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History and Environmental Setting of LASL Near-Surface Land Disposal Facilities for Radioactive Wastes (Areas A, B, C, D, E, F, G, and T)

A Source Document

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HISTORY AND ENVIRONMENTAL SETTING

OF LASL NEAR-SURFACE LAND DISPOSAL FACILITIES

FOR RADIOACTIVE WASTES (AREAS A, B, C, D, E, F, G, AND T)

A Source Document

by

Margaret Anne Rogers

ABSTRACT

The Los Alamos Scientific Laboratory (LASL) has been disposing of radioactive wastes since 1944. The LASL Materials Disposal Areas examined in this report, Areas A, B, C, D, E, F, G, and T, are solid radioactive disposal areas with the exception of Area T which is a part of the liquid radioactive waste disposal operation. Areas A, G, and T are currently active. Environmental studies of and monitoring for radioactive contamination have been done at LASL since 1944.

I. INTRODUCTION

This report evolved into a source document as the result of an extensive review of solid radioactive waste management operation at the Los Alamos Scientific Laboratory (LASL) which is operated by the University of California for the ERDA/AEC.* It contains extensive quotes and other material sequestered here for easy access. This compilation represents the effort to date. It is our intent to supplement this report as further information is developed.

The desire to determine the environmental impact of solid waste disposal has led to the reexamination of the concept of land burial as a means of permanent disposal. An evaluation of site monitoring practices, both past and present, is in progress or planned for all major ERDA sites by the United States Geological Survey (USGS) under contract to ERDA and in cooperation with ERDA contractors. The evaluation at the Los Alamos Scientific Laboratory began in September 1973, and included Materials Disposal Areas A, B, C, D, E, F, G, and T (see Fig. 1). T. E. (Tim) Kelly of the USGS Water Resources Division, Albuquerque, and Margaret Anne Rogers, LASL/H-8, the investigators.

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*The U. S. Atomic Energy Commission (AEC) was absorbed by the Energy Research and Development Administration (ERDA) in January 1975.

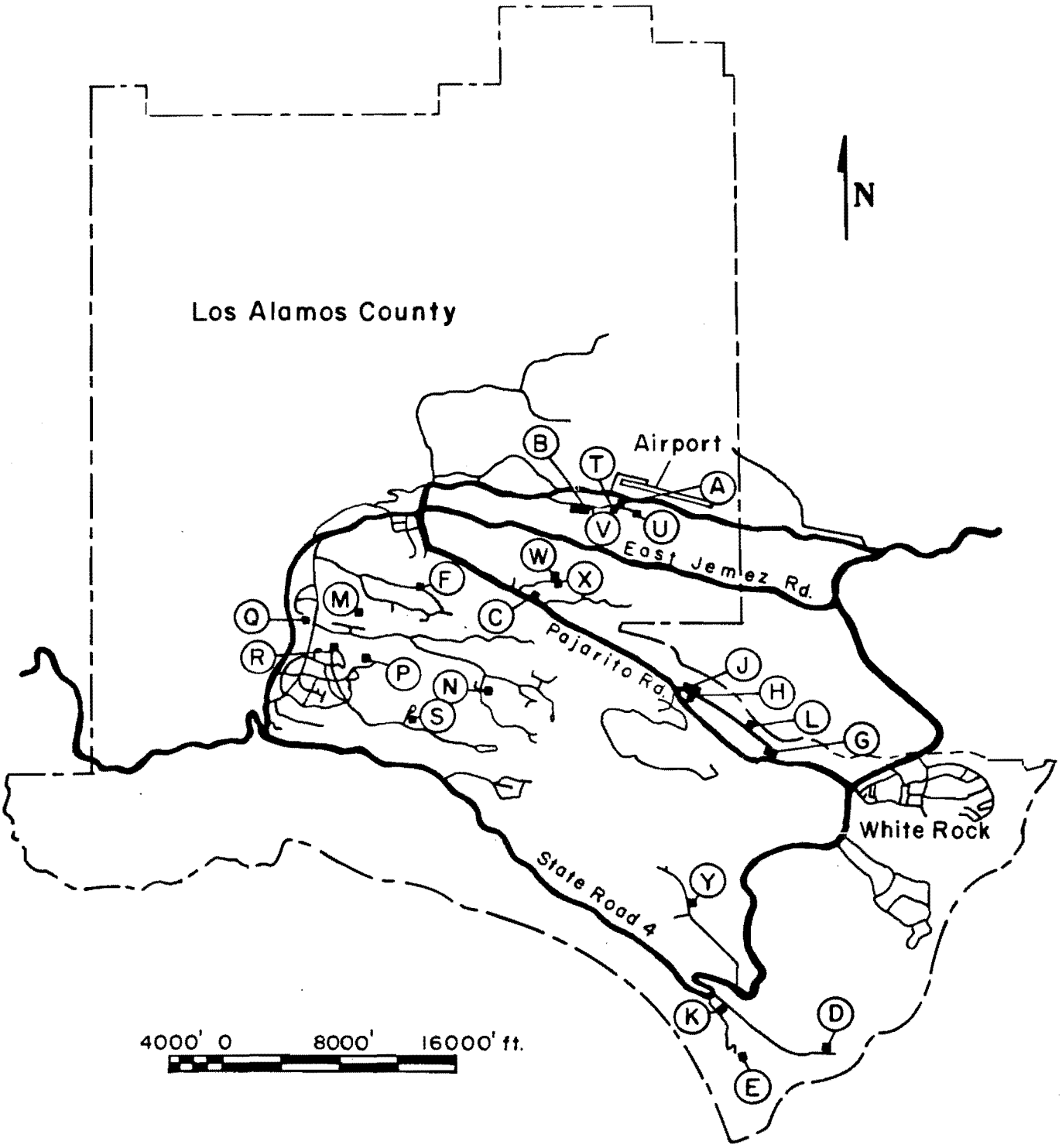


Fig. 1.
Map of Materials Disposal Areas.

As the data were being collected for the evaluation, it became apparent that LASL had a need for a report which would parallel the USGS Report to the ERDA but which would include much more detail.

This report has been compiled to provide a readily available source of accurate, in-depth information for reference by LASL personnel. It is as comprehensive as time and information sources allowed.

In compiling the information presented in this report, opinions and conclusions as to the accuracy of any particular source material have been avoided. All sources on a given subject are presented, despite apparent contradictions. The reader must therefore draw his own conclusions as to which sources may have the greater validity. By presenting all sources, bias is hopefully minimized.

General information on Areas A, B, C, D, E, F, G, and T can be found in the Summary; comprehensive information is given under individual area discussions. Appendixes A, B, and C are lists of known photographs, photographic slides, and engineering drawings, respectively, of Areas A, B, C, D, E, F, G, and T.

Metric units followed by English conversion in parentheses are used throughout this document except in quoted material, which has been left in its original form.

A. History of Los Alamos

From 1918 until late 1942, Los Alamos was the site of a boy's ranch school.[1] Because of its isolated location and existing facilities, the school was acquired by the Army, November 25, 1942, for use by the Manhattan Engineer District. As a patriotic gesture[1] the University of California accepted the contract to operate the new laboratory January 1, 1943. After the war, Los Alamos continued as a site of government sponsored scientific research operated by the University under the auspices of the USAEC through 1974 and continues under the auspices of ERDA.

B. Location

Los Alamos and the Los Alamos Scientific Laboratory are located on the Pajarito Plateau, which flanks the eastern side of the volcanic Jemez Mountains in north-central New Mexico. The plateau is 16-24 km (10-15 mi) wide and more than 48 km (30 mi) long. It is bounded on the west by the Sierra de los Valles, on the east by the Rio Grande, on the northeast by the Puye Escarpment, and on the southwest by Canada de Cochiti (Figs. 2a and 2b).

The plateau slopes eastward from an elevation of 2377 m (7800 ft) abutting the Sierra de los Valles to an elevation of 1890 m (6200 ft) adjacent to the Rio Grande. It is cut 61-122 m (200-400 ft) deep by numerous southeast trending intermittent streams. The dissected eastern margin of the plateau rises 91-305 m (300-1000 ft) above the Rio Grande.

Los Alamos is 38.6 km (23 mi) northwest of Santa Fe and 92.8 km (58 mi) north-northeast of Albuquerque.

C. Radioactive Wastes Generated by the LASL

LASL radioactive wastes are categorized as routine or nonroutine. Most of the waste is routine, consisting of Laboratory trash (mostly combustible), equipment, chemicals, oil, animal tissue, chemical treatment sludge, cement paste, hot-cell waste, and classified materials. Nonroutine waste, generated during facility renovation and decommissioning projects, consists of building debris, large equipment items, and soil or rock removed during site cleanup.

The wastes may be contaminated by transuranic radionuclides (^{239}Pu, ^{238}Pu, or ^{241}Am), uranium (enriched, depleted, normal or ^{233}U), fission products, induced activities, or tritium. Wastes contaminated by fission products, induced activities, and tritium are small in volume, 1-3% of the whole, but high in total curies disposed of by LASL.

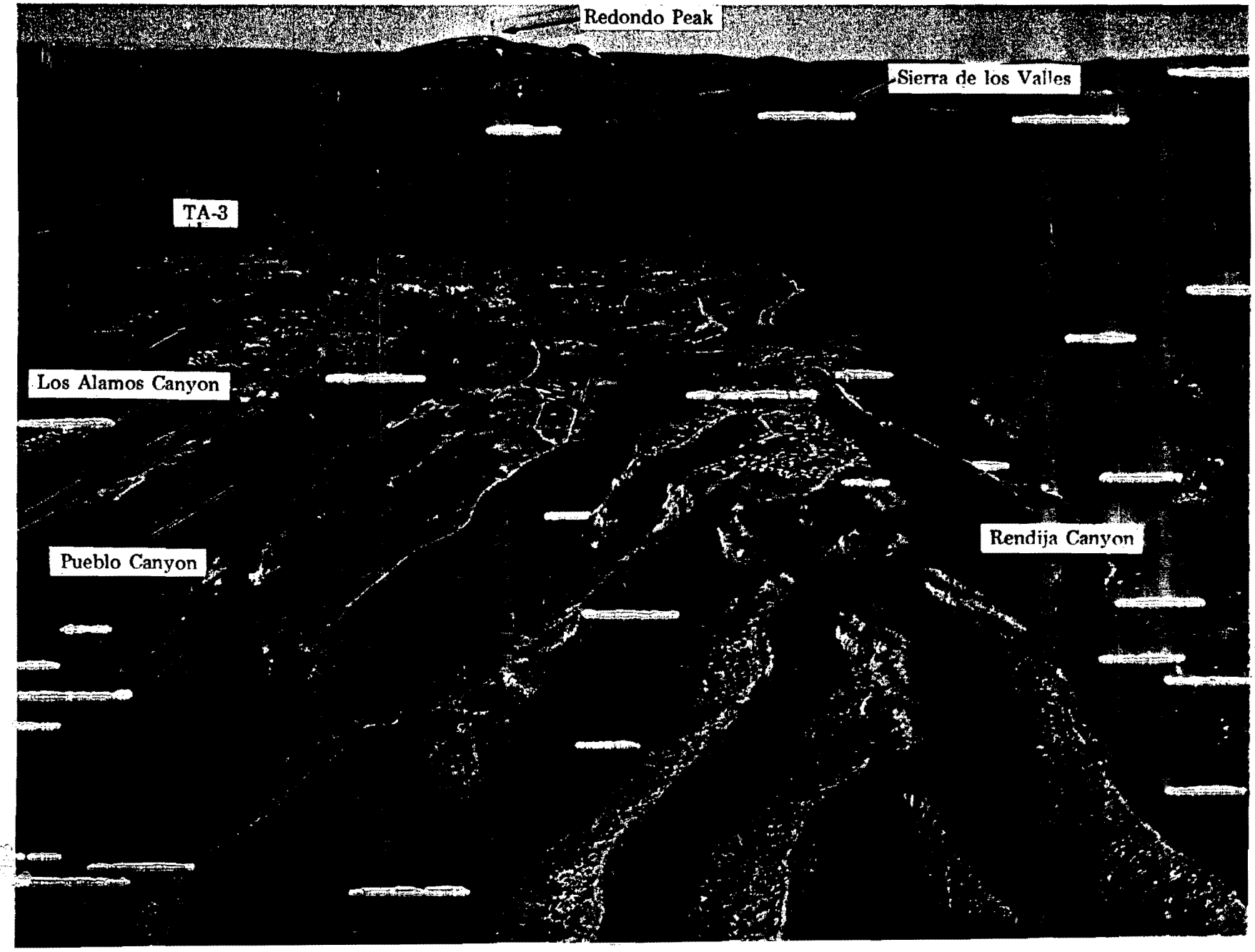

Redondo Peak
Sierra de los Valles
TA-3
Los Alamos Canyon
Pueblo Canyon
Rendija Canyon

Fig. 2a.

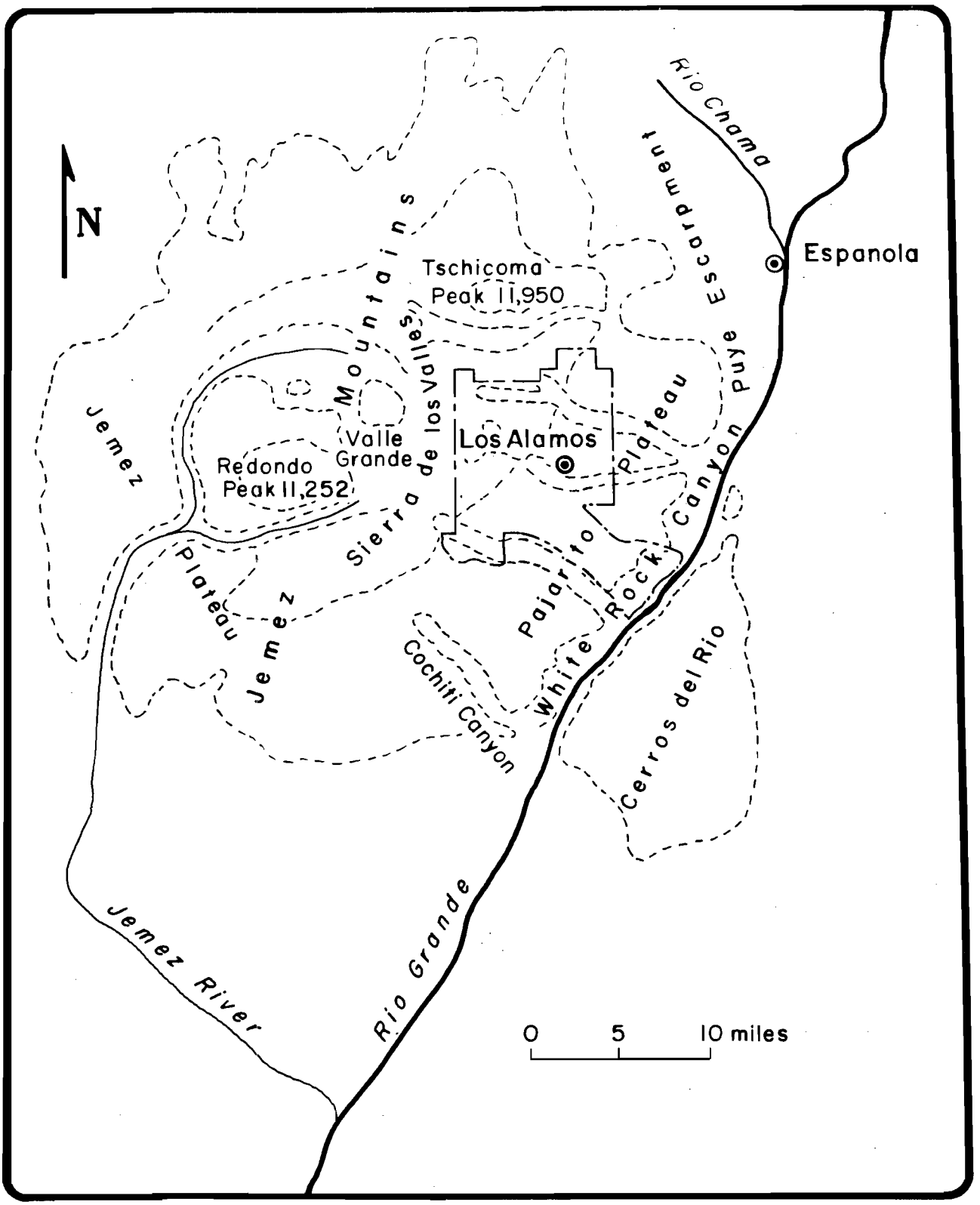


Fig. 2b.
Map showing general geography of Jemez Mountains.

Over the past 20 years waste volume has averaged 5073 m^3 (6631 yd^3) per fiscal year (see Fig. 3). During the past 10 years the volume has varied from 7792 m^3 (10 185 yd^3) in 1964 to 4250 m^3 (5556 yd^3) in 1972. For the period 1965-1975 approximately 3542 m^3 (4630 yd^3) to 4250 m^3 (5556 yd^3) is the waste volume per fiscal year is due to routine waste.

Appendix C contains correspondence pertaining to LASL radioactive solid waste management policy.

II. SUMMARY AND CONCLUSIONS

A. General

The Los Alamos Scientific Laboratory has been disposing of solid radioactive wastes since 1944. Throughout the history of the Laboratory, the principal means of disposal has been pits. In the late fifties shafts began to be used as well as pits. Geometrically, pits are rectangular prisms and shafts are cylinders.

The LASL Materials Disposal Areas examined in this report, A, B, C, D, E, F, G, and T, are solid radioactive waste disposal areas, with the exception of Area T which has always been part of the liquid waste disposal operation at LASL. All the areas except Areas A, T, and G are currently inactive. Areas A, B, C, D, E, F, and T were used in the forties; Areas C, E, G, and T were used in the fifties; and Areas A, C, G, and T were used in the sixties and seventies.

In the late fifties waste disposal documentation improved greatly; therefore, knowledge of Areas C, G, and T is much better than of Areas A, B, D, E, and F. Knowledge of Area G far exceeds that for any other area.

Disposal-area fires seem to be a thing of the past since the following policies were simultaneously put into effect: (1) uncontaminated hazardous chemicals are not buried with contaminated solid waste, and (2) flammable solid waste is covered immediately after it is placed in a pit.

Radioactive contamination studies and monitoring have been done at LASL since 1944. Through the years the USGS has performed a large part of this work. Available information indicates that the USGS did the majority of the specific migration studies and a significant amount of the monitoring in the fifties and sixties.

B. By Site

Area A, located at TA-21, has been used intermittently since 1945. It was the second common burial ground for radioactive waste at the Laboratory. The oldest Area A disposals were made in two pits situated in the eastern part of the area. The "Generals's Tanks"* which are in the western part were filled shortly after the pits. The central (and largest) pit was dug in 1969 and continues in active use today, July 1976. Records on disposal have not been located for the pits. Some records on the liquid waste placed in the General's Tanks are available. The only known study related to environmental monitoring conducted in the area is a geologic inspection of the 1969 pit.

Area B, located south of DP Road, is the first common burial ground for radioactive waste at the Laboratory. Only the outline of Area B is shown on engineering drawings. Location of the series of pits which were in use from 1944 until 1948 has not been established. Waste disposal records from 1944 through January 5, 1947, have not been located. Records are available from January 6, 1947, through the closing of Area B. The site was studied by the USGS before establishment of the boat and trailer storage yard within the area.

Area C, north of Pajarito Road near TA-50, became inactive April 8, 1974. Its history of use covers 26 years. There are seven pits within the area, one of which was reserved exclusively for the disposal of non-radioactive hazardous chemical wastes and 108 shafts, none of which are greater than 1 m (3 ft) in

*Two storage tanks designated TA-21-107 and TA-21-108.

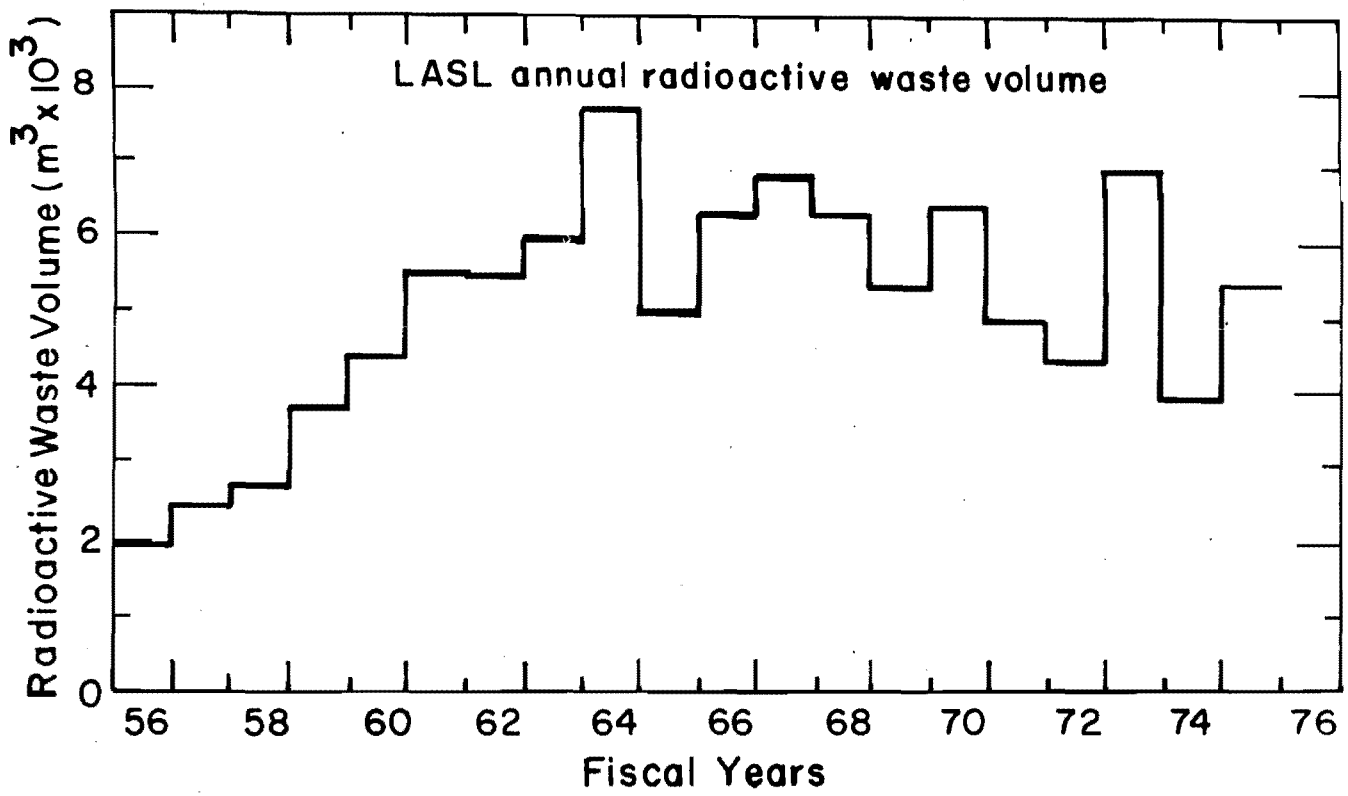


Fig. 3.
Record of waste volume over last 20 yr.

diameter and 7.6 m (25 ft) deep. Area C is the first burial ground for which detailed records were kept. Few studies related to environmental monitoring have been conducted in Area C.

Area D is two underground chambers used in 1948 at "Hot Point," TA-33. Chamber 2 was contaminated by polonium and it is assumed Chamber 1 was likewise. (The available records do not support the idea of other radioactive contaminants.) A minimum of 22 years has passed since any experimentation. With a half-life of 138 days for polonium, it is unlikely any radioactive contamination remains. Studies are limited to surveys made shortly after the chambers were used.

Area E, located at "New Hot Point," TA-33, includes an underground chamber destroyed in 1950 and six pits. The area was in use through 1962. Records on the underground chamber and the pits have not been found. No environmental monitoring studies have been conducted in the area.

Area F, TM Site, TA-6, may not be a radioactive waste disposal area. The first pit was dug in 1946. The exact size, location, and number of pits is not known. No records of disposal have been found. There is no indication any environmental monitoring studies have been done in Area F.

Area G, TA-54, is the largest disposal area at LASL. It has been in operation since early 1957. The site was originally picked because of its isolated location and because it offered ample space for disposal activities over a period of years. Although it is not as isolated as it once was, it still has enough space for disposal needs in the foreseeable future. Area G has 16 pits, 2 trenches, and 81 shafts. Detailed disposal records have been kept throughout the history of Area G. Most of the pits and some of the shafts received a geologic inspection before being put in use. Environmental monitoring activities are increasing in Area G.

Area T, west of Area A at TA-21, has been in use since 1945. It reflects the thinking and practices in liquid radioactive waste disposal from the time the Laboratory began. Four absorption beds were constructed in 1945. They received untreated and treated wastes from 1945-1967. Since mid-1968, treated wastes have been mixed with cement and pumped down shafts augered between the south absorption beds and the north absorption beds. The shafts are 2.4 m (8 ft) in diameter and as deep as 19.8 m (65 ft). Though small in physical size, Area T has received more intensive study from an environmental monitoring viewpoint than any other waste disposal area at the Laboratory.

C. Recommendations

1. Site Improvement

- Specific boundaries should be designated for Areas T, D, and F.
- Areas A, D, F, and T are not adequately fenced and should be. If Area D is to be considered just the two underground chambers, there is no need to fence it.
- Identification signs and radioactive contamination warning signs should be posted for all areas.
- Individual pits and shafts within each area should be clearly identified. In some cases this involves replacing existing signs and in others erecting new markers. Areas affected are A, C, E, F, G, and T.
- Areas which should receive restoration treatment are A, E, F, G, and T.

2. Studies and Monitoring

- The "History and Environmental Setting of LASL Near-Surface Land Disposal Facilities for Radioactive Wastes (Areas A, B, C, D, E, F, G, and T)" should be a continuing project for the next several years and thereafter periodically updated. With the exception of Area G, it is quite possible that there are existent records which have merely not been located. An extensive effort should be made to locate all records as soon as possible, lest the passage of time render the task impossible. One way to gain insight on some of the areas is through interviews with LASL personnel, LASL retirees, and previous LASL employees.

- Detailed geologic mapping for each area should be done to establish fracture patterns and stratigraphy in order to have a basis for monitoring. The mapping project should extend from Area to Area, with special emphasis as necessary at any particular Area, and should not result in eight individual maps which cannot be easily related to each other.
- Vegetative mapping in the Areas should be done. In the case of Areas B, C, D, and F, mapping can provide insight for revegetation of other areas.
- A comprehensive ion-exchange study should be done. "Soil Absorption of Radioactive Wastes at Los Alamos"[2] is based on too few samples to generalize on the ion-exchange capacity of the soil, fracture fillings, and tuff in the Los Alamos area. Because of the variability in the physical and chemical properties of the tuff, which in turn creates variability in the soils and fracture fillings, more work should be done on ion exchange.
- A program should be designed for site-specific monitoring of disposal areas. The present monitoring network is intended to monitor disposal areas only in a general way.

III. GEOLOGY

A. Stratigraphy

Introduction. For the purposes of this report the Los Alamos area is defined roughly as the area bounded by the Rio Grande on the east, the Rito de los Frijoles on the south, the crest of the Sierra de los Valles on the west, and Guaje Canyon on the north.

The volcanic and sedimentary rock cropping out in this area range in age from Tertiary to Quaternary. Stratigraphic nomenclature varies. There is general agreement on the unit definitions for the volcanic rocks whose origin is the Valles or Toledo Calderas; however, there appears to be considerable disagreement on unit definition and usage for the sedimentary rocks and basalt flows which form the basin fill for the Rio Grande Rift.

The oldest sedimentary sequence cropping out in the Los Alamos area has been referred to as the Santa Fe Formation, a restricted usage, or as part of the Santa Fe Group, a usage which includes all basin-fill rocks regardless of origin. Spiegel and Baldwin (1963),[3] Griggs (1964),[4] and Galusha and Blick (1971)[5] favor use of the Santa Fe Group designation; Bailey, Smith and Ross (1969)[6] favor use of the older term, Santa Fe Formation. These four reports define stratigraphic nomenclature for the Los Alamos area since all use rock sequences in or adjacent to the area to define their unit usage. Other authors such as Baltz, Abrahams, and Purtymun (1962),[7] have adopted the unit usage of one of these four reports (see Fig. 4).

The same named unit does not necessarily refer to the same rock and/or include the same subunits. Spiegel and Baldwin, Griggs, and Galusha and Blick agree the term Santa Fe should have group status, but the three reports do not use the same subunits. The term Puye seems to be applied to the same sequence of rocks by three of the reports, although it receives different treatment by each. Spiegel and Baldwin recognize the Puye Gravel as used by Smith (1938, p. 937).[270] Griggs (1964, p. 28)[4] gave the Puye formal status as a formation with a specified type locality, *"the belt of exposures along Guaje Canyon between Guaje Mountain and the Puye Escarpment."* He also changed the name from Puye Gravel to Puye Conglomerate because *"the formation is sufficiently consolidated to stand in vertical cliffs"* and separated it into two members of alluvial origin — the Totavi Lentil and the fanglomerate member. Bailey, Smith and Ross (1969, p. 12)[6] propose to call the Puye the Puye Formation because *"most of the constituent materials of the formation are of ultimate pyroclastic origin, and many of the component beds, especially those close to the source areas in the Jemez Mountains, are pumiceous tuffs and lithic lapilli tuffs that show only slight alluvial reworking."*[6]

This report does not propose to solve the stratigraphic nomenclature problems which have been briefly outlined in the preceding paragraphs. A comparison of unit usage by Galusha and Blick; Bailey, Smith and Ross; Griggs; and Spiegel and Baldwin is shown in Fig. 5. Descriptions of all stratigraphic units in use in the Los Alamos area follow:

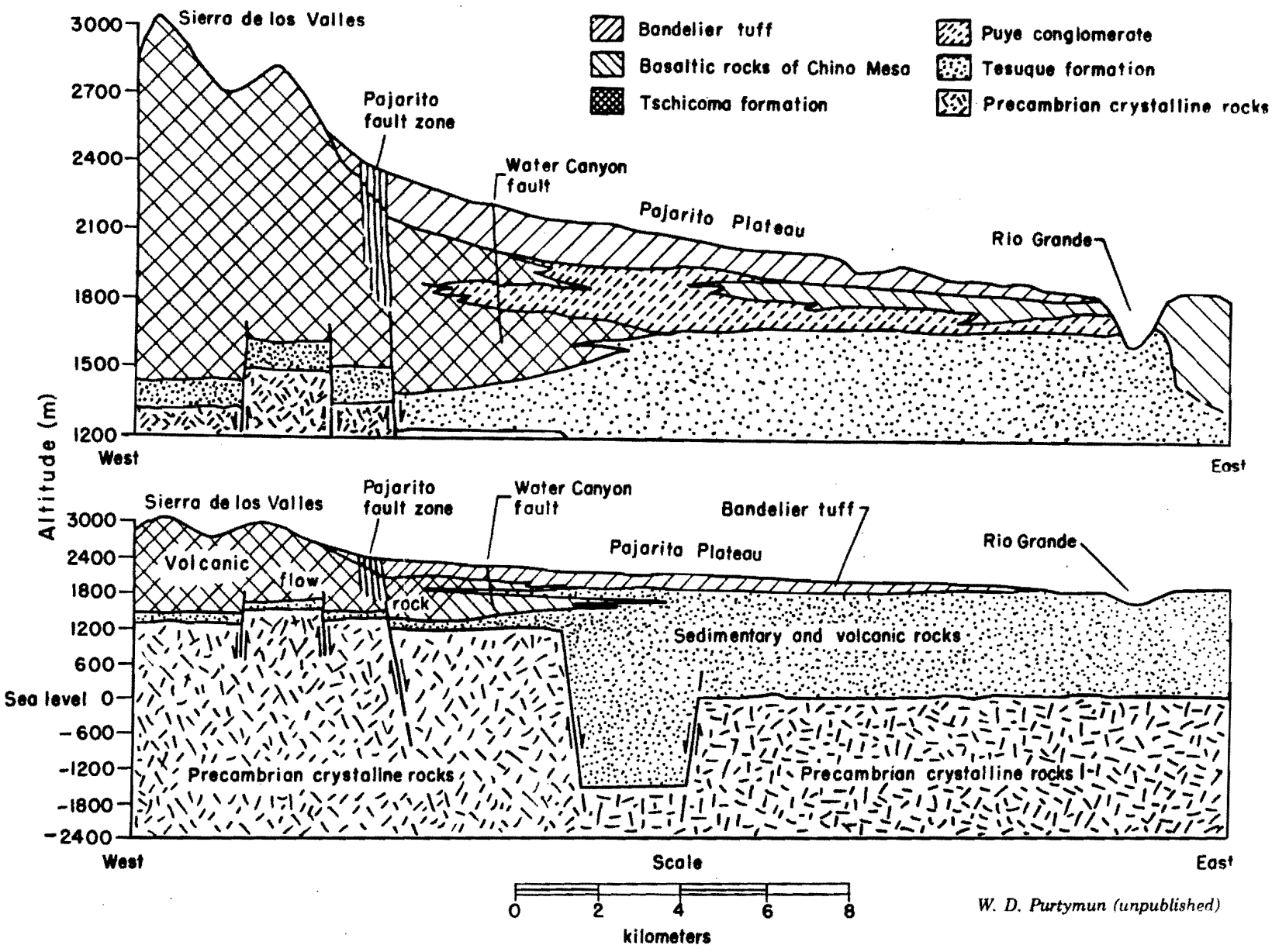


Fig. 4.

Geologic cross section showing generalized stratigraphic and structural relationship of rocks in the Los Alamos Area.

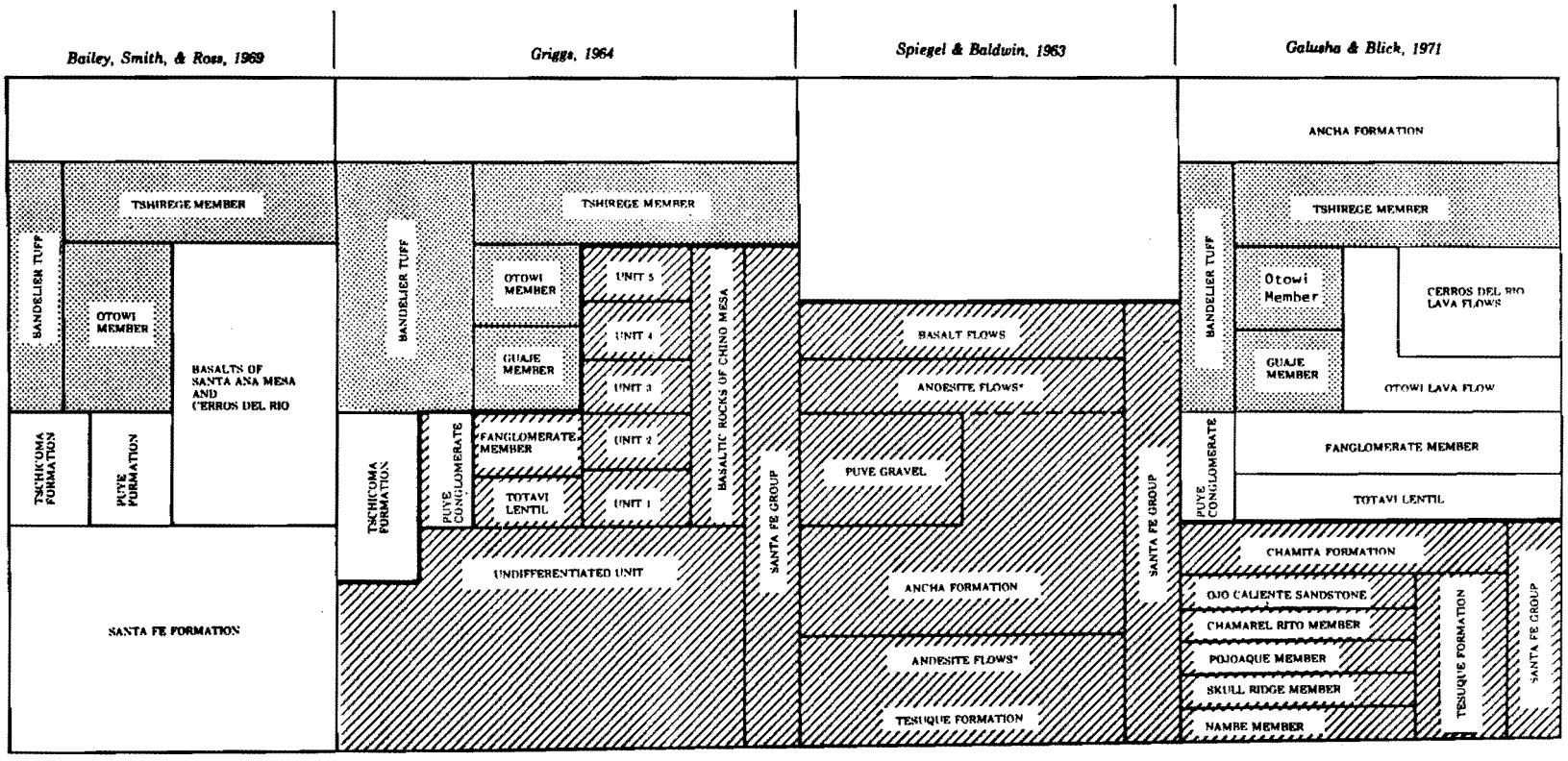


Fig. 5.
Nomenclature of the tertiary-quarternary rocks in the Los Alamos area.

**Same unit. It is stratigraphically lower than the Ancha Formation, which correlates with the top of the Santa Fe Formation (Bailey, Smith & Ross, 1969, p.2) and possibly the top of the Undifferentiated Unit (Griggs, 1964, p.2). However, the Andesite Flows have been correlated with Unit 3 of the Basaltic Rocks of Chino Mesa (Spiegel & Baldwin, 1963, p.53). Obviously, it cannot comply with both correlations.*

Santa Fe Group

Spiegel and Baldwin proposed the term Santa Fe be raised to group status. They considered the Santa Fe Group to include sedimentary and volcanic rocks which ranged in age from middle(?) Miocene to Pleistocene (?) and were related to the Rio Grande Rift. They placed all rocks above the latitic and limburgitic flows and breccias exposed in the Cienega area in the Santa Fe Group. This definition includes the terrace deposits and alluvium of present valleys.

Tesuque Formation. The Tesuque Formation (Spiegel and Baldwin, 1963, p. 39)[3] is middle (?) Miocene to early Pliocene in age. It consists of several hundred meters of pinkish-tan, soft arkosic, silty sandstone and minor conglomerate with two minor volcanic units. Most of the sediments were derived from siltstone Precambrian rocks. Named for the town of Tesuque, its arbitrary type section is along the north boundary of T. 17 N., extending 14 1/2 km (9 mi) westward from Tesuque Creek (NE 1/4 sec. 5, T. 17 N., R. 10 E.) to a point three-fourths of a mile east of the Buckman Road (NE 1/4 NW 1/4 sec. 2, T. 17 N., R. 8 E.).

The Tesuque Formation (Galusha and Blick, 1971, p. 44)[5] is restricted to beds of dominantly granitic origin with a total thickness of more than 1130 m (3700 ft) in the Espanola Valley. It is divided from bottom to top as follows: (1) the Nambe Member, (2) the Skull Ridge Member, (3) the Pojoaque Member, (4) the Chama-el rito Member, and (5) the Ojo Caliente Sandstone. Only the Pojoaque Member crops out in the Los Alamos area.

The Tesuque Formation crops out in the eastern part of the Los Alamos area along the Rio Grande.

Andesite Flows. Basaltic andesite makes up part of the high mesas of Cerros del Rio. These flows are considered older (Spiegel and Baldwin, 1963, p. 50)[3] than the flows several hundred feet below which form the main level of the lava mesa. The andesite flows intertongue with the Ancha Formation along Ancha Canyon.

Ancha Formation. The Ancha Formation (Spiegel and Baldwin, 1963, p. 45)[3] rests with angular unconformity on the Tesuque Formation. A late Pliocene or Pleistocene age is inferred for the Ancha from physiographic relations. It consists of up to 91 m (300 ft) of arkosic gravel, sand, and silt. The formation is named for Canada Ancha.

The Ancha Formation (Galusha and Blick, 1971, p. 78)[5] rests with angular unconformity on the Pojoaque Member of the Tesuque Formation. It is considered Pleistocene, approximately equivalent to or slightly post-Bandelier Tuff in age.

In the Los Alamos area, (defined as west of the Rio Grande), the Ancha has never been mapped.

Chamita Formation. The contact between the Ojo Caliente Sandstone (Galusha and Blick, 1971, p. 67)[5] and the Chamita Formation (Galusha and Blick, 1971, p. 71)[5] is an unconformity. The medial Pleistocene Chamita Formation is predominantly fluviatile in origin and consists of as much as 213 m (700 ft) of pinkish, brownish, gray, or white tuffaceous and quartzitic sands, gravels, and conglomerates. It is named for the village of Chamita and has its type section south of Black Mesa between the Chama River and the Rio Grande, specifically the NW 1/4 sec. 10 and the W 1/2 sec. 3, T. 21 N., R. 8 E. The Chamita Formation crops out in the northeastern part of the Los Alamos area in Los Alamos Canyon and along the Rio Grande.

Puye Conglomerate. Mid-Pliocene (?)[5] in age, the Puye Conglomerate (Griggs, 1964, p. 28)[4] consists of well-rounded pebbles, cobbles, and small boulders of quartzite, quartz, and granite with some volcanic debris in a matrix of arkosic sand. The type locality is Guaje Canyon between Guaje Mountain and the Puye Escarpment. The Puye Conglomerate is divided into two members, the Totavi Lentil and the Fanglomerate. Outcrops of the Puye Conglomerate are found in the northeastern part of the Los Alamos area and along the Rio Grande.

Totavi Lentil

The Totavi Lentil (Griggs, 1964, p. 29)[4] is the lower member of the Puye Conglomerate. The type locality is a quarry north of State Highway 4 and about 402 m (a quarter mile) west of the community of Totavi from which it derives its name. As much as 23 m (75 ft) thick, the Totavi is a channel deposit of poorly consolidated conglomerate composed of Precambrian rocks.

Fanglomerate Member

The upper member of the Puye Conglomerate is a fanglomerate composed of latitic debris derived from the Tschicoma Formation. The fanglomerate member (Griggs, 1964, p. 31)[4] ranges in thickness up to 183 m (600 ft.) It thins southward and wedges out southwest of Otowi Bridge.

Basaltic Rocks of Chino Mesa. Those flows which form the steep walls of White Rock Canyon and cap the high mesas to the east are the basaltic rocks of Chino Mesa (Griggs, 1964, p. 37).[4] The sequence of flows, erupted from centers in the Cerros del Rio, is greater than 396 m (1300 ft) thick at Chino Mesa. Their age is late Pliocene to middle or late Pleistocene.

The basaltic rocks of Chino Mesa have been divided into five units. Unit 1 rests unconformably on the undifferentiated unit (Griggs, 1964, p. 20)[4] and interfingers with the Totavi Lentil. Unit 2 conformably overlies unit 1, interfingers with the upper tongue of the undifferentiated unit, rests on the Totavi Lentil, and abuts the fanglomerate member. Unit 3 is disconformable on unit 2, rests on the fanglomerate member, and interfingers with the old alluvium unit (Griggs, 1964, p. 41). Unit 4 rests unconformably on the undifferentiated unit, the Puye Conglomerate, and unit 2. In some places unit 4 abuts unit 2 and unit 3. Unit 5 consists of cinder cones and local flows which unconformably overlie all older rocks with which they are in contact.

Polvadera Group. Polvadera Group is the name proposed by Smith, Bailey, and Ross (1969, p. 10)[6] for the sequence of basaltic, andesitic, dacitic, and rhyolitic rocks 1524 m (5000 ft) thick, which form part of the central and most of the northern Jemez Mountains. The group is divided into three formations: the Lobato Basalt, the Tschicoma Formation, and El Rechuelos Rhyolite. The Tschicoma Formation is the only one which crops out in the Los Alamos area.

Tschicoma Formation. The Tschicoma Formation (Griggs, 1964, p. 42)[4] of the Polvadera Group consists of andesites, dacites, rhyodacites, and quartz latites. Radiometric dates of 6.7 to 3.7 million years [G. B. Dalrymple, written communication, 1967 (Bailey, Smith and Ross, 1969, p. 11)][6] on the rocks indicate an age of middle to late Pliocene. The Tschicoma Formation crops out along the western margin of the area in the Sierra de los Valles. It is greater than 793 m (2600 ft) thick in the Los Alamos area.

Puye Formation. Penecontemporaneous with the Tschicoma Formation is the Puye Formation (Bailey, Smith, and Ross, 1969, p. 12).[6] It is described as essentially a broad alluvial and pyroclastic fan flanking the east side of the northern Jemez Mountains. It interbeds with the Tschicoma Formation and the basalts of Chino Mesa (Cerros del Rio) and unconformably overlies the Santa Fe Formation. The formation is not assigned to any group.

Tewa Group. The name Tewa Group was given by Griggs (1964, p. 45)[4] to the rhyolitic tuff and the rhyolite and quartz latite domes which constitute the latest eruptive rocks of the Jemez Mountains. The group consists of the Bandelier Tuff, Cerro Toledo Rhyolite, Cerro Rubio Quartz Latite, and the Valles Rhyolite. In the Los Alamos area the Bandelier Tuff is the only formation which crops out.

Bandelier Tuff. In the Los Alamos area the Bandelier Tuff can be subdivided into three members (Griggs, 1964, p. 46).[4] These members are, from bottom to top: (1) The Guaje Member, a bedded pumice-fall deposit, (2) The Otowi Member, a massive pumiceous tuff breccia of ash-flow origin, and (3) the Tshirege Member, a succession of cliff-forming welded ash flows. Away from the Los Alamos area, this

subdivision is not used. The Otowi Member is defined (Bailey, Smith, and Ross, 1969, p. 13)[6] to include a basal pumice fall, the Guaje pumice bed (Guaje Member of Griggs), and the overlying ash-flow units (Otowi Member of Griggs). The Tshirege Member is defined (Bailey, Smith, and Ross, 1964, p. 13) to include a basal pumice fall, the Tsankawi pumice bed, and the overlying ash-flow units (Tshirege Member of Griggs). Due to the lack of detailed stratigraphic mapping, it is unclear whether in the Los Alamos area the Bandelier will continue to be subdivided into three units or the more general usage outside the immediate area of two units will be adopted.

The Los Alamos area is also unique in that the Tshirege Member has been subdivided into seven numbered units, unit 1a; unit 1b; unit 2; unit 3; unit 4; unit 5; and unit 6, by Weir and Purtymun (1962)[9] and into five numbered units, unit 1a; unit 1b; unit 2a; unit 2b; and unit 3 by Baltz, Abrahams and Purtymun (1963)[7] Weir and Purtymun give the type section for their units as the south wall of Water Canyon — NW 1/4 NE 1/4 sec. 3 (projected) T. 18 N., R. 6 E. Units 1a and 1b of Baltz, Abrahams, and Purtymun (1963, p. 29) correlate with unit 1b of Weir and Purtymun. Unit 2 (Weir and Purtymun, 1962, p. 121) seems to correlate with units 2a and 2b (Baltz, Abrahams, and Purtymun, 1963, p. 26-27); and unit 3 (Weir and Purtymun, 1962, p. 124) seems to correlate with unit 3 (Baltz, Abrahams, and Purtymun, 1963, p. 28). It is not clear with which unit the Tsankawi Pumice Bed of Bailey, Smith, and Ross (1969, p. 14)[6] correlates.

The Bandelier Tuff is Pleistocene in age. The basal unit of the Tshirege Member, the Tsankawi Pumice Bed, has been dated radiometrically as 1.1 million years old (Doell and others, 1968).[10]

In the Los Alamos area the Bandelier Tuff, 79-320 m (260-1050 ft thick)[4] crops out on the Pajarito Plateau. See Table I for a chemical analysis of the tuff.

TABLE I

CHEMICAL ANALYSIS* OF LOS ALAMOS TUFF[11]

	%
SiO_2	76.3
Al_2O_2	13.1
Fe_2O_3	1.9
FeO	0.25
MgO	0.32
CaO	0.51
Na_2O	3.9
K_2O	4.6
H_2O	1.3 (chemically bound)
TiO_2	0.26
P_2O_5	0.06
MnO	0.06
CO_2	>0.05

*Rapid Rock Method

Recent Alluvium. Recent alluvium is found in the canyons cutting the Pajarito Plateau. For those canyons which head in the Sierra de los Valles the alluvium consists mainly of detritus derived from the Tschicoma Formation. For those canyons which head on the Pajarito Plateau the alluvium consists of detritus derived from the Bandelier Tuff.

B. Structure

The Los Alamos area is on the Pajarito Plateau which flanks the eastern side of the volcanic Jemez Mountains. Volcanism began approximately 12 million years ago in late Miocene or early Pliocene time. Finally, in mid-Pleistocene time (about 1 million years ago) volcanism was climaxed by two gigantic pyroclastic outbursts, which produced the Bandelier Tuff (Smith and Bailey, 1966).[6] Each outburst deposited nearly 209 km^3 (50 mi^3) of rhyolite ash and pumice, mainly as ash flows, and was followed by caldera collapse. The first outburst (first cycle) produced the Toledo Caldera, of which only a semicircular portion is now preserved. The second outburst (second cycle) some 300 000 yrs later produced the Valles Caldera. Its collapse truncated the southwestern part of the Toledo Caldera and destroyed much of the evidence of the Toledo Caldera's postcollapse history. The Valles Caldera had a relatively long and complex postcollapse history, which included upheaval of the center of the caldera floor and three stages of rhyolite volcanism (Smith and Bailey, 1968, p. 617).[12]

The Jemez Mountains are located along the western border of the Rio Grande Rift, a linear structure and topographic depression formed by faulting beginning about 20 million years ago in Middle Miocene time (Budding and Purtymun, 1976).[13] The Jemez volcanic rocks are faulted progressively downward to the east by numerous north-trending faults (Smith, Bailey, and Ross, 1961).[14] The major fault in the Los Alamos area, the Pajarito Fault, separates the Pajarito Plateau from the Sierra de los Valles.

The Pajarito Fault displaces the Bandelier Tuff; therefore, faulting took place after deposition of the Bandelier. Using the radiometric date of 1.1 million years (Doell and others, 1968)[10] on the Tsankawi Pumice Bed of the Tshirege Member, faulting occurred less than 1.1 million years ago.

Earth tremors have been felt in the Los Alamos area recently. At 4:30 a.m. on February 17, 1971, an earth tremor of magnitude 1.8 (Richter Scale) occurred (written communication from Allan R. Sanford, New Mexico Institute Mining and Technology). The earth tremor was of such a low order of magnitude that while it was felt on Barranca Mesa, it could not be felt on South Mesa, an approximate distance of 3.4 km (2.1 mi). There seems to be no geologic or cultural evidence to suggest intensive earthquakes have occurred for hundreds, possibly thousands, of years in this region.

> *"A number of pinnacles 10 to 50 feet high, eroded from soft formations and capped with boulders 2 to 5 times the diameter of the supporting pinnacle, lie in Rendija Canyon, just north of Los Alamos. These formations are unstable and it is reasonable to think that they would topple under the influence of any sizeable ground tremors. We note that a 60 foot pinnacle would require 75,000 to 120,000 years to develop with the erosion rate normal in the major canyons in the area.*
>
> *Remains of Indian dwellings constructed with free standing walls with little lateral support indicate the absence of strong tremors for at least 500 years. Nearby pueblos that have been occupied continuously since the late sixteenth century, buildings in Santa Fe constructed by the Spanish in the early seventeenth century, and a lack of references to earthquakes in surviving records add support to this contention."*[15]

Tectonic fractures in the Los Alamos area are related to development of the Rio Grande Rift and the Jemez volcanic complex. Cooling fractures are also present in the area.

No area or regional studies of joint pattern have been done. See individual disposal sites for scattered data.

Identification of faults in the Los Alamos area is the result of other specific geological studies. No study as yet has had as its principal goal the drawing of a structural map at either a local or regional level. Four named faults in the area are: the Pajarito Fault, the Los Alamos Fault, the Guaje Mountain Fault, and the Water Canyon Fault (see Fig. 6). All four faults are north trending faults with vertical or near vertical displacements. The Pajarito Fault is downthrown to the east with a maximum surface displacement of 121.9 m (400 ft).[13] The Los Alamos Fault is downthrown to the west with a maximum surface displacement of 6 m (20 ft).[13] The Guaje Mountain Fault is downthrown to the west with a maximum surface displacement of 16 m (52 ft).[13] The Water Canyon Fault is downthrown to the east with a maximum surface displacement of 9.1 m (30 ft).[13]

C. Hydrology

Climatology and Meteorology

Los Alamos has a semiarid continental mountain climate. The average annual precipitation is slightly greater than 450 mm (18 in.). Seventy-five percent of this precipitation falls from May to October. Shower activity peaks in August when 3 mm (1/10 in.) or more of rain can be expected on one day out of four. Winter precipitation consists of snow. An average winter has 1000 mm (50 in.) of snow with as much as 150 mm (6 in.) or more often falling in 24 h.

The mean humidity value is 41%. The lowest humidity values average 30% in late spring, and the highest humidity values near 50% during July and August.

Prevailing winds are out of the south. They are 10 mph or less almost 80% of the time.

The maximum temperature reaches 32°C (90°F) on an average of 2 days per year with 35°C (95°F) the highest recorded. July is the hottest month. Freezes have been recorded in all months except July and August. An average winter includes only 18 days when mercury fails to rise above freezing. Below-zero readings can be expected only once a year (see Table II).

Main Aquifer

The water table is within the main aquifer. Beneath the plateau it is at an approximate depth of 400 m (1200 ft) along the western margin, and at an approximate depth of 200 m (600 ft) along the eastern margin[16] (see Fig. 7). The aquifer is recharged through the intermountain basins formed by the Valles Caldera,[8] and to a limited extent along the eastern margin of the Sierra de los Valles. Water moves eastward from the recharge area toward the Rio Grande at a rate of approximately 30 cm (1 ft) per day;[16] the actual rate at any point being dependent on the permeability of the aquifer and the elevation gradient on the water table. A portion of the water is discharged through seeps and springs along the Rio Grande.

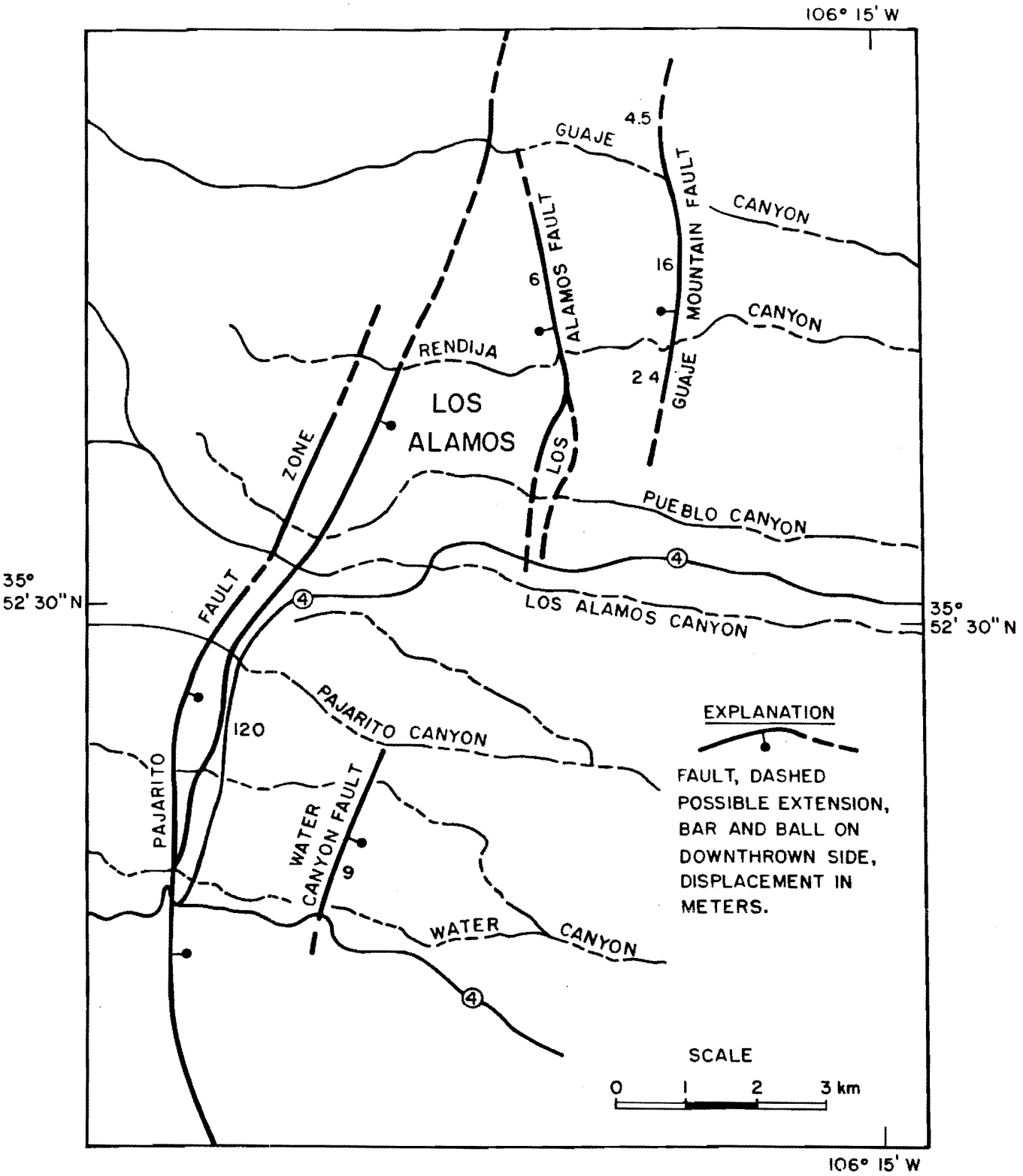
Beneath the plateau the zone of saturation lies within the Tesuque Formation of the Santa Fe Group. This formation consists of beds of siltstone and sandstone with lenses of clay and conglomerate. It crops out along the Rio Grande where the upper part of the formation is above the zone of saturation. Some of the lower Tschicoma volcanic flow rocks are within the zone of saturation beneath the western part of the plateau.

The Puye Formation, a conglomerate of volcanic debris from the Tschicoma Formation interbedded with basalt, is above the zone of saturation along the Rio Grande. Beneath the plateau the lower part is in the zone of saturation.

Throughout the plateau the Bandelier Tuff which forms the plateau surface is above the zone of saturation (see Fig. 8).

Perched Water

Perched water occurs in the interbedded basalts of the Puye Formation near the eastern edge of the plateau in Pueblo, Los Alamos, and Sandia Canyons. The perched water in the basalts is probably replenished from water moving from the small bodies of perched water contained in recent alluvium in



Budding and Purtymun, 1976[13]

Fig. 6.
Faults in the Los Alamos area.

TABLE II

CLIMATOLOGICAL SUMMARY 1910-1974[a]

	TEMPERATURE (°C)							PRECIPITATION TOTAL (mm)										MEAN NO. OF DAYS[b]		
	MEANS			EXTREMES				RAIN[c]					SNOW/FROZEN PRECIPITATION							
Mo	Max	Min	Mo Mean	High	Yr	Low	Yr	Mean	Daily Max	Yr	Mo Max	Yr	Mean	Daily Max	Yr	Mo Max	Yr	Precip. ≥2.5mm	Max Temp ≥2.67°C	Min Temp ≤9.4°C
Jan	3.9	-7.9	-2.0	17.8	1963	-27.8	1963	21.21	62.23	1916	171.45	1916	246.1	381.0	1913	989.2	1949	2	0	8
Feb	6.1	-5.8	0.1	18.9	1936	-25.6	1951	17.38	26.67	1915	61.89	1948	204.8	330.2	1915	604.2	1948	2	0	6
Mar	9.4	-3.4	3.1	21.7	1971	-19.4	1948	25.38	57.15	1916	104.4	1973	261.3	457.2	1916	938.8	1973	3	0	3
Apr	14.6	1.0	7.8	26.7	1950	-15.0	1925	24.69	36.83	1969	117.86	1916	103.9	304.8	1958	853.4	1958	3	0	0
May	19.9	6.0	12.9	31.7	1935	- 4.4	1938	32.16	45.72	1929	113.54	1929	19.7	228.6	1917	431.8	1917	3	1	0
Jun	25.3	10.9	18.1	33.9	1954	- 2.2	1919	34.64	34.80	1931	141.49	1913	0.0	0.0	--	0.0	—	3	14	0
Jul	26.9	12.9	19.9	35.0	1935	2.8	1924	86.06	70.61	1968	202.69	1919	0.0	0.0	—	0.0	—	8	19	0
Aug	25.4	12.3	18.9	33.3	1937	4.4	1947	94.53	57.40	1951	283.97	1952	0.0	0.0	—	0.0	—	8	12	0
Sep	22.4	8.9	15.7	34.4	1934	- 5.0	1936	50.02	56.13	1929	147.07	1941	4.9	152.4	1913	152.4	1913	5	5	0
Oct	16.7	3.2	9.9	27.8	1930	- 8.9	1970	41.31	88.39	1919	171.96	1957	36.9	228.6	1972	228.6	1959 1972	3	0	0
Nov	9.4	-3.1	3.2	20.6	1937	-20.0	1957	17.77	37.08	1931	83.82	1957	126.4	335.6	1931	876.3	1957	2	0	2
Dec	4.9	-6.8	-1.0	16.7	1933	-23.3	1924	23.01	34.29	1965	72.39	1965	266.8	457.2	1915	1049.0	1967	3	0	6
Year	13.4	2.3	8.9	35.0	1935	-27.8	1963	468.16	88.39	1919	283.97	1952	1270.8	457.2	1915	1049.0	1967	45	51	25

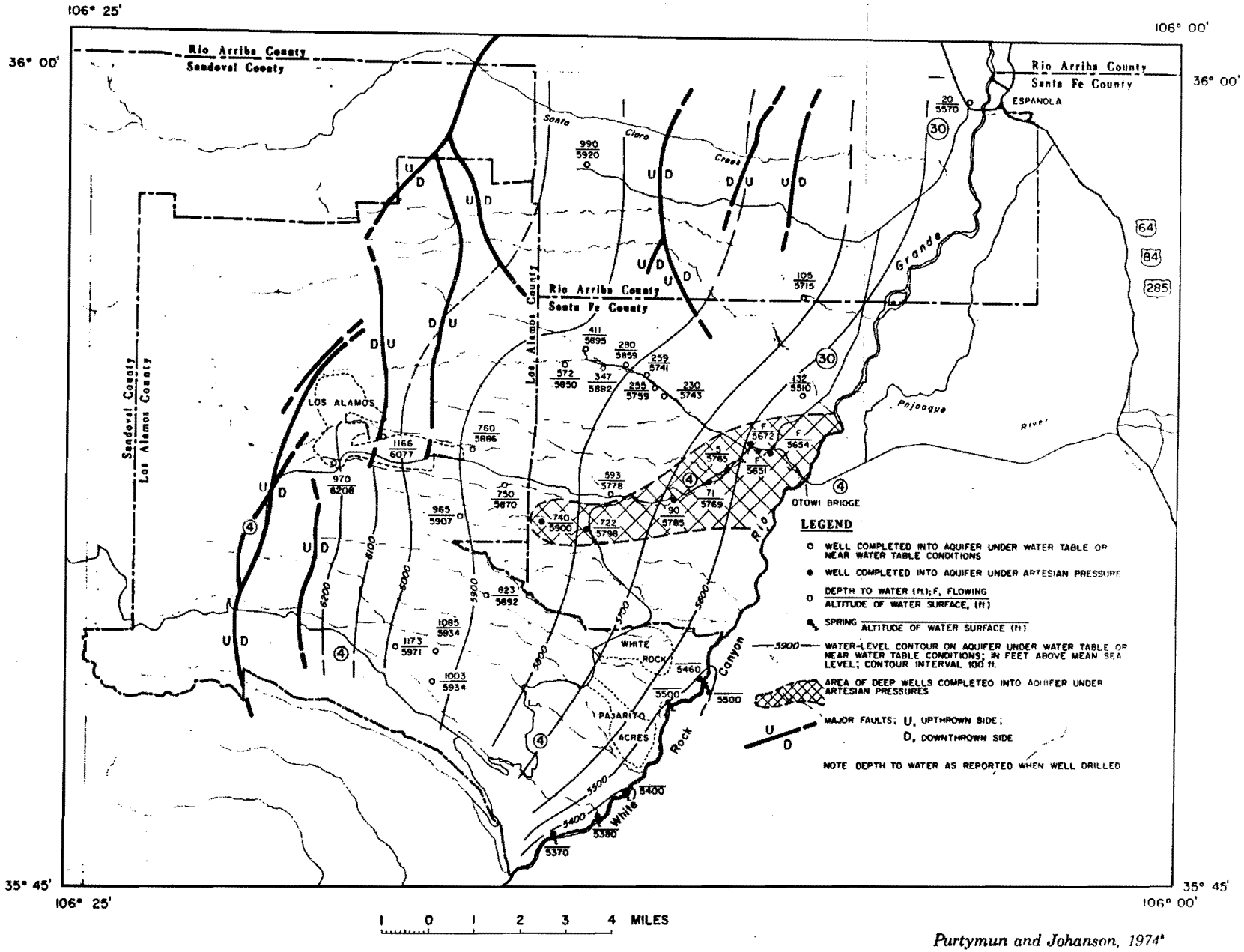
CLIMATOLOGICAL SUMMARY 1975[a]

	TEMPERATURE (°C)					PRECIPITATION TOTAL (mm)				NO. OF DAYS[b]		
	MEANS (Daily Values)			EXTREMES		RAIN[c]		SNOW/FROZEN PRECIPITATION		NO. OF DAYS		
Mo	Max	Min	Mo Mean	High	Low	Total	Daily Max	Total	Daily Max	≥2.5mm	≥26.7°C	≤9.4°C
Jan	3.7	-9.5	-2.9	16.1	-23.3	32.8	17.5	399.0	165.0	3	0	14
Feb	4.3	-7.5	-1.6	11.7	-20.0	46.7	24.4	584.0	267.0	3	0	9
Mar	8.4	-2.7	2.9	15.6	-11.1	32.5	8.1	305.0	76.0	5	0	4
Apr	11.8	-1.1	5.4	21.1	- 7.8	82.0	50.8	843.0	508.0	3	0	0
May	18.7	4.3	11.5	24.4	- 3.3	4.1	1.5	0.0	0.0	0	0	0
Jun	25.0	10.0	17.5	31.0	0.0	8.9	5.8	0.0	0.0	1	14	0
Jul	25.6	12.0	18.8	28.9	9.4	98.6	29.2	0.0	0.0	11	13	0
Aug	26.0	12.0	19.0	29.0	9.0	41.4	11.2	0.0	0.0	4	17	0
Sep	19.9	7.8	13.9	28.0	1.0	115.6	29.0	0.0	0.0	7	2	0
Oct	16.8	2.3	9.6	23.3	- 7.8	5.6	2.5	0.0	0.0	1	0	0
Nov	9.1	-3.8	2.7	18.9	-14.4	15.0	7.6	38.1	25.4	2	0	5
Dec	5.4	-6.7	-0.7	12.2	-13.9	7.6	4.3	76.2	63.5	2	0	8
Year	14.6	1.4	8.0	31.0	-23.3	490.8	50.8	2245.3	508.0	42	46	40

[a]Los Alamos, New Mexico; Latitude 35° 32' North, Longitude 106° 19' West; Elevation 2260 m

[b]26.7°C = 80°F; -9.4°C = 15°F

[c]includes liquid water equivalent of frozen precipitation



Purtymun and Johanson, 1974

Fig. 7.
Contour map of Los Alamos aquifer.

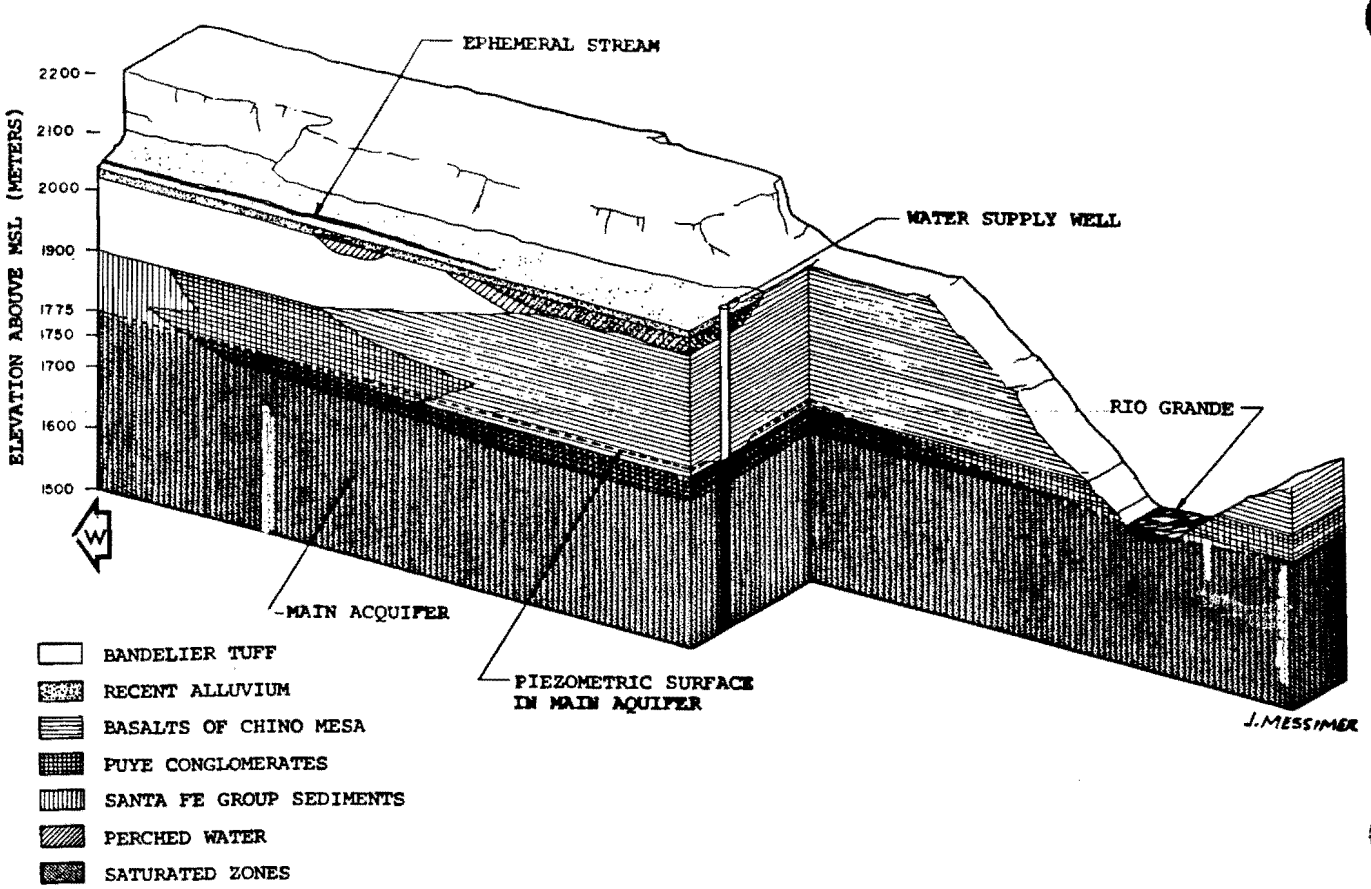


Fig. 8.
Conceptual hydrological cross section of the Los Alamos area.

Pueblo, Los Alamos, and Sandia Canyons. Perched water is also found in small bodies in the recent alluvium of Pajarito and Mortandad Canyons. It probably occurs seasonally in upper parts of other canyons which receive seasonal runoff from the mountains and plateau.

The absence of perched water in the tuff or volcanic sediments above the main aquifer is believed[15] to indicate that infiltration of water from alluvium in stream channels into the underlying tuff is small due to the low permeability of the tuff.

Surface Water

The only perennial streams in the area are the Rio Grande, which flows along the eastern edge of the plateau, and the Rito de los Frijoles which defines the southern boundary of the area. The upper reaches of Los Alamos and Guaje Canyons have natural perennial flow. This flow is depleted by evaporation and infiltration before it crosses the western third of the plateau. In the upper and middle reaches of Pueblo and Sandia Canyons the perennial flow is due to the release of treated sewage effluent. DP Canyon and the mid-reach of Mortandad Canyon have intermittent flow due to the release of treated industrial effluents.

Surface runoff from most canyons to the Rio Grande occurs generally during periods of great precipitation (summer thunder showers). Some small canyons with small drainage areas never receive enough precipitation for storm runoff to reach the Rio Grande.

IV. STUDIES AND MONITORING

Concern, expressed as action, about radioactive contamination of the Los Alamos environs by Laboratory activities dates back to early 1944, "Report on Contamination of Creek Water — II."[16] March 2, 1944, water analyses made by the USGS of water taken from (1) the west end of building "D" (Room 103), (2) room U-18 of "U" building, and (3) water mains at Don Gaspar Avenue and Water Street, Santa Fe, New Mexico, were received by the Laboratory.[17]

In 1945[18] and 1946[18] interest in the chemical and sanitary sewer lines and Los Alamos and Pueblo Canyons seems to have become more intense.[19,20,21,22] From the "Preliminary Survey of Sewer System,"[19] June 11, 1946:

"It is evident that most every sewer line originating in the Tech Area or at DP site is contaminated. They are poorly planned, and even more poorly used and maintained. In several instances the septic tanks are too small and in almost every instance the septic tanks are not operating properly because of improper bacterial action.

It is very desirable that water and earth samples be taken at each sewer location to determine the degree of hazard. Further, it is desirable that some type of check be made by qualified technicians to determine why the sanitary sewers are contaminated or why the acid sewer should show evidence of refuse from sanitary installations."[19]

February 20, 1947, "Survey of Los Alamos and Pueblo Canyon for Radioactive Contamination and Radioassay Tests Run on Sewer-Water Samples and Water and Soil Samples Taken from Los Alamos and Pueblo Canyons,"[23] (LAMS-516) was published.

"Chemical sewers and sanitary sewer lines draining the Tech Area, D.P. Site, CMR-12 Laundry, and surrounding residential areas flow into Pueblo and Los Alamos Canyon streams. The water flow formed in these two canyons winds southeastward to the Rio Grande River after joining beside the old Lowdermilk camp site east of the junction of Route 4 and the road to Post 1. In order to determine the extent and sources of radioactive contamination in these localities it is necessary to collect and radioassay fluid samples from each of the sewers, soil samples from the ground surrounding the sewer exits, and water and soil samples from selected spots in or near each of the two canyon streams. Some preliminary radioassay work was carried out in July, 1945 and previously reported, but because of the importance of the work and the possibility of increasing amounts of radioactive materials accumulating in the area the analyses and surveys were repeated using more exacting methods.

Four groups of radioassay determinations were run. The first group of assays was made on water samples from all sanitary and chemical sewer outlets. Samples were collected and assayed in July, 1946 and in September, 1946. The second group of assays (October and November, 1946) was made on soil samples taken from the ground surrounding all sewer outlets that were found contaminated when surveyed with a portable alpha survey instrument. In some cases, however, soil samples were collected from the ground surrounding exits where the presence of radioactive contaminants, by instrument survey, was not indicated but was suspected. This was done to insure a complete and accurate survey of the entire area and to insure a positive check of spots where any possible contamination might be present even though it might not be detectable by direct instrumentation. Pictures

were taken of most of these samples sources. The third group of assays (September, 1946) was made on samples of water taken from stagnant pools in both Pueblo and Los Alamos Canyons. These samples were collected from pools as far down as the Rio Grande River. The fourth group of assays (October and November, 1946) was made on soil samples taken from points in the stream beds in Pueblo and Los Alamos Canyons. As in the case of the soil samples taken from near the sewer exits, pictures were taken of the sources of the soil samples in the canyons where alpha contamination was found to be appreciable by survey with a portable alpha survey meter."[23]

Similar monitoring continued at least through 1949.[24,25,26,27,28]

At the meeting of the AEC Waste Processing Committee at Los Alamos in October 1950, the USGS presented a paper "Geologic Background of Waste and Water-Supply Problems at Los Alamos,"[29]

"The U. S. Geological Survey in cooperation with the U. S. Atomic Energy Commission and the University of California, Los Alamos Scientific Laboratory, began a program in 1949 to monitor the chemical and radiochemical concentrations in surface and ground water in the Los Alamos area. Water samples for chemical and radiochemical analyses were collected downgradient from waste disposal points, industrial-waste treatment plants, and disposal pits."[36]

"The purpose of collecting these data is to determine if, or to what extent, low-level radioactive effluents from the operation of the Los Alamos Scientific Laboratory contaminate surface and groundwater systems downgradient from Los Alamos."[39]

There were at least eleven reports in this series describing monitoring of surface and ground water in the Los Alamos area. The first report, "Geologic and Hydrologic Environment of Radioactive Waste Disposal Sites at Los Alamos, New Mexico,"[30] was released in February 1963.

"A systematic sampling program was started about 1959, and a period of intensive sample collection lasted from July 1957 through July 1959, after which the program was reduced and sampling was done on a less intensive and a more selective basis."[30]

Other reports in the series presented basic data on the chemical and radiochemical analyses of water and on the hydrology of the Los Alamos area:

"The Hydrology and the Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, 1949-55."[31]

"The Hydrology and the Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, January, 1956 through June, 1967."[32]

"The Hydrology and the Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July, 1957 through June, 1961."[33]

"The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July 1961 through June 1962."[34]

"The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July, 1962 through June, 1963."[35]

"The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July, 1963 through June, 1964."[37]

"The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July, 1964 through June, 1965."[38]

"The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July, 1965 through June, 1966."[39]

"The Chemical and Radiochemical Quality of Surface and Ground Water at Los Alamos, New Mexico, July, 1966 through June, 1967."[39]

"Chemical and Radiochemical Analyses of Water in the Los Alamos Area, New Mexico, Made by the U.S. Geological Survey, 1960 through 1968."[40]

"The chemical and radiochemical quality-of-water data are presented in five parts: (1) Pajarito Plateau, test and supply wells, and surface water; (2) Mortandad Canyon, surface water and observation wells; (3) Los Alamos and DP Canyon, surface water and observation wells; (4) White Rock Canyon, springs and streams entering Rio Grande; and (5) Rio Chama and Rio Grande surface water.

The water samples were collected by personnel of Group H-6 of the Los Alamos Scientific Laboratory and by the U. S. Geological Survey. Radiochemical analyses were made by Group H-6 ... Chemical analyses were made by Group H-7 ..."[39]

"Soil Adsorption of Radioactive Wastes at Los Alamos,"[12] appeared in the December 1958 **Sewage and Industrial Wastes.**

"Certain of the results obtained in this study are not in complete agreement with those of Swope[1] *who found that both cesium and hardness broke through resin columns at about the same point. McHenry et al.*[2] *indicate a marked effect of the presence of cesium on the breakthrough of strontium. These studies did not show a similar effect. It is possible that the discrepancies are related to the different exchange properties of the basic adsorbents under study.*

Orcutt et al.[8] *have developed excellent expressions for dispersion and exchange phenomena applicable to radionuclides as they move through soils. Whether nuclides in low concentrations that are amenable to soil disposal will follow accepted physical laws is not known. Thomas*[4] *has stated that it remains to be proved that elements at concentrations of* 10^{-7}**M** *follow classical chemistry or the accepted physical laws of ion exchange. It is possible that a demonstration of the applicability of the mathematical treatment of Orcutt et al. to solutions where concentrations of solute approach* 10^{-7}**M** *will indicate the nature of their chemistry.*

It has been demonstrated that the tuff local to Los Alamos has a rather high capacity for the retention of various nuclides. This is especially notable since this particular material has an ion exchange capacity which is about as low as any to be found in nature. Cs^{137} *is apparently very tightly bound to the tuff and resists leaching by any of the common agents.* Pu^{239} *likewise is readily retained by the tuff and from actual experience at Los Alamos, plutonium in wastes discharged into the ground appear* (sic) *to remain at the point of discharge. However, from what is known about the chemistry of plutonium, it is entirely possible that this nuclide could be released at some future time by inadvertent discharge of solutions such as versene in the same area. Work on this phase is being conducted at Los Alamos.*

Sr^{90} is not retained by the tuff nearly so well as cesium and plutonium and it is much more easily released. It is becoming increasingly apparent that its fixation poses a most important problem, and it remains the controlling isotope in the disposal of radioactive wastes. Disposal of this isotope to soils is to be undertaken with extreme caution and only with foreknowledge of the nature of the soil and its capacity for the ions known to be present in the waste. Because Sr^{90} can be leached by other ions, a disposal area receiving this isotope must be closely guarded so that no other wastes will be discharged which might contain concentrations of ions sufficient to dislodge the already adsorbed nuclide."[2]

"(1) Swope, G. H., "Ion Exchange Technology," Nachod and Schubert, Academic Press, Inc., New York, NY, pp. 458-520, (1956).

(2) McHenry, J. R., Rhode, D. W. and Rowe, P. P., "Sanitary Engineering Aspects of the Atomic Energy Industry." A Seminar Report TID-7517 (Part 1A), pp. 170-190 (Dec. 1955).

(3) Orcutt, R. G., Rifai, M.N.E., Klein, G., and Kaufman, W. J., "Underground Movement of Radioactive Wastes." This Journal, 29, 7, 791 (July 1957).

(4) Thomas, H. C., private communication."

Conclusions from the 1966 USGS study, "Hydrology of Waste Disposal Systems, Los Alamos, New Mexico, 1949 through 1961,"[41] state:

"Chemical and radiochemical contamination at Los Alamos is limited to the canyon disposal areas receiving treated industrial effluent. It is greatest near points of effluent discharge; even here concentrations are usually below MPC and they diminish downgradient in the canyons. Test and supply wells completed in the main zone of ground water saturation indicate no chemical or radiochemical contamination. Monitoring of ground water at the supply wells and of surface water in the Rio Grande and at springs emptying to the river confirms that no detectable contamination has reached these waters.

Chemical treatment of liquid wastes and burial of solid wastes as practiced by the Los Alamos Scientific Laboratory reduce likelihood of serious contamination. Chemical treatment is complemented by the effectiveness of local geologic and hydrologic conditions in containing chemical wastes within narrow areal and spatial limits.

Practices, conditions and their interrelationships pertinent to the conclusion that it is unlikely that significant contamination could reach the river or the supply wells are summarized as follows:

1. Liquid wastes are treated to one-tenth MPC of radioactivity before discharge into the disposal areas.

2. Storm runoff and treated sewage dilute the effluent and reduce the already low levels of radioactivity.

3. Chemistry of the liquid wastes, especially their high pH, promotes the exchange of radioactive components in the effluent with ions in clay, and attachment of effluent components to clay particles.

4. Clay minerals, montmorillonite and illite are weathering products of the tuff and are in large quantity in the canyons. They effectively bind radioactive ions or molecules. Clay particles, with attached radioactive materials, are dispersed down gradient and laterally in the canyon disposal areas by sudden strong flows of effluent or storm runoff. Seepage also disperses radioactive material by carrying some of it vertically and laterally to buried clays. These factors combine to decrease the likelihood of occurrence of a larger anomalous concentration.

5. Sludge produced in chemical treatment of liquid wastes is mixed with vermiculite or cement and put in barrels to prevent leakage or leaching.

6. Soil around the solids disposal pits and the compacted tuff used to cover the pits when they are filled inhibit the infiltration of water from precipitation through the waste.

7. The tuff of the plateau can retain certain nuclides by ion exchange.

8. The large volume of unsaturated volcanic rock and sediment under the plateau is a potential reservoir for storage of contaminated water.

9. The slow movement of ground water (about 360 feet per year) would allow an interval greater than 70 years for chemical reaction and for radioactive decay of contaminants between the time that they might enter the ground water and the time that water would reach the river or the zone from which water is being pumped."[41]

From 1968 through 1970 LASL reported measurements of air particulate radioactivity and activity in precipitation:

"Radioactivity in Environmental Air at Los Alamos, New Mexico, for the Period November 17, 1958 through December 31, 1959,"[42]

"Strontium-90, Cesium-137, and Radioactive Rare Earths in Environmental Rain and Air at Los Alamos, New Mexico, 1958-June 1963,"[43]

"Strontium-90, Cesium-137, and Radioactive Rare Earths in Environmental Rain and Air at Los Alamos, New Mexico, 1963-1964."[44]

"Beta-Gamma Radioactivity in Environmental Air at Los Alamos, New Mexico, for 1960."[45]

"Beta-Gamma Radioactivity in Environmental Air at Los Alamos, New Mexico, for 1961."[46]

"Beta-Gamma Radioactivity in Environmental Air at Los Alamos, New Mexico, for 1962."[47]

"Beta-Gamma Radioactivity in Environmental Air at Los Alamos, New Mexico, for 1963."[48]

"Beta-Gamma Radioactivity in Environmental Air at Los Alamos, New Mexico, for 1964."[49]

"Beta-Gamma Radioactivity in Environmental Air at Los Alamos, New Mexico, for 1965."[50]

"Beta Radioactivity in Environmental Air and Precipitation at Los Alamos, New Mexico, for 1966."[51]

"Beta Radioactivity in Environmental Air and Precipitation at Los Alamos, New Mexico, for 1967."[52]

"Beta Radioactivity in Environmental Air and Precipitation at Los Alamos, New Mexico, for 1968."[53]

"Beta Radioactivity in Environmental Air and Precipitation at Los Alamos, New Mexico, for 1969."[54]

"Beta Radioactivity in Environmental Air and Precipitation at Los Alamos, New Mexico, for 1970."[55]

In 1962, a study on "Plants As Monitors of Radioactive Contamination of the Environment of Los Alamos, New Mexico,"[56] was published.

The "Los Alamos Environmental Monitoring Program,"[57] published in 1970, gives an outline of

> *"the surveillance methods used throughout Los Alamos County and outside restricted areas to determine the effect of Laboratory operations on the environmental radioactivity. Gamma radiation measurements are routinely made. Scheduled samples of air and water are taken, assayed for gross alpha and beta activity, and also for certain specific nuclides which may be present in some concentration. Soil samples are taken when considered necessary."*[57]

Beginning in 1970 there is a series of reports which give the data outlined above:

"Los Alamos Environmental Monitoring Program, July through December, 1970,"[58]

"Environmental Monitoring in the Vicinity of the Los Alamos Scientific Laboratory, January through June, 1971."[59]

"Environmental Monitoring in the Vicinity of the Los Alamos Scientific Laboratory, July through December, 1971."[60]

"Environmental Monitoring in the Vicinity of the Los Alamos Scientific Laboratory, Calendar Year 1972."[61]

"Environmental Surveillance at Los Alamos during 1973."[62]

"Environmental Surveillance at Los Alamos during 1974."[63]

"Environmental Surveillance at Los Alamos during 1975."[271]

See Fig. 9 for thermoluminescent dosimeter (TLD) and air sampler locations, Fig. 10 for regional surface water, sediment and soil sampling locations; Fig. 11 for water sampling locations in White Rock Canyon of the Rio Grande; and Fig. 12 for water, sediment, and soil sampling locations on or near the LASL site.

Specific studies done in recent years are:

"Regional Survey of Tritium in Surface and Ground Water in the Los Alamos Area, New Mexico, August 1966 through May 1969."[64]

"Plutonium in Stream Channel Alluvium in the Los Alamos Area, New Mexico."[65]

"Plutonium and Strontium in Soil in the Los Alamos, Espanola, and Santa Fe, New Mexico, Areas."[66]

"Plutonium and Strontium in Soil Near Technical Area 21, Los Alamos Scientific Laboratory, Los Alamos, New Mexico,"[67]

"Los Alamos Land Areas Environmental Radiation Survey 1972."[68]

"Ecological Investigation of Radioactive Materials in Waste Discharge Areas at Los Alamos for the Period July 1, 1972 through March 31, 1973."[272]

"Dispersion and Movement of Tritium in a Shallow Aquifer in Mortandad Canyon at the Los Alamos Scientific Laboratory,"[69]

"Storm Runoff and Transport of Radionuclides in DP Canyon, Los Alamos County, New Mexico,"[70]

"The Distribution of Plutonium in Liquid Waste Disposal Areas at Los Alamos."[273]

"Distribution of Plutonium in Soil Particle Size Fractions of Liquid Effluent-Receiving Areas at Los Alamos."[274]

"The Distribution of Plutonium and Cesium in Alluvial Soils of the Los Alamos Environ."[275]

"Cesium-137 and Plutonium in Liquid Waste Disposal Areas at Los Alamos."[276]

"Accumulation and Transport of Soil Plutonium in Liquid Waste Discharge Areas at Los Alamos."[277]

"The Availability of Environmental Radioactivity to Honey Bee Colonies at Los Alamos."[278]

A proposed plan for environmental monitoring of waste disposal areas was made by H-8, December 27, 1973.

"It is the intention of the Environmental Section to establish a routine environmental monitoring program around all waste burial or storage areas both active and inactive....

From the standpoint of environmental surveillance we would like to document any current release or dispersion of contaminants from the disposal areas whether by atmospheric dispersion or by hydrologic transport. In consideration of the local ecology we would like to determine whether or not the buried materials have any effect on revegetation programs or ecological succession over completed waste pits; this would be in contrast to the normal disruption of the areas resulting from physical disturbance and operation of heavy equipment. Finally, for the waste management studies we would like to provide data which could be used to evaluate the longer range probabilities of migration of materials from the disposal site.

For the evaluation of atmospheric dispersion from active waste pits, we plan to install high volume air samplers to be operated on limited duty cycles only during pit filling operations.... From these air samplers we would like to obtain data on general dust loadings of the atmospheric (sic) *resulting from waste burial operations in addition to the identification of any releases of radioactive or chemical contaminants from the burial operations.*

The monitoring of dispersion into the tuff or the migration of moisture through the filled pit and the surrounding tuff would be by means of sampling tubes extending from the surface to the level of the bottom of the pit or lower in an array around each pit.... We would intend to measure soil moisture profiles through these access tubes by means of a neutron moisture gauge. We would also sample any moisture that might be found in the sampling tubes as well as collecting core samples of the tuff at the bottoms of the access tubes.

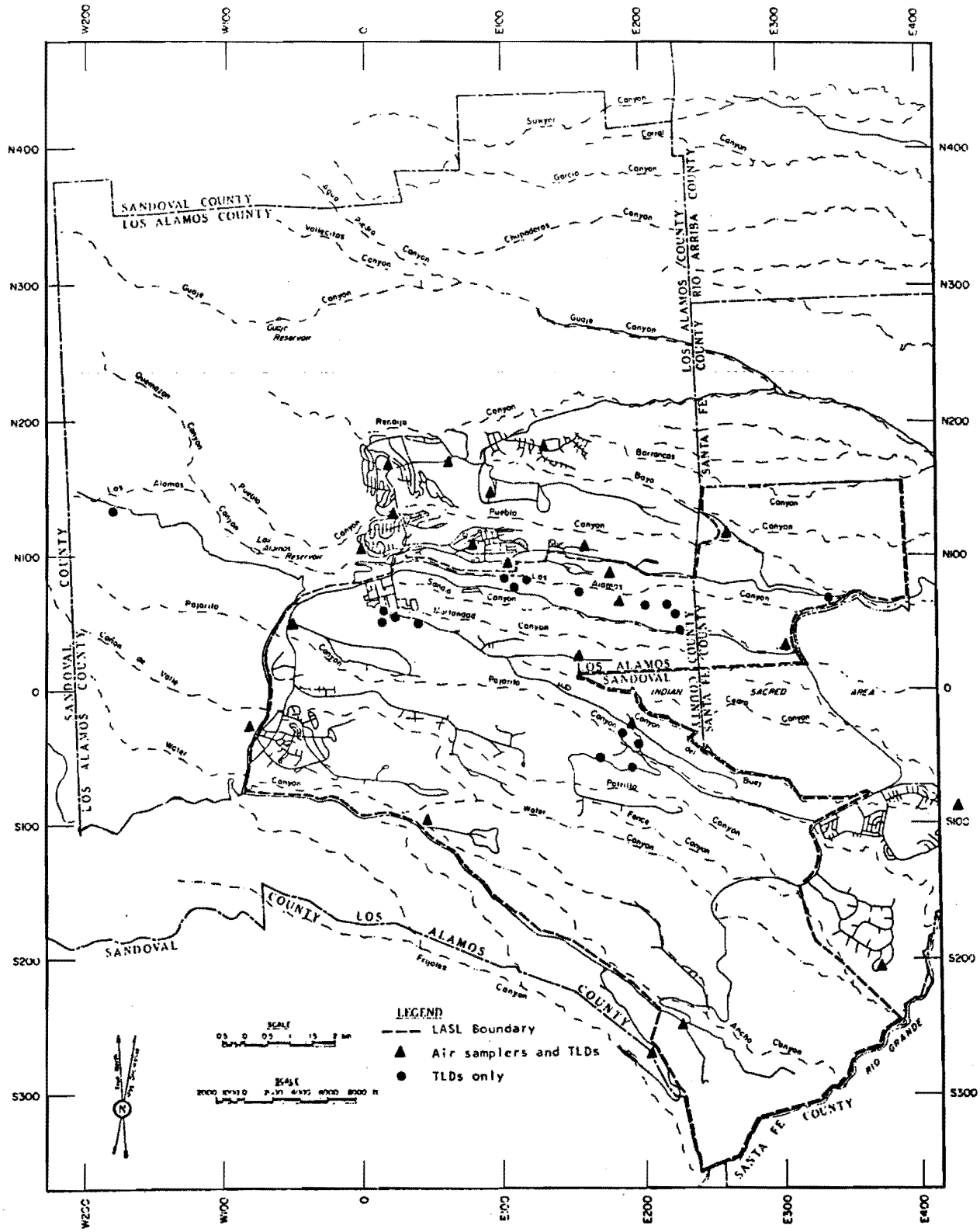


Fig. 9.
TLD and air sampler locations.

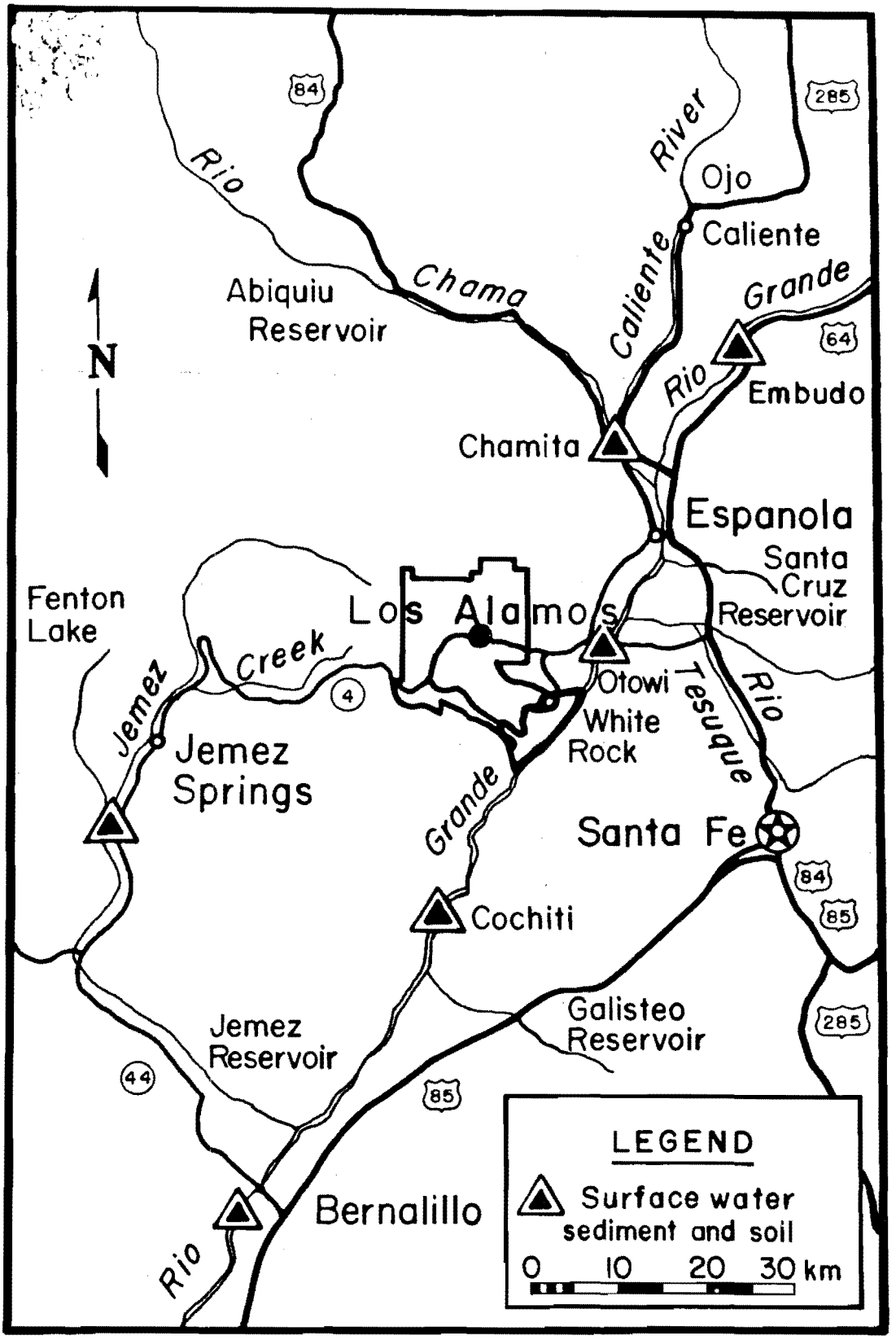


Fig. 10.
Regional surface water, sediment and soil sampling locations.

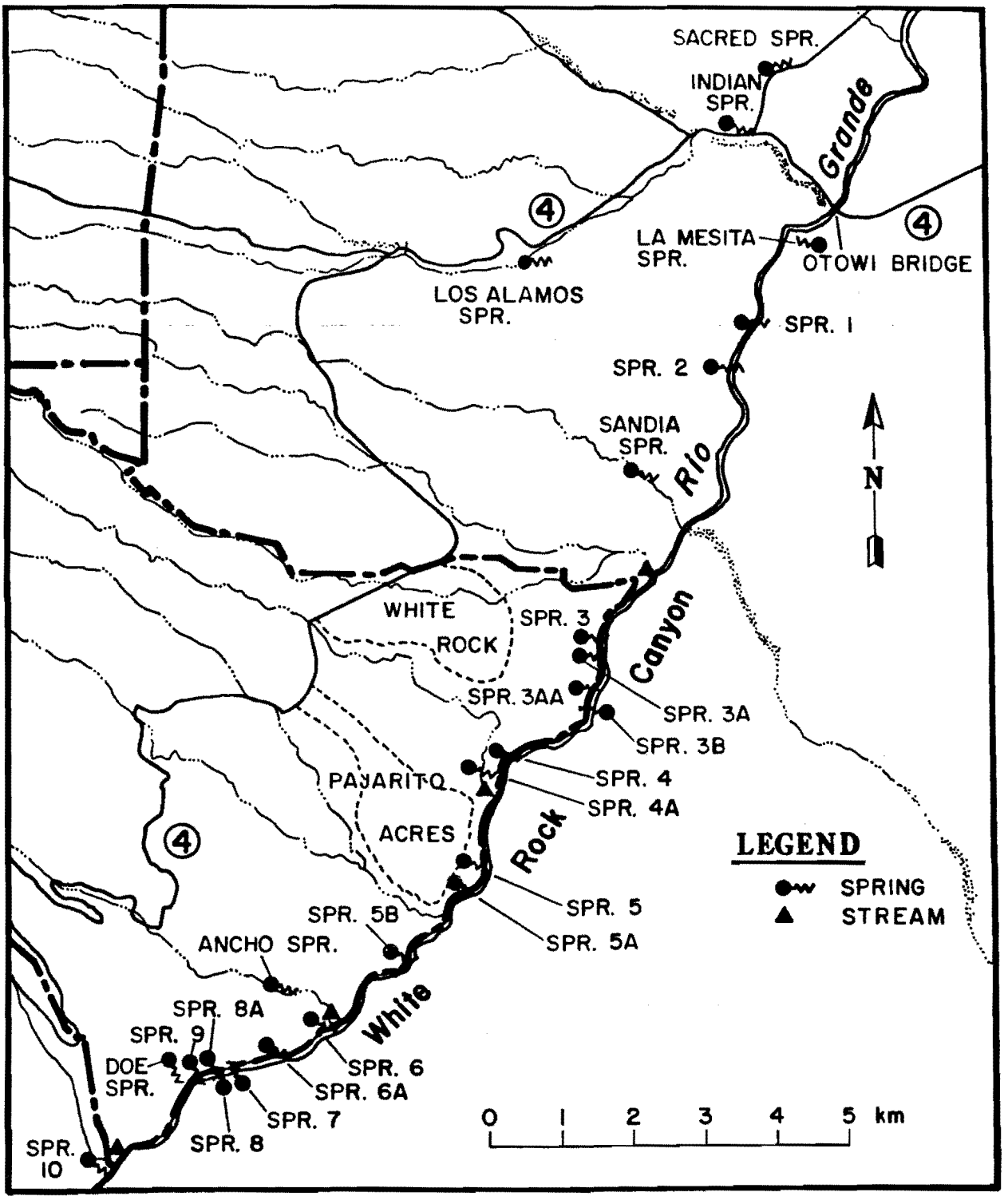


Fig. 11.
Water sampling locations in White Rock Canyon of the Rio Grande.

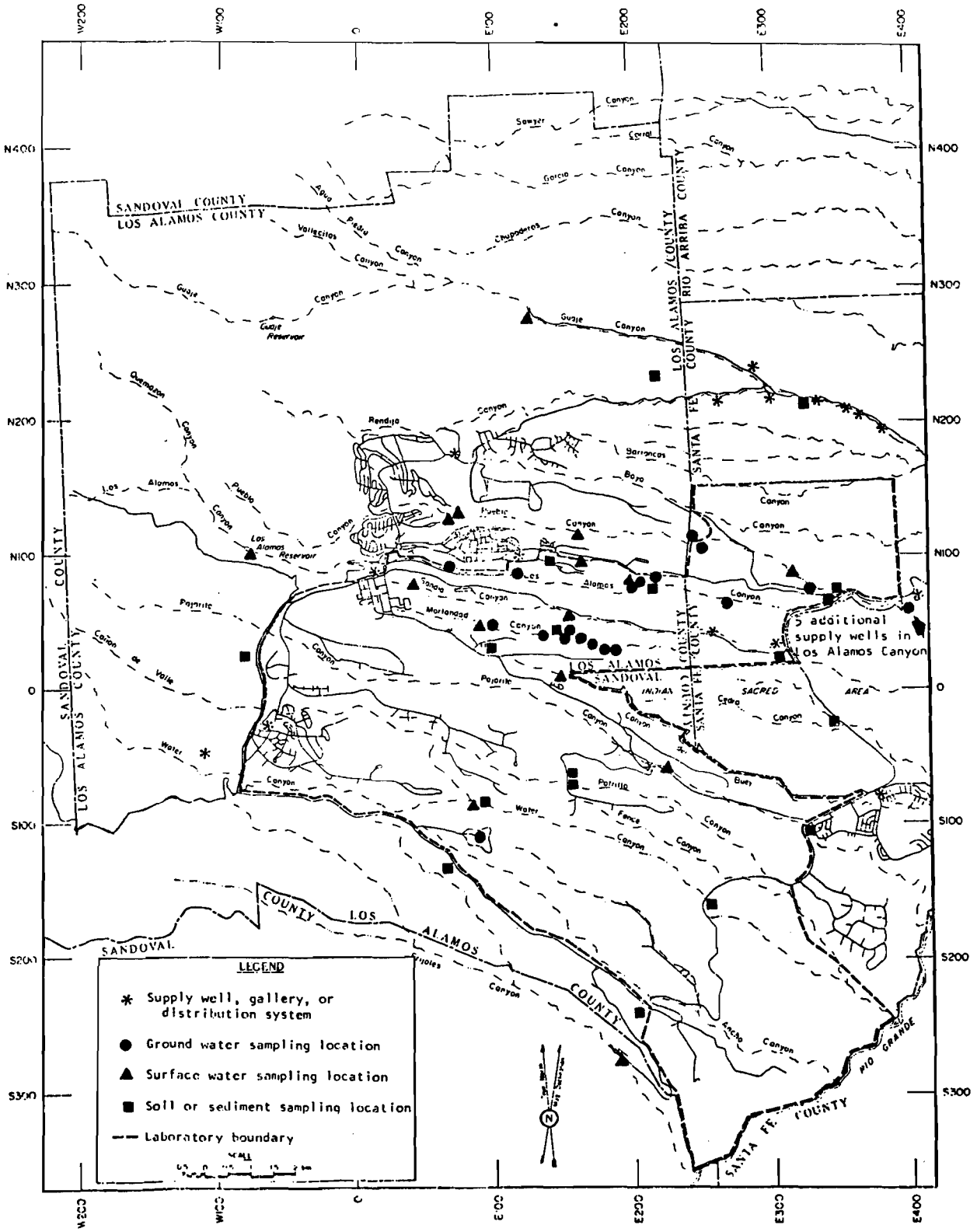


Fig. 12.
Water, sediment, and soil sampling locations on or near the LASL site.

An additional effort should be undertaken...to determine the moisture balance at or near the surface of filled pits. This would include meteorological data on precipitation (both total amounts and precipitation rates) and on evaporation rates in order to determine the net moisture budget of the fill material in the pit...

Sampling of vegetation over completed disposal pits will be undertaken to determine whether or not any of the contaminants buried in the pit have migrated to the surface and are being absorbed by plant tissues."[71]