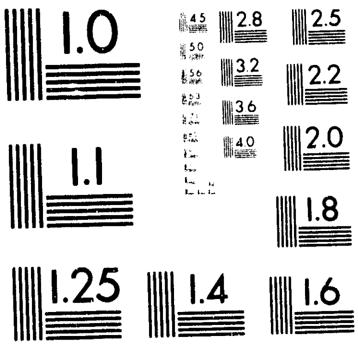
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REMEDIAL ACTION PLAN AND SITE DESIGN FOR STABILIZATION OF THE INACTIVE URANIUM PROCESSING SITE AT NATURITA, COLORADO

Remedial Action Selection Report
Attachment 2, Geology Report

Preliminary Final

August 1993

Appendix B of the
Cooperative Agreement
No. DE-FC04-81-AL16257

DOE/AL/62350-40PF

REMEDIAL ACTION PLAN AND SITE DESIGN FOR STABILIZATION OF THE INACTIVE URANIUM PROCESSING SITE AT NATURITA, COLORADO

Preliminary Final

August 1993

This report supersedes report number UMTRA-DOE/AL-050517.0000

Prepared for
U.S. Department of Energy
UMTRA Project Office
Albuquerque, New Mexico

REMEDIAL ACTION SELECTION REPORT

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AEC	Atomic Energy Commission
ALARA	as low as reasonably achievable
CDH	Colorado Department of Health
cm/s	centimeters per second
cm^2/s	square centimeters per second
DOE	U.S. Department of Energy
EA	environmental assessment
EPA	Environmental Protection Agency
ft/day	feet per day
ft^3/s	cubic feet per second
g	gram
g/cm^3	grams per cubic centimeter
km	kilometer
ME	maximum earthquake
mg/L	milligrams per liter
µg/g	micrograms per gram
µR/hr	microroentgens per hour
MK-ES	Morrison Knudsen-Environmental Services
NGDC	National Geophysical Data Center
NRC	U.S. Nuclear Regulatory Commission
pCi/g	picocuries per gram
pCi/L	picocuries per liter
pCi/m^2s	picocuries per square meter per second
PMF	probable maximum flood
PMP	probable maximum precipitation
POC	point of compliance
ppm	parts per million
RAC	Remedial Action Contractor
RAP	remedial action plan
RAS	remedial action selection report
SF&C	standard format and content
SRP	standard review plan
TAC	Technical Assistance Contractor
TAD	Technical Approach Document
t_c	time of concentration
TDS	total dissolved solids
TER	technical evaluation report
UMTRA	Uranium Mill Tailings Remedial Action
UMTRCA	Uranium Mill Tailings Radiation Control Act of 1978
USGS	U.S. Geological Survey
VCA	Vanadium Corporation of America

1.0 INTRODUCTION

The uranium processing site near Naturita, Colorado, is one of 24 inactive uranium mill sites designated to be cleaned up by the U.S. Department of Energy (DOE) under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), Public Law 95-604. Part of the UMTRCA requires that the U.S. Nuclear Regulatory Commission (NRC) concur with the DOE's remedial action plan (RAP) and certify that the remedial action conducted at the site complies with the standards promulgated by the U.S. Environmental Protection Agency (EPA). Included in the RAP is this *Remedial Action Selection Report* (RAS), which serves two purposes. First, it describes the activities that are proposed by the DOE to accomplish remediation and long-term stabilization and control of the radioactive materials at the inactive uranium processing site near Naturita, Colorado. Second, this document and the rest of the RAP, upon concurrence and execution by the DOE, the state of Colorado, and the NRC, become Appendix B of the cooperative agreement between the DOE and the State of Colorado.

1.1 EPA STANDARDS

It is the intent of the DOE, as required by the UMTRCA, to comply with EPA regulations in Subparts A through C of 40 CFR 192 in the preparation of this RAP. All remedial action planning and design considerations contained herein reflect the incorporation of this regulatory guidance. Therefore, by performing all remedial action activities in accordance with the design presented in this RAP, the DOE will meet the standards of 40 CFR 192.

On January 5, 1983, the EPA promulgated final standards for the disposal (Subpart A) and cleanup (Subpart B) of the inactive uranium processing sites under the UMTRCA (48 FR 590). The standards became effective on March 8, 1983. However, on September 3, 1985, the groundwater provisions of the regulations (40 CFR 192.20(a) (2)-(3)) were remanded to the EPA by the U.S. Court of Appeals for the Tenth Circuit. A proposed revision to the standards was issued by the EPA on September 24, 1987 (EPA, 1987). The proposed revision is the standard referred to in this document.

Under the UMTRCA, the DOE must comply with the proposed standards until the standards are promulgated in final form. As a result, remedial actions taken with regard to the Naturita and Dry Flats sites would not preclude subsequent design enhancements if needed to achieve compliance with the standards. The DOE has characterized the sites and determined that the proposed remedial action would comply with the requirements of Subpart A of the proposed EPA groundwater protection standards. Groundwater cleanup will be addressed under the groundwater remediation phase of the UMTRA Project.

The EPA regulations are summarized as follows:

- The disposal site shall be designed to stabilize and control the tailings and other residual radioactive materials for 1000 years to the extent reasonably achievable and, in any case, for at least 200 years (40 CFR 192.02(a)).

- The disposal site design shall prevent the emission of radon-222 from the residual radioactive materials to the atmosphere such that the flux rate does not exceed 20 picocuries per square meter per second (pCi/m^2s) or increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than 0.5 picocuries per liter (pCi/L) (40 CFR 192.02(b)).

- The remedial action shall be conducted to provide reasonable assurance that the concentration of radium-226 in land averaged over 100 square meters does not exceed the background level by more than 5 picocuries per gram (pCi/g) over the first 15 centimeters of soil below the surface and 15 pCi/g averaged over 15-centimeter-thick layers of soil more than 15 centimeters below the surface, as a result of any residual radioactive materials at any designated processing site (40 CFR 192.02(a)).

1.2 SITE AND PROPOSED ACTION

History

The Naturita mill was built in 1930 by the Rare Metals Company. It did not become operational until 1939, when Vanadium Corporation of America (VCA) acquired the mill and converted it to a salt-roast, water-leach process for vanadium recovery. The process was modified again in 1942 so that uranium could be extracted. At the end of World War II the mill was shut down. It reopened under contract to the Atomic Energy Commission (AEC) in 1947. Uranium concentrates were shipped to the AEC until 1958, when the mill was again shut down. From 1961 until 1963, an upgrader was operated at the site by VCA. The mill was dismantled in 1963. In 1967, VCA merged with Foote Mineral Company, and the site ownership passed to Foote.

The portion of the site occupied by the tailings was purchased by Ranchers Exploration and Development Corporation (Ranchers) of Albuquerque, New Mexico, from Foote in 1976. During 1977 through 1979, the tailings were removed by Ranchers from the site area to a heap leach processing plant located along Colorado State Highway 90, about 3 miles southwest of the intersection of Highways 90 and 141 at Vancorum (Durita facility). After reprocessing, the tailings were placed in new tailings ponds at the new location and were stabilized with 2 to 10 feet of cover material.

During the operation of the Naturita mill, 704,000 tons of ore were processed. Prior to the 1958 shutdown, the ore averaged 0.38 percent uranium oxide and 1.8 percent vanadium oxide. During the upgrader operation, ore averaging 0.25 percent uranium oxide and 1.65 percent vanadium oxide was processed. The ore came from throughout the Uravan mineral belt and from other areas

Description

The Naturita mill site is located in Montrose County, Colorado, approximately 2 miles northwest of the town of Naturita along Colorado State Highway 141. The mill site is in Section 15, Township 46 north, Range 16 west (Figure 1.1). The designated site encompasses about 53 acres that include the former tailings area, the mill facility and ore buying station, and the adjacent ore storage area (Figure 1.2). The former tailings area, which covers about 27 acres, is owned by Hecla Mining Corporation (obtained through the acquisition of Ranchers). The 14-acre mill facility and ore buying station and the 12-acre former ore storage area are owned by Cyprus Foote Mineral Company.

The designated site is multilevel, with the former tailings area at the lowest elevation of only a few feet above the streambed of the San Miguel River. An equipment and scrap material storage area is on the next higher terrace, followed in ascending order by the mill structures and shop buildings area, the ore buying area, and the former ore storage area on the west side of Highway 141. The vertical relief across the designated site is 90 to 100 feet.

Contaminated materials

The Naturita site is unique in that no tailings pile remains at the site due to the removal and reprocessing activities by Ranchers Exploration and Development Corporation (Ranchers). The contaminated materials include soils in the mill yard and ore storage area, windblown tailings adjacent to the designated site, several buildings, used mill equipment stored on the site, foundation soils in the former tailings area, and off-site vicinity property material that makes up less than 0.1 percent of the contaminated materials to be stabilized.

The quantities of contaminated materials that would be removed from the designated site and immediately adjacent areas are presented in Table 1.1 and are distributed as shown in Figure 1.3. The removal of these contaminated materials from the Naturita processing site will satisfy the EPA standards in 40 CFR 192. However, it is logical to consider applying the supplemental standards provisions of 40 CFR 192 to adjacent windblown areas and portions of the designated processing site where the following justifications are met: cleanup would be costly and difficult because of the steep slopes and rocky terrain; the windblown material does not pose a health risk; major environmental impacts would occur because of cleanup; or workers would be exposed to unsafe conditions. Areas where the use of supplemental standards will be considered are areas D, F, and G on Figure 1.3, riverfront wetlands on both banks of the San Miguel River, and an area containing a high-pressure gas pipeline. An appropriate application will be developed and submitted for agency concurrence. The current design includes the remediation of these areas; therefore, the design will be revised when and if the supplemental standards applications are approved.

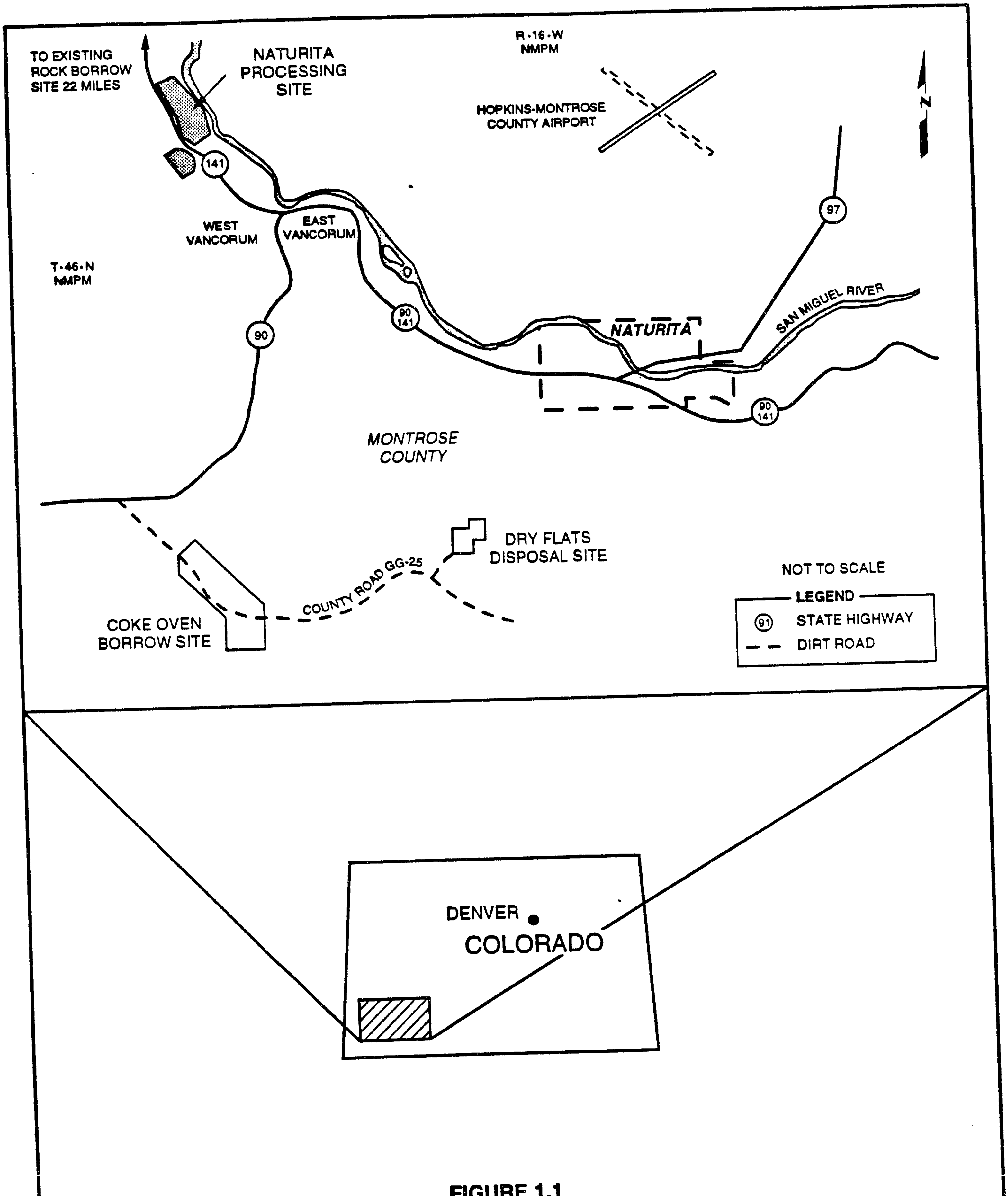

FIGURE 1.1
LOCATION OF THE NATURITA SITE, COLORADO

MAC: SITE RELATED/NAT/RAP/SITE LOC MAP

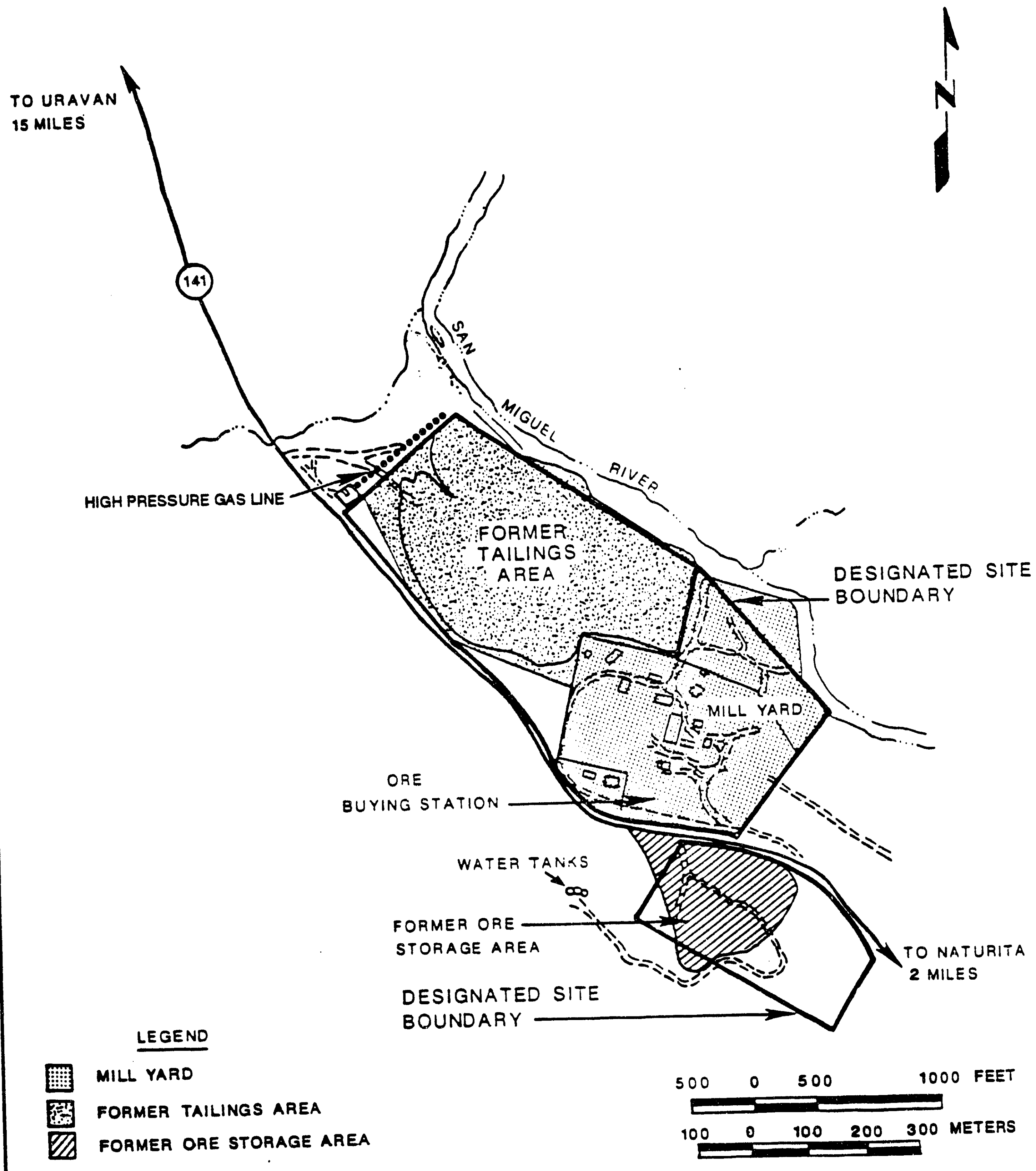

FIGURE 1.2
PRESENT CONDITIONS AT THE NATURITA SITE, COLORADO

Table 1.1 Contaminated material volume at the Naturita site, Colorado

Location[a]	Area (acres)	Volume	Radium-226 (pCi/g)
Mill yard	14	115,000	127
Former ore storage area	12	12,000	75
Windblown/other material (areas A through G)	196	295,000[b]	37.7[d]
Former tailings area	27	117,000	90
Demolition debris		8,000[c]	
TOTAL	249	547,000	

[a]See Figure 1.3.
[b]Design volume estimate contains a 25 percent contingency.
[c]Design volume estimate contains a 50 percent contingency.
[d]Volume-weighted average of subareas A through G.
pCi/g = picocuries per gram.

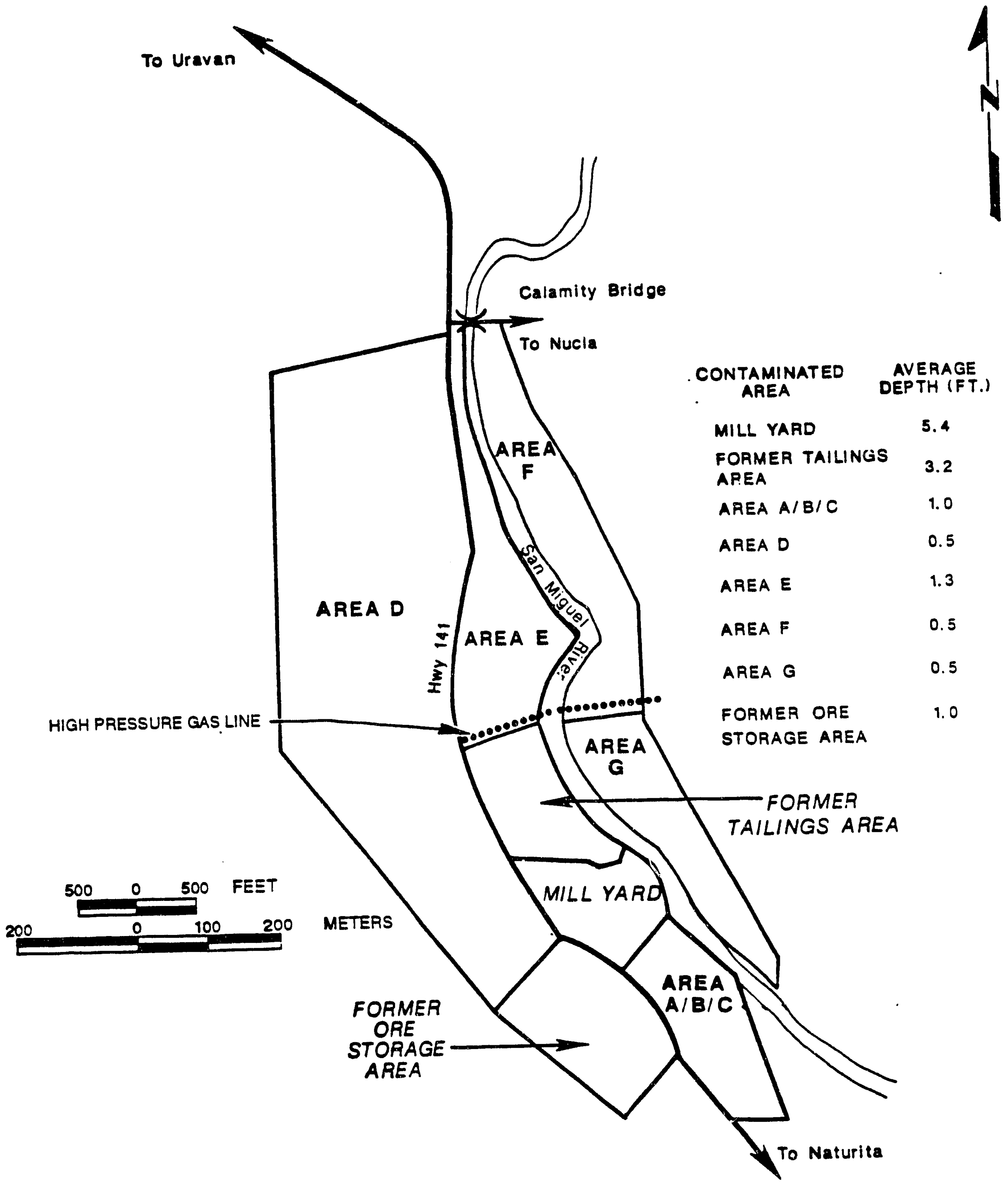

FIGURE 1.3
EXTENT OF CONTAMINATION AT THE NATURITA SITE, COLORADO

Remedial action

The proposed remedial action for the disposal and stabilization of the contaminated materials is to relocate them to the Dry Flats disposal site, shown on Figure 1.4. The Dry Flats disposal site is approximately 6 road miles southeast of the Naturita processing site.

The disposal cell will be configured as shown in Figure 1.5, and a typical cross section is shown on Figure 1.6. The proposed layout for the disposal cell is prismatoid and is designed so that all on-pile runoff will flow off and away from the pile. To protect the toe of the pile against erosion, an apron consisting of 7- to 12-inch diameter erosion-resistant rock will be placed around the perimeter. The disposal cell will be located slightly to the east of a drainage divide and will therefore be subject to only minor amounts of off-site runoff plus the runoff from the surface of the disposal cell. The riprap apron will be constructed to intercept this runoff and convey it off the site into existing natural drainage ways. The design for the disposal cell topslope and sideslope cover will be as follows, in descending order: 1) a 12-inch-thick rock riprap layer; 2) a 6-inch bedding layer; 3) a 36-inch frost protection layer; and 4) an 18-inch radon/infiltration barrier. The radon/infiltration barrier on both the top and sides will consist of low permeability materials placed over the relocated, contoured, and compacted contaminated materials and will inhibit radon emanation and infiltration of water into the tailings.

All areas excavated and disturbed will be recontoured to promote positive drainage. Areas outside the final restricted area will eventually be released for use upon completion of the remedial action.

1.3 SCOPE AND CONTENT

This RAS report describes the proposed remedial action for the Naturita site. An extensive amount of data and supporting information has been generated and evaluated for this remedial action. These data and supporting information are not incorporated into this single document but are included or referenced in the supporting documents. An additional summary of the proposed remedial action is presented in Attachment 1, *Information for Reviewers, Final Design for Review, UMTRA Project, Naturita, Colorado.* The RAP consists of this RAS and the following supporting documents:

Attachment 1: Specifications, design drawings, calculations, information for reviewers, information for bidders, and subcontract documents contain detailed information on the remedial action design. Attachment 1 includes the following documents:

- *Subcontract Documents, Final Design for Review.*
- *Information for Reviewers, Final Design for Review.*
- *Calculations, Final Design for Review,* Volumes I-IV.
- *Information for Bidders, Final Design for Review,* Volumes I-IV.

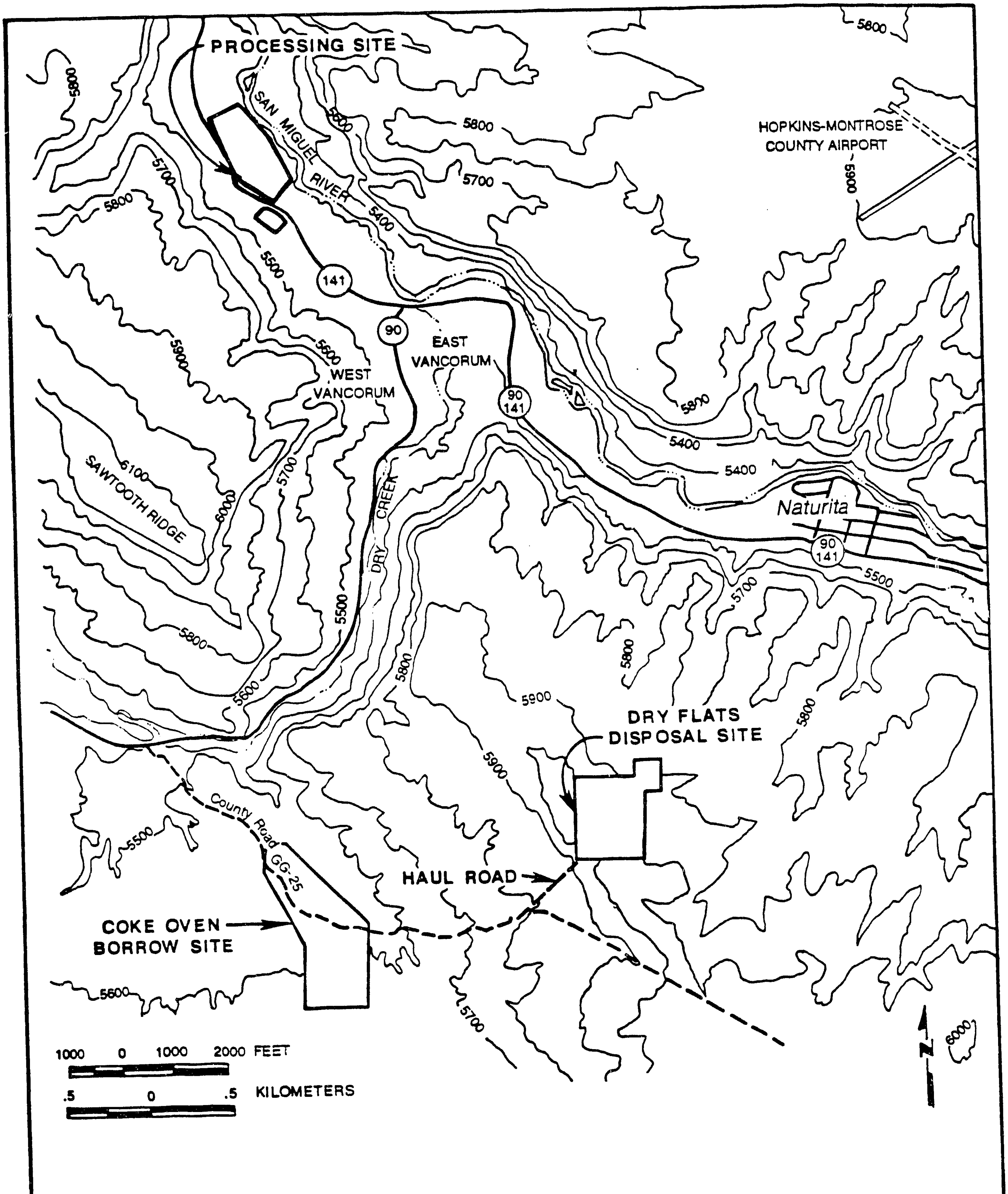

FIGURE 1.4
LOCATION OF THE DRY FLATS DISPOSAL SITE, COLORADO

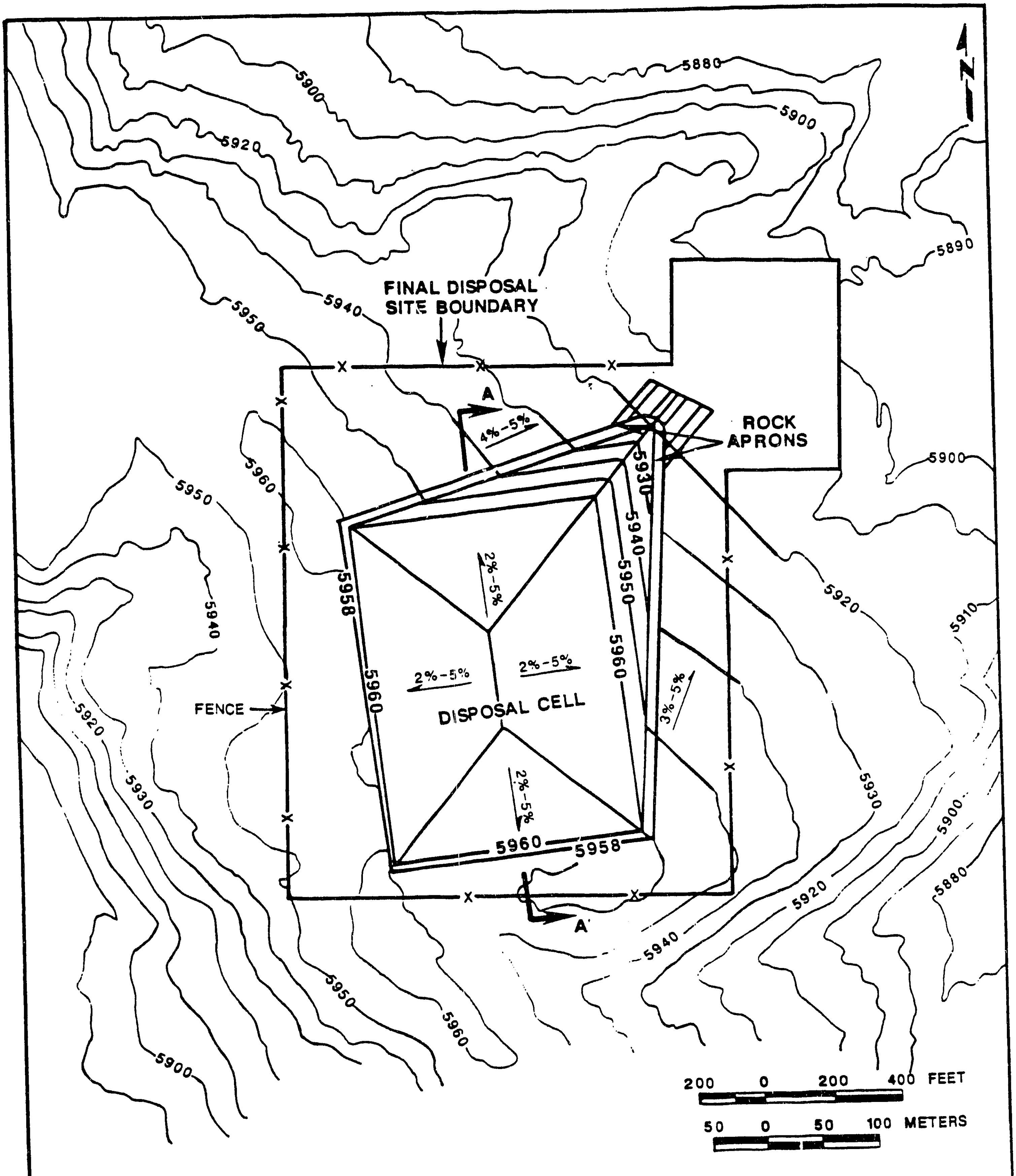

FIGURE 1.5
FINAL CONDITIONS AT THE DRY FLATS DISPOSAL SITE, COLORADO

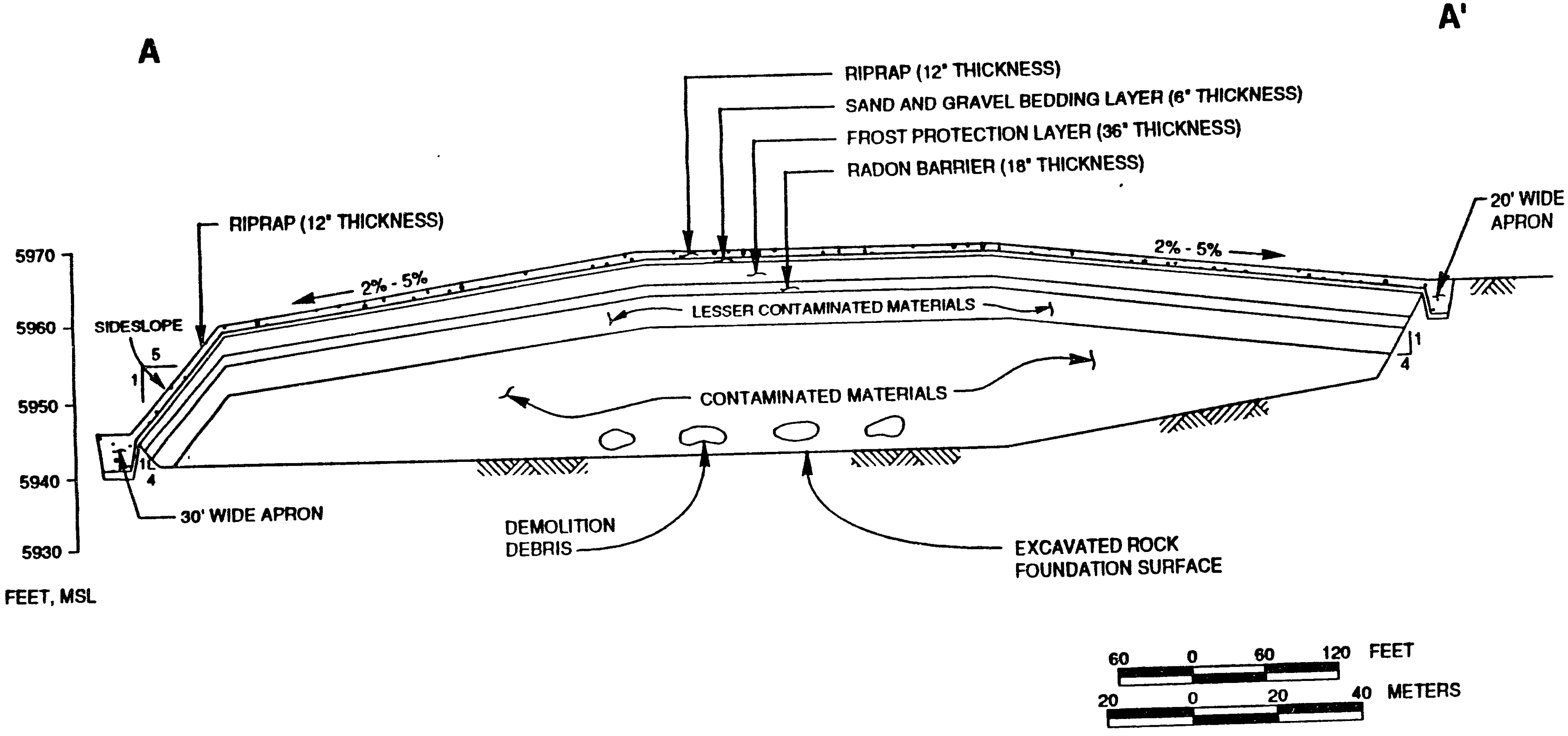

FIGURE 1.6
TYPICAL CROSS SECTION
OF THE DRY FLATS DISPOSAL SITE, COLORADO

MAC: SITE/NAT/RAP/TYPX-SEC

Attachment 2: *Geology Report*; describes the details of geologic, geomorphic, and seismic conditions at the Dry Flats disposal site.

Attachment 3: *Groundwater Hydrology Report*; describes the hydrogeology, water quality, and water resources at the processing site and Dry Flats disposal site and includes the Hydrological Services calculations.

Attachment 4: *Water Resources Protection Strategy*; describes how the remedial action will be in compliance with the proposed EPA groundwater standards.

These reports provide data, analysis, and a more detailed description of the various aspects of the RAP.

1.4 COLLATERAL DOCUMENTS

The environmental assessment (EA) of the Naturita remedial action describes existing conditions at the processing and disposal sites and the environmental impacts of the remedial action. The EA summarizes the proposed remedial action, the alternatives, and the associated environmental impacts and includes environmental details not reported in the RAP.

The *Technical Approach Document* (TAD) (DOE, 1989a) describes the technical approaches and procedures used on the Uranium Mill Tailings Remedial Action (UMTRA) Project. Contained in the document are discussions on major technical areas; design considerations; surface water hydrology and erosion control; geotechnical aspects of the disposal cell design; radiological issues, in particular as they pertain to the radon barrier; and the protection of groundwater resources.

Copies of these documents, as well as supporting data and calculations for the Naturita project, are on file in the UMTRA Project Office in Albuquerque, New Mexico.

1.5 RAS ORGANIZATION

Section 2.0 through Section 6.0 of the RAS have been organized by technical disciplines. The compilation and presentation of information contained in this RAS have been modeled after the approach taken in the NRC's site technical evaluation reports (TER). The RAS has been formatted in accordance with the requirements of the NRC's standard format and content (SF&C) guide for documentation as applicable to the UMTRA Project site (NRC, 1989). This document has been generated to facilitate the NRC's preparation of a TER for the proposed remedial action at the Naturita site. The RAS does not contain any of the design details of the proposed remedial action. However, the design details or criteria are available in supporting documents, reports, drawings, specifications, and calculations, which are summarized in Table 1.2.

Table 1.2 Design details or criteria

Design detail or criterion	Calculation number	Title	Remarks
Pile location	---		Contaminated materials from the Naturita mill site and surrounding areas will be relocated to a disposal cell at the Dry Flats site.
Pile layout	17-730-01-01 Vol I	Radiological Characterization - Excavation Plan and Quantities	The disposal cell will be constructed abovegrade; it will have a footprint of about 22 acres. The maximum height of the cell above existing ground surface will be about 40 feet. Top of pile slopes at 2 to 5%. Sides slope at 5H:1V.
	17-740-04-00 Vol II	Disposal Cell Capacity	
Geomorphology	Attachment 2	Geology Report	The disposal cell is located adjacent to a drainage divide; this results in minimal off-site flow. Thus, the potential of gully formation that could undercut into the disposal cell apron is minimized. In addition, the apron is keyed into the bedrock, which is located within 2 feet of the ground surface. Also see remarks under Surface Water.
Seismicity	Attachment 2	Geology Report	M_L = 7.1, 14.9 miles from site. On-site peak horizontal acceleration = 0.25 g (a_{max}).
Hydrogeology	Attachment 3	Groundwater Hydrology Report	See other related items under Radon/Infiltration Control.
Surface water	17-723-01-01 Vol. I	Disposal Site Hydrology, PMP Analysis	The design basis for all permanent drainage facilities at the Dry Flats disposal site is the PMP.
	17-723-01-01 Vol. I	Processing Site, Flood Studies - San Miguel River Flooding Extent	The design basis for all drainage facilities at the processing site is the 10-year storm.
Geotechnical	17-737-01-01 Vol. II	Design Geotechnical Parameters for Materials at Dry Flats Disposal Site	Data used for stability and settlement analysis.

Table 1.2 Design details or criteria (Continued)

Design detail or criterion	Calculation number	Title	Remarks
Geotechnical (continued)	17-740-01-01 Vol II	Disposal Cell Design - Slope Stability Analysis, Liquefaction Analysis	Slope factors of safety are adequate. There is no liquefaction potential at the disposal site as pile is founded on bedrock.
	17-740-02-01 Vol. II	Disposal Cell Design - Settlement and Radon Barrier Cracking Potential	Total and differential settlements are relatively small and will not adversely affect the embankment.
	17-741-03-01 Vol. III	Disposal Cell - Frost Penetration Depth	The cover layers provide adequate frost protection to the radon barrier.
Radon/Infiltration Control	17-741-02-01 Vol. III	Disposal Cell Design - Radon/ Infiltration Barrier Thickness	The radon/infiltration barrier thickness provided will adequately reduce radon emission from the disposal cell under the following conditions: • Contaminated materials with the lowest level of radium content (in pCi/g) will be placed adjacent to the top and sideslopes of the cell. • Contaminated materials with higher radium content will be placed away from top and sideslopes and toward inner cell.
Erosion barrier	17-744-01-00 Vol. III	Inventory and Test of Rock Sources Suitable for Use as Riprap Erosion Protection at Dry Flats Site	This study identifies the most economical rock sources that can provide the required size and quantity and also pass the NRC quality criteria.
	17-739-02-01 Vol. I	Erosion Protection - Disposal Cell	D_{50} min. rock sizes calculated for disposal cell sideslope and topslope.
	17-739-03-01 Vol. I	Disposal Cell - Riprap Toe Protection	D_{50} min. rock sizes calculated for apron and key trench.
	17-739-04-01 Vol. I	Riprap Gradation and Layer Thicknesses	Gradation limits of rock riprap and drainage/filter layers calculated.

Table 1.2 Design details or criteria (Concluded)

Design detail or criterion	Calculation number	Title	Remarks
Construction	17-706-01-01 Vol. IV	Construction Water Requirements	Estimates of construction water requirements at the Naturita processing site and the Dry Flats disposal site.
	17-717-01-00 Vol. I	Construction Activities - Construction Sequence and Approach	
	17-748-05-00 Vol. IV	Transportation Route - Culvert Design at Dry Creek Crossing	
	17-725-03-01 Vol. IV	Disposal Site Surface Water Control - Temporary Drainage Ditches and Wastewater Retention Basin	

PMP - probable maximum precipitation.

2.0 GEOLOGIC STABILITY

This section presents the data and analyses that show that the DOE has adequately characterized the Dry Flats disposal site with regard to the impact of geologic conditions on the long-term performance objectives of the remedial action as defined by 40 CFR Part 192.02.

The EPA standards listed in 40 CFR Part 192 do not include generic or site-specific requirements for the characterization of the geological conditions at UMTRA Project sites. Rather, 40 CFR Part 192 requires the stabilization and control of the tailings to be effective for 1000 years to the extent achievable, and in any case for at least 200 years. For this long-term stability to be achieved, certain geologic performance objectives must be met. For example, as noted in the NRC standard review plan (SRP) (NRC, 1985), information is required about the basic regional and site geology and stratigraphy. This information is required as a basis for the geotechnical and groundwater aspects of the disposal cell performance evaluation described in Sections 3.0 and 5.0. An evaluation of the potential for geomorphic hazards is required, and the DOE should show that potential geomorphic change will not affect the site or the disposal cell's integrity for its design life. The geological characterization of the site should provide estimates of earthquake-induced ground accelerations that could occur at the site, as well as the potential for other types of tectonic hazards that could affect the disposal cell's performance. In addition, geological site characterization must also demonstrate that future resource development will not adversely affect the disposal cell stability over the design life. Additional criteria contained in the TAD (DOE, 1989a) form the basis of the work described in this document and the evaluation of the adequacy of the site and regional geology.

2.1 SCOPE OF WORK

Detailed investigations of geologic, geomorphic, and seismic conditions at the site were conducted by the Technical Assistance Contractor (TAC). The geologic investigations were carried out in accordance with the procedures and approaches described in the TAD (DOE, 1989a) in order to gather the data specified in the NRC SRP and SF&C guide. These investigations included, but were not limited to, the compilation and analysis of previously published and unpublished geological literature and data; the review and analysis of historical and instrumental seismic data; geological field mapping and observations; refraction seismic surveys; the review of site-specific subsurface geologic and geotechnical data, including borehole logs and samples from boreholes, test pits, and analysis of stereo-pair aerial photographs; and studies of previous work. Details of the data gathering and interpretation procedures are provided in the documents referenced in this section.

Special attention was given to the geologic potential for ground rupture and exposure of seepage downdip because they were identified as the most significant features likely to affect the disposal cell's long-term stability.

2.2 REGIONAL GEOLOGY

A description of the regional geology is required to provide a background of the detailed site geology. As noted in the NRC SRP, the regional geology must be defined in sufficient detail to provide a clear perspective and orientation to site-specific subsurface information.

The DOE has characterized the regional geologic conditions in Attachment 2, the site *Geology Report*, and in the TAD (DOE, 1989a). Most of this information was derived from published studies referenced in the report.

For the purpose of this characterization, the site region is defined as the area within a 40-mile radius of the disposal site on the basis of relevant seismic attenuation distance.

2.2.1 Regional physiography

The Dry Flats site region is in the Canyon Lands subprovince of the Colorado Plateau. The Canyon Lands are characterized by deeply incised drainages, isolated mesas, and gently dipping strata. Elevations in the site region range from 5000 to 7500 feet above mean sea level.

As required in the NRC SF&C guide (NRC, 1989), the following criteria and descriptions are the main physiographic features of the region.

- Type of geomorphic surface surrounding the site: The surface topography results from resistant outcrops of the Dakota Sandstone Formation on the crest of an anticlinal structure.
- General relief and topography of the region: The site, positioned at the top of the drainage divide, is 489 feet above the base level drainage of the San Miguel River channel on the north, while the Coke Oven Valley floor to the south is 300 feet lower than the Dry Flats site. The Dry Creek Canyon that dissects the site ridge between Coke Oven Valley and the San Miguel River is approximately 400 feet lower than the site.
- Regional drainage systems: The drainages occur in deep v-shaped valleys that have incised gently dipping Cretaceous and Jurassic sandstone and mudstone stratigraphy. Both structural control and superposed drainage systems occur in the regional drainage.
- Major regional geomorphic processes: The incision of regional drainage that accompanied uplift of the Colorado Plateau is responsible for the development of the Canyon Lands topography.

Further details of the regional physiographic setting and the basis for the above brief description are contained in Section 2.1 of Attachment 2, which describes the geomorphic land forms, the relief and topography of the region, the drainage systems, and the types and rates of the major geomorphic processes.

2.2.2 Stratigraphic setting

Bedrock in the site region consists of a thick sequence of marine and continental sedimentary rocks representing the Paleozoic and Mesozoic ages. Tertiary deposits, if any, have been entirely eroded from the region. In the northeastern portion of the region, the Uncompahgre Plateau has Middle Triassic-aged rocks resting directly on peneplained Precambrian igneous and metamorphic rocks. In the site area, the Mancos shale of Cretaceous age is the youngest rock exposed; however, it is typically eroded from the higher elevations. The only Quaternary deposits are narrow strips of river terrace deposits along the incised river valleys.

Further details of the technical approach to and the results of the characterization of the regional and site stratigraphy are in Section 2.2 of Attachment 2. Figures 2.2, 2.3, and 2.7 of Attachment 2 show the lithologic characteristics at the site and within the site region for rocks of the Colorado Plateau and the unconsolidated deposits within the drainages. Table 2.1 of Attachment 2 describes the stratigraphic units. Attachment 2 shows further details of the age, name, thickness, lithology, induration, relations to adjacent units, and geographic distribution.

2.2.3 Structural setting

The Colorado Plateau is a stable intercontinental subplate having a greater thickness than the adjoining provinces. Its margins exhibit crustal structures similar to the more disturbed provinces that border it. During Precambrian time, two major shear zone systems (lineaments) were established and formed the framework that influenced the trend of subsequent structures. The Uncompahgre Uplift is aligned along the Olympic-Wichita Lineament. The Paradox Basin structure of salt core anticlines is also aligned along the trend of this lineament. The Paradox Basin was depressed as the adjoining Uncompahgre Uplift was formed during the Pennsylvanian Period. During the Laramide Orogeny at the end of the Mesozoic Period, the salt anticlines in the Paradox Basin were enhanced by compressional forces and uplift of the Uncompahgre Uplift was renewed.

The dissection of the meandering, superposed Dolores River across the structures removed overburden above the salt core, resulting in salt flow in the salt core anticlines. Salt flow toward the river incisions caused the deflation and collapse of these anticlines, creating grabens and synclinal valleys. The Uncompahgre Uplift has experienced recurrent activity since at least the end of the Paleozoic time. The latest movement apparently began during the Miocene or Pliocene and may have persisted into the Pleistocene.

Greater details of the site structural setting are described in Section 2.3 of Attachment 2. The regional structural elements (Figures 2.4, 2.5, 2.6, 2.7, 3.1, and 3.2 of Attachment 2) show the relationship of the site region to adjoining structural provinces. These documents show the structures and the current stress regime of the province within which the site lies relative to adjoining elements.

The bedrock structure of the disposal site foundation is described in Attachment 2, Section 3.1, and illustrated in Attachment 2, Figures 3.1, 3.2, and 3.3.

2.2.4 Seismotectonics

The DOE has characterized in the local and regional structures the potential for tectonic activity that may contribute to earthquake generation and affect the suitability of the site and design as follows:

Seismicity

There has been only one earthquake recorded by the National Geophysical Data Center (NGDC) within the 65-kilometer (km) site region. This earthquake was a magnitude 4.0 event that occurred in 1970 and was located 41 km (25 miles) southeast of the site near the boundary of the Paradox Basin, the San Juan Mountains, and the Uncompahgre Uplift. There are several faults in the vicinity; however, none can be directly attributed to this recorded activity.

The earthquake data file for a radius of 300 km (186 miles) was reviewed for the seismic analysis. Because of the attenuation-distance relationship, earthquakes beyond the 65-km site region are considered but are not relevant to the design of seismic stability when a floating earthquake of magnitude 6.2 or greater is considered as a minimum design event. The maximum earthquakes for the site area and adjacent seismotectonic province are presented in Attachment 2, Table 2.2 and discussed in Attachment 2, Sections 2.4 and 4.2.

Nontectonic sources of seismic activity occur within the site region. This phenomenon is related to salt flow near deep potash mines in the Moab, Utah, area. Studies have indicated the maximum earthquake from this source could be on the order of magnitude 3.0.

The seismic record is discussed in detail in Section 2.4 of Attachment 2. This section also describes seismic activity that may be related to known or suspected fault systems (Section 4.2 of Attachment 2) and details the expected acceleration resulting from the largest regional earthquakes.

The information discussed here and in Sections 3.0 and 4.2 of Attachment 2 forms the basis of the parameters used in the design of the pile to be stable against earthquake-induced instability.

2.2.5 Resource development

To ensure that future resource development will not jeopardize the disposal cell, the occurrence of recoverable earth resources in the disposal site area must be characterized. Resources of concern are those which, if exploited, could result in inadvertent intrusion into the disposal site.

Potential economic resources in the disposal site region consist essentially of gas and oil, uranium and potash, and minor amounts of coal. The most abundant developed resource in the region has been uranium. Potash occurs in the greatest abundance, but at such depths that little development is economically feasible. The nearest economic resources are gas and oil leases that are within 1 mile of the site. A small coal strip mine is located on private land 3 miles east of the disposal site. However, there has been no development of any economic resources within the disposal site area.

Further details of the economic resources of the site and region are presented in Section 2.5 of Attachment 2. The locations of regional mineral resources are shown on Figures 2.10 and 2.11 of Attachment 2.

2.3 SITE GEOLOGY

Geological conditions at the site are characterized primarily to provide the basic information required for the geotechnical stability evaluations (Section 3.0 of Attachment 2) and for the groundwater performance assessments of the site (Section 5.0 of Attachment 2). Surficial geologic conditions are characterized to establish the geomorphic history and processes at the site and, thereby, determine that long-term stability standards will be met.

The procedures used to characterize the site geology and the details of that site characterization are contained in Sections 1.2 and 3.0, respectively, of Attachment 2. Figures 3.2 through 3.6 in Attachment 2 are presented to characterize the site geology and geomorphology by the use of topographic base maps, cross sections, and sketch drawings. Following is a brief description of the salient site geologic features:

2.3.1 Bedrock geology

The rocks underlying the site consist of sandstone and shale-mudstone of the Dakota Sandstone Formation. Further details of the bedrock at the site are described in Section 3.0 of Attachment 2 and as applicable in Section 3.3 of Attachment 2. As described in Attachment 2, the bedrock is stable and not subject to erosional or seismic instability in the future that could affect the stability of the remedial action.

A special study reported in a memo dated April 9, 1990, to C. Watson from G. Lindsey and K. Lambert presented evidence that the bedrock would not be conducive to lateral migration or seepage of contaminants from the disposal cell. A summary of the study results is incorporated in the *Groundwater Hydrology Report*, Section 3.2.3 of Attachment 3.

The bedrock materials are nonreactive with tailings effluent. The carbonaceous shales and thin coaly seams are expected to aid in attenuation of organics and metals.

2.3.2 Surficial geology

Surficial unconsolidated deposits are discussed in Section 3.2 of Attachment 2. These deposits consist of 1 to 3 feet of fine-grained sandy soils with no soil cover on high elevations or drainages, as discussed in Section 2.3.3 below and shown in Figure 3.3 of Attachment 2.

The DOE has developed detailed descriptions of the Quaternary deposit beneath the disposal site and the depositional environment as applicable to these deposits. These deposits will be removed from beneath the cell location, stockpiled, and used to regrade and revegetate the disturbed areas around the cell. Excess material may be used for fill at the processing site.

2.3.3 Geomorphology

Site geomorphology is characterized in order to confirm the stability of the current landscape and to provide reasonable assurance that the stability will be maintained for the performance period required by EPA standards. The DOE has characterized the regional and site geomorphology by reference to published literature, topographic maps, site inspections, and the procedures described in the TAD. The regional geomorphology and the site-specific geomorphology are described in detail in Sections 2.1 and 3.3, respectively, of Attachment 2. Geomorphic stability is addressed in Section 4.1 of Attachment 2. Figure 3.3 of Attachment 2 shows the geomorphic features of the site area.

The site geomorphology is controlled by the structure and lithology of the Dakota Sandstone Formation. The site is located at the drainage divide formed by the anticline structure of the ridge. Joint patterns in the bedrock have defined the position of the drainages on the slopes downdip from the site. The moderately resistant sandstone underlying the entire site will provide an effective base level of erosion over the design life of the cell.

In Section 3.3 of Attachment 2, the DOE has examined the geomorphic processes that could affect site stability and has described the geomorphic processes that determined the site's landforms and the future geomorphic processes likely to take place in the future. This characterization is considered sufficient to undertake an assessment of the geomorphic stability of the site, as described in Section 2.4.1 of this report (where the DOE confirms that there is a reasonable assurance that stability will be maintained for the performance period of the design standards).

2.4 GEOLOGIC STABILITY

This section describes the local geologic and seismic conditions likely to affect the geotechnical stability of the disposal cell and the long-term stability of the landscape environment. The analysis also considers the characteristics of unconsolidated deposits and geomorphic processes at the site that may affect the long-term stability. In general, this section shows that the site lithology, stratigraphy, and structural conditions are suitable as a foundation for the disposal cell. This section is also a basis for a performance assessment of the potential interaction of tailings leachate with the groundwater. This section demonstrates that geomorphic processes are not likely to affect the long-term stability of the disposal cell. Potential geologic events, including seismic shaking, liquefaction, on-site rupture, ground collapse, and salt core flow, are ruled out as potential disturbing forces on the disposal cell, either because they will not occur or because the geotechnical design of the cell is formulated to resist such forces.

2.4.1 Geomorphic stability

The DOE provides evidence of the long-term stability of the site in Section 3.3 of Attachment 2. Following is a brief discussion of the main aspects of the projected geomorphic stability of the site.

The site will be protected from geomorphic processes by its position near the drainage divide and by the erosion-resistant Dakota Sandstone Formation on which the site will be situated. Exposed areas of shale and thin soil cover, with slopes greater than 1.5 percent, will need to have erosion protection added.

There is little likelihood of salt core flow inducing and developing collapse structures adjacent to the site, given the present stability of the region and of the Colorado Plateau. The site was little disturbed by the Tertiary activity that developed Coke Oven Valley and Paradox Valley, since it lies on the flanks of the salt core structure.

The relative age of the geomorphic surfaces has been established in the preceding sections. The long-term geomorphic processes that could influence the disposal cell have been identified and quantified by the DOE. Specific projections relating to recommendations and engineering designs for site stability are presented regarding the potential for flooding, slope failure, seepage, scarp retreat, and headward advance of gullies. On the basis of these evaluations, the DOE concludes that the site is geomorphically stable and will continue to be stable for the performance period of the disposal cell.

2.4.2 Seismotectonic stability

The DOE has determined that the disposal site and cell design will provide long-term stability during seismic events by analyzing the anticipated ground motion at the site as a result of these events. This analysis and technical approach are described in Section 4.2 of Attachment 2. The potentially active faults and the remote seismotectonic sources are shown in Tables 2.2 and 4.1 of Attachment 2 with the calculated maximum earthquake (ME), as well as the estimated ME of previous studies. Using the appropriate attenuation relationships for the site region, the criticality of these faults is evaluated in Figure 4.1 of Attachment 2. Four fault groups were shown to be within critical distance and to have critical length regardless of known capability. One salt core structure was also determined to be in the critical group.

The determination of parameters for the design earthquake is presented at the conclusion of Section 4.2 of Attachment 2 and includes the consideration of the effects of deep, unconsolidated deposits. The following is a brief summary of the main points.

The design earthquake for this site was determined to be an M_L = 7.1 event occurring at a distance of 24.1 km (14.9 miles) from the site based on the conservative assumption that the largest critical tectonic fault was capable. Although this fault does not exhibit Quaternary activity, the Uncompahgre Uplift structure has been shown to be tectonically active. The peak horizontal acceleration of bedrock at the site is estimated to be 0.25 g. The duration of the design earthquake for the bedrock at the site is 26 seconds.

Specific seismic parameters to be used for the design are presented below. These criteria were used in conjunction with appropriate soil strength parameters, pile geometry, and groundwater information to assess slope stability and liquefaction potential. The results are presented in the geotechnical stability section of this document.

Seismic design parameters were derived using procedures set forth in the TAD. The acceleration attenuation relationship of Campbell (1981) was used to derive the on-site peak horizontal acceleration.

Design criteria

- Long-term slope stability seismic coefficient: K = 0.17 (two-thirds of peak horizontal acceleration).
- Short-term slope stability seismic coefficient: K = 0.13 (one-half of peak horizontal acceleration).
- Liquefaction analysis: ground surface horizontal acceleration a_{max} = 0.25 g.

2.5 GEOLOGIC SUITABILITY

On the basis of the site characterization described in this section and supporting documents, the details of the final remedial action plan, and the provisions for stability included in the design of the disposal cell, the DOE concludes that there is a reasonable assurance that the regional and site geologic conditions have been characterized adequately to meet 40 CFR Part 192. Conditions potentially affecting long-term stability have been identified and either avoided by design layout or mitigated by the details of the remedial action design, as follows:

- Possible geomorphic instability may result from concentration of flow over shale or soil-covered slopes where natural slopes are 3 to 4 percent. Approximately 20 percent of the site is underlain by shale-mudstone bedrock; the remainder is underlain by moderately resistant sandstone units of the Dakota Sandstone Formation.

- The seismic potential for the site has a design criterion of 0.25 g peak horizontal acceleration. Because of the stability of the bedrock that underlies the cell foundation, the potential for failure of the foundation is considered negligible.

3.0 GEOTECHNICAL STABILITY

This section and associated reference documents describe the geotechnical engineering aspects of the proposed remedial action at the Naturita, Colorado, site. The following aspects of the remedial action are described: the geotechnical information and design details related to the disposal site; the disposal site and its cover; and the materials associated with the remedial action, including the foundation and excavation materials, tailings, and other contaminated materials. Related geologic aspects such as geology, geomorphology, and geomorphic and seismic characterization are presented in Section 2.0 of this report. Surface water and erosion control are described in Section 4.0. Remedial Action Contractor (RAC) calculations are available through the UMTRA Project Office, Albuquerque, New Mexico, and are part of the DOE's preliminary design for review.

3.1 SITE AND MATERIAL CHARACTERIZATION

The Naturita processing site consists of the abandoned Naturita mill, former tailings pile area, and ore buying station located on the floodplain of the San Miguel River, between Highway 141 to the west and the San Miguel River to the east. The ore storage area, which is also part of the processing site, is located to the west of Highway 141.

No tailings remain at the Naturita site. Remaining contaminated materials include: 1) soils in the mill yard; 2) windblown and waterborne contaminated material adjacent to the designated site and east of the San Miguel River; 3) several buildings; 4) used mill equipment on the site; and 5) foundation soils in the former tailings area.

The disposal cell will cover approximately 22 acres and will contain approximately 547,000 cubic yards of contaminated materials. The actual quantity will depend on the extent of contaminated materials excavated during construction. The disposal cell configuration is shown in Figures 1.5 and 1.6.

Bedrock outcrops occur under the footprint of the disposal cell at the Dry Flats site. In some locations, there is a shallow cover of 1 to 2 feet of clayey, or silty, sandy soils, which is underlain by weathered sandstone. The topsoil at the site is suitable for use in final grading at the site, for reclamation of the Coke Oven borrow site, or for fill material at the processing site.

3.1.1 Geotechnical investigations

This section describes the scope and results of the geotechnical investigations performed to define the location and properties of the subsurface materials at and in the vicinity of the proposed disposal cell, the borrow and quarry materials, and the contaminated materials to be incorporated into the disposal cell.

Geotechnical investigations and site characterization programs were performed at the mill site, the disposal site, and the borrow sites. The data obtained during these characterization programs are presented in the *Information to Bidders*, Volumes II, III, and IV.

The scope of the geotechnical investigations included excavating test pits and drilling boreholes. Information from monitor well installation was also obtained. The borings and test pits were logged by a field engineer. The locations of test pits, boreholes, and monitor wells are shown in Vol. II of the *Information to Bidders* for the Naturita processing site, Vol. III of the *Information to Bidders* for the Dry Flats disposal site, and Vol. IV, Section I for the Coke Oven site and Vol. IV, Sections J and K for fine-grained and sand and gravel materials, respectively. Subsurface investigations for material properties of the underlying soil at the processing site were carried out in conjunction with the investigation to define the limits of contamination. The resulting samples of site materials were tested and analyzed in the laboratory to develop an insight into the specific engineering characteristics of the materials.

Test pits were excavated with a tracked backhoe. Bulk soil samples were collected from the pits. Individual borehole logs provide precise information about the drilling methods used. Generally, hollow stem augers (6.5 inches) were used until refusal; thereafter, a rotary bit (4.0 inches) and casing were used to bedrock. Three sampling methods were used: the Standard Penetration Test (ASTM D1586); a 2.42-inch inside diameter, ring-lined, split barrel sampler; and a 3.0-inch, thin-walled Shelby tube.

The data from the field investigations and laboratory tests were used to construct stratigraphic sections (see Section 3.1.4), contribute to the geological characterization of the site (see Section 2.0), and define the engineering properties of the soils to be incorporated into the cell (see Section 3.2).

3.1.2 Testing program

The materials at the three sites were classified according to the Unified Soil Classification System (ASTM D2487). Atterberg limits (ASTM D43180) and gradation tests (ASTM D422) were performed on selected samples to classify the soils. In addition, the following tests were done: specific gravity (ASTM D854), compaction (ASTM D698), saturated and unsaturated hydraulic conductivity, consolidation (ASTM D2435), shear strength (EM 1110-2-1906), radon barrier erodability (Crumb test, STP 623; dispersion, ASTM D4221; and pinhole, STP 623), and erosion barrier durability. The results of the individual tests are contained in the *Information to Bidders*. Summary tables are in Morrison Knudsen-Environmental Services (MK-ES) Calculation 17-737-01-01.

The testing program was consistent with the needs of the proposed remedial action; representative samples of construction materials and samples of geotechnical materials that may affect or be affected by the remedial action were tested. The number of samples tested is considered sufficient to support the necessary geotechnical analyses described in subsequent sections. In particular, the testing approach is consistent with the NRC SRP and the TAD. Samples were tested in accordance with the standard procedures. Quality assurance and quality control were performed in accordance with standard UMTRA Project procedures.

3.1.3 Groundwater conditions

This section addresses groundwater conditions to the extent they affect the geotechnical performance of the disposal cell. The details of the groundwater characterization program are included in Section 5.1 of this report.

The Dry Flats disposal site is underlain by sandstone and shale-mudstone of the Dakota Sandstone. The only shallow groundwater at the site exists as a thin saturated zone in the underlying bedrock (Burro Canyon Formation) approximately 200 feet below the surface. The presence of this groundwater has no effect on the stability of the site.

3.1.4 Stratigraphy

The Dry Flats disposal cell will rest on a bedrock terrace approximately 600 feet above the San Miguel River. The bedrock at the disposal cell location is overlain by a thin (1-foot-thick) layer of soil that will be excavated prior to cell construction. The bedrock directly beneath the cell consists of the Dakota Sandstone. All bedrock at the site is stable (see Section 2.3.1). The nearest groundwater at the site is a perched layer 200 feet beneath the surface.

Details of the stratigraphic setting of the Dry Flats disposal site are included in Section 2.2 of Attachment 2 and are summarized in Section 2.0 of this report. Figure 2.2 of Attachment 2 shows a simplified stratigraphic column of the disposal site, and Figures 3.4, 3.5, and 3.6 of Attachment 2 show typical geologic cross sections.

3.2 GEOTECHNICAL ENGINEERING EVALUATION

This section and referenced supporting documents present the engineering evaluation of the information and analyses that were undertaken to demonstrate that the proposed remedial action design will meet the relevant EPA standards for long-term stability, including slope stability, settlement, liquefaction, and cover cracking. The analyses were performed for design basis events such as the design earthquake (see Section 2.2.4), design flood (see Section 4.2), and extreme meteorological conditions.

The methods of analysis used are identified in this section or listed and described in the relevant supporting and referenced calculations.

3.2.1 Slope stability

The slope stability analyses are presented in MK-ES Calculation 17-740-01-01 and summarized on Sheet 2 of the calculation. These analyses show that for both static and dynamic conditions, the cell will be stable and will not fail or adversely affect the long-term performance. The following briefly describes the work done to support these conclusions.

Location selected for analysis

One cell cross section location was chosen for modeling with the UTEXAS3 computer code. This location represents the worst-case condition during construction, after construction, and for the long-term stability analyses. The cross section is shown on Sheets 8-9 of MK-ES Calculation 17-740-01-01.

Adopted design procedures

Sheet 14 of MK-ES Calculation 17-740-01-01 lists the geotechnical design parameters used in the stability analyses. The properties of the soils that make up the cell and sideslopes and the field and laboratory data used to establish design parameters are described in detail in MK-ES Calculation 17-737-01-01. The assignment of geotechnical parameters for slope stability analysis followed conventional geotechnical engineering practice and was done in accordance with the NRC SRP and the TAD.

Methods of analysis

The stability analyses performed are described in MK-ES Calculation 17-740-01-01. The analysis was performed using Bishop's Method of Slices for circular sliding surfaces and the infinite slope method of analysis for shallow failure conditions. These are appropriate methods that are widely accepted in standard geotechnical engineering practice. Seismic conditions were analyzed using the pseudostatic method.

The horizontal coefficients were selected on the basis of the information in Section 2.4.2 and in accordance with the procedures found in the TAD. The use of the pseudostatic method is acceptable in view of the inherent conservatism in the soil parameters and flat slopes.

Results of analysis

The minimum factors of safety against failure of the slopes of the disposal cell are summarized on Sheet 2 of MK-ES Calculation 17-740-01-01. These factors of safety exceed the minimum acceptable values established in the TAD.

Accordingly, the DOE concludes that the slopes will be stable in accordance with the requirements of the EPA standard (40 CFR 192.02(a)) for long-term stability.

3.2.2 Settlement

Settlement calculations are in MK-ES Calculation 17-740-02-01. Forty-nine locations on four section lines (shown on Sheet 6 of MK-ES Calculation 17-740-01-01) within the site were selected such that the resulting settlement profiles could be used to predict worst-case cracking of the radon barrier. The locations of the four sections are shown on Sheets 6 and 7 of MK-ES Calculation 17-740-02-01. Profiles of the proposed Naturita embankment are presented on Sheet 8 of the calculation. Based on logs of borings and test pits at the Dry Flats disposal site, the disposal cell footprint is underlain by less than 3 feet of silty sand, or sandy clay, which in turn is underlain by competent layers of sandstone, siltstone, limestone, and shale (see Attachment 2 for details).

During preparation of the site, the top layers of silty sand or sandy clay will be removed, leaving the exposed bedrock to form the foundation of the cell. The settlement of the bedrock due to construction of the cell will be elastic, uniform, instantaneous, and trivial. Therefore, settlement of the foundation bedrock is not expected to cause any adverse effects (cracking) in the radon barrier.

The materials that are expected to settle during or after construction are the relocated contaminated material and the radon barrier material. These will settle both from their own weight and from the weight of the materials above them. Hence, they will undergo both immediate and secondary (creep) settlement but not consolidation. The relocated contaminated material and the radon barrier material will be unsaturated when placed, and both materials are expected to remain unsaturated over a long period of time.

Sheets 13 and 14 of MK-ES Calculation 17-740-02-01 summarize the settlement calculations. The largest total settlement calculated is 14.01 inches, and the smallest is 0.54 inch. Profiles of vertical settlements, horizontal settlements, and horizontal strains and horizontal movement are provided on Sheets 21 through 28 of the calculation.

The horizontal settlements and strains were computed using the vertical settlements and the methods approved in the TAD. The peak horizontal strain was estimated to be 0.016 percent. Using the methodology outlined in the TAD, the strain required to produce cracking is estimated to be 0.05 percent.

From this analysis, the DOE concludes that settlement does not pose a threat to the performance of the Dry Flats disposal cell.

3.2.3 Liquefaction potential

The disposal cell will be constructed as a compacted and comparatively dry engineered fill, and as such will not be susceptible to liquefaction. In addition, the cell will be supported by stable bedrock. Therefore, the DOE concludes there is no potential for liquefaction at the Dry Flats site.

3.2.4 Cover design

The disposal cell is designed to stabilize and control the tailings and other residual radioactive materials for 1000 years to the extent reasonably achievable and, in any case, for at least 200 years (40 CFR 192.02(b)). The Dry Flats disposal cell cover is designed to resist degradation, minimize infiltration, meet radon protection standards, and withstand differential settlement throughout its design life. The ability to withstand the predicted differential settlement is documented in Section 3.2.2, erosion resistance is documented in Section 4.4, and rock durability is described in Section 4.5. Radon protection is described in Section 6.0.

The disposal cell cover will consist of several distinct layers, as shown in Figure 1.6. The design functions of the various layers are described below.

The design of the 18-inch-thick radon/infiltration barrier is detailed in MK-ES Calculation 17-740-02-01. The barrier will be constructed from materials obtained from the Coke Oven borrow site. Properties of these materials were determined in MK-ES Calculation 17-737-01-00. The purpose of the barrier layer is threefold: 1) to limit radon flux to 20 pCi/m^2s; 2) to limit radon concentration in the air above the disposal site to 0.5 pCi/L; and 3) to reduce the cover flux to 10^{-7} centimeters per second (cm/s). Laboratory tests indicate that a saturated hydraulic conductivity of 10^{-7} cm/s can be obtained for the infiltration barrier using the Coke Oven materials. A barrier thickness of 10 inches is required to control radon emissions with 4 feet of windblown material placed directly under the cover; hence, the TAD-specified 18-inch minimum thickness is used.

The 12-inch-thick rock erosion layer is to protect the frost protection and radon barrier from erosion. It will be constructed of Type A riprap, which has a D_{50} of 1.5 inches. The design of this layer is in accordance with the procedures outlined in the TAD. A 6-inch bedding layer under the rock layer should prevent movement of the rock into the frost barrier.

The 36-inch-thick frost barrier protects the radon barrier from the effects of freezing and thawing. Frost depths and layer thickness calculations using TAD procedures are provided in MK-ES Calculation 17-741-03-02.

The 12-inch-thick rock layer will be constructed on top of the disposal cell, with a 2.0 to 5.0 percent slope. The rock is designed to resist erosion under the probable maximum precipitation (PMP) event. Supporting calculations are in MK-ES Calculation 17-741-02-01.

The 5 horizontal to 1 vertical (5H:1V) sideslopes of the disposal cell will be protected by a 12-inch-thick layer of riprap. Sizing of this layer is also discussed in MK-ES Calculation 17-739-02-01 and in Section 4.4.3 and was selected to resist the PMP. The erosion protection layer extends into the apron constructed around the base of the cell and keys into the bedrock. Details of the apron are shown on Drawing NAT-DS-10-1728 in Attachment 1.

3.3 CONSTRUCTION DETAILS

Implementation of the final remedial action plan will require construction activities to be conducted at the processing site and at the disposal site. The salient features of construction activities are described below.

A complete set of drawings and specifications is available in Attachment 1.

3.3.1 Construction methods and features

The following paragraphs provide an overview of the implementation of remedial action. Construction features include staging areas, decontamination facilities, temporary drainage ditches, and wastewater collection and retention systems. Locations and sizes of construction features may be changed to facilitate construction activities.

A barbed wire perimeter fence will be constructed around the disposal site to control traffic in and out of the sites and to prevent unauthorized entry. Existing barbed wire and chain link fences will be relocated as necessary at the processing site, with new gates installed to control access to the site. A gate on the access road will provide access to a site. Decontamination pads will be constructed at both sites. Vehicles leaving contaminated areas will be monitored and washed, if necessary, to prevent the spread of contamination.

Temporary diversion ditches will be constructed to prevent off-site surface water runoff from entering the sites during remedial action operations. Collection ditches on the sites will channel on-site contaminated runoff water to the wastewater retention basins. In addition to the wastewater retention basins, which will collect contaminated runoff, a smaller washwater recirculation pond will also be constructed at each site. The washwater recirculation pond is designed to receive water from truck decontamination and wash basins and shower facilities.

Dewatering activities during contaminated material excavations are expected to be minimal since excavation depths are generally shallow. Should dewatering be necessary during an unusually high flood stage of the adjacent San Miguel River, a contractor-designed dewatering system will be installed at the Naturita processing site to remove groundwater from the excavation(s). At both the Naturita and Dry Flats sites, a portable wastewater treatment plant could be used at the end of construction to process any accumulated contaminated water before discharge.

Drainage, erosion control, and wastewater retention basin

Surface water runoff from uncontaminated areas at both sites will be diverted to off-site areas. Surface water runoff from contaminated areas will be collected and drained to a wastewater retention basin.

Contaminated runoff will either be retained in the retention basin and evaporated or treated as necessary and discharged. To the extent practical, contaminated water will be evaporated or used as compaction water to moisture-condition tailings and other contaminated materials.

Treatment and discharge may be necessary if runoff during the construction period exceeds the basin capacity or if the water in the retention basin does not evaporate before completion of construction. Controlled discharges from the retention basins will meet effluent limits established by a Federal or state point discharge permit. An uncontrolled emergency discharge will be used only if necessary to prevent failure of the retention basin.

Temporary diversion ditches, designed to carry runoff resulting from a 10-year, 24-hour storm event, will prevent uncontaminated runoff from entering the site. Stormwater collection ditches are also designed to carry peak flow from a 10-year, 24-hour storm to the retention basin.

The wastewater retention basins and washwater recirculation ponds at the Naturita and Dry Flats sites will receive discharge from the following:

- Contaminated areas.
- Decontamination of trucks and other equipment. Normally, the truck and equipment washwater will be collected in the washwater recirculation pond, recycled, and reused until it gets too contaminated for further use as washwater. At that time, it will be discharged into the retention basins.
- Washbasins and shower facilities.

The retention basins at the two sites are sized to retain runoff resulting from a 10-year, 24-hour storm, in addition to the maximum storage required for normal stormwater runoff and wastewater generated from remedial action activities. The retention basins will also have sufficient capacity to hold the total estimated sediment inflow during construction operations. The basin spillway at the processing site will safely discharge peak runoff from a 25-year storm while 1 foot of freeboard is maintained between the top of the embankment and the water surface at a time when the spillway is flowing at the design elevation.

The cleanup work at the Naturita processing site will be performed in small lots, one area at a time, and will begin from higher elevations to lower elevations. Site restoration will immediately follow the removal of contaminated material. This excavation procedure will eliminate the generation of contaminated stormwater runoff at the Naturita processing site after the demolition debris at the site is removed. Upon removal of the demolition debris and vicinity material stockpiled in the mill yard area, the wastewater retention basin, sediments, and associated collection ditches will be removed and placed in the disposal cell. The washwater recirculation pond will be used to collect the small amount of wastewater produced at the site from truck washings and shower facilities.

Wastewater treatment

If required, a portable wastewater treatment plant will be moved to the Dry Flats site at the end of construction to treat any contaminated runoff accumulated in the wastewater retention basins over the construction period. The retention basin has been sized to accumulate all runoff over a 31-month construction period. If the runoff approaches the capacity of the basin, the portable treatment plant could be brought to the site and the wastewater could be treated and discharged as needed.

Dewatering and moisture conditioning

The depth of excavation planned in the San Miguel River floodplain areas is generally shallow—between 1.5 and 5 feet. Hence, elaborate seepage controls, such as a slurry wall, will not be needed during excavation. Furthermore, excavation in the floodplain areas will be scheduled during a low water stage in the San Miguel River, which will minimize dewatering needs. If this is not possible, a dewatering system will be designed and any contaminated water generated from dewatering operations will be stored on the site and hauled to the disposal site for use as dust control water or compaction water.

Based on the moisture content of the contaminated materials, there will be no need to add water to condition the materials. Only the radon barrier material, foundation excavation materials, and frost protection barrier materials will require moisture conditioning during compaction (MK-ES Calculation 17-706-01-01). To the extent practicable, conditioning of contaminated materials can be performed by using waters accumulated in the retention basin. Arrangements for a supply of additional construction water will have to be made, such as from the San Miguel River or from a deep well at the disposal site for compaction water requirements for the radon barrier material and frost protection material.

Demolition

All buildings and structures at the Naturita mill site will be demolished. The demolition material, including several scrap heaps of metals and miscellaneous debris, will be placed in layers in the bottom of the disposal cell. Radiologically contaminated asbestos will be buried within the tailings embankment. Nonradiological hazardous materials will be sent off the site to approved disposal sites.

Equipment decontamination pad

Equipment leaving contaminated areas will be monitored for contamination. To prevent contaminated materials from being carried out of the construction areas, a decontamination pad with a holding tank and pump will be provided to wash contaminated equipment.

At both sites, one or more decontamination pads and associated equipment will be needed so that trucks can be washed often enough to meet the construction schedule. It will be up to the subcontractor to use as many decontamination pads as necessary to meet the construction schedule.

Dust control

Dust generated by excavation, earth movement, vehicle use, temporary stockpiling of materials, and similar activities will be controlled by spraying water or water and water-based surfactants. Special care will be taken to control dust created by decontamination and demolition of buildings and by temporary stockpiling or mixing of contaminated materials.

Retention basin water can be used to control dust on the tailings embankment; however, only uncontaminated water will be used to control dust in uncontaminated areas.

Schedules for spraying the roads and embankment areas will vary daily and will be adjusted as required. The frequency of spraying will increase when combinations of low soil moisture and high wind speed are encountered. It is estimated that up to 243 acre-feet of water could be required for dust control at the processing site, disposal site, Coke Oven borrow area, and gravel haul road (MK-ES Calculation 17-706-01-00, Sheet 2).

Construction sequence

The following construction sequence is planned for the remedial action. However, the construction subcontractor will be allowed to execute the work with flexibility within the constraints of the project specifications and with the RAC's approval. The actual construction sequence, therefore, may differ somewhat from the planned sequence. A more detailed construction sequence can be found in Attachment 1.

- Mobilize and construct temporary construction facilities at the Naturita processing site, including access control, decontamination facilities, wastewater retention basin, washwater recirculation pond, and stormwater collection ditches in the mill yard area. Abandon and seal existing monitor wells at the processing site and improve the highway drainage system, such as culverts and ditches on the east side of Highway 141, to divert surface runoff off the site from work areas. Install a silt fence along the San Miguel River to prevent suspended solids discharge to the river during remediation activities.

- Conduct demolition activities at the Naturita processing site, including the removal and disposal, or stockpiling, of hazardous materials removed from the demolished structures. Demolish all discarded mechanical equipment at the processing site and stockpile demolished material in designated stockpile areas in the mill yard.

- Conduct vicinity property remedial actions in Naturita and surrounding areas and stockpile debris in designated areas in the mill yard at the Naturita processing site.

- Mobilize at the Dry Flats disposal area and improve/reconstruct the existing gravel and dirt county road to a two-lane gravel road for use as a haul road between State Highway 90 and the disposal site. Construct the wastewater retention basin, washwater recirculation pond, stormwater collection ditches, decontamination facilities, and access control facilities and excavate the foundation for the disposal cell at the Dry Flats disposal area. Remove and stockpile the foundation materials for use in restoration of the disposal site, Coke Oven borrow site, and Naturita processing site.

- Excavate contaminated materials at the Naturita processing site and dispose of these materials and stockpiled demolition material in the Dry Flats disposal cell. Demolition debris shall be placed evenly in lifts in the lower elevations and inner portions of the cell. Removal of contaminated materials from the processing site will be done in the following sequence in order to place the materials with the highest levels of contamination toward the bottom of the cell:

  - Former ore storage area materials.

  - Mill yard materials, including stockpiled demolition debris and vicinity property materials.

  - Wastewater retention basin and ditches, including synthetic membrane liners.

  - Former tailings pile area soils.

  - Adjacent windblown area soils.

  After removal of the ore storage area and mill yard area materials, the cleanup work at the processing site will be done in small increments, one area at a time, working from higher elevations to lower elevations, with restoration of cleaned-up areas completed immediately after excavation has been completed. Working in this manner will eliminate production of contaminated runoff from upland areas during remediation work.

- Place windblown area materials in the cell last and at least 4 feet thick over the more highly contaminated materials previously placed in the cell.

- Develop the Coke Oven borrow area to supply radon barrier and frost protection materials for the disposal cell and fill material for site restoration at the processing site.

- Dismantle/demolish all temporary facilities that cannot be decontaminated and place these in the disposal cell. This applies to sediments from the wastewater retention basins and washwater retention ponds and any contaminated soils adjacent to temporary facilities.

- Following placement of all contaminated materials, construct the radon/infiltration barrier on the sides of the disposal cell, followed by placement of the frost barrier on the sides of the cell. Construct the radon/infiltration barrier on the top of the cell, followed by the frost protection barrier. Place the bedding materials and rock riprap erosion layers on the cell. Construct the riprap aprons, key trenches, and the permanent site grading. Restore all disturbed areas, including borrow areas and wetlands, and clean up and demobilize the site.

Construction schedule

The overall remedial action at the Naturita Project is currently scheduled to last about 31 months, including two winter shutdowns (Figure 3.1).

3.3.2 Testing and inspection

The Naturita site remedial action inspection plan (which is in preparation) will provide the details of the methods, procedures, and frequencies by which construction materials and activities are to be tested and inspected to verify compliance with the design specifications.

Quality assurance audits and in-process surveillances shall be conducted by the DOE and the TAC to verify and ensure that remedial action activities are performed in accordance with approved UMTRA Project requirements and the DOE/UMTRA *Quality Assurance Plan* (DOE, 1990a).

3.4 SUMMARY

Based on the design presented and described in this RAS, the supporting documents, the design drawings, the specifications, and the attachments, the DOE concludes that the design complies with the long-term stability aspects of the EPA standards (40 CFR 192.02(a)).

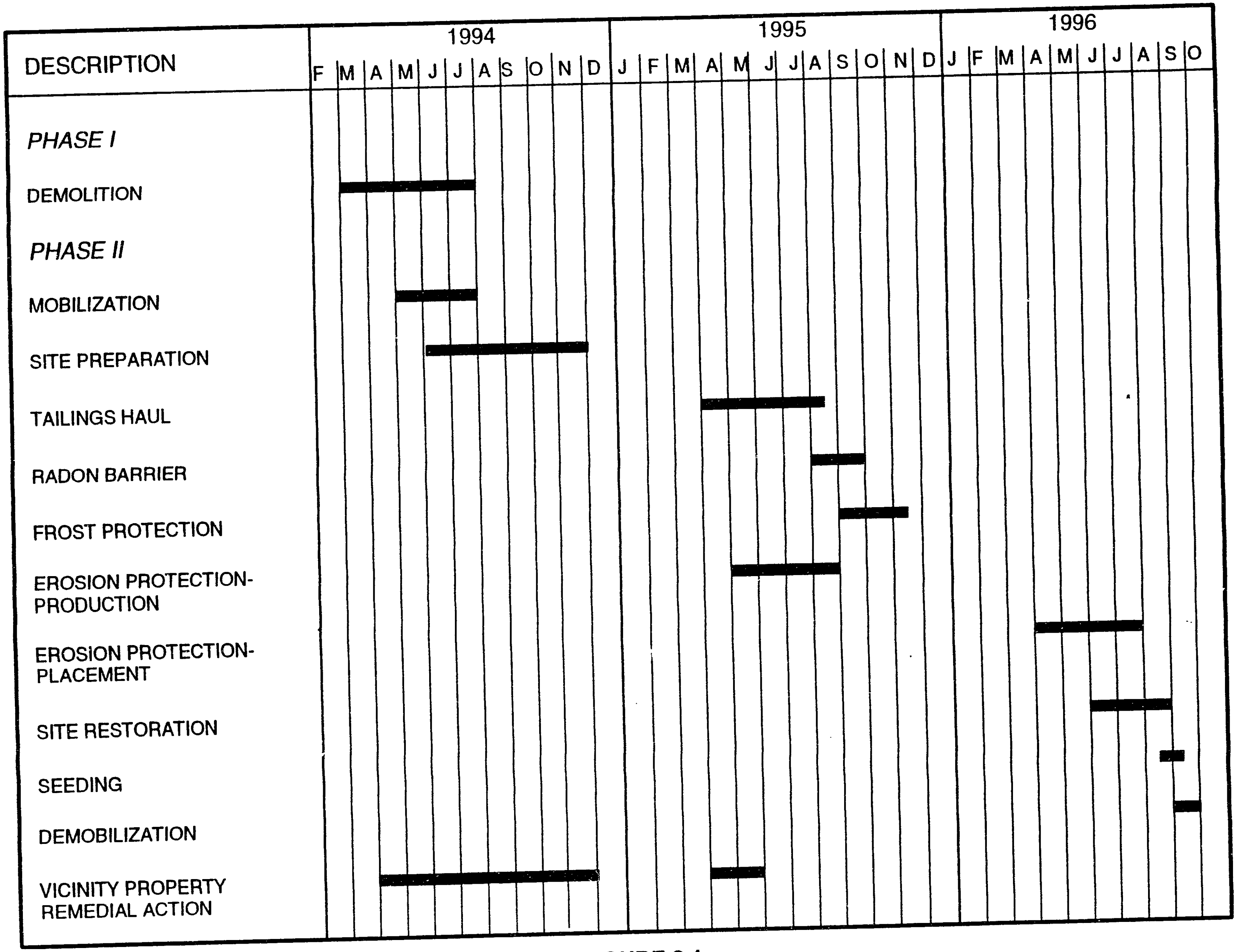

FIGURE 3.1
CONSTRUCTION SCHEDULE
NATURITA, COLORADO

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4.0 SURFACE WATER HYDROLOGY AND EROSION PROTECTION

4.1 HYDROLOGIC DESCRIPTION AND REMEDIAL ACTION DESIGN

The Naturita processing site is approximately 650 feet from the San Miguel River. Portions of the site are within the 100-year floodplain. The disposal cell will be located approximately 6 road miles southeast of the existing processing site and 600 feet above the San Miguel River. Details of the flood conditions, PMP conditions, drainage design, and erosion protection are provided in the following sections.

4.2 FLOODING DETERMINATION

To determine site impacts from flooding, the DOE analyzed peak flows and velocities and evaluated the need for erosion protection features at the disposal site. The DOE estimated the time of concentration (t_c) for the small drainage areas, the PMP, and the probable maximum flood (PMF). The values were used to estimate runoff flow quantities and velocities for the design of erosion protection features. In no case were less critical events such as a 10-year or 50-year storm used to design permanent features.

4.2.1 Probable maximum precipitation

The disposal site design PMP was determined as described in MK-ES Calculation 17-723-01-01. A PMP rainfall depth of 8.2 inches in 1 hour was calculated for the small drainage area of the disposal cell using standard and conservative analytical procedures.

4.2.2 Infiltration losses

To calculate the peak flow to size the erosion protection rock, the DOE assumed a conservative assumption of zero infiltration in the upgradient area.

4.2.3 Time of concentration

The t_c is the amount of time required for runoff to reach the outlet of a drainage basin from the most remote point in the basin. The peak runoff for a given drainage basin is inversely proportional to the t_c for that basin. If the t_c is conservatively computed to be small, the peak discharge will therefore be conservatively large.

Various t_c's for the aprons and disposal cell were estimated using the Kirpich Method. For the very small drainage areas associated with the disposal cell and aprons, the DOE utilized t_c's as low as 2.5 minutes (MK-ES Calculations 17-739-02-01 and 17-739-03-01).

4.2.4 Rainfall distribution

Rainfall intensities for durations as short as 2.5 minutes were used to determine peak flood flows (this is standard UMTRA Project technical approach). The peak rainfall intensity was calculated to be approximately 54.1 inches per hour in a 6-hour period (MK-ES Calculation 17-723-01-01).

4.2.5 Computations of the flood event

The potential for flooding of the Dry Flats site was evaluated by the DOE. The assessment was based on a review of historical data and PMF calculations for adjacent waterways.

Adjacent waterways

The U.S. Geological Survey (USGS) gaging station on the San Miguel River at Naturita, Colorado, is 3.5 miles upstream from the Dry Flats disposal site. There is a contributing drainage area of approximately 140 square miles between the gaging station and the processing site. The flows recorded at the gaging site were adjusted to account for this additional contributing area. The methods used were taken from the Colorado Water Conservation Board's Technical Manual No. 1. These methods and specific reference to their use are provided in MK-ES Calculation 17-732-02-00.

The peak flood recorded between 1918 and 1981 occurred in 1942 and was 7100 cubic feet per second (ft^3/s) at the gaging station, or approximately 7800 ft^3/s at the processing site. Based on the data available and the methods in the TAD, the 100-year flood is estimated to be approximately 11,000 ft^3/s (MK-ES Calculation 17-732-02-00).

Using this information and the Hydrologic Engineering Center (HEC-2) computer code, the 100-year flood could be at an elevation of approximately 5300 feet above sea level (MK-ES Calculation 17-732-02-00, Figure 1). Because the lowest point of the disposal cell is at an elevation of 5910 feet, flooding from the San Miguel River poses no threat to the cell.

For a PMF of 200,000 ft^3/s for the San Miguel River at the Naturita mill site, the maximum water surface elevation is 5320 feet above mean sea level. As the lowest elevation of the Dry Flats disposal cell is 600 feet higher than the Naturita site, the PMF does not pose a threat to the site.

On-site drainage

Because the disposal cell will be located against a drainage divide, it will be subject to only minor amounts of runoff from its surface.

4.3 WATER SURFACE PROFILES AND CHANNEL VELOCITIES

The 100-year flood of the San Miguel River was modeled with HEC-2. A plan view of the 100-year flood stage of the San Miguel River both before and after remediation is shown in Figure 2.1, Attachment 1, of the Naturita environmental assessment (EA) (DOE, 1993). The flood stage would be well below (approximately 600 feet) the disposal cell and would pose no threat to the cell.

4.4 EROSION PROTECTION

The top layer of the pile cover is a 12-inch-thick, 1.5-inch (D_{50}) rock riprap. The rock will resist erosion for slopes of 2 to 5 percent (see MK-ES Calculation 17-739-02-01) under PMP conditions. Because the topslope of the disposal cell is 2 to 5 percent, the design is deemed adequate.

The sides of the embankment are protected by a 12-inch-thick layer of 3.5-inch (D_{50}) riprap. The design of the riprap is presented in MK-ES Calculation 17-739-02-01. The riprap was designed to resist the PMP event using the Safety Factor Method (TAD) (DOE, 1989a).

4.5 ROCK DURABILITY

An inventory and test results of rock sources that are suitable for use as riprap are provided in Table I, Sheet 7, of MK-ES Calculation 17-744-01-00.

Thirteen different sites were identified as possible rock sources, but only four appear to be suitable. The pits contained river or glacial moraine gravels of igneous and metamorphic composition. Four of the sites appear to be able to provide the rock for the erosion protection, with two of the pits capable of supplying all of the different rock sizes required. Two of the pits, the Hendrickson and the Cotter Pit, both have rock durability scores of more than 80 using the rating system outlined in the TAD. The Pinon Pit and Southwestern Redimix scored a 79. There is a sufficient quantity of material available from these sources to provide all the rock required. Pit selection will be made by the contractor and may include more than one pit, depending on haul distances and costs for the rock. Locations of all of the pits are shown on Sheet 6 of MK-ES Calculation 17-744-01-00.

4.6 QUALITY CONTROL

The Naturita site remedial action inspection plan (which is in preparation) will provide details of the quality control procedures to be used at the site. This plan will be submitted by the RAC as part of the final design package. Once sources of the rock have been properly identified (see Section 4.5), rock placement will be monitored in accordance with Section 4.2.1 of the TAD (DOE, 1989a).

4.7 UPSTREAM DAM FAILURES

There are no impoundments on the San Miguel River whose failure could affect the site.

4.8 SUMMARY

The DOE, after careful consideration, concludes that the contaminated materials from the Naturita site will be safely contained within the Dry Flats disposal cell. The cell design will meet EPA requirements as stated in 40 CFR 192 with regard to flood design measures and erosion protection. An adequate hydraulic design has been provided to ensure stability of the contaminated materials at Dry Flats for a period of 1000 years.

5.0 WATER RESOURCES PROTECTION

Summaries of the hydrogeologic characterization at the Naturita processing site and Dry Flats disposal site are presented in Sections 5.1 and 5.2. A detailed groundwater hydrology report is included as Attachment 3. Sections 5.3 through 5.9 summarize the water resources protection strategy and compliance with the EPA groundwater protection standards for the Dry Flats disposal site. Attachment 4 provides details about the water resources protection strategy.

5.1 HYDROGEOLOGIC CHARACTERIZATION OF THE PROCESSING SITE

5.1.1 Identification of hydrogeologic units

The Naturita processing site is located in the San Miguel River Valley of the Colorado Plateau physiographic province and is underlain by unconsolidated alluvial floodplain deposits and fill material. The alluvium was deposited by the San Miguel River prior to the alteration of the river course by the addition of fill material at the processing site. The alluvium is considered the uppermost aquifer at the processing site and is contaminated from processing-related activities. The alluvium is underlain by the Brushy Basin and the Salt Wash Members of the Jurassic Morrison Formation. The Brushy Basin consists of interbedded shale, sandstone, and conglomerate lenses. The Salt Wash consists predominantly of sandstone with some shale. The Brushy Basin and the Salt Wash have not been affected by uranium processing activities. The bedrock strata dip 2 to 4 degrees to the northeast.

5.1.2 Hydraulic and transport properties

Unconfined groundwater occurs within the alluvial floodplain deposits and ranges from 3 to 18 feet below land surface. The observed saturated thickness is approximately 15 feet in the vicinity of the site. Groundwater is confined in the Salt Wash, with the potentiometric surface higher in elevation than the water table in the alluvium. These two hydrostratigraphic units are separated by an aquitard (Brushy Basin) consisting of thick, laterally extensive, interbedded shales with some sandstones.

The occurrence of shallow groundwater in the alluvial aquifer is limited by the lateral extent of the alluvium in the vicinity of the site. The average hydraulic conductivity for the alluvial aquifer is 3.0 feet per day (ft/day) (1×10^{-3} cm/s) and the average linear groundwater velocity is 0.06 ft/day (2×10^{-5} cm/s). The alluvial aquifer is recharged principally by the San Miguel River southeast of the site and also from infiltration of precipitation. The groundwater flow direction in the alluvium is approximately subparallel to the San Miguel River. Groundwater discharges from the alluvial aquifer into the San Miguel River northwest of the site where the river valley narrows.

The Salt Wash Member is a major regional groundwater system in the Naturita area. The recharge area for the Salt Wash aquifer consists of the upturned edge of this formation on the southwestern flank of the Uncompahgre Uplift. The potential area of natural discharge from the Salt Wash aquifer is the San Miguel River northwest of the Naturita processing site before the river reaches Uravan, Colorado. The point where the Salt Wash contacts the downcutting San Miguel River northwest of the processing site has not been determined, but this appears to be the most likely area of discharge based on available literature.

5.1.3 Characterization methods

Standard approaches to characterization of hazardous constituents in tailings at UMTRA Project tailings sites include pore water sampling using lysimeters or well points; batch leach tests or solution extracts; column leach tests; and characterization of on-site or subpile groundwater contamination at the processing site (DOE, 1989a). Because of the lack of residual radioactive materials and the gravel and cobbles in the alluvium at the Naturita processing site, lysimeters could not be used to sample pore water to characterize hazardous constituents. Instead, batch leach tests and solution extract tests on representative samples of contaminated soils and characterization of groundwater contamination at the processing site were used to characterize hazardous constituents at the site. Sections 3.1.5 and 3.1.6 of Attachment 3 provide a detailed discussion of the characterization of hazardous constituents at the Naturita site.

Results of tests on the soil samples indicate a maximum uranium concentration of 858 micrograms per gram (μg/g) and a maximum vanadium concentration of 5440 μg/g. Other hazardous constituents and elements contained in hazardous constituent compounds found in the soil above the laboratory method detection limits include silver, arsenic, barium, beryllium, cadmium, cobalt, copper, fluoride, molybdenum, lead, nitrate, radium-226, and zinc. Leachate analyses from the batch leach tests with deionized water on composite samples indicate a maximum uranium concentration of 0.313 milligrams per liter (mg/L) and a maximum vanadium concentration of 700 mg/L. Other hazardous constituents and elements contained in hazardous constituent compounds found in the leachate above the laboratory method detection limits include aluminum, antimony, arsenic, barium, beryllium, cadmium, cyanide, chromium, copper, fluoride, molybdenum, nitrate, lead, radium-226, selenium, strontium, thallium, tin, and zinc. Radium-228 was not analyzed for in the soil because the activity of thorium-232 is low, based on soil analysis, and radium-228 is a decay product of thorium-232.

5.1.4 Extent of existing contamination

To determine whether uranium processing activities at the Naturita processing site influenced groundwater quality in the alluvial aquifer, the DOE collected samples from on-site/downgradient monitor wells and analyzed for constituents listed in Table 8.1 of the TAD (DOE, 1989a).

The pH values for on-site/downgradient alluvial groundwater range from 6.72 to 7.63, and the average total dissolved solids (TDS) concentration is 1705 mg/L. The groundwater is characterized as a mixed cation (sodium, potassium, calcium, magnesium)/mixed anion (chloride, bicarbonate, sulfate) type. The alluvial groundwater on the site and downgradient has similar pH, but a higher TDS concentration and different water type than background groundwater quality. This probably indicates the effects of the processing activities at the site. Hazardous constituents found in groundwater samples above the laboratory method detection limits include arsenic, aluminum, antimony, barium, cadmium, copper, cyanide, fluoride, lead, mercury, molybdenum, nickel, nitrate, selenium, silver, strontium, thallium, tin, uranium, and zinc, and activities of net gross alpha and radium-226 and -228. Concentrations of arsenic, cadmium, chromium, molybdenum, selenium, and uranium, and activities of net gross alpha and radium-226 and -228 exceed the proposed EPA MCLs (Table 3.16 of Attachment 3). Analyses show a maximum observed uranium concentration of 5.2 mg/L and a maximum observed vanadium concentration of 9.3 mg/L.

In summary, concentrations of arsenic, cadmium, molybdenum, selenium, and uranium, and activities of net gross alpha and radium-226 and -228 exceed the proposed EPA MCLs. Also, water quality analysis of samples collected from on-site/downgradient monitor wells show significant statistical variation from background groundwater quality for concentrations of arsenic, fluoride, molybdenum, tin, and uranium. Vanadium and cadmium do not exhibit a significant statistical variation from background water quality but will be included in future analyses. An analysis of variance was not conducted on antimony, chromium, lead, nitrate, silver, strontium, thallium, radium-226 and -228, and gross alpha on on-site/downgradient samples. In addition, toluene and methylene chloride were present in concentrations above analytical detection limits. Therefore, a complete list of hazardous constituents that may be potential contaminants in alluvial groundwater at the processing site includes arsenic, cadmium, chromium, fluoride, methylene chloride, molybdenum, selenium, strontium, thallium, tin, toluene, uranium, and vanadium, and activities of net gross alpha and radium-226 and -228.

Groundwater in the Salt Wash is not contaminated as a result of milling operations at the processing site. Groundwater samples from two monitor wells in this aquifer have shown that concentrations of uranium have approached the MCL of 0.044 mg/L. Concentrations of selenium and molybdenum and activities of radium-226 and -228 and net gross alpha have also sporadically approached and exceeded the MCL. These elevated concentrations and activities are most likely a result of oxidation and dissolution of uranium mineralization within the Salt Wash.

5.1.5 Water use

Seven wells located within 2 miles of the processing site are used for domestic purposes. Four wells in the alluvium and one in the Salt Wash are hydraulically upgradient of the processing site. The two remaining wells are located on the opposite side of the river (north), one in the San Miguel River Valley downgradient of the site and one southwest of the town of Nucla. There is no potential for contamination of these wells. The Salt Wash aquifer is not hydraulically interconnected with the alluvium, and the river represents a discharge point for the alluvial groundwater.

The shallow alluvial groundwater has a very low potential for use since it is limited to the small area of alluvium in and adjacent to the San Miguel River. Alternative supplies of reliable, good quality water are available from the town of Naturita. Future use of groundwater in the alluvium for domestic consumption is not expected.

5.2 HYDROGEOLOGIC CHARACTERIZATION OF THE DISPOSAL SITE

5.2.1 Identification of hydrogeologic units

Hydrogeologic units beneath the Dry Flats disposal site (and approximate thicknesses) are the Cretaceous Dakota Sandstone (100 to 150 feet) and Burro Canyon Formation (100 to 150 feet), and the Brushy Basin (450 feet) and Salt Wash (350 feet) Members of the Jurassic Morrison Formation. It is difficult to determine actual thicknesses and contacts between formations in the area because of similarities between the lithologies and gradational contact zones between the units. Based on estimated thicknesses of units in the area, it appears that the top of the Salt Wash is approximately 700 feet below land surface and was not penetrated by the deep drilling (maximum depth drilled was 610 feet).

The Dakota consists of a shale-claystone unit with a thin coal seam at the base, grading downward into a highly resistant, thick sandstone unit. The total formation thickness varies greatly over a short distance. The Burro Canyon consists of mudstone in the upper part and mainly sandstone in the lower part. It is reported to be approximately 100 feet thick (Craig, 1981). The distinction between the Dakota and Burro Canyon is poorly defined at the disposal site because of the discontinuity of the major sandstone units. The Brushy Basin is composed of variegated, interbedded shales, mudstones, and conglomerate lenses. The Salt Wash is composed predominantly of interbedded sandstones and siltstones with some shales.

5.2.2 Hydraulic and transport properties

Groundwater occurs beneath the Dry Flats disposal site in two distinct and separate hydrogeologic units. Groundwater occurs initially in basal sandstones of the Burro Canyon at depths below the ground surface from 185 to 200 feet. Groundwater is unconfined and the saturated thickness at the base of the Burro Canyon ranges from 5 to 22 feet. The Burro Canyon sandstone overlies a regional confining layer (mudstones in the upper part of the Brushy Basin). The next occurrence of groundwater is in sandstones in the lower part of the Brushy Basin at a depth of approximately 500 feet below the ground surface. Groundwater is confined by mudstones in the upper part of the Brushy Basin, and the potentiometric surface ranges from 370 to 400 feet below the ground surface. There is no observed hydraulic connection of groundwater between the Burro Canyon and the Brushy Basin in the vicinity of the disposal site. The saturated portion of the basal sandstone of the Burro Canyon is considered the uppermost aquifer beneath the Dry Flats disposal site.

The mean saturated hydraulic conductivity of the upper 60 feet of the Cretaceous stratigraphic unit is 3 x 10^{-1} ft/day (1 x 10^{-4} cm/s) and over the entire thickness of the unit the calculated hydraulic conductivity averages 1 x 10^{-1} ft/day (4 x 10^{-5} cm/s). In the Burro Canyon, the average hydraulic conductivity is 5 x 10^{-4} ft/day (2 x 10^{-7} cm/s). The Burro Canyon groundwater system has a low hydraulic conductivity and is not capable of yielding 150 gallons per day of water to a well. The migration of groundwater is toward the northeast along the dipslope of the bedrock strata. Recharge to the saturated zone in the Burro Canyon is restricted, with the principal source of water being infiltration of precipitation. Based on review of aerial photographs and site reconnaissance, there is no evidence of discharge of groundwater from the Burro Canyon zone in the vicinity of the site.

5.2.3 Geochemical conditions

The geochemical properties of soils and lithologic materials at the Dry Flats disposal site control the solubility and adsorption of contaminants that could leach from the residual radioactive materials. To characterize and quantify further the chemical interactions between residual radioactive material leachate and Dry Flats material that affect contaminant migration, samples from core holes were examined to determine material properties and mineralogy. Also, batch leach tests with deionized water were used to estimate source concentrations of residual radioactive material and evaluate the adsorption potential of lithologic material at the disposal site. Geochemical modeling was also performed to speciate contaminants to predict their solubility under field Eh and pH conditions.

Results of material and mineralogical characterization, batch leach test studies, and geochemical modeling suggest that uranium, vanadium, molybdenum, and arsenic could potentially become soluble or desorbed from native materials in the unsaturated zone at the disposal site. However, the presence of clay minerals and ferric oxyhydroxides along microfractures within the carbonaceous shales and mudstones should enhance adsorption processes involving these hazardous constituents. Also, relatively reducing conditions exist within the carbonaceous shales and mudstones due to the presence of pyrite and solid organic carbon. The reducing conditions may promote precipitation reactions with these hazardous constituents. Carbonaceous shales and mudstones comprise approximately 30 percent of the material in the Cretaceous unit at the disposal site. Therefore, both adsorption and precipitation processes should reduce concentrations of these hazardous constituents in solution under unsaturated flow conditions.

5.2.4 Water use

Within a 2-mile radius of the disposal site, the only domestic water wells are those located in Coke Oven Valley to the west and the San Miguel River Valley to the north. Three domestic wells are located in Coke Oven Valley, two wells are associated with a uranium leaching operation, and one well is for a private residence. None of the wells obtain groundwater from the water-bearing formations present at the disposal site. Eight wells in the alluvium and one in the Salt Wash Member are located in the San Miguel River Valley. Three of the wells in the river valley supply water to a trailer court outside the town limits of Naturita, and the remaining six wells supply water to residents of Naturita.

The potential use of groundwater in the Burro Canyon at the site is very low because of the low yield. Groundwater in the Salt Wash aquifer at the site has a low value because of the great depth. Alternative supplies of good quality water are available from the town of Naturita. Future use of groundwater in the vicinity of the disposal site is not expected to occur because of the isolated location and lack of development on public land administered by the Bureau of Land Management (BLM).

5.3 DESIGN CONSIDERATIONS AND FEATURES FOR WATER RESOURCES PROTECTION

The disposal option proposed for the Naturita processing site involves relocation of contaminated materials to the Dry Flats disposal site. The materials will be placed in a partially below-grade disposal cell excavated into the unsaturated Dakota/Burro Canyon stratigraphic unit. The contaminated materials will be covered with a rock/clay cover including, in descending order: a riprap erosion layer, a gravel/sand bedding layer, a frost protection layer, and a radon/infiltration barrier. The cover on the sideslopes will include a rock erosion protection layer, a bedding layer, a frost protection layer, and a radon/infiltration barrier.

5.4 GROUNDWATER PROTECTION STANDARDS FOR DISPOSAL

The proposed disposal cell at the Dry Flats site is designed to control radioactive materials and nonradioactive contaminants in conformance with the proposed EPA groundwater protection standards in 40 CFR 192.02(a)(3). The DOE proposes the application of supplemental standards because of Class III (limited use) groundwater in the uppermost aquifer based on low yield. The basal sandstone of the Cretaceous Burro Canyon Formation is the uppermost aquifer beneath the disposal site.

The EPA groundwater protection standards consist of three components: 1) a list of hazardous constituents; 2) a corresponding list of proposed concentration limits for the constituents; and 3) a point of compliance (POC). These three components are discussed in the following paragraphs.

5.4.1 Hazardous constituents

Hazardous constituents were identified that are reasonably expected to be in or derived from residual radioactive material to be stabilized at the disposal site. The hazardous constituents were identified by characterization of residual radioactive material, groundwater quality data, and description of the process and reagents used in processing uranium. The hazardous constituents at the Naturita site are summarized in Table 3.1 of Attachment 4.

5.4.2 Proposed concentration limits

To achieve compliance with the standards, the DOE proposes a narrative supplemental standard rather than establishing numerical concentration limits for constituents in groundwater at a POC. To comply with the concept that the remedial action comes as close to meeting the otherwise applicable standard as is reasonable under the circumstances, hypothetical concentration limits have been established for constituents in groundwater. The proposed hypothetical concentration limits for the hazardous constituents at the Dry Flats disposal site were the EPA MCLs or the statistical maximum of background groundwater quality for those hazardous constituents without MCLs. Concentration limits are provided in Table 3.1 of Attachment 4.

5.4.3 Point of compliance

A POC has not been established for the proposed Dry Flats disposal site because groundwater monitoring will not be required under the supplemental standards compliance strategy.

5.5 SUPPLEMENTAL STANDARDS

To achieve compliance with the proposed EPA groundwater protection standards, the DOE proposes the application of narrative supplemental standards based on Class III (limited use) groundwater [40 CFR 192.21(g)]. Groundwater in the uppermost aquifer (basal sandstone of the Burro Canyon Formation) beneath the Dry Flats disposal site is not a current or potential source of drinking water because the quantity of water available is less than 150 gallons per day [40 CFR 192.11(e)(3)].

The low yield of groundwater from wells in the Burro Canyon (uppermost aquifer) beneath the proposed Dry Flats disposal site has been demonstrated. Aquifer performance testing has been conducted in monitor wells at the disposal site to test the ability of the aquifer to consistently yield groundwater to a well. Field data indicate that the anticipated yield is consistently less than 150 gallons per day, thereby fulfilling the requirement for supplemental standards based on Class III (limited use) groundwater because of low yield. Based on field reconnaissance at the Dry Flats disposal site, there are no domestic or stock wells in the saturated basal sandstones of the Burro Canyon (uppermost aquifer) within a 2-mile radius of the site. Also, there is no evidence of hydraulic interconnection between the uppermost aquifer, surface water, or underlying units containing groundwater.

To demonstrate the proposed disposal cell design's compliance with the proposed EPA groundwater protection standards, design parameters were evaluated in conjunction with the hydrogeologic characteristics of the Dry Flats site. The evaluation shows that the disposal cell will minimize and control releases of hazardous constituents to groundwater and that hydrogeologic conditions will limit subsurface contaminant migration and potential pathway access to receptors to the extent necessary to protect human health and the environment.

5.6 PERFORMANCE ASSESSMENT

The DOE is required to demonstrate that the performance of the disposal cell at the disposal site will comply with the EPA groundwater protection standard (40 CFR 192.02(a)(3)). To achieve compliance, the DOE proposes the application of supplemental standards because of Class III groundwater based on low yield.

The DOE has assessed the performance of the proposed disposal site in conjunction with the hydrogeological system and has shown that the disposal unit will minimize and control releases of 1) hazardous constituents to groundwater and surface water, and 2) radon emanations to the atmosphere to the extent necessary to protect human health and the environment. Assessments of hydrogeologic characteristics and geochemical attenuation are discussed in Section 3.3 of Attachment 4.

5.7 CLOSURE PERFORMANCE ASSESSMENT

The DOE has demonstrated that the proposed remedial action at the disposal site will comply with the proposed EPA groundwater protection standards by applying supplemental standards because groundwater in the uppermost aquifer is considered Class III based on low yield. The DOE has assessed the performance of the designed disposal unit at the site in conjunction with the hydrogeologic system and has shown that the disposal unit will minimize and control releases of 1) hazardous constituents to groundwater and surface water, and 2) radon emanations to the atmosphere to the extent necessary to protect human health and the environment. Natural, stable materials have been proposed for use in construction of the Dry Flats disposal cell so that long-term performance is ensured. The DOE has also demonstrated that the design features necessary for compliance with groundwater protection standards minimize the need for active maintenance of the disposal site.

5.8 PERFORMANCE MONITORING AND CORRECTIVE ACTION PLANS

The DOE will implement a monitoring program, to be carried out during the post-disposal period, which is adequate to demonstrate that the initial performance of the disposal cell is in accordance with design requirements. The appropriate method for performance monitoring of the disposal site will be determined and described in the long-term surveillance plan. Although POC wells will not be required under the supplemental standards compliance strategy, the DOE may consider monitoring groundwater in the uppermost aquifer downgradient from the disposal cell for a period of time following completion of remedial action as a best management practice.

The disposal cell has been designed and will be constructed to be effective for up to 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years. The design of the cell has incorporated standard safety factors and should therefore perform for a period of greater than 1000 years with minimal maintenance. It is not anticipated that the designed disposal cell at the site will fail, because all natural materials will be utilized and the infiltration/radon barrier will be adequately protected from disruption by frost and biointrusion.

5.9 GROUNDWATER CLEANUP

The DOE is required to demonstrate that cleanup or control of existing process-related groundwater contamination at the Naturita site will comply with the proposed EPA groundwater protection standards in Subpart B or 40 CFR 192. Groundwater cleanup will be addressed under a separate DOE program and National Environmental Policy Act (NEPA) process using strategies and options outlined in a programmatic environmental impact statement being developed for the UMTRA Project. The need for and extent of groundwater cleanup at the Naturita site will be evaluated based on the extent of existing contamination, the potential for current or future use of groundwater from the uppermost aquifer, and protection of human health and the environment. The current level of characterization at the Naturita processing site is sufficient to address only whether the remedial action will comply with the proposed EPA groundwater protection standards. Additional investigations will be conducted as necessary to determine the appropriate groundwater cleanup strategy for the Naturita processing site. The proposed surface remedial action will not preclude or interfere with any potential groundwater remediation activities at the processing site.

6.0 RADON ATTENUATION AND SITE CLEANUP

6.1 INTRODUCTION

This section summarizes the disposal cell design and relevant parameters selected in evaluating the radon barrier. A discussion of the radiation survey plan is also included with respect to reasonable assurance that compliance with EPA standards outlined in 40 CFR 192 will be achieved.

6.2 DESIGN

The proposed remedial action will consolidate contaminated materials from the former tailings pile, mill yard, and ore storage areas within the designated Naturita site boundary, as well as windblown and waterborne material distributed over adjacent vicinity properties, into a single disposal cell at the Dry Flats site with an approximate volume of 547,000 cubic yards. Contaminated material will be removed from remote vicinity properties in the Naturita community (approximately 300 cubic yards) and included in the main disposal cell. In addition, an estimated 8000 cubic yards of contaminated demolition debris from the office building, 11 other site structures, and a large quantity of on-site scrap metal and milling equipment will be incorporated into the main disposal cell. Efforts will be made to place materials with relatively low radium-226 concentrations over material with higher concentrations. Accordingly, the mill yard/ore storage material will be placed at the base of the cell, followed by the former tailings pile foundation and windblown soils. A compacted (95 percent) earthen radon barrier 18 inches thick will be placed directly over the contaminated material. Eighteen inches is the minimum cover thickness required for a radon barrier as stated in the TAD (DOE, 1989a). The sequencing of contaminated material within the cell will be such as to reduce the radon flux below the EPA standards in accordance with the intent to attain levels "as low as reasonably achievable" (ALARA).

Additional cover components will be sequentially placed above the primary earthen radon barrier. On the gradual topslope, these components will consist of a 36-inch-thick frost protection layer, a 6-inch-thick sand/gravel bedding layer, and a 12-inch-thick erosion protection rock riprap layer. The 5-to-1 sideslopes will also contain the same sequence of material on top of an 18-inch-thick earthen radon barrier.

The radon barrier, sand/gravel bedding layer, soil frost protection layer, and rock riprap layer all contribute to the reduction of surface radon flux in order to meet the EPA standards. However, only the radon barrier was considered in the radon diffusion calculations. The other components provide added assurance that the cover design will comply with EPA standards.

6.3 RADON BARRIER PARAMETERS

The radon barrier design parameters and support calculations were used in conjunction with the RAECOM model (NRC, 1984) to determine the cover thickness necessary to control radon flux to meet EPA standards of 20 pCi/m^{2}s. The radon barrier thickness was determined based on procedures specified in the TAD (DOE, 1989a).

Specific parameters discussed include 1) long-term moisture content, 2) radon diffusion, 3) radon emanations, 4) bulk density, 5) specific gravity, 6) porosity, 7) layer thickness, and 8) average radium-226 concentrations. The RAECOM input parameters for the Naturita materials are presented in Calculation 17-741-02-01 (*Radon Barrier Design*).

6.3.1 Long-term moisture

The average long-term moisture content for the earthen barrier and contaminated material was determined by sample testing to assess minus 15 bar capillary moisture content. In general, the average value obtained from a series of individual sample tests was selected to characterize the media. Eight radon barrier soil samples from the Coke Oven borrow site were separately tested. Minus 15 bar capillary moisture content ranged from 14.2 to 18.7 percent by weight. The average value of 16.4 percent was chosen to characterize this medium.

Separate sample sets were tested for the former tailings area (eight samples) and the mill yard (three samples) to determine their respective long-term moisture contents. Minus 15 bar moisture measurements of radiologically contaminated material from the former tailings pile area (five samples) ranged from 3.62 to 6.98 percent by weight for radiologically contaminated material and averaged 5.10. On the other hand, similar tests of three samples of uncontaminated soil from the former tailings pile area yielded values of 10.48, 7.48, and 4.22 percent by weight and averaged 5.32. Although combining the two data sets yielded an average of 5.18, the minus 15 bar value of 5.10 percent by weight was conservatively selected for the former tailings pile subsoil.

Similar testing of mill yard materials yielded 11.47, 12.66, and 11.9 percent by weight, and the average value of 12.01 percent was selected as representative of the mill yard materials.

Capillary moisture testing of the windblown, vicinity property, and ore storage soils was not performed. Since the geotechnical properties of these materials are similar to those of the tested mill yard soils, a value of 12.01 percent by weight was also assumed for the windblown, vicinity property, and ore storage materials.

6.3.2 Radon diffusion

Average radon diffusion coefficients for the earthen radon barrier material and contaminated mill yard, ore storage, and off-site material (windblown areas) were determined using eight different cover soil samples and a single soil sample from each contaminated area. Radon diffusion for each type of material was measured in the laboratory as a function of moisture content ranging from 3.5 to 20 percent by weight. For each soil sample, approximately five diffusion measurements were made, each at a different moisture content within the moisture content range. Test results for cover and contaminated material were separately plotted and a best fit curve was obtained for each material category using a least squares methodology. At 73.2 percent saturation, corresponding to an average moisture content of 16.4 percent by weight, a radon diffusion coefficient of 0.0031 square centimeters per second (cm^2/s) was derived for the earthen component of the radon barrier. Diffusion coefficients of 0.017, 0.019, and 0.018 cm^2s were estimated for the contaminated material to be excavated from the mill yard, ore storage, and windblown areas, respectively. Each diffusion coefficient value selected corresponds to the individual estimated long-term moisture content of 12.01 percent by weight for the subarea's material, or 43 and 37 percent saturation for the combined mill yard/ore storage layer and windblown material, respectively. Considering the diffusion coefficient measurements of the mill yard and ore storage soil samples as independent samples of the combined mill yard/ore storage layer, the average diffusion coefficient for the layer is the arithmetic mean of the values obtained at the 43 percent saturation, or 0.018 cm^2/s. Since the diffusion coefficient measurements of contaminated materials from the former pile area were not made as a function of moisture, it was assumed that the diffusion coefficients could be estimated using their empirical derived dependence on moisture (NRC, 1984). A value of 0.0297 cm^2/s was chosen for the former tailings pile material at a 5.10 percent long-term moisture content. This value was compared with diffusion coefficient measurements, at the 5.10 percent moisture content, for mill yard and ore storage soils and was shown to be conservative relative to assuming that the former mill tailings foundation soil could be represented by either of the two materials.

6.3.3 Radon emanation

Twelve standard measurements of radon emanation for contaminated materials from the mill yard, ore storage, and windblown areas ranged from 0.06 to 0.35. In general, radon emanation has been shown to be statistically independent of both moisture and radium-226 concentrations using standard regression and statistical analysis.

Average emanation factors of 0.34, 0.10, and 0.22 were calculated from four measurements made on a sample of contaminated material from the mill yard, ore storage, and windblown areas, respectively, with corresponding standard error of the means of 0.01, 0.02, and 0.01. Since the mill yard, ore storage, and vicinity property materials and demolition debris are to be combined as a single mixed layer at the base of the disposal cell (see Section 6.3.5, *Layer Thickness*), the volume-weighted average emanation factor for the mill yard and ore storage results, 0.33, was used to characterize this layer. An average emanation factor of 0.22 was used for the windblown material, which will be stabilized as a single layer. No emanation measurements were performed on the former pile material; the largest emanation factor of 0.35 for contaminated material, measured for a mill yard sample, was conservatively assumed to be representative of this material.

6.3.4 Dry densities and porosities

The dry densities, specific gravities, and porosities for the earthen radon barrier and various types of contaminated material were determined using standard tests and procedures and assuming a design compaction of 95 and 90 percent, respectively. Radon barrier soils had maximum dry densities and specific gravities ranging from 1.56 to 1.97 grams per cubic centimeter (g/cm^3) for separate measurements made on 10 cover soil samples, and specific gravities ranging from 2.63 to 2.79 for separate measurements made on 11 cover soil samples. An average density at 95 percent compaction of 1.68 g/cm^3 and an average specific gravity of 2.71 were used to obtain a representative porosity of 0.38 for the radon barrier.

Eleven maximum dry density and five specific gravity measurements of material from contaminated areas ranged from 1.20 to 2.09 g/cm^3 and 2.51 to 2.80, respectively. The respective average compacted density in grams per cubic centimeter (90 percent compaction) and specific gravity for each contaminated area were 1.73 and 2.70 for the former tailings area (five samples measured for density only), 1.49 and 2.71 (three samples) for the mill yard and 1.47 and 2.51 for the ore storage area (one sample), and 1.44 and 2.76 for the windblown area. Since no specific gravity measurements were made on the soils from the former tailings pile area, the average 2.70 value calculated for the mill yard was assumed to be indicative of this material. In addition, since the mill yard, ore storage, and vicinity property material and demolition debris are to be combined as a single mixed layer at the base of the disposal cell, the density and specific gravity to characterize this layer was calculated by volume weighting the densities and specific gravities of the constituents. An average dry density and specific gravity of 1.47 g/cm^3 and 2.60 were assumed for the vicinity property material, and corresponding values of 2.40 g/cm^3 and 3.00 were used for demolition debris. On this basis, estimated porosities for contaminated soils from the former pile, mill yard, ore storage, and windblown areas were 0.36, 0.45, 0.41, and 0.48, respectively.

6.3.5 Layer thickness

The specific thickness of three discrete layers of contaminated materials was calculated for 1) mill yard soil/ore storage/vicinity property/demolition debris, 2) former tailings pile foundation soil, and 3) windblown materials. Thicknesses for the contaminated layers were calculated based on estimated volumes of materials and their ultimate geometric location in the disposal cell, with layers sequentially placed in increasing numerical order from the bottom to the top. Volumes of materials were determined from radiometric measurements and radiological analyses of soil samples, and from boring and test pit material collected across the Naturita site. Information on layer thicknesses can be found in Calculation 17-740-04-00 (*Calculation of Embankment Design--Pile Capacity*) and Calculation 17-741-02-01 (*Radon Barrier Design--Radon Barrier Thickness for Radon Control*) of Attachment 1.

6.3.6 Radium-226 concentrations

Average radium-226 concentrations were estimated for each contaminated subarea of the Naturita site based on an assessment of radiometric measurements (hand held and borehole gamma logs), and radiochemical and gamma spectroscopic measurements of contaminated material collected from surface soil samples, test pits, and boreholes constructed within the subareas. The division of the site into subareas is shown in Figure 1.3. Incremental radium-226 depth profiles were constructed at each measurement grid point within the subarea. The average radium-226 concentration for the subarea was determined by integrating the profiles over the volume contained between the topographical surfaces defining the ground surface and the excavation depth required to comply with EPA cleanup standards. Estimated design volumes, areas, and mean radium-226 concentrations for contaminated materials at the Naturita site are shown in Table 1.1. Based on these data, volume-weighted average radium-226 concentrations were calculated for each disposal cell layer.

6.3.7 Ambient radon concentration

An ambient radon concentration in air of 2.3 pCi/L was obtained from background air samples collected for 24 hours in the vicinity of the Naturita processing site using continuous radon samplers (FBDU, 1981). However, recent pre-remedial action radon monitoring at the disposal site for four quarters (April 25, 1989, through March 12, 1990) using integrating Track-Etch® detectors indicates that an ambient radon concentration of 0.6 pCi/L would be more appropriate (DOE, 1990b) and therefore was used for RAECOM calculations.

6.4 EVALUATION OF RADON BARRIER

The radon barrier was evaluated with respect to compliance with the EPA radon flux standard of 20 pCi/m^2s using the previously discussed parameters in the RAECOM code. Only the high clay content earthen layer directly over the contaminated material was considered. A variety of cases were evaluated due to the potential application of supplemental standards, which would reduce the amount of lesser contaminated material, in several areas adjacent to the processing site (Calculation 17-730-02-00, Attachment 1). The cases analyzed included those with and without the application of supplemental standards. In addition, since the current design calls for a minimum windblown thickness of 4 feet to be placed between the radon barrier and the former tailings pile material, this case was also analyzed. For each case, a baseline analysis, using the average volume-weighted material and radon diffusion properties previously discussed, and a "worst case" analysis, using material and radon diffusion property values determined in accordance with sensitivity analysis guidelines found in the TAD for the UMTRA Project (DOE, 1989a), were evaluated. The results and calculational methodology used for each of these cases are presented in Calculation 17-741-02-01, Attachment 1. The results of the analysis indicate that the largest of the minimum reported radon barrier thickness determined for the cases analyzed is 10.2 inches for the 4-foot windblown "worst case" analysis. Since the minimum constructable thickness is 18 inches, 18 inches was selected for the radon barrier thickness. The design is based on maintaining a 4.0-foot-thick layer of relatively low contamination material between the radon barrier and the higher-level contaminated materials to be placed in layers below it. This design requirement would be unaffected by the proposed supplemental standard applications. Consequently, under these conditions, it was concluded that a minimum radon barrier of 18 inches, dictated by constructability, would suffice for both the topslope and sideslopes.

The additional frost protection, bedding, and riprap layers above the primary radon barrier provide additional assurance that the average surface radon flux will be well below the 20 pCi/m^2s EPA standard.

6.5 SITE CLEANUP

Extensive field sampling and radiological surveys have been conducted by a number of investigators to determine the extent and degree of contamination at the Naturita site. Drawing NAT-PS-10-1715 in Attachment 1 shows the distribution of contaminated materials as a function of excavation depths.

6.5.1 Radiological site characterization

Details of site characterization data are presented in Calculation 17-730-01-01 (*Contaminated Material Excavation--Excavation Extent and Depth, Volume and Radium-226 Concentration*) in Attachment 1. Measurements of background radioactivity near the Naturita site and measurements of existing radiological site conditions are summarized in Table 6.1.

Approximately 497,000 cubic yards of contaminated materials cover 131 acres at the Naturita processing site and immediately adjacent vicinity properties, excluding approximately 50,000 cubic yards of contaminated soil thinly dispersed over 61.8 acres in area D west of Highway 141 (Figure 1.3). A 30 percent contingency factor was imposed to yield a 570,000-cubic yard design volume, and application for supplemental standards to exclude the remediation of area D and other areas adjacent to the processing site will be made and submitted to the Colorado Department of Health (CDH) and the NRC for approval prior to implementation. Estimated design volumes, areas, and average radium-226 concentrations for the various major contaminated materials are presented in Table 1.1. Depths of contamination range from 0.5 feet for windblown areas to the west of Highway 141 and on the east bank of the San Miguel River to 18 feet in the mill yard, with a volume-weighted average depth of contamination of approximately 2 feet. The radium-226 contamination on the site and vicinity properties ranges from 0.5 to 822 pCi/g, and has a volume-weighted average of 62.1 pCi/g.

6.5.2 Standards for cleanup

The DOE is committed to removing radiologically contaminated materials and placing them in an engineered, off-site disposal cell such that all EPA standards in

Table 6.1 Background radioactivity and radiological conditions at the Naturita site

Parameter	Background data	Site data
Gamma exposure rate[a]		
Range (μR/hr)	11.8 - 15.1	8 - 369
Average (μR/hr)	13.5	36[b]
Radon concentration		
Range (pCi/L)	0.4 - 0.6	0.8 - 2.9
Average (pCi/L)	0.5	2.0
Radium-226 concentration		
Range in soil (pCi/g)	1.8 - 2.0	0.5 - 822
Average in soil (pCi/g)	2.3	62.1[c]
Radon flux		
Range (pCi/m^2s)	N/A	2.4 - 30
Groundwater (pCi/L)[d]	N/A	
Natural uranium		5.2 (ppm)[e]
Radium-226		28.6
Lead-210		13.5

NA = Not available
[a]μR/hr = microroentgens per hour.
[b]Area-weighted average.
[c]Volume-weighted average.
[d]Maximum on-site concentration from monitor well.
[e]ppm = parts per million

40 CFR 192 are met. All disturbed areas on the processing site and vicinity properties will be restored to grade for adequate control of surface drainage. No contaminated materials or buildings are to be released for unrestricted use. All buildings on the site will be demolished, and all contaminated debris and building components will be disposed of in the engineered disposal cell.

The supplemental standard provisions of 40 CFR 192 appropriate to vicinity properties are being considered for application in several areas as described in Calculation 17-730-07-00, *Proposed Supplemental Standards Areas*, of Attachment 1. These areas include steep slopes where conventional cleanup techniques cannot be employed and where disturbances would likely cause future erosion problems; areas containing protected vegetation, wildlife habitat, or cultural resources; and utility easements such as the high-pressure gas line within Area E.

Subsoil conditions in the alluvial floodplain at the Naturita site generally consist of a high percentage of barren cobbles and gravels greater than a number 4 mesh sieve (74 percent by weight) that are essentially free from radiological contamination. Radiological contamination is associated with the finer fraction passing a number 4 mesh sieve (0.19-inch x 0.19-inch openings). Excavation depths estimated from available characterization data will remove radium-226 concentrations in the finer fraction to less than 5 and 15 pCi/g for surface and subsurface soils. However, if radium-226 concentrations exceeding 15 pCi/g in the finer fraction are encountered below these initial excavation limits during construction, soil cleanup will be based on *bulk* radium-226 concentrations of 5 and 15 pCi/g of radium-226 above background in accordance with the NRC's concurrence on the bulk applicability of EPA soil cleanup standards for radionuclides (see NRC correspondence dated September 17, 1991, in Appendix A).

The average bulk soil cleanup standards for thorium-230 in 15-cm-thick soil layers, averaged over grid areas of 100 square meters, will be determined on a grid-specific basis. Measured residual bulk radium-226 concentrations (less than 5 and 15 pCi/g for 15-cm surface and subsurface soil layers, respectively) will be used to calculate appropriate excavation depths for bulk thorium-230 removal to ensure that the effective bulk radium-226 concentration, residual bulk radium-226 and that which grows in in 1000 years due to the radioactive decay of thorium-230, will not exceed the 5 and 15 pCi/g soil cleanup standard for bulk radium-226 concentrations. This approach is outlined in the Generic Protocol section of a general procedure titled *Generic Protocol for Thorium-230 Cleanup/Verification at UMTRA Project Sites* (see Appendix A) for the cleanup of thorium-230 and has been submitted to the NRC for concurrence and implementation at Naturita and other UMTRA Project sites. Residual bulk thorium-230 concentrations in areas excavated to depths greater than 8 feet, where remediation will require backfilling with clean fill, will be determined such that the working level in a hypothetical structure built on a 100-square-meter area will not exceed 0.02 working levels using appropriate modeling techniques (thorium-230 cleanup protocol for contamination at depth). Finally, bulk thorium-230 encountered below the water table in the saturated zone will be assessed and, if appropriate, supplemental standards will be developed for CDH and NRC approval prior to implementation (thorium-230 cleanup protocol for contamination in the saturated zone).

Uranium concentrations in subsoil encountered after radium-226 and thorium-230 have been removed to the EPA standards will be assessed, if necessary, using a pathway analysis approach to evaluate potential environmental, groundwater, and public health impacts. The need for additional remedial action for uranium will be based on this analysis, and any required cleanup criteria will be developed as a supplemental standard under criterion (f) of 40 CFR 192.21 and the provision that residual uranium concentrations will be ALARA. CDH and NRC approval for the derived supplemental standard will be sought for implementation.

6.5.3 Verification of cleanup

Excavation control monitoring will be conducted during remedial action to ensure that the 5 pCi/g and 15 pCi/g above background bulk radium-226 concentration standards promulgated by the EPA are met for respective surface and subsurface soils averaged over 15-cm depth increments and a 100-square-meter area. Verification sampling will prevent both inadequate underexcavation and costly overexcavation. The intent of the verification survey is to provide reasonable assurance of compliance with the standards.

Independent radiological surveillances and health/safety audits will be conducted by the DOE and the TAC during remedial action to ensure that all activities are performed to meet Federal, state, and local standards and guidelines. Quality control and assurance requirements and procedures are in place to ensure that adequate cleanup and subsequent verification are properly implemented and documented (DOE, 1990a).

Final verification surveys will be performed to document average bulk radium-226 concentrations on all 100-square-meter areas remediated. Four percent of the grids in the mill yard and off-site areas and 100 percent of the grids in the former tailings pile area will be assessed for thorium-230, as recently proposed for NRC consideration and concurrence. Any requirements for uranium concentration verification will be derived as part of any supplemental standards application for this radionuclide. Nine-plug composite surface soil samples will be collected for each 100-square-meter area at the final excavation depth and analyzed by gamma spectroscopy or radiochemical methods to verify compliance with EPA standards for radium-226 or approved supplemental standards for other radionuclides. For cobbly soils, an NRC-approved procedure (*Soil Verification Using Cobbles-to-Fines Correction*, Appendix A) will be implemented at the site for bulk radionuclide determination, excavation control, and site verification. Up to 30 test pits will be constructed in the former pile area to determine the average mass partition function for the site and its lower 95 percent confidence limit, as well as the average radionuclide concentration (at the upper 95 percent confidence limit) of the large soil size fraction retained on a number 4 mesh sieve [*Statistical Mass Partition Function--Alternative 1 (Test Pits)*, Section 5.4, in the NRC-approved cobbly soil cleanup procedure in Appendix A]. Site verification will use these site parameters and radiometric measurements for every 100-square-meter grid of the finer soil fraction passing a number 4 mesh sieve to assess bulk radionuclide concentrations. Background bulk radionuclide concentrations will also be determined for three background locations containing cobbly surface/subsurface soils.

In addition, a nine-point composite gamma measurement technique may be used in windblown contaminated areas north of the former tailings pile. Regression analysis will be used to correlate composite nine-point gamma count-rate measurements per 100-square-meter grid with radium-226 concentration measurements. Accordingly, verification of windblown areas would be based on the mean gamma count rate at the upper 95 percent confidence level corresponding to total radium-226 concentrations for 5 and 15 pCi/g for surface and subsurface soil remediation. If the site health physics manager decides that the nine-point composite gamma measurement technique is appropriate for these areas, a hand-held verification protocol will be developed for site-specific conditions and must be approved by the DOE UMTRA Project Office prior to implementation. The RTRAK mobile detection unit may also be used for verification of contaminated areas that are too large to sample by hand methods and along the haul road to the Dry Flats disposal site.

6.6 SUMMARY AND CONCLUSION

The disposal cell and radon barrier design will reduce the surface radon flux to levels below the EPA standards stated in 40 CFR 192.02(b). The DOE has committed to clean up the Naturita site and associated vicinity properties in accordance with EPA standards, NRC guidelines, and UMTRA Project health and safety requirements. Appropriate supplemental standards will be developed to exclude those areas identified in Calculation 17-730-02-00 of Attachment 1 from remedial action and will be submitted to CDH and the NRC for approval. Data have been collected, verified, and analyzed to provide a reasonable preliminary design. Additional characterization and media testing will be performed to provide more representative material and radon diffusion parameters for the former tailings pile, mill yard, ore storage, and windblown soils. The final design will be based on measurements of the as-built bulk radium-226 depth distribution and associated emanation factors. These additional activities will complement the available data base and ensure the fulfillment of the DOE's commitment to clean up the site in accordance with the UMTRCA and EPA standards.

7.0 LIST OF CONTRIBUTORS

The following individuals contributed to the preparation of this RAP.

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C. Yancey	Site management, document review
D. Thalley	Technical editing, document production coordination
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APPENDIX A

DEPARTMENT OF ENERGY/NUCLEAR REGULATORY COMMISSION CORRESPONDENCE

GENERIC PROTOCOL FOR THORIUM-230 CLEANUP/VERIFICATION AT UMTRA PROJECT SITES

PROCEDURE FOR BULK RADIONUCLIDE DETERMINATION, EXCAVATION CONTROL, AND SITE VERIFICATION FOR SOILS CONTAINING COBBLES

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SEP 0 6 [illegible]

FEDERAL EXPRESS

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Dear Mr. Surmeier:

Historically, the majority of Ra-226 contaminated materials being cleaned up at Uranium Mill Tailings Remedial Action (UMTRA) Project sites consisted of tailings, ore spoils, tailings intermixed with fine-grained soils (windblown and vicinity properties) and fine-grained soils under residual milling waste (tailings and raffinate ponds). However, in 1988, conditions encountered while remediating Th-230 contamination which persisted once Ra-226 had been removed at both the Riverton, Wyoming, and Durango, Colorado, sites were substantially different.

At both sites, which were located on alluvial floodplains, subsurface soils consisted of a large percentage of cobbles and gravels which were retained on a #4 sieve (4.76 mm). In addition, it was determined that approximately 95 percent of the total concentration of radioactivity was deposited on the fines (those soils passing a #4 sieve).

Based on these considerations and the fact that cleanup verification sampling routinely employed by the Remedial Action Contractors did not readily accommodate sampling and analysis of materials greater than #4 sieve, the following protocol for Th-230 cleanup/verification to a bulk subsurface concentration of 35 pCi/g was adopted and approved by the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) in modifications to the Remedial Action Plans for those sites.

1. Determine the "fines mass fraction" by collecting several (10) representative bulk field samples, and separating fractions greater than and less than a #4 sieve:

   fines mass fraction = mass fines/mass total = unitless fraction

If you should have any further questions regarding this request, please call Mr. Don Metzler of my staff at (FTS) 845-5657.

Sincerely,

Clinton B. Smythe
for Mark L. Matthews, P.E.
Project Manager
Uranium Mill Tailings Remedial Action
Project Office

cc:
F. Bosiljevac, UMTRA
S. Hill, TAC
M. Miller, TAC
D. Gonzales, TAC
J. Oldham, MK-F
D. Carlson, MK-F
M. Madsen, CN-Geotech

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SEP 17 1991

Mr. Mark L. Matthews P.E.
Project Manager
Uranium Mill Tailings Remedial Action
Project Office
Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

Dear Mr. Matthews:

Your letter of September 6, 1991, requested U.S. Nuclear Regulatory Commission (NRC) concurrence in the use of a procedure for determining and verifying radium-226 concentrations at locations with large quantities of cobbly material. Your letter states that at several Title I sites, DOE has encountered large quantities of radium-226 or thorium-230 contaminated material with a high content of cobbly material (greater than a No. 4 sieve size). Your tests show that the contained radioactivity is concentrated in the finer fraction with the coarse fraction containing negligible quantities (less than 5 percent). Procedures presently in use by your contractors for sampling and analyses are designed for relatively fine grained homogeneous soils with a minimum of larger material and are not adequate to characterize the radioactive concentrations in the heterogeneous size material being encountered. Your proposed approach would rely on measurement of the radium-226 or thorium-230 content in the finer fraction to obtain an average concentration for the entire sample.

We agree that determining an average radium-226 or thorium-230 content over an entire sample would be consistent with the Environmental Protection Agency (EPA) standards in 40 CFR 192 if the radium-226 content of the two size fractions and the percentage of each size fraction are properly factored. Part 192.12 states that the concentration of radium-226 in land can be averaged over an area of 100 square meters to meet the standards of not exceeding background level by more than 5 pCi/g averaged over the first 15 cm of soil below the surface and 15 pCi/g averaged over 15 cm thick layers of soil more than 15 cm below the surface.

You plan to address the details of the procedure in a section to be added to Procedure RAC-015 which will define when the procedure would be used, the number and distribution of samples to be taken, the determination of the radium-226 distribution and size fractions, and other appropriate details.

We agree that the proposed approach has the potential for maintaining compliance with EPA's standards while avoiding over excavation of contaminated

NRC/UMTRA92 - 0018

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

APR 4 1992

Mr. Albert R. Chernoff, Project Manager
Uranium Mill Tailings Remedial Action
Project Office
U.S. Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

Dear Mr. Chernoff:

We have reviewed the procedure on "Bulk Radionuclide Determination, Excavation Control, and Site Verification For Cobbly Soils" sent with your letter of March 26, 1992, and supplemented by a revised Page 12 sent by facsimile on March 30, 1992. We hereby concur with its use on U.S. Department of Energy Uranium Mill Tailings Remedial Action Project sites containing a high percentage of cobbly subsoil. This procedure, designated RAC-OP-003, should be referenced in the specific Remedial Action Plans for those sites where it will be used.

One item of note concerns the section of the procedure discussing authority (Section 1.3). This section should be revised to reference this letter of concurrence rather than the September 17, 1991, letter cited, which agreed with the concept but did not concur with the procedure.

Any questions should be addressed to Allan Mullins of my staff at FTS 964-2578.

Sincerely,

John J. Surmeier, Chief
Uranium Recovery Branch
Division of Low-Level Waste Management
and Decommissioning, NMSS

cc: D. Metzler, DOE Alb
P. Mann, DOE Alb
D. Gonzalez, TAC

Generic Protocol for Thorium-230 Cleanup/Verification at UMTRA Project Sites

The excavation of materials contaminated with thorium-230 (Th^{230}) at one or more UMTRA Project sites may require extensive, deep removal of soil materials to ensure that the radium-226 (Ra^{226}) concentrations will comply with EPA's surface and subsurface soil cleanup standards (i.e., 40 CFR 192). The following discussion presents a unified approach for the future application of standards for Th^{230} at the UMTRA Sites.

1. Introduction

The cleanup of radiologically contaminated soils on UMTRA Project sites provides explicit requirements for the remediation of soils contaminated with Radium-226 (Ra^{226}), which include limits of 5 and 15 picocuries/gram (pCi/g) for the initial and successive 15 centimeter (cm) deep layers, respectively, averaged over an area of 100 m^2. If other radionuclides are encountered in sufficient quantities and concentrations to constitute a significant radiological hazard, the supplemental standards provisions of 40 CFR 192.21 and 40 CFR 192.22 provide guidance for performing remedial action for these radionuclides in a manner that comes as close to meeting the applicable standard as is reasonable under the circumstances.

Thorium-230 (Th^{230}), which naturally decays, with a half-life of 77,000 years, to form Ra^{226} is also present in uranium mill tailings and contaminated soils. Therefore, it may be readily shown that for soils containing initial Ra^{226} and Th^{230} concentrations, at time $t=0$, of $Ra^{226}(t=0)$ and $Th^{230}(t=0)$, respectively, the Ra^{226} concentration at any later time, t, is:

$$Ra^{226}(t) = Ra^{226}(t=0)\, e^{-\lambda t} + Th^{230}(t=0)\,(1 - e^{-\lambda t}),$$

where λ is the decay constant for Ra^{226}, or 4.32×10^{-4} yrs^{-1}.

Furthermore, the geochemical behavior of Ra^{226} and Th^{230} in typical UMTRA site environments have been observed to be significantly different. Under neutral or basic soil conditions, neither Ra^{226} nor Th^{230} are preferentially mobile geochemically (i.e., both radionuclides will form chemical compounds that have similar potential for migrating into soils). However, under acidic conditions, the chemical forms taken by these radionuclides are significantly different in their potential for depth migration in soil, with Th^{230} being more mobile than Ra^{226}.

In windblown tailings areas, mill yards, and ore storage areas of UMTRA sites, it has been observed that: 1) the surface and subsurface soils are normally at neutral pH; 2) the radiological material does not contain abundant quantities of free acid; and 3) the Ra^{226} and Th^{230} concentrations are in near secular equilibrium (their activities are approximately equal). The near secular equilibrium for the radiological contamination in these areas results from the fact that most of the uranium ores processed were in near equilibrium. Therefore, the application of soil cleanup procedures for Ra^{226} according to EPA standards would also reduce the Th^{230} concentrations to acceptable levels by default, and the total Ra^{226} as a function of time will not exceed 5 or 15 pCi/g, for surface and subsurface soil respectively.

However, under acidic soil conditions that may prevail in the foundation soil under uranium mill tailings, the subpile region, or in surface and subsurface soils of raffinate or evaporation pond, the different geochemical interactions of Ra^{226} and Th^{230} will cause these radionuclides to differentially migrate. Generally, under these conditions, Ra^{226} is adsorbed or co-precipitated on soil within a depth of one to two feet, and Th^{230} migrates deeper into the subsoil until neutralization of the transporting pore water occurs, where it is removed from solution by the formation of insoluble precipitates or co-precipitates (thorium or thoro-ferro hydroxides, for example). For example, at the Spook, Wyoming site, Th^{230} differentially migrated as deep as 20 feet below the raffinate pond before being stabilized by neutralization. In order to be in harmony with the supplemental standards provisions to reduce Th^{230} concentrations to as low as reasonably achievable (ALARA), and to come as close to meeting otherwise applicable standards as is reasonable under the circumstances, an excavation depth less than 20 feet was selected as a viable solution for this site.

It may be concluded that the cleanup of the initial Ra^{226} contamination according to standards does not necessarily mitigate against the ultimate ingrowth of residual Ra^{226} with time due to the radioactive decay of residual Th^{230} in all areas within a site. As a consequence, residual Ra^{226} concentrations at a later date, due to ingrowth from Th^{230} contamination, may pose an undesirable health hazard. Therefore, the supplemental standards provision of 40 CFR 192 requires the development of a cleanup criterion for Th^{230}, which is health protective by reducing exposures to levels that are ALARA, keeping in consideration the measures necessary to implement the remedial actions under the circumstances that exist at the site. The following procedure establishes appropriate remedial action concentration limits for Th^{230}, and is proposed to be implemented at UMTRA Project sites after concurrence from all governing agencies involved with activities at each site agree to its implementation.

2. Generic Protocol

As can be seen from the equation presented in the introduction, the overall 1000-year maximum concentration of Ra^{226} in the soils will either be equal to the present Ra^{226} inventory (if Th^{230} concentrations are equal to or less than Ra^{226} concentrations), or the total Ra^{226} inventory one thousand years in the future (if Th^{230} concentrations exceed Ra^{226} concentrations). If Ra^{226} concentrations are equal to or exceed Th^{230} concentrations, the site will already meet the Th^{230} supplemental standard by default when the site is remediated to the 40 CFR 192 standards for Ra^{226}.

(1) Therefore, the supplemental standard chosen for Th^{230} needs only to ensure that the overall Ra^{226} concentration one thousand years in the future, when averaged over 100 square-meter areas, will not exceed either 5 pCi/g in the first 15 cm layer or 15 pCi/g in successive 15 cm layers.

It should be noted that, in keeping with the NRC interpretation of the EPA's soil cleanup standards, the Ra^{226} concentrations are considered to be bulk concentrations, as determined by the recently developed, NRC-approved protocol for excavation control and soil verification of cobbly subsoils.

2.1 Protocol for Contamination at Depth

As the depths of excavations become deeper to remove elevated Th^{230}, the thickness of overlying fill material that is eventually used to remediate the site will increase. As a result, attenuation of radon-222 (Rn^{222}) diffusing through the overlying fill material will also increase. Therefore, as the overlying clean fill material thickness increases, the resultant attenuation of the radon generated from the associated ingrowth of Ra^{226} will allow higher residual concentrations of Th^{230} to be left in place, while still attaining a level of protection equivalent to the intent of the Ra^{226} soil cleanup standards. To determine this concentration, the NRC model (presented in the Draft Generic Environmental Impact Statement on Uranium Milling; NUREG-0511; April 1979) can be used to determine the radon-222 (Rn^{222}) flux that would produce 0.02 Working Levels (WL) in a hypothetical structure built on a 100 square-meter (m^2) grid. The following equation was used:

$C = FAB/VR*1000$, where:

C = Rn^{222} concentration (pCi/l)
F = Rn^{222} flux (pCi/m^2-s)
A = Area over which the flux enters (m^2)
B = Flux reduction factor for entering structure (unitless)
V = Volume of the structure (m^3)
R = Effective Rn^{222} removal rate (s^{-1})
1000 = conversion factor (l/m^3)

In areas where basements are feasible (based on local construction practices and deep groundwater table), it should be assumed that the thickness of fill material is eight feet less than the depth of the excavation. Using $A = 103m^2$, $B = 0.5$, $V = 250m^3$, and $R = 1.98 \times 10^{-4}\ s^{-1}$, a flux of 3.9 pCi/$m^2$-s would produce indoor air concentrations of approximately 4.0 pCi/l Rn^{222}. Assuming radon daughters are present at 50% equilibrium, this would correspond to 0.02 WL.

(2) Thus, the RAECOM computer code can be used to calculate the resultant flux from higher concentrations at depth in order to determine if further excavation is warranted. As long as the calculated flux is less than 3.9 pCi/m^2-s, it can be assumed that equivalent protection is provided. The calculations shall use site-specific parameters when available. Reasonably conservative parameters that consider the expected site conditions shall be used when site-specific data are unavailable.

2.2 Protocol for Contamination in the Saturated Zone

Another scenario potentially impacting excavations to remove elevated Th^{230} concentrations is when groundwater is encountered at shallow depths. Since the Th^{230} contamination has been present within the saturated zone long enough for soluble constituents to have been mobilized, it is reasonable to assume that any remaining Th^{230} that may be encountered within a saturated zone will not be appreciably mobilized by pH neutral groundwater. Furthermore, it is known that the diffusion coefficient decreases dramatically as soils approach full saturation until it reaches values typical of water (Radon Attenuation Handbook for Uranium Mill Tailings Cover Design; NUREG/CR-3533; April 1984). It is therefore reasonable to assume that Rn^{222} generated within a saturated zone generally will not diffuse to the surface. Finally, it is very difficult to perform deep, cost effective excavations within a saturated zone.

(3) Therefore, whenever shallow groundwater is encountered, the following options will be considered:

(a) Excavation into the saturated zone will be considered when water pumping or other controls are reasonable and when high concentrations of Th^{230} extend only a short distance into the saturated zone.

(b) An ALARA analysis will be performed in cases where a major portion of the site contains Th-230 which extends into the saturated zone, and excavation into the zone is impractical. The ALARA analysis will use reasonably conservative assumptions to project future doses.

(c) If water pumping or other controls are not reasonable, excavation will halt at the level of the saturated zone.

3. Verification Sampling

Under typical site conditions, verification of the Th^{230} supplemental standard is to be achieved by a three-tiered sampling approach.

(4) In areas within an UMTRA processing site that are suspected of preferentially mobilizing thorium contamination over radium contamination (e.g., under raffinate pits), based upon process knowledge or other sources such as previous sampling data, 100% of the grids are to be sampled and analyzed for Th^{230}.

(5) In subpile areas, 10% of the grids will be sampled.

(6) In areas where process knowledge and characterization data indicates no potential for preferential mobilization (e.g., windblown tailings and ore storage areas), grids will not be sampled for Th^{230}.

An analysis of verification data from the Tuba City, Arizona, UMTRA site, which has completed remediation and used this strategy, found no instances in the area sampled at the rate of 1 out of 25 grids where Th^{230} concentrations would cause future (i.e., at t = 1000 years) expected Ra^{226} concentrations to exceed 40 CFR 192 standards for Ra^{226}. Furthermore, preliminary results confirm the expectation that Th^{230} concentrations are generally equal to or less than Ra^{226} concentrations in areas other than beneath the raffinate pits, and Ra^{226} concentrations are well correlated to Th^{230} concentrations in these areas.

If any verification samples exceed the Th^{230} criteria of this protocol, the surrounding eight grids will be examined to determine whether or not these grids also exceed the criteria. If sample results have not been generated for the surrounding grids already, archived samples of such grids will be analyzed. If any of the surrounding grids also exceed the Th^{230} criteria, the surrounding eight grids around such grids will also be examined. This process will continue until no more of the surrounding grids exceed the Th^{230} criteria. All grids that exceed the criteria will undergo further remediation unless there is sufficient justification and concurring parties agreement to do otherwise.

4. Conclusion

Based upon the above discussions, the following generic protocol shall be used for the excavation of Th^{230} at all future UMTRA Project sites:

(1) Excavate bulk Th^{230} to a 1000-year corrected bulk Ra^{226} concentration of 5 or 15 pCi/g (as appropriate) in 15-cm layers;

(2) For deeply buried material, stop excavations when the RAECOM computer code, using site-specific parameters, calculates a Rn^{222} flux of 3.9 pCi/m^2-s;

(3) Consider the following options whenever shallow groundwater is encountered:

(a) Excavate into the saturated zone when water pumping or other controls are reasonable, especially when high concentrations of Th^{230} extend only a short distance into the saturated zone.

(b) An ALARA analysis will be performed in cases where a major portion of the site contains Th-230 which extends into the saturated zone, and excavation into the zone is impractical. The ALARA analysis will use reasonably conservative assumptions to project future doses.

(c) Halt excavations at the level of the saturated zone when water pumping or other controls are not reasonable.

(4) Perform verification sampling for bulk Th^{230} in all grids underneath raffinate pits or other areas suspected of having a mechanism to preferentially mobilize Th^{230} over Ra^{226};

(5) Perform verification sampling for bulk Th^{230} in 10% of the grids underneath sub-pile areas; and

(6) Do not perform verification sampling for bulk Th^{230} in grids for which process knowledge and characterization data indicates no potential for preferential migration.

Health Physics Standard Operating Procedures

Title:	SOIL VERIFICATION USING COBBLES-TO-FINES CORRECTION		
Procedure No.: OP-003-4	Rev. No.: 0		Page 1 of 15

APPROVAL HP CONTROLLED COPY 101

APPROVED: [signature] 4-17-92
Project Director, Remedial Actions Contractor, UMTRA Project

APPROVED: David S. Carlson 4/17/92
Health Physics and Environment Manager, Remedial Actions Contractor, UMTRA Project

APPROVED: [signature] 4/17/92
Health Physics Programs Manager, Remedial Actions Contractor, UMTRA Project

APPROVED: [signature] 4-17-92
Health Physics Operations Manager, Remedial Actions Contractor, UMTRA Project

1.0 SCOPE

1.1 Purpose

This procedure will be used for determining and verifying average bulk radionuclide concentrations for radium-226 (Ra-226), thorium-230 (Th-230), and, if necessary, thorium-232 (Th-232) at locations where the subsoil consists of a percentage of cobbles in the bulk sample sufficient to affect measurement of the total radionuclide concentration. Excavation control and verification will be based on bulk concentrations determined by this procedure.

1.2 Applicability

This procedure may be applied in areas designated for routine soil excavation and verification (see RAC-OP-003) where the subsoil media contains a high percentage of cobbles.

1.3 Authority

Letter to A.R. Chernoff, DOE/UMTRA from J.J. Surmeier, NRC dated April 4, 1992.

2.0 REFERENCES

2.1 RAC Health Physics Procedure RAC-RP-005 - Radiological Instrumentation.

2.2 RAC Health Physics Procedure RAC-OP-002 - Excavation Control Procedure

2.3 RAC Health Physics Procedure RAC-OP-003

3.0 DEFINITIONS

3.1 Cobbles - The portion of a composite soil sample which will not pass through a #4 mesh sieve.

3.2 Fines - The portion of a composite soil sample which will pass through a #4 mesh sieve.

3.3 Mass partition function, f, of a cobbly soil sample - the ratio of the dry mass of the cobbles ($M_{>4}$), to the dry mass of the fines ($M_{<4}$):

$$f = M_{>4}/M_{<4} \text{ (cobble to fine ratio),}$$

where the total dry mass of the sample, M_T, is

$$M_T = M_{>s4} + M_{<s4}.$$

3.4 Radiological concentration (Ra-226, Th-230, or Th-232), in picocuries per gram (pCi/g), for the fines or cobbles, are designated by $C_{<s4}$ and $C_{>s4}$, respectively.

3.5 Bulk radionuclide concentration (Ra-226, Th-230, or Th-232), in pCi/g, is designated by C_s, and calculated using

C_s = Total Sample Radioactivity (pCi) / Total Dry Mass of Sample (g)

$$C_s = (C_{<s4} \times M_{<s4} + C_{>s4} \times M_{>s4}) / (M_{<s4} + M_{>s4})$$

$$C_s = C_{<s4} (1/(1+f)) + C_{>s4} (f/(1+f)).$$

3.6 Student t distribution (t) - the mathematical quantity used to define the distribution of test statistics for small sample populations; used herein to determine the lower and upper 95 percent confidence values for mass partition function and cobble radionuclide concentrations respectively.

3.7 Running Average - The determination of statistical quantities based on the available data and recalculated as more data becomes available.

3.8 Statistical Mass Partition Function (f_L) - The mass partition function (f), at the lower 95 percent confidence value calculated from test pit or running average data.

3.9 Statistical Cobble Radionuclide Concentration ($C_{>U}$) - The cobble radionuclide concentration ($C_{>s4}$) at the upper 95 percent confidence value calculated from test pit or running average data.

4.0 REQUIREMENTS

4.1 Prerequisites

4.1.1 All instruments used under this procedure shall have valid calibration.

4.1.2 Backup data (correlations, etc.) must be acquired, retained on-site, and made available for audit, on all methods and analyses used for excavation control and verification measurements.

4.2 Tools, Material, Equipment

4.2.1 Buckets, wheelbarrows, #4 mesh sieves or screens (4.8 millimeter), shovels or backhoe, weighing scale up to 200 lbs., drying oven, and other materials, as necessary, to obtain representative bulk soil samples. It should be noted that a 1/4 inch hardware cloth is approximately equivalent to a #4 mesh sieve, and may be used in lieu of a #4 mesh sieve.

4.3 Precautions/Limits

N/A

4.4 Acceptance Criteria

N/A

5.0 PROCEDURE

5.1 Site Evaluation

5.1.1 This guidance applies to processing sites and vicinity property areas. If the work area under consideration is less than 0.5 acre, the mass partition function (f) will be based on soil sampling from one centrally located test pit.

5.1.2 The statistical mass partition function (f_L) and statistical cobble radionuclide concentration ($C_{>u}$) may be determined by analysis of samples collected from test pits prior to construction. The purpose for developing a statistical mass partition function is only to obtain an estimate of the excavation depth required for compliance with radiological cleanup standards.

5.1.3 Approximately 30 uniformly distributed sampling locations (test pits) will be used for the entire site. Fewer test pits may be used on small sites with prior approval from the HP & E Manager.

5.1.4 If test pit excavation activities are performed during remedial action, the statistical mass partition function (f_L) shall be obtained by calculating a running average of the corresponding parameters obtained as test pit work progresses across the site.

5.2 Test Pit Soil Sampling and Analysis

5.2.1 Dig each test pit to the estimated depth of contamination at the location, and record the test pit surface elevation and maximum depth of each test pit.

5.2.2 Collect one composite sample from each test pit. The composite soil sample shall be comprised of all the material contained in a standard shovel from each one foot increment (no material shall be discarded). Sampling shall begin at the cobbly soil surface or tailings/cobbly soil interface and continue through a minimum of 5 feet of cobbly material or all the cobbly material (whichever is less).

5.2.3 Sieve the composite sample through a #4 mesh sieve, collecting the fines and cobbles in separate buckets of known weight. Weigh both fractions separately. Thoroughly mix the fine fraction and extract two (2) representative 500 gram can samples.

5.2.4 Determine the percent moisture content by weight of one of the can samples and calculate the adjusted dry weight of the fines. Calculate the adjusted dry weight of the cobbles assuming a moisture content of 1.5 percent. Record all pertinent information on the Cobbles to Fines Calculation Sheet (Attachment 1). Calculate the mass partition function (f) for the test pit using the adjusted dry weight of the fines and cobbles in the relation defined in Definition 3.3.

5.2.5 The second can shall be analyzed by the site laboratory for Ra-226 (and Th-232 if necessary) and sent to the vendor laboratory for Ra-226 and Th-230 analysis (and Th-232 if necessary). Record on-site and vendor analysis results on Attachment 1.

Note: Analysis for Th-232 shall only be performed if the site characterization indicates Th-232 is present.

5.2.5.1 Using the initial on-site analysis results and the vendor analysis results for all test pit or running average samples, a Ra-226 correction factor shall be established using the following equation:

$$Ra\text{-}226\ C.F. = \frac{R_1 + R_2 + \ldots R_n}{n}$$

where, C.F. = correction factor,
R_n = Vendor results (pCi/g) divided by initial OCS. results (pCi/g) for the n^{th} sample (i.e., 1, 2, ...n), and
n = number of ratios.

5.2.5.2 The correction factor shall be updated using the pertinent analyses results from QA samples (section 5.10).

5.2.6 Ship the fraction retained on the #4 sieve from each test pit to the vendor laboratory, in the 5-gallon bucket. This material shall be cleaned, crushed, and analyzed for Ra-226, Th-230 and, if necessary, Th-232. Record vendor analysis results on Attachment 1.

5.2.7 Calculate the bulk radionuclide concentration (C_B) for the test pit using the mass partition function (f) for the test pit (section 5.2.4), the vendor radiological concentration of the fines ($C_{<\#4}$), and the radiological concentration of the cobbles ($C_{>\#4}$) in the equation defined in Definition 3.5. Bulk radionuclide concentrations should be calculated for Ra-226, Th-230, and Th-232 (if necessary).

5.3 Establish background bulk radionuclide concentrations for Ra-226, Th-230, and, if necessary, Th-232, by the sampling and analyses detailed in steps 5.2.1 through 5.2.6 at three uncontaminated background locations containing cobbly subsoil.

5.4 Statistical Mass Partition Function - Alternative 1 (Test Pits)

5.4.1 Upon completion of test pit sampling, pertinent data shall be compiled on the Statistical Data Sheet (Attachment 2), and the statistical mass partition function shall be calculated using the following equation:

$$f_L = \bar{f} - t(s/\sqrt{n})$$

where, f_L = statistical average mass partition function at the lower 95 percent confidence value,
$\bar{f}$ = mean mass partition functions of n samples,
s = sample standard deviation for the n samples,
t = t from Attachment 3, and
n = number of observations.

5.4.2 The mean of the sample population is determined as follows:

$$\bar{f} = \frac{f_1 + f_2 + \dots f_n}{n}$$

where, $f_{1,2 \dots n}$ = the value of f for sample 1, 2, or n; and
n = the number of samples.

5.4.3 The standard deviation is calculated as follows:

$$S = \frac{\sqrt{\sum_{n=1}^{n} (f_n - \bar{f})^2}}{n - 1}$$

where, S = sample standard deviation,
f_n = value of f for sample n,
$\bar{f}$ = mean of f for n samples, and
n = number of samples.

5.4.4 The statistical cobble radionuclide concentration for Ra-226, Th-230 and Th-232 (if necessary) shall be calculated using the following equation:

$$C_{>u} = \bar{C} + t(s/\sqrt{n})$$

where, $C_{>u}$ = The statistical cobble radionuclide concentration at the upper 95 percent confidence value,
$\bar{C}$ = mean radionuclide concentration of the n samples,
s = standard deviation of the 30 samples,
t = t from Attachment 3, and
n = number of samples.

5.5 Statistical Mass Partition Function - Alternative 2 (Running Average)

5.5.1 The statistical mass partition function (f_L) and the statistical cobble radionuclide concentration ($C_{>u}$) may be obtained by calculating a running average of the corresponding parameters using the equations in sections 5.4.1 and 5.4.4 respectively. Compile data on the Statistical Data Sheet and recalculate f_L and $C_{>u}$ as data is obtained from each new test pit.

5.6 The statistical mass partition function and statistical cobble radionuclide concentration for alternative 1 or 2, will only be used for excavation control to obtain an estimate of the final excavation depth to comply with EPA's radiological cleanup standards. Final excavation depths and verification will be determined as described in section 5.7 through 5.9.

5.6.1 By solving the equation in section 3.5 for $C_{<\#4}$ and using the statistical mass partition function (f_L) and the statistical cobble radionuclide concentration ($C_{>u}$) an estimate of the allowable fines radionuclide concentration may be obtained as follows:

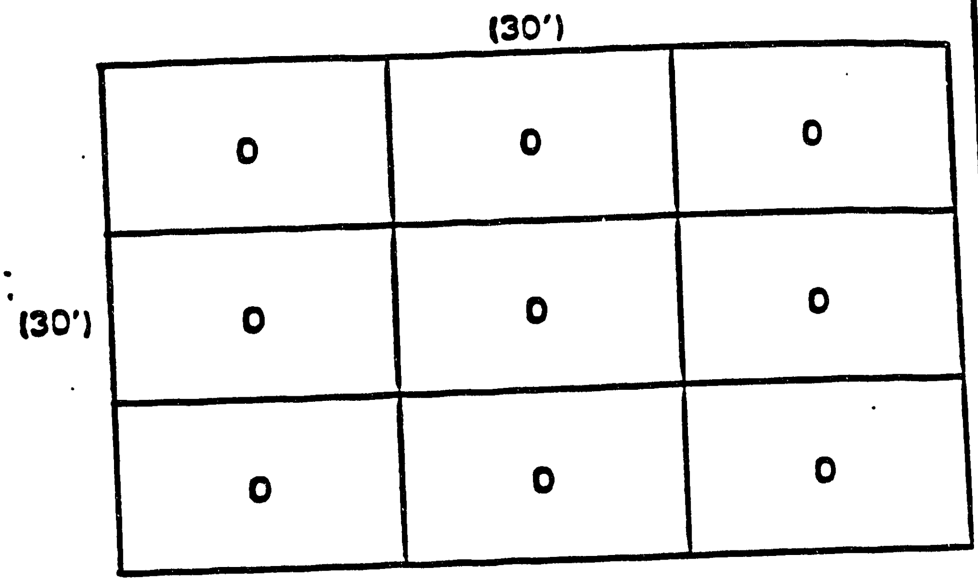
$$C_{<\#4} = \frac{C_s - C_{>u}\,[f_L/(1 + f_L)]}{[1/(1 + f_L)]}$$

where, $C_{<\#4}$ = The estimated fines radionuclide concentration,
C_s = the applicable limit (i.e., 5 or 15 pCi/g for Ra-226 or Th-232 or 35 pCi/g for Th-230),
f_L = statistical mass partition function, and
$C_{>u}$ = statistical cobble radionuclide concentration.

5.7 Verification Soil Sampling & Analysis

5.7.1 Grid the entire site into squares of 100 yd² (~100 m²). Grids shall be uniformly distributed over the site so as to obtain representative data. Record location and elevation for each 100 yd² grid.

5.7.2 Further subdivide each grid where excavation control is being performed into approximately 10 x 10 foot squares (see below). Subdividing grids may normally be done visually by the technician performing the survey. Soil sample extraction will be performed at each of the nine 10 x 10 foot squares within the grid. Each soil plug should consist of all the material contained in a standard shovel. This will include soil, rock, and small/large gravel. No material is to be discarded. The soil plug will be taken to a depth of 15 centimeters (cm). Sample collection shall be random (non-biased).



0 = sample location

5.7.3 The nine soil plugs (80-100 lbs combined weight) comprise a composite sample.

5.7.4 Sieve the composite sample through a #4 mesh sieve, collecting the fines and cobbles in separate buckets of known weight. Thoroughly mix the fine fraction.

5.8 Site Verification Alternative 1 (Grid Specific)

5.8.1 For verification alternative 1, weigh both fractions separately and record information on Attachment 1.

5.8.2 Extract two (2) 500g can samples of the fine fraction for moisture content and radiological analysis.

5.8.3 Determine the moisture content of the fines and calculate the adjusted dry weight. Calculate the adjusted dry weight of cobbles assuming a moisture content of 1.5 percent. Calculate and record the mass partition function for the grid (Attachment 1).

5.8.4 Analyze the second can sample of fines for Ra-226 and, if necessary, Th-232 with the on-site OCS. Calculate the corrected radionuclide concentration using the site Ra-226 correction factor determined in section 5.2.5.1.

5.8.5 Calculate the bulk radionuclide concentration C_B for the grid using the grid specific mass partition function, radionuclide concentration of the fines (the initial corrected concentration shall be used for calculating the Ra-226 bulk radionuclide concentration) and the statistical cobbles radionuclide concentration ($C_{>u}$) in the formula in section 3.5. All data shall be recorded on Form F1-OP-003-4.

5.8.6 Dry, seal and store the sample for 20 day on-site analysis.

5.8.7 After a minimum of 20 days, reanalyze the sample and calculate the final bulk radionuclide concentration (C_B) for the grid.

5.9 Site Verification Alternative 2 (Statistical)

5.9.1 For each 100 m^2 grid, a 9-plug composite soil sample of the fines soil will be obtained following the technique outlined in Section 5.7.

5.9.2 Extract a 500g can sample of the fine fraction for radiometric analysis. Discard the larger size soil fraction.

5.9.3 Analyze the can sample for Ra-226 and, if necessary, Th-232 with the on-site OCS. Calculate the corrected radionuclide concentration using the site correction factor determined in section 5.2.5.1.

5.9.4 Calculate the bulk radionuclide concentration for the grid using the radionuclide concentration of the fines (the initial corrected concentration shall be used for calculating the Ra-226 bulk radionuclide concentration), the statistical mass partition function (f_L) and the statistical cobble radionuclide concentration ($C_{>u}$) in the formula from section 3.5 as modified below.

$$C_B = C_{\le u}[1/(1 + f_L)] + C_{>u}\,[f_L/(1 + f_L)]$$

Record the pertinent data on the Alternative 2 Bulk Concentration Data Sheet (Attachment 4).

5.8.6 Dry, seal and store the sample for 20 day on-site analysis.

5.8.7 After a minimum of 20 days, reanalyze the sample and calculate the final bulk radionuclide concentration (C_B) for the grid.

5.10 The verification sample from the 25th 100 m^2 grid of each block will be sent to an outside Vendor laboratory for independent Ra-226, Th-230, and, if necessary, Th-232 analyses in accordance with Quality Assurance requirements.

6.0 RECORDS/REPORTS/NOTIFICATIONS

6.1 All data shall be recorded on the appropriate data sheet.

7.0 ATTACHMENTS

7.1 Attachment 1 - Cobble to Fines Calculation Sheet (F1-OP-003-4)

7.2 Attachment 2 - Statistical Data Sheet (F2-OP-003-4)

7.3 Attachment 3 - Critical Values of t.

7.4 Attachment 4 - Alternative 2 Bulk Concentration Data Sheet (F4-OP-003-4)

COBBLES TO FINES CALCULATION SHEET

Site: ____________________ Sheet ____ of ____

Sample/Grid I.D. ____________________ Date: ____________

Fines	Cobbles	Moisture Content Fines
Wt. Sample & Bucket ______	Wt. Sample & Bucket ______	Wet Wt. Sample/Pan ______
Wt. Bucket ______	Wt. Bucket ______	Dry Wt. Sample/Pan ______
Wt. Sample ______	Wt. Sample ______	Tare Wt. Pan ______
Adjusted Dry Wt. ($M_{<as}$)* ______	Adjusted Dry Wt. ($M_{>as}$)** ______	Wt. Water* ______
		Wt. Soil** ______
		Percent Water(*/**) ______

* Adjusted Dry Wt. of the Fines = Wt. Sample x (1 - % water)

** Adjusted Dry Wt. of the Cobbles = Wt. Sample x (1 - .015)

Mass Partition function (f) = $M_{>as}/M_{<as}$ = ____________

Radiological Analysis	^{226}Ra (pCi/g)	^{230}Th (pCi/g)	^{232}Th (pCi/g)	COMMENTS
Cobbles ($C_{>as}$)				
On-Site Analysis Fines ($C_{<as}$)	* / ** / ***	N/A		
Vendor Analysis Fines ($C_{<as}$)				
Bulk Radionuclide Concentration (C_B)	# / ## / ###			

* Initial; ** Initial Corrected; *** 20 day IN/A for Test Pit or Running AVE.)

\# Using Vendor; ## Using Initial Corrected; ### Using 20 day IN/A for Test Pits or Running AVE.)

^{226}Ra Correction Factor: ____________________

Reviewed By: ____________________ Date: ____________

STATISTICAL DATA SHEET

Date: ______________ Sheet _____ of _____

Site: ______________________

Test Pit No.	f	$C_{>\#4}$ Vendor			$C_{<\#4}$ On-Site		$C_{<\#4}$ Vendor			$^{226}Ra_2/^{226}Ra_1$
		^{226}Ra	^{230}Th	^{232}Th	$^{226}Ra_1$	^{232}Th	$^{226}Ra_2$	^{230}Th	^{232}Th	

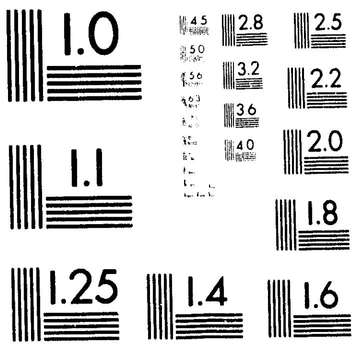
Statistical Mass Partition Function (f_L) = ______________

Statistical Cobble Radionuclide Concentration ($C_{>u}$) = ^{226}Ra __________ ^{230}Th __________ ^{232}Th __________

^{226}Ra Correction Factor (C.F.) = ______________

Reviewed By: ______________________ Date: ______________

F2-OP-003-4


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6

2 of 2

CRITICAL VALUES OF t

n-1	$t_{.050}$
1	6.314
2	2.920
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.860
9	1.833
10	1.812
11	1.796
12	1.782
13	1.771
14	1.761
15	1.753
16	1.746
17	1.740
18	1.734
19	1.729
20	1.725
21	1.721
22	1.717
23	1.714
24	1.711
25	1.708
26	1.706
27	1.703
28	1.701
29	1.699
inf.	1.645

ALTERNATIVE 2 BULK CONCENTRATION DATA SHEET

Radiological Analysis (Fines)

SITE: ______________________ DATE: ______________________

Grid I.D. Number	[illegible] ^{226}Ra (pCi/g) Initial	[illegible] ^{226}Ra (pCi/g) Initial Corrected	Bulk ^{226}Ra Concentration (pCi/g) Initial Corrected	$C_{<60}$ ^{232}Th (pCi/g)	Bulk ^{232}Th Concentration (pCi/g)	^{228}Th Vendor Results	Bulk ^{228}Th Concentration (pCi/g)
	20 Day		20 Day				

Bulk Concentration $C_B = C_{<60}[1/(1+f)] + C_{>s}[f/(1+f)]$

Statistical Cobbles Radionuclide Concentration $C_{>s}$ __________ Statistical Mass Partition Function f_i __________ ^{226}Ra correction factor __________

Reviewed By: ______________________ Date: ______________________

F4.OP 003.4

ATTACHMENT 2

GEOLOGY REPORT

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
BLM	Bureau of Land Management
EPA	U.S. Environmental Protection Agency
FE	floating earthquake
km	kilometer
MCE	maximum credible earthquake
ME	maximum earthquake
M_L	local magnitude
MMI	Modified Mercalli Intensity
NRC	U.S. Nuclear Regulatory Commission
PHA	peak horizontal acceleration
UMTRA	Uranium Mill Tailings Remedial Action

1.0 INTRODUCTION

Scope and previous studies

Detailed investigations of geologic, geomorphic, and seismic conditions at the Dry Flats disposal site were conducted. The purpose of these studies was basic site characterization and identification of potential geologic hazards that could affect long-term site stability. Subsequent engineering studies, such as analyses of hydrologic and liquefaction hazards, used the data developed in these studies. The geomorphic analysis was employed in the design of effective erosion protection. Studies of the regional and local seismotectonic setting, which included a detailed search for possible capable faults within a 65-kilometer (km) [40-mile (mi)] radius of the site, provided the basis for seismic design parameters.

The scope of work performed included the following:

- Compilation and analysis of previous published and unpublished geologic literature and maps.
- Review of historical and instrumental earthquake data.
- Review of site-specific UMTRA Project subsurface geologic data, including logs of exploratory boreholes advanced in the site area.
- Photogeologic interpretations of existing LANDSAT and conventional aerial photographs.
- Ground reconnaissance and mapping of the site region.

The site itself and the immediately surrounding area, out to a radius of about 1.6 km (1 mile), are referred to in this section as the site area. The surrounding region, encompassing southwest Colorado and adjoining southeastern Utah, to a radius of 65 km (40 miles) will be referred to as the site region.

The following topics relevant to the stabilization of mill tailings at the Dry Flats site are discussed:

- Characterization of the regional geologic setting and its correlation to site geology.
- Identification of geomorphic hazards and suggestions for mitigative measures.
- Seismotectonic evaluation to provide initial design earthquake and acceleration parameters. Subsequent engineering analyses fully assess the liquefaction potential and slope stability.
- Identification of other geologic hazards, including secondary seismic hazards; impact from future mineral resources development; and problems related to site stratigraphy or unconsolidated deposits, fractures, or structure.

Content and organization

This attachment is divided into five sections plus one addendum, included in Attachment 1 and containing a list of earthquake epicentral data, and one plate.

In this section, the purpose of the study and the basic criteria and definitions are discussed, and a summary of the work that was performed for the study is presented. Sections 2.0 through 4.0 present the basic information on the regional setting and natural processes acting on the site region, as well as a more detailed discussion of on-site conditions. Section 5.0 summarizes the geologic suitability of the Dry Flats area for a disposal site.

1.1 CRITERIA AND DEFINITIONS

The following is a discussion of the standards and definitions that were applied to the evaluation of geologic hazards at the Dry Flats disposal site.

- Design life. As specified by the U.S. Environmental Protection Agency (EPA) standards for remedial actions at inactive uranium processing sites (10 CFR Part 40), the controls implemented at Uranium Mill Tailings Remedial Action (UMTRA) Project sites are to be effective for up to 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years. In the case of assessing seismic and geomorphic hazards, the criteria established and the methodologies applied seek to ensure that the reclaimed wastes will not be damaged by earthquake ground motions, related ground rupture, or erosional encroachment for up to 1000 years.

- Design earthquake. For the UMTRA Project sites, the magnitude of the earthquake that produces the largest on-site peak horizontal acceleration (PHA) is the magnitude of the design earthquake. This controlling earthquake could be the floating earthquake or an earthquake whose magnitude is derived from a relationship between fault rupture or fault length and maximum magnitude. The latter case is applied for a verified, capable fault of known rupture length.

- Floating earthquake. A floating earthquake is an earthquake within a specific seismotectonic province that is not associated with a known tectonic structure. Before assigning the maximum floating earthquake magnitude, the earthquake history and tectonic character of the province are analyzed.

- Capable fault. A capable fault is a fault that has exhibited one or more of the following characteristics:

  - Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.

  - Macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.

- A structural relationship to a capable fault such that movement on one fault could be reasonably expected to cause movement on the other.

  This definition is essentially the one adopted by the U.S. Nuclear Regulatory Commission (NRC) for the siting of nuclear power plants (10 CFR Part 100, Appendix A).

- Acceleration. Within the context of the UMTRA Project studies, acceleration is defined as the mean of the peaks of the two horizontal components of an accelerogram record. The exact term used is "peak horizontal acceleration." The design acceleration is determined from the constrained attenuation relationship based on distance and magnitude developed by Campbell (1981). The mean plus one standard deviation (84th percentile) value is adopted. The design value is considered a nonamplified, free-field PHA.

- Magnitude and intensity. Magnitude was originally defined by C. F. Richter as the base-10 logarithm of the amplitude of the largest deflection observed on a torsion seismograph located 100 km (62 miles) from the epicenter. This local magnitude value may not be the same as the body-wave and surface-wave magnitudes derived from measurements at teleseismic distances. Unless specified otherwise, local magnitude (M_L) values are used in the UMTRA Project seismic hazard evaluations.

  Intensity is the index of the effects of an earthquake on the human population and man-made structures. The Modified Mercalli Intensity (MMI) scale is used in the UMTRA Project studies.

  Because preinstrumental earthquakes are reported in intensity and more recent instrumental records are in magnitude, there may be a need to relate these values. Several equations have been proposed. Unless otherwise specified, the relationship developed by Gutenberg and Richter (1956) is applied. This equation is as follows:

  $$M = 1 + 2/3\ I_o$$

  Where M = magnitude on the Richter scale and I_o = Modified Mercalli Intensity (MMI) in the epicentral area.

- Maximum earthquake. The term maximum earthquake (ME) was defined by Krinitzsky and Chang (1977) as "the largest earthquake that is reasonably expected" on a given structure or within a given area. That definition is applied in UMTRA Project seismic hazard studies. No recurrence interval is specified for such an event. Essentially, the ME is equivalent to the maximum credible earthquake (MCE) event as defined in 10 CFR 40, Appendix A, Criterion 4(e).

1.2 SCOPE OF WORK

Compilation and analysis of previous work

All pertinent stratigraphic, lithologic, tectonic, seismologic, geophysical, geomorphic, mineral resource, and soils literature, and maps of the site region were reviewed. A GeoRef data search was employed to ensure complete coverage of all published information. References used during this study are listed at the end of this attachment.

Subsurface geologic data

Subsurface geologic data obtained in the site area for this study consist of logs of boreholes and backhoe test pits advanced on the site. Boreholes were drilled to depths ranging from 173 feet to 610 feet to assess groundwater conditions, subsurface stratigraphy, and engineering characteristics. Test pits were advanced to depths of 4.5 to 10 feet. Thirteen wells were completed and seven core holes were drilled. Eleven test pits were dug by the Technical Assistance Contractor and approximately 30 were dug by the Remedial Action Contractor.

Logs of all TAC boreholes and test pits are included in the attachment.

Ground reconnaissance

Ground reconnaissance and field verification of geologic and geomorphic features in the site region were performed by geologists concurrently with the other phases of this study from July through August 1988 and April through June 1989.

Mapped faults and unmapped faults and lineaments delineated by inspection of aerial photographs covering 40 km (25 miles) around the Dry Flats site were examined in the field. This group included faults that could potentially be design faults.

Particular attention was paid to potential geomorphic hazards at the site, including gully erosion, landslides, and mudflows.

Photogeologic analysis

Photogeologic analyses performed for the Dry Flats site included analysis of conventional aerial photographs, both color and black and white, in stereoscope.

The aerial photographs were also used in the geomorphic characterization of the site and during identification of potential geomorphic hazards.

Low-sun-angle aerial reconnaissance

No low-sun-angle aerial reconnaissance flights were conducted for this site because the features are well documented and because many of the Paradox Basin faults are related to salt anticline structures as opposed to tectonic activity. It was determined that the critical tectonic faults could be adequately examined by aerial photographs and by field inspections.

2.0 GEOLOGIC SETTING

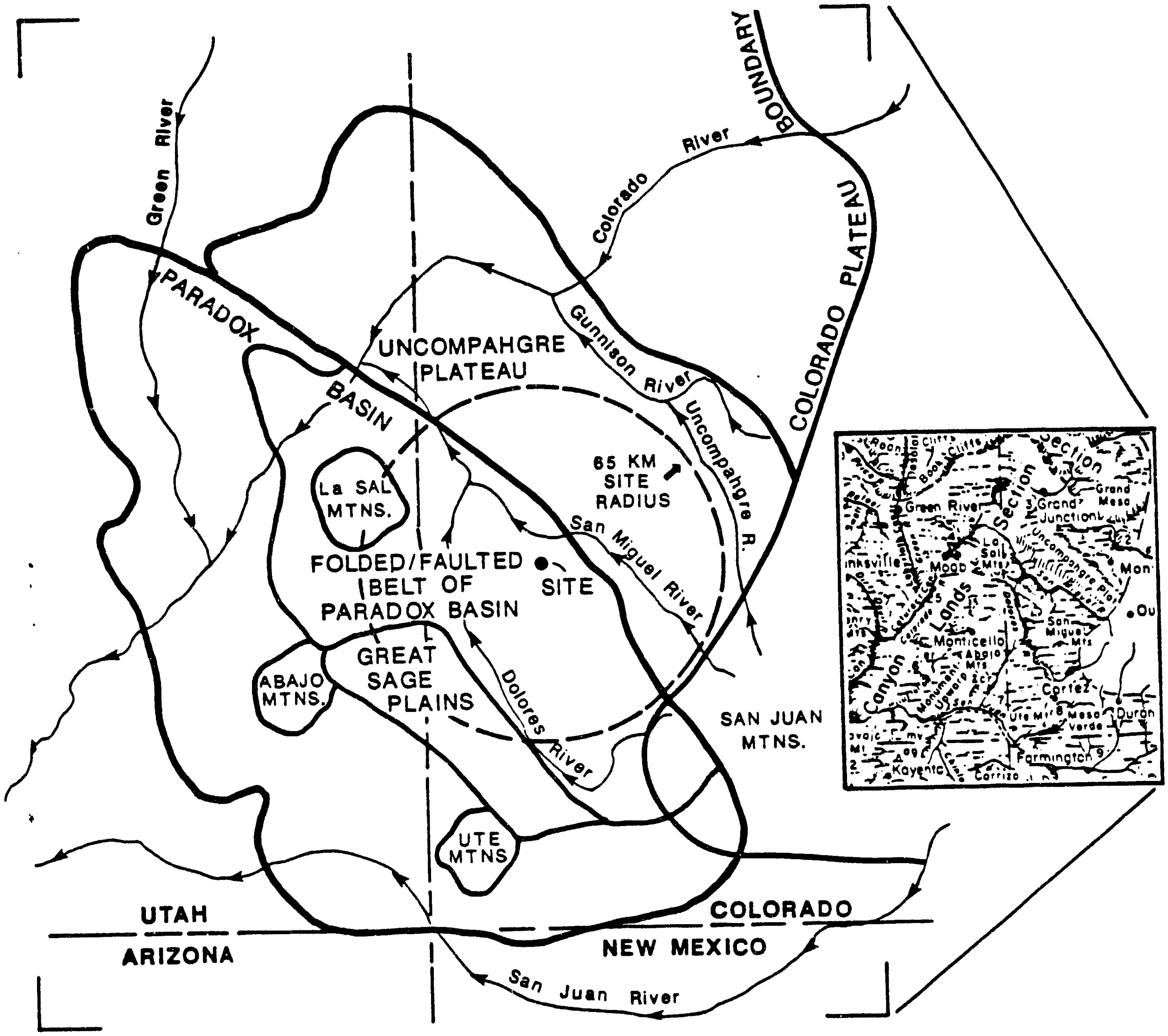
2.1 REGIONAL PHYSIOGRAPHY

The site region lies entirely in the Canyon Lands section of the Colorado Plateau physiographic province (Hunt, 1967) (Figure 2.1.) The Canyon Lands are characterized by deeply incised drainages and isolated mesas. The dominant landform of the region is the broad Uncompahgre Plateau in the northeast portion of the site region, which has been dissected to a depth of 3000 feet by Unaweep Canyon. The plateau is bounded on the southwest by subprovinces within the Paradox Basin that consist of the folded/faulted belts containing the collapsed diapiric salt anticlines and the broad, relatively flat plain of the Great Sage Plains. The Paradox Basin proper is defined by stratigraphy rather than by physiography.

The evolution of the present topography dates largely from the uplift of the Colorado Plateau in Late Miocene time. This uplift resulted in a northward tilt of the entire plateau. The drainages that formed on the low-relief Miocene surface became entrenched as uplift progressed. Cater (1970) offers evidence that uplift may still be continuing. The following paragraphs describe the physiographic subprovinces within the site region and the development of the geomorphic features.

__Uncompahgre Plateau__. This structure is gently tilted to the northwest, resulting in deep gulches eroded in the Cretaceous and Jurassic rocks that are separated by long, narrow mesas extending northwest toward the Gunnison River Valley. The southwest side of the plateau is approximately bounded by the San Miguel River, which later converges with the Dolores River to flow on a fairly direct northwest trend to its junction with the Colorado River as it flows around the northwest end of the plateau. Unaweep Canyon represents the ancestral channel of the Gunnison River that flowed south across the width of the plateau in Late Tertiary time. It is now drained by two opposite-flowing minor creeks that are tributaries to the Dolores River on the southwest and to the modern Gunnison River to the northeast. The canyon, which is about a mile wide and incised about 2000 feet into the Precambrian basement rock, provides evidence for the age and extent of uplift of the Uncompahgre Plateau. Elevations on the plateau range from 9545 feet at the axis of the uplift to 6000 feet on the nearby floor of the Unaweep Canyon (Cater, 1966).

__Paradox Basin__. Several of the folds that include the faulted collapsed salt anticlines have been dissected by the Dolores River and its tributaries. The erosional cycle, caused by the Miocene uplift, superposed the meanders of the Dolores River upon the underlying structures (Cater, 1970; Hunt, 1969). This was partly accomplished by the widespread, very thick deposits of the Mancos Shale, and perhaps Early Tertiary sediments that overlay the region. The low-relief surface formed on these easily eroded sediments exerted very little structural control on the drainage (Cater, 1970). Except for localized occurrences, the soft Mancos Shale has been eroded from the region, exposing the anticlinal structures. The full thickness of the Mancos Shale is still present outside the Paradox Basin in the southeast edge of the region. In contrast to the Dolores River, the San Miguel River is primarily aligned



AFTER: WOODWARD-CLYDE CONSULTANTS, 1983; HUNT, 1967

0 50 100 150 MILES

0 50 100 KILOMETERS

FIGURE 2.1
PHYSIOGRAPHIC PROVINCES OF DRY FLATS SITE REGION, COLORADO AND UTAH

with the northwest trend of the folded and faulted belt of the salt anticlines along the southeast margin of the Uncompahgre Plateau. Both drainages, however, originate within a few miles of each other on the western flanks of the San Juan Mountains. This range, which lies in the Western Mountains physiographic province, marks the southeast limits of the Paradox Basin and Uncompahgre Plateau as well as the eastern boundary of the Colorado Plateau.

Great Sage Plains. This subprovince is characterized by low relief, generally flat-lying bedrock with little folding, and relatively shallow incisions of the regional drainage. Bedrock exposed in the area is the Dakota Sandstone, the same formation that is exposed on mesa tops throughout the Paradox Basin and the Uncompahgre Plateau.

Regional geomorphology

With the uplift of the Colorado Plateau in the Miocene age and the differential uplift of the Uncompahgre Uplift during the Pliocene, the modern drainages became established as a result of the accelerated erosion. It is uncertain whether tectonic activity essentially stopped before or shortly after the end of the Pliocene or has continued into the present time. Sinnock (1981a) and Cater (1970, 1966) believe that the Unaweep Canyon was formerly occupied by the Gunnison River and that the Colorado River has been in essentially the same position since the Miocene. Cater (1970, 1966) believes that the uplift of the Uncompahgre Plateau continued into the early Pleistocene and that the major trunk streams have not greatly deepened their canyons for some time. In the Paradox Basin area, downdip migration of structurally controlled drainages is relatively inactive at the present because the base level of the master stream of the region, the Dolores River, is being lowered very slowly.

The development of the present landforms of the river valleys was strongly influenced by Pleistocene glaciation. Sinnock (1981b) identified four sets of glacial moraines of Bull Lake and Pinedale age in the upper Gunnison River area that are correlated with episodes in the San Juan Mountains. Evidence for successive periods of glaciation has also been recognized on the La Sal Mountains to the northwest and Battlement Mesa to the northeast.

Correlation of periods of erosion are also provided by dating of basalt flows capping Grand Mesa, north of the site. Potassium-argon dates for the basalt at an elevation of 4920 feet (1500 meters) above the Colorado River give a Pliocene age of 9.7 ± 0.485 million years (USGS, 1966). Assuming that the basalt formerly covered the area now occupied by the river, a minimum average rate of downcutting by the Colorado River of six inches (0.15 meter) per thousand years has occurred during this period. The rate of downcutting would have been greatest during the glaciation periods of major advances of the ice.

Terraces occur at various elevations above the Colorado, Dolores, San Miguel, and Gunnison Rivers as well as various creeks in the site area. They contain stream deposits that range in age from Early to Late Pleistocene. The oldest gravels are from 33 to 492 feet (10 to 150 meters) above modern stream levels and may be of pre-Bull Lake age. Younger terraces correlated with Pinedale and Bull Lake glaciations (Whitney, 1981; Sinnock, 1981a, Epis *et al.*, 1980) generally occur between 16 and 82 feet (5 to 25 meters) above the modern channels. The modern floodplains are composed of unconsolidated deposits that have thicknesses of 66 feet (20 meters) or more along the Colorado River.

Erosion rates may be estimated by three general methods: 1) by empirical relationships of climate and topography; 2) from sedimentation rates in rivers and reservoirs; and 3) from geomorphic relationships that are developed with a drainage basin using correlated events. The empirical relationships have not been fully developed and tend to yield erosion rates several times that of sediment yield data (Woodward-Clyde Consultants, 1983).

Based on historical sediment concentrations in rivers and reservoirs, the erosion (denudation) rates for this region of the Colorado Plateau ranges from 0.32 to 0.81 feet (0.1 to 0.25 meter) per 1000 years. The highest rate is based on study of the San Juan River in Colorado, and the lowest rate is estimated from a study of the Colorado River in Colorado. Studies in 1960 and 1964 for other reaches of the Colorado River in Utah and Arizona show that these erosion rates fall in the middle of this range (Woodward-Clyde Consultants, 1983). Denudation rates for small basins in the Mancos Shale outcrop regions range from 2 to 8 feet (0.6 to 2.4 meters) per 1000 years. These rates are much higher than the regional rates because they do not reflect the temporary sediment storage in foot-slope, channel, and floodplain deposits that occurs in larger drainage basins. However, the rates may represent a maximum for small basins near the Dry Flats site that are underlain directly by shale (Godfrey, 1979; Bronson and Owen, 1970). Erosion rates in clay soils depend on factors such as swell potential, sandstone content, soil/bedrock exposure, and vegetative cover (Lusby, 1979; Schumm, 1964; Schumm and Lusby, 1963).

Geomorphic relationships that use correlations of ages determined from volcanic ash beds, basalt, or charcoal to compare with heights of river terraces have resulted in channel incision rate estimates ranging from 0.06 to 0.83 feet (0.018 to 0.25 meter) per 1000 years. The lowest of these rates was determined by Hunt (1969) for the Dolores River and Unaweep Canyon. The higher rate was determined by Cooley (1962) for the Colorado Plateau. The period covered in these studies was for the last 1.8 million years (Woodward-Clyde Consultants, 1983).

Scarp retreat is the dominant process of valley widening on the Colorado Plateau and is particularly important in the Canyon Lands physiographic province (Schumm and Chorley, 1966). Hunt (1969) has estimated scarp retreat on the Colorado River in Utah as 1.8 feet (0.55 meter) per 1000 years and a maximum average of 74 feet (22.6 meters) per 1000 years on the Book Cliffs escarpment in Utah and Colorado. This higher rate may be erroneous (Woodward-Clyde Consultants, 1983; Heyman, 1983).

Climate. Annual precipitation in the Paradox Basin ranges from 10 to 15 inches (25 to 38 centimeters) annually. In the Uncompahgre Plateau at elevations from 8000 to 9500 feet (2440 to 2895 meters), the precipitation may be as much as 25 inches (63 centimeters) per year. Snow remains on the Uncompahgre Plateau as late as June, but in lower elevations rarely lasts for more than a few weeks (Cater, 1970). From a weather station at nearby Uravan, for the period of 1973 through 1977, temperatures ranged from -10°F to 106°F and rainfall ranged from 8.0 to 12.2 inches (20 to 31 centimeters) per year. The net evaporation rate determined was 2 gallons per minute per acre, or 36 inches (91 centimeters) per year (Chen and Associates, Inc., 1984).

Vegetation. Vegetation in the lower elevations consists of piñon and juniper on rocky terrain and sagebrush on deep soil areas. Riparian vegetation is comprised of cottonwood, willow, and tamarisk (salt cedar). Scrub oak, serviceberry, and chokeberry are common in higher elevations with stands of ponderosa pine, fir, and spruce occurring in some areas of the Uncompahgre Plateau (Cater, 1970).

Paleoclimate. In the western United States, the last full glacial period occurred about 18,000 to 14,000 years ago. In the Rocky Mountains the time of deglaciation varied with altitude. Low mountain ranges were free of ice by 14,000 years ago and glaciers in mountain valleys disappeared by 14,000 to 11,500 years ago. Almost all ice fields were gone by 9000 years ago (Porter *et al.*, 1983; Cole and Sexton, 1981). Carrara *et al.* (1984) believed that the San Juan Mountains were deglaciated 15,000 years ago. Meierding and Birkeland (1980) postulate that the altitude of glaciation in the site region was near 11,500 feet (3500 meters), which indicates that the Uncompahgre Plateau was not subject to glaciation.

Various studies suggest that the full glacial, mean annual temperature in the site region may have been 5 to 10°C lower than present and precipitation was not greater than 25 percent more than at present (Dohrenwend, 1984). Broad changes in Holocene post-glacial temperatures have been documented for the western United States. However, few of the paleoenvironmental data available have been used to derive quantitative estimates of climate change. The time following the last glaciation has been divided into three climatic intervals: a transitional period from 13,000 to 7500 years ago, a slightly warmer period ending around 4000 years ago, and a slightly cooler period continuing to the present (Baker, 1983). General trends in temperatures indicate regional cooling from the late 1860s until about 1930, followed by regional warming. Generally, trends in precipitation are roughly inverse to those for temperature but are less consistent. For the next few hundred to 1000 years, average temperature and precipitation will probably fluctuate within the same ranges as during the recent past.

2.2 STRATIGRAPHIC SETTING

Bedrock in the site region consists of a thick sequence of marine and continental sedimentary rocks, representing the Paleozoic and Mesozoic Systems. Tertiary-aged sediments, if any existed, have been eroded from the surface. The northeastern portion of the site region, comprised of the Uncompahgre Plateau, has mostly nonmarine sedimentary rocks with the Paleozoic sequence missing so that Middle Triassic-aged rocks are resting uncomformably on Precambrian basement rocks. In the southwestern portion of the site region, comprised of the Paradox Basin, the Precambrian basement rocks are overlain by marine limestones and shales of Cambrian to Mississippian age and an extremely thick sequence of Late

Paleozoic evaporites and clastics. The stratigraphic column of formations found in the site region is shown on Figure 2.2, and Table 2.1 contains a description of the units.

Because of the extensive erosion that has occurred in this Canyon Lands section of the Colorado Plateau and the relatively deep incision of the drainages, unconsolidated Quaternary deposits, mostly river terrace sediments, are largely restricted to the narrow valleys.

The bedrock on the Uncompahgre Plateau is essentially undisturbed and dips gently to the northeast. In the Paradox Basin, most areas have nearly flat-lying to gently dipping sandstone-capped mesas that contrast with the faulted ridges and moderately to steeply dipping slopes that form the flanks of collapsed salt anticline valleys. The bedrock geology for the site region is shown on Figures 2.2 and 2.3.

2.3 STRUCTURAL SETTING

The Dry Flats site is located in the northeastern part of the Colorado Plateau. The Colorado Plateau is a stable, intercontinental subplate having a greater thickness than the adjoining regions. Its margins exhibit crustal structures similar to the more disturbed bordering provinces, while the central portion exhibits characteristics of large continental plates.

Several episodes of major orogenies have produced the structural configuration of the plateau. During Precambrian time, two major shear zone systems were established that formed the framework which influenced development of subsequent structures (see Figure 2.4). These were the northeast-trending Colorado Lineament, extending from Arizona to Minnesota, and the opposite northwest-trending Olympic-Wichita Lineament, which reaches from southern Oklahoma to Washington. These broad zone lineaments intersect within the site region (Baars and Stevenson, 1981a). Stone (1969) characterized the shear zones as left lateral and right lateral wrench faults because of the vertical component of the movement. Movement was observed as 1) reversal of fault dip along a fault line; 2) development of belts of en echelon parafold features; and 3) abrupt stratigraphic changes across the zone.

Regional structures that developed during the second major orogeny in Late Paleozoic (Pennsylvanian time) include the following:

- The Ancestral Uncompahgre-San Luis Uplift, which was aligned along the Olympic-Wichita Lineament.
- The Paradox Basin, where subsidence occurred simultaneous with uplift of the Uncompahgre Uplift.
- The uplift of the Ancestral Rocky Mountains. It was the development of the these northward-trending structures in Central Colorado that defined the configuration of the Colorado Plateau (Tweto, 1980).

GEOLOGIC AGE	FORMATION	THICKNESS (FT)	CHARACTERISTICS	
CRETACEOUS	MANCOS SHALE	2,000-5,000	GRAY SHALE; FORMS VALLEYS AND SLOPES; AQUICLUDE	
	DAKOTA SANDSTONE	0-200	GRAY AND BROWN SANDSTONE, SHALE AND CONGLOMERATE; CAPS MESAS AND FORMS CLIFFS; LOW QUALITY, LOW QUANTITY AQUIFER	← DRY FLATS DISPOSAL SITE
				UNCONFORMITY
	BURRO CANYON FORMATION	50-250	BLUFF, CONGLOMERATIC SANDSTONE AND MAROON AND GREEN MUDSTONES; FORMS SLOPES, SANDSTONES FORM CLIFFS; LOW QUALITY, LOW QUANTITY AQUIFER	
JURASSIC	MORRISON FORMATION	300-500	BRUSHY BASIN MEMBER; VARICOLORED SHALES, SOME SANDSTONE; FORMS SLOPES; SANDSTONES YIELD WATER	← NATURITA PROCESSING SITE
			SALT WASH MEMBER; LIGHT COLORED SANDSTONE, RED MUDSTONE; OCCASIONAL LIMESTONE; FORMS BENCHES; SANDSTONES YIELD WATER	
	SUMMERVILLE FORMATION	0-400	VARICOLORED MUDSTONES; THIN SANDSTONE UNITS; FORMS SLOPES; AQUICLUDE	
	ENTRADA SANDSTONE	50-1,000	MOAB MEMBER; FINE GRAINED WHITE SANDSTONES; FORMS STEPS; AQUIFER	
			SLICK ROCK MEMBER; LIGHT COLORED MASSIVE SANDSTONE; FORMS CLIFFS; AQUIFER	
				UNCONFORMITY
TRIASSIC(?)	KAYENTA FORMATION	0-200	LENTICULAR SANDSTONES AND RED-PURPLE MUDSTONES; FORMS BENCHES; SANDSTONES ARE POTENTIAL LOW QUANTITY AQUIFERS	
TRIASSIC	WINGATE SANDSTONE	200-400	LIGHT COLORED MASSIVE SANDSTONES; FORMS CLIFFS; LOW QUANTITY AQUIFER	

OLDER SEDIMENTARY ROCKS

REF. FBDU, 1981

FIGURE 2.2
SIMPLIFIED STRATIGRAPHIC COLUMN FOR THE NATURITA AREA, COLORADO

Table 2.1 Description of stratigraphic units in Dry Flats site area

Age (geologic period)	Unit group or formation	Approximate thickness in site area (feet)	Description
Quaternary	Unconsolidated alluvium		Undifferentiated alluvial river terrace deposits.
Tertiary		0	No sedimentary deposits in site area. Igneous intrusives occur largely as dikes intruded in the Precambrian rocks of the Uncompahgre Plateau.
Upper Cretaceous	Mancos Shale	0-150	Uniform gray-blue marine shale; contains some distinctive sandstone marker beds. Typically 4000 feet thick in uneroded section. Due to erosion, only isolated localities remain in salt anticline areas.
Lower Cretaceous	Dakota Sandstone	180	Chiefly sandstone; consists of a basal unit that contains chert pebbles. A middle gray-to-black carbonaceous shale unit contains a thin coal seam. The upper marine sandstone unit is missing at most places. Cross-bedding is common.
Lower Cretaceous	Burro Canyon Formation	180	Gray-to-light-brown fluvial sandstone with a basal conglomerate overlain by a shale-mudstone. Colored light-red, purple to grayish-green. The mudstone contains abundant limestone modules in some areas.
Upper Jurassic	Morrison Formation	820	Brushy Basin Member. Composed of variegated bentonitic and montmorillonite fluvial and lacustrine shale, mudstone, and sandstone. Has conglomeratic lenses that locally may be mineralized with uranium and vanadium ore. Common colors are red, purple, gray, and pink. Bedding typically is lenticular.

Table 2.1 Description of stratigraphic units in Dry Flats site area (Continued)

Age (geologic period)	Unit group or formation	Approximate thickness in site area (feet)	Description
			Salt Wash Member. Consists of interbedded fluvial sandstone and siltstone. The sandstone is commonly gray to yellow to pale orange, fine- to medium-grained with local seams of pebbles. Bedding is lenticular to cross-bedded. The upper units of sandstone may contain major uranium and vanadium ore deposits in this area.
Jurassic	Summerville Formation	100	Chocolate-colored to red or white marine shale with siltstone. It interfingers with the underlying Entrada Sandstone in some areas. Characteristically has ripple marks with some mud cracks.
Jurassic	Entrada Sandstone	110	Moab Member. Interfingers with the Summerville Formation in some areas. Generally white and cross-bedded sandstone that grades into horizontal bedding. Slick Rock Member. Usually forms the entire Entrada Formation over most of Colorado. Consists of a light-brown, buff, or pink fine-grained sandstone and forms smooth, unjointed slopes or cliffs from which it gets its name. Dewey Bridge Member. This lower unit interfingers with the Carmel Member west of the region. It consists of reddish-brown, massive bedded siltstone and contains scattered, well-rounded, coarse sand grains called Entrada berries.
Jurassic	Navajo Sandstone	0	This formation is missing at the site area but rapidly thickens in the western part of the site region to about 250 feet. It consists of fine-grained, cross-bedded sandstone, colored orange-gray to light-gray. It is considered a classic example of eolian deposition.

Table 2.1 Description of stratigraphic units in Dry Flats site area (Continued)

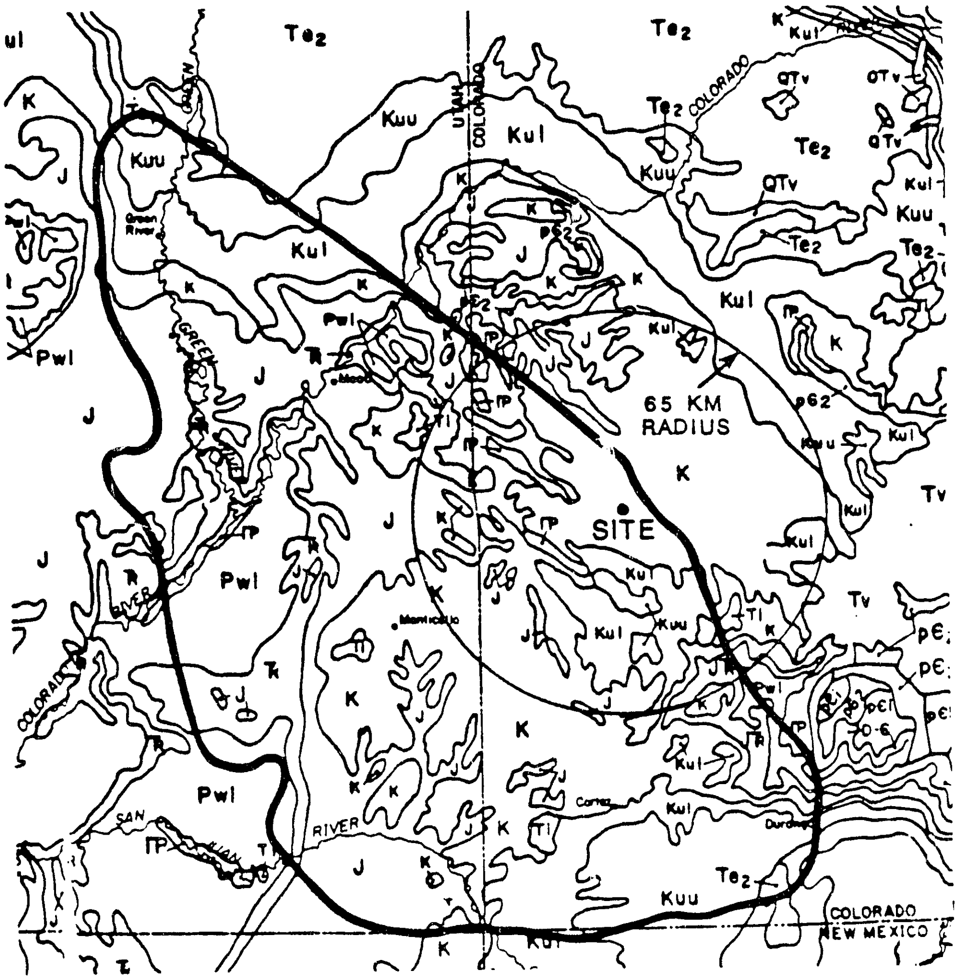
Age (geologic period)	Unit group or formation	Approximate thickness in site area (feet)	Description
Upper Triassic	Kayenta Formation	200	Irregularly bedded fluvial red, buff, gray, and lavender conglomeratic sandstone with some interbedded siltstone and shale. The finer sediments are usually dark reddish-brown.
Triassic	Wingate Sandstone	200	Eolian deposit of fine-grained, well-sorted, cross-bedded sandstone with occasional thin lenses of limestone. It forms prominent red-brown to tan cliffs in the site region.
	Chinle Formation	200	Reddish-brown and orange-red siltstone interbedded with lenses of sandstone, shale, and mudstone. Locally contains lenses of limestone deposited in shallow lakes.
	Moenkopi Formation	90	Includes red-brown siltstone, claystone, sandstone, conglomerate, and some distinctive limestone units. It contains ripple marks, cross-bedding, salt casts, and shrinkage cracks.
Permian	Cutler Formation	200 to 1400	Continental clastic consisting of coarse arkosic material derived from uplifted Uncompahgre highlands. Locally attained thicknesses up to 15,000 feet. The overburden pressure of this unit caused salt flowage and diapirism in underlying saline deposits. It is a crudely bedded, poorly sorted, cross-laminated, purplish-red-maroon conglomerate with thin portions of shale and mudstone.
Pennsylvanian	Hermosa Group	13,000	Honaker Trail Formation. Near the Uncompahgre Uplift the unit is a gray-green arkosic sandstone that grades westward into a sequence of cherty limestone and red-gray calcareous siltstone. Up to 2000 feet thick.

Table 2.1 Description of stratigraphic units in Dry Flats site area (Continued)

Age (geologic period)	Unit group or formation	Approximate thickness in site area (feet)	Description
			Paradox Formation. Composed of cyclical evaporite deposits and black shales grading outward from the center of Paradox Basin into carbonates (dolomite and limestones) at the edge of the basin. Only sediments, including evaporites such as halite, gypsum, and potash, are included in this formation. The carbonates are considered parts of overlying (Honaker) or underlying (Pinkerton Trail) formations. Because of salt flowage and diapirism, the original maximum thickness of 5000 to 7000 increased locally to 14,000 feet.
			Pinkerton Trail. Light- to dark-gray silty shale overlain by fossiliferous limestone. It was the last normal marine deposit before major subsidence began in the basin. It is the oldest sedimentary deposit exposed in the site region.
Pennsylvanian	Molas Formation	200	Reddish-brown to variegated siltstone, red shale, calcareous mudstone, and lenses of gray limestone. The deposition fills the karst topography of the red wall limestone.
Lower Missis-sippian	Redwall Limestone	275	Equivalent to the Leadville Limestone name used in the eastern part of the region. It consists of thick and thinly bedded limestone interbedded with dolomite and contains fossiliferous chert.
Late Devonian	Ouray Formation	75	Persistent thickness from 50 to 150 feet that is widespread over the Colorado Plateau. It consists of limestone with distinctive green waxy shale beds at top and bottom.
Devonian	Elbert/Aneth Formation	250	Thinly bedded dolomite interbedded with dark shales.

Table 2.1 Description of stratigraphic units in Dry Flats site area (Concluded)

Age (geologic period)	Unit group or formation	Approximate thickness in site area (feet)	Description
Cambrian	Muav Lime-stone/Bright Angel Shale	350	Massive limestone with shale partings underlain by alternating sequences of sandstone, siltstone, and limestone.
	Ignacio Formation	150	Basal conglomerate sandstone formed on top of the Precambrian basement rock.
Precambrian	Basement Complex	Unknown	Undifferentiated granite, schist, gneiss, and pegmatite dikes.



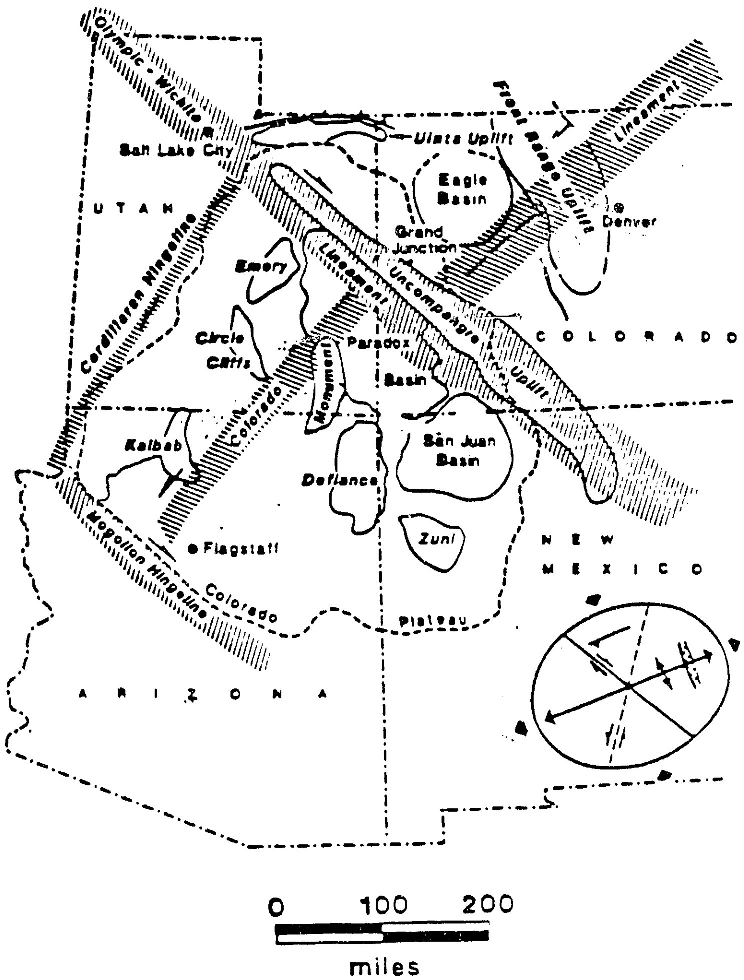
FROM: WOODWARD-CLYDE CONSULTANTS, 1983

NOTE: BOLD OUTLINE SHOWS PARADOX BASIN

EXPLANATION OF GEOLOGIC SYMBOLS

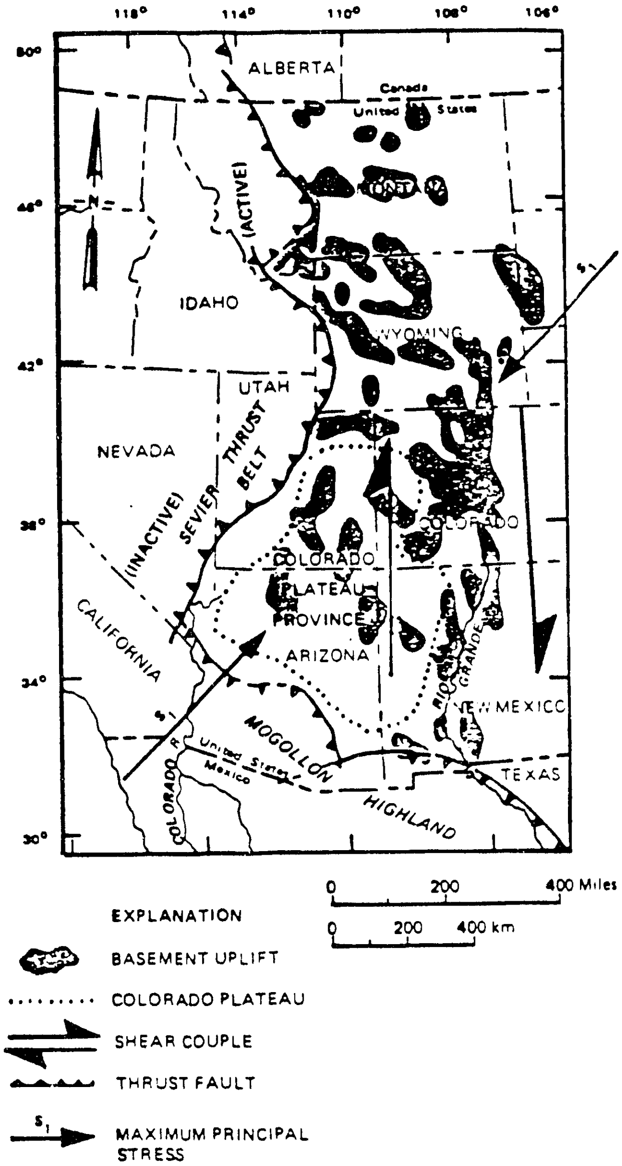
QUATERNARY	Qa	Alluvium
QUATERNARY / TERTIARY	QTv	Volcanic rocks
TERTIARY	Ti	Intrusive igneous rocks
TERTIARY	Te_3	Duchesne River and Uinta Formations
TERTIARY	Tv	Volcanic rocks
TERTIARY	Te_2	Green River and Wasatch Formations
TERTIARY	Te_1	Flagstaff and Fort Union – North Horn Formations
CRETACEOUS	Kuu	Mesaverde Group
CRETACEOUS	Kul	Mancos Shale
CRETACEOUS	Ku	Cretaceous rocks, undifferentiated
CRETACEOUS	K	Dakota Sandstone
JURASSIC	J	Morrison Formation; San Raphael Group
TRIASSIC	℞	Glen Canyon Group; Chinle and Moenkopi Formations
PERMIAN	Pwl	White Rim (De Chelley) Sandstone
PERMIAN	Pw	Cutler, Cedar Mesa, Elephant Canyon, Halgaito, Organ Rock Formations
PENN	IP	Hermosa Group

FIGURE 2.3
GEOLOGIC MAP OF DRY FLATS SITE REGION, COLORADO AND UTAH



FROM: BAARS AND STEVENSON, 1981a

MAJOR PRECAMBRIAN LINEAMENTS
THAT FORMED REGIONAL
STRUCTURAL FRAMEWORK



FROM: WOODWARD-CLYDE
CONSULTANTS, 1983

STRUCTURAL FEATURES OF COLORADO PLATEAU
AFFECTED DURING LARAMIDE OROGENY

FIGURE 2.4

TECTONIC FRAMEWORK FOR COLORADO PLATEAU AND DRY FLATS SITE REGION, COLORADO AND UTAH

A third episode of major structural development was the Laramide Orogeny into Late Cretaceous continuing into Early Tertiary. The effects within the site region are seen as a folded belt through the Paradox Basin and uplifts primarily along alignments of existing basement faults. Structures created within the Colorado Plateau were the Piceance Basin and the Uinta Basin separated by the Douglas Creek Arch in the northern plateau region; the initiation of the Uncompahgre Uplift; and the Monument Upwarp and the San Juan Basin in the southern part of the Plateau (see Figure 2.5).

The Uncompahgre Uplift, which comprises about 40 percent of the site region, developed along the approximate boundaries of the Ancestral (Pennsylvanian) Uncompahgre Uplift within the site region except that the southeast portion does not extend beyond the boundary of the Colorado Plateau as it formerly did, but terminates against the San Juan Mountains' volcanic center.

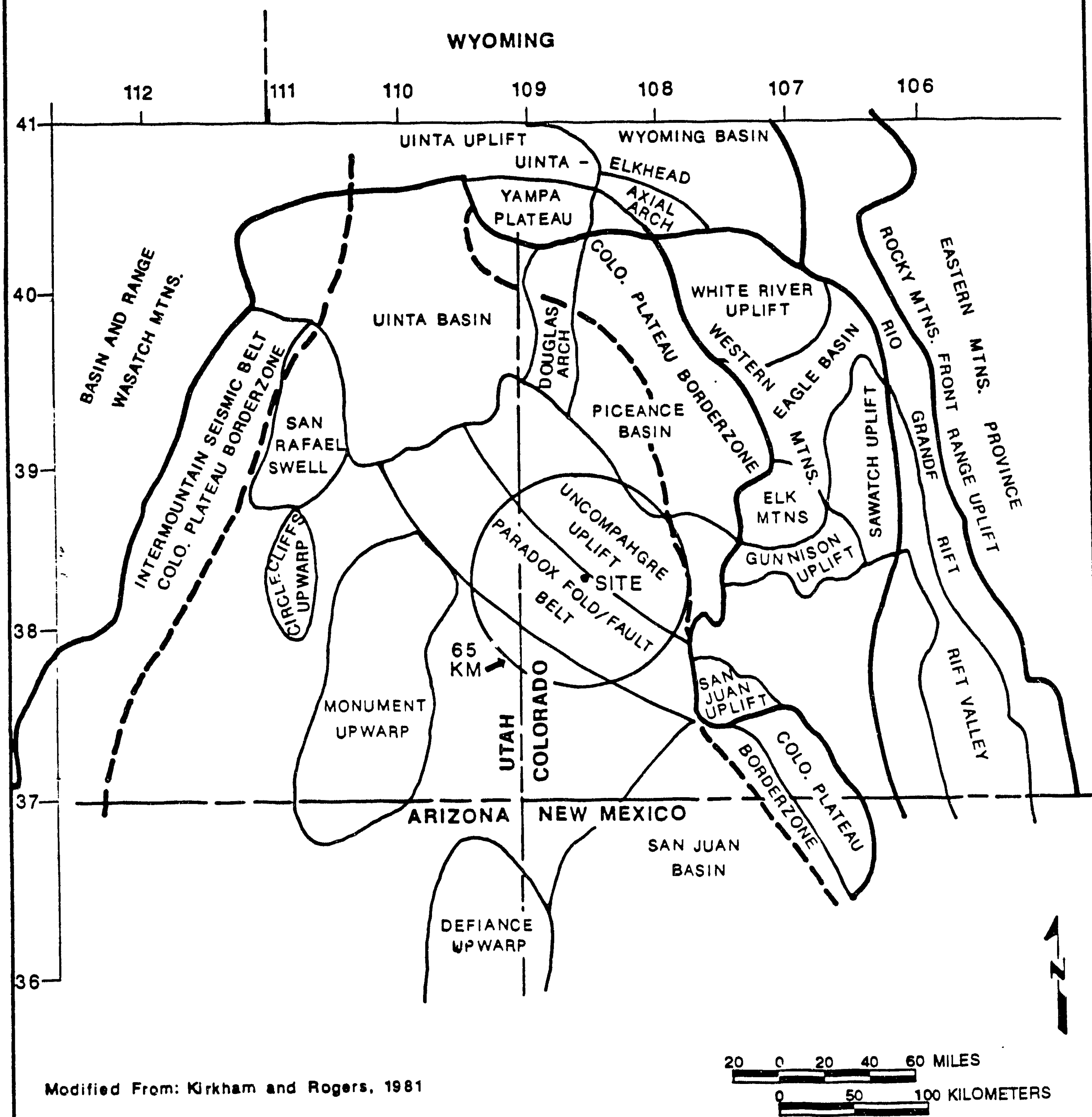
The effect of the Laramide Orogeny was much more pronounced on structures bordering the Colorado Plateau on the east and the north. Baars and Stevenson (1981a) noted that the plateau as a whole resisted the extensive thrust faulting that occurred to the west and south by the wave of compressional tectonism.

Following the Laramide Orogeny, which ended in the Eocene epoch, was a period of volcanism during Oligocene time primarily in the Rio Grande Rift (Thompson and Zoback, 1979). The rift lies 177 km (110 miles) to the east of the site and separates the Western Mountains Seismotectonic Province from the Eastern or Rocky Mountain Province. The Colorado Plateau was otherwise in a period of tectonic quiescence. Most of the structures of the Colorado Plateau were rejuvenated by a fourth period of orogeny following a long period of stability in Miocene time (Tweto, 1980).

The site region contains two major structural elements: the Uncompahgre Uplift and the folded and faulted belt within the Paradox Basin, which both trend northeast along the alignment of the Olympic-Wichita Lineament.

- Uncompahgre Uplift. There is some disagreement of when the major uplift occurred but there is general agreement that there was activity on the faulted monoclinal folds on its southwestern and northeastern boundaries. Cater (1970, 1966) believes that most of the movement occurred in mid-Pliocene and probably continued into the Pleistocene. The uplift appears as a northeast-tilted fault block but has a slight anticline fold axis located very close to the southwestern flank. The uplift is approximately 25 to 30 miles wide and more than 1000 miles long (see Figure 2.5).

- Paradox Basin and faulted folded belt. The Paradox Basin was formed as a faulted depression that complemented the uplift movement of the Ancestral Uncompahgre Uplift (Baars and Stevenson, 1981b). The limits of the basin are defined by the zero-deposition contour of the Paradox salt member of the Hermosa Formation. The deepest part of the evaporite deposit, where it is at least 4000 feet thick, is in a faulted zone bordering the uplift. As the clastic detritus accumulated, eventually amounting to about 15,000 feet thick, the overburden pressure together with continued fault movement resulted in diapiric



Modified From: Kirkham and Rogers, 1981

LEGEND

Seismotectonic Provinces

Structural Provinces

FIGURE 2.5
STRUCTURAL AND SEISMOTECTONIC SETTING OF DRY FLATS SITE REGION, COLORADO AND UTAH

(piercement) intrusion of the salt into the overburden. The growing salt cores formed anticlinal folds controlled by the location of the faults and salt thickness (Baars and Stevenson, 1981b; Cater, 1970) (see Figures 2.6 and 2.7).

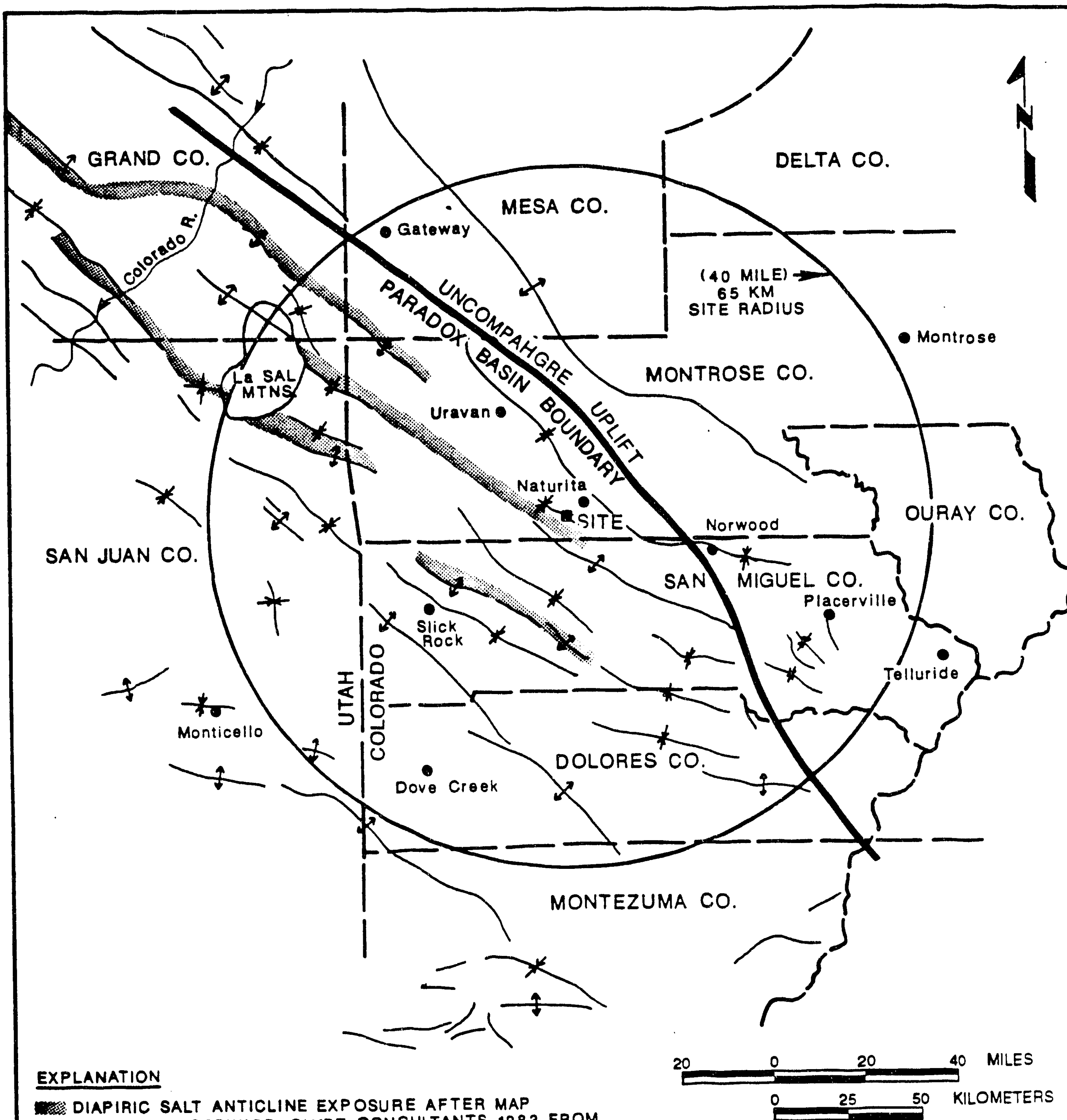
Nearly 6000 feet of displacement has occurred on the basement faults underlying one of these structures, the Paradox Valley anticline (Cater, 1970) as shown in Figure 2.7a. The salt anticlines were enhanced by compressional folding stress during the Laramide Orogeny, which resulted in a series of folds across the width of the Paradox Basin trending northwest and aligned parallel to the uplifted block of the Uncompahgre Plateau. Subsequently, the first of two stages of collapse occurred as compressional forces relaxed, initiating graben faulting on the crests of the salt anticlines with blocks downfaulted as much as several hundred feet. The salt cores were deeply buried at this time.

The second stage of collapse of the salt anticlines occurred as a result of deep incision of regional drainages. After a long period of quiescence, the Colorado Plateau was strongly uplifted and tilted slightly to the north. Streams which had meandered across the low relief of the Miocene surface deeply eroded the region and were superposed across the buried anticlinal structures. The Dolores River eventually dissected the Gypsum and Paradox salt anticlines. Cater (1970) believed that dissolution of the salts occurred along the river as a result of stream flow and increased groundwater circulation. He theorizes that this relief of overburden pressure by erosion and by dissolution caused salt flowage within the core toward the river, and the beds in the crest collapsed gradually outward from the river incision.

This process is important in understanding the role of dissolution and salt flowage in the assessment of potential future disturbances on the salt anticlines and in the site area. Cater (1970) points out that dissolution of salt has been shown to be ineffective at depths as shallow as 1000 feet; however, graben blocks are known to have foundered to depths of 3000 feet into the salt anticline cores, as shown in Figure 2.7. He has observed that in the southeast end of the Paradox Valley, in the area of the Dry Flats site, beds only as thick as 1500 feet have downsagged as much as 200 feet lower than the outcroppings on the flanks (see Figure 2.7c).

<u>**Other regional structures**</u>

Laccolith igneous intrusions caused the development of the La Sal Mountains, located at the northeast perimeter of the site region. This intrusion in Middle Miocene, when the Colorado Plateau was otherwise relatively quiet, occurred at the intersection of the continental lineaments (see Figure 2.4). The same fault system that caused the salt accumulation and the subsequent diapiric salt anticlinal structure of Paradox Valley focused the igneous intrusion of the La Sal Mountains, which pierced the salt anticline (Cater, 1970) (see Figure 2.6). A similar laccolith intrusion, Abajo Mountain, developed along the Colorado Lineament southwest of the La Sal Mountains. The San Juan Mountains, which bound the Uncompahgre Uplift to the southeast, are Laramide uplift structures consisting of an intrusive dome with volcanic calderas on its flanks.



EXPLANATION

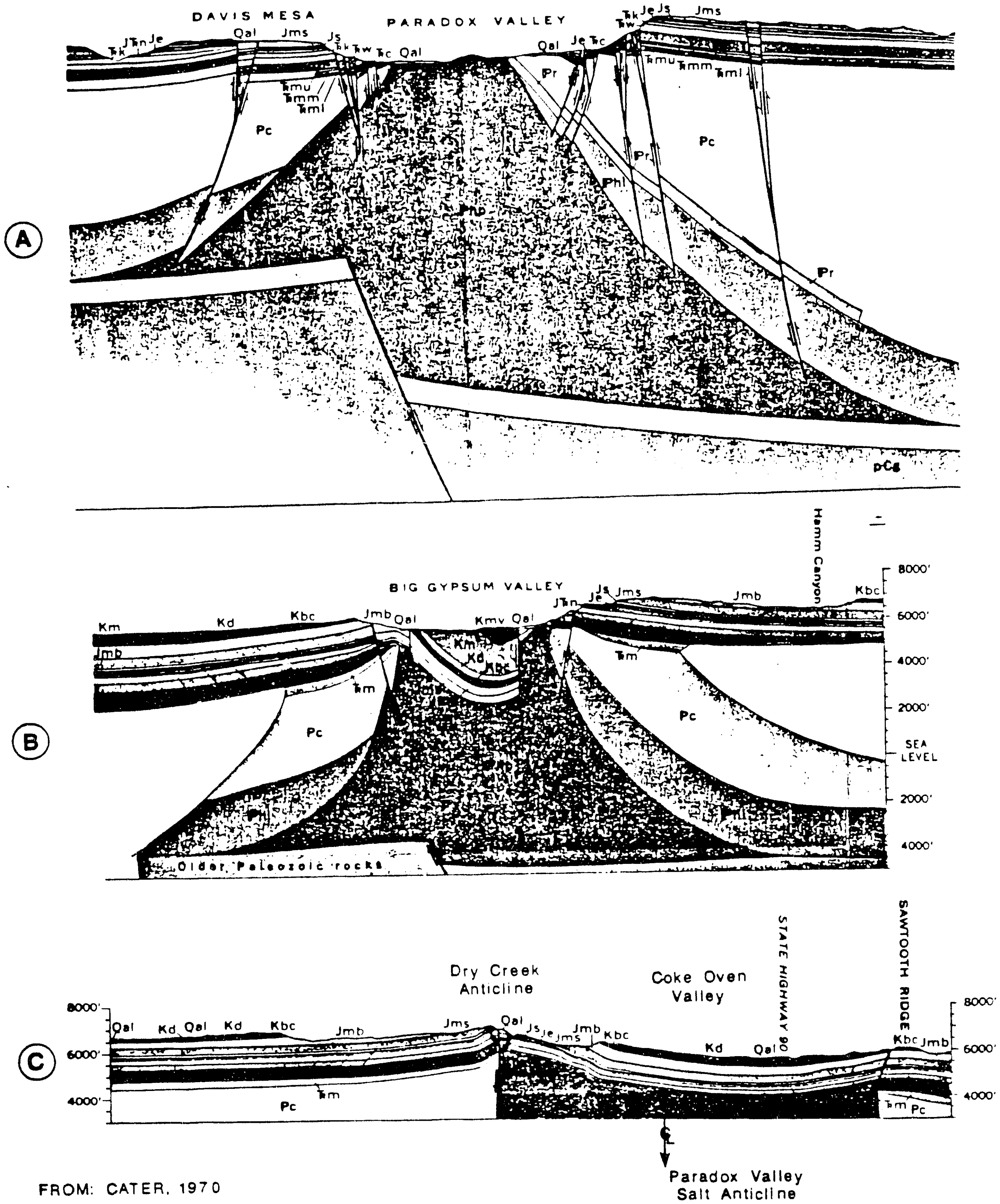
DIAPIRIC SALT ANTICLINE EXPOSURE AFTER MAP COMPILED BY WOODWARD-CLYDE CONSULTANTS, 1983 FROM NUMEROUS SOURCES

NOTE: STRUCTURES SHOWN FOR EXPOSED DIAPIRIC SALT ANTICLINE INDICATE SURFACE COLLAPSE FEATURES RATHER THAN THE DIAPIRIC STRUCTURE

(SEE ALSO FIGURE 2.11)

FIGURE 2.6

MAP OF FOLDED STRUCTURES IN DRY FLATS SITE REGION, COLORADO AND UTAH



FROM: CATER, 1970

FIGURE 2.7

CROSS SECTIONS OF SALT ANTICLINE STRUCTURES INCLUDING NEAR VICINITY OF DRY FLATS SITE, COLORADO

(A) Cross Section of Paradox Valley Salt Anticline. Located 13 miles northwest of site. The section shows: 1) position of the basement fault relative to the diapiric structure; 2) graben faulting on the flanks on the anticline.

(B) Cross Section of Big Gypsum Valley Salt Anticline. Located 14 miles southwest of site. The section shows: 1) foundering by salt flowage of the graben fault block in the salt core to 3000 feet depth.

(C) Cross Section of Coke Oven Valley at Southeast End of Paradox Valley Salt Anticline. Located 2.5 miles west of site and 10 miles east of Section A. The section shows: 1) site geologic setting of Sawtooth Ridge relative to the graben fault; 2) sag of the Coke Oven Valley that is foundering on the crest of the salt anticline; and 3) upturned strata of the Dry Creek anticline (Naturita Ridge) formed on the flank of the Paradox Valley anticline.

Explanation of Geologic Symbols

Qal	Quaternary	alluvium, unconsolidated
Kd, Kbc	Cretaceous	Dakota Sandstone, Burro Canyon Formation
Jmb, Jms, Js, Je	Jurassic	Brushy Basin Member and Salt Wash Member of Morrison Formation; Summervile Formation; Entrada Sandstone
JTrn, Trk, Trw, Trc, Trm	Triassic	Navajo Formation; Kayenta Formation; Wingate Formation; Chinle Formation; and Moenkopi Formation
Pc	Permian	Cutler Formation
Phi, Php	Pennsylvanian	Honaker Trail and Paradox Salt Members of Hermosa Group
pCg	PreCambrian	Undiferentiated granitic igneous rock

FIGURE 2.7
EXPLANATION FOR CROSS SECTIONS OF SALT ANTICLINE STRUCTURES INCLUDING NEAR VICINITY OF DRY FLATS SITE, COLORADO (CONCLUDED)

2.4 SEISMOTECTONICS

The first recorded earthquake in the Colorado Plateau region occurred in 1870, so the historical record covers a period of about 119 years. In areas of sparse population, the epicentral locations of preinstrumental events are poorly defined. As a general rule, the historical record is probably reliable for moderate to large earthquakes since about 1890, while the instrumental record is probably reliable for magnitudes of 4.0 to 4.5 between 1950 to 1962, with a location uncertainty of 50 km (80 miles). For magnitudes of 3.5 or greater since 1963, the instrumental record is probably reliable with a location uncertainty of 20 km (12 miles) (Wong and Simon, 1981).

For site region seismicity, the distance-attenuation relationships for acceleration forces of earthquakes indicate that the largest probabilistic earthquake for the Western Interior of 8.0 (Algermissen *et al.*, 1982) would theoretically attenuate to less than 0.1 g in 110 km (68 miles) and less than 0.20 g within 60 km (37 miles) (Campbell, 1981). This suggests an outer limit for the radius of concern where the minimum design acceleration is 0.1 g and the recommended floating earthquake design (magnitude 6.2 earthquake at a radial distance of 15 km) for areas having no capable faults results in an acceleration of 0.21 g at the site (DOE, 1989).

The recorded seismicity of the 65-km site region, based on the NGDC/NOAA (1989) earthquake data file, indicates only one epicenter, a magnitude 4.0 event in 1970.

In the absence of a reliable long-term record, probabilistic analyses of future seismic risks are of limited use. Therefore, seismic risk analyses are based largely on studies of the geologic and seismotectonic setting, Cenozoic geologic history, and geomorphic evidence of Late Tertiary and Quaternary fault movements. The boundaries of seismotectonic provinces in the site region, as defined for this study, are shown in Figure 2.8. Also shown are the most recent plots of earthquake epicentral locations for the Colorado Plateau and the seismotectonic provinces adjacent to the site region.

The estimated maximum earthquake magnitudes based on regional source zones are presented in Table 2.2. The boundaries of the source zones vary substantially within the referenced publications.

Colorado Plateau. The Colorado Plateau is composed of a stable interior bounded on the east and west sides by more active border zones.

Wong and Simon (1981) have observed that seismicity in this interior portion of the Colorado Plateau is more analogous to the mid-continent than to the Western Mountains region of the United States. The study concluded that the seismicity of the Paradox Basin has been and will continue to be at a very low level. A 15-month seismic monitoring program in the Paradox Basin detected 230 events ranging in magnitude from 1.0 to 2.4, of which 95 percent were confined to the Colorado River Valley. The focal depths were from 2 to 10 km and indicate that these were all within the Precambrian basement rock, not in the salt diapiric

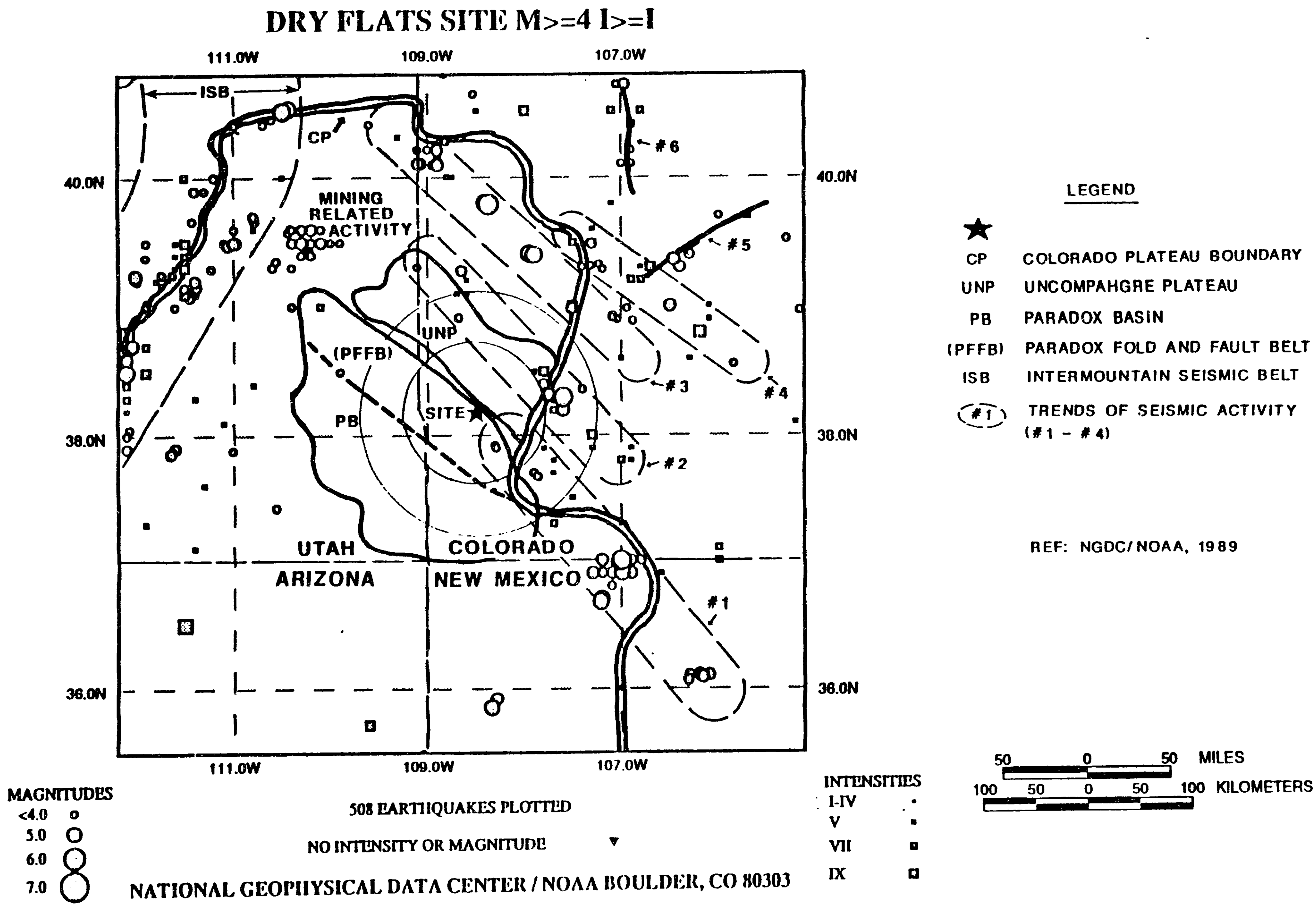


FIGURE 2.8
EPICENTRAL COMPILATION OF ALL RECORDED EARTHQUAKES FOR THE COLORADO PLATEAU AND ADJACENT SEISMOTECTONIC PROVINCES

Table 2.2 Estimated maximum magnitude, intensity, and acceleration for Dry Flats site region

Source	Maximum magnitude (M_L)	Source region	Probabilistic estimate	
			Intensity	Acceleration
Liu and DeCapua (1975)	7.0 6.5	Utah Colorado	IV	0.02g (100-year return interval)
Algermissen *et al.* (1982)	6.1 7.3	Paradox Basin Uncompahgre-San Juan Mountains		0.07 0.12 90% probability of no exceedance in 250 years
Thenhaus (1983)	6.0 6.5	Paradox Basin Uncompahgre-San Juan Mountains	Not given	
Kirkham and Rogers (1981)	5.5-6.5 6.0-6.5	Colorado Plateau Western Mountains	Not given	

structures. The fault solution of the seismicity indicated that the source had a strike-slip movement, suggesting the Colorado Lineament as the origin. Wong and Simon (1981) also concluded that the Colorado River may in some way be a triggering influence for the seismicity.

The border zones may be defined as separate subprovinces with the boundary drawn to include all of the larger earthquakes within the Colorado Plateau in an approximately 50-mile-wide strip along the east and west margins of the plateau, as shown in Figure 2.5. The border zones are characterized, in contrast to the plateau interior, by greater seismic activity, a crust that is transitional from the thinner crust of the areas adjoining the plateau to the thicker interior region, higher heat flow, common normal faulting, and greater occurrences of volcanism. The Colorado Plateau is bordered on the west by the Basin and Range Seismotectonic Province marked by the Wasatch Frontal Fault System and on the east by the Western Mountains Seismotectonic Province. Figure 2.5 shows the location of the border zone and the adjacent provinces relative to the structural elements contained within these areas. The Colorado provinces are defined by Kirkham and Rogers (1981) and are based largely on structural boundaries and partly on seismic trends.

The western border zone and the Great Basin Province are overlapped by the Intermountain Seismic Belt, which trends from Montana to southern Nevada (Smith and Sbar, 1974). Some of the largest earthquakes in the western United States have occurred in this belt. To the east, the boundary with the Western Mountains Province, which includes the eastern edge of the site region (see Figure 2.8), has experienced some moderate-sized earthquakes. An area of recurring seismic activity near Montrose, Colorado, may be related to the fault system that terminates the southeast end of the Uncompahgre Uplift (Kirkham and Rogers, 1981).

To the north, the Colorado Plateau is bordered by the Uinta-Elkhead Seismotectonic Province. Besides the relatively simple structure of the Wyoming Basin, this province also includes the Uinta Uplift and the Axial Basin, a complex series of west-northwest-trending folds and collapsed anticlines superimposed over major basement fault systems whose pre-Tertiary history is similar in many respects to the Uncompahgre Uplift.

Seismic trends. Analysis of the trends of epicentral locations for all recorded earthquakes indicates that activity may be associated with an apparent series of parallel, northwest-trending lineaments (see Figure 2.8). Since the features do not align too closely with structural elements, their pattern suggests that basement structures are responsible. Brief descriptions of these seismic trends are as follows:

- Lineament 1. Extends from the Dulce, New Mexico, area, along the southern flank of the San Juan Mountains, directly into the site region with the single epicentral location in the site region marking the northerly extent.

- Lineament 2. This trend appears to approximate the northeast border of the Uncompahgre Uplift and falls at the northeast edge of the site region.

- Lineament 3. This trend, which is about 62 miles north of Lineament 2, parallels the edge of the Colorado Plateau within the border zone, beginning at the Elk Mountains and extending the length of the Piceance Basin.

- A fourth lineament lies close to Lineament 3 and closely follows the alignment of the Grand Hogback, a faulted monoclinal fold at the edge of the White River Uplift that marks the boundary of the Colorado Plateau.

The northeast-trending Colorado Lineament (Brill and Nuttli, 1983) is not apparent as a controlling seismic feature in the study region on the basis of seismicity trends (see Figure 2.4). However, Brill and Nuttli (1983) believe the Colorado Lineament to be one of the source zones for the larger historical earthquakes of the west-central United States. Baars and Stevenson (1981a) argued that major northeast- and northwest-trending structures in the Precambrian basement intersect in the northeastern part of the Colorado Plateau near the La Sal Mountains. The northwest-trending Uncompahgre Uplift and Paradox Basin are associated with the Olympic Wichita Lineament under this interpretation. Hite (1975) described features within the Paradox Basin, which he determined to be evidence of extensive movements on northeast-trending faults as late as Eocene time. However, the predominant structural and tectonic grain of surface geologic features is northwest-trending. Contemporary seismicity has been characterized by Wong and Humphrey (1989), who also present new concepts for extension rather than compression stress for the Colorado Plateau. They believe this concept supports the idea of the Plateau as a coherent, relatively stable crustal block.

Paradox Basin fold and fault belt

The site area is located in the Paradox Basin southwest of the Uncompahgre Uplift. The folds are Laramide Orogeny structures and include several preexisting salt core diapiric anticlines that were modified by the compressional stress. The crests of the salt anticlines collapsed by graben block faulting at the end of the Laramide disturbance. The anticlines are believed to be controlled by large subsurface faults, which have experienced several episodes of activity since the Late Paleozoic. The anticlines themselves have apparently experienced movement in the Quaternary and may be capable of movement today (Kirkham and Rogers, 1981; Cater, 1970; Hunt, 1956). The current episode of collapse may have begun when the Colorado Plateau was uplifted during the Miocene, during which time the anticlines were breached and their cores exposed by erosion. Rapid dissolution and flowage followed exposure, causing complex faulting.

It is unlikely that these features can generate earthquakes having a magnitude larger than 4.0 or 5.0, according to Kirkham and Rogers (1981), or 3.0, according to Wong *et al.* (1987). However, the large subsurface faults that control the locations of the anticlines are not exposed, and it is not known if they are presently capable.

Uncompahgre Uplift

The Uncompahgre Uplift is one of the few features lying within the interior of the Colorado Plateau that has been identified as potentially capable of seismic activity (Kirkham and Rogers, 1981; Sinnock, 1981a; Cater, 1966). It is a large, northwest-trending, asymmetrical block composed of a core of Precambrian igneous and metamorphic rock overlain by Mesozoic sedimentary units, bounded on the northeastern and southwestern flanks by abrupt, locally faulted monoclines. The northwest-trending salt anticlines of the Paradox Basin lie to the southwest, paralleling the trend of the uplift (Plate 1). On the northeast, the uplift is flanked by the Colorado, Gunnison, and Uncompahgre River Valleys, Grand Mesa, and the Piceance Basin. The southeast end of the uplift is terminated by the Ridgway fault and the San Juan volcanic field, which also mark the boundary of the Colorado Plateau and Western Mountain Provinces. To the northwest, the uplift plunges beneath the Tertiary sedimentary sequence of the Uinta Basin.

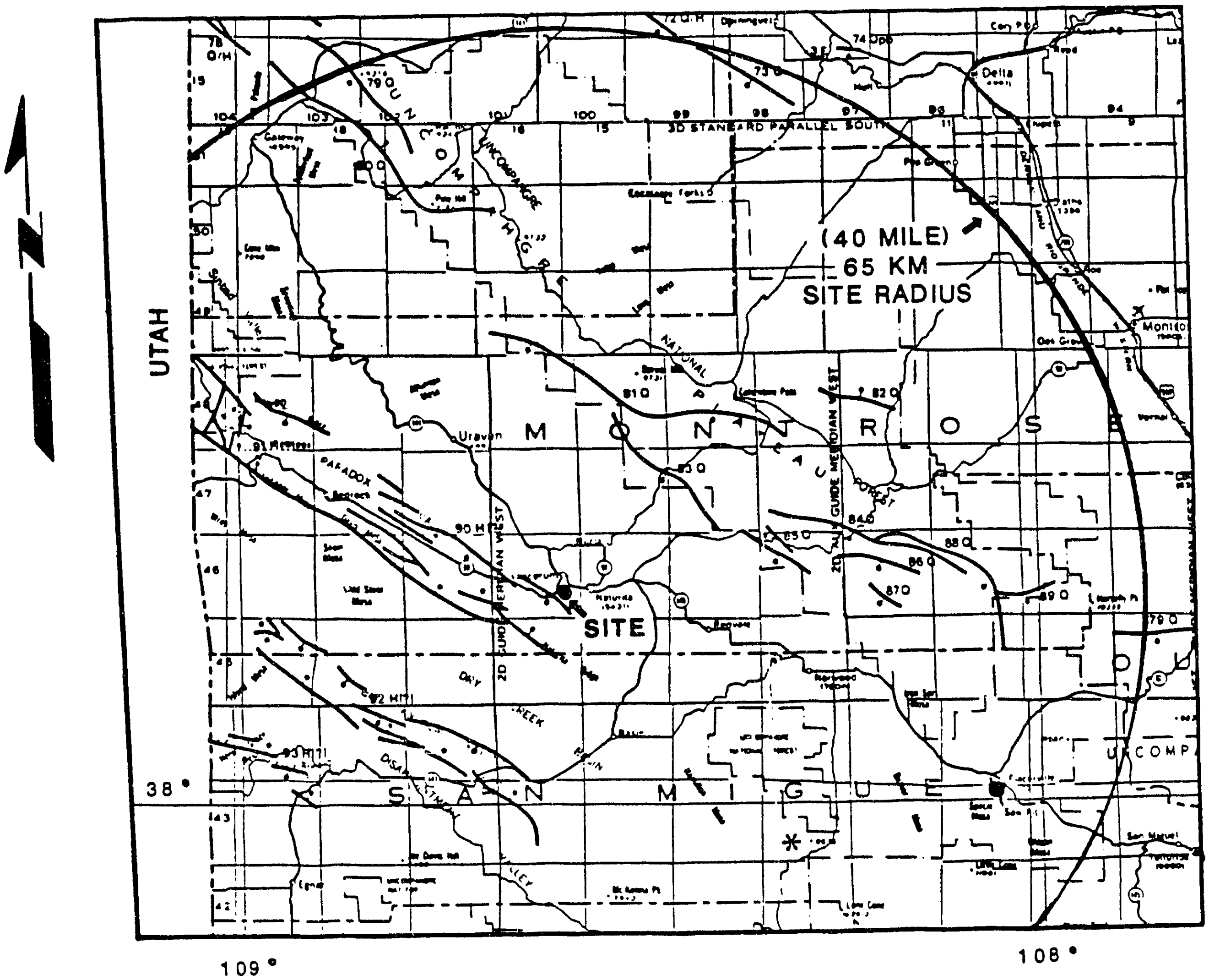
The Uncompahgre Uplift has experienced recurrent activity since at least the end of the Paleozoic and may be controlled by deep-seated faults that were established during Precambrian time. It was a prominent structural feature during the "Ancestral Rockies" disturbance in Late Paleozoic (Late Mississippian to Permian) time (De Voto, 1980a,b; Cater, 1970). Movement also occurred on bounding faults and monoclines during the Laramide Orogeny in Late Cretaceous to Eocene time (Kirkham and Rogers, 1981; Tweto, 1980). The modern Uncompahgre Uplift is a northeast-tilted block that has apparently experienced considerable Neogene uplift. The timing of Neogene deformation is uncertain. Movements apparently began during the Miocene or Pliocene and may have persisted into the Pleistocene (Kirkham and Rogers, 1981; Sinnock, 1981a; Cater, 1966).

Kirkham and Rogers (1981) indicate that movements may be continuing at the present time. They identified about 25 potentially capable faults of Late Cenozoic age flanking the uplift on the northeast and southwest (Figure 2.9 and Plate 1). These faults range in length from about 8 to 40 km (5 to 25 miles).

Ely *et al.* (1986) have reported a microseismic earthquake (less than 3.5 magnitude) of magnitude 2.9 accompanied by smaller postshocks and aftershocks in 1985 near the Ryan Creek Fault [identified as fault no. 78,79 in the Ute Creek Graben by Kirkham and Rogers (1981)]. This is near the crest of the Uncompahgre Plateau, north of Gateway, Colorado, about 13 km (8 miles) beyond the 65-km outer radius.

Other seismic activity related to the Uncompahgre faults occurred in the Grand Junction area on the northeast flank of the uplift 120 km (74 miles) north of the site. One event, with an intensity (MMI) of II, which occurred on March 1, 1915, may have been related to the Redlands fault complex (fault no. 65 of Kirkham and Rogers, 1981).

The event of March 1, 1915, was preceded on February 28, 1915, by an event of estimated intensity (MMI) III whose epicenter apparently was located about 7 km (4.5 miles) to the northeast, on the opposite bank of the Colorado River. A second event occurred very close to the epicenter of the February 1915 event on January 30, 1975. This event had a body wave magnitude of 4.4 and an intensity



REF

FAULTS FROM KIRKHAM AND ROGERS, 1981

NOTE: FAULTS SHOWN ON MAP LIST ALL FAULTS IN SITE REGION REPORTED BY REFERENCED STUDY FOR STATE OF COLORADO. FAULT NUMBERS 65-89, FLANK THE UNCOMPAHGRE UPLIFT. FAULTS THAT ARE IN SALT ANTICLINE COLLAPSE STRUCTURE ARE NUMBERED 90-93.

* EPICENTER OF ONLY EARTHQUAKE RECORDED IN SITE REGION

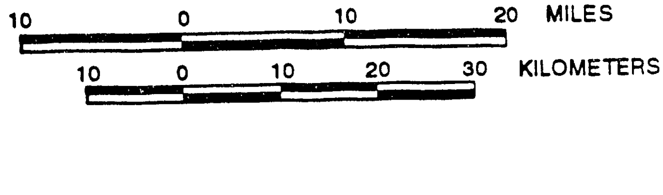


FIGURE 2.9
POTENTIAL CAPABLE FAULTS IN DRY FLATS SITE REGION, COLORADO

(MMI) equal to V. No faulting has been recognized to date in the area of these epicenters.

During the fieldwork performed for this study, all critical faults within a 65-km radius of the site were carefully examined for evidence of Quaternary movement (see Section 4.2). No direct geologic evidence was found for Quaternary movements on any faults associated with the Uncompahgre Uplift.

Piceance Basin

The northwest-trending Piceance Basin, which lies mostly in the border zone of the Colorado Plateau, originated during the Late Cretaceous-Eocene Laramide Orogeny. During this time, the basin subsided and received about 2500 meters (8200 feet) of sediment from adjoining uplifted areas (Tweto, 1980). The basin is bounded on all sides by Laramide uplifts. On the north it is bounded by the White River Uplift, on the south and southeast by the Elk and West Elk Mountains, on the southwest by the Uncompahgre Uplift, and on the west by the Douglas Creek Arch (Ochs and Cole, 1981).

The basin is bounded on the southeast by faults of the Uncompahgre Uplift that may be capable of seismic activity (Kirkham and Rogers, 1981). Within the basin itself, however, and along its eastern flank, no faults suspected of being capable have been definitely identified. As discussed above, the interior of the basin has been the locus of a low level of historical seismicity, but these events have not been correlated to known structures.

Western Mountain Province

The Western Mountain Province (Kirkham and Rogers, 1981) comprises the mountainous areas lying between the Rio Grande Rift and the Colorado Plateau in west-central Colorado. This area approximately corresponds to the Southern Rocky Mountains of Hunt (1967). The province is characterized by north-south-trending, Precambrian-cored, anticlinal mountain ranges that commonly reach elevations of 4300 meters (14,100 feet). The ranges are commonly fault-bounded and separated by narrow intermontane basins. This province includes the San Juan, Elk, and West Elk Mountains, the west flank of the Sawatch Range, and the White River and Gunnison Uplifts (Kirkham and Rogers, 1981). Included are a series of volcanic centers of Late Tertiary age, the largest of which forms the San Juan Mountains (Larson *et al.*, 1975).

Relatively few Quaternary faults are known in this province. Late Tertiary volcanics in the San Juan Mountains are offset by faults related to caldera collapse; however, these are not considered to be capable at the present time (Kirkham and Rogers, 1981).

Minor evidence of Late Tertiary reactivation of west- or northwest-trending Precambrian faults, such as the Cimarron fault (Fault No. 94 of Kirkham and Rogers, 1981) and a few others scattered throughout the province, has been identified, but none are major tectonic faults that have experienced any significant known Quaternary activity.

2.5 RESOURCE DEVELOPMENT

The principal resources for the site region are gas and oil, uranium, coal, and potash. Figure 2.10 shows the location of production of these resources relative to the site. The mining and processing of uranium ore has caused the most disturbance of surface conditions in the site area.

The Naturita processing site and the Dry Flats disposal site lie just east of the Uravan Mineral Belt and the nearest mining district (Chenoweth, 1980, 1978). Major uranium occurrences are found in the Salt Wash Member of the Morrison Formation of Jurassic age. Minor quantities have been found in the Triassic-aged Chinle Formation and in the Permian-aged Cutler Formation. Host rocks are sandstone units formed by fluvial channels associated with floodplain deposits of mudstone. A few mineralized zones are known to have been localized along fold crests or fault zones. The nearest known uranium production mines are located about 8 miles west and northwest of the Dry Flats site (Woodward-Clyde Consultants, 1983).

Most of the fuel production in the site region is of natural gas, with oil production being relatively minor. Production is from faulted anticline structures and from stratigraphic traps in the Paradox Basin. Scott and Klippen (1981) reported that there had been over 280 miles of seismic reflection data to investigate petroleum potential in the Paradox Basin. Most production has been from the Permian Cutler Formation and the Honaker Trail Formation of Pennsylvanian age (Krivanek, 1981). The nearest production to the Dry Flats site has been the Montrose Dome gas field, 3 miles southwest, which was operated in 1958. The nearest present gas field is Andy's Mesa field located 10 miles south of the Dry Flats site. There are no known oil production fields in the site region (Woodward-Clyde Consultants, 1983).

Potash occurs with the Paradox salt member of the Pennsylvanian-aged Hermosa Formation. The only known production comes from the Moab, Utah, area located outside the site region, although nearly all of the basin within the site region has a potential for potash deposits (see Figure 2.11). Conventional mining procedures were used until 1970, when solution mining was adapted to avoid the problems associated with salt flowage in deep tunnels (Wong *et al.*, 1987). The study by Woodward-Clyde Consultants (1983) shows that most commercial mining zones are below 2500 feet but are known to occur at depths from 430 feet to 10,000 feet or more. The economic cutoff depth is approximately 4000 feet because of salt flowage. Some mining-induced seismicity has occurred with the operation in Utah.

Minerals associated with natural brines in the Paradox Basin could be important sources for several metals. Most natural brine occurrences are too small for economic purposes; however, some artificial brines (by solution mining) are produced in the Moab, Utah, area (Woodward-Clyde Consultants, 1983).

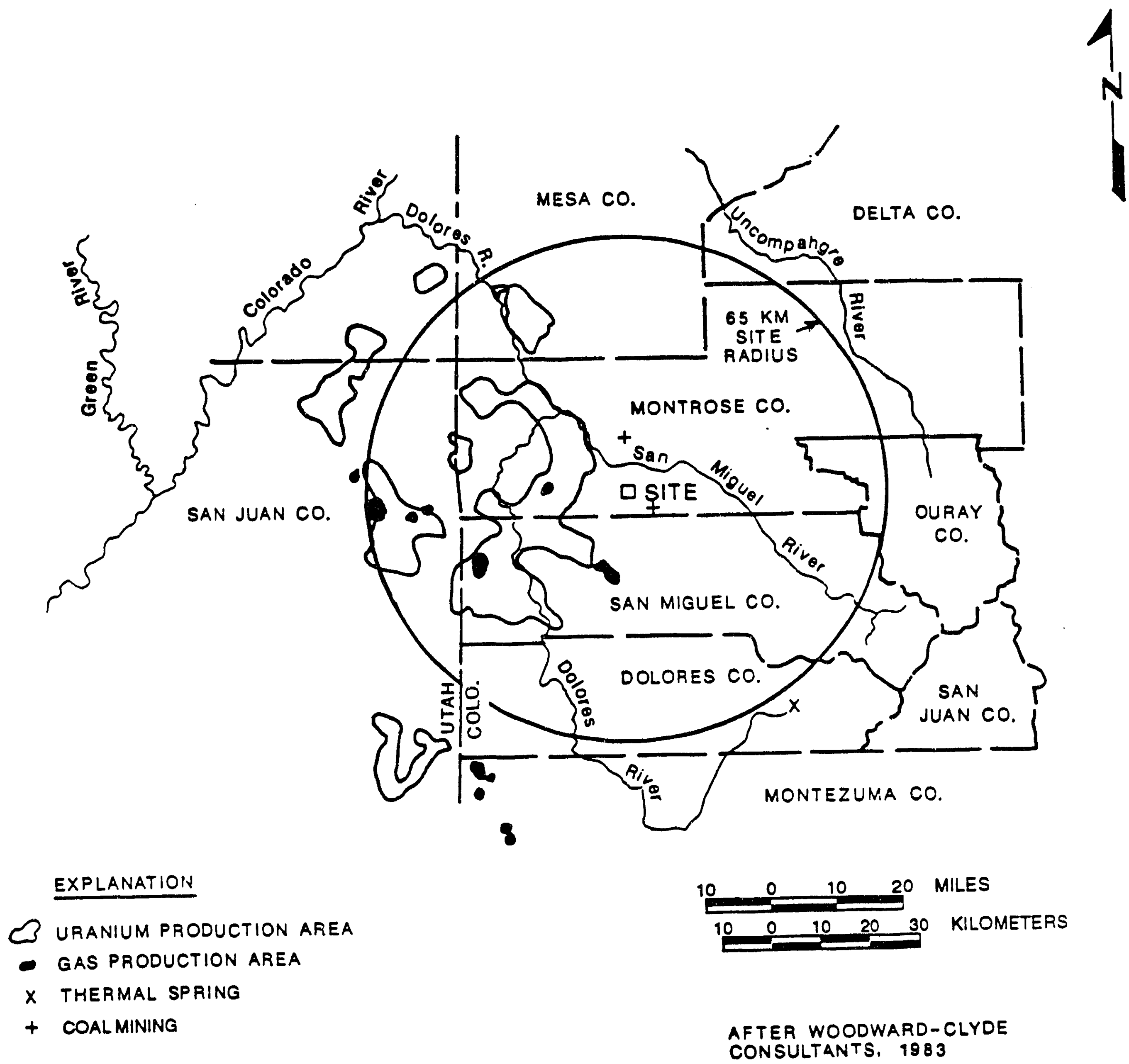
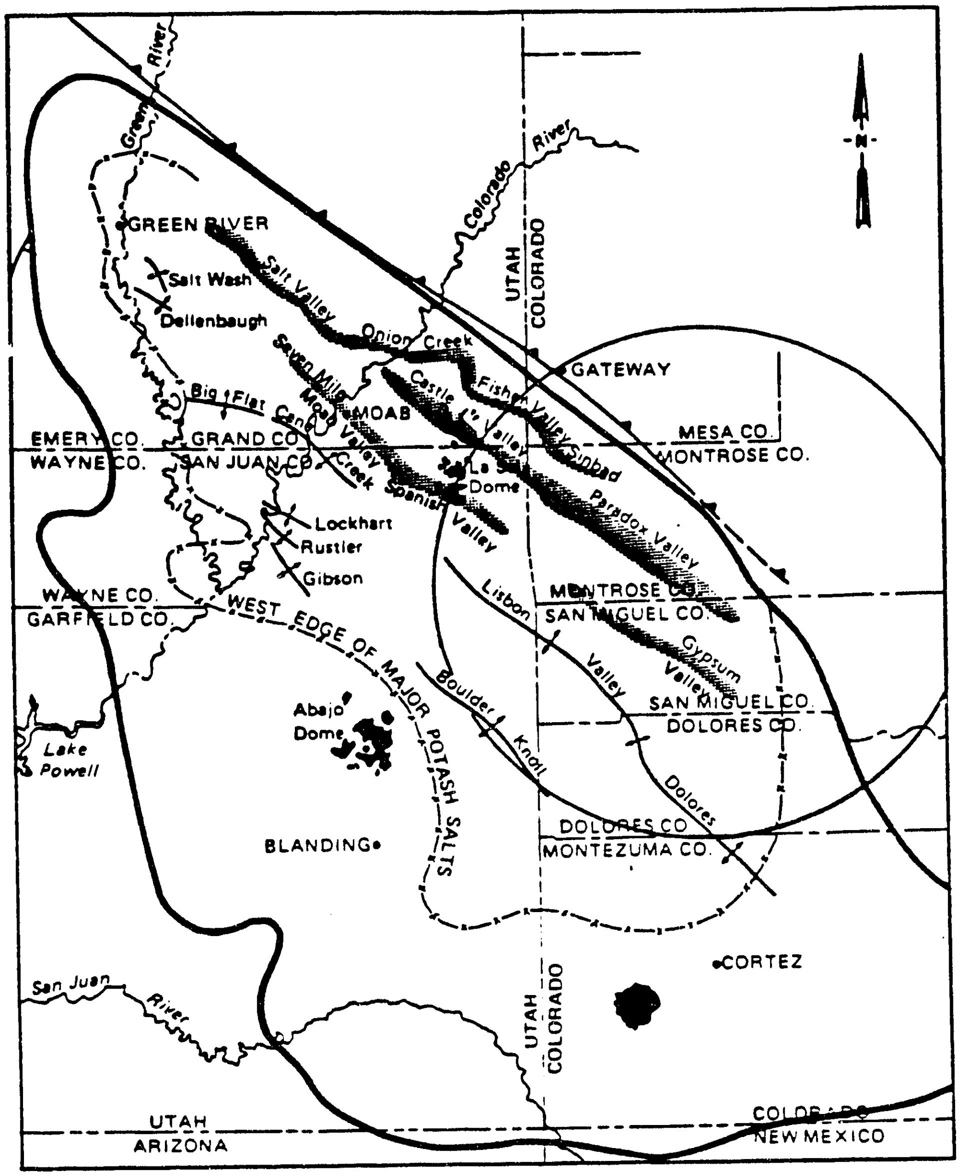


FIGURE 2.10
AREAS OF MINERAL RESOURCE DEVELOPMENT IN DRY FLATS SITE REGION, COLORADO



EXPLANATION

- Approximate location of zero thickness of saline facies (Boundary of Paradox Basin)
- Anticline in which intrusive salt (Paradox Formation) is exposed
- Igneous intrusive center, generally a domal uplift
- Overthrust margin of Uncompahgre Uplift; barbs on overthrust block
- Anticline within area of potash deposition
- Limit of major potash deposition

FROM: WOODWARD-CLYDE CONSULTANTS, 1983

0 10 20 30 40 50 60 70 miles

0 20 40 60 80 100 kilometers

FIGURE 2.11

MAP OF POTENTIAL MINERAL RESOURCES RELATED TO SALT ANTICLINE AND PARADOX SALT MEMBER FOR DRY FLATS SITE REGION, COLORADO

There are two mines within 8 miles of the Dry Flats site that obtain coal from the Dakota Formation. The nearest mine, the Hamilton strip mine, is 3 miles east of the site and produces coal from a seam about 3 to 4 feet thick from depths less than 24 feet (BLM, 1993a). The coal is currently used for a small power plant near Nucla, Colorado. Coal deposits at the Dry Flats site consist of a few seams typically 1 to 2 inches thick that occur within a carbonaceous shale ranging from 10 to 30 feet below the surface.

The site region lies just outside of the Colorado Metallic Mineral Belt, which includes the Telluride, Ouray, and Rico mining districts in the volcanic caldera region on the edge of the San Juan Mountains. Most mineralization there occurs in the volcanic rocks (Romberger, 1980).

3.0 SITE GEOLOGY

General geologic setting

The site is located at the southeast end of Paradox Valley, isolated from the main portion of the collapsed salt anticlinal valley by the transecting trend of Dry Creek. Dry Creek is superposed across the anticline structure, deeply dissecting the flanking ridges of Naturita Ridge (Dry Creek Anticline) and Sawtooth Ridge. The adjacent Coke Oven Valley is a sag structure that has foundered in the core of the salt anticline. The valley ends a short distance east of the site with the merging of the Sawtooth Ridge and Naturita Ridge into a relatively flat-topped mesa. There, the mesa is dissected by gulches draining north to the San Miguel River near the town of Naturita, Colorado.

Elevations at the Dry Flats site, an extension of Sawtooth Ridge, range from 5955 to 5920 feet. The site lies 300 feet above the Coke Oven Valley drainage, 4500 feet to the south; 540 feet above the San Miguel River Valley, 6000 feet to the north; and 400 feet above Dry Creek Canyon, 6000 feet to the northwest of the site.

Subsurface data is based on logs of seven core holes, 13 monitor well borings, and numerous test pit excavations. Previous studies applicable to the site area include the following: an assessment of geomorphic conditions at Coke Oven Valley (DOE, 1986); studies performed for the Hecla Mining Company (Fox, 1982) and the mill site in Coke Oven Valley (FCERI, 1977); and a preliminary characterization of the Naturita mill site (FBDU, 1977).

The relationship of the structure and topography at the site, located at the extreme southeast end of Paradox Valley, to this collapsed salt anticlinal structure as well as to the adjacent Big Gypsum Valley has been explained by Cater (1970). The map on Figure 3.1 and the cross sections on Figures 2.7 and 3.2 show these structures. The ridge on which the Dry Flats site lies and the sharp-crested ridge on the other side of the narrow valley (Naturita Ridge) are the opposing limbs of the same salt anticlinal structure that underlies the Paradox Valley. Coke Oven Valley represents the sagged crest of the anticline and the southernmost extent of the collapse of the Paradox Valley anticline. The north boundary fault, whose nearest trace lies on the slope approximately 600 feet south of the site, is the southeastern extension of the splayed graben fault on the north limb. The fault that is prominent in the Dry Creek Canyon 1.2 miles northwest of the site becomes splayed into numerous fractures and merges near the site into a fold that wraps around the end of Coke Oven Valley. The crestal fault on Naturita Ridge is the opposing graben fault on the south limb. Both of these faults merge eastward into a fold, creating secondary folded structures, Dry Creek Anticline on the south, and Dry Flats anticline on the north flank. The fault planes of the graben west of the site are very steep to nearly vertical (Figure 2.7a).

As Cater (1970) has noted, the process of dissolution has had an indirect role in the final stage of collapse of the salt anticlines at the site. By causing and sustaining the breach in the salt core at the Dolores River, it has created the necessary differential pressure to initiate salt flowage. The base level of the Dolores River where it incises the Paradox Valley and the rate at which Holocene downcutting is proceeding appear to be the primary factors for stability of the structure, especially for the foundered block of the Coke Oven Valley.

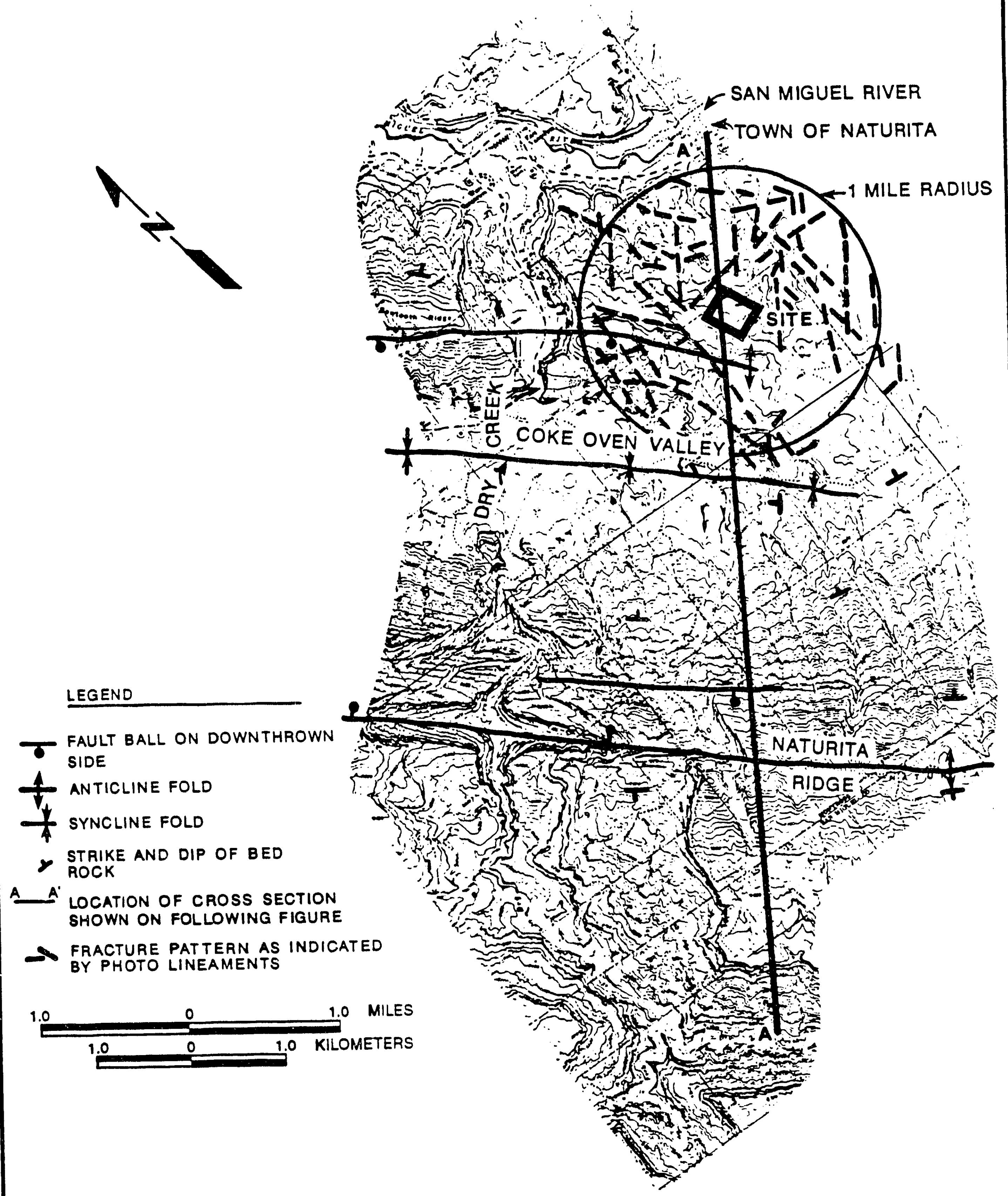


FIGURE 3.1
STRUCTURE AND TOPOGRAPHY OF
DRY FLATS SITE VICINITY, COLORADO

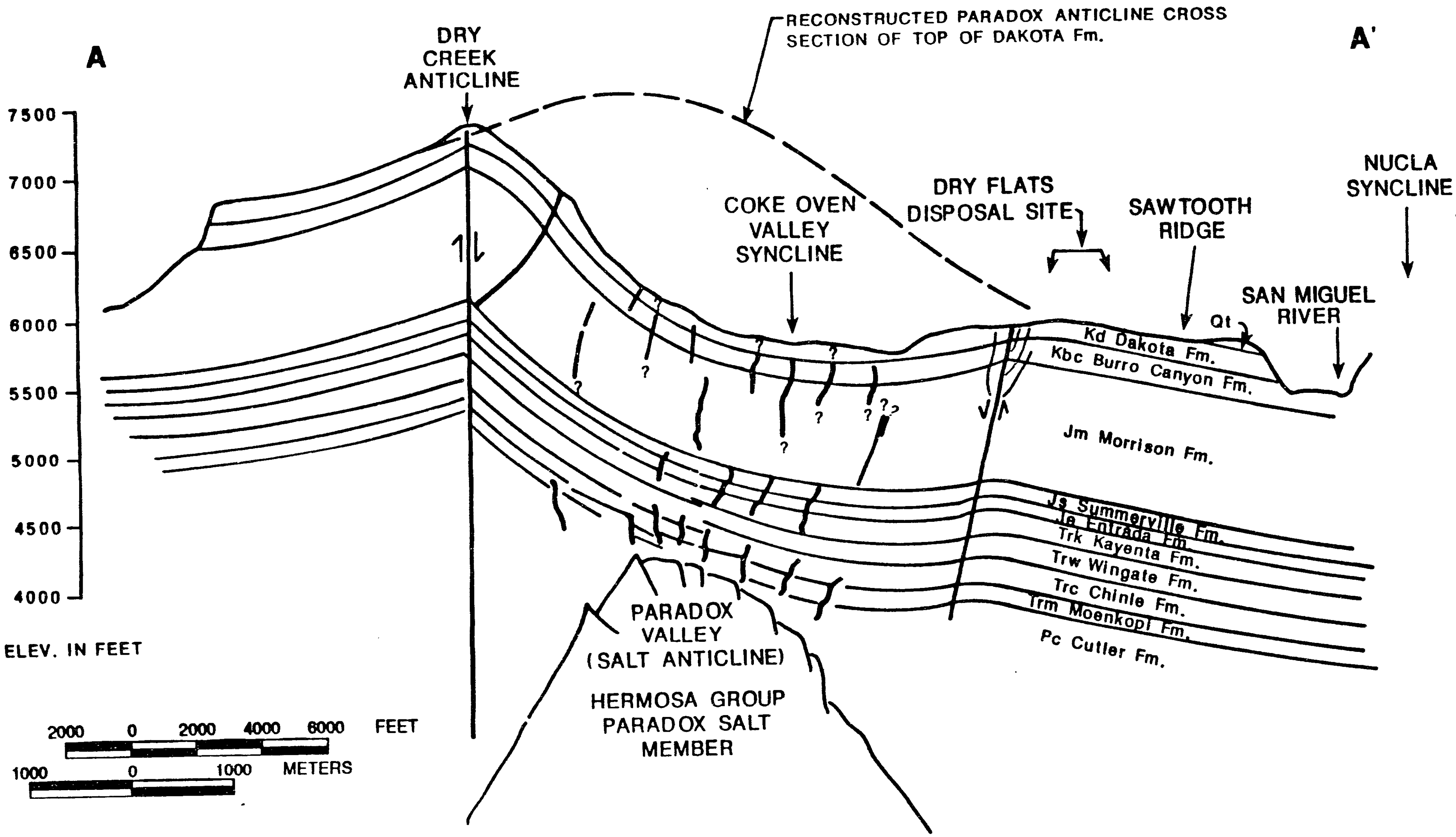


FIGURE 3.2
GEOLOGIC CROSS SECTION A–A'
DRY FLATS SITE, COLORADO

Of the two flanking limbs of the salt anticline, the Naturita Ridge (Dry Creek Anticline) has been the most disturbed by preferential southward lateral stress of the collapsing graben block. In contrast, the north side limb of the anticline, Sawtooth Ridge, on which the Dry Flats site is located, appears relatively undisturbed. The preferential stress toward the south flank has been diagramed by Cater (1970). The relative stability of the Dry Flats site during the collapse suggested that any future instability of the salt anticline would likely continue to be reflected primarily in Coke Oven Valley rather than on the adjacent ridges.

3.1 SITE BEDROCK

The bedrock and surface geology is shown on Figures 3.2, 3.3, 3.4, 3.5, and 3.6. The Dakota Sandstone Formation underlies the site area. The uppermost unit consists of a 4- to 6-foot-thick sandstone stratum underlain by an easily erodible gray/black shale claystone unit (Figures 3.4 and 3.5). A thin coal seam (zero to 2 feet thick) forms the lower contact of this shale and grades downward into a highly resistant thick sandstone stratum.

The cumulative sandstone thickness of the total Dakota Formation thickness varies substantially (56 to 90 percent) over a short distance as a result of facies changes. The bottom contact of the Dakota Sandstone, like the Burro Canyon Formation that underlies it, is reportedly marked by an unconformity that may be represented by a thin, discontinuous basal/pebble zone. However, the distinction between the two formations is poorly defined at the Dry Flats site because of the discontinuity of the major sandstone units (Molenaar, 1981). Craig (1981) reports that the Burro Canyon Formation is about 30 meters (98 feet) thick at this location. The upper part is typically greenish mudstone and the lower part is mostly sandstone. The mudstone is described as a nonswelling type clay that contrasts with the swelling clay of the Morrison Formation. It is presumed that the combined thickness of the two formations is about 200 to 250 feet and that the underlying 200 feet of claystone is the upper part of the Morrison Formation (see Figures 3.4 and 3.5). Thin zones of groundwater are perched on this thick claystone unit near this contact, as indicated on Figure 3.5. However, after close inspection, no springs or seeps have been observed along this contact in downslope drainages or in the cliff face of the San Miguel River Canyon above the town of Naturita. The Brushy Basin Member of the Morrison Formation of Jurassic age is mostly mudstone at this location and contains no potential significant aquifers; however the Salt Wash Member contains a sandstone aquifer encountered in the deepest boring at the site.

Figure 3.1 shows the fracture and joint pattern of bedrock in the site vicinity. There are three sets of joints, with the predominant set most affecting the drainage alignment trending N40°E. The next most significant set trends N80°E, and a third set trends due north. North of the site, adjacent to the San Miguel River, a fourth set trends N30° to 45°W, paralleling the river and the Uravan Syncline fold axis at this point. The rock cores from the site shows that there are minor horizontal fractures at the bedding contact between competent and incompetent strata. Additionally, shear fractures with little vertical displacement were observed in the exposed surface of the sandstone underlying the site. This may be the result of the lateral displacement that resulted during the collapse of the Paradox salt anticline,

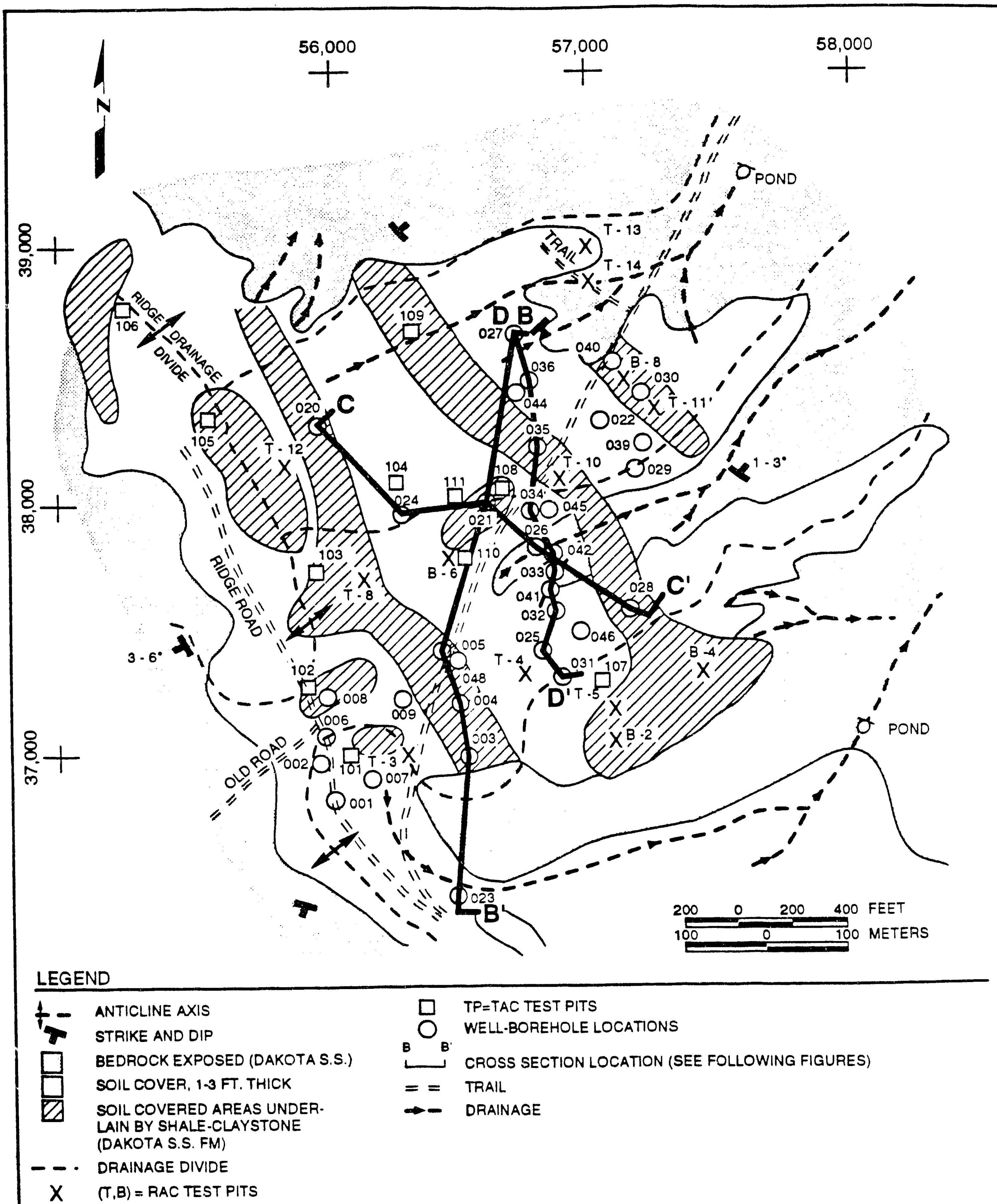


FIGURE 3.3
SITE GEOLOGY AND DRAINAGE MAP, DRY FLATS SITE, COLORADO

MAC: SITE/NAT/SITE GEO

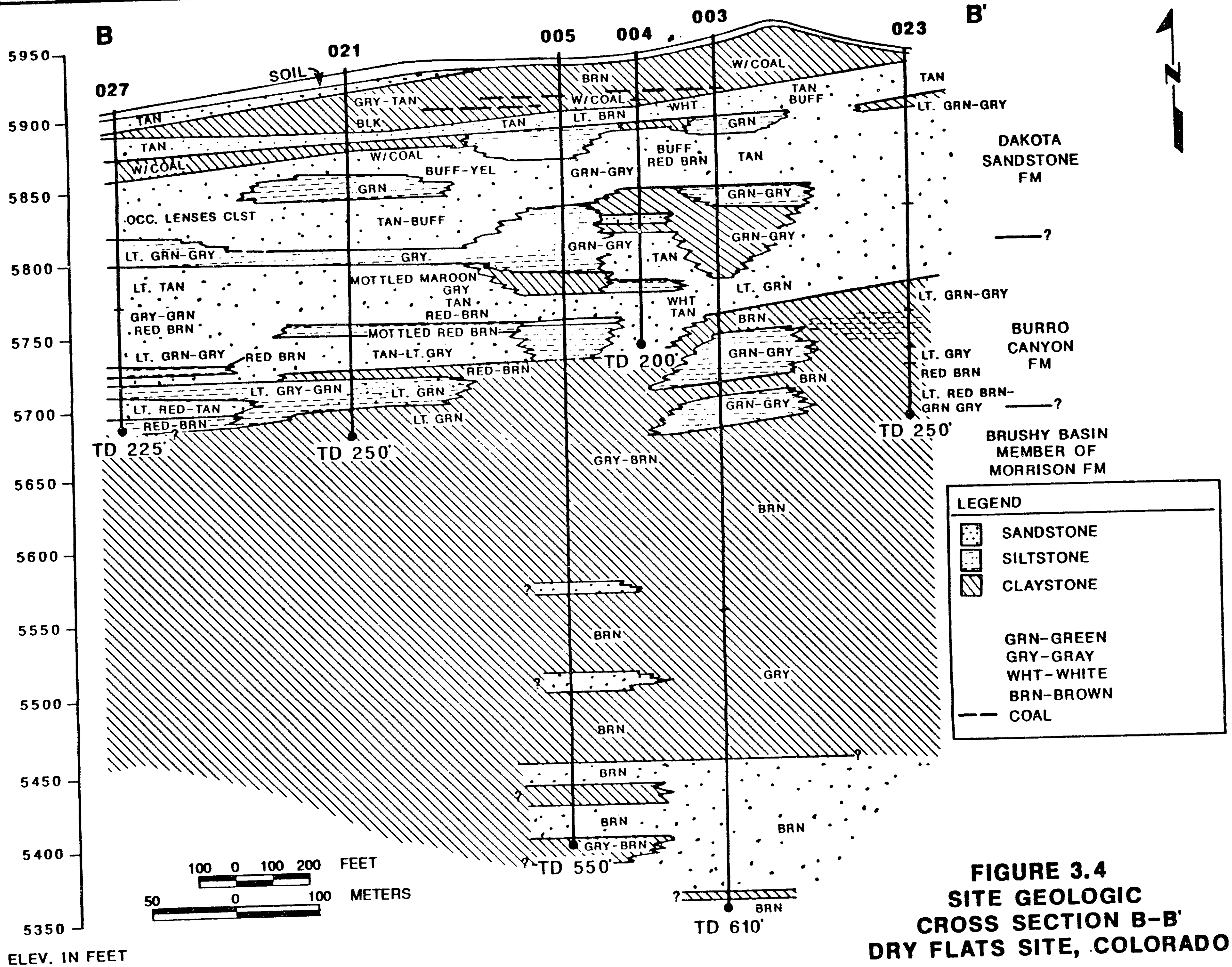


FIGURE 3.4
SITE GEOLOGIC
CROSS SECTION B-B'
DRY FLATS SITE, COLORADO

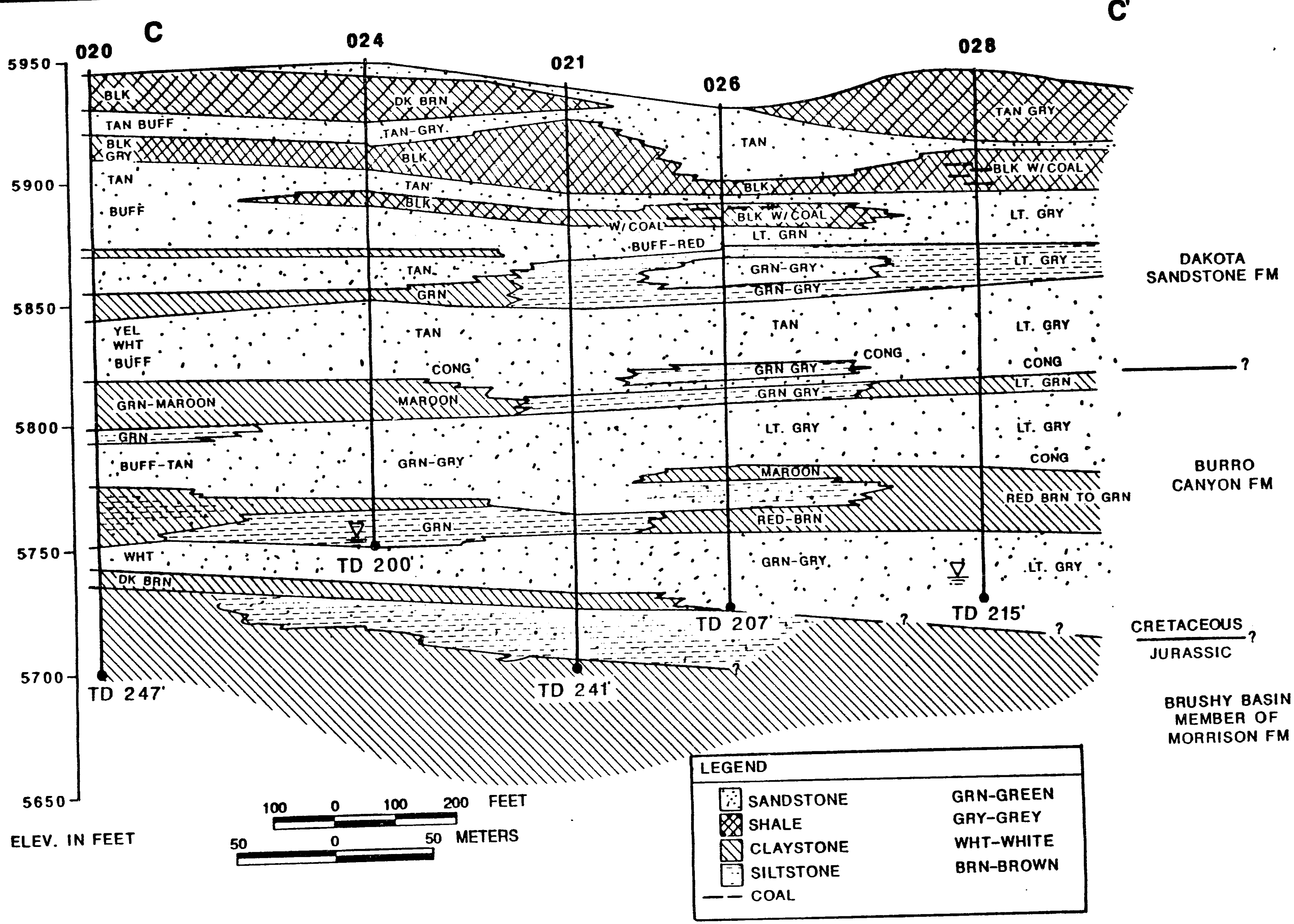


FIGURE 3.5
SITE GEOLOGIC CROSS SECTION C–C' DRY FLATS SITE, COLORADO

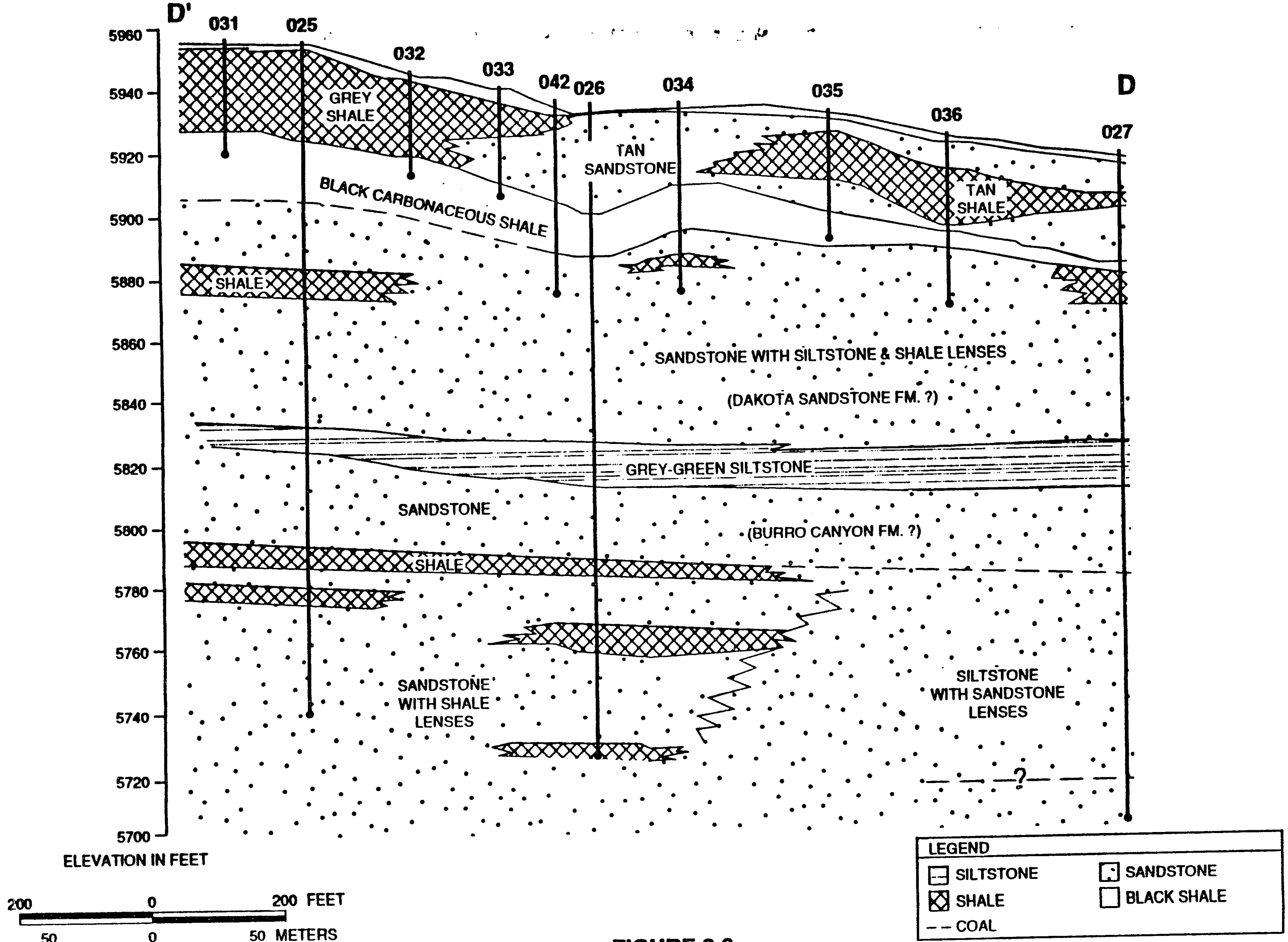


FIGURE 3.6
SITE GEOLOGIC CROSS SECTION D-D', DRY FLATS SITE, CO.

MAC: SITE/NAT/X-SEC

as discussed in Section 2.3. Because of the mostly lateral displacement, vertical fractures will have little continuity between strata; also, the interbedded claystone strata are expected to provide a fairly impervious barrier to infiltration and migration.

3.2 UNCONSOLIDATED DEPOSITS

The thickness of the soil ranges from 1 to 3 feet and consists primarily of clayey silt with some fine sand. Variations across the site range from nonplastic, silty, fine sand to silty clay. The soils appear in most instances to be eolian sediment perhaps deposited in the protected cover of the stands of piñon and juniper and sustained by the sagebrush and grass cover. The soil in some areas, where underlain by claystone, appears to be residual soil and grades into the weathered shale-claystone of the Dakota Formation.

3.3 GEOMORPHOLOGY OF THE SITE AREA

The Dry Flats site is located near the crest of a low anticlinal ridge. About 600 feet south of the flat crestal area the slope breaks abruptly to 10.0 percent (5.5°) at the dipslope of the sandstone bedrock outcrops. The Coke Oven Valley floor is about 300 feet below the crest. North of the crest marking the axis of the anticline the surface slopes northward, also following the dipslope of the bedrock strata, with drainages becoming increasingly more sharply defined on the lower slope of the site. The average slope across the site is 2.6 to 5.8 percent (1.5° to 3.5°) with a vertical relief across the site of about 40 feet. The drainages become deeply incised in the Dakota Sandstone as it approaches the edge of the San Miguel River channel at an elevation of 500 feet below the site.

Figure 3.3 shows the exposure of bedroc'. on the site. Bedrock is exposed in lower drainages and also in higher-relief areas that form the drainage divides of the local subbasins. The unconsolidated soil deposits occupy broad, shallow subbasins along the crest of the ridges between low bedrock-supported drainage divides. Moderate stands of juniper and small piñon trees appear to coincide with areas of very thin soil cover or exposed sandstone outcrops. Sandstone that is exposed in the drainages and occupies the higher elevation on the site resists gully incision, but locally may be stripped of soil to expose the gently dipping bedding plane surfaces.

Weathered shale-claystone strata containing some thin coal seams underlie the shallow soil in about 20 percent of the area below the cell (Figure 3.3). The exposed, moderately resistant sandstone surfaces, however, provide a local base level for erosion for the design life of the project. The downgradient maximum base level for the site is the town of Naturita at an elevation of 5431 feet, so that the distance-height relationship is 6500 to 489, or 13.3 to 1.

The denudation rates for the fine-grained soils and weathered claystone-shale deposits is estimated for small basins at 2 to 8 feet (0.6 to 2.4 meters) per 1000 years (Bronson and Owen, 1970). The soils at the site within the shallow subbasin at the crest of the ridge are reworked eolian deposits formed by deposition within the protected vegetated surface afforded by small sagebrush and grass, with juniper and piñon trees around the perimeter. Under these natural conditions deposition has exceeded erosion. Sometime in the last 20 years, the Bureau of Land Management (BLM) has encouraged grass growth by stripping the sagebrush from these small, soil-covered flats to create pasture lands. For the lower portion of the site where slopes exceed 3.0 percent, erosion has stripped the soil from the bedrock in most drainages.

4.0 GEOLOGIC STABILITY

4.1 GEOMORPHIC STABILITY

Because of the elevated topographic position of the site and the dip-slope outcrop of the resistant Dakota Sandstone underlying all surfaces on gentle to moderate slopes, the concern of instability for most geomorphic processes is eliminated. This includes flooding, channel migration, infringement by colluvium or eolian deposits, landslides or slope failures, seepage, scarp retreat, and headward advance of gullies.

The only concern for geomorphic stability is the erosion potential of the soils and weathered, fine-grained (siltstone and claystone) that underlie some portions of the site. Slopes for unprotected soil in those areas should be designed not to exceed 1.5 percent. Where this slope is exceeded, the surface should be armored with erosion protection rock. On lateral (northwest or southeast sides of the pile) sideslopes, the toe foundations should extend into bedrock.

The potential for instability of the salt anticlines is related to the downcutting of the dissecting streams (primarily the Dolores River), causing rejuvenation of dissolution and subsequent flowage of the salt cores. Cater (1966) observed that although uplift in the region had continued until early Pleistocene, the major trunk streams have not greatly deepened their canyons for some time. Sugiura and Kitcho (1981) have also observed that localized collapse structures (sinkholes), related to dissolution of the near-surface Paradox salt member, were formed before Quaternary time. It is unlikely that the site will be affected by any instability of the salt anticline during the design life of the cell as a result of salt flowage or tectonic activity. The north flank of the Paradox salt anticline where the site is located is essentially intact and less vulnerable to instability compared to the graben block formed by the Coke Oven site, which has foundered in the salt crest of the anticline (see Figure 3.2).

4.2 SEISMOTECTONIC STABILITY

Technical approach for seismic stability analysis

The objectives of the seismic stability analysis performed for this study were as follows:

- Selection of the design earthquake and estimation of the on-site PHA for use in subsequent engineering analysis.
- Recognition of any potential for on-site rupture.
- Recognition of any potential for earthquake-induced slope failure or subsidence.

The technical analysis performed for this study involved a critical review of all the information developed during the study and a step-by-step approach to estimating seismic stability.

The first step was the determination of the largest credible magnitude of floating earthquakes (FE) in the seismotectonic province in which the site is located. The resulting on-site acceleration was calculated using the acceleration-attenuation relationship of Campbell (1981).

The second step was to assess the maximum possible on-site acceleration resulting from earthquakes occurring in adjacent and remote seismotectonic provinces. A detailed analysis of individual faults was not performed unless they lie within the site region. The maximum earthquake (ME) values for the remote provinces are estimated based on published studies and personal communication with workers active in the area. The boundaries of such provinces are also obtained from published maps and literature. The ME was then assumed to occur at the closest approach of each remote province to the site, and the resulting potential on-site acceleration was calculated.

After completion of these first two steps, the largest value of resultant acceleration at the site, from the FE or the ME, was taken as the critical acceleration on which to evaluate regional fault capability.

Based on the review of published and unpublished geologic data and the aerial photography interpretation, a compilation of all mapped faults and suspected faults for the site region was made for a working base map. The fault length and distance from the site is evaluated for each fault or lineation to assess its relative potential when compared to the critical acceleration defined in the above paragraph. This assessment of acceleration potential is based on the fault/magnitude relationship of Bonilla *et al.* (1984) and the distance/attenuation relationship of Campbell (1981). Any feature theoretically capable of producing larger on-site acceleration than the critical acceleration of either the FE or ME requires a field investigation to determine if it is a capable fault (capable of activity within the design life of the disposal cell).

The critical fault investigation consisted of inspection of the mapped trace on aerial photographs, aerial reconnaissance, and ground reconnaissance for evidence of Late Pleistocene or Holocene movement.

If any evidence was found to indicate that the critical fault or faults are capable, the calculated on-site acceleration, being larger than that for the FE or ME, became the design acceleration value, the fault was designated as the controlling fault, and the ME for the fault was specified as the design earthquake. If none of the theoretically critical faults were found to be capable, the largest of the two acceleration values, calculated from the FE and ME, became the design acceleration and that earthquake magnitude became the design earthquake.

Floating earthquake (FE) analysis

The very slight modern seismicity of the region is in contrast to the recurring activities that may have persisted into Early Pleistocene time and is suspected by some investigators as perhaps continuing into the present time (Cater, 1970). Several factors make this difficult to assess: the absence of Tertiary deposits; the near absence of Quaternary deposits; and the possibility that the salt anticline collapse structures may mask tectonic activity in underlying basement faults.

Conservatively, the potential maximum earthquake that could occur on an unknown structure would be at the established threshold for ground rupture (DOE, 1989) as a magnitude 6.2 event (M_L). This magnitude is adapted for the Dry Flats site as the FE and is assumed to occur at an epicentral distance of 15 km (9.3 miles) from the site and result in an on-site PHA of 0.21 g.

Seismicity analysis

Based on the earthquake data file for the National Geophysical Data Center (NGDC/NOAA, 1989), there has been only one recorded earthquake within the site region. This was a magnitude 4.0 event in 1970 at a distance from the site of 41 km (25 miles). This earthquake was 44 km (28 miles) from any other epicentral location and is not known to be associated with any specific fault, considering the accuracy for this order of magnitude. The epicenter is at the base of Lone Cone Peak in the vicinity of several faults, approximately at the boundary between the Uncompahgre Uplift and the San Juan Mountains Uplift. Lone Cone Peak is one of several igneous intrusive bodies near the San Juan Mountains Uplift.

The nearest seismic source area with recurring activity is also located along the Uncompahgre uplift boundary, due east of the site at a distance of 70 to 90 km (43 to 56 miles). This active area, also the border of the Colorado Plateau, has recorded a maximum magnitude of 5.5, the largest recorded event within 110 km (68 miles) of the site. The largest recorded earthquake within a 300-km (186-mile) site radius was a magnitude 5.7 event, which was rated an intensity of VII. This 1977 event was located 177 km (110 miles) north of the site.

Besides seismicity from tectonic causes, there is also a potential for seismicity due to salt flowage within the salt anticlines in Paradox Basin, either induced by potash mining or from natural occurrences. Wong *et al.* (1987) observed that the natural microseismicity in salt anticlines, in a special study of activity near the Moab, Utah, potash mining area, is typically less than magnitude 3.0. They considered that the activity may possibly be related to growth of the Cane Creek salt anticline, although there is no other evidence to support this. The study also noted that mining-related activity by subsidence in deep potash mines in Canada resulted in activity on the order of magnitude 2.9 to 3.1. Wong *et al.* (1987) considered that the magnitude 4.0 mining-induced seismicity attributed to the Book Cliffs, Utah, coal mining area was triggered by either earthquakes or coincidental tectonic seismicity rather than from rock burst or roof failure due to mining.

Wong and Simon (1981) have observed that seismicity in this interior portion of the Colorado Plateau is more analogous to the mid-continent than to the Western Mountains region of the United States. The study concludes that the seismicity of the Paradox Basin has been and will continue to be at a very low level. A 15-month seismic monitoring program in the Paradox Basin detected 230 events ranging from magnitude 1.0 to 2.4, of which 95 percent were confined to the Colorado River Valley. The focal depths were from 2 to 10 km and indicate that these were all within the Precambrian basement rock and not in the salt structures. The fault solution of the seismicity indicated that the source had a strike-slip movement suggesting the Colorado Lineament as the origin. Wong and Simon (1981) also concluded that the Colorado River may in some way be a triggering influence to the seismicity.

The nearest known seismically active tectonic fault is the Ridgway Fault, approximately 61 km (38 miles) due east of the site. The fault offsets Quaternary gravel and was found to have microseismicity directly associated with it in a 1979 study (Kirkham and Rogers, 1981). The west end of the 15-km (9-mile) long fault extends into the site region.

Fault assessment

Most of the faults within the site region can be placed in one of three categories: those related to salt anticline collapse; those related to uplift of the Uncompahgre Plateau; or those related to mostly Laramide structures at the boundary of the Colorado Plateau. The potential seismicity associated with salt flowage is of low magnitude and is not critical to the design earthquake. However, tectonic faults in the Precambrian basement rock underlie the nontectonic faults in the salt anticline areas, so these areas are included in this assessment. The following section describes 12 fault groups that lie within the site region. The faults within each group exhibit the same relationship to structural features of the area or are spatially associated and have similar trends that distinguish them. The fault groups are identified on Plate 1, and an analysis for potential criticality is shown in Table 4.1.

Fault group description

No. 1--Paradox-Sinbad Valleys. A collapsed salt anticline with foundered graben fault block in the salt core, consisting of numerous, nontectonic, closely spaced normal faults along valley walls. The group includes fault nos. 90 and 91 of Kirkham and Rogers (1981). The length of the valley system is 53 km (33 miles), although mapped fault segments are discontinuous for this length. The longest segment is 24 km (15 miles). Distance from the site is 1.6 km (1 mile). The salt core is known to be underlain by tectonic faults in the basement rock. This fault group is evaluated as a tectonic fault to assess criticality to the site.

Table 4.1 Fault analysis for Dry Flats site region, Colorado

The faults shown in this analysis are the longest and closest faults to the site without regard to age within the particular group.

Fault group No.	Fault group Name[a]	Map source[b]	Fault no.[c]	Fault length (km)	Distance from site (km)	Maximum magnitude (M_s)[d]	Potential for design fault[e]
1	Paradox-Sinbad Valleys	A,B,C	90	24	1.6	7.0	Yes
2	Big Gypsum Valley and Dry Creek Basin	A,B,C		23.3	19.3	7.0	Yes
3	Lisbon Valley	A,B,C, D	(a)	18.5	45		No
			(b)	66	45		No
4	Belmear-Glade grabens	B,C,E, F	(a)	19.3	46.7		No
			(b)	10.4	37.8		No
5	SW flank of Uncompahgre Uplift	B,C	83	17.7	18.5	6.9	Yes
			81	33.8	24.1	7.1	Yes
6	Ute Creek	C		29	45		No
7	Norwood vicinity	B,C	84	22	26	7.0	Yes
			85	4.4	23.3		No
			86	9.6	27.3		No
			87	6.4	32		No
			88	19.3	37		No
			89	4.8	48		No
			(a)	22.5	46.7		No
			(b)	16.9	31.4		No
8	NE flank of Uncompahgre Uplift	B,C	73	14.5	62		No
9	Roubideau Creek	B,C	82	6.4	40.2		No
			(a)	12.9	31.4		No
			(b)	17.7	44.2		No
10	San Miguel Mountain	C,E,F	a	15.3	51.5		No
			b	8.0	38.6		No
11	House Creek	C,E		21	61		No

Table 4.1 Fault analysis for Dry Flats site region, Colorado (Concluded)

Fault group No.	Fault group Name[a]	Map source[b]	Fault no.[c]	Fault length (km)	Distance from site (km)	Maximum magnitude $(M_s)^d$	Potential for design fault[e]
12	East Paradox anticline	C,E		11.3	19.3	6.8	Yes

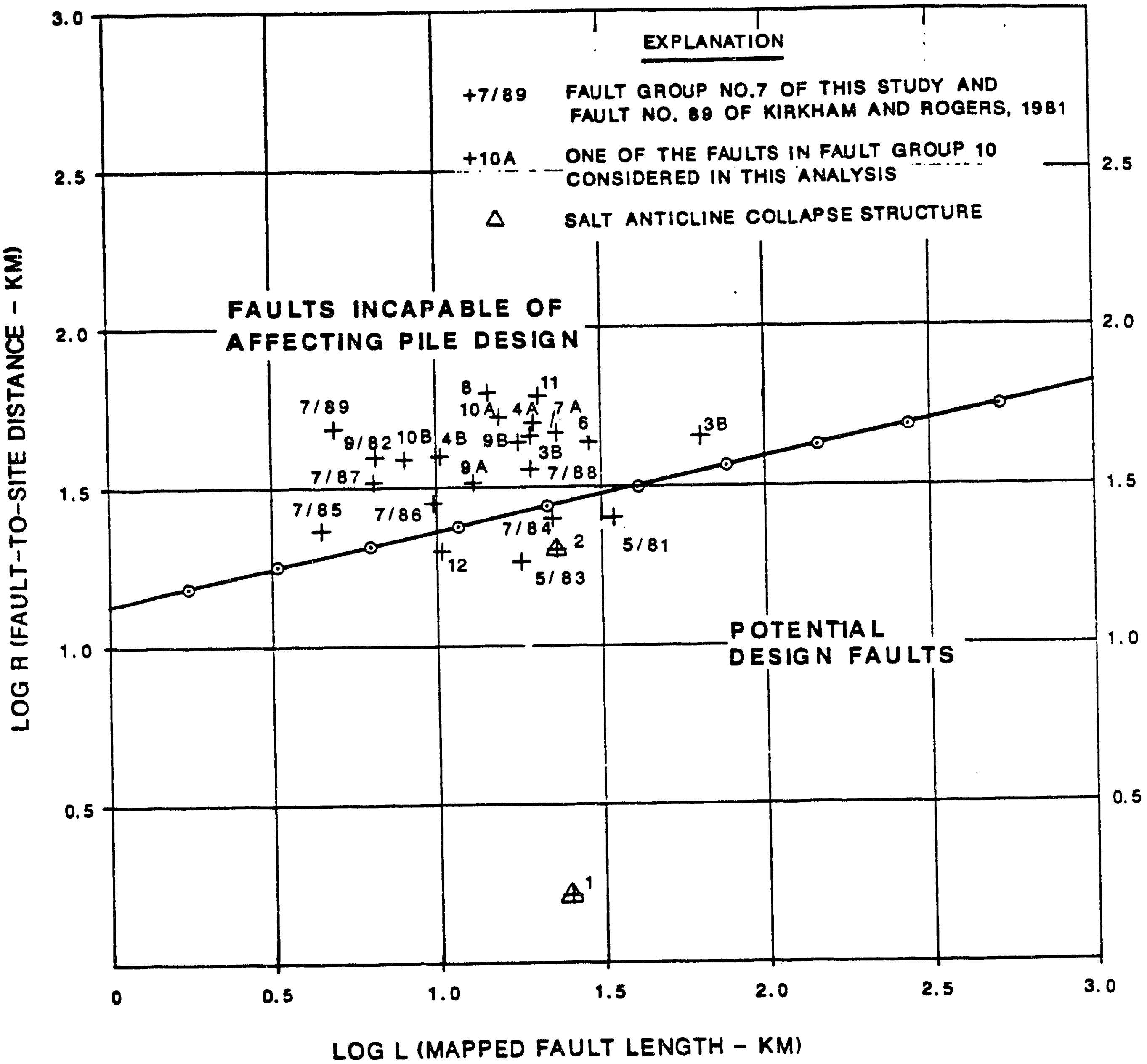
[a]Fault group names arbitrarily assigned from geographic local.
[b]Map sources:
A Cater, 1970.
B Kirkham and Rogers, 1981.
C Woodward-Clyde Consultants, 1983.
D Kitcho, 1981.
E Haynes *et al.*, 1972.
F Hite, 1975.
[c]Fault numbers were assigned by Kirkham and Rogers (1981). Letters a and b are arbitrary assignments to unnumbered fault in each group which appear to be potentially critical faults based on length and distance from the site.
[d]The maximum magnitude is shown only for those faults that are potentially design faults. See Figure 4.1.
[e]"yes" indicates that it falls within the critical range. This designation is based on Figure 4.1 and does not imply capability.

No. 2--Big Gypsum Valley-Dry Creek Basin. A continuous system of a collapsed salt anticline similar to fault group 1. It includes fault no. 92 of Kirkham and Rogers (1981). The length is 79 km (49 miles) and distance from the site is 19 km (12 miles). For purposes of the criticality assessment, the fault lengths are considered as tectonic, as in group 1 above.

No. 3--Lisbon Valley. A salt anticline structure similar to groups 1 and 2, it includes fault no. 93 of Kirkham and Rogers (1981). The length is 66 km (44 miles) (Kitcho, 1981) and distance from the site is 45 km (28 miles).

No. 4--Belmear-Glade grabens. A system of en echelon faults that lies south of the Laramide folded structures and about 40 km (25 miles) south of the site. The east-west trend of the system is contrary to the northeast trend of the Paradox Basin-Uncompahgre Uplift. The maximum length of the Belmear system is 19 km (12 miles). Tweto (1980) has mapped a basement fault that directly underlies this trend with the east end located, coincidentally, at the epicenter of the 1970 earthquake (see seismicity analysis paragraph). The echelon orientation of the faults suggests a left lateral shear zone.

No. 5--Southwest flank of Uncompahgre Uplift. This system lies at the southwest side of the uplift and has the south-side-down displacement of a normal fault. The two faults in this group are nos. 81 and 83 of Kirkham and Rogers (1981), with lengths of 34 km and 18 km (21 and 11 miles), respectively. The nearest approach to the site is 18 km (11 miles). These are estimated as Quaternary on the basis of the geomorphic relationships found by Cater (1970) in Unaweep Canyon.



$\text{LOG R} = 0.23 \text{ LOG L} + 1.126$

$r^2 = 0.9997$

—o— 0.21g ISOPLETH

FOR LOG L = 3.0

LOG R ≈ 1.82

∴ R, AREA OF FAULT INVESTIGATION ≈ 66 km

REFERENCE: BONILLA ET AL., 1984, CAMPBELL, 1981.

FIGURE 4.1

GRAPHIC DETERMINATION OF FAULTS TO BE EVALUATED FOR DRY FLATS SITE REGION, COLORADO

No. 6--Ute Creek. Parallel faults form a graben at the anticlinal crest of the Uncompahgre Uplift and are approximately bisected by the Unaweep Canyon. This group includes fault nos. 76 through 80 of Kirkham and Rogers (1981). Post-Triassic displacement has been estimated at 400 meters (1310 feet) on the northeastern graben fault. Cater (1970) estimated that uplift activity extended into the Pleistocene. Maximum fault length in the system is 29 km (18 miles). The nearest distance to the site is 45 km (28 miles). Ely *et al.* (1986) reported that a magnitude 2.9 earthquake occurred on this fault system 78 km (48 miles) from the site.

No. 7--Norwood vicinity. This group appears as a broad fault swarm at the southeast boundary end of the Uncompahgre Uplift, mostly trending northwest. There are 30 faults in this group, including fault nos. 84 through 89 of Kirkham and Rogers (1981). The longest fault is 22 km (14 miles), and the nearest approach to the site of any fault is 23 km. Kirkham and Rogers (1981) have designated these as possibly of Quaternary age. Faults 84, 85, and 86 were examined in the field. No evidence for Quaternary displacement was observed. Typically, drainages are aligned along fault traces.

No. 8--Northeast flank of the Uncompahgre Uplift. This group has been described by Kirkham and Rogers (1981) as fault nos. 66 through 74. This study cites fault 74 as the only fault on the flanks of the Uncompahgre Uplift where there is evidence of disturbed Quaternary deposits. This refers to pebbles in the alluvium that may have been rotated in the fault plane. The study also reports that there is no evidence of the fault trace in the alluvium on either side of the roadcut where the fault is exposed. Fault 73, the only one of the group that lies within the site region, is 15 km (9 miles) long and 62 km (38 miles) from the site. The faults are aligned with the monoclinal fold that bounds the edge of the uplift.

No. 9--Roubideau Creek. This group consists of two fault systems on the north slope of the Uncompahgre Uplift that appear distinct from the northern fault-fold boundary of the uplift. The eastern end segment of the south fault trace is designated fault no. 82 by Kirkham and Rogers (1981) as a possible Quaternary fault. Slide deposits, resulting from the natural susceptibility of the underlying Brushy Basin Member, apparently have been dissected by the fault. Assuming that the other segments in the group are of the same system, the nearest approach of this fault group to the site is 31 km (19 miles). The length of the fault is 13 km (8 miles).

No. 10--San Miguel Mountains. A system of mostly graben faults lying on the north side of this Tertiary igneous intrusive complex (dikes, sills laccoliths, and plutons) on the southeast corner of the Uncompahgre Uplift. It is bordered on the southeast by the San Juan Mountains. There are at least 20 mapped faults in this group, mostly north-trending, but some trend northeast. These latter faults may be part of fault group no. 11. Lone Cone Peak (elevation 12,600 feet) sits at the junction of fault groups 2, 4, and 10, and is near the epicenter of the magnitude 4.0 1970 earthquake. Thermal springs occur on the north slope of this peak. The longest fault in the group is 15 km (9 miles) and the nearest approach to the site is 39 km (24 miles).

No. 11--House Creek Fault. This fault group is located at the edge of the site region. Several of these northeast-trending faults form grabens and control the drainage. House Creek Fault is mapped by Haynes *et al.* (1972) with a length of 21 km (13 miles), but only a very short segment lies within the site region. The system trends with the alignment of a single anticline structure contrary to other folds and appears as a frontal fault to a basement uplift.

No. 12--East end of Paradox Valley anticline. This group consists of three randomly trending faults that do not appear to be associated with any of the adjoining groups. They lie on either side of the southeast end Paradox Valley Anticline, which is otherwise unfaulted in this area, where it intercepts the boundary of the Uncompahgre Uplift. The longest fault in the group is 11 km (7 miles) long and is 19 km (12 miles) from the site.

Critical fault analysis

An analysis was made of significant faults whose length or proximity to the site, regardless of the age of last movements, could theoretically result in an earthquake with a PHA on the site greater than that for an FE of 6.2 at a radial distance of 15 km (9.3 miles) with a PHA of 0.21 g on the disposal site. Faults that exceed the FE design are termed critical.

Figure 4.1 shows the analysis for 22 faults selected from the fault map (Plate 1) on the basis of being the longest fault or nearest long fault from each fault group. Where faults that did not have numbers assigned by Kirkham and Rogers (1981) were selected, these were arbitrarily designed as A, B, and the like for that group.

The salt anticline collapse structures comprising fault groups 1, 2, and 3 are bounded by prominent graben faults not related to tectonic stress. Although these structures mask tectonic faults at depths that are known to have had large displacements in the Pennsylvanian and Permian Periods, these nontectonic faults cannot be analyzed based on surface characteristics for seismic capability. One of the collapse structure faults that falls into the critical category was in the Big Gypsum Valley fault group.

Four faults that require critical analysis as indicated by Figure 4.1 are as follows: fault 81, group 5; fault 83, group 5; fault 84, group 7; and the longest fault in group 12. Faults 81, 83, and 85 represent the major faults on the southwest flank of the Uncompahgre Uplift. The alignment of these faults suggests that they are related and continuous; however, the fault groups appear distinctive from one another.

Faults 81, 83, and 84 are all accessible by roads and are covered by stereo-pair aerial photographs. Faults 81 and 84 show the greatest displacements, on the order of several hundred feet. The fault traces and the upper scarp faces are dissected by deep drainages and exhibit no evidence of Quaternary movement. Quaternary deposits are limited, and most of what is observed is probably Holocene in age, primarily because of the relief of the mountainous terrain. The primary indication of age is the extent of erosion on the scarp face and the lack of terraces or fans where older drainages cross the fault trace. These three faults show the same geomorphic age relationships. Since the Uncompahgre Uplift was below the elevation affected by Pleistocene glaciation, the effects of such severe erosional processes on the lower slopes have not been a factor in the lack of scarp preservation. Based on these observations, the faults are considered as not capable under the present seismotectonic stress regime.

Fault A in group 12 is the longest fault in this group and one that appears perpendicular to the trends of all other systems in adjacent fault groups. It is accessible on its north end by a county road and is covered by aerial photographs. It appears to dissect the structural boundary between the Paradox Basin and the Uncompahgre Uplift. Its south end terminates on the axis of the Paradox anticline. This fault consists of a broad zone of distinct fractures based on stereo-pair aerial photograph examination. These fractures appear as old scarps preserved in resistant rock strata. The fault does not control any drainages and where it crosses Naturita Creek near Redvale there is no evidence of offset Quaternary terraces. Based on these observations, the fault does not exhibit Quaternary activity and is not considered capable under the present stress regime.

Selection of design earthquake

Because the capability of the Paradox Basin-Uncompahgre Uplift boundary faults that underlie the site cannot be completely understood, it is prudent to consider the largest critical tectonic fault, fault 81, as the design fault. Based on its length and distance from the site and using relationships established by Bonilla *et al.* (1984), Krinitzsky and Chang, (1977), and Campbell (1981), the design earthquake will have the following seismic parameters:

- Magnitude = 7.1.
- On-site PHA = 0.25 g.
- Duration = 26 seconds.

5.0 GEOLOGIC SUITABILITY

There are no potential deficiencies in the geologic condition that might adversely affect the disposal cell during its design life. Uncertainties regarding seismotectonics and possible instability of the salt anticline structures are minimized by the stable Dakota Sandstone bedrock foundation conditions and by the site's structural and topographic setting relative to these features. Possible geomorphic instability of unprotected shale outcrops and soils around the toe of the cell may result from concentrated flows over natural slopes of 3 to 4 percent. This condition can be stabilized by standard grading and erosion protection design procedures. Because the soil is relatively thin in most areas, only about 1.5 feet on average, and is underlain by sandstone over 80 percent of the site, mass grading of the soil to reduce slopes will not be possible without cutting through the upper sandstone unit. Substantial cuts of 5 to 6 feet will expose more of the shale-claystone unit.

Hazards not directly related to geomorphic processes or primary seismic effects that were evaluated are volcanic activity; seeps and springs; future development of natural resources; various types of slope failure; conditions related to soil or bedrock stratigraphy; and dissolution of evaporite deposits (see Section 3.0).

Volcanic hazards. The nearest center of past volcanic activity is the San Juan Mountains, located outside the Colorado Plateau and beyond the site region. Extrusive activity there has been dated as Oligocene age, at least 25 million years old (Tweto, 1980). The youngest volcanic activity in central Colorado occurred 19 million years ago in Early Miocene (Epis *et al.*, 1980). The last intrusive activity that occurred in the Colorado Plateau interior, in the form of dikes, stocks, and laccoliths, has been dated at the La Sal Mountains as 24 million years old. Volcanic activity is not considered a hazard under the present tectonic regime.

Seeps and springs. Because of the relief around the site, 300 feet above the valley on the south, 500 feet above the San Miguel River valley on the north, and 400 feet above Dry Creek to the west, the site area is well-drained and without significant recharge. Close inspection of the slopes below the site, including the terrace cut above the town of Naturita, shows no evidence of any seepage areas on the lower slopes. Consequently, the inducement of slope failure or transport of contaminants to the surface is not considered as a hazard.

Slope failure. Slope failure has occurred within the site region as a result of two factors: the presence of high-plasticity clays of the Brushy Basin Member of the Morrison Formation near the surface on moderate to steep slopes; and the oversteepening of embankments in similar incompetent strata. The latter instance has been caused by vertical graben faults along the collapsed salt anticlines and by undercutting along streambanks in claystone/shale bedrock areas. Neither of these conditions occurs within the site area. Colton *et al.* (1975) have mapped slide deposits on the lower slopes of the north and south walls of Coke Oven Valley and also on the west side of Dry Creek Canyon between Coke Oven Valley and the San Miguel River. The Coke Oven Valley slides are mostly intact slides along dip slopes. The factors that contribute to the stability of the slopes adjacent to the site are the slight dip (4 percent) of the bedrock of the northerly slope of the Dry Flats site and the thick, competent strata of the underlying Dakota Sandstone (see Figures 3.4 and 3.5).

Salt dissolution. The occurrence of sinkholes has been studied in the Paradox Basin (Sugiura and Kitcho, 1981); however, the phenomenon is associated with shallow evaporite deposits and circulating groundwater conditions, and sinkholes are believed to have formed before or during Tertiary time. The nearest known sinkholes are 15.5 miles northeast of the site. The depth of soluble evaporites has been reported by Woodward-Clyde Consultants (1983) at approximately 2000 feet below Coke Oven Valley. This depth is well below where Cater (1970) has shown that dissolution can occur. It is concluded that sinkholes from salt dissolution are not a hazard at the Dry Flats site.

Future development of natural resources. The nearest known natural resources are gas and oil deposits at Montrose Dome, 3 miles from the site. This petroleum exploration at the east end of Coke Oven Valley has apparently been active since 1958. The underlying bedrock contains no mineable coal or uranium resources as described in Section 2.5. It is presumed that there are some potash deposits below the site because potash is in most of the Paradox Basin; however, the only mining of this mineral has been outside the site region. Oil and gas leases C-40091 and C-41997 underlie the Dry Flats disposal site. Future exploration or development of mineral resources is not expected to be affected by the disposal cell because of the depths at which these resources occur. For the same reason, the disposal site should not be affected by such activities. The graben faults that form traps for petroleum deposits have been translated locally into folded structure instead. Since these faults terminate west of Dry Flats, the potential for differential displacement from subsidence due to mining is not a concern. The site lies within the Lillylands-West grazing allotment.

Soil or bedrock conditions. Besides the erodible soils, claystone, and coal seam deposits (see Section 4.1) that overlie portions of the site on top of the sandstone strata, no other conditions might pose a potential hazard to the placement of the tailings. Most of the fractures that occur on the site appear as lateral shear fractures. These fractures occur primarily along bedding planes between claystone and sandstone units and are most evident in the surfaces of thinly bedded sandstones. Typically, the shear fractures are tight but are not cemented or mineralized, and show two or more sets of intersecting fractures with variable directions. Since displacement is mostly lateral and the massive sandstone units are little affected, the fractures will have little effect on infiltration pathways. The low permeability of the thick, interbedded claystone strata should also be effective in dispersing infiltration and eliminating direct flow paths. No seeps or springs have been observed in the lower elevations of the Dry Flats site mesa.

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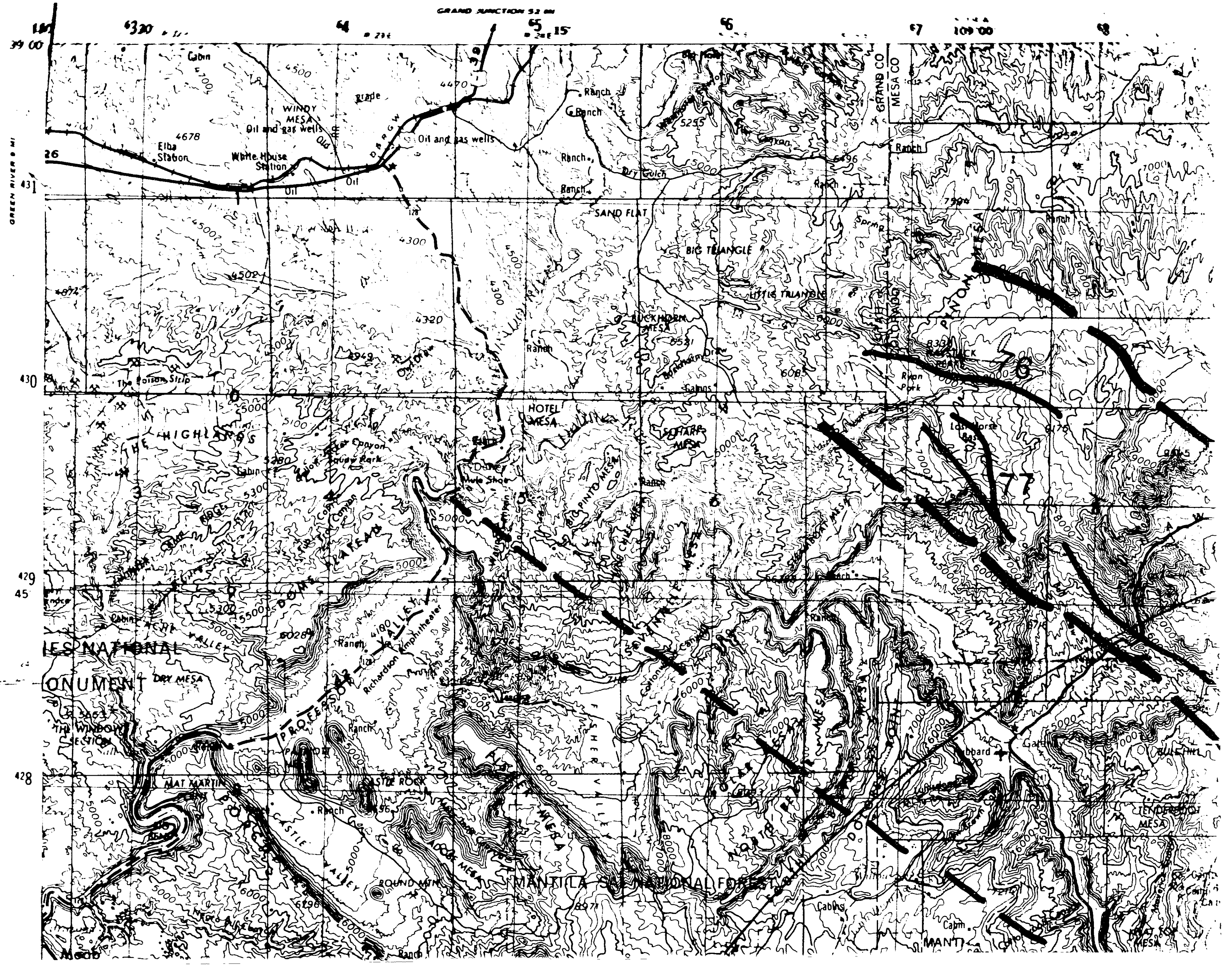
CODE OF FEDERAL REGULATIONS

10 CFR 40, "Domestic Licensing of Source Material," Title 10, *Code of Federal Regulations*, Part 40, U.S. Nuclear Regulatory Commission, Office of the Federal Register, National Archives and Records Administration, Washington, D.C.

10 CFR 100, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," Title 10, *Code of Federal Regulations*, Part 100, U.S. Nuclear Regulatory Commission, Office of the Federal Register, National Archives and Records Administration, Washington, D.C.


GRAND JUNCTION 52 MI
GREEN RIVER 8 MI
WINDY MESA
Oil and gas wells
Elba Station
White House Station
SAND FLAT
BIG TRIANGLE
LITTLE TRIANGLE
BUCKHORN MESA
HOTEL MESA
THE HIGHLANDS
The Poison Strip
SITTERS MESA
BIG PINTO MESA
DOME PLATEAU
PROFESSOR VALLEY
Richardson Amphitheater
FISHER VALLEY
CASTLE ROCK
CASTLE VALLEY
ROUND MTN
ADOBE MESA
MAT MARTIN
DRY MESA
THE WINDOW SECTION
MANTI LA SAL NATIONAL FOREST
GRAND CO
MESA CO
UTAH
COLORADO
PINON MESA
TENDERFOOT MESA
FISHER MESA
Ranch
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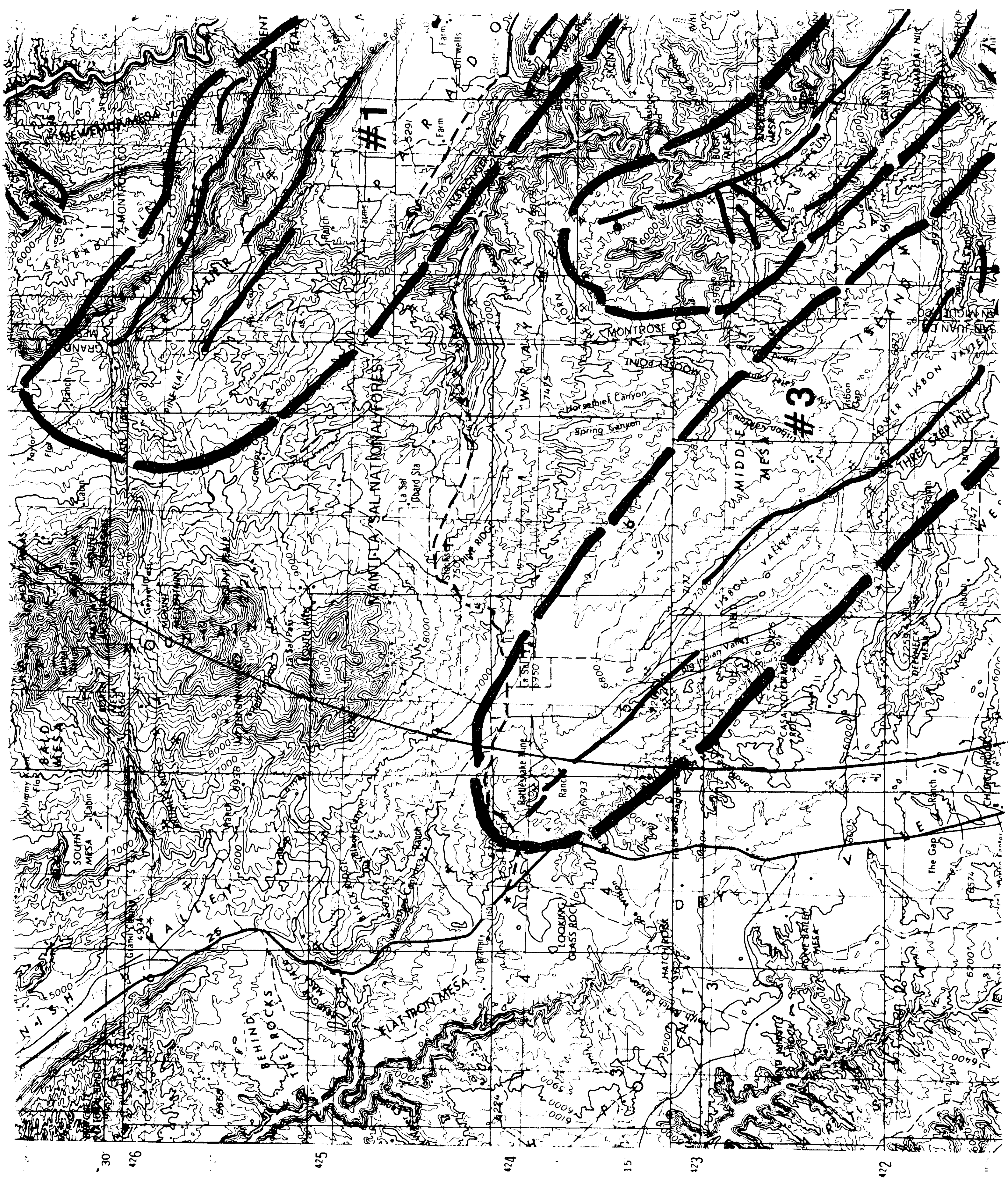
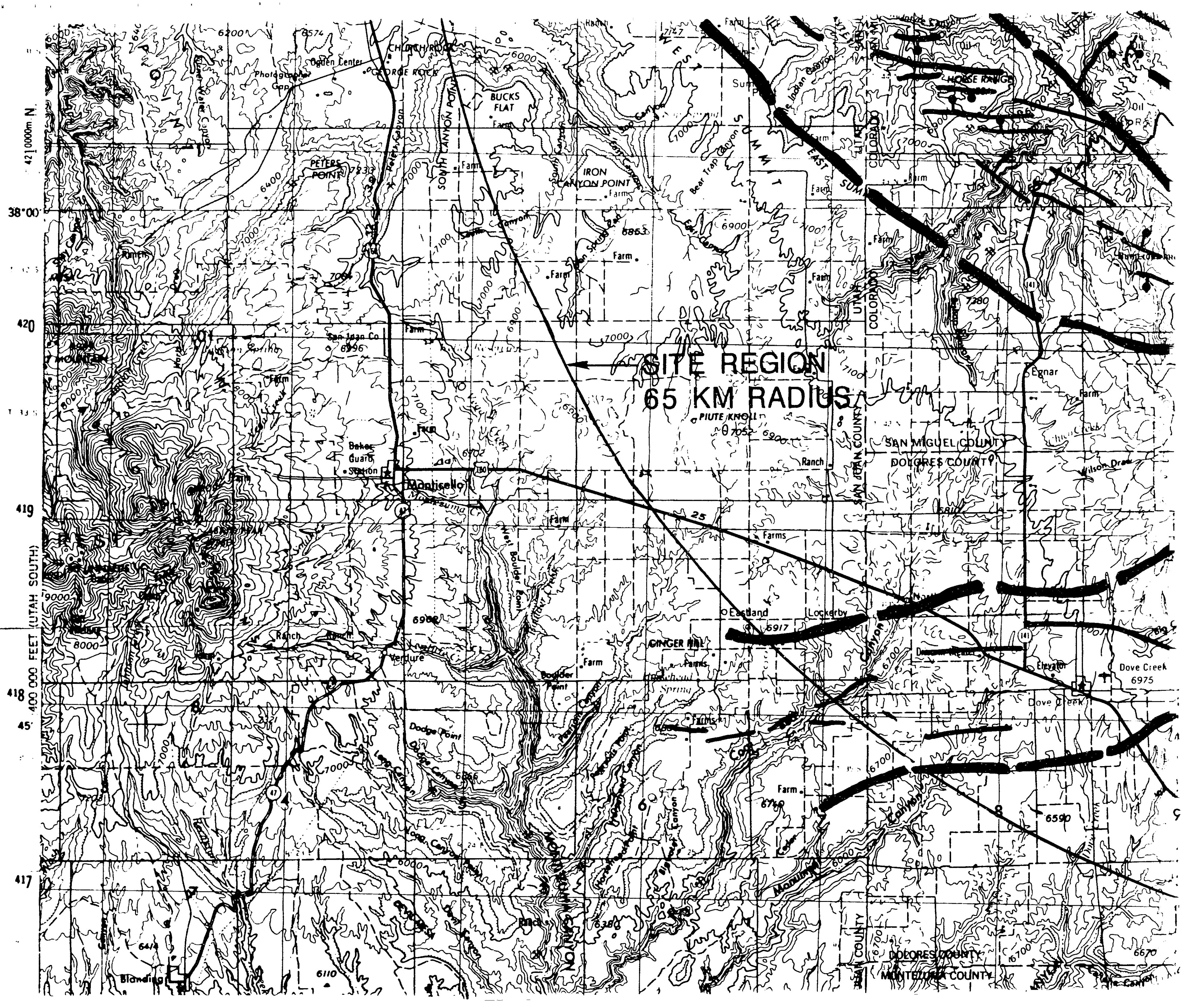
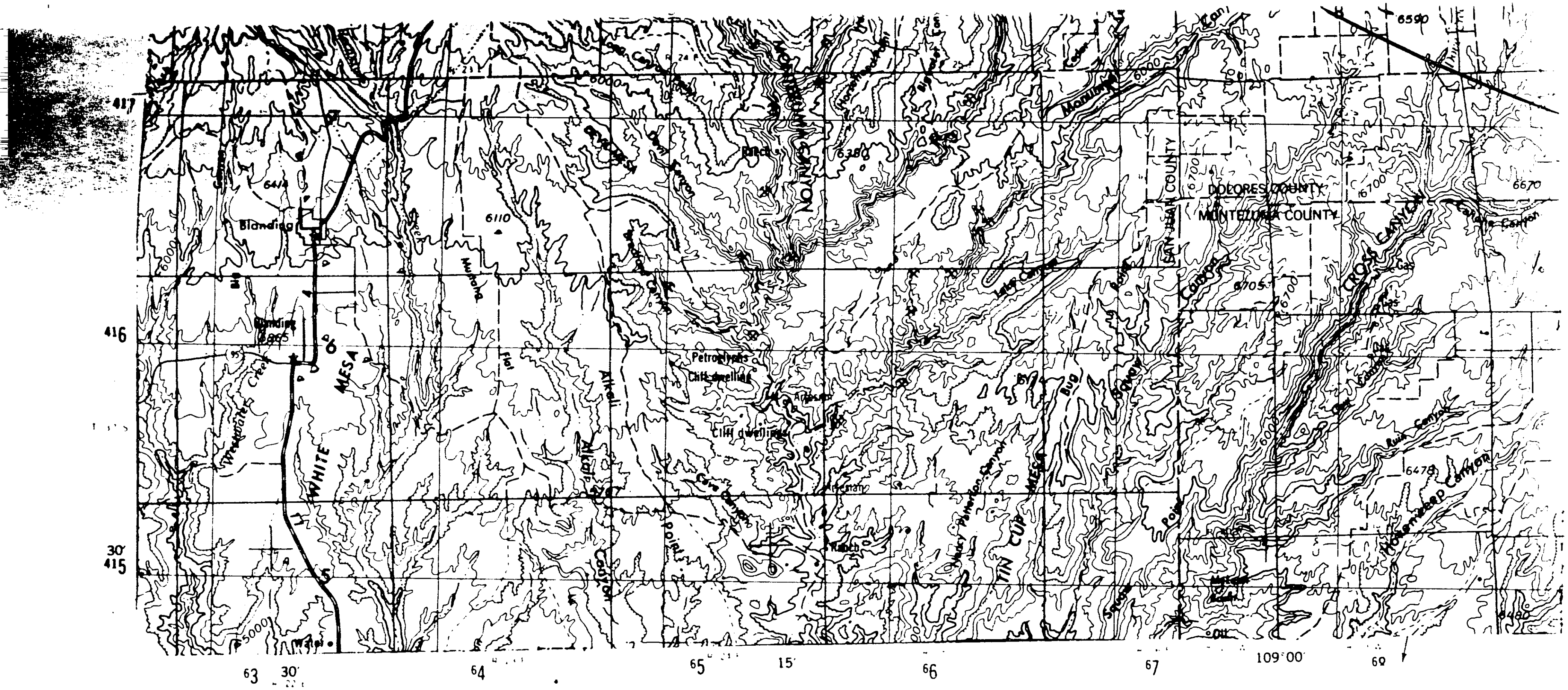
Cabins
Spring
Dry Gulch
Lost Horse Basin
Ryan Park
Mule Shoe
MANTI
Moab
39 00
109 00
77



#1
#3
MONTROSE CO
MANTI-LA SAL NATIONAL FOREST
Horsethief Canyon
Spring Canyon
MIDDLE MESA
THREE STEP HILL
LOWER LISBON VALLEY
LISBON VALLEY
Big Indian Valley
Rattlesnake Mine
LOOKING GLASS ROCK
HATCH ROCK
FLAT IRON MESA
BEHIND THE ROCKS
SOUTH MESA
BALD MESA
The Gap
La Sal Guard Sta
PINE RIDGE
PINE FLAT
Taylor Flat
430
426
425
424
15
423
422


SITE REGION
65 KM RADIUS
Monticello
Blanding
Dove Creek
Eastland
Lockerby
Verdure
Egnar
PIUTE KNOLL
GINGER HILL
BUCKS FLAT
PETERS POINT
IRON CANYON POINT
SOUTH CANYON POINT
CHURCH ROCK
GEORGE ROCK
West Boulder Point
Dodge Point
Dodge Canyon
MONTEZUMA CANYON
HORSE RANGE
SAN MIGUEL COUNTY
DOLORES COUNTY
MONTEZUMA COUNTY
SAN JUAN COUNTY
UTAH
COLORADO
EAST SUMMIT
WEST SUMMIT
Bear Trap Canyon
Baker Guard Station
San Juan Co
Elevator
38°00'
45'
420
419
418
417
421 0000m N.
400 000 FEET (UTAH SOUTH)



Scale 1:250,000

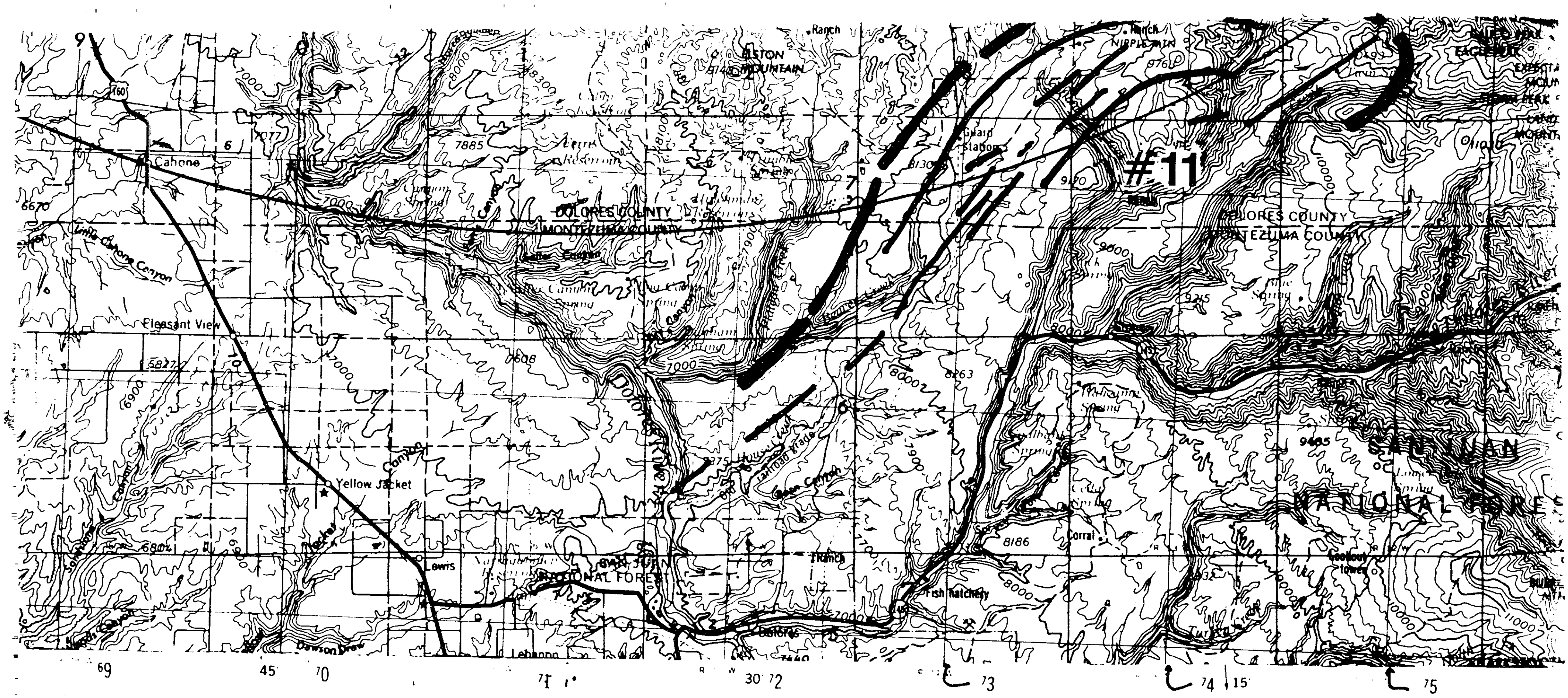
5 0 5 10

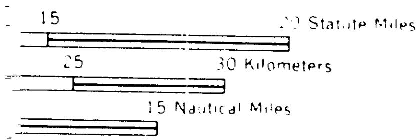
5 0 5 10 15 20

5 0 5 10

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS

TRANSVERSE MERCATOR PROJECTION

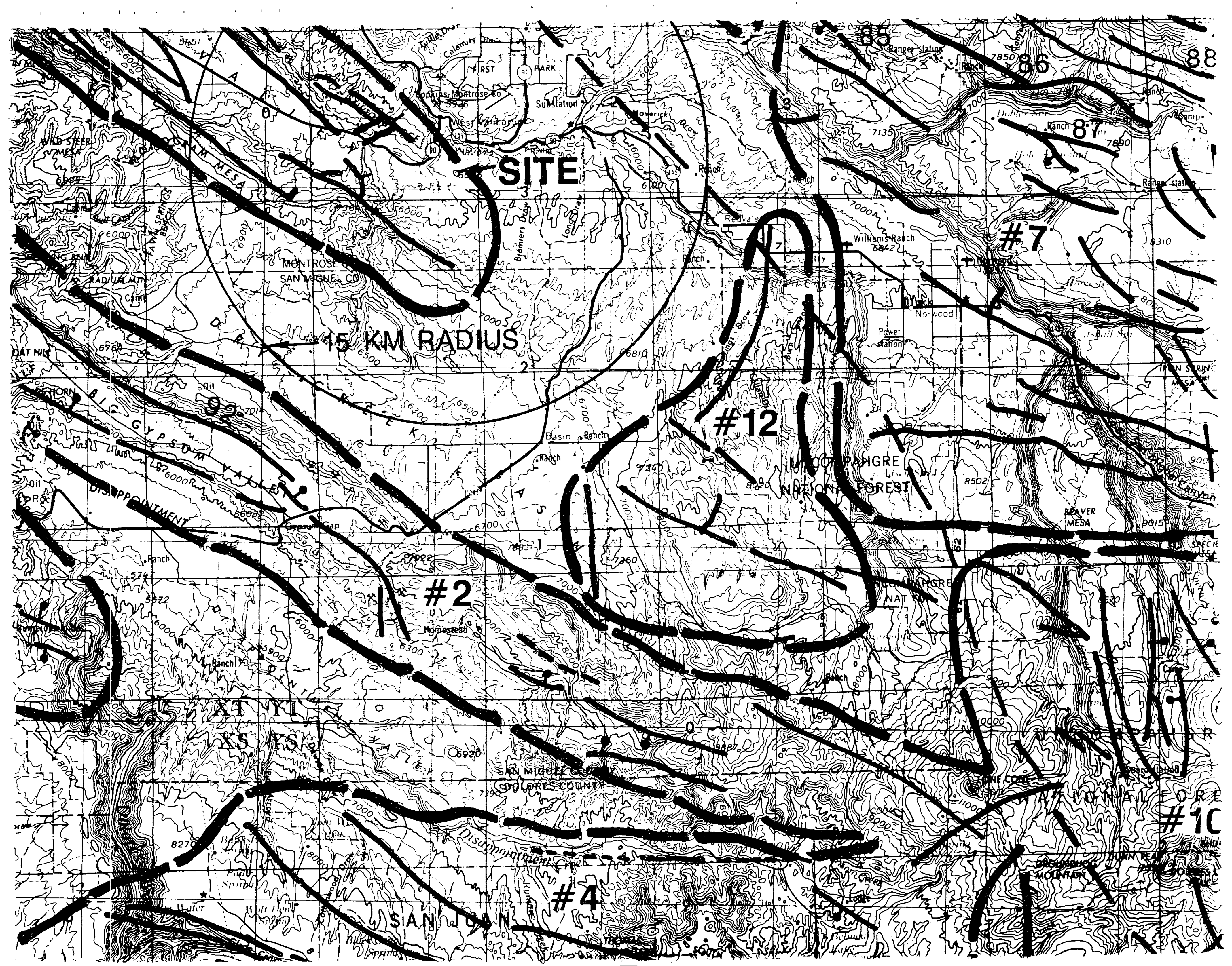




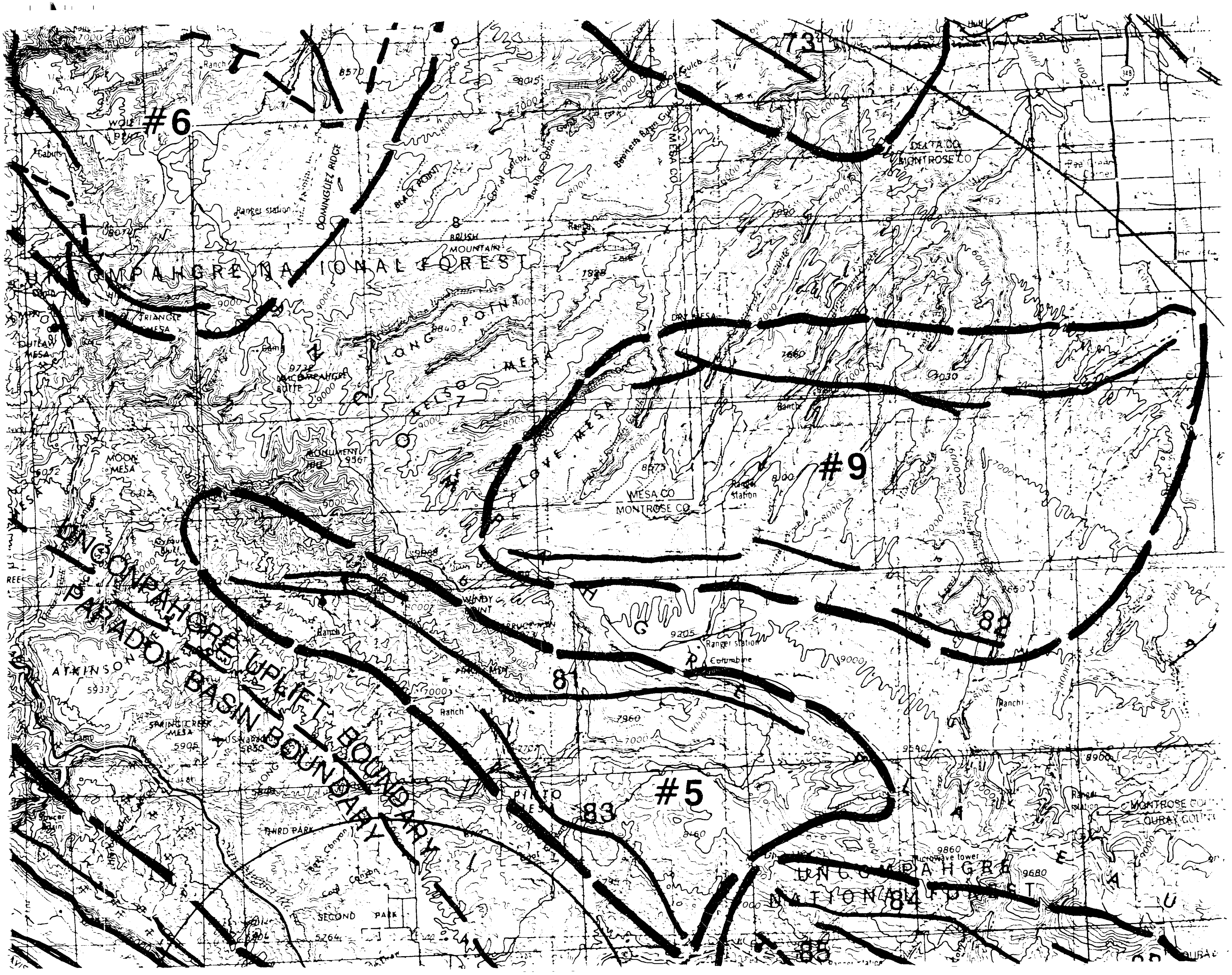
LEGEND

76	FAULT WITH BALL ON DOWN-THROWN SIDE NUMBER INDICATES FAULT NUMBER OF KIRKHAM AND ROGERS (1981)
#2	FAULT GROUP NUMBER

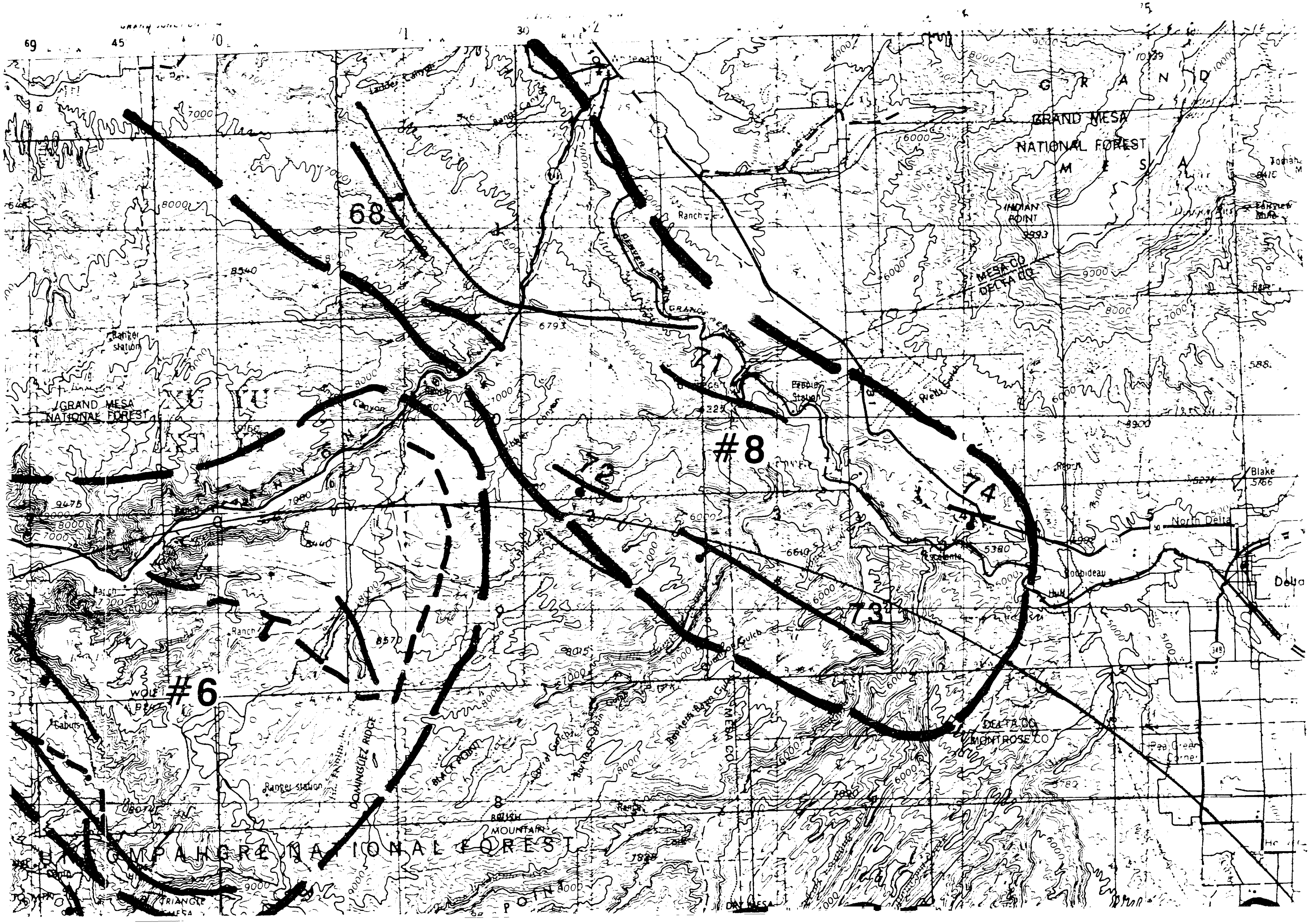
NOTE: MAP COMPILED FROM USGS TOPOGRAPHIC QUAD. MAPS: MOAB (1969), MONTROSE (1977), CORTEZ (1969), AND DURANGO (1945)



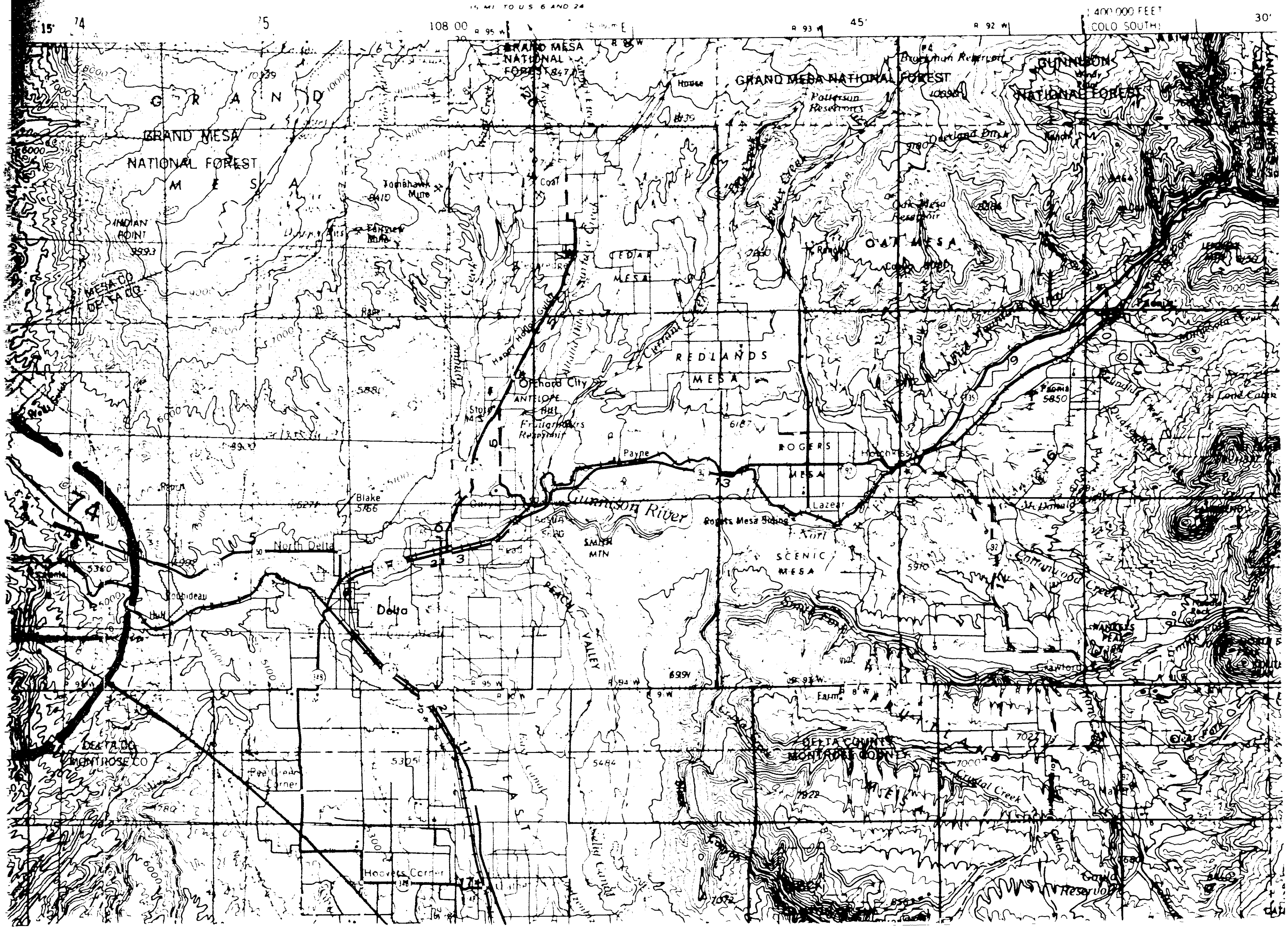
SITE
15 KM RADIUS
#2
#4
#7
#10
#12
85
86
87
88
MONTROSE CO
SAN MIGUEL CO
UNCOMPAHGRE
NATIONAL FOREST
BIG GYPSUM VALLEY
DISAPPOINTMENT
SAN MIGUEL COUNTY
DOLORES COUNTY
SAN JUAN
Norwood
Basin
Gypsum Gap
Substation



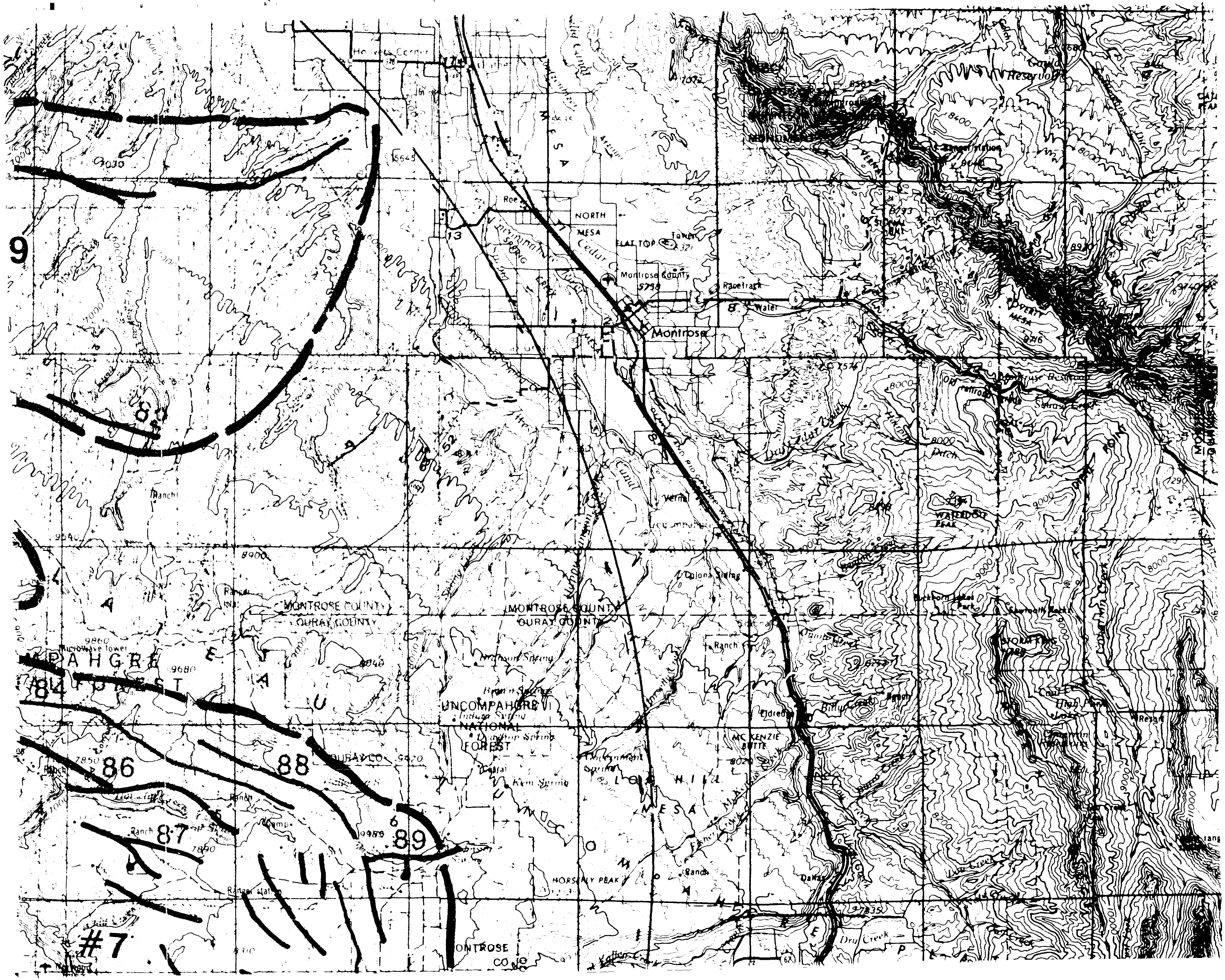
#6
#9
#5
73
81
82
83
84
85
UNCOMPAHGRE UPLIFT BOUNDARY
PARADOX BASIN BOUNDARY
UNCOMPAHGRE NATIONAL FOREST
DELTA CO
MONTROSE CO
MESA CO
DOMINGUEZ RIDGE
LONG POINT
LOVE MESA
ATKINSON
MOON MESA
WINDY POINT
Ranger station
Columbine
THIRD PARK
SECOND PARK
OURAY COUNTY



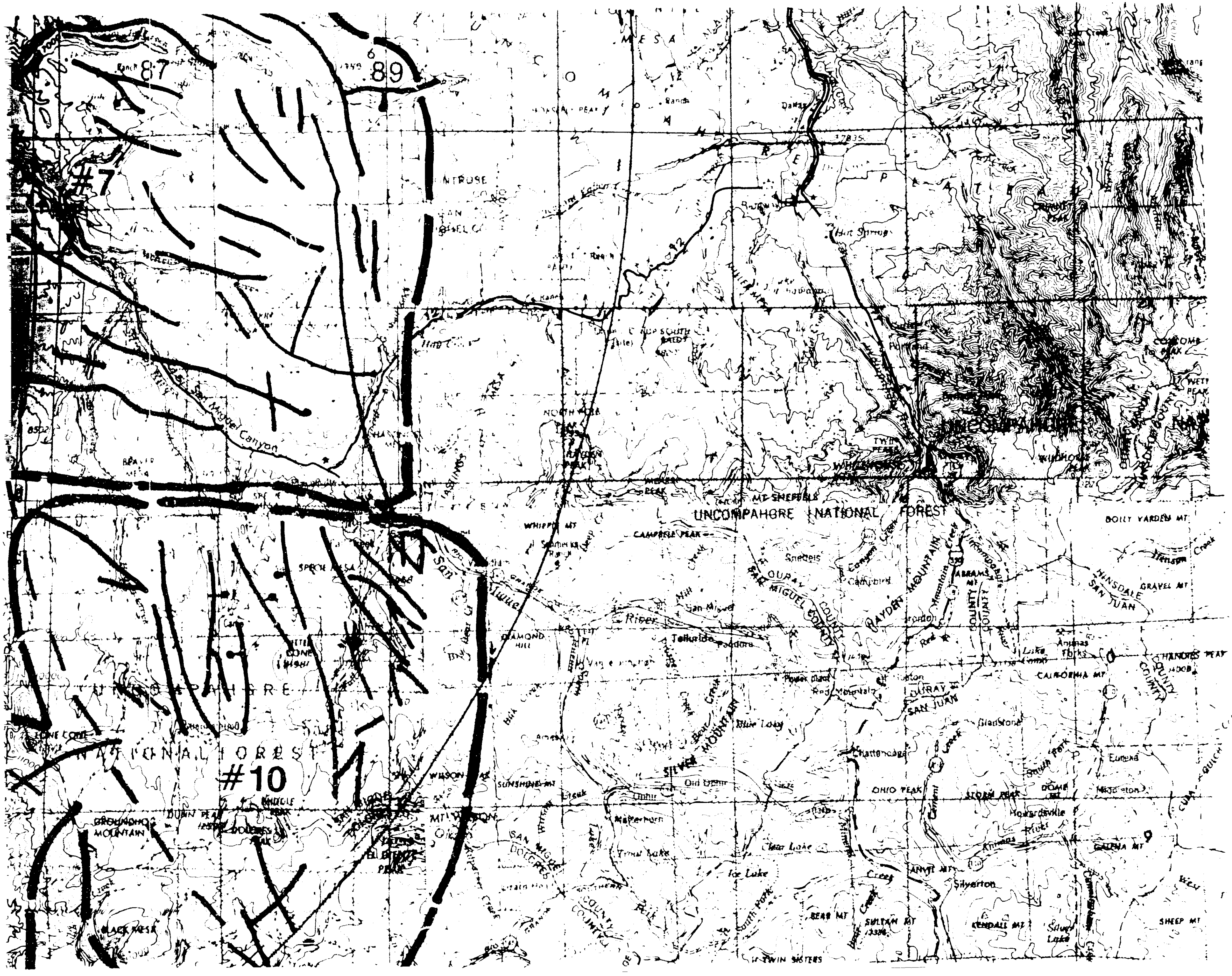
68
71
72
73
74
#8
#6
GRAND MESA
NATIONAL FOREST
GRAND MESA
NATIONAL FOREST
INDIAN POINT
MESA CO
DELTA CO
DELTA CO
MONTROSE CO
MESA CO
North Delta
Delta
Blake
Escalante
Roubideau
Peach
Ranger station
DOMINGUEZ RIDGE
BLACK POINT
BRUSH MOUNTAIN
UNCOMPAHGRE NATIONAL FOREST
TRIANGLE MESA
DRY MESA



15 MI TO U S 6 AND 24
1 400 000 FEET
COLO SOUTH
108 00
45'
30'
GRAND MESA
NATIONAL FOREST
GRAND MESA NATIONAL FOREST
GUNNISON
NATIONAL FOREST
G R A N D M E S A
Patterson Reservoirs
INDIAN POINT
Tomahawk Mine
MESA CO
DELTA CO
CEDAR MESA
OAK MESA
REDLANDS MESA
Orchard City
ANTELOPE HILL
Fruitgrowers Reservoir
ROGERS MESA
Hotchkiss
Payne
Gunnison River
Rogers Mesa Siding
Lazear
SCENIC MESA
SMITH MTN
North Delta
Delta
Roubideau
Blake
PEACH VALLEY
EAST
Cottonwood Creek
Crawford
DELTA COUNTY
MONTROSE COUNTY
DELTA CO
MONTROSE CO
Hoovers Corner
Peo Gredn Corner
Reservoir
Paonia
74



Montrose
NORTH
MESA
FLAT TOP
Montrose County
Racetrack
MONTROSE COUNTY
OURAY COUNTY
UNCOMPAHGRE
NATIONAL
FOREST
MC KENZIE
BUTTE
HORSEFLY PEAK
Dallas
Colona Siding
POVERTY
MESA
WATERDOG
PEAK
Ranch
84
86
87
88
89
#7
9



#7
87
89
#10
UNCOMPAHGRE NATIONAL FOREST
NATIONAL FOREST
San Miguel Canyon
San Miguel River
Telluride
Pandora
San Miguel
Ophir
Old Ophir
Matterhorn
Trout Lake
Ice Lake
Clear Lake
Silverton
Howardsville
Eureka
Gladstone
Chattanooga
Red Mountain
Ironton
Sneffels
Camp Bird
Portland
Hot Springs
Dallas
Ridgway
Animas River
Animas Forks
Mineral Creek
Cement Creek
Uncompahgre
Henson Creek
HAYDEN MOUNTAIN
SILVER MOUNTAIN
OURAY COUNTY
SAN MIGUEL COUNTY
SAN JUAN COUNTY
HINSDALE
SAN JUAN
DOLORES
SAN MIGUEL
COUNTY
MT SNEFFELS
WHIPPLE MT
CAMPBELL PEAK
DIAMOND HILL
SUNSHINE MT
WILSON PEAK
MT WILSON
GROUNDHOG MOUNTAIN
DUNN PEAK
DOLORES PEAK
MIDDLE PEAK
LONE CONE
BLACK MESA
BEAVER MESA
SPRUCE MESA
NORTH POLE PEAK
TWIN PEAKS
WILDHORSE
COXCOMB PEAK
WETTERHORN PEAK
DOLLY VARDEN MT
GRAVEL MT
HANDIES PEAK
CALIFORNIA MT
OHIO PEAK
STORM PEAK
DOME MT
GALENA MT
ANVIL MT
SULTAN MT
BEAR MT
KENDALL MT
SHEEP MT
TWIN SISTERS
Silver Lake
Blue Lake
Power plant
Hot Springs
MESA
MONTROSE
Canyon Creek
Mill Creek
Bear Creek
Lake Fork
South Fork
Cunningham Gulch

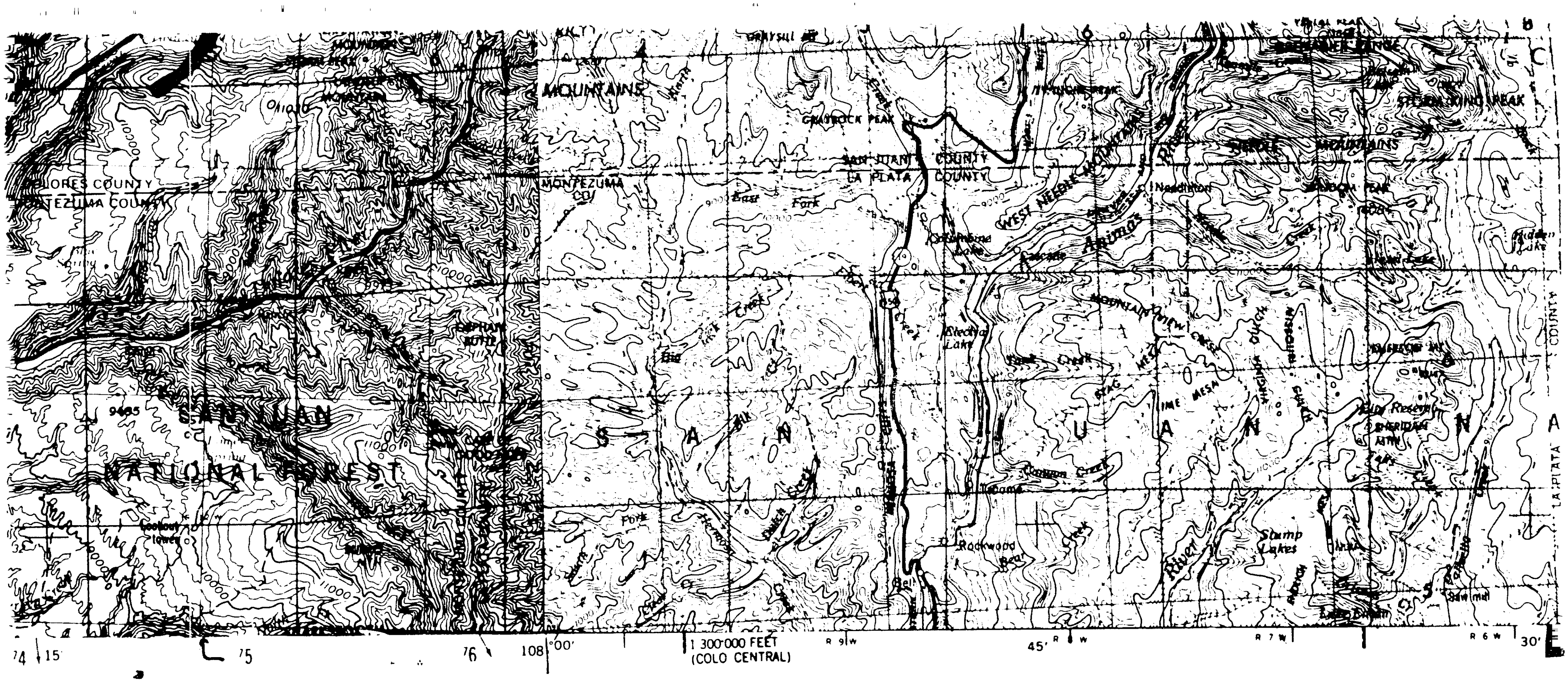


PLATE 1

SEISMIC AND FAULT MAP OF DRY FLATS SITE REGION

DATE FILMED

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END