Bill Ford FYI

UCRL- 95539 Rev. 1
PREPRINT

HYDROLOGY DOCUMENT NUMBER 162

Influence 6f Stress-Induced Deformations on Observed Water Flow in Fractures at the Climax Granitic Stock

Dale G. Wilder

This Paper Was Prepared for Submittal to
28th U.S. Symposium on Rock Mechanics
Tucson, Arizona
June 26-July 1, 1987

June 1987

Lawrence Livermore National Laboratory

Influence of stress-induced deformations on observed water flow in fractures of the Climax Granitic Stock*

D. G. Wilder
Lawrence Livermore National Laboratory

ABSTRACT

Three examples of stress-induced displacement influence on fracture-dominated hydrology were noted in drifts 1400 ft below surface in granite. Seepage into drifts was limited to portions of shears near a fault zone. No water entered the drifts from the fault itself, although its orientation relative to Basin and Range extension is favorable for fracture opening. Localization of seepage appears to result from excavation induced block motion that increased apertures of the shear zones in contrast to the fault where asperities had been destroyed by earlier shearing thus minimizing aperture increases.

Seepage was also noted, in an adjoining drift, from a set of shallow-dip healed fractures that intersected the rib, and from vertical fractures that intersected the crown. The restricted location of this seepage apparently was a result of shear opening of the joints that occurred because of cantilevered support of tabular rock between joints.

The third indicator of stress influence was noted in the mineralization of the joints themselves. Interpretation of paleostresses based on joint chronologies and orientations indicates that sets subjected to shear stresses at a time when normal stresses were low contained mineral infilling. Sets subjected to shear stresses at a time when the normal stresses were significant had minimal mineral infilling.

1 INTRODUCTION

Flow observed in excavations approximately 1400 feet underground is related in this study to stress conditions.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.
Prepared by Nevada Nuclear Waste Storage Investigations (NNWSI) Project participants as part of the Civilian Radioactive Waste Management Program. The NNWSI Project is managed by the Waste Management Project Office of the U.S. Department of Energy, Nevada Operations Office. NNWSI Project work is sponsored by the Office of Geologic Repositories of the DOE Office of Civilian Radioactive Waste Management.

The work evolved from studies of storage of spent nuclear reactor fuel in the Climax granitic stock at the Nevada Test Site (Ramspott et al., 1979) called the Spent Fuel Test-Climax (SFT-C). The general geology of the Climax Stock is shown in Figure 1.

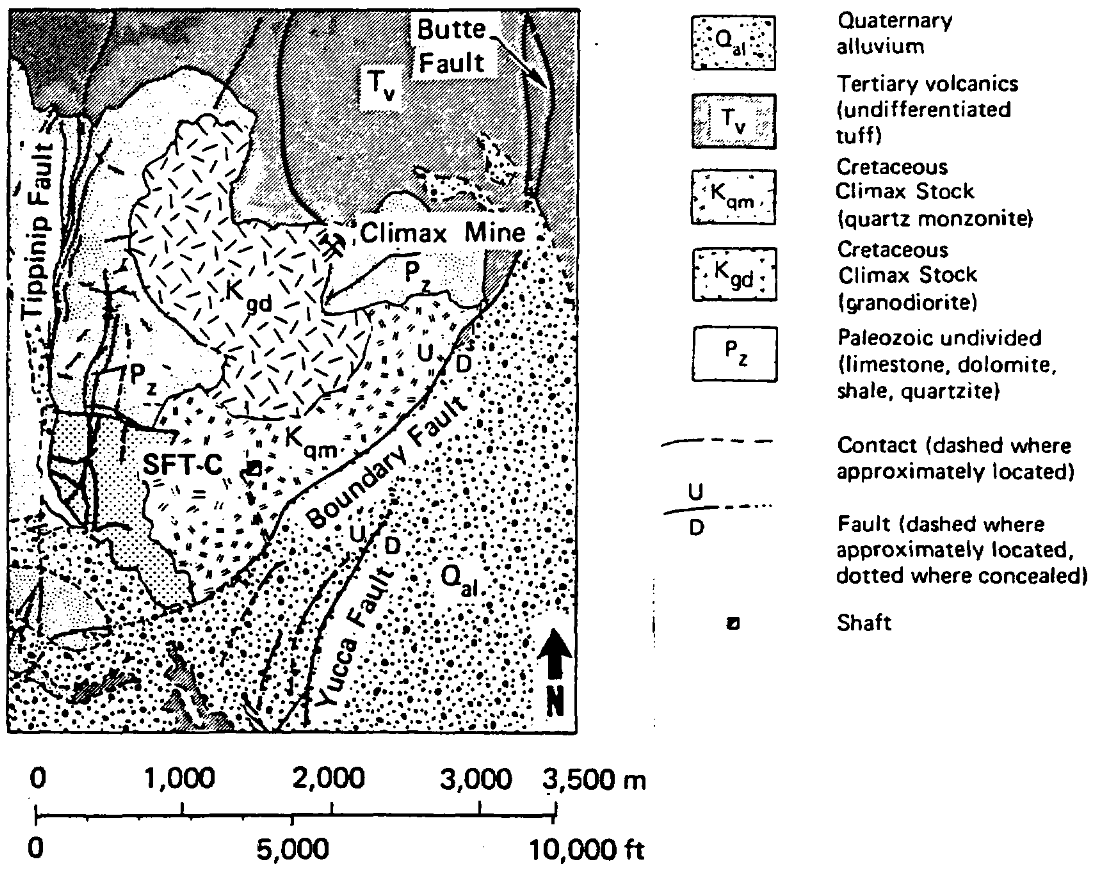

Figure 1. Climax geology map.

Underground facilities consisted of three parallel SFT-C drifts and drifts excavated at the same level, more than a decade earlier, for other tests. Orientations of earlier drifts differed from those of the SFT-C drifts. The drifts are located above the zone of saturation, and during the SFT-C the drifts were essentially dry except for limited areas of weeping associated with shear zones and faults.

The stock is moderately to heavily fractured. Eight joint sets (Figure 2a), three shear sets (Figure 2b), and one fault zone (Figure 3) were identified (Wilder and Yow, 1984). The possible stress conditions at the time of formation of each of the joint sets were also evaluated. The changes in stress and the resulting deformations of the fractures have also been evaluated (Wilder and Yow, 1987). Observations of the locations of seepage relative to the fractures and their orientations relative to changes in stress form the basis of this paper.

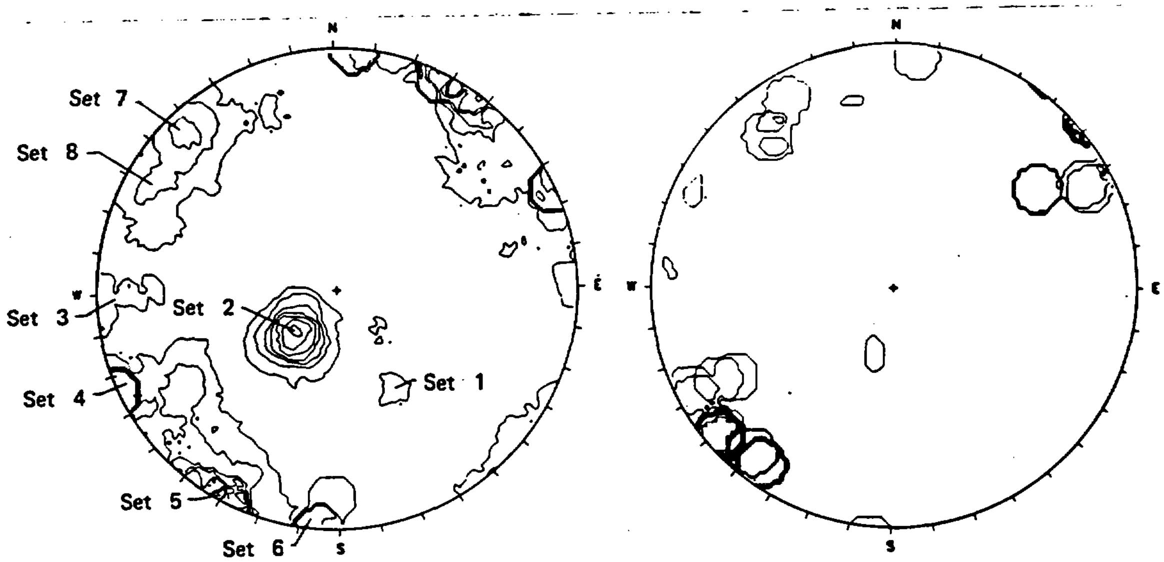

Figure 2. Lower hemisphere equal area plot showing: a) joint sets-1% contour interval and b) shear sets-2% contour interval

2 DISCUSSION

Joint sets 1 and 2 have shallow dips ($\approx 34^{o}$ and 22^{o} respectively) and are healed by hydrothermal mineralization. Other joints are nearly vertical; and though tight are essentially open having clean surfaces, minor or discontinuous mineralization (usually secondary, i.e., calcite or clay) and limited alteration. Shear sets are also vertical and are typified by crushed minerals, closely spaced fractures and by prevalent clay infillings.

The shear zones are the only fractures along which water was observed to weep into the SFT-C drifts (see Figure 3). Lack of seepage into the drifts is not unexpected since drifts are above the level of saturation (Murray, 1981); nor is it surprising that water was not found in all fractures since flow is a function of aperture and fracture interconnections. However, seepage at the SFT-C was limited to only shear zones in locations near the fault.

When the fault was exposed during excavation, a 12-16 inch thick clay gouge was found that was moist and plastic. The gouge was subsequently dried by ventilation. Water was never observed to weep directly from the fault. Since the fault has a significant fracture zone associated with it, and is oriented nearly perpendicular to the Basin and Range extension direction (see Figure 3), it was surprising that water entered the drifts along shear zones near the fault but not from the fault itself. This behavior apparently results from excavation induced block motion. As seen in Figure 3, the fault and shear intersect to form a wedge that could move into the North Heater Drift at the location of the most significant seep. The assumed sense of motion of this block would cause shear displacements along both block faces. However, as discussed by Barton et al. (1985)

shear displacement is a function of fracture roughness and length along which shearing occurs, not merely a function of stress. Roughness is destroyed by shear displacement. Thus, shear strength of the fault is expected to be lower than that of the shears, so that more excavation induced shear displacement would occur on the fault. This would result in both normal and shear displacements along the shear zones, which would increase the aperture more than shear displacement alone. This would allow preferential entry of water into the drifts along the shear zones.

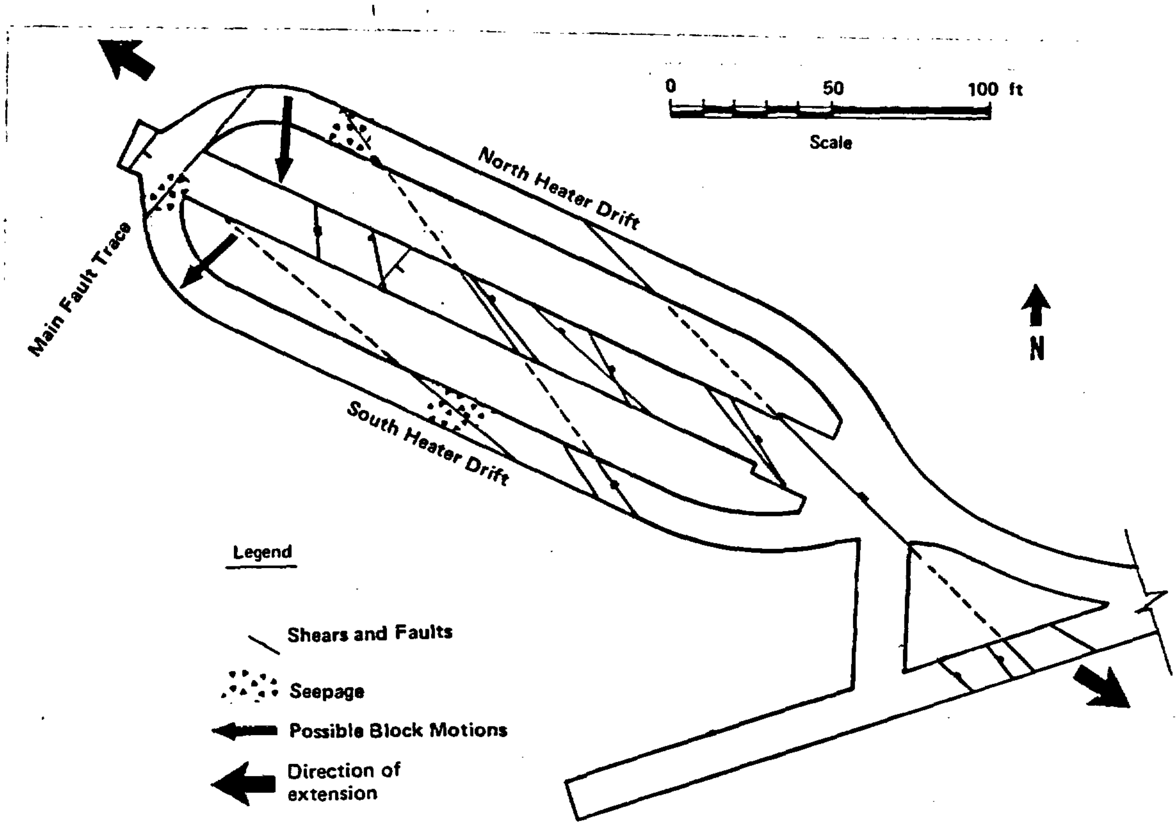

Figure 3. Location of shear zones, faults and seepage in the SFT-C drifts.

Because the fault was previously subjected to significant shear displacements, its asperities and roughness have been reduced. Greater dilation results from shearing of rough fractures than from shearing of smooth fractures. More dilation is expected for longer fractures. Therefore, the dilation of the fault would be greatest, compared to that of the shear, in the North Heater drift block where the length of fault and shear along which block displacements would occur are approximately equal. Estimates of the relative dilation of the fault and the shear zone were made using techniques of Barton et al. (1985). Measurements by Yow (1985) indicate Joint Roughness Coefficients (JRC) of approximately 5 to 10 for shear fractures and faults in the Pile Driver drift. In the analysis of relative dilation made in this study, a JRC of 10 was assigned to shear zones and a range of JRC from 2 to 10 was assumed for the fault. As seen in Figure 4, the dilation of the shear zone would be greater than the dilation of the fault except for the unlikely case where the JRC of the fault was equal to or greater than that of the shear zone.

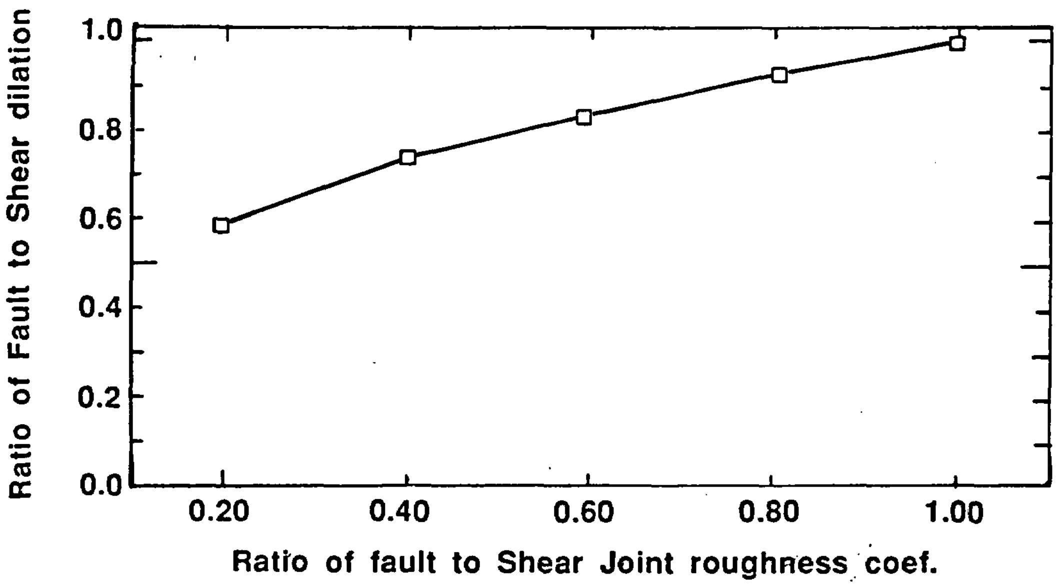

Figure 4. Fault and shear fracture dilations that result from equal amount of shear displacement on the fractures.

Moist gouge is an indicator that water percolates through the fault on its way to the saturated zone. Apparently the gouge acts as a barrier restricting flow to fractures that extend for several feet on the hanging wall side of the gouge. Another indication that water flows through the fault was seen in photographs of an access borehole that was drilled, prior to drift excavation, from the surface to the area where seepage occurs in the central drift. Water was entering the borehole from fractures that appear to be part of the fault zone. Whether the source of this water was drill water or percolating groundwater cannot be determined. However, seepage into the drifts continued for several years, thus indicating that the source of seepage into drifts is percolating water in the fault.

The reason seepage is restricted to shear zones appears to be that when the shear zones that intersect the fault are preferentially opened, as discussed above, they divert water away from the fault. Since the amount of water in the fault is limited (unsaturated conditions), the diversion of water is sufficient to essentially drain the fault. Thus, the water flow path is as shown in Figure 5. This is consistent with fact that seepage was not noted from the shear zones immediately after excavation, and was not observed until much later in the South Heater drift.

Opening of the shear zone in the South Heater drift that connects with the fault would not have occurred until after the central drift was excavated. The flow would have then taken some time after that to travel from the fault to the drift.

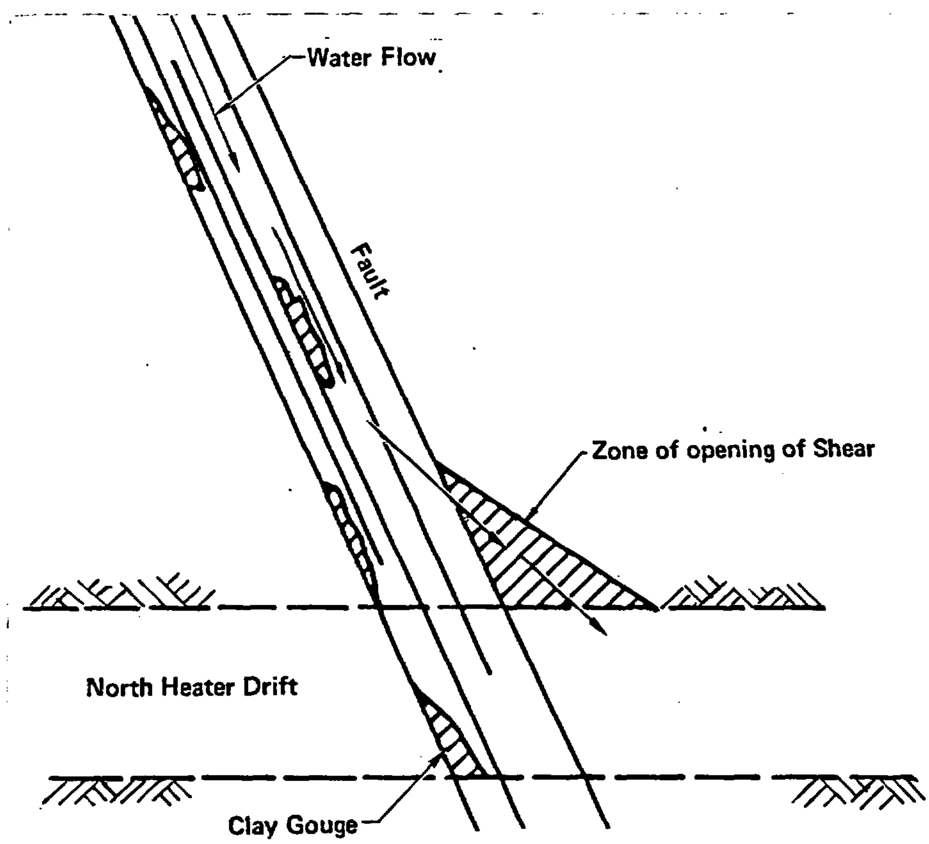

Figure 5. Cross-section of shear zone-fault intersection showing water flow path (view is in plane of shear zone).

Block motion described earlier were interpreted from the geometry of fracture-drift intersections. No deformation measurements were made at the time of excavation. However, subsequent deformation measurements made during heating and cooling cycles of the SFT-C support the block motions interpreted for the excavation stage. Specifically, measurements of fracture displacements indicate that, during the cooldown cycle, the wedge in the North Heater Drift moved in a direction similar to that estimated for the excavation phase (Wilder and Yow, 1987). Cooldown and excavation responses should be similar since both result from reductions in compressive stress.

Seepage continued during the heating phase. Work by Bandis et al. (1983) documents that, upon cyclic loading and unloading of natural fractures, a portion of the deformation from the first cycle is not recovered during subsequent cycles. Excavation of the SFT-C drifts probably represents the first major unloading cycle. This was followed by partial reloading (thermal phase) and by a second cycle of unloading (cooldown). Thus, the fractures would not completely reclose during the thermal phase, which allowed seepage to continue. This is particularly true where shear deformations result.

Another area of observed seepage was noted in previously constructed Pile Driver Drifts (Figure 6). This was the only significant area of seepage noted within these drifts and was the only place where seepage was associated with the low-angle, healed joints (Thorpe and Springer, 1981). In this case, the seepage appears to result from shear induced opening of the healed joints. The segment of the Pile Driver Drift where the seepage is located is oriented such that the low-angle joints intersect the ribs with their strike perpendicular to the drift; thus forming tabular masses of rock which act as beams extending into the drift. In the lower sections of the ribs, the beams are fully supported. In the springline area, the beams are essentially cantilevered so that their ends will deflect (see Figure 7). Above the crown, the beams are cut by fractures so that these beams would also be cantilevered. Because of the cantilevered support, deformation is more significant near the ends of the beams. This results in shear which opens the joints and allows water to flow, as was the case along the ribs where seepage was noted as well as where water was collected from the crown.

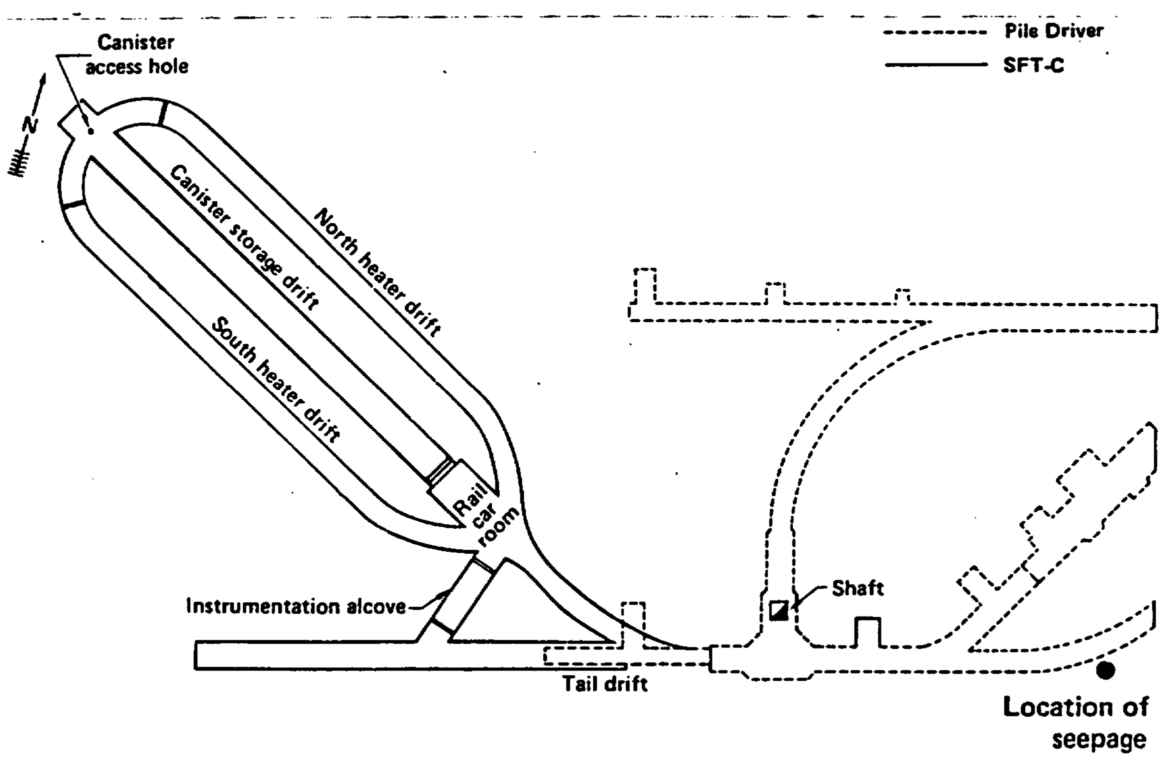

Figure 6. Location of seepage in Pile Driver drifts.

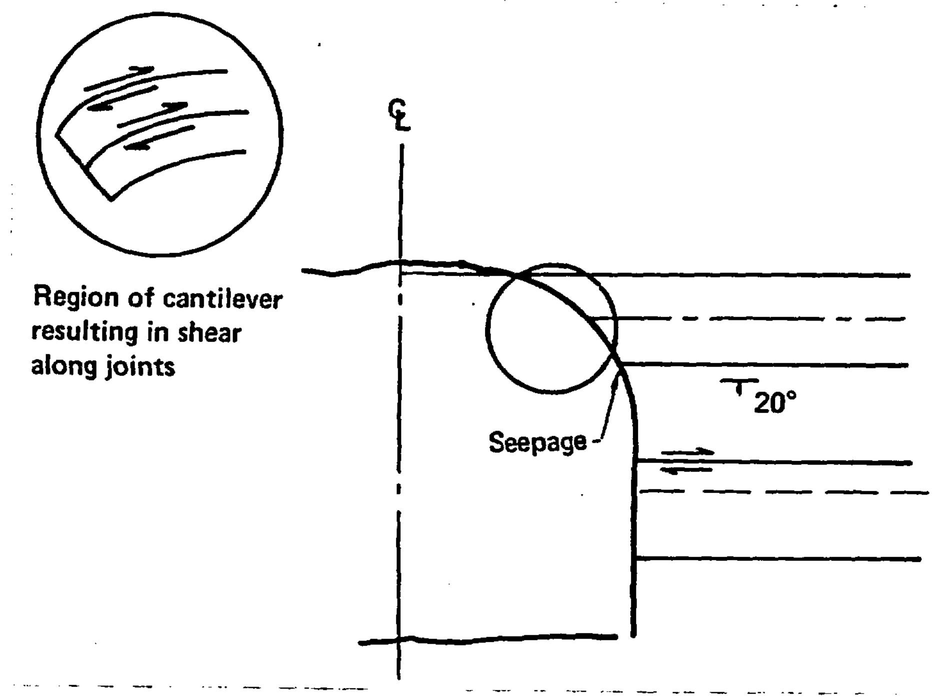

Figure 7. Cross-sections of the Pile Driver drifts showing intersections of low-angle joints, and deformations in relation to seepage.

Further indications of the influence of stress conditions on hydrology are obtained from consideration of joint fillings and possible past states of stress. Past states of stress are determined by combining the chronology of jointing at Climax (Wilder and Yow, 1984), with fracture mechanics analyses for the six vertical joint sets. The analyses were based on: 1) the orientation of the least principal stress at the time of formation of each of the extensional joint sets being perpendicular to the joint plane, and 2) orientations of joint sets that existed at the time of formation of the joint set being considered. This analysis indicates that joint sets 4, 5 and 6 were all subjected to shear stress and low normal stresses when subsequent joints formed. In contrast, joint set 3 had significant normal stress at the time that all subsequent joint sets (except set 4) formed. If aperture increase is a function of shear displacement, then joints subjected to shear stresses while normal stresses were low should allow more water flow than those subjected to shear when normal stresses were higher, since the former had greater potential for shear displacement. Secondary mineralization and alteration of joints are indicators of water flow. At Climax, calcite was identified in joint sets 4, 5, and 6 (the joints subjected to shear displacement) but not in set 3 (Wilder and Yow, 1984). Also, shear was noted on sets 4, 5, and 6. Joint sets 7 and 8 are oriented such that they have only experienced present day stresses, and therefore have only been subjected to extension (not shear) displacements.

3 CONCLUSIONS

Three examples of the influence of stress-induced displacements on hydrology have been identified in fractured granite at the SFT-C. The first is preferential seepage into underground workings from shear zones near a fault zone. The mechanism for this preferential seepage was opening of shears by block displacements. The second is seepage from low-angle joint sets that are healed and tight. This seepage was allowed by shear displacements of fractures due to beam bending near the ribs. The third example is the mineral infilling of vertical joints which indicates preferential seepage through some of these joints over extended periods of time. This seepage is related to shear stresses existing on the fractures at a time when normal stresses were low.

REFERENCES

Bandis, S., A.C. Lumsden, N.R. Barton 1983. Fundamentals of rock joint deformation. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr., Vol 20, pp 249-268.

Barton, N.R., S. Bandis, & K. Bakhtar 1985. Strength, deformation and conductivity coupling of rock joints. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr., Vol 22, No. 3, pp. 121-140.

Murray, W.A. 1981. Geohydrology of the Climax Stock granite and surrounding rock formations, NTS. UCRL-53138 Lawrence Livermore National Laboratory.

Ramspott, L.D., et al, 1979. Technical concept for a test of geologic storage of spent reactor fuel in the Climax granite, Nevada Test Site. UCRL-52796 Lawrence Livermore National Laboratory.

Thorpe, R.K. & J. Springer 1981. Fracture mapping for radionuclide migration studies in the Climax granite. UCID-19081 Lawrence Livermore National Laboratory.

Wilder, D.G. & J.L. Yow, Jr 1984. Structural geology report, Spent Fuel Test-Climax, Nevada Test Site. UCRL-53381 Lawrence Livermore National Laboratory.

Wilder, D.G. & J.L. Yow, Jr 1987. Geomechanics of the Spent Fuel Test--Climax. UCRL 53767, in preparation, Lawrence Livermore National Laboratory.

Yow, J.L., Jr. 1985. Field Investigation of Keyblock Stability. PhD Dissertation. UCRL-53632, Lawrence Livermore National Laboratory.

Technical Information Department · Lawrence Livermore National Laboratory
University of California · Livermore, California 94550