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Geohydrology of the Climax Stock Granite and Surrounding Rock Formations, NTS

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ABSTRACT

The location of the water table and the degree of saturation of the granitic rocks in the Climax stock are presently unknown. Based on existing knowledge and an extrapolation of available geohydrologic data, it appears that the water table may lie at about 1100-1200 m above mean sea level (MSL) in the northeastern part of the stock and at about 800-900 m in the southwest. A drilling program would be required to establish these levels precisely. The degree of saturation at a given underground elevation may be approximated by a detailed inventory of seeps at that level. More precise determination of degree of saturation will require a water budget.

INTRODUCTION

The Nevada Test Site (NTS) is a U.S. Department of Energy facility primarily used for nuclear weapons testing. The Climax stock is a granitic rock mass that has intruded through Paleozoic sedimentary rocks and Tertiary volcanics at the northern end of NTS, where it crops out over an area of about 4 km^2 (see Fig. 1).

Initial exploration of the Climax stock was conducted in the late 1950s to determine the suitability of the rock mass for nuclear tests and to estimate the water content of the rock. Rock composition and properties (including permeability) were determined from core sample tests and in situ field tests. Subsequently, two shafts were excavated in the Climax stock for nuclear tests, the "Tiny Tot" and the "Pile Driver" shafts (see Fig. 2). Extensive horizontal tunnel complexes are associated with the Pile Driver shaft. At the 250-m depth level, there are drifts from the "Hard Hat" event; and at the 420-m depth level, drifts from the Pile Driver event (see Fig. 3).

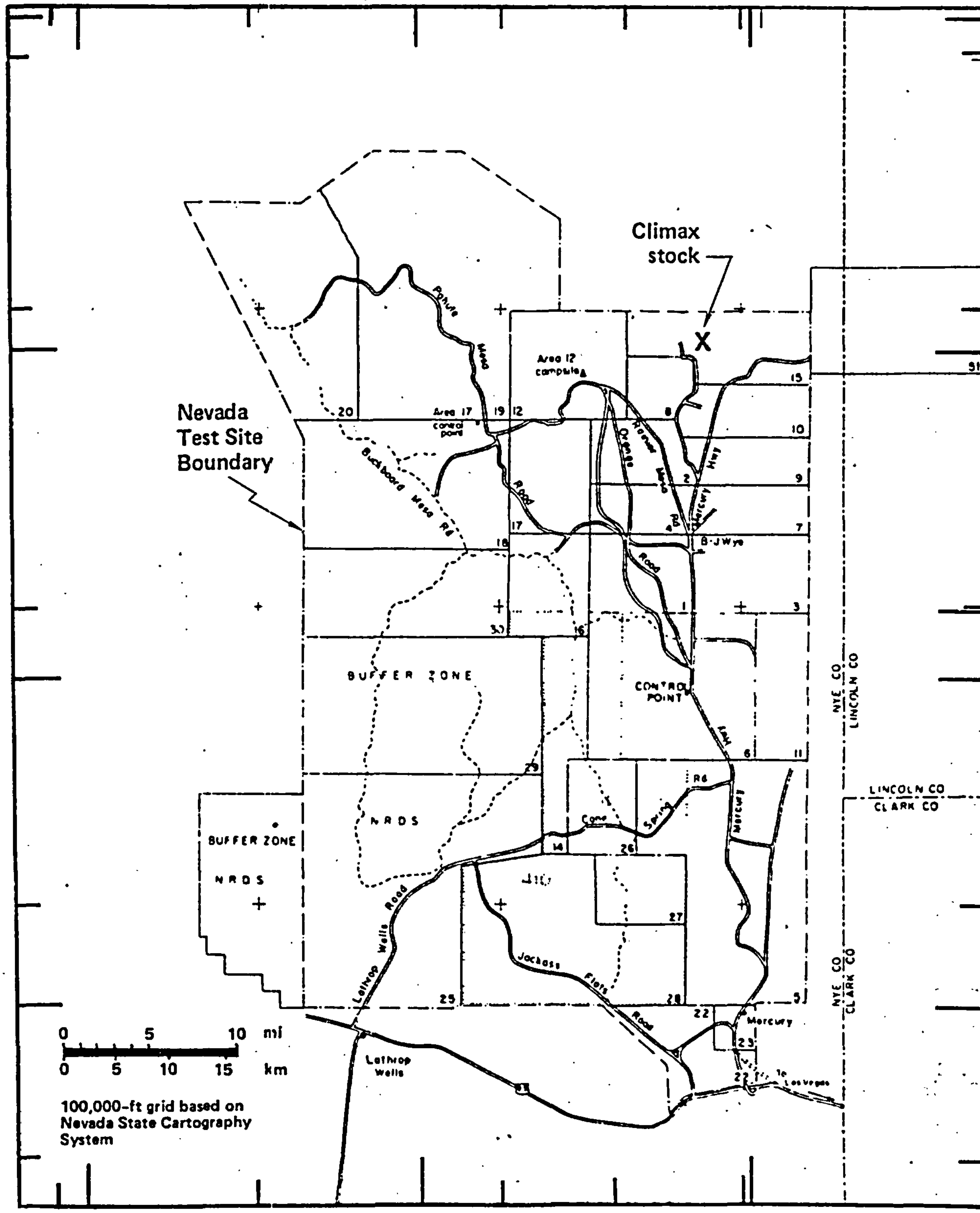

FIG. 1. Index map showing location of Climax stock in Area 15, NTS (from Maldonado, 1977).

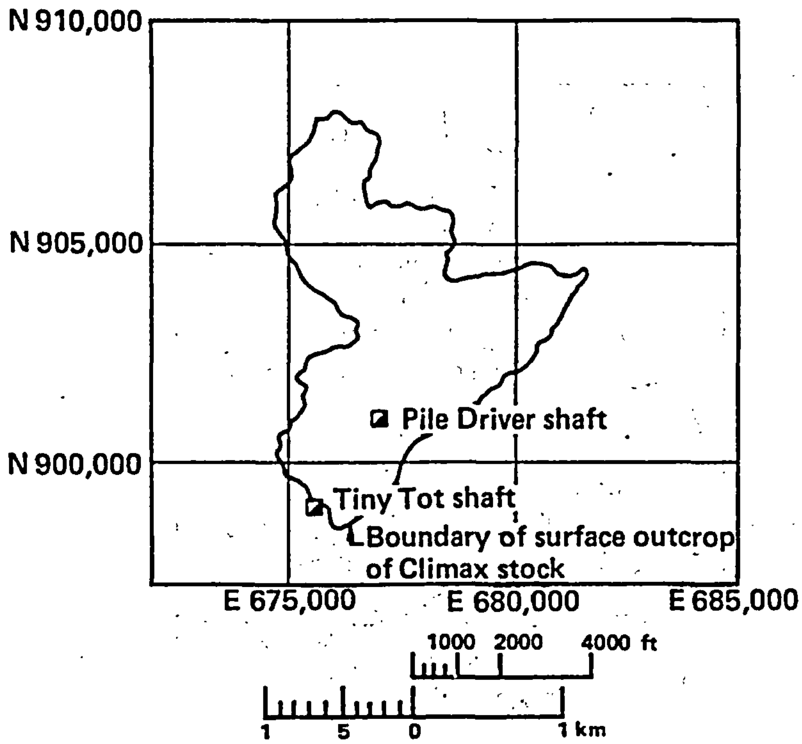

FIG. 2. Shaft locations in the Climax stock.

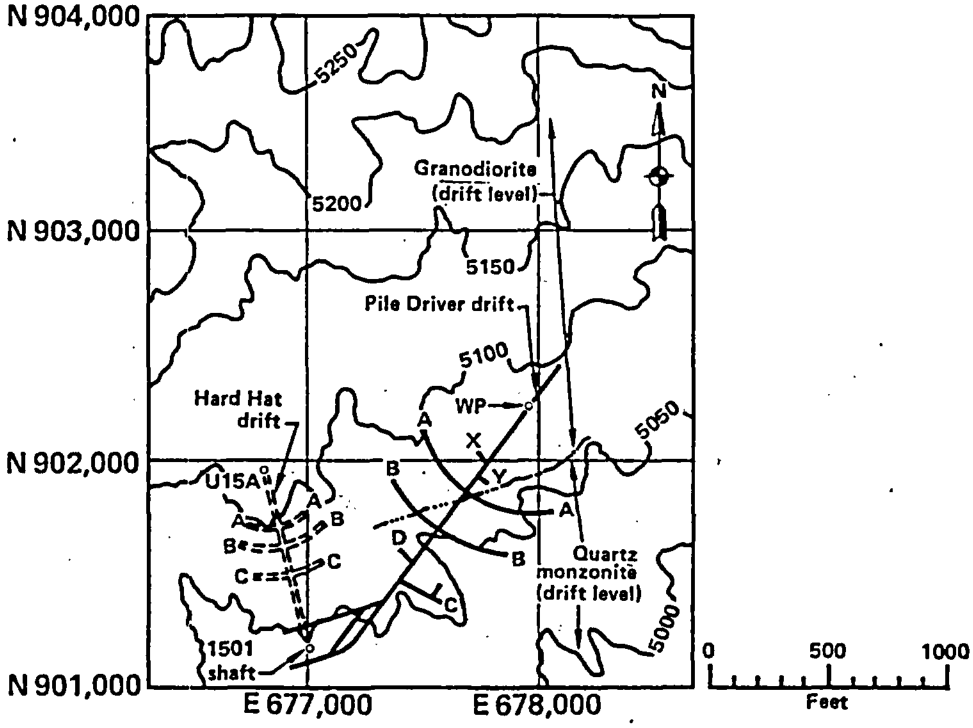

FIG. 3. Pile Driver and Hard Hat tunnel complexes. Contours show elevation in feet above sea level (from Borg, 1970).

The existing underground facilities have enabled a detailed physical description of the granitic mass and have provided ready access to the Climax granite at a considerable depth. The facilities are, therefore, ideal for in situ tests. Geologic storage of spent reactor fuel (the Spent Fuel Test-Climax; Ramspott, et al., 1979) is being generically tested in newly mined drifts adjacent to the older drifts at the 420-m depth level of the Pile Driver shaft. Also, the recently initiated Radionuclide Migration Test (Isherwood, et al., 1980) is being conducted in an existing drift from the Pile Driver event. The layout of these tests relative to the preexisting Pile Driver tunnel complex is shown in Fig. 4.

As an adjunct to the Spent Fuel Test, it has been proposed to establish a "Rock Mechanics Test Facility" in the Climax granite. This facility would be used to define relevant rock mechanics tests for a hard-rock repository and would test Climax stock granite on site. However, the suitability of the Climax granite site for rock mechanics testing has been questioned because the present working level apparently lies above the regional water table. Specifically the following question has been asked:

> Which rock mechanics tests can be conducted in a partially saturated medium that will be generally applicable to the design of hard-rock repositories in saturated rock?

The answer to this question is addressed in a recent report by Heuze (1981). However, the fact that the present working level at 420 m below the ground surface is generally accepted to be above the regional water table has raised two questions:

> Where is the water table within the Climax stock?

and

> What is the degree of saturation of the rock mass at the present working level?

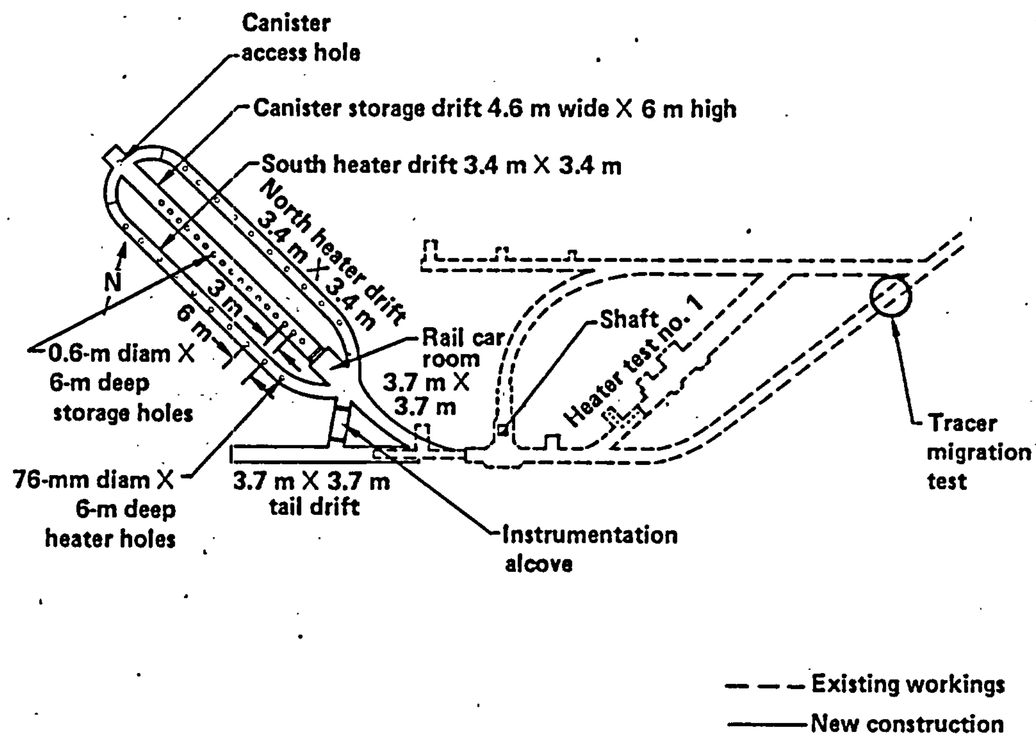

FIG. 4. Layout of the Spent Fuel Test facility and adjacent workings (from Ramspott et al., 1979).

The question of water table location within the Climax stock has not yet been satisfactorily answered. A water table may not occur in the moderately fractured rock mass the way it does in an alluvial deposit. If the fractures are not well interconnected, only isolated pockets of water may occur at different elevations. However, this report assumes that the fractures in the rock mass are sufficiently interconnected to permit a regional water table aquifer (in addition to local pockets of perched water) and to transmit water through the Climax stock.

In an attempt to answer the latter two questions above, this report:

- Summarizes the existing knowledge of geology and hydrology of the Climax stock and surrounding rock formations.
- Extrapolates existing data (from regional hydrology, NTS-scale hydrology, and local structural geology) to deduce the location of the water table within the Climax stock, the source of water at the working level of 420 m depth, and the possible degree of saturation in the rocks of the Climax stock.

GEOGRAPHY AND GEOLOGY

PHYSIOGRAPHY

The Nevada Test Site in Nye County covers about 3600 km^2 (see Fig. 5) and lies in the south-central part of the Great Basin section of the Basin and Range physiographic province. Yucca Flat, Frenchman Flat, and Jackass Flats are the major intermontane valleys within NTS, and their floors range in elevation from 850-1200 m above MSL. Pahute and Rainier Mesas in the northwestern portion of NTS have the highest elevation, over 2100 m. There is an overall ground-surface slope to the southwest across the site towards Death Valley, which has a minimum elevation of 85 m below MSL (Borg et al., 1976).

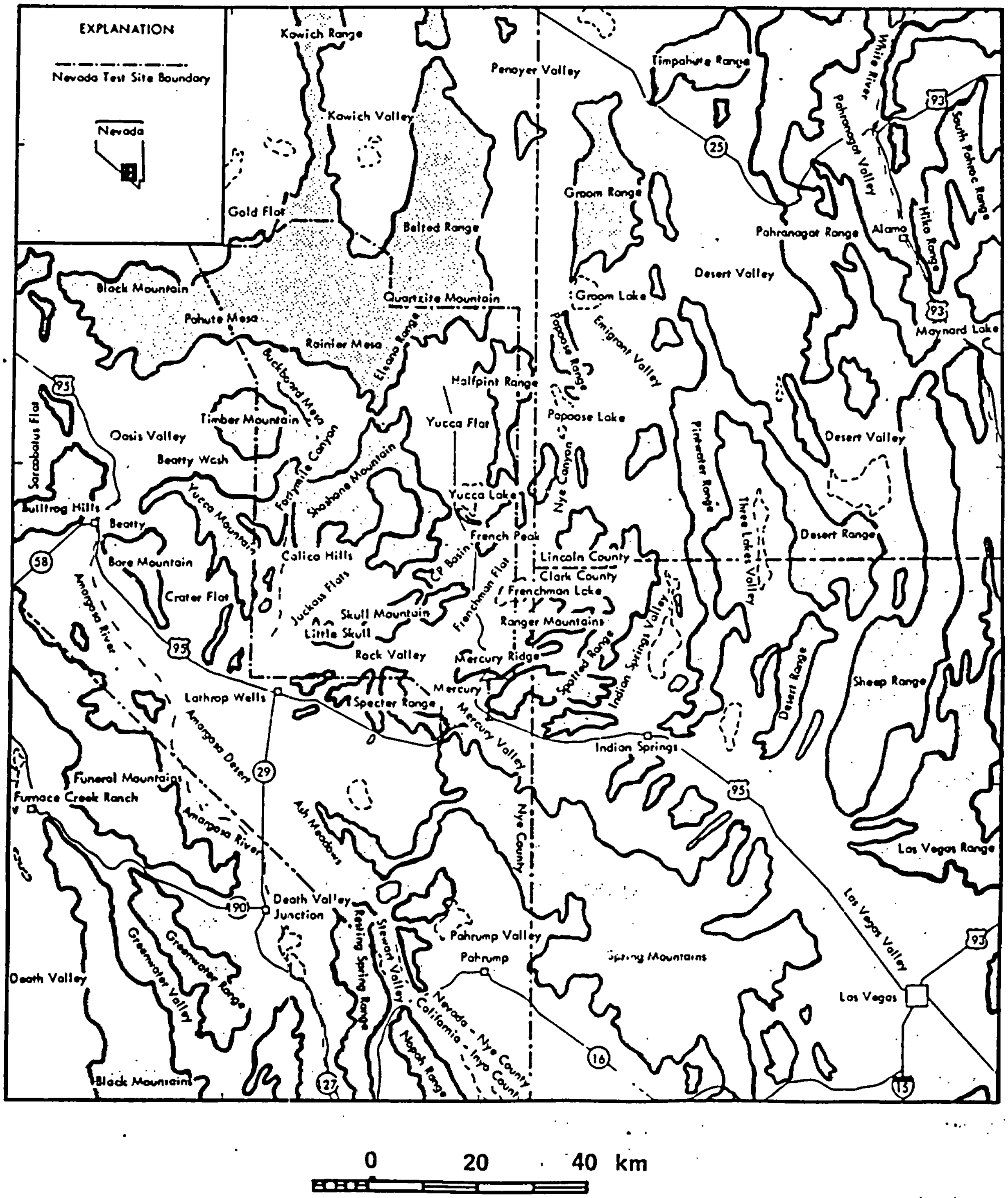

FIG. 5. Index map of Nevada Test Site and vicinity (from Winograd and Thordarson, 1975).

Over the Climax stock outcrop the ground-surface elevation varies from about 1500 m (4900 ft) at the southern edge to about 1800 m (5900 ft) in the north (see Fig. 6). The Climax stock is situated at the north end of Yucca Flat (as can be seen in Fig. 8) and elevations rise steeply to the north and west of the stock. There is a large upland area to the north and west of the Climax stock that consists of Pahute and Rainier Mesas, and the Eleana and Belted Ranges. Elevations in these uplands exceed 2100 m. Two drainage areas, watershed A and watershed B, have been delineated on Fig. 6, which shows the Climax stock lying almost totally within the smaller drainage area, watershed A. However, a small portion of the southern tip of the stock lies in the larger drainage area, watershed B, which contains watershed A.

The climate of the test site area is arid, and the vegetation is typical of that in desert regions. The average annual precipitation in the valleys ranges from 80-150 mm, and averages less than 250 mm on most ridges and mesas (Winograd and Thordarson, 1975). Based on an isohyetal map presented by Winograd and Thordarson, average annual precipitation over the Climax stock area may vary from 150-200 mm. This includes the entire area shown in Fig. 6. The average annual precipitation at the NTS Experimental Farm, 3 km SE of the Climax stock, is about 190 mm for the 14-yr period from 1965 through 1978. Monthly variations in precipitation, temperature, and relative humidity as recorded at the Experimental Farm are shown in Fig. 7. As can be seen, there are two precipitation peaks, one in February and the other in August.

Several washes drain watershed A directly across the Climax stock outcrop. This provides the opportunity for direct infiltration into the stock through the permeable, coarse-grained, unconsolidated material providing a thin cover over the intact granitic rocks. The relatively large Oak Spring wash drains most of watershed B past the southern edge of the stock into the alluvium of Yucca Flat. Water carried by this wash can infiltrate alluvium overlying the intruded rock, subsequently reaching the granitic mass at a slightly greater depth.

The amount of total precipitation to eventually recharge the groundwater system by deep percolation depends on the amount of evapotranspiration and surface runoff. Because of the arid climate at

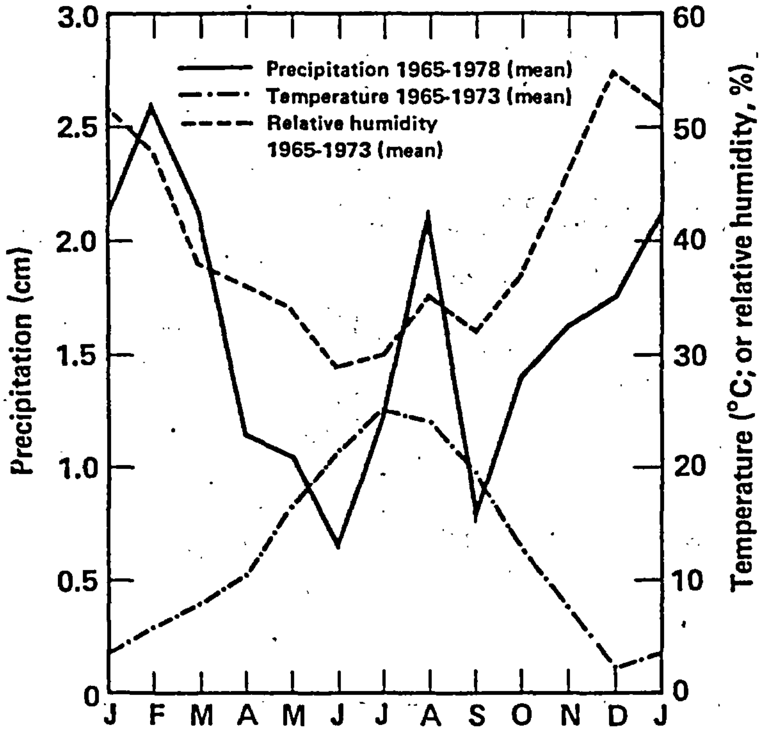

FIG. 7. Average monthly precipitation, temperature, and relative humidity at NTS Experimental Farm, about 3 km southeast of Climax stock (data from DOE, 1980).

NTS, evapotranspiration is high. Borg et al. (1976) conclude it is reasonable to assume that annual precipitation is exceeded by annual evapotranspiration in the valleys of NTS. However, precipitation may exceed evapotranspiration in upland areas for limited periods of time, especially in the winter months. Furthermore, snowmelt from upland accumulations probably results in infiltration and recharge of the ground water at higher elevations. This is likely in some of the area surrounding the Climax stock.

GEOLOGIC SETTING

The rocks surrounding the Climax stock at the ground surface are shown in Figs. 8 and 9. Vertical sections as depicted in Fig. 10, are shown in Figs. 11 and 12. Paleozoic sedimentary rocks completely bound the stock on the west. The Paleozoics are overlain by Tertiary volcanic tuffs to the north and east; and Quaternary alluvium overlies the tuffs to the south and, to a small degree, to the east. The entire NTS region is geologically complex. It lies within the miogeosynclinal belt of the Cordilleran geosyncline, in which 11,300 m of marine carbonates and clastics accumulated during the Precambrian and Paleozoic eras. Except for small intrusive masses (e.g., the Climax stock) no rocks of Mesozoic age are found in the area. The region also lies within a Tertiary volcanic province in which extrusive volcanic rocks are locally more that 4000 m thick (Winograd and Thordarson, 1975). In the Climax area, volcanics form layers over the Paleozoic rocks a few hundred meters in thickness. Quaternary alluvium fills most of the valleys and is found to be about 100 m thick southeast of the Climax stock.

The Climax stock is an intrusive granitic mass of Cretaceous age consisting primarily of granodiorite and porphyritic quartz monzonite. The stock outcrops over an area of 4 km^2 at the northern end of Yucca Flat (see Fig. 8), and intrudes a sequence of sedimentary rocks of Paleozoic age (mainly limestone, dolomite, and shale). This sedimentary sequence is overlain by Tertiary pyroclastic rocks of the Oak Spring Formation, consisting of tuff, welded tuff and breccia (Allingham and Zietz, 1961). The detailed outcrop pattern and adjacent rock types are shown in Fig. 9.

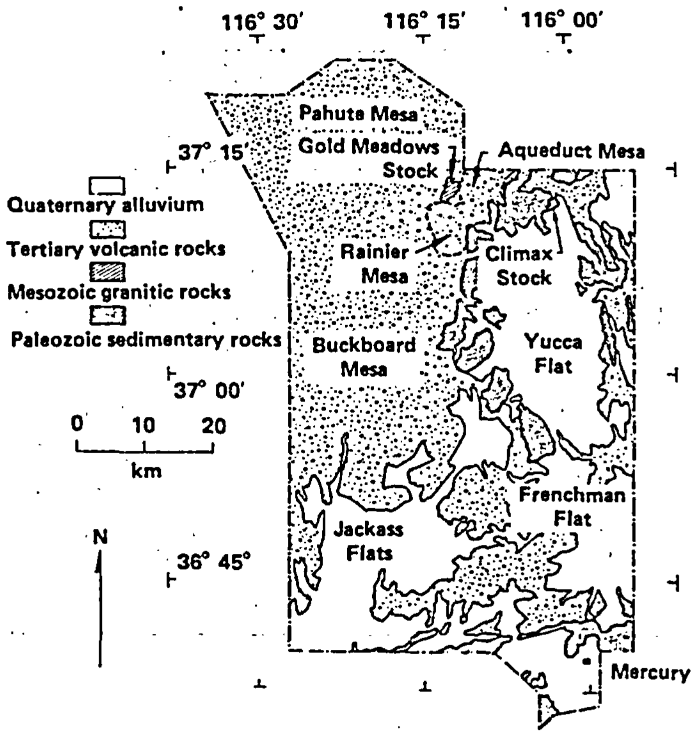

FIG. 8. Principal rock types and test areas at Nevada Test Site (modified from Barnes, et al, 1963).

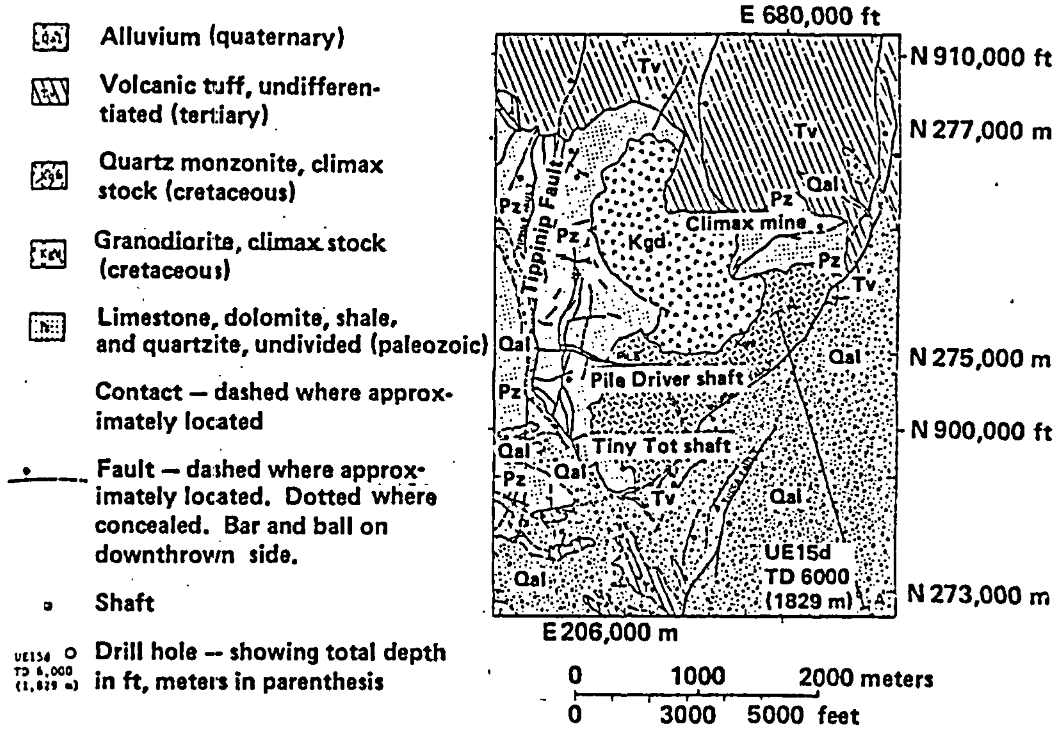

FIG. 9. Geologic map of Climax stock (modified from Barnes, et al, 1963).

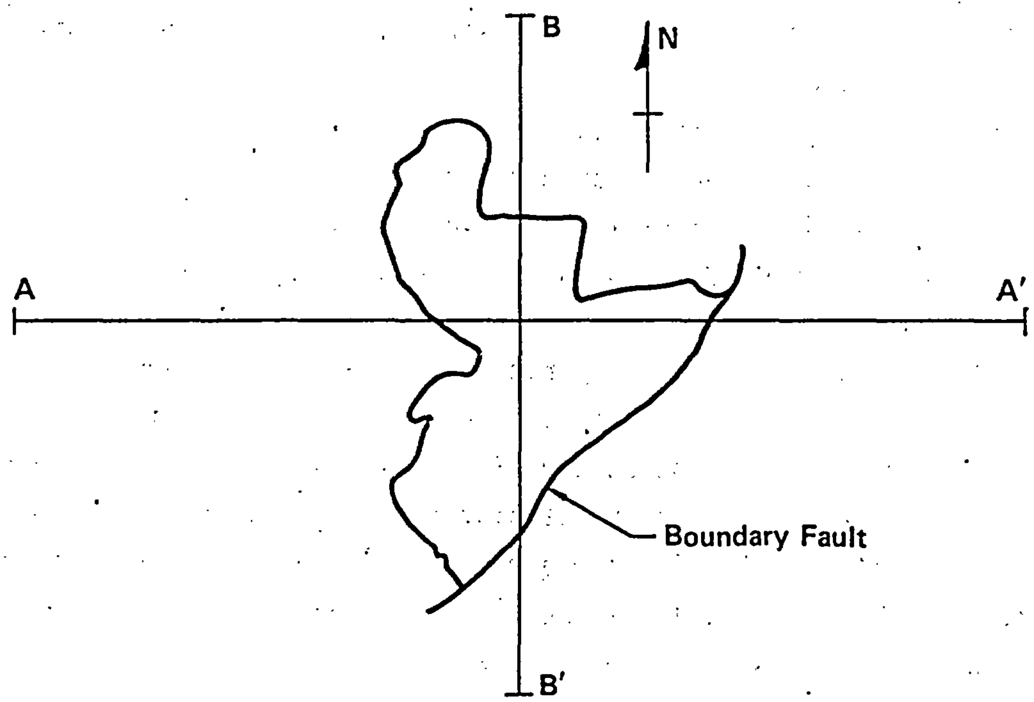

FIG. 10. Locations of vertical sections through the Climax stock.

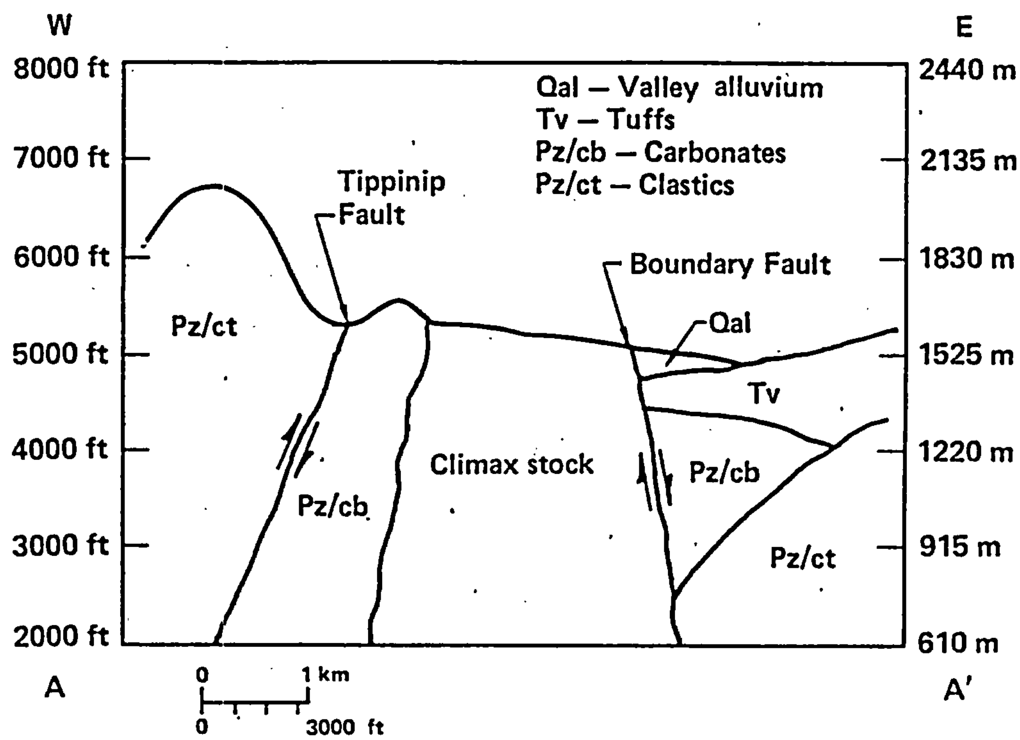

FIG. 11. Geologic section through Climax stock, east-west (modified from Houser and Poole, 1960).

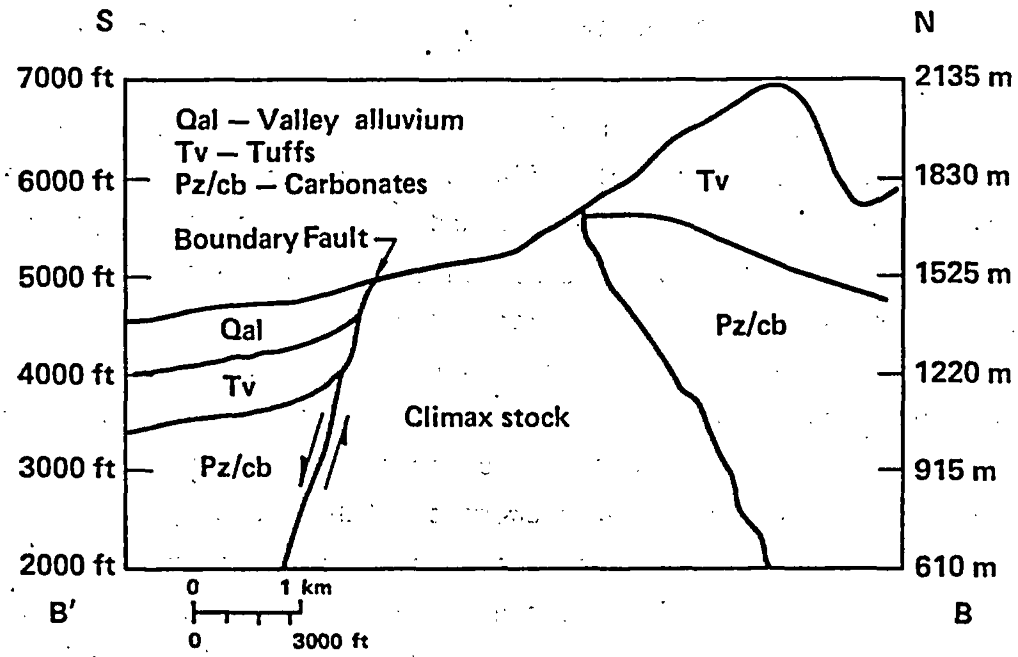

FIG. 12. Geologic section through Climax stock, north-south (modified from Houser and Poole, 1960).

Allingham and Zietz (1961) conducted a three-dimensional analysis of a detailed aeromagnetic survey. They established that the stock is shaped like a truncated cone, whose diameter increases from about 2 km at the surface to at least 10 km near sea level. Their computations also show that the intrusion is at least 4600 m thick. Figure 13 shows the best fit of the computed magnetic curve to the observed east-west profile across the igneous outcrop. The general size and shape of the Climax intrusive are also shown.

Maldonado (1977) has summarized the geology and physical properties of the Climax and portions of his summary are reproduced below. Three major faults are found in the vicinity of the stock (Fig. 9), the Tippinip Fault, the Boundary Fault and the Yucca Fault. The Tippinip Fault is located west of the Climax stock and trends north-northeast, displacing the Paleozoic sedimentary rocks, the west block down relative to the east block. The Tippinip Fault intersects the projection of the Boundary Fault southwest of the stock. The Boundary Fault, which trends northeast, is located on the southeast side of the stock, placing the stock in fault contact with alluvium and tuff. In the southern part of the stock, the dip of the fault has been measured at 75^{o} SE; the southeastern block is displaced downward relative to the northwest block. The Yucca Fault, the principal exposed structural feature within the Yucca Flat area, is located south of the Climax stock. It trends northward through the middle of Yucca Flat and northeastward near the Climax stock, displacing the east block downward relative to the west block. The Yucca Fault possibly joins the Boundary Fault just south or southeast of the stock.

The granitic rock of the Climax stock is jointed and contains numerous shear and fault zones where it has been mapped both on the surface and in underground workings (Ege and Davis, 1965). There are three predominant joint trends in the stock located approximately:

- NW and low angle
- NW and high angle
- NE and vertical or dipping at a high angle to the SE.

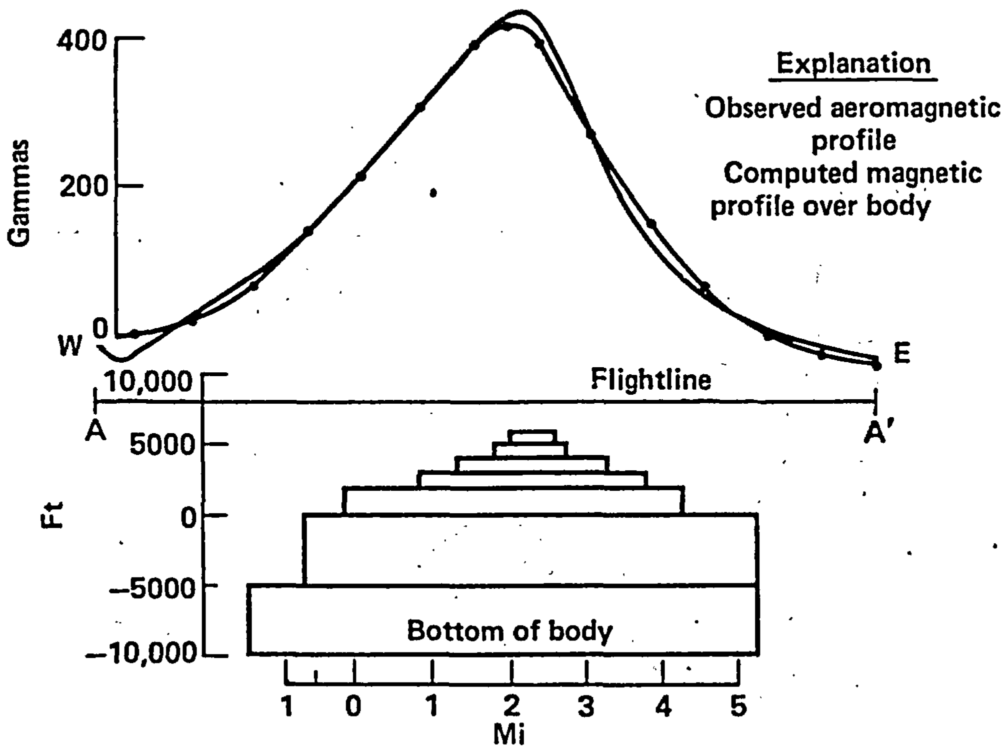

FIG. 13. Approximation of Climax stock shape and depth (Allingham and Zietz, 1961).

Joints in outcrops are weathered and open, but are commonly filled in the subsurface and, in some instances, completely healed with chlorite, quartz, secondary feldspar, clay minerals, calcareous clay, calcite, and sulfide minerals. The nearly vertical fractures tend to be more open than the low-angle ones.

Faults, joints, and shear zones have been mapped for both the Hard Hat and Pile Driver tunnel complexes. Of particular interest are the shear zones. Figures 14 and 15 show mapped locations of shear zones in the Hard Hat and Pile Driver tunnel complexes. Shear zones are a series of closely spaced fractures that define a zone of crushed rock. The rock is crushed to granular size in places, and the zone is highly porous. The porosity of the intact granite has an average value of about 0.6%. However, the porosity of the shear zones may be as high as 20 or 30%. Two samples of shear-zone crushed rock were collected and analyzed in the laboratory for grain size distribution. In each case, about 64% (by weight) of the total sample consisted of granitic rock fragments larger than 1 1/4 cm. The remainder of each sample (about 36% by weight) was subjected to a standard sieve analysis. The results of the sieve analysis are shown in Fig. 16. It can be seen that there is very little fine-grained material. Both silt- and clay-sized fractions are essentially nonexistent. It is also interesting to note that the grain size distribution is very similar in both of the shear zones. The two zones are located about 40 m apart in the Pile Driver tunnel. The shear zones in the stock, especially the larger, more extensive ones, are probably very significant hydrologically. This will be discussed further in the geohydrology section of this report.

When the drifts were excavated for the Spent Fuel Test, (Ramspott et al., 1979) many shear zones were encountered, and they appear to occur extensively throughout the stock. Also encountered during this excavation was a rather large fault. This fault has a 30-cm-wide clay gouge plus a wider zone of fractured and crushed rock. Evidence indicates movement in excess of several meters has occurred along the fault. The fault strikes about N50^{o}E, dipping about 65^{o} to the southeast. Figure 17 shows its approximate surface location. The fault probably extends completely through the stock and could hence form a significant hydrologic barrier, due to the associated clay gouge. Figure 18 shows the location of the fault in the Spent Fuel Test workings.

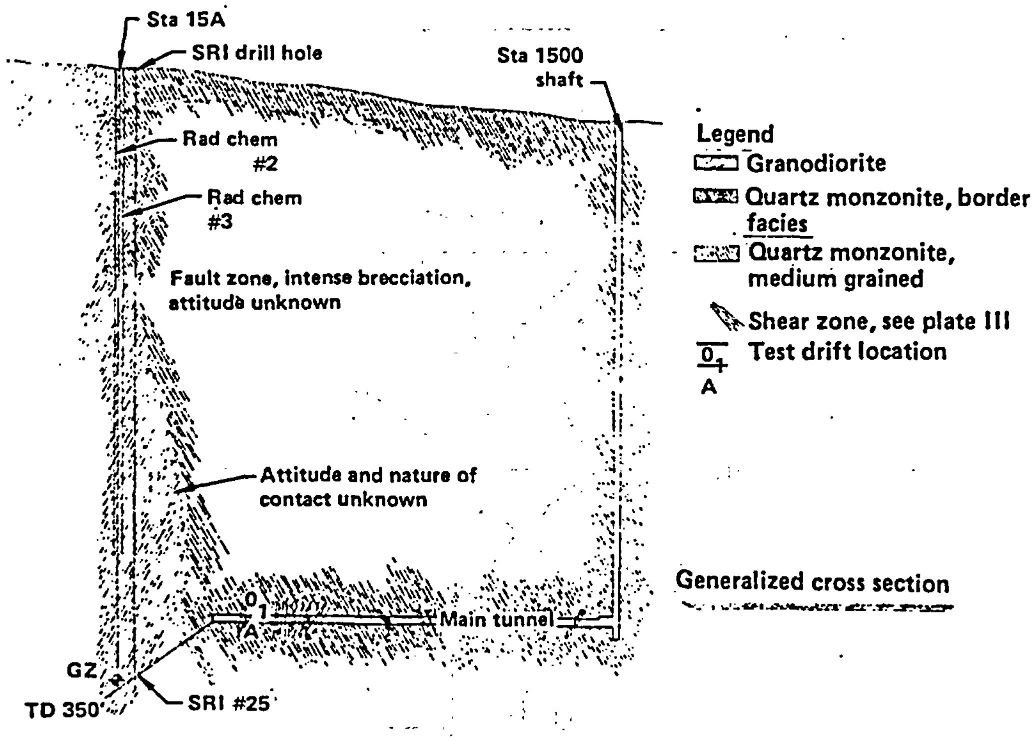

FIG. 14. Locations of shear zones-vertical section (Hard Hat workings).

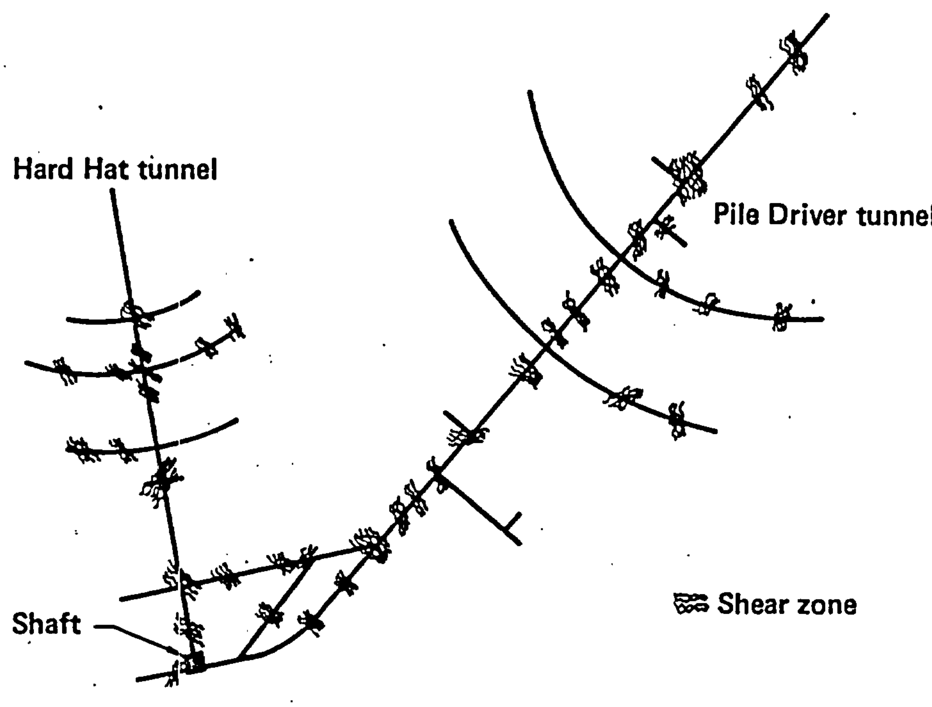

FIG. 15. Locations of mapped shear zones in underground workings (plan view).

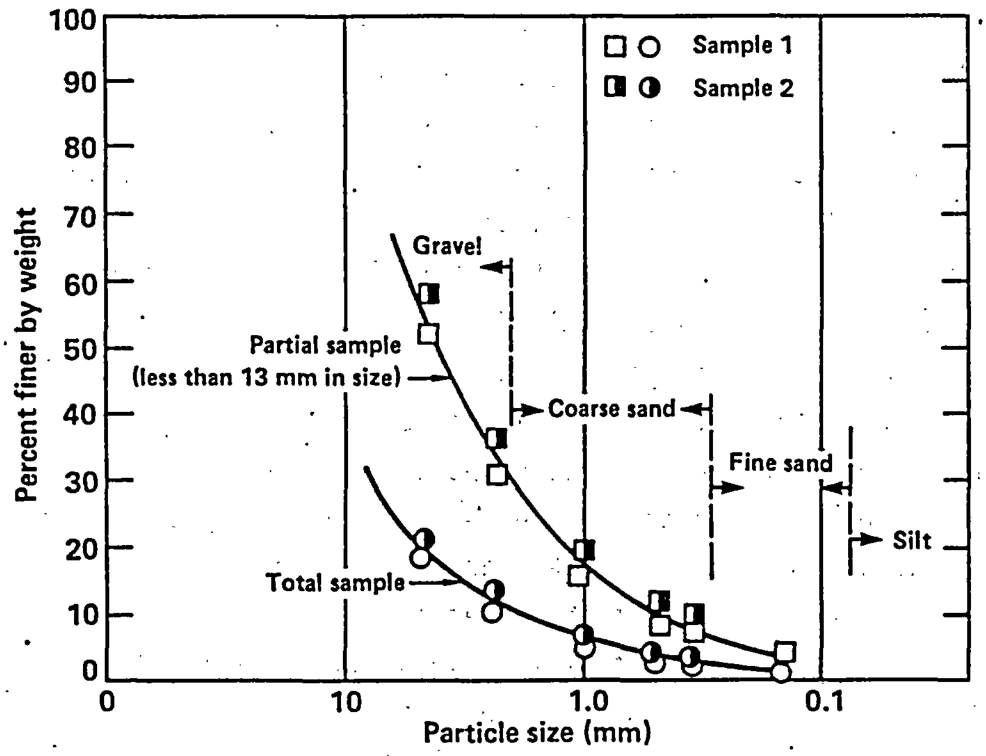

FIG. 16. Particle-size distribution of shear zone material.

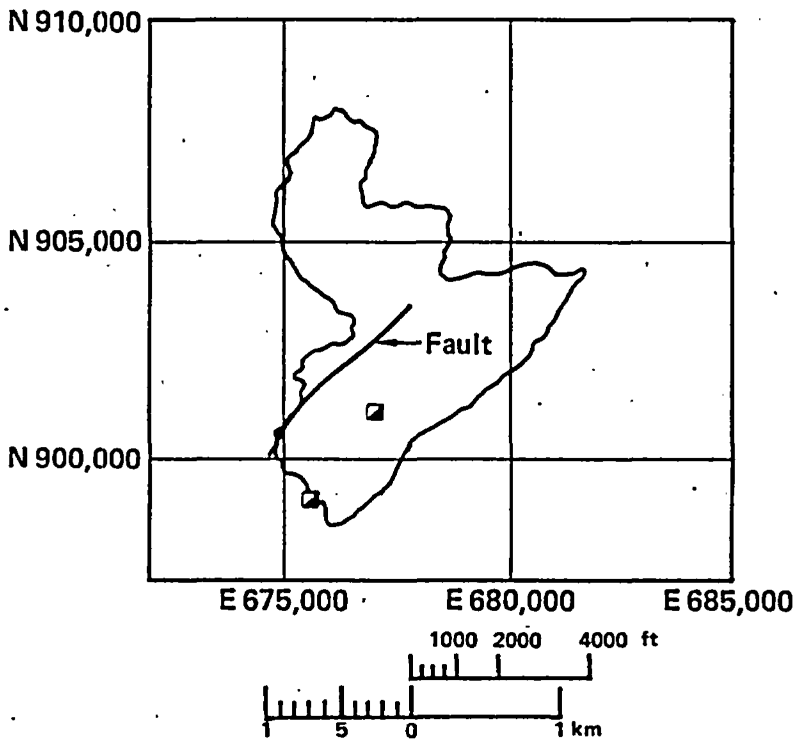

FIG. 17. Climax stock showing inferred fault location (modified from Wilder, 1979).

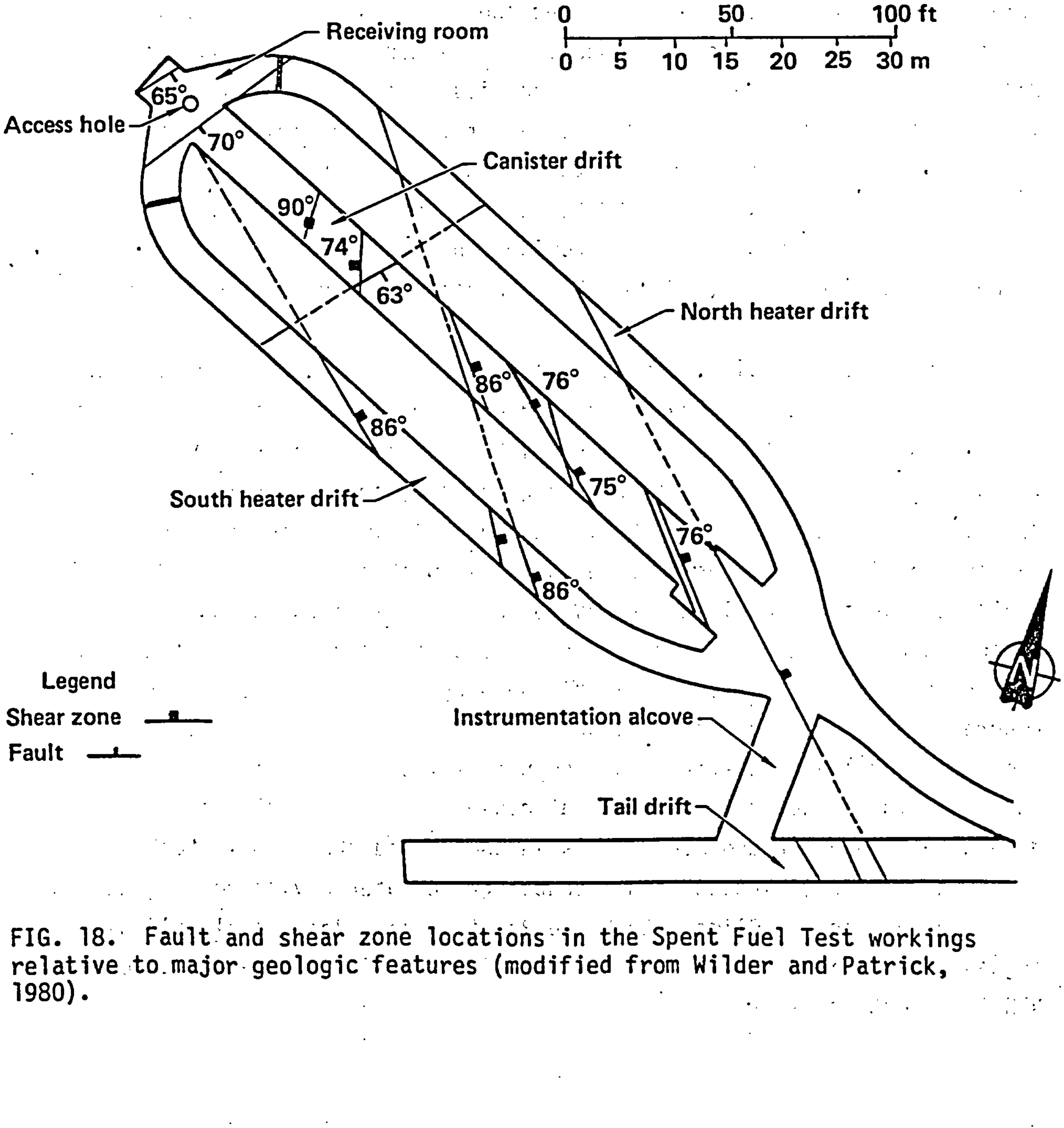

FIG. 18. Fault and shear zone locations in the Spent Fuel Test workings relative to major geologic features (modified from Wilder and Patrick, 1980).

GEOHYDROLOGY

REGIONAL FLOW--SOUTHERN NEVADA

Mifflin (1968) conducted a study to delineate the groundwater flow systems in Nevada. Several techniques for flow system delineation were investigated, including water budget, chemistry, and temperature interpretation. Although Mifflin recognized the potential value of groundwater temperature as an indication of flow system configuration, he did not fully explore it. He postulated, however, that if most thermal groundwater in Nevada is not generated by shallow, high-temperature bodies of rock, the fluid potential of thermal water may indicate the general direction in which deeply circulated groundwater flows. The potentiometric map in Fig. 19 was produced by contouring the fluid potentials of known groundwater occurrences equal to or greater than 80^{o} F. This map may indicate fluid potentials in deeply circulating interbasin flow. The location of NTS and the Climax stock is also shown on the map. It can be seen that the general groundwater flow direction is north to south across NTS and that the fluid potential level varies from about 1200 m (4000 ft) above MSL in the north to about 760 m (2500 ft) in the south. At the Climax stock this deeply circulating interbasin flow potential is about 1100 m (3600 ft).

NTS FLOW PATTERNS

The geohydrology of the Nevada Test Site has been reported by Winograd and Thordarson (1975) and summarized by Borg et al. (1976). Test drilling at the site has proven that at least five, and probably seven, intermontane basins are hydraulically connected by groundwater movement through the Paleozoic carbonate strata. The carbonate aquifers of the miogeosyncline are compartmentalized by major structural features that form prominent hydraulic barriers between or within the intermontane

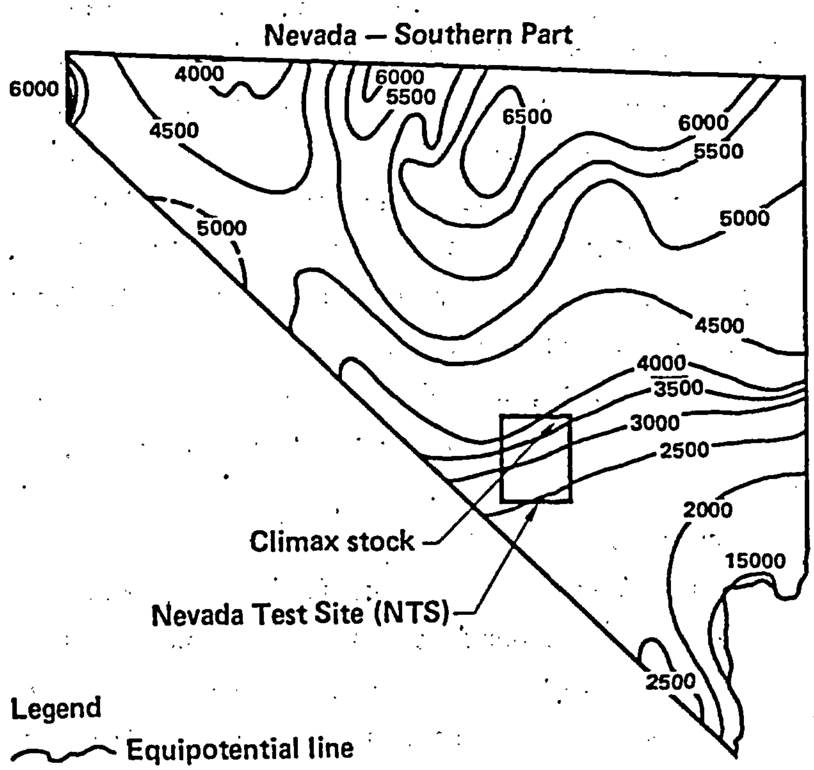

FIG. 19. Equipotential map of groundwater equal to or greater than 80°F (from Mifflin, 1968).

basins. Hence, the aquifer flow systems are very complex on a local scale. Winograd and Thordarson have grouped the stratigraphic units of NTS into 10 hydrogeologic units. Of these, the lower carbonate aquifer, the lower clastic aquitard, and the upper clastic aquitard have a major influence on groundwater levels around the Climax stock. The valley fill aquifer, tuff aquifer, and tuff aquitard play more minor roles. The Paleozoic carbonates have fracture transmissibilities ranging from 12-12000 m^2/day (1,000-1,000,000 gal/day/ft). The transmissibilities of the clastic rocks are, on the other hand, extremely low (less than 12 m^2/day). Therefore, structural juxtaposition of the clastic and carbonate rocks should result in prominent hydraulic discontinuities (Winograd and Thordarson, 1968). Such phenomena occur near the Climax stock.

Within the Test Site, the general direction of groundwater movement is north to south, from areas of recharge in the uplands at the northern end of NTS, through the carbonate rocks beneath Yucca and Frenchman Flats, under Mercury Valley to discharge areas (springs) in the Amargosa Desert south of NTS (see Fig. 20). In a qualitative sense, groundwater levels and flow directions compare favorably with those of Fig. 19. As would be expected, local exceptions to the general north-to-south direction of flow abound. In the volcanic tuffs of Pahute Mesa the flow is more nearly to the west within NTS boundaries, and in Yucca Flat (where the carbonate rocks are bounded on the east and west by clastic rock aquitards) a north-to-south trough cuts into the regional flow pattern. The structural geology that causes this trough also has a direct bearing on groundwater levels in and around the Climax stock.

Figure 20 also indicates a probable groundwater divide running north to south between the Climax stock and Pahute Mesa. Borg et al. (1976) suggest that this divide is fairly extensive, running completely through NTS from north to south.

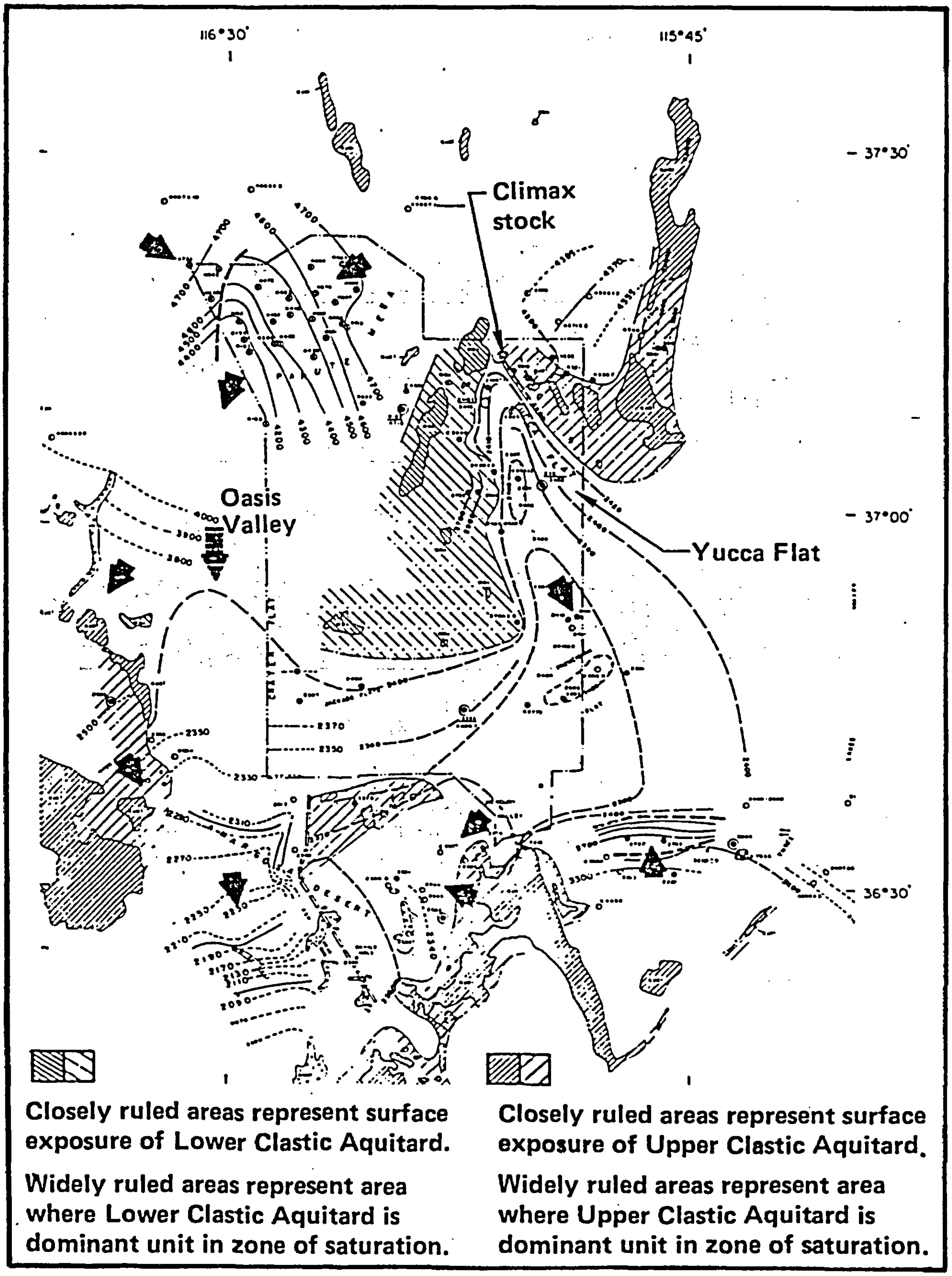

FIG. 20. Potentiometric contours (Nevada Test Site and vicinity) are dashed where inferred and given in feet above MSL (from Winograd and Thordarson, 1968).

GROUNDWATER IN THE AREA SURROUNDING THE CLIMAX STOCK

The Climax stock is bounded by Yucca Flat to the south, whose potentiometric levels are fairly well defined; Eleana Range and Quartzite Mountain to the west, for which measured potentiometric levels are nonexistent; and Belted Range to the north and Halfpint Range to the east, in which few potentiometric levels have been measured. These measured levels are the basis for the contours drawn in Fig. 20. It should be noted, however, that most of the contour lines in the vicinity of the Climax stock are shown dashed, meaning they are inferred. Hence, there are insufficient data to establish these contours with certainty. This simply reflects the paucity of measured water levels for such a geologically complex area. However, groundwater levels are certainly high to the north of the stock, probably as high as 1300-1350 m (4250-4400 ft) above MSL, and low to the south in Yucca Flat, around 750 m (2500 ft).

Beneath northern Yucca Flat, the lower and upper clastic aquitards apparently isolate the lower carbonate aquifer from adjacent valleys. Thus, any interbasin flow of groundwater into the lower carbonate rocks beneath Yucca Flat would have to pass through the clastics. However, on the west, the upper clastic rocks are underlain by the lower carbonates, while on the east, the lower clastics are underlain by Precambrian clastics and crystalline basement rocks. Therefore, the upper clastic rocks do not necessarily retard movement of groundwater into Yucca Flat from the west or northwest where movement could occur through carbonate aquifers hundreds of meters below ground surface. This, of course, depends on the nature of the Tippinip thrust fault, which could, at least partially, isolate the lower carbonates to the west (Winograd and Thordarson, 1975).

In northeastern Yucca Flat, the lower clastics form an effective hydraulic barrier, as is shown in Figs. 21 and 22. The extremely steep gradient from the lower clastics into the carbonate rocks of Yucca Flat is indicative of the low transmissibility of the clastic rocks (Fig. 22). However, it is also possible that the large drop in potentiometric level could be caused by Yucca Fault acting as a hydraulic barrier.

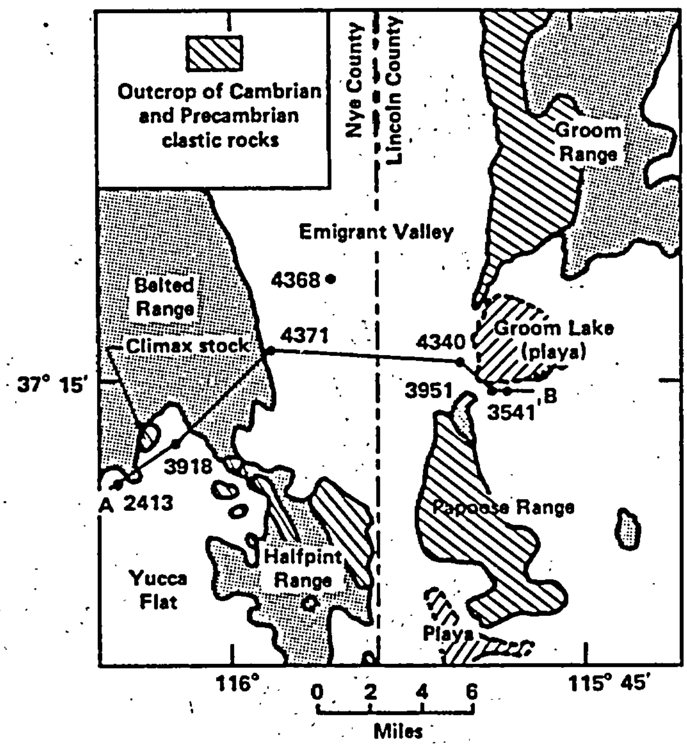

FIG. 21. Plan location of vertical section AB shown in Fig. 22; numbers represent water levels in feet above MSL (from Winograd and Thordarson, 1968).

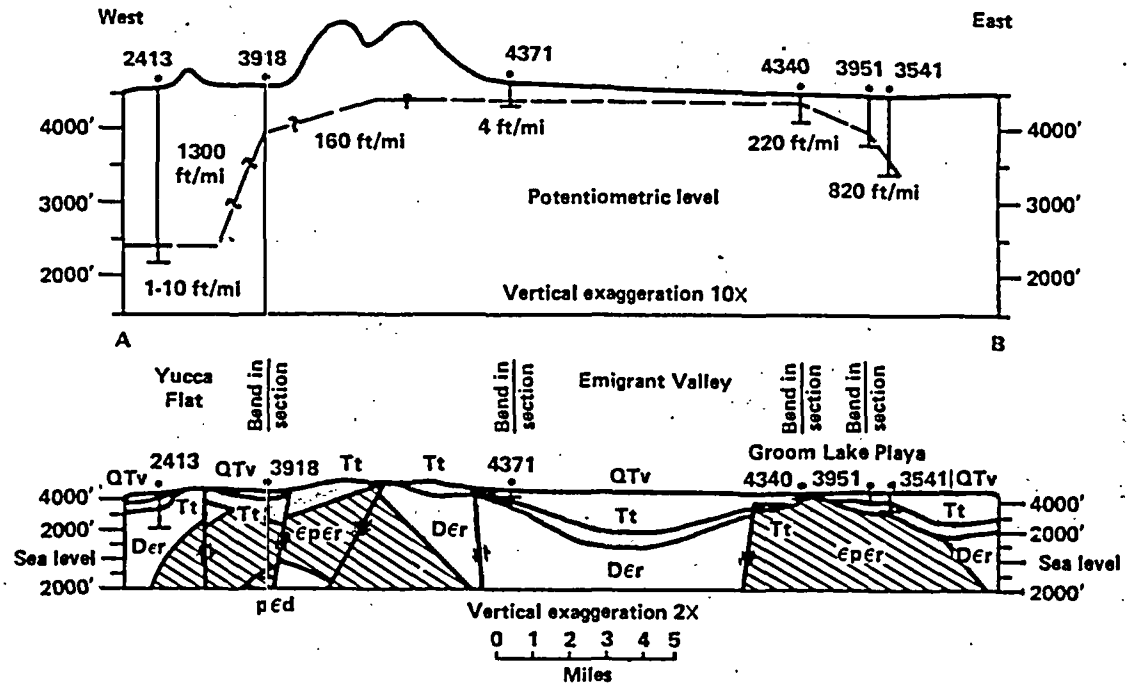

FIG. 22. Geologic and hydrologic cross section (location shown in Fig. 21): Qtv, Quaternary and Tertiary valley fill; Tt, Tertiary tuff; DCr, Devonian to Cambrian carbonate rocks; CpCr, Lower Cambrian to Precambrian clastic rocks; pCd, Precambrian dolomite (from Winograd and Thordarson, 1968).

Figures 23 and 24 show the geology near the Climax stock at the 730-m (2400-ft) elevation and two geologic sections running east to west, one through the Climax stock, and the other just south of the stock. It is logical to assume from these geologic interpretations that groundwater flows from regions of high potential north of the Climax stock, around the stock to the west, through the lower carbonate aquifer into Yucca Flat. However, flow around the stock to the east is apparently blocked by the lower clastic aquitard. It is not known to what extent north-to-south trending fault lines inhibit lateral flow from the west into Yucca Flat, or enhance flow from north to south through the lower clastic aquifer.

Figure 25 shows the location of test wells near the Climax stock and their reported water levels. Also shown are water table contours from the USGS map of Yucca Flat (1976) and the regional, deep-circulating water level contours from Mifflin (1968). The potentiometric levels in the Paleozoic rocks and in Quaternary and Tertiary units are also given (Winograd and Thordarson, 1975). The relatively high 915-m water table contour is largely inferred, based on a few water levels in wells that penetrate the clastic rocks. Because clastic rocks do not exist south of the Climax stock (they lie in bands that run in a north-to-south direction both east and west of the stock), it is thought that this 915-m contour may not close south of the stock as shown. This contour may, instead, intersect the stock or encircle it to the north, remaining in the clastic rocks to the east and west. Water levels are expected to remain lower in the carbonate rocks that abut the stock to the south and southwest. Also, since the 1189-m contour is based on a single borehole water level, its direction may tend more to the east of the stock rather than intersecting it as shown. Water level measurements do, however indicate higher potentiometric levels in the Quaternary alluvium and Tertiary volcanics than those of the lower carbonate aquifer. Hence, in the northern Yucca Flat area, water flows vertically downward through the Quaternary alluvium and Tertiary volcanics into the lower carbonate aquifer. This indicates that the Climax stock is in a recharge area for the lower carbonate aquifer.

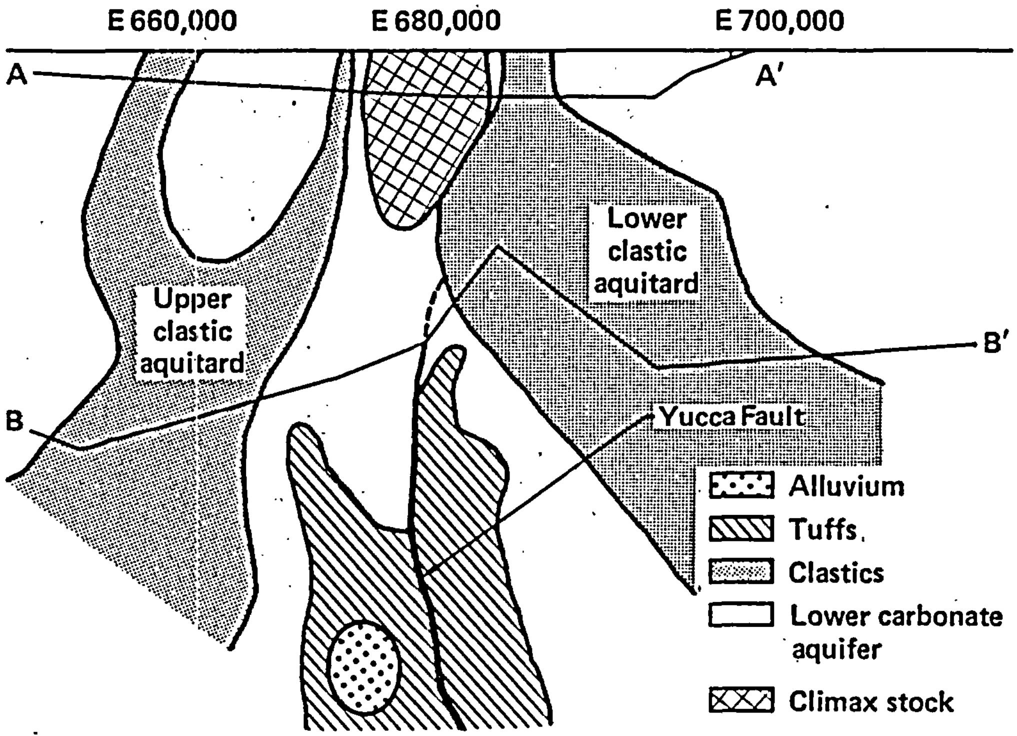

FIG. 23. Geology at 732 m, ground surface at 1220-1830 m (from Winograd and Thordarson, 1975).

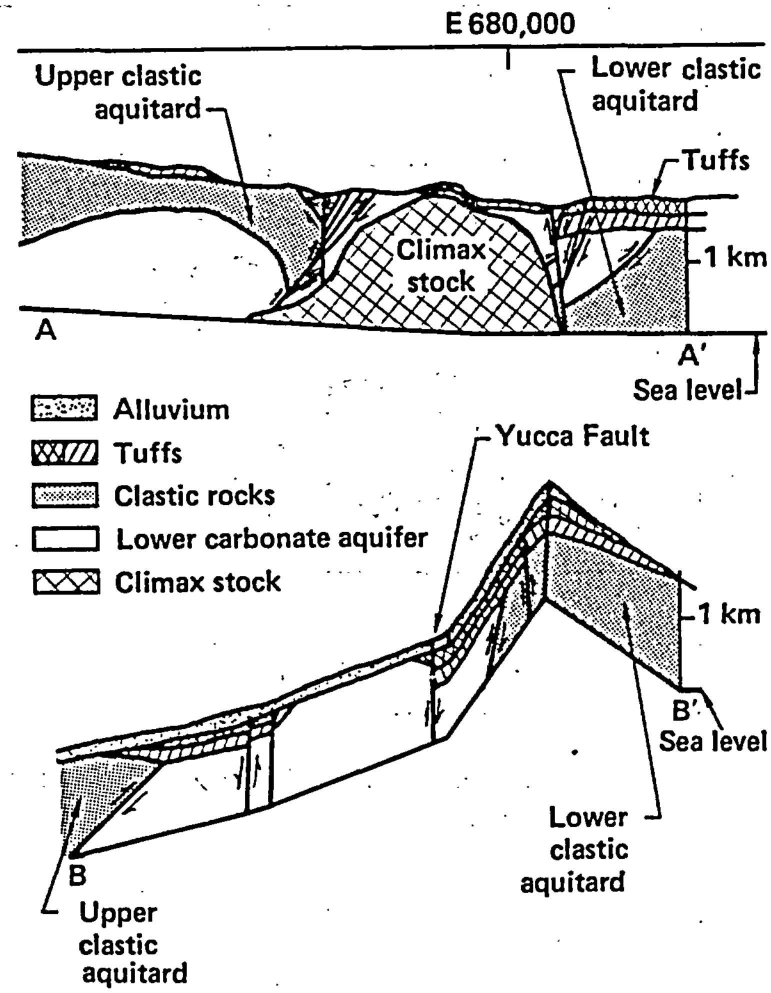

FIG. 24. Geologic sections whose locations are shown in Fig. 23 (from Winograd and Thordarson, 1975).

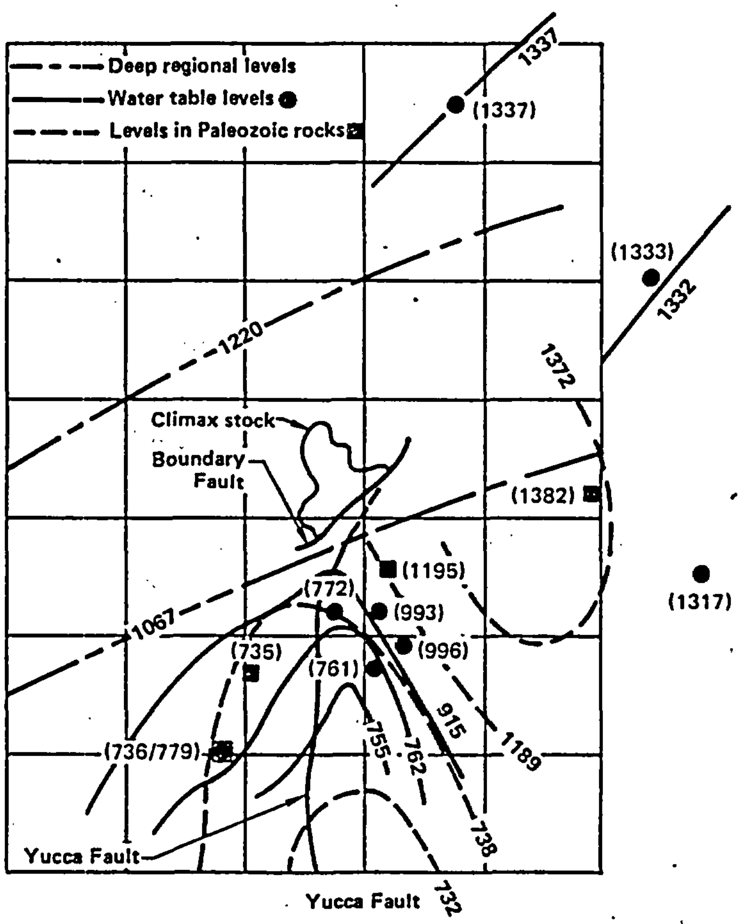

FIG. 25. Potentiometric levels in meters surrounding the Climax stock above MSL. Numbers in parentheses indicate measured water levels (where two numbers are separated by a slash, the first refers to the Paleozoic rocks; the second is the water table in the Cenozoic rocks).

GROUNDWATER IN THE CLIMAX STOCK

Borehole investigations by the USGS were conducted from 1959-1961 to estimate the quantity of groundwater in the Climax stock (Walker, 1962). The location of these exploratory boreholes in the granite and the adjacent quartzite and limestone west of the stock are shown in Fig. 26. Table 1 summarizes total depth and water level in each borehole. Walker notes that the erratic and wide range of water levels suggests that no extensive zone of saturation exists within the stock at the levels tested. Furthermore, since none of these holes penetrated to the level of the regional water table, the locally occurring water is perched. This perched groundwater is thought to exist only in small zones where the rock is highly fractured, and is thought to result from infiltration due to precipitation on the ground surface in the immediate area.

In a summary of permeability tests conducted in the Climax stock, Murray (1980) indicates that the bulk rock permeability can be highly variable. In moderately to highly fractured zones, the permeability values may lie in the range of 10^{-4} to 10^{-1} D. On the other hand, the permeability of intact rock or healed fractures is found to be less than 10^{-9} D.

The underground workings (elev. 1120 m MSL) at the Pile Driver shaft are also above the regional water table and almost devoid of groundwater with the exception of a few isolated seeps. These seeps may indicate the quantity of deep percolation recharging the regional flow. The geologic features of major hydraulic significance are the many shear zones and the fault, which was discovered while excavating drifts for the Spent Fuel Test. These features will have a major impact on the groundwater flow through the interconnected fracture system in the Climax stock.

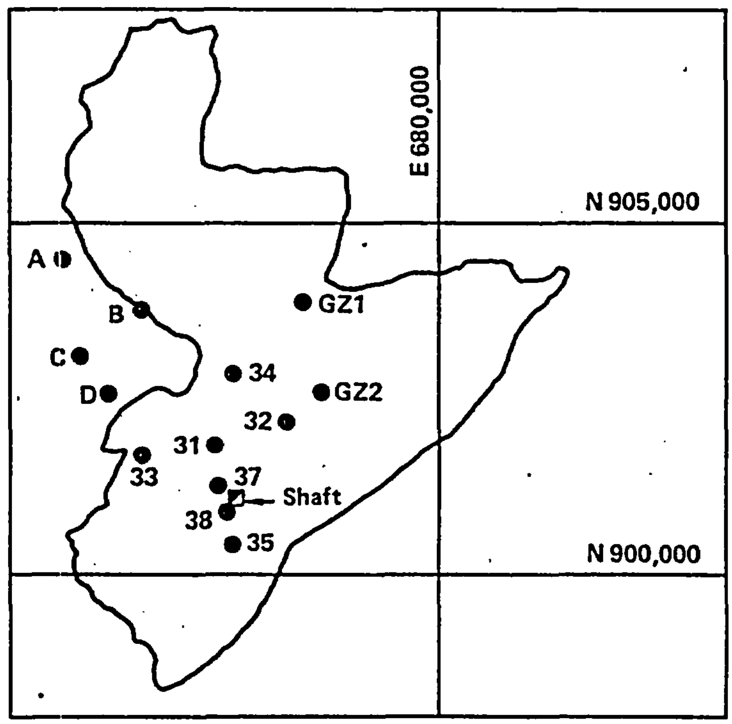

FIG. 26. Borehole locations in the Climax stock (see also Table 1).

TABLE 1. Boreholes in the Climax stock and vicinity.[a]

Borehole (cf. Fig. 25)	Ground surface elevation[b] (m)	Hole depth (m)	Water level[b] (m)	Comments
A	1674	362	1387	perched water
B	1599	60	1549	perched water
C	1621	298	1475	perched water
D	1588	115	1486	perched water
31	1559	366	1502	perched water
32	1548	277	1418	perched water
33	1571	301	----	dry
34	1571	301	1363	perched water
35	1519	246	1494	perched water
37	1543	508	----	dry
38	1536	610	----	may be dry
GZ-1	1590	549	----	unknown
GZ-2	1550	549	----	unknown

(a) From Walker (1962) and Thordarson, et al. (1966).
(b) Referenced to MSL.

The crushed rock in the shear zones is highly permeable. This was determined qualitatively from infiltration tests conducted by pouring water directly on a shear zone. Typically, 200 ml of water disappeared in less than a minute. Permeameter tests were conducted on samples from two of the shear zones (the same samples used in the grain size distribution determinations described earlier). Only material smaller than 1.25 cm was used. The crushed rock was initially placed into a water-filled permeameter; hence, the sample was in a loose state for initial tests. Subsequent tests were conducted after compacting the sample by striking the sides of the permeameter. Before final testing the water-saturated rock sample was allowed to stand for 18 h. This gave the fine clay (which was in suspension) enough time to settle. Values of hydraulic conductivity ranged from 3 X 10^{-3} cm/s to 6 X 10^{-2} cm/s (3 to 60 darcies). The large value is typical for the loose, unconsolidated state, and the small value is typical for the compacted state after settling 18 h. The laboratory values cannot be construed to indicate values in situ, but do indicate the hydraulic nature of the material. The in situ value probably tends to be near the largest of the laboratory-determined values.

Depending on the extent and interconnectivity of the shear zones, highly permeable flow paths could exist throughout the Climax stock. Furthermore, the crushed rock of relatively large porosity in the shear zones would act as a storage reservoir, supplying water to discrete fractures in the stock.

In the hope of locating the regional water table within the Climax stock, one of the exploratory boreholes (UG-02) from the Spent Fuel Test was extended to 160 m below the present working level. After drilling to extend the borehole was concluded (September 25, 1980), a water level monitoring program was started. Table 1 summarizes the water level observations and a water level hydrograph for UG-02 is presented in Fig. 27. The hydrograph indicates that the water level (initially high due to excess drilling water) had stabilized by late November at about 974 m MSL (14 m of water in the borehole). Bailer tests were conducted in February and March, 1981. Analyses of data from these tests indicate that the permeability is about 10^{-5} D.

It can be seen from the hydrograph (Fig. 27) that the water level in UG-02 is slowly rising (about 0.25 m/mo, November-May). The rising trend is perturbed by the bailer test events, but the water level rapidly recovers to the trend. This indicates that the borehole has intercepted an extensive area of saturated fractures that are being recharged. The observed recharge phenomenon may be part of the annual cyclic fluctuation that typically occurs in water table aquifers, and this may be the location of the regional water table within the Climax stock. Continued monitoring and additional boreholes are needed to determine if this, in fact, is the regional water table location.

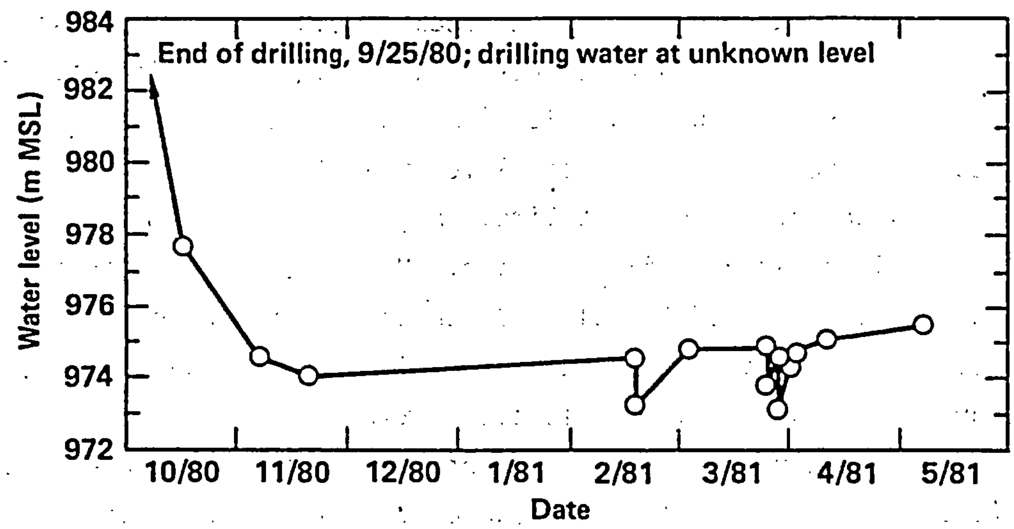

FIG. 27. Water level hydrograph for exploratory borehole UG-02.

TABLE 2. Water levels in exploratory borehole UG-02.[a]

Date	Time	Water level (m MSL)	Comments
09/25/80	--	--	Drilling ended
10/14/80	1200	977.7	
11/06/80	1200	974.5	
11/19/81	1200	974.0	
02/18/81	1017	974.6	
02/18/81	1528	973.2	Bailer Test #1
03/04/81	1000	974.9	
03/25/81	1035	974.9	
03/25/81	1520	973.8	Bailer Test #2
03/27/81	1000	974.6	
03/27/81	1137	973.1	Bailer Test #3
03/30/81	0900	974.3	
04/01/81	1300	974.7	
04/09/81	1300	975.1	
05/07/81	1200	975.4	New probe on water level indicator

[a]UG-02 is a 3-in.-diameter cored borehole.

INFERRING THE WATER TABLE LOCATION

Inferring the location of the water table within the Climax stock depends on several factors: permeability of the granitic rock mass (with respect to the surrounding rock formations); quantity of recharge due to deep percolation from precipitation (with respect to the amount of underflow from north of NTS); and degree of fault influence when faults act as barriers or as flow conduits.

Rock permeability can be placed in one of two broad categories -- that of an aquifer or of an aquitard. As shown in Figs. 23 and 24, the Climax stock is bounded in a complicated manner by clastic aquitards and the carbonate aquifer. There is a dearth of boreholes in the Paleozoic rocks adjacent to the stock and, therefore, neither water levels nor permeability values are known. However, the fact that the hydraulic gradient is much steeper in aquitards than in aquifers can be used to qualitatively assess the water table location.

Examples of the steep gradient in an aquitard (compared with the much flatter gradient in an adjacent aquifer) can be seen from water level data in the carbonate aquifer and surrounding clastic aquitards of Yucca Flat (see Figs. 20, 21, and 22). These differences in gradient indicate relative values of permeability in the aquitards and the aquifer. Furthermore, since the lower carbonate aquifer abuts the south end of the Climax stock (see Fig. 22), it is assumed that groundwater levels remain low here, even though they may rise sharply in the clastic rocks to the east and west.

The quantity of recharge through deep percolation of direct precipitation in the Climax stock area is important in determining the water table location within the stock. Perched ground water found in the stock has been attributed to vertical recharge from precipitation (Walker, 1962). Hence, there has been significant percolation to depths of several hundred meters.

The question then arises as to how much deep percolation has reached the regional water table. Water can certainly percolate to the regional water table if it has percolated to the perched locations. However, most of this precipitation infiltration may be intercepted by the perched aquifers, which could effectively block further deep percolation.

The isolated seeps in the underground workings at the 420-m level may be indicative of the amount of deep percolation that is not intercepted by or is overflow from perched water locations. If it is indicative, a crude estimate of the quantity of deep percolation (at least below the 420-m level) could be made by performing an inventory of the seeps along the roof area of the underground workings, and by monitoring evaporative transport due to the ventilation system. This could also be turned into a crude estimate of rock saturation at the present working level.

The influence of faults on the groundwater flow system near the Climax stock may be a very important consideration. As can be seen from Fig. 24, the fault pattern around the stock is complex. To assess the influence of faults, their nature must be carefully investigated. This is often best inferred from water level measurements. However, the area's dearth of boreholes for water level measurements precludes this type of assessment at the present time. Figure 22 gives some indication that Yucca Fault could be a flow barrier. However, this effect is masked because of the presence of the clastic aquitard. The sharp drop in water level from east to west into Yucca Flat could be caused by Yucca Fault as well as by the low-permeability clastic rocks.

The fault that runs through the north end of the Spent Fuel Test drifts (see Figs. 17 and 18) would behave as a flow barrier because of its wide zone of clay gouge. If this fault continues entirely through the Climax stock and if its composition remains similar to that encountered in the Spent Fuel Test workings, it would certainly form an effective barrier to flow from north to south through the stock. Hence, the groundwater flow would tend to detour around the stock, and there would probably be an abrupt drop in water table elevation across the fault.

Based on the geologic and hydrologic information available, the following inferences are made:

1. The trough in the water table, which runs along the length of Yucca Flat, probably continues to the north, past the Climax stock, because of flow through the relatively high-permeability carbonate aquifer that travels continuously from the north to the south around the west side of the Climax stock (see Figs. 23 and 24).

2. The north-south hydraulic gradient in the carbonate aquifer on the west side of the stock may be fairly steep since the available cross-sectional flow area is small. However, the extensive faulting here (see Fig. 24) may counteract this area-reduction effect by increasing overall rock permeability.

3. On the east side of the Climax stock the lower clastic aquitard blocks north-south flow and keeps water levels high.

4. Groundwater flow through the stock probably moves from the northeast toward the southwest in response to water levels in the surrounding rocks (which are high to the northeast and lower to the southwest).

5. If the shear zones in the stock are extensive and interconnected, the bulk rock mass will appear to be highly permeable and, consequently, the water table will be relatively flat throughout the stock. However, if the fault encountered in the Spent Fuel Test workings is extensive and filled with clay gouge throughout, there would be an abrupt change in water level across the fault.

6. Water table elevations within the Climax stock may lie from 1100-1200 m in the northeast to 800-900 m in the southwest. These water levels were chosen as reasonable possibilities, based on extensions from known water levels, the surrounding geology, and the assumption that the regional water table must be no higher than about 975 m at the Spent Fuel Test location (in borehole UG-02). However, if (as postulated in item 5 above) the bulk permeability of the stock is large, the water table may remain lower in the northeast. This would induce a very steep gradient in the lower clastic rocks adjacent to the stock in the northeast.

CONCLUSIONS

The water table location in the Climax stock granitic intrusive, and the degree of saturation of the rock at the present working level (1120 m MSL) have not been definitively determined. However, it has been suggested (based on analysis of known geological and hydrological data) that the water table elevation in the stock may slope down from about 1100-1200 m in the northeast to 800-900 m in the southwest; and that it may lie at an elevation of 975 m MSL beneath the location of the Spent Fuel Test. It has also been suggested that the degree of saturation may be approximated by a detailed inventory of isolated seeps into the underground workings along with monitoring of moisture transport via the ventilation system.

More definitive conclusions regarding the hydrologic regime in the Climax stock can only be supplied through a carefully planned investigatory program. A water budget would be required to determine the source of water deep within the stock, and to help establish the degree of saturation of the unsaturated rocks above the water table. Deep wells would be needed in the Paleozoic rocks adjacent to the granitic-intrusive mass to determine water table elevations surrounding the stock. These elevations would provide the boundary conditions for water levels and water movement within the stock. Finally, boreholes would have to be drilled within the Climax stock to determine not only the location of the water table, but also the influence of shear zones, faults, and discrete fractures on groundwater flow through the stock.

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