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SOME FUNDAMENTAL HYDROLOGIC ISSUES PERTINENT TO ENVIRONMENTAL ACTIVITIES AT LOS ALAMOS NATIONAL LABORATORY, NEW MEXICO

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Abstract—Monitoring/restoring the 2000+ contaminated sites at Los Alamos National Laboratory (LANL) and protecting ground water in future waste-disposal activities, requires an understanding of the hydrologic system(s) on the Pajarito Plateau. Despite previous work, the conceptual hydrogeologic model for LANL is incomplete. Some fairly basic questions about ground-water occurrence, movement and quality remain. For example, what is the number of perched-water zones, the depth of ground water, the extent of perched-water zones, the possibility of recharge through the tuff, the ground-water flow direction near well fields, the origin of springs in White Rock Canyon, the fate of perched ground water, the water budget for the Pajarito Plateau, the background hydrochemistry for the saturated zones and the inventory of radionuclides in canyons receiving effluent? Answering these involves synthesis of existing information, collection of new data and rethinking of current concepts.

INTRODUCTION

Radioactive and hazardous waste has been generated and disposed of at Los Alamos National Laboratory (LANL) since its inception in 1943 (Kelly, 1975). More than 2000 potentially contaminated sites or solid waste management units were recognized at LANL in 1995 (Anonymous, 1995a). The monitoring and restoration of these sites, as well as protection of ground water in future waste-disposal activities, requires a thorough understanding of the hydrologic system(s) at LANL.

The New Mexico Environment Department (NMED) entered into an agreement with the Department of Energy (DOE) in October 1990 (renewed in September 1995) to provide guidance regarding applicable state laws and regulations as well as technical comments on environmental activities. These include air quality, surface-water quality, ground-water quality and hazardous-and-radioactive-materials issues. In January 1995, a separate NMED bureau was created to handle these functions. Oversight at LANL is provided by a staff of seven based in White Rock, supplemented, as necessary, by technical support staff based in Santa Fe and Albuquerque.

LANL is situated on the Pajarito Plateau, the expanse of deeply dissected Bandelier Tuff between the Jemez Mountains and the Rio Grande. Much has been learned about the hydrogeology of the Pajarito Plateau since Purtymun and Johansen (1974) described it in the New Mexico Geological Society's last guidebook on the area. For example, the U.S. Geological Survey developed a four-layer numerical model of the regional hydrology (McAda and Wasiolek, 1988). This was recently modified into an eight-layer model to incorporate new hydrogeologic findings (Frenzel, 1995). Despite this previous work, the conceptual hydrogeologic model for LANL (Fig. 1) is still incomplete and some questions remain.

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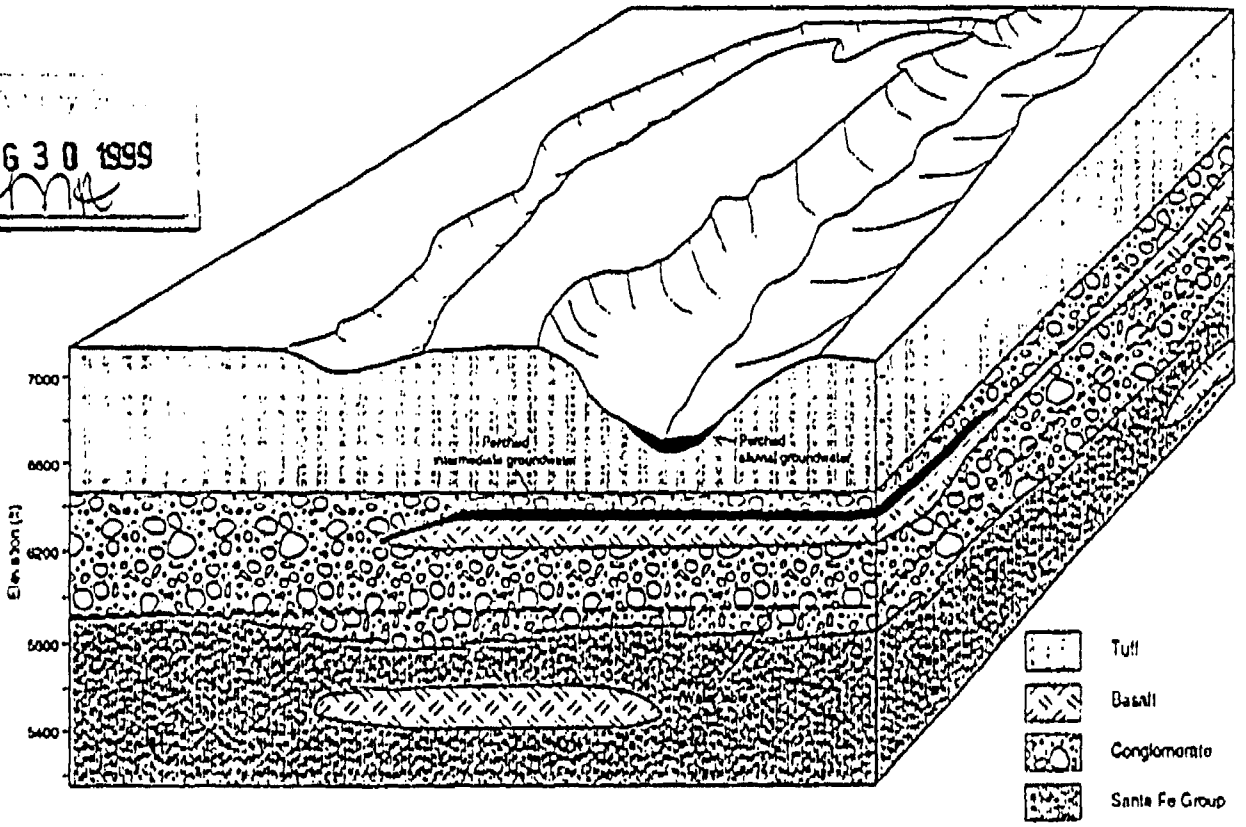

FIGURE 1. Conceptual hydrogeologic model for LANL (Anonymous, 1995b, fig. 3-2).

This paper identifies and discusses some hydrologic issues of concern in environmental efforts at LANL. Many issues could be included and omission of a specific issue here does not mean NMED considers it unimportant. In view of space limitations, 10 of the more fundamental issues have been selected. They span all areas of the conceptual hydrogeologic model: ground-water occurrence, movement and quality. In other words, where is the water, where does it come from, where does it go and what is its chemistry? Below, issues are presented in the form of questions, followed by a summary of what is known, what is not known and possible solutions. The observations made herein are offered in the spirit of technical comment and do not represent the regulatory position of NMED.

GROUND-WATER OCCURRENCE ISSUES

The occurrence of saturated zones at LANL must be known in order to protect, monitor or remediate them. More specifically, this includes determining the stratigraphic as well as geographic position of ground-water bodies. Of special interest are perched saturated zones—their occurrence, depth and lateral extent.

How many perched-water zones are there?

Significant water-yielding media are often called "aquifers". More specifically, an aquifer is a geologic material whose saturated portion has sufficient porosity, permeability, thickness and extent to yield useful quantities of water to wells. Since what constitutes "useful quantities" is subjective so too is the designation of materials as aquifers.

The recognition of aquifers at LANL has had an interesting history. The initial and long-standing view has been that there is only one saturated material capable of providing a water supply at Los Alamos, the so-called "main aquifer". It consists mainly of the Santa Fe Group and overlying Puye Formation (the conglomerate in Fig. 1) and contains the regional water table. However, as more holes were drilled, various perched saturated zones were encountered. Initially, this included the perched water bodies associated with alluvium in canyons (shallow perched water; Devaurs and Purtymun, 1985; Purtymun and Stoker, 1990) and with basalt or sedimentary units of the Puye Formation (intermediate perched water; Purtymun, 1975, 1995). However, in some places the intermediate perched water was found to be in the tuff. Griggs (1964) reported that a 2000-ft test hole to the Tschicoma Formation in upper Los Alamos Canyon (sec. 17, T19N, R6W) encountered perched water in both the alluvium and the Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff. Higher perched saturated zones also have been discovered in the Bandelier Tuff (Gardner et al., 1993; Broxton et al., 1995; Dale and Yanicak, this volume).

Although none of these perched zones appears to be a potential source of water supply, they have sometimes been referred to as aquifers because they generally yield more water than the surrounding materials. The term "perched aquifer" is not strictly correct as it is the water that is perched, not the geologic material containing it. In fact, the perched water may occur in the same geologic unit as the regional water table. Several standard hydrology texts apparently share this concern as they refer to "perched ground water" but not "perched aquifers".

The piecemeal evolution of nomenclature associated with the various saturated zones has led to communication problems. A simple scheme of designating them as "shallow", "intermediate" and "deep" will not work. That is, the practice of calling the ground water in the canyon alluvium the "shallow perched water" and that in the saturated Puye sediments or basalt above the regional water table the "intermediate perched water" is not strictly valid in view of the discovery of still shallower perched water in the tuff, not to mention other perched-water zones occurring in different geologic units than these. Of course the regional or "main aquifer" remains the "deep aquifer".

We need to know more about all of the materials containing perched water; their lithology, thickness and hydraulic properties across the Pajarito Plateau are not documented. This would require further drilling and aquifer testing. Additionally, we need to know where ground water is unconfined and where it is confined. It was recognized very early that water in the main aquifer is confined in some places (Cushman, 1965). Although recent studies of water-level fluctuations in the main aquifer confirm this (McLin, 1993), the specific areas where this applies should be delineated and mapped.

How deep is ground water?

Knowledge of the depth to various saturated zones at LANL is critical not only for understanding the hydrogeologic system in general, but also for ground-water protection, monitoring and remediation activities. Water-depth data come from measurements in wells and observations at springs. Thus, the understanding of ground-water depth is only as good as the well network and water-level data base. According to LANL's latest annual surveillance report (Kohen et al., 1995, table VII-1), this includes one spring for the water perched in the tuff, 19 wells for water perched in the canyon alluvium, two wells and one spring for the water perched in the basalt and sediments of the Puye Formation and 17 wells and 28 springs for the deep or main aquifer.

As noted in NMED's evaluation of the monitoring at LANL (Stone et al., 1993), this network is not adequate. There are too few wells for monitoring perched water in the tuff or the Puye, and large gaps in the coverage of the deep or main aquifer. Too many of the monitoring points are production wells with long screen intervals and too many are clustered at the same location. The need for additional drilling and better spacing of wells is now recognized by LANL and remedies are proposed in their Draft Ground Water Protection Management Program Plan (Anonymous, 1995b).

What is the extent of the perched-water zones?

In addition to depth, the lateral extent of the perched-water zones is pertinent to conducting/evaluating environmental activities. Perched ground water probably occurs in the alluvium of most of the canyons, especially in the western part of the Pajarito Plateau (Purtymun, 1995). However, its extent is best documented in Los Alamos, Mortandad and Pajarito Canyons (Devaurs and Purtymun, 1985; Purtymun, 1995).

The extent of other perched-water zones is poorly known. For example, although water is known to be perched in the Bandelier Tuff in some mesas, based initially on springs and now on drilling, its lateral extent there or under other mesas has not been determined. Similarly, although water is known to be perched in the basalt and sediments of the Puye Formation beneath Pueblo, Los Alamos and Sandia Canyons, its lateral extent has not been determined.

GROUND-WATER MOVEMENT ISSUES

Understanding ground-water movement is also essential to environmental activities at LANL. This includes movement of water between streams and saturated zones, between the various saturated zones and within saturated zones. More specifically, this involves a knowledge of the recharge, flow and discharge of ground water.

Is there recharge through the tuff?

As the Bandelier Tuff caps the Pajarito Plateau, it is the medium encountered by infiltrating precipitation, runoff and effluent. It was long thought that this material is sufficiently tight to prevent downward fluid movement. However, various lines of evidence suggest that while the tuff may retard percolation, it does not prevent it. The perching of ground water in the canyon alluvium on the tuff attests to its low permeability, but modeling of such perched water in Mortandad Canyon has suggested that there is considerable leakage into the tuff (Koenig and McLin, 1992; Geddis, 1992; Stone, 1995). Further, where the deep aquifer is unconfined, it presumably is in contact with the atmosphere through the tuff. Although the tuff lacks primary porosity and permeability, especially where welded, cooling and tectonic fractures are common. Such fractures often exhibit clay skins, suggesting water has moved along them. The importance of these features as potential pathways for contaminant transport has been recognized by LANL and an excellent study of the fractures in the north wall of Los Alamos Canyon has been made by Wohletz (1995). However, it is not clear whether fractures run all the way through the tuff or are interconnected enough to permit water to migrate to the underlying units. As noted by Rogers (1995), tectonic fractures may be more important as migration pathways than cooling joints. Another line of evidence that the tuff is not a barrier to flow is the occurrence of water within the tuff itself. Water that was not introduced

during drilling has been encountered in two holes in mesa settings (Gardner et al., 1993). Also, springs have been observed discharging from the tuff in the Pajarito Canyon and Canyon De Valle areas (Dale and Yanicak, this volume).

What is the ground-water flow direction around the well fields?

Water-level maps for LANL show that the regional ground-water flow direction is easterly (Fig. 2). Thus, monitoring is focused on detecting movement of contaminants toward the Rio Grande. However, near water-supply well fields, cones of depression associated with pumping can reverse flow direction, causing contaminants to move toward production wells rather than the river. The capture zone for each production well should be determined and cones of depression reflected on water-level maps. Both of these should be considered in placing future monitoring wells.

Why are all the springs in White Rock Canyon attributed to the main aquifer?

Water levels for the main aquifer decrease toward the Rio Grande and it is the logical discharge area for the regional saturated zone (Fig. 2). Presumably such discharge would be at river level, as shown in various LANL reports (e.g., Purtymun, 1984, fig. 2). However, of the 27 springs monitored by LANL, 15 are reported to be above the river or on the canyon wall and, based on the elevations given by Purtymun (1980, table 1), five more are also above the river. Thus, 20 of the 27 springs in White Rock Canyon discharge above the river and thus above the regional water table.

Various alternative interpretations are possible. The simplest is that the elevated springs represent discharge of some perched saturated zone(s) rather than that of the main aquifer. Other scenarios involve some splitting of the regional ground-water flow around basalt bodies, resulting in discharge at both perched and river-level positions. This could be tested by means of an east-west water-level profile across the plateau. However, construction of such a profile is hindered by uncertainty as to the elevation of the springs. Different reports give different values; for example, the elevation for Spring 6 (of Purtymun et al., 1980) is given as 5412 ft, as 5380 ft by Purtymun (1995) and as 5480 ft in a LANL memo to DOE (Rogers, personal commun., 1995).

Where does perched ground water beneath the Pajarito Plateau go?

Understanding the movement of perched water at LANL is important not only for conceptualizing the hydrogeologic system, but also for predicting the fate of water-borne contaminants. Such contaminants may reach the perched waters by recharge from contaminated surface waters, especially in the canyons. Leakage from perched-water zones may permit contamination of the regional aquifer. For example, tritium has been detected at depths of at least 195 ft beneath Mortandad Canyon (Stoker et al., 1991). The perched saturated zones in the tuff come to the surface via springs along canyons, where the water issues from fractures. The

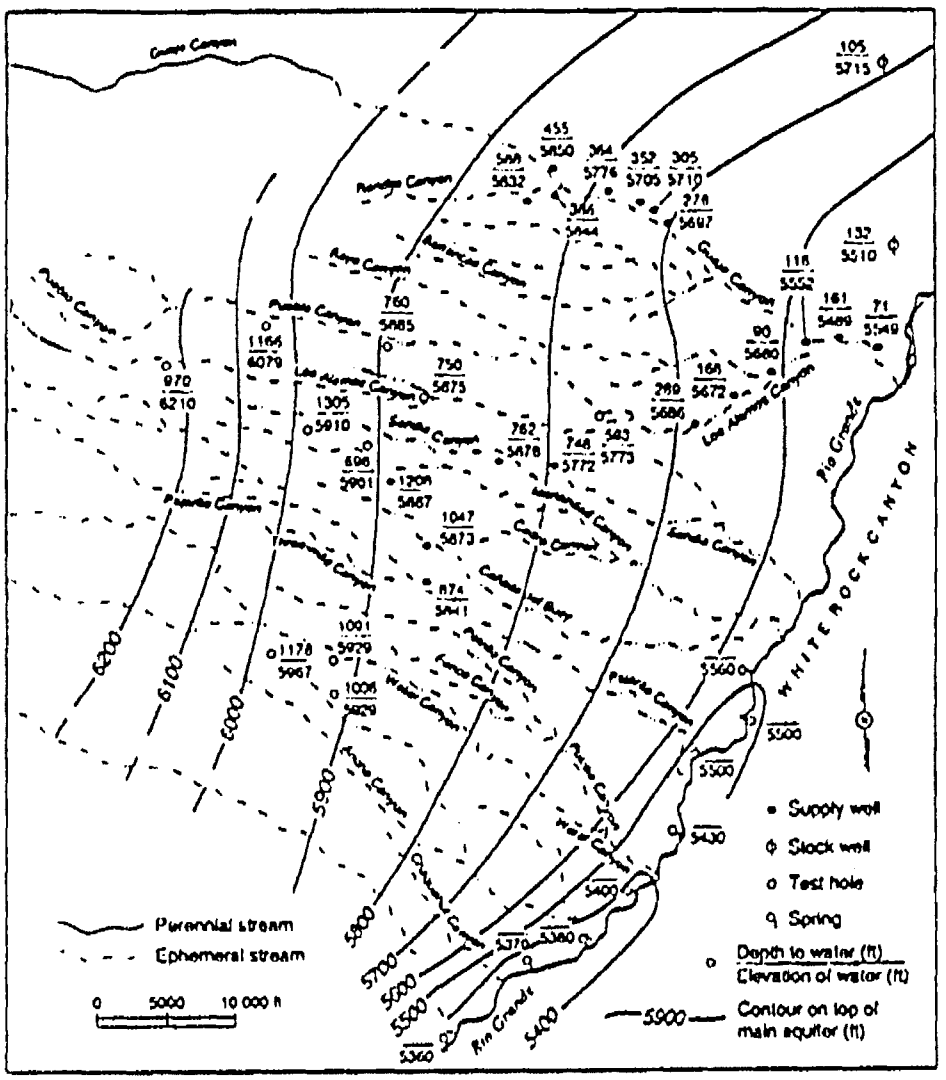

FIGURE 2. General water-level map for LANL (Purtymun, 1995, fig. 1-AE).

vertical position of the springs may be controlled by the degree of welding in the tuff.

The fate of water perched in the canyon alluvium is less obvious. Based on findings for Mortandad Canyon, it appears to be lost by leakage into the underlying tuff (Stone, 1995). Where there is a perched zone in the Puye beneath the canyon, it is recharged by downward percolating water from the tuff. In some canyons, however, there is no second perched zone. For example, Mortandad and Pajarito Canyons lack perched zones in the Puye, in the latter case despite the presence of basalt (Devaurs and Purtymun, 1985).

Water percolating downward from all of the perched saturated zones eventually reaches the regional aquifer. The fewer perched zones there are, the more direct the communication with the surface.

What is the water budget for the Pajarito Plateau?

The water budget for an area is essential in understanding its hydrologic system. Such budgets relate the various parameters of the hydrologic cycle. A common form deals with the redistribution or partitioning of precipitation: precipitation (P) = runoff (RO) + evapotranspiration (ET) + recharge (R). However, the quantification of these parameters at LANL is incomplete. Recent instrumentation has expanded the capability for assessing rates of P, RO and ET, but R remains essentially undefined. Separate water budgets for selected canyons of concern will be essential for contaminant-transport modeling.

GROUND-WATER QUALITY ISSUES

Another important attribute of the hydrologic system at LANL relating to environmental activities is water chemistry. An understanding of both natural and impacted ground-water chemistry is essential to interpreting monitoring results and determining clean-up levels.

What is the background hydrochemistry for each of the saturated zones ?

Although the various ground waters at LANL have been sampled and analyzed for many years, a definitive synthesis of background water quality has not been made. In other words, what are normal constituents in waters of the Pajarito Plateau and what is their normal concentration (range, mean, etc.)?

What is the inventory of radionuclides in the canyons?

Effluent containing radionuclides has been discharged into Acid, DP, Los Alamos and Mortandad Canyons. Most of the radionuclides become bound to alluvial sediments, so their concentration in the canyons increases. Because these sediments are then carried out of the canyons by storm runoff (Purtymun, 1974), the quantity of radionuclides in the canyons should be determined and monitored. The amount of radionuclides present in Mortandad Canyon as of 1978 was determined by Purtymun et al. (1983). They also projected that by 1990 this inventory would increase by 80%. A follow-up study would permit an evaluation of their projection as well as compliance with DOE concentration (activity) guides.

SUMMARY AND SUGGESTIONS

This paper has addressed some fundamental hydrologic issues for environmental activities at LANL. Their resolution will require the synthesis of information already available, the collection of some new data and, in some cases, the rethinking of current concepts.

1. The conceptual hydrogeologic model for LANL should be modified to include all the perched-water zones known and a nomenclature developed for them that eliminates confusion.
2. The lithology, thickness and hydraulic characteristics of the material making up such zones should be determined where necessary and compiled in a sitewide data base.
3. Additional wells should be drilled to permit adequate characterization of all saturated zones, especially near contaminated sites.
4. The Bandelier Tuff should no longer be assumed to be a hydrologic barrier.
5. The vertical extent of fractures in the Bandelier Tuff should be determined as far as possible.
6. Capture zones should be determined for each water-supply well.
7. Cones of depression for the producing wells should be reflected by contours on water-level maps.
8. The source of water issuing from the springs in White Rock Canyon should be reconsidered.
9. The fate of the various perched waters should be investigated, especially where they are near contaminated sites and could convey contamination back to the environment outside the lab or to deeper saturated zones.
10. The geologic control of the vertical position of springs in the tuff deserves more study.
11. A water budget should be constructed for the Pajarito Plateau and perhaps selected canyons of concern.
12. Background water chemistry for all waters should be determined, as far as possible.
13. An inventory of radionuclides in canyons should be carried out.

The current climate of budget cuts and staff reductions has led some to conclude that, "the time for study is over and the time for clean-up is here". Although that is a catchy phrase, where fundamental information is lacking or incomplete, studies are still needed.

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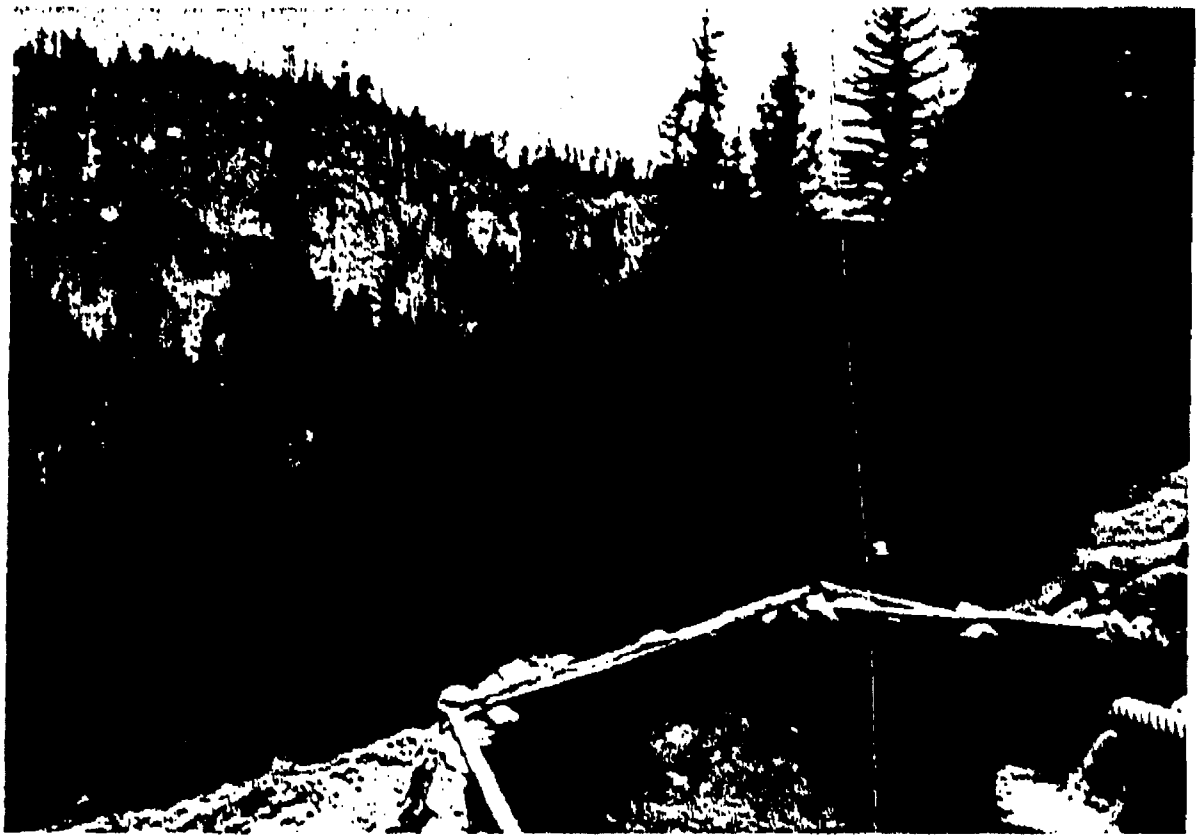

View to north of San Antonio hot spring (about 41°C), which issues from the contact of San Antonio Mountain rhollte and Redondo Creek Rhyolite. This spring is a favorite destination of cross country skiers in winter. Cliff in background is composed of Otowi Member, Bandelier Tuff, overlying Permian red beds of the Abo Formation.