pinabete, Brimhall, Hunter and Coal Creek flow sporadically in a westerly direction to the Chaco River, while Kimbetoh and Escavada washes flow toward the Chaco in a more southerly direction. Blanco and Largo canyons drain the area north into the San Juan River. The southeastern portion of the plateau is drained by tributaries of the Rio Puerco (which eventually empties into the Rio Grande). Stabilized dunes, ridges and ephemeral ponds are common on the plateau surfaces. Elevations range from 7,470 feet at Huerfano Mountain to 5,000 feet at the confluence of the San Juan and Chaco rivers.

This central portion of the San Juan Basin features gently dipping beds of the Mesa Verde Group, the Lewis Shale, the Kirtland Shale and the Fruitland Formation, as well as portions of the Ojo Alamo Sandstone, Nacimiento Formation and San Jose Formation. Nearly all relief in this portion of the study area is the result of differential erosion. Peaks like Huerfano Mountain, Huerfanito Peak and Angel Peak are resistant remnants of the San Jose Formation standing above beds of the Nacimiento Formation. Little or no volcanic activity has occurred on the Chaco Plateau. In some portions of the Fruitland Formation, however, spontaneous combustion of coal has cooked overlying shale beds into erosionally resistent "clinker" hills which often look like small volcanic cinder cones from a distance.

Chaco Slope

The Chaco Slope lies between the Zuni Uplift and the Chaco River and is bounded on the east by the Mount Taylor volcanic field and on the west by the Chuska Valley. Throughout this area, the structural contours of the San Juan Basin dip smoothly and gently to the north, with a structural relief of approximately 2,500 feet between Crownpoint and the Chaco River. Ephemeral streams flow north toward the Chaco and include Coyote Canyon, Standing Rock Wash, Indian Creek, Kim-me-ni-oli Wash and tributaries of the Rio Puerco east of the continental divide.

Topography is developed on sandstones and shales which have been subjected to considerable erosion to form mesas, cuestas, small rock terraces and numerous incised dry washes with sandy bottoms. Little volcanic activity has occurred in the area with the exception of some small volcanic necks near the Mount Taylor volcanic field. Elevations range from 8,620 feet at Hosta Butte to 5,500 feet at the great bend in the Chaco River where it begins to flow north to the San Juan River.

Geology of this area is mainly characterized by large exposures of the Menefee Shale bordered by other members of the Mesa Verde Group on the north and south. Resistant portions of the Cliffhouse Sandstone of the Mesa Verde Group have formed the cliffs and deep valleys of Chacra Mesa and Chaco Canyon National Monument along the Chaco River. To the south, the resistant, cliff-forming Hosta Tongue and Point Lookout Sandstone form the high relief areas on the edge of the Zuni Uplift south of the highway between Crownpoint and Coyote Canyon. Numerous northeast trending faults on the eastern half of the Chaco Slope cluster around the Ambrosia Lake area.

Puerco Fault Belt

This part of the study area lies on the southeastern edge of both the San Juan Basin and the Colorado Plateaus Province. As defined by Kelley (1955:23), the Puerco Fault Belt is bounded on the north by the Sierra Nacimiento, on the south by the Lucero Uplift, on the east by the Rio Grande trough and on the west by the Mount Taylor volcanic field and the Chaco Slope. Local relief rarely exceeds 300 feet, with elevations averaging around 5,700 feet. Elevations range from 7,785 feet at Cabezon Peak to 5,379 feet where the Rio Puerco passes under I-40.

The Rio Puerco, an intermittent tributary of the Rio Grande, is the main stream draining the Puerco Fault Belt, although the Rio Salado drains some portions of the northern end of the faulted area. Both these streams are characterized by deeply incised meanders with vertical standing walls. Much of the presently observable downcutting is thought to have occurred since 1880 (Peckham n.d.). Numerous side arroyos with vertical active headwalls are typical of the area.

As the name implies, the Puerco Fault Belt is characterized by extensive fracturing of the local geological units in sets of parallel faults. These faults have a northeasterly trend and have produced a series of narrow horsts and grabens. Displacement along the faults varies from 20 to 500 feet with offsets often apparent on the surface of the upper Cretaceous rocks. Large scale block faulting related to the Rio Grande depression occurs on the eastern side of this part of the study area.

Bedrock includes parts of the Jurassic Morrison Formation, Dakota Sandstone and undifferentiated sections of the Mesa Verde Group of Cretaceous age. Geologic units in this area have been subjected to several cycles of regional tilting and compression, including large-scale synclinal warps caused by regional deformation.

Mount Taylor Volcanic Field

The Mount Taylor volcanic field overlaps portions of the Puerco Fault Belt. Hunt (1938) counted nearly 50 basaltic necks in the Rio Puerco Valley. These cores of old volcanic cones range from 800 to 1,500 feet high and their dark color contrasts with the lighter Cretaceous rocks into which they intrude. The exposed necks are typically cylindrical with prominent columnar jointing on the sides and scoriaceous basalt on top. Cabezon Peak is the most impressive of the necks, rising nearly 2,000 feet above the surrounding plain; its base is about 1,500 feet in diameter. Navajo legends say this is the head of an ancient giant buried eons ago, which may explain how the name of the neck was derived.

The Mount Taylor field lies between the eastern margin of the Puerco Fault Belt and the Chaco Slope, bounded on the south by the Malpais lava flow and extending northeast to Cabezon Peak and the Rio Puerco.

Major physiographic features include Mesa Chivato, La Jara Mesa, San Fidel Mesa and Horace Mesa which together make up a "pedestal" about 8,000 feet high under Mount Taylor. The plateau-like expanses of these mesas define the remnants of the earliest pediments developed around Mount Taylor volcanic peak, which rises to an elevation of 11,301 feet. The surfaces of the mesas are covered with basalt flows associated with numerous small vents and cones. Dutton (1885) estimated between 100 and 200 volcanic cones on Mesa Chivato alone.

Mount Taylor's original volcanic crater has been enlarged by erosion to about a five-mile square amphitheater, breached on the eastern side by Water Canyon Creek. Many small streams in the volcanic field drain into the Rio San Jose, the Rio Puerco or run north into the Chaco River. Some of the small streams are perennial near their heads along the rim of Mesa Chivato.

Local geology is characterized by basaltic necks and flows intruding or covering sedimentary rocks of late Cretaceous age. A major downwarp feature, the McCarty Syncline, underlies the central axis of the volcanic field. It is possible that structural movements related to the syncline are responsible for the fusion of deep-seated sediments and subsequent volcanism (Hunt 1938). Age of the volcanics ranges from Miocene to Pliocene for Mount Taylor and Mesa Chivato as well as some of the volcanic necks in the Rio Puerco Valley. Very recent flows can be observed south of Mount Taylor along the Rio San Jose. Vents near Bluewater, Laguna and along the eastern edge of the Zuni Mountains were the sources for these recent flows (Shomaker 1967).

Zuni Uplift

The Zuni Uplift is on the southern boundary of the study area, bounded on the east by the Mount Taylor field, on the north by the Chaco Slope and on the west by the Gallup Sag. This highland area was formed by an elongated, gently domed and faulted uplift from which much of the sedimentary rock has been stripped, leaving a core of ancient crystalline rocks exposed. Spectacular cliffs have been formed along the Nutria Monocline, which bounds the southwest edge of the uplift and along the Sedgwick and San Rafael faults on the eastern margin of the uplift. Elevations range from 9,256 feet at the summit of Mount Sedgwick to approximately 6,600 feet at San Rafael.

Major drainages in the uplift are Cottonwood Creek and Bluewater Creek, which empty into Bluewater Lake. The Rio Pescado and Rio Nutria drain southwest into the Zuni River while Aqua Fria Creek and Bonita Canyon drain the area to the southeast. Numerous small canyons drain north into the heads of the Rio San Jose and the Puerco River.

The Zuni Mountains contain modest amounts of Precambrian rocks in several large areas along the crest of the uplift. These rocks include granites and foliated gneisses and schists. Surrounding the Precambrian rocks, a wide band of Permian sediments forms the major surface of the highland. Outside the Permian outcrops, Mesozoic rocks have been eroded into the valleys, hogbacks and mesas which define the outer limits of this physiographic unit.

One of the most distinctive features of the Zuni Uplift is the Nutria Monocline, which is about 32 miles long and one to two miles wide with dip angles ranging from low to steeply overturned. In addition, this uplift is the most heavily faulted of the uplifts in the Colorado Plateaus Province and the pattern of faults and joints seems diverse. In some areas, block faulting has produced horsts and grabens. Early tectonic events in this area can be interpreted in various ways but the major portion of the modern uplifting began in late Cretaceous through Eocene time, about 50 million years ago.

Gallup Sag

The Gallup Sag is a narrow embayment between the Zuni Uplift and the Defiance Uplift (Chuska Mountains). This feature is about 70 miles long and 8 to 28 miles wide and plunges north into the San Juan Basin. The central part of the sag is known as the Allison-Nakaibito Syncline, with a northward plunge rate of about 60 feet per mile. The topography is characterized by numerous wide outwash plains, rolling shale hills and narrow sandstone ledges. Elevations range from 6,500 to 6,000 feet and topographic relief is rarely more than 200 feet. Major washes which drain north into Chaco Canyon include Mexican Wash, Grey Ridge Canyon and Coyote Canyon. On the southern margin of the sag, minor washes empty into the Puerco River.

Geologic units in the sag area are mainly shales and sandstone stringers of the Menefee Shale and Crevasse Canyon Formation of the Mesa Verde Group. The downwarping crustal deformation which produced the Gallup Sag and the large monoclines on either side of it occurred during the Larimide period of mountain building in late Cretaceous and early Tertiary times (from 50 to 70 million years ago).

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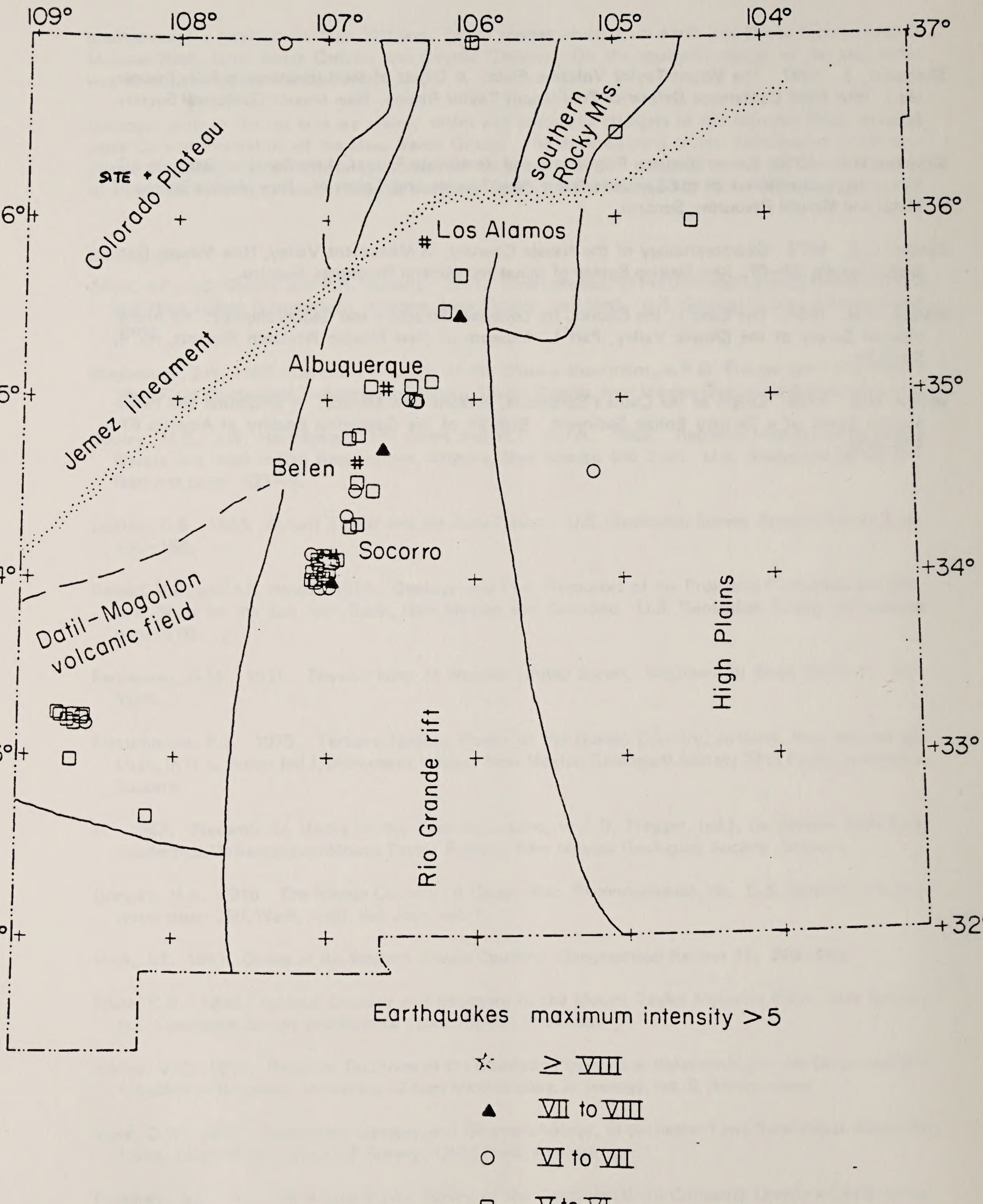
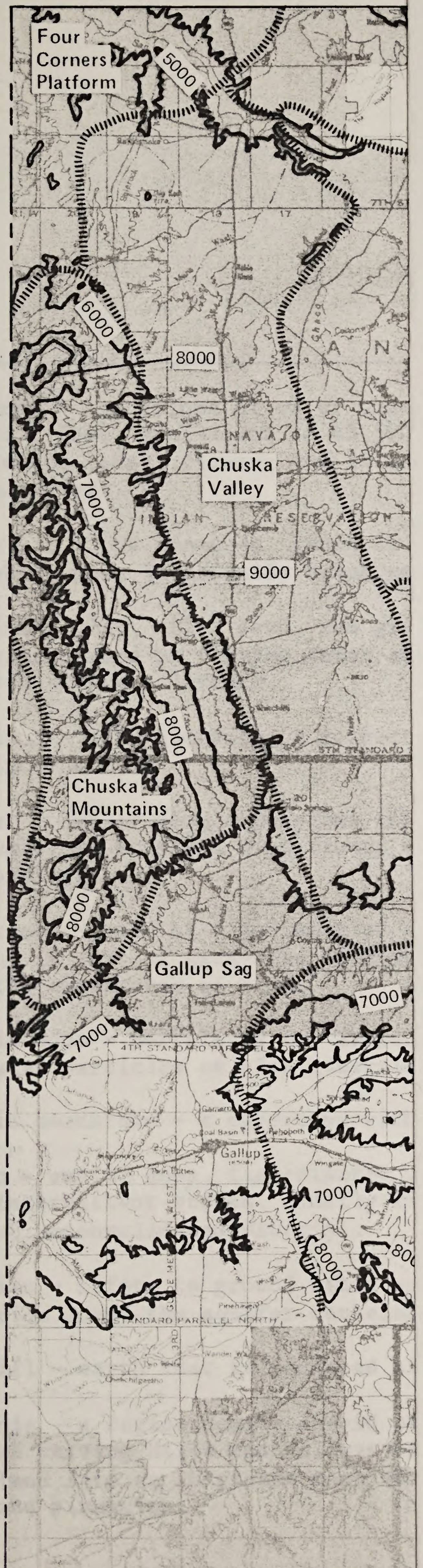


FIGURE 1—Locations of earthquakes reported prior to 1962 with maximum intensities of V or greater. Also shown on the map are the major physiographic provinces in New Mexico.



PHYSIOGRAPHY OF THE STUDY AREA

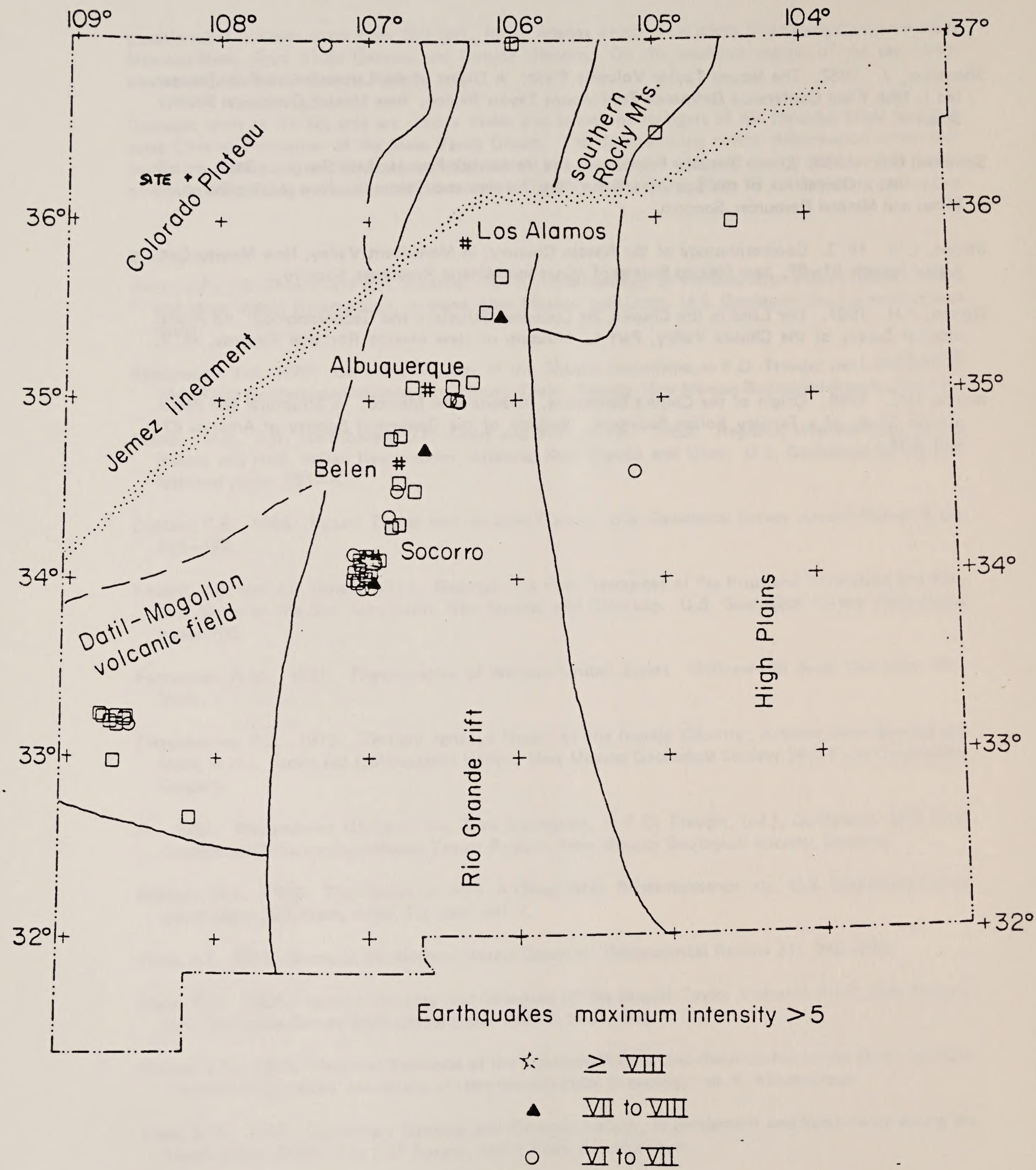
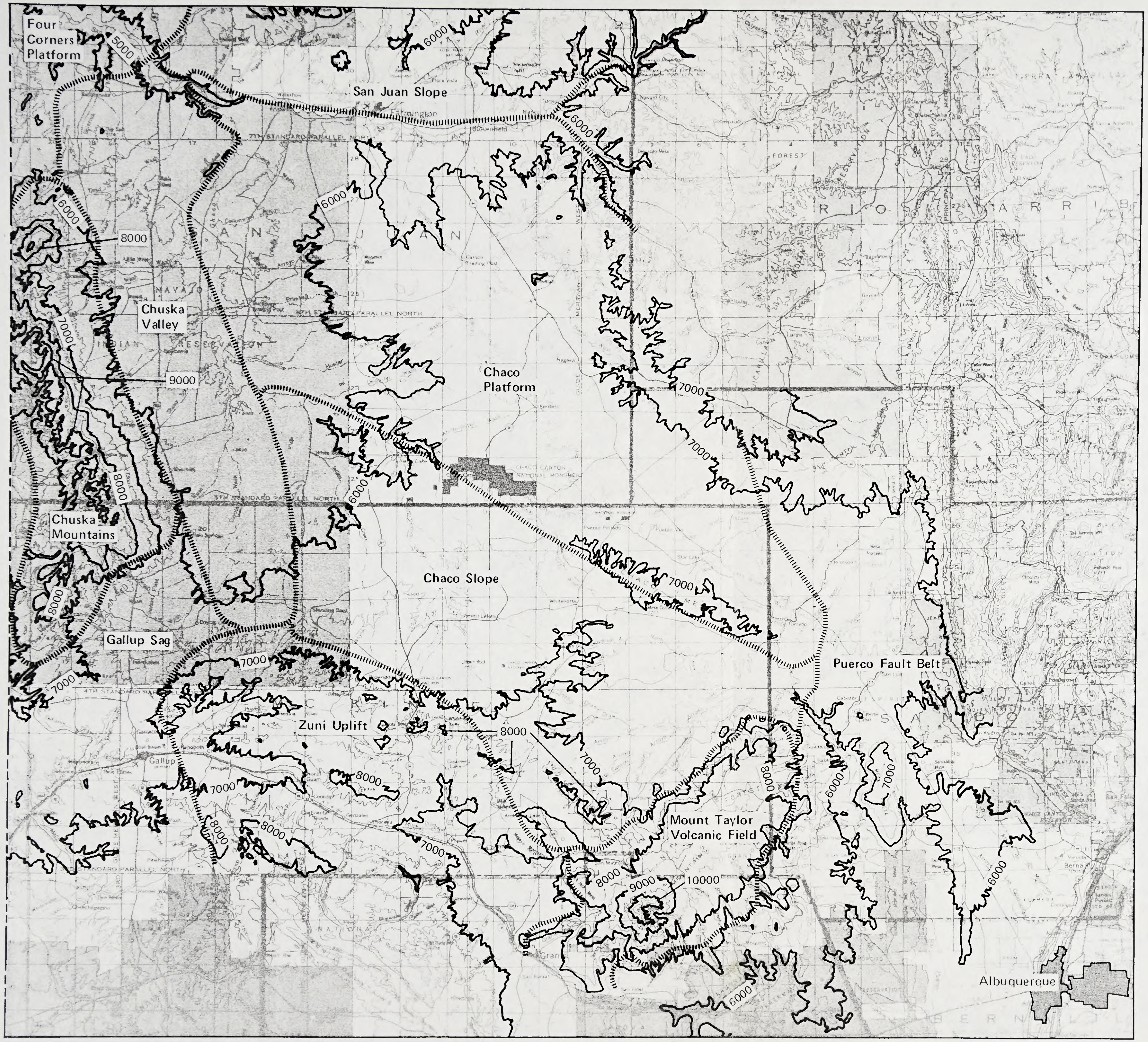
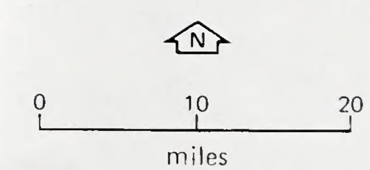


FIGURE 1—Locations of earthquakes reported prior to 1962 with maximum intensities of V or greater. Also shown on the map are the major physiographic provinces in New Mexico.





PHYSIOGRAPHY OF THE STUDY AREA

GLOSSARY

Acre-foot - the volume of water that would cover 1 acre to a depth of 1 foot, equivalent to 43,560 cubic feet. One cubic foot per second (cfs), flowing for 24 hours, is equivalent to 1.983 acre-feet.

Active pit - the elongate trench or opening in a surface mine from which coal is actually being extracted.

Alluvium - clay, silt, sand, and gravel or other rock material transported by flowing water and deposited as sorted or semisorted sediments.

Andesitic - like andesite, a dark-colored, fine-grained extrusive igneous rock.

Aquifer - one or more formations that contain sufficient permeable material to yield significant quantities of water to wells and springs.

Arenaceous - said of a sediment or sedimentary rock consisting wholly or in part of sand-size fragments or having a sandy texture or the appearance of sand.

Argillaceous - pertaining to, largely composed of, or containing clay-size particles or clay minerals.

Arkosic sandstone - a sandstone with considerable feldspar.

Arroyo - small, deep, flat-floored channel or gully of an ephemeral or intermittent stream, usually with vertical or steeply cut banks of unconsolidated material.

Artesian - refers to ground water under sufficient hydrostatic head to rise above the aquifer containing it.

Backfill - earth that is replaced after a construction excavation.

Badlands - a region nearly devoid of vegetation where erosion, instead of carving hills and valleys of the ordinary type, has cut the land into an intricate maze of hollow ravines and sharp crests and pinnacles.

Basin (struc. geol) - a syncline that is circular or elliptical in plan, i.e., the outcrop of each formation is essentially circular or elliptical and the beds dip inwards.

Bedrock - a general term for the rock, usually solid, that underlies soil or other consolidated, superficial material.

Blade (verb) - smooth-out ground surface with blade of bulldozer or grader.

Borrow area - area from which earth material is obtained for use elsewhere.

Calcarenite - a limestone consisting predominantly (more than 50%) of detrital calcite particles of sand size.

Calcareous - said of a substance that contains calcium carbonate.

Carbonaceous - said of a sediment containing organic matter.

Cathodically protected - protected against corrosion by means of a weak electric current applied to the pipeline to offset the galvanic action causing metal corrosion.

Clastic - consisting of fragments of rocks or of organic structures that have been moved individually from their places of origin.

Claystone - an indurated clay having the texture and composition of shale but lacking its fine lamination or fissility.

Coal gasification - the process of coal mining and the subsequent chemical conversion to a high-Btu, clean-burning, sulfur-free, substitute natural gas (SNG).

Coal reserve - that portion of the identified coal resource that can be economically mined at the time of determination. The reserve is derived by applying a recovery factor so that components of the identified coal resource are designated as the reserve base.

Coal resource - concentrations of coal in such forms that economic extraction is currently or may become feasible.

Colluvium - loose, unconsolidated clay, silt, sand, and gravel at the foot of a slope, brought there chiefly by gravity.

Conductance (or specific conductance) - a measure of the ability of water to conduct an electrical current, expressed in micromhos per centimeter at 25°C. Conductance serves as an index to the concentration of dissolved solids in water.

Confined ground water - is under pressure significantly greater than atmospheric, and its upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than that of the material in which the confined water occurs.

Confining bed - a body of "impermeable" material stratigraphically adjacent to one or more aquifers.

Conformable - strata characterized by an unbroken sequence in which the layers are formed in parallel order by regular uninterrupted disposition under the same general conditions, also the contacts between such strata.

Contact - a plane or irregular surface between two types or ages of rock.

Continental divide - a drainage divide that separates streams flowing toward opposite sides of a continent.

Cretaceous - the final period of the Mesozoic era thought to have covered the span of time between 135 and 65 million years ago.

Cut-and-fill - excavation and grading operation entailing achievement of uniform grade by moving excess material from hills into valleys.

Decommissioning - the act of taking a power generating or industrial facility out of service, sometimes referred to as mothballing.

Deposition - the constructive process of laying, placing, or throwing down of any kind of rock material.

Dike - berm or embankment designed to contain a body of water.

Dip - the angle that a structural surface makes with the horizontal, measured in the vertical plane.

Displacement - a general term for the relative movement of two sides of a fault, measured in a chosen direction.

Dissected plateaus - a plateau in which a large part of the original surface has been deeply cut by streams.

Dome - an uplift or anticlinal structure in which rocks dip away in all directions.

Drainage - the pattern and manner in which the waters of an area pass or flow off by surface streams or subsurface conduits.

Dune - a low mound, ridge, or hill of wind blown granular material.

Effluent - the mixture of substances, gases, liquids, and suspended matter discharged into the atmosphere (or ground, river, ocean) as the result of a given process.

Emission - a substance, whether gaseous or particulate, released by human activity into the air or water.

Eolian - erosion and deposition performed by wind action.

Epeiric - applied to shallow seas that cover or have covered large parts of continents without being disconnected from the ocean.

Ephemeral stream - a stream or reach of a stream that flows briefly only in direct response to precipitation in the immediate locality and whose channel is at all times above the water table.

Epoch - a geologic-time unit longer than an age and shorter than a period during which the rocks of the corresponding series were formed.

Erosion - the general process or processes whereby rock material is loosened, dissolved, or worn away, and simultaneously moved from one place to another by natural agencies.

Extrusive - igneous rock that has been erupted on the surface of the earth; includes lava and pyroclastic rock.

Facies - the aspect belonging to a geologic unit of sedimentation, including mineral composition, type of bedding, fossil content, etc.; also, a stratigraphic body as distinguished from other bodies of differing appearance or composition.

Fault trace - the surface expression of a fault plane.

Floodplain - lands that are periodically covered by flood waters.

Fluvial - produced by the action of a stream or river.

Formation - a persistent body of rock having easily recognizable boundaries that can be traced in the field.

Friable - a rock or mineral that crumbles naturally or is easily broken, pulverized, or reduced to powder.

Gamma-ray log - a bore-hole measurement of gamma rays originating from the rock formation to a detector shielded from the source. The amount of scattering is proportional to electron density and thus proportional to mass concentration so that the measurement, after certain corrections, yields a density log of the formation penetrated.

Geologic unit - a recognizable rock unit based either on its lithologic (mappable) or its time-stratigraphic characteristics; a discrete body of rock recognizable by unique characteristics.

Ground water - that part of the subsurface water that is the zone of saturation, supplies water to wells, and provides water that sustains the low flow of perennial streams.

Grouting - injection of soil or rock with chemicals, cement, or other materials to improve the strength or reduce the permeability.

Gypsum - widely distributed mineral, hydrous calcium sulfate $CaSO_4 \cdot 2H_2O$, associated with evaporites.

Holocene - an epoch of the Quaternary period covering the span of time from 8 thousand years ago to the present.

Hydraulic conductivity - the volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hydraulic gradient - the change in static head per unit of distance in a given direction.

Intake - the place at which a liquid (primarily water) is taken into a pipe, channel, etc.

Intermittent stream - (a) a stream or reach of a stream that drains a watershed of at least 1 square mile, or (b) a stream or reach of a stream that is below the local water table for at least some part of the year, and obtains its flow from both surface runoff and ground-water discharge.

Intrusive - an igneous rock solidified, never having been extruded onto the earth's surface.

Joint - a surface of fracture or parting on which no displacement has occurred. The surface is usually a plane, and generally occurs with parallel joints to form a joint set.

Jurassic - the second period of the Mesozoic era thought to have covered the time span between 190 and 135 million years ago (see Table G-1).

Lacustrine - pertaining to, produced by, or formed in a lake or lakes.

Landslide - a general term covering a wide range of landforms and processes involving the downslope, under gravitational influence, of soil and rock material en masse.

Table G-1. GEOLOGIC TIME CHART

Era	Period	Epoch	Beginning of interval. Approximate number of years before present.	Approximate length of interval in years.
Cenozoic	Quaternary	Holocene	11,000	11,000
		Pleistocene	1.8 million	1.8 million
	Tertiary	Pliocene	7 million	5.2 million
		Miocene	26 million	19 million
		Oligocene	38 million	13 million
		Eocene	54 million	16 million
		Paleocene	65 million	11 million
Mesozoic	Cretaceous		136 million	71 million
	Jurassic		195 million	59 million
	Triassic		225 million	30 million
Paleozoic			570 million	345 million

*Adapted from "Major Stratigraphic and Time Divisions," Geologic Names Committee, U.S. Geological Survey, 1972.

Liquefaction - the transformation of a solid to a liquid state as a result of increased pore pressure and reduced effective stress.

Lithologies - the physical character of rocks including color, mineralogic composition, and grain size.

Littoral beach deposit - the gravel, sand, and other material dropped on a shoreline between the high- and low-water lines.

Mesa - a very broad, flat topped, usually isolated hill or mountain of moderate height bounded on at least one side by a steep cliff or slope and representing an erosional remnant.

Mesozoic - an era of geologic time, spanning the time period between about 225 to 65 million years ago (see Table G-1).

Mineral reserve - that portion of the identified resource from which a usable mineral or energy commodity can be economically and legally extracted at the time of determination.

Mineral resource - a concentration of naturally occurring solid, liquid, or gaseous materials in or on the earth's crust in such form that economic extraction of a commodity is currently or potentially feasible.

Modified Mercalli Scale - an earthquake <u>intensity</u> scale with twelve divisions, ranging from I (not felt by people) to XII (damage nearly total).

Monocline - a local steeping in an otherwise gentle uniform dip.

Mudstone - an indurated mud having the texture and composition of shale, but lacking its fissility or fine lamination.

Neck - a vertical, pipe-like intrusion that represents a former volcanic vent. This term generally refers to the form as an erosional remnant.

Normal fault - a fault in which the hanging wall appears to have moved down in relation to the foot wall.

Overburden - the earth, rock, and other materials that lie above a mineral deposit.

Paleocene - an epoch of the early Tertiary period and the corresponding worldwide series of rock (see Table G-1).

Paleontology - a science that deals with the life of past geological periods and is based on the study of fossil remains of plants and animals.

Percolation - slow movement of water through small openings within porous material such as sandstone.

Perennial stream - a stream or part of a stream that flows continuously during all of the calendar year as a result of ground water discharge or surface runoff. The term does not include intermittent stream or ephemeral stream.

pH - a number that represents the negative logarithm, base 10, of the hydrogen-ion activity of a solution. A pH less than 7 indicates an acid solution; a pH greater than 7 indicates an alkaline solution.

Plateau - a comparatively flat area of great extent and elevation commonly limited on at least one side by an abrupt descent.

Pleistocene - an epoch of the Quaternary period and the corresponding series of rock between 2-3 million and 8 thousand years ago.

Pliocene - an epoch of the Tertiary period and the corresponding series of rock (see Table G-1).

Porosity - the property of a rock or soil of containing interstices or voids and may be expressed as the ratio of the volume of its interstices to its total volume.

Potentiometric surface - the surface which represents the static head of water. The levels to which water will rise in tightly cased wells. Water table is a particular potentiometric surface.

Quaternary - the second period of the Cenozoic era as well as the corresponding system of rocks. It began two to three million years ago and extends to the present (see Table G-1).

Regressive - pertaining to a retreat or contraction of the sea from land areas.

Relief - the elevations or differences in elevation, considered collectively, of a land surface.

Reserve - that portion of the identified coal resource that can be economically mined at the time of determination.

Reservoir - a subsurface volume of rock that has sufficient porosity and permeability to permit the accumulation of crude oil or natural gas under adequate trap conditions (petroleum). An artificial or natural storage place for water, such as a lake or pond, from which water may be withdrawn (water).

Resistivity - that factor of the resistance of a conductor (depending on the material and its physical condition) to an electrical current traversing it longitudinally.

Riparian - of, on, or pertaining to the bank of a river or stream, or a pond or lake.

Riprap - a foundation or sustaining wall of stones (as on an embankment slope) to prevent erosion.

Rockfall - the relatively rapid free falling movement of rock from a cliff or other steep slope.

Runoff - that part of precipitation appearing in surface streams.

Saline - a general term of the naturally occurring soluble salts, such as common salt, sodium carbonate, sodium nitrate, potassium salts, and borax.

Sandstone - any clastic sedimentary rock containing individual particles that are visible to the unaided eye or slightly larger.

Saturated zone - the zone of saturation; a subsurface zone below which all rock pore space is filled with water.

Sediment - solid fragmental material that originates from the weathering of rocks.

Sedimentation - the process of forming or accumulating sediment in layers.

Sedimentary - rocks that are formed by the deposition of a sediment.

Seismicity - measure of frequency of earthquakes.

Semi-arid - characterized by light rainfall and high evaporation: having from about 10 to 20 inches of annual precipitation.

Shale - a fine-grained sedimentary rock formed by the consolidation of clay silt or mud. It is characterized by a finely laminated structure which imparts fissility parallel to bedding.

Siltation - the deposition or accumulation of silt that is suspended throughout a body of standing water.

Siltstone - an indurated silt having the texture and composition of shale but lacking its fine lamination or fissility.

Slope angle - the angle that a sloping surface makes with the horizontal, measured in the vertical plane.

Slope stability - the resistance of a natural or artificial slope or other inclined surface to failure by landsliding.

Sludge - a semifluid, slushy, murky mass of sediment resulting from treatment of water, sewage, or industrial and mining wastes.

Soil (engineering geology) - all unconsolidated materials above bedrock; (soil geology) the natural medium for growth of land plants.

Specific capacity - the rate of discharge of a well divided by the drawdown of water level within the well.

Specific yield - the volume of water which a rock or soil, after being saturated, will yield by gravity divided by the volume of the rock or soil. The definition implies that gravity drainage is complete.

Spoil (coal) - debris or waste material from a coal mine.

Strata - layers of sedimentary rock visually separable from other layers above and below.

Stratigraphic trap - a trap for oil or gas that is the result of lithologic changes rather than structural deformation.

Stratigraphy - the branch of geology that studies the arrangement of strata, especially as applied to geographic position and chronologic order or sequence.

Strike - the course or bearing of the outcrop of an inclined bed or structure on a level surface; the direction or bearing of a horizontal line in the plane of an inclined stratum, joint, fault, cleavage plane, or other structural plane. It is perpendicular to the direction of the dip.

Structural trap - a trap for oil and gas that is the result of folding, faulting, or other deformation.

Subbituminous coal - a black coal intermediate in rank between lignite and bituminous coals.

Subsidence - movement in which surface material is displaced vertically downward.

Substrate - soil, organic, and/or rock materials found on the bottom of aquatic habitat.

Syncline - a fold that is generally concave upward, of which the core contains the stratigraphically younger rocks.

Tectonic - a branch of geology dealing with the regional assembling of structural or deformational features; a study of their mutual relations, origin, and historical evolution.

Tertiary - the first period of the Cenozoic era, thought to have covered the time span between 65 and 3 to 2 million years ago (see Table G-1).

Topography - the general configuration of a land surface or any part of the earth's surface, including its relief and the position of its natural and man-made features.

Total dissolved solids (TDS) - an aggregate of carbonates, bicarbonates, chlorides, sulfates, phosphates, and nitrates of calcium, magnesium, manganese, sodium, potassium, and other cations that form salts and are dissolved in water. High TDS values can adversely affect humans, animals, and plants. TDS is often used as a measure of salinity.

Trace element - a chemical element found in small quantities (less than 1 percent) in a mineral or compound.

Transgressive - pertaining to a spread of extension of the sea over land areas.

Transmissivity - the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Unconfined ground water - water in an aquifer that has a water table.

Unsaturated zone - a subsurface zone in which not all rock pore space is filled with water.

Uplift - a structurally high area in the crust, produced by positive movements that raise or upthrust the rocks.

Vent - the opening at the earth's surface through which volcanic materials are extruded.

Vuggy - applied to rocks or mineral deposits abounding in cavities (sometimes lined with mineral deposits of different composition than those surrounding the vug).

Wash - a term applied to the broad, gravelly, normally dry bed of an intermittent stream, often situated at the bottom of a canyon.

Water table - that surface in a ground-water body at which the water pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water.

Tectonic--a branch of geology dealing with the broad architecture of structural or deformational features; a study of their mutual relations, origin, and historical evolution.

Tertiary--the first period of the Cenozoic Era, thought to have covered the span of time between 65 and 1 or 2 million years ago from today.

Topography – the general configuration of a land surface or any part of the earth's surface, including its relief and the position of its natural and man-made features.

Total dissolved solids (TDS) – an aggregate of carbonates, bicarbonates, chlorides, sulfates, phosphates, nitrates, etc. of calcium, magnesium, manganese, sodium, potassium, and other cations which form salts. [illegible] inorganic salts [illegible] human, animals, and plants. TDS is often used as a measure of salinity.

Trace element – a chemical element found in small quantities in a mineral or compound.

Transpiration – [illegible] land areas.

Transmissivity – the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

Unconfined ground water – water in an aquifer that has a water table.

Unsaturated zone – [illegible] is filled with water.

Upland – a term loosely used for high land in the state, generally of positive elements that rise above the plains.

Vent – the opening at the earth's surface through which volcanic materials are extruded.

Volcanic – [illegible] deposits [illegible] less than 4 mm in diameter.

Wash – a term applied in the West to the [illegible] generally dry stream, gulley, arroyo, [illegible] bottom of a canyon.

Water table – the surface in a ground-water body at which the water pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water.

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