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Paper 1

GEOLOGIC BACKGROUND OF WASTE AND WATER-SUPPLY PROBLEMS AT LOS ALAMOS

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INTRODUCTION

One of the problems that the Atomic Energy Commission and the U. S. Geological Survey are investigating at Los Alamos is the probable disposition underground of plutonium- and fluorine-bearing laboratory wastes that have been discharged in that vicinity in the past. The problem essentially consists in tracing this material underground as well as possible, envisioning its probable course, and considering its reactions with the rock materials through which it must percolate. To trace its course underground obviously demands a knowledge of the underground circulation of water and this in turn demands as a first requisite a knowledge of the rock materials through which the water circulates and of the rocks that limit its circulation or, in other words, the geology of the area.

GEOLOGIC FEATURES OF LOS ALAMOS AREA

A traveler leaving Albuquerque by air or land for Los Alamos is conscious of the mountain ranges bordering the valley on the east. The first of these, at Albuquerque, is Sandia Mountain, a name arising from the geology of the mountain. Sandia means watermelon, and despite some argument as to origin, must have arisen from the resemblance of the mountain, particularly in its sunset coloring, to a gigantic longitudinal slice of watermelon. The red meat of the watermelon is formed by Pre-Cambrian granite, and the rind is formed by the whitish curving band of limestone around it. Farther north the Sangre de Cristo Range extends from Santa Fe north into Colorado. (See map of this area, Fig. 1.1.) These mountain ranges with their deep-seated granitic cores form an effective barrier to confine the ground water of the area within the Rio Grande Valley.

To the west of the river the traveler sees volcanic cones, evidences of widespread outpourings of lava on the west side of the Rio Grande from the southern part of New Mexico to the center of Colorado. These old volcanoes are not so continuous as the mountains on the east side of the river, but where present they form barriers to the movement of water through them.

One of these old volcanoes is of particular interest to us. It is the Jemez Volcano, or the Sierra de los Valles, in the shadow of which Los Alamos lies. The name means the Mountain of the Valleys, so named because the center of the mountain is occupied by broad valleys; the geologic significance of the name will be apparent later. At present, it should be pointed out that the core of this mountain, a succession of lava flows of andesite, forms an effective barrier to the movement of water to the west of the river at Los Alamos.

As Los Alamos is approached from the air, the gorge of the Rio Grande south of Los Alamos can be seen. This gorge is White Rock Canyon, which appears to be a misnomer, since the prominent rocks are black basalt lavas. At the south end of the canyon east of the river is a group of low volcanic cones,

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the Cerros del Rio, or River Hills, which were the source of much of the lava seen in White Rock Canyon. The road from Santa Fe to Los Alamos crosses the Rio Grande [illegible] above this canyon and south of a broad valley called the Espanola Valley. The traveler coming [illegible] car from Santa Fe passes through the north end of one of these lava flows just past the gravel pits [illegible] the road west of the Rio Grande.

While traveling by car from Santa Fe to Los Alamos, the most conspicuous materials are the pink, light buff and whitish silty and sandy beds of the mesas between Santa Fe and the river. These form the Santa Fe formation, which is the most important formation with which the hydrologist has to deal in this area. The broad plains seen along the river from the air are mostly underlain by the Santa Fe formation.

By driving from the river to Los Alamos, the gravel pits can be seen that were the source of nearly all the aggregate used in construction at Los Alamos. The traveler may perhaps notice in the road cuts and the lower cliffs near the river the boulders and cobbles that were exploited in these pits. This material is the Puye gravel, which in the area of our interest is confined to the vicinity of the Jemez Volcano, from which it was largely derived. It is several hundred feet thick.

Finally, the most conspicuous natural sights at Los Alamos are the pinkish cliffs that bound the mesas on which Los Alamos is situated. These cliffs are composed of the Bandelier tuff, which is a deposit of fine ash and other debris blown out of the Jemez Volcano.

GEOLOGIC HISTORY

Some of the features affecting the hydrology of the Los Alamos area were initiated in the earliest of geologic time, when the first rocks of our continent were formed. This was a complex process resulting in the formation of a mass of dense crystalline rock that is now exposed in the mountains to the east of the Rio Grande. These old Pre-Cambrian rocks were planed off toward the end of the Paleozoic age; limestone (of Pennsylvanian age), shales, sand, and other limestone were laid down partly in the sea and partly on the low-lying continent in the late Paleozoic and Mesozoic ages. These rocks are now exposed in the eastern and western parts of New Mexico but they have been deeply buried in the Rio Grande Valley.

In late Tertiary time, when mammals were dominant on the earth, the area began to undergo changes. Perhaps the changes were initiated by the emergence of the Jemez Volcano, since similar activity began at this time in southwestern Colorado in the San Juan Mountains. However, no definite evidence of this activity has been found in the region itself, and the succeeding deposits of the Santa Fe formation contain no material eroded from this ancestral volcano. If it had ever attained any prominence before this time, it had been nearly eroded before the later deposits were laid down.

In late Miocene or early Pliocene time, a trough began form[illegible] in what is now the Rio Grande Valley. Presumably, this trough was formed largely by faulting, which occurred little by little leaving the ancestral Sangre de Cristo Range standing on the east above the valley that was forming and some similar highlands on the west of the valley.

From the then-existing mountains great alluvial aprons were spread out and formed what is now referred to as the Santa Fe formation. The materials of these deposits were coarser near the mountains and grew finer as the distance they were transported increased. Little by little the Rio Grande Valley was downdropped with relation to the mountains, and thicker and thicker grew the deposits of material eroded from the mountains. In the Los Alamos region the aprons apparently grew out from the Sangre de Cristo for, in general, the materials grew finer toward the west across the valley. It is suspected that there was an ancestral Rio Grande draining the area but if so, its course, which would be marked by gravels deposited in its channel, probably lay to the west of Los Alamos, perhaps over the site of the present Jemez Mountains which then either had not yet been born or, if in existence, had been planed off by earlier erosion. The Rio Grande trough was eventually lowered during this period until its original surface was at least 2000 ft below the present Rio Grande; the water-supply wells at Los Alamos penetrate this thickness of Santa Fe formation and do not reach its bottom. The total thickness of the Santa Fe was much greater than this, because at one time the top of this formation must have stood a few thousand feet above the present Rio Grande. At this time the climate of the area was more humid than it is today; it supported a vegetation for the sustenance of the great mammals of the period. In the Santa Fe formation have been found bones of mastodon, rhinoceros, camel, deer, three-toed horse, dog, weasel, oreodont (an early hog), and beaver.[1]

During and probably before this period volcanoes were erupting. Beds of fine volcanic debris (tuff) were laid down with the other materials making up the Santa Fe formation. In the Chama drainage north of the Los Alamos area, a deposit of tuff from 500 to probably more than 1000 ft thick was laid down largely before the Santa Fe was deposited.[2] There is no known evidence of the presence of the Jemez Volcano at this time. However, there were probably small volcanoes in the Cerros del Rio area and probably fissures that were erupting molten lava, which flowed out upon the existing surface of the alluvial debris in the White Rock Canyon section and is now interbedded as black basalt flows with the silt and sand of the Santa Fe formation in that canyon.

By this time many of the geologic features that determine ground-water movements in the vicinity of Los Alamos, and hence the characteristics of the water supply at Los Alamos and the underground movement of wastes, had already been initiated. The spreading out of the alluvial aprons from the relatively distant ancestral Sangre de Cristo had the result that the deposits in the Los Alamos area are relatively fine and of low permeability. The deposition by the ephemeral floods off the mountains resulted in a material that in one layer was somewhat coarser, in the next layer somewhat finer, and so continuing. The emergence of the lava in the Cerros del Rio section began to seal off the lower end of the Espanola Valley.

Succeeding the deposition of the sand and silt of the Santa Fe formation in the Los Alamos area are materials that are the first clear indication of the presence of the Jemez Volcano. Streams began to erode the old volcano and pile up around its base a deposit of boulders and cobbles derived from it, as much as 500 ft thick—the Puye gravel. The valley was downdropped relative to the volcano, or perhaps the volcano may have been growing at this time. At any rate, about this time, it was an imposing sight, rising probably some 2000 ft above its present greatest height, built up largely of flows of a dark-gray rock, andesitic in composition. Erosion cut deep canyons along the flanks of this old cone.

These events were occurring at just about the beginning of Pleistocene or Glacial time. During most of the Glacial age, erosion was the dominant process around Los Alamos and the Espanola Valley. Renewed faulting raised the mountains relative to the valley. The Santa Fe formation was planed down into the broad sloping plains characteristic of the country east of Santa Fe. The plain on which Santa Fe is situated was graded by erosion to a level of the old Rio Grande about 500 ft above its present position; then a lower plain was cut to a river level about 250 ft above the present. During this period, vulcanism was again, or still, active. Sheets of basaltic lava were poured out on these surfaces, in the neighborhood of Los Alamos, from the Cerros del Rio and other vents east of the river. These flows interfered with the deepening of the Rio Grande gorge, filled up the then-existing gorge several times, and forced the river to begin cutting a new one. One of these sheets is crossed by the highway to Los Alamos just west of the Lowdermilk gravel pit. It dammed up the Rio Grande for a while, and a mass of laminated clay formed in the old valley about 100 ft thick extending north of the edge of this flow. This clay is exposed among other places in the road cut at the north end of the hairpin turn about a mile west of the gravel pits.

When the Rio Grande had cut down almost to its present level, almost yesterday in geologic time, the Jemez Volcano again exploded, with an energy that makes Los Alamos' further explosive efforts anticlimactic. These eruptions began with an explosion of gas-laden volcanic glass that covered the vicinity of the volcano with a layer of pumice some 30 ft thick. There followed a comparatively mild explosion that spewed out ash and pumice lumps, which covered the territory between the volcano and the Rio Grande, and territory to comparable distances in other directions from the volcano, with a layer of whitish tuff more than 100 ft thick. Succeeding this mild explosions, a series of belchings occurred; hot gas laden with incandescent debris from the volcano rushed down the valleys cut in the old volcano and spread out as fiery clouds over the plain. The incandescent particles dropped from these clouds partly fused together and formed the welded tuff deposits, several hundred feet thick, which are exposed in the pinkish cliffs surrounding Los Alamos and which also form the plug at the head of Quemazon Canyon through which the tunnel of the abandoned water-supply project to bring eventually passes through the Santa Fe formation, since the water table drops below the base of the Puye in the neighborhood of production well number 4 of the present Los Alamos water system.

The Santa Fe formation in this area is not very permeable; it is probably one of the poorest aquifers in the country from which large quantities of water are withdrawn. Pumping tests on wells going 1800 ft below the water table indicate an average permeability such that about 8 gal a day would move through a square-foot cross section under a unit gradient, or as used by the U. S. Geological Survey the coefficient of permeability is about 8. Studies made by Griggs of the U. S. Geological Survey on outcrops of the formation east of the river indicate that about 10 per cent of the material has a coefficient of permeability between 35 and 50, about 20 per cent has a coefficient of 10 or 15, and about 70 per cent has a coefficient of 1 or 2. The materials in a good aquifer have a permeability of several hundred.

The interlayered beds of varying permeability in the Santa Fe have the effect of reducing the water-carrying capacity of the formation still more. The horizontal movement of ground water is governed by the weighted average permeability of the beds, as if the hydraulic circuits were connected in parallel. However, the vertical motion of the water is governed by the sum of the resistances or the reciprocals of the permeabilities of the various beds, as if they were connected in series. Hence the vertical movement of the water is greatly impeded and water being recharged at the surface of the formation in the western part of the area and discharging into the river at the east edge of the area has difficulty in penetrating to the lower part of the aquifer and rising again from the lower part to the surface at or near the river. The vertical exaggeration of the diagram in Fig. 1.2 is about 12.5, and this exaggeration happens to represent about that which would be used in a hydraulic model of the formation using a uniform material. Because of the anisotropic character of the formation, the movement of ground water at depth in the formation is slower than it would be otherwise. However, there is one compensating factor: water at depth in the formation is warmer because of the geothermal gradient of the earth. Being therefore less viscous, it is moved through the pores of the formation more easily.

The water supply of Los Alamos is drawn from the Santa Fe formation. The more productive wells are about 2000 ft deep and do not reach the bottom of the formation. They produce only from 4 to 6 gal of water per foot of drawdown, owing to the low permeability of the formation, whereas in good aquifers, similarly constructed wells of much less depth produce from 20 to 100 gal and more per foot of drawdown. Because of the great horizontal extent of the Santa Fe formation, there is a tremendous quantity of water in storage and there is no possibility of exhausting the reservoir under any foreseeable demands on it, although because of its low permeability, the process of extraction will be relatively expensive. Because the materials of the Santa Fe are derived largely from granitic rocks, the water is soft and unusually high in silica. Probably because Los Alamos is at the site of an old volcano, the water is somewhat high in fluorine content, averaging about 1.5 ppm. Fluorides are a common component of volcanic gases, and it seems that these gases are slowly emitted in volcanic regions long after active vulcanism has ceased. The fluoride in Los Alamos water is probably contributed from below; hence it will likely be found that the deeper and more slowly moving part of the water is higher in fluoride than that at shallower depths.

DISPOSAL OF WASTES

Up to the present time the laboratory wastes at Los Alamos have been disposed of at the surface just above the location of the westernmost test well shown on Fig. 1.2 in a short tributary of Pueblo Canyon. These wastes carry varying amounts of fluorine and plutonium. The wastes are discharged over Bandelier tuff. Within a distance of about one-half mile, the plutonium content has been reduced to safe levels by adsorption or base exchange with the slightly weathered tuff over which it flows, and within another one-half mile, the flow disappears into the ground.

The tuff is a porous but not very permeable rock made up of fine particles of glass and small crystals of sanidine ($KAlSi_3O_8$) and quartz. The agglomeration of fine particles has a very large total surface area. Incomplete tests made in the Industrial Waste Laboratory at Los Alamos have indicated

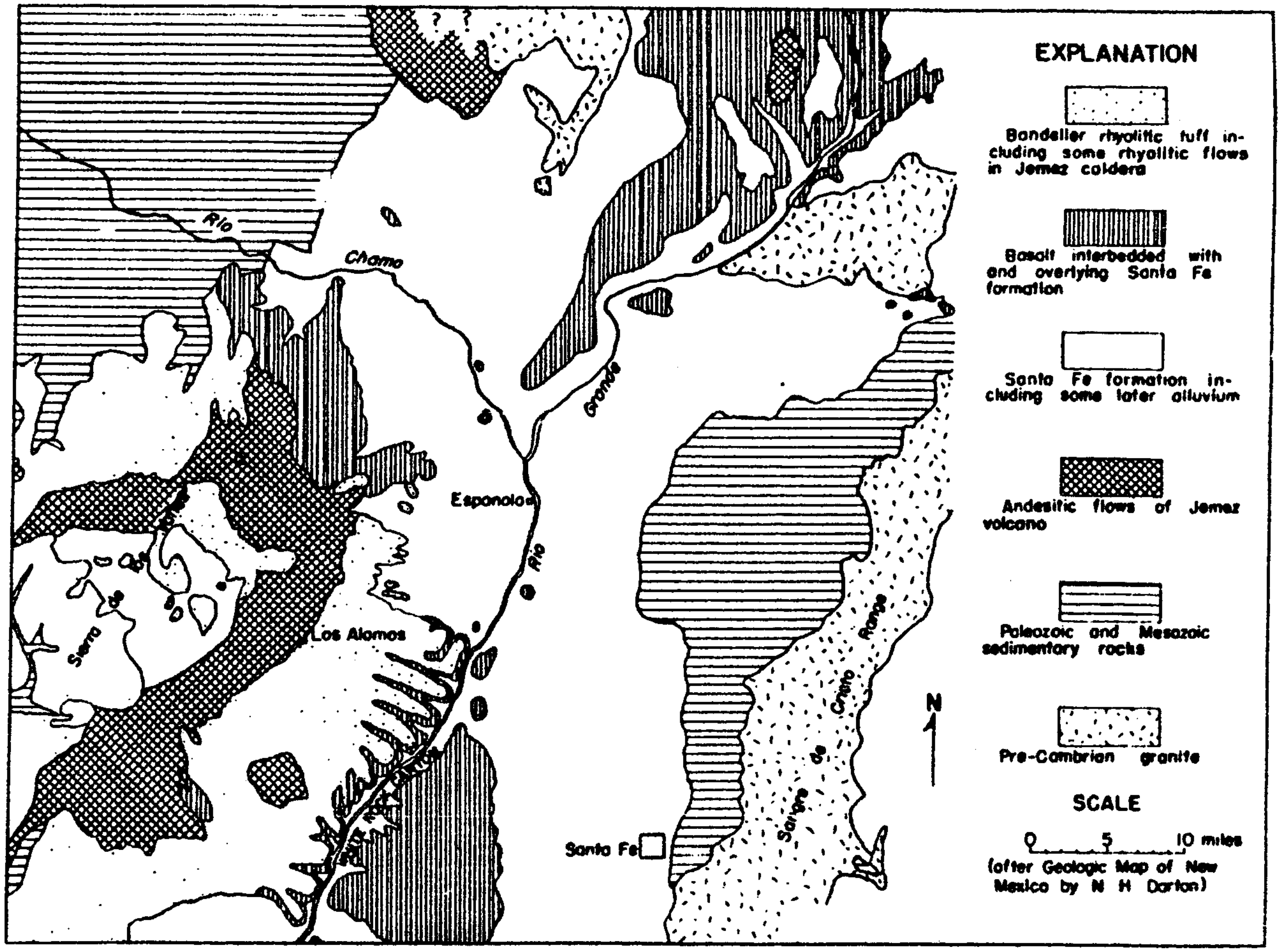

Fig. 1.1—Geology of Los Alamos area.

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UNITED STATES ATOMIC ENERGY COMMISSION

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MEETING OF AEC WASTE PROCESSING COMMITTEE AT LOS ALAMOS, NEW MEXICO

October 1950

Atomic Energy Commission

Technical Information Service, Oak Ridge, Tennessee

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