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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

COMPILATION OF RESULTS OF THREE-DIMENSIONAL STRESS DETERMINATIONS MADE IN RAINIER AND AQUEDUCT MESAS, NEVADA TEST SITE, NEVADA

By

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COMPILATION OF RESULTS OF THREE-DIMENSIONAL STRESS DETERMINATIONS MADE IN RAINIER AND AQUEDUCT MESAS, NEVADA TEST SITE, NEVADA

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ABSTRACT

Since 1971, the U.S. Bureau of Mines overcore method has been used to determine the state of stress at nine locations within Rainier and Aqueduct Mesas at the Nevada Test Site, Nevada. Results of these determinations indicate a generally consistent pattern of relatively high stress in a northeast-southwest direction and relatively low stress in a northwest-southeast direction within the mesas. The pattern is consistent with estimates of the regional stress orientation based on geologic and geophysical evidence, including earthquake focal-plane solutions. The state of stress in Rainier and Aqueduct Mesas is probably mostly tectonic in origin, with significant modifications in stress magnitude and orientation owing to the topography of the mesas, their location above the average regional elevation, and influence of local geologic features at individual measurement locations.

INTRODUCTION

During the last several years the U.S. Geological Survey (USGS) has conducted in situ stress investigations within Rainier and Aqueduct Mesas at the Nevada Test Site (NTS). These investigations were part of the larger program of geotechnical support provided to, and funded by, the Defense Nuclear Agency (DNA) underground nuclear weapons testing program. Interest in obtaining rock stress data in Rainier Mesa first appeared in the early 1960's, and Obert (1964) reported the results of stress-determination work using the U.S. Bureau of Mines (USBM) overcoring technique. These results, however, were obtained and reported as secondary principal stresses and failed to define the complete state of stress at any particular site. The first complete three-dimensional stress determination in Rainier Mesa was made in 1971 by the USBM (V. E. Hooker and D. L. Bickel, written commun., 1971). After that time in situ stress investigations gradually became a routine aspect of the geotechnical research and site characterization work conducted by the USGS in Rainier and Aqueduct Mesas.

A major aspect of the stress-investigation program has been the determination of the complete state of stress at the proposed working points of underground nuclear events and at other selected tunnel locations. Several of these stress determinations have been previously reported (Ellis and Ege, 1975; Miller and others, 1975; Ege, 1977; Ege and others, 1976; Ellis, 1979). The intent of this report is to compile, in one document, all of the three-dimensional stress determinations that have been conducted at nine locations in Rainier and Aqueduct Mesas. With the exception of the stress determination in the U12n.07 tunnel, all of the stress determinations were conducted by personnel of the USGS. During the early phases of USGS involvement in overcoring stress determinations, the USBM provided valuable technical assistance and advice.

LOCATION OF STRESS DETERMINATIONS

Rainier and Aqueduct Mesas are located in the northwestern part of the NTS in southern Nevada (fig. 1). Figure 2 is an index map of Rainier and Aqueduct Mesas showing the location of the four tunnel complexes in which the stress determinations were conducted. Overburden thicknesses for the nine locations range between 325 and 445 m, with an average of 394 m. Tunnel portal elevations range from 1,707 to 1,864 m.

General Geology

Rainier Mesa is composed of horizontal to gently dipping ash flows, beds of ash-fall, reworked ash-fall tuff, and tuffaceous sandstones. The general stratigraphy of Rainier Mesa is shown on figure 3. All of the stress determinations were made in tunnel bed units 3 and 4. The type and pattern of faulting in the vicinity of Rainier Mesa is typical of the Basin and Range. However, Rainier Mesa itself is relatively unfaulted except for the area between it and Aqueduct Mesa. Figure 4 is a map showing surfaced faults on the Rainier and Aqueduct Mesa area between Rainier Mesa and Aqueduct Mesa.

The tuffs in which the stress determinations were made are typically low-strength, low-modulus rocks. The unconfined compressive strengths normally average less than 20 MPa. Elastic moduli of overcore samples from the nine sites range between 1.4 and 10.0 GPa, with the majority of samples less than 6.9 GPa. The rocks behave essentially elastically but do exhibit various degrees of nonlinear elasticity. Anisotropy is sometimes encountered, but not to the degree that it significantly affects results of the stress determinations. A comprehensive tabulation and statistical treatment of physical and mechanical properties of Rainier Mesa rocks is reported by Brethauer and others (1980).

METHOD OF STRESS DETERMINATIONS

All of the stress determinations compiled in this report were made with the well-documented USBM overcoring technique (Hooker and Bickel, 1974). Elastic moduli for overcore samples were determined with a biaxial loading device and the USBM three-component borehole-deformation gage (Fitzpatrick, 1962). The overcoring measurements were made at drill-hole depths believed to be outside the zone of significant influence of underground openings. As such, the data should be representative of free-field in situ stresses.

THREE-DIMENSIONAL STRESS COMPILATION

Figures 5 through 12 and Tables 1 through 9 summarize the results for each of the nine locations, and are grouped according to the four tunnel complexes in which the stress determinations were made. For each tunnel complex, there is a map showing where the measurements were made, listing the results for each stress determination made, and a graphical representation of the principal stresses for each location. Table 10 is a listing of the nine locations showing the principal stress magnitudes and the orientation of the maximum and minimum stress components.

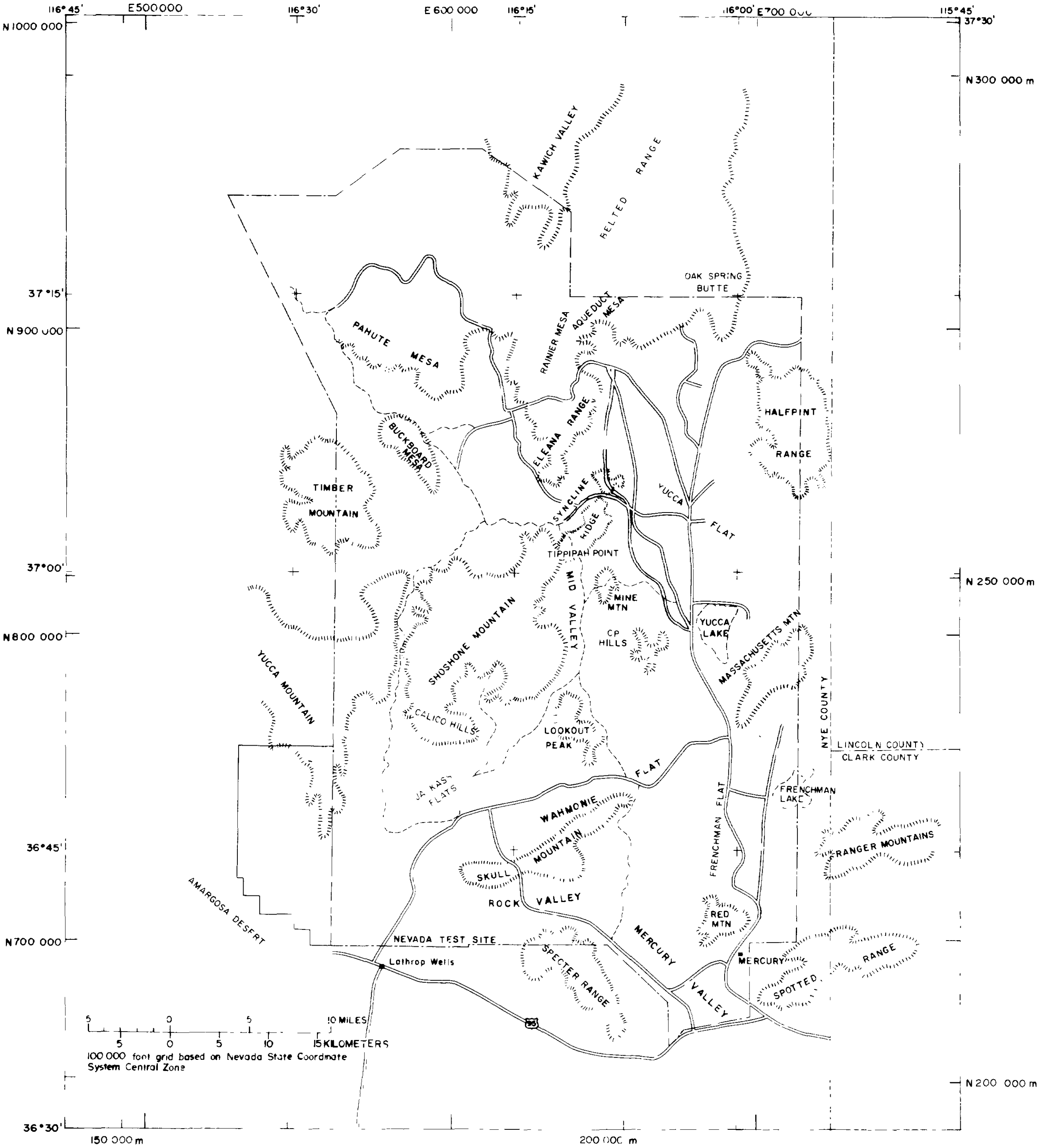


Figure 1.--Index map of the Nevada Test Site showing location of Rainier and Aqueduct Mesas.

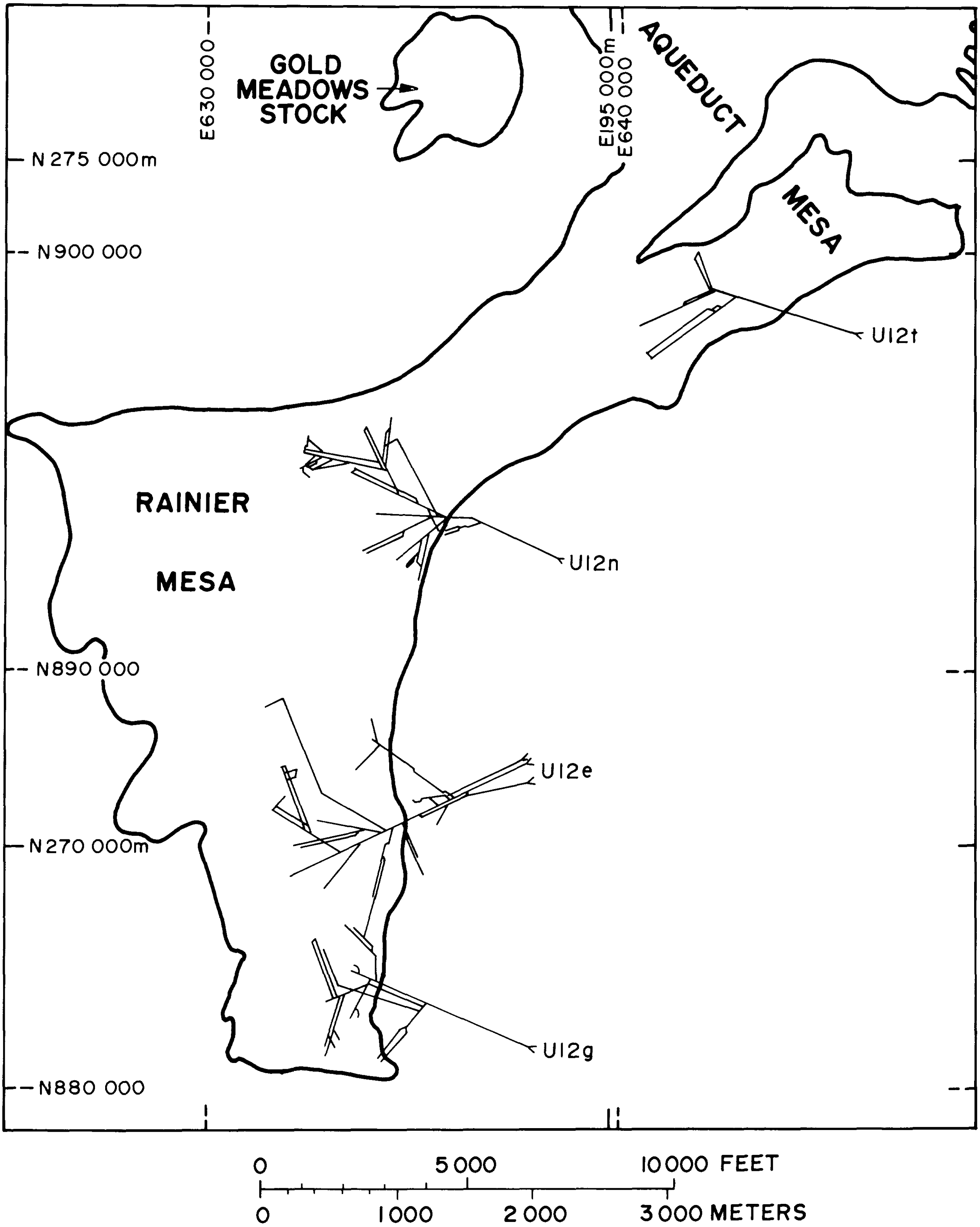


Figure 2.--Index map of Rainier and Aqueduct Mesas showing tunnel complexes U12g, U12e, U12n, and U12t.

Era	System	Series	Formation	Member or unit and symbol
		Pliocene	Timber Mountain Tuff	Rainier Mesa Member Tmr
			Paintbrush Tuff	Tiva Canyon Member Tpc Tp
			Stockade Wash Tuff	Tsw
			Bedded and ash-flow tuffs of Area 20	Trab
			Bedded tuff of Dead Horse Flat Tdhb	
			Belted Range Tuff	Grouse Canyon Member Tbg
				Unit 5 Tt5
CENOZOIC	Tertiary	Miocene	Tunnel beds	Unit 4 Tt4 Subunits AB, CD, E, F, G, H, J, K[1]
				Unit 3 Tt3 Subunits A, BC, D[2]
			Belted Range Tuff	Tub Spring Member Tbt
			Tunnel beds	Unit 2 Tt2
			Crater Flat Tuff	Tcf
			Tunnel beds	Unit 1 Tt1
			Redrock Valley Tuff	Trv
			Older tuffs	Tot
			Paleocolluvium	Tc
MESOZOIC	Cretaceous		Gold Meadows stock	Kqm
PALEOZOIC	Devovian Silurian Ordovician Cambrian		Paleozoic rocks, undivided	Pz [3]
			Wood Canyon Formation	€p€w
PRECAMBRIAN			Stirling Quartzite	p€s p€[3]

[1]K is the youngest.
[2]D is the youngest.
[3]In some drill holes, paleocolluvium of Tertiary age (Tc) rests on Paleozoic or Precambrian rocks.

Figure 3.--General stratigraphy of Rainier Mesa area, Nevada Test Site.

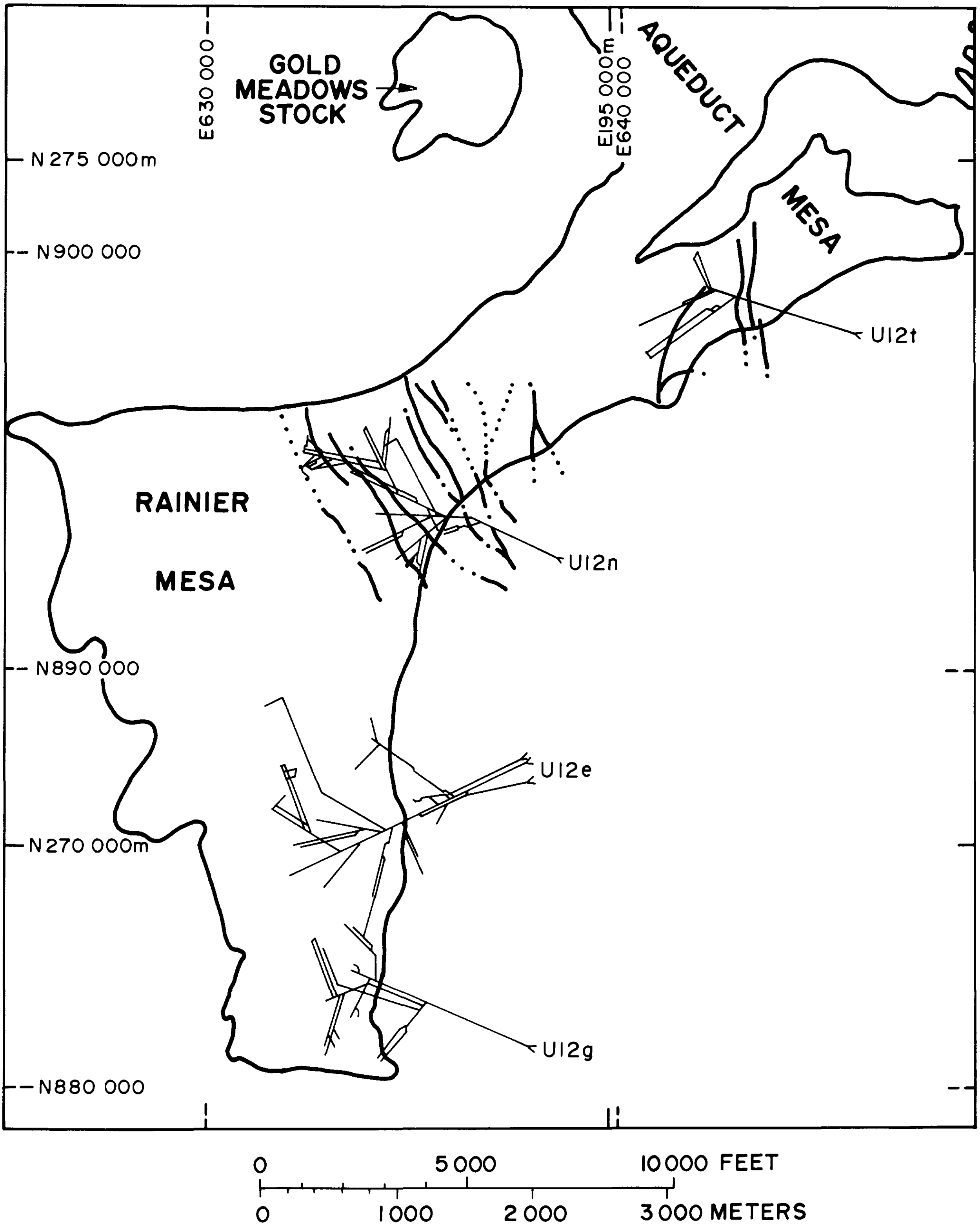


Figure 4.--Map showing surface faults on Rainier and Aqueduct Mesas. Dotted where concealed.

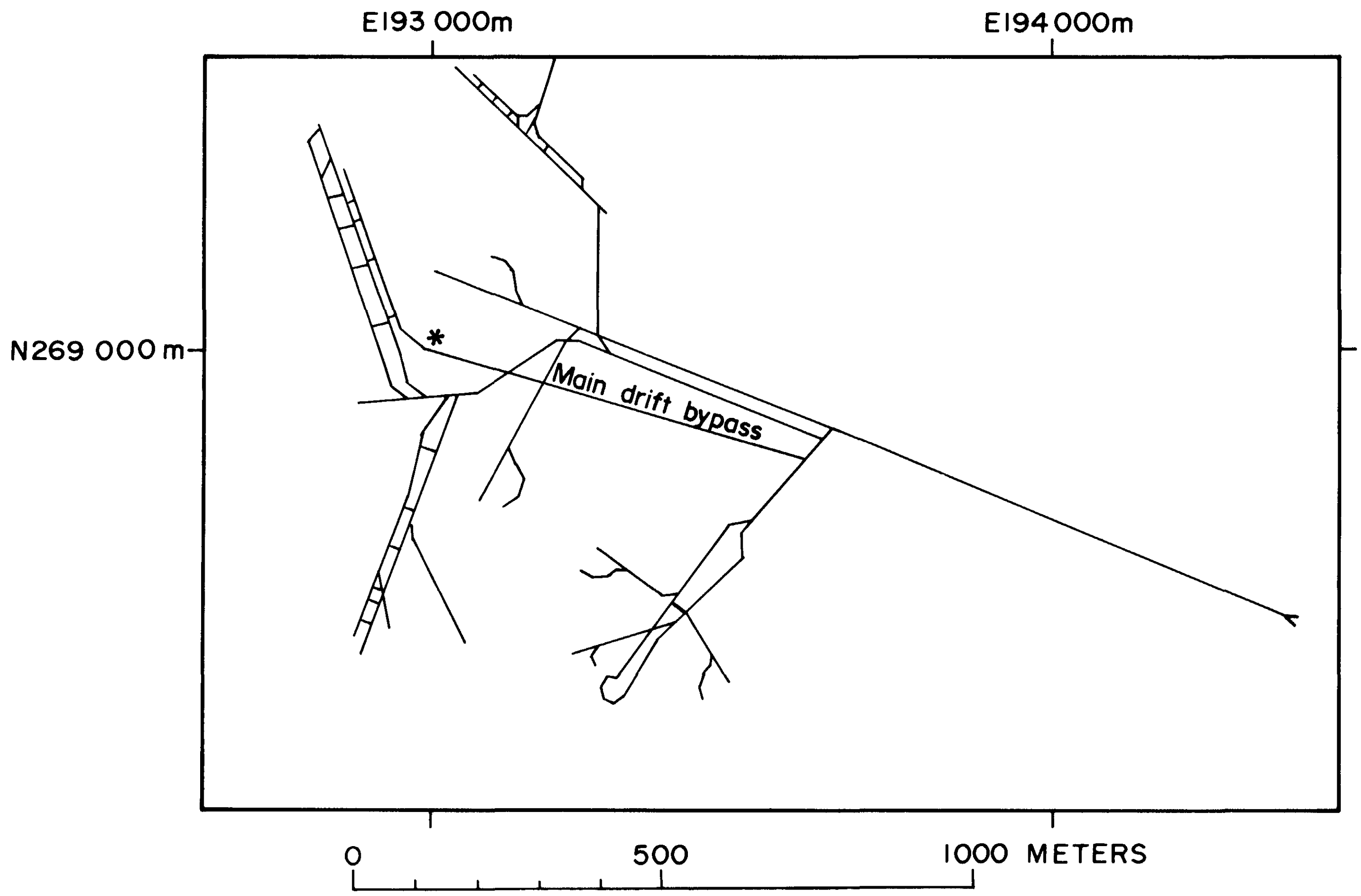


Figure 5.--Location of stress determination (*) in U12g tunnel complex.

Table 1.--State of stress determined in U12g tunnel main drift bypass (USBM overcore method)

[---, not applicable]

	Stress magnitude	Standard deviation	Bearing	Inclination
	MPa	MPa		+ degrees above horizontal - degrees below horizontal
Principal stresses				
	(+, compression)			
S_1 (minimum)	+2.6	±0.4	N. 68° W.	-7°
S_2 (maximum)	+8.5	±0.5	N. 21° E.	+2°
S_3 (intermediate)	+6.8	±0.3	N. 83° W.	+82°
Normal stress components in X, Y, Z (east, north, vertical) coordinate system				
	(+, compression)			
σ_x	+3.5	±0.3	East	Horizontal
σ_y	+7.7	±0.5	North	Horizontal
σ_z	+6.7	±0.3	---	Vertical
Shear stress components in X, Y, Z coordinate system[1/]				
τ_{xy}	+2.0	±0.3	---	---
τ_{yz}	+0.3	±0.3	---	---
τ_{zx}	-0.5	±0.2	---	---

[1/] Positive or negative sign on shear stress magnitude indicates direction of shear stress with respect to X, Y, Z coordinate system.

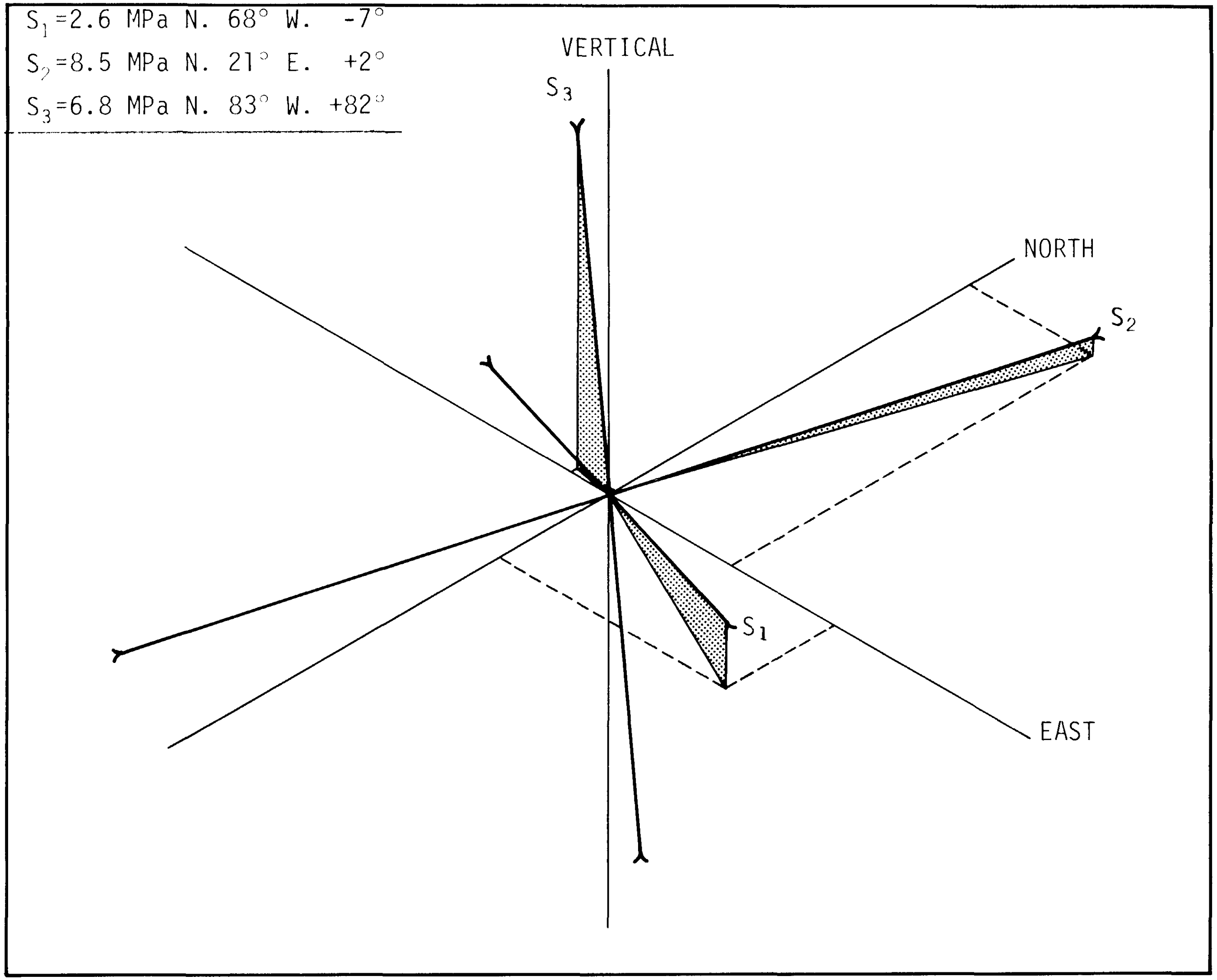


Figure 6.--Graphical representation of principal stress axes, U12g tunnel.

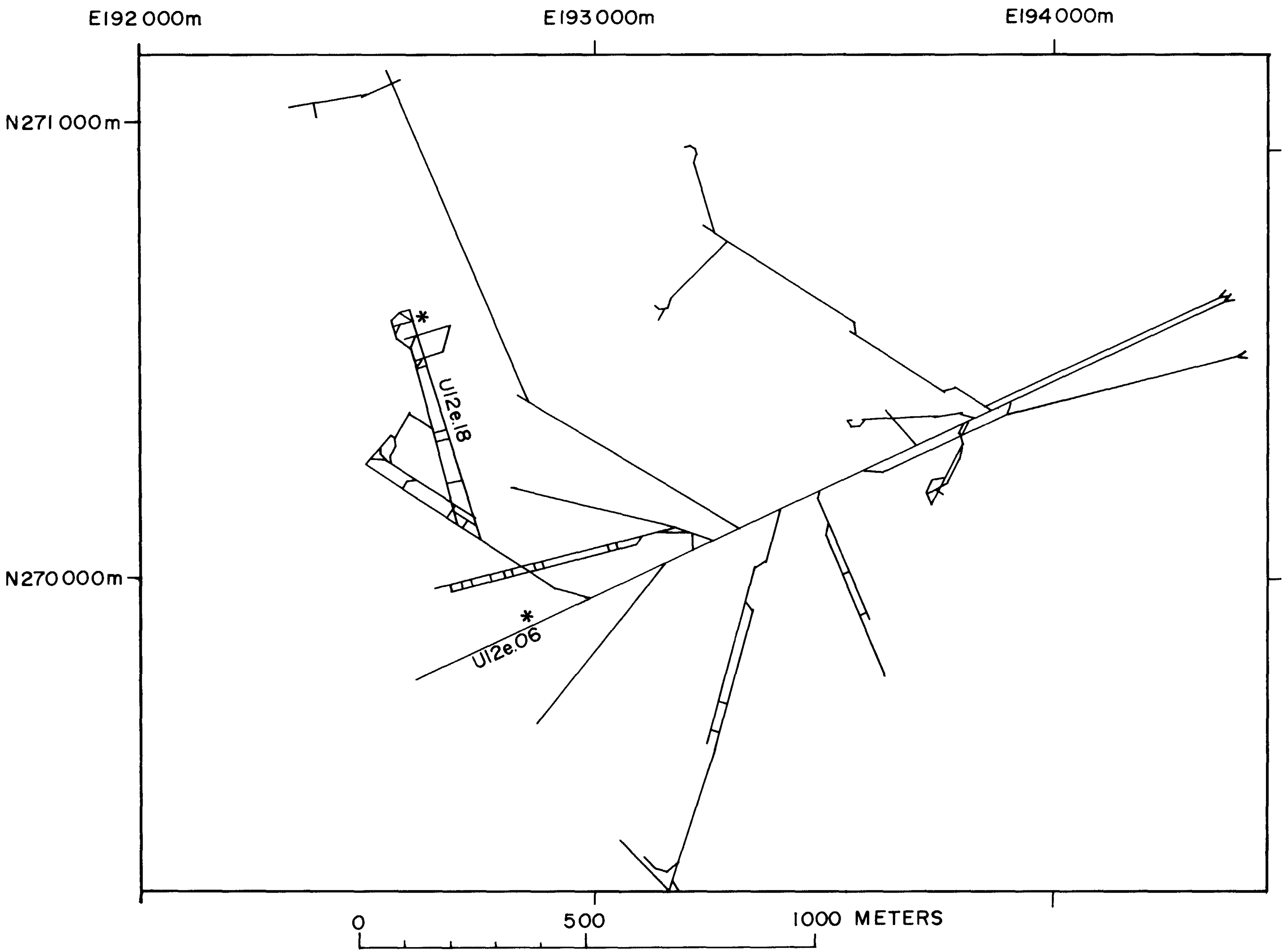


Figure 7.--Locations of stress determinations (*) in U12e tunnel complex.

Table 2.--State of stress determined in U12e.06 drift (USBM overcore method)

[---, not applicable]

	Stress magnitude	Standard deviation	Bearing	Inclination
	MPa	MPa		+ degrees above horizontal - degrees below horizontal
Principal stresses				
	(+, compression)			
S_1 (minimum)	+3.7	±0.5	N. 88° E.	-20°
S_2 (maximum)	+6.6	±0.5	N. 51° W.	-64°
S_3 (intermediate)	+4.7	±0.4	N. 4° E.	+16°
Normal stress components in X, Y, Z (east, north, vertical) coordinate system				
	(+, compression)			
σ_x	+4.0	±0.4	East	Horizontal
σ_y	+4.8	±0.4	North	Horizontal
σ_z	+6.1	±0.5	---	Vertical
Shear stress components in X, Y, Z coordinate system[1/]				
τ_{xy}	-0.2	±0.3	---	---
τ_{yz}	-0.5	±0.3	---	---
τ_{zx}	+0.9	±0.4	---	---

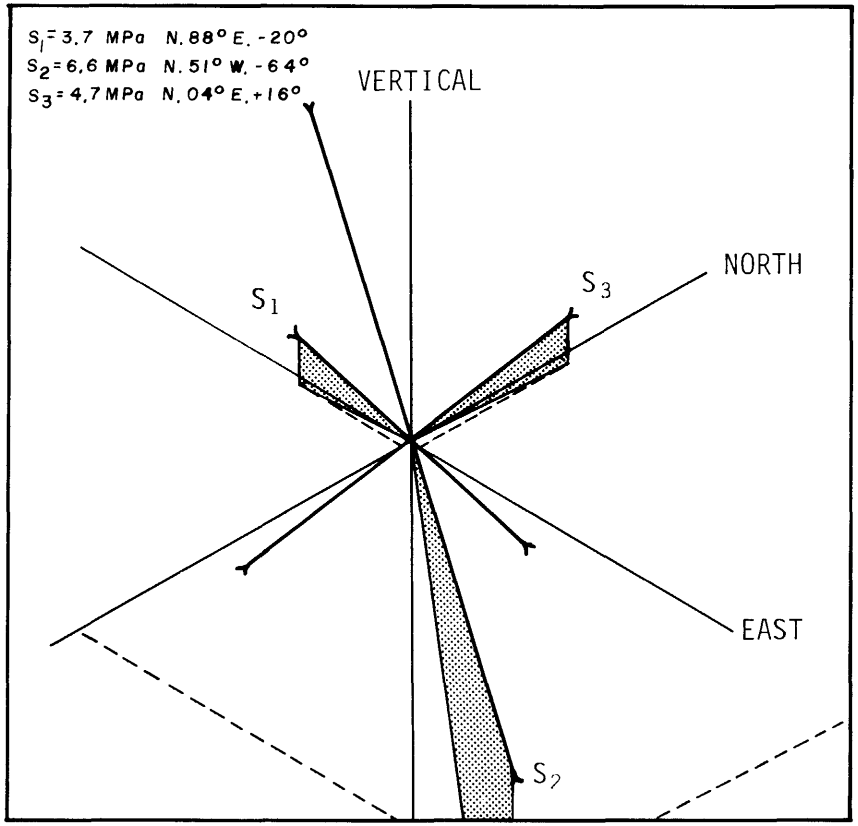
[1/] Positive or negative sign on shear stress magnitude indicates direction of shear stress with respect to X, Y, Z coordinate system.

Table 3.--State of stress determined at U12e.18 working point (USBM overcore method)

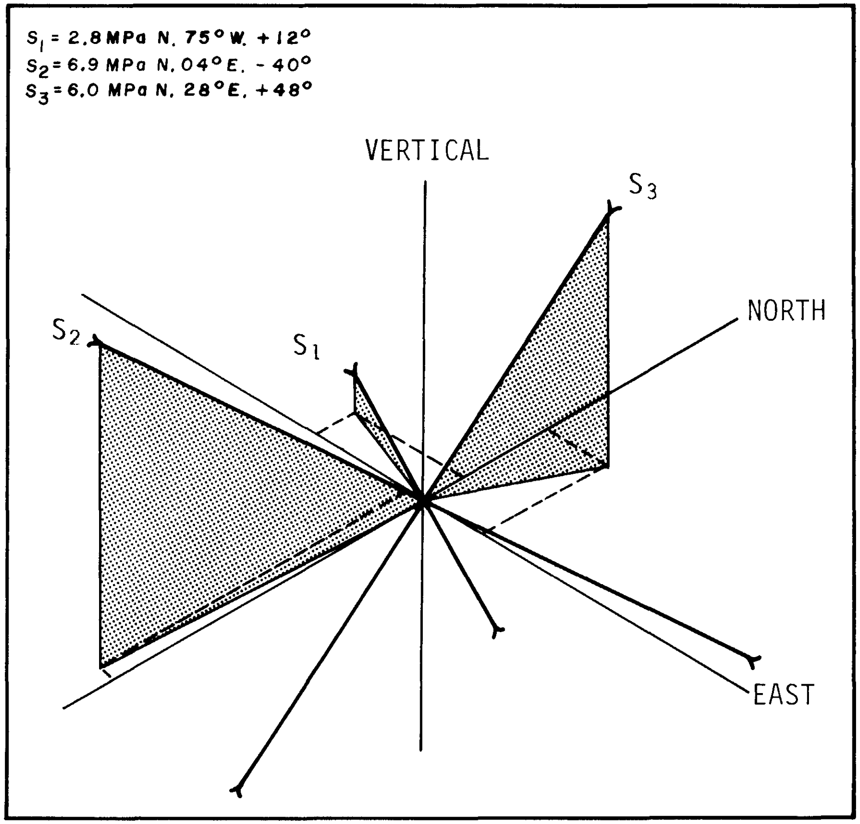
[---, not applicable]

	Stress magnitude	Standard deviation	Bearing	Inclination
	MPa	MPa		+ degrees above horizontal - degrees below horizontal
		Principal stresses		
	(+, compression)			
S_1 (minimum)	+2.8	±0.4	N. 75° W.	+12°
S_2 (maximum)	+6.9	±0.4	N. 4° E.	-40°
S_3 (intermediate)	+6.0	±0.4	N. 28° E.	+48°
		Normal stress components in X, Y, Z (east, north, vertical) coordinate system		
	(+, compression)			
σ_x	+3.1	±0.4	East	Horizontal
σ_y	+6.3	±0.4	North	Horizontal
σ_z	+6.2	±0.3	---	Vertical
		Shear stress components in X, Y, Z coordinate system[1]		
τ_{xy}	+0.8	±0.3	---	---
τ_{yz}	-0.6	±0.3	---	---
τ_{zx}	+0.6	±0.3	---	---

[1] Positive or negative sign on shear stress magnitude indicates direction of shear stress with respect to X, Y, Z coordinate system.



U12e.06 drift



U12e.18 working point

Figure 8.--Graphical representations of principal stresses determined in U12e tunnel complex.

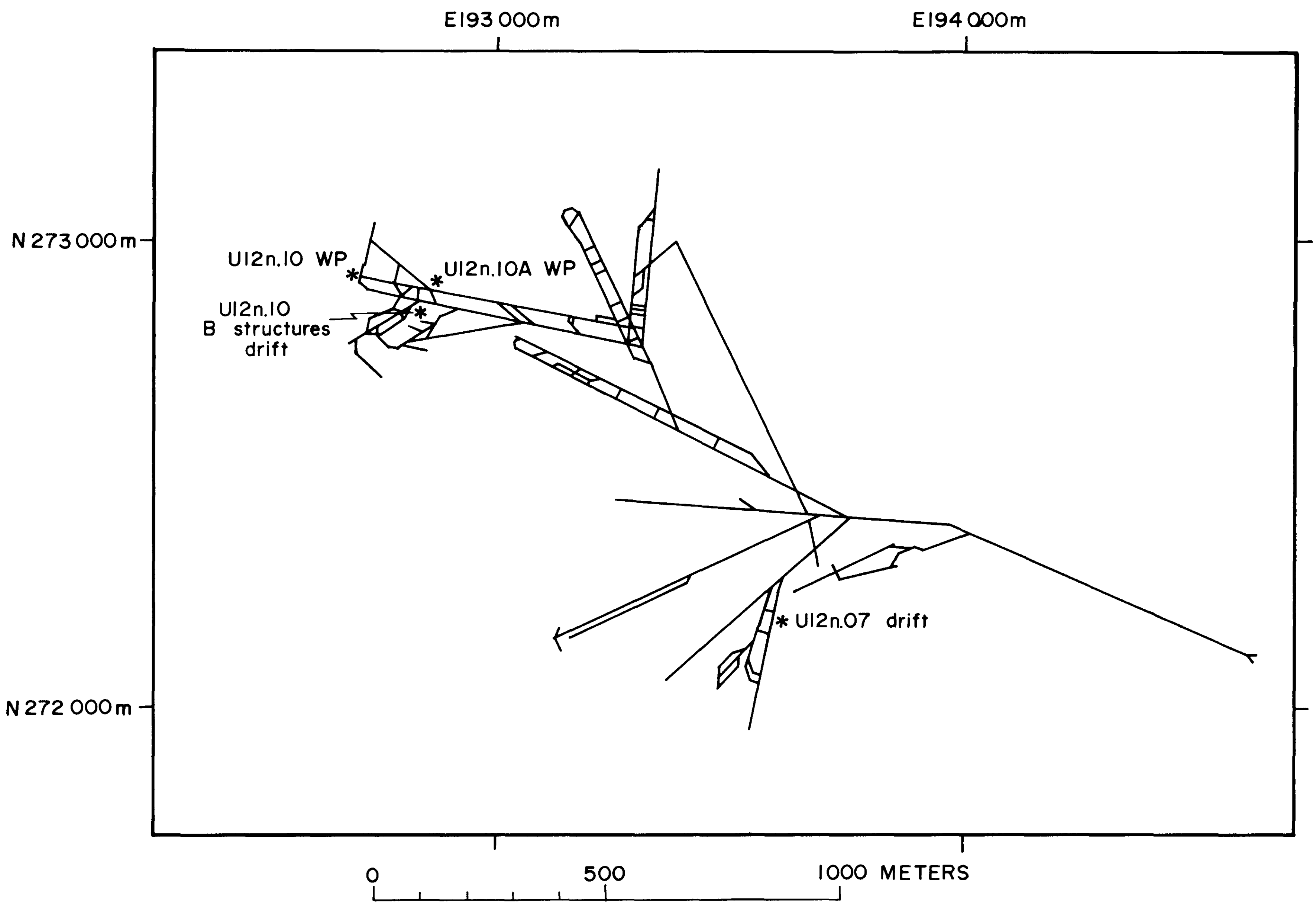


Figure 9.--Locations of stress determinations (*) in U12n tunnel complex.

Table 4.--State of stress determined in U12n.07 drift (USBM overcore method)
[---, not applicable]

	Stress magnitude	Standard deviation	Bearing	Inclination
	MPa	MPa		+ degrees above horizontal - degrees below horizontal
Principal stresses				
	(+, compression)			
S_1 (minimum)	+2.4	±0.9	N. 44° W.	-2°
S_2 (maximum)	+8.5	±0.5	N. 47° E.	-20°
S_3 (intermediate)	+5.6	±0.4	N. 42° E.	+70°
Normal stress components in X, Y, Z (east, north, vertical) coordinate system				
	(+, compression)			
σ_x	+5.4	±1.0	East	Horizontal
σ_y	+5.2	±0.4	North	Horizontal
σ_z	+6.0	±0.4	---	Vertical
Shear stress components in X, Y, Z coordinate system[1/]				
τ_{xy}	+2.9	±0.5	---	---
τ_{yz}	-0.6	±0.3	---	---
τ_{zx}	-0.7	±0.5	---	---

1/Positive or negative sign on shear stress magnitude indicates direction of shear stress with respect to X, Y, Z coordinate system.

Table 5.--State of stress determined at U12n.10 working point (USBM overcore method)
[---, not applicable]

	Stress magnitude	Standard deviation	Bearing	Inclination
	MPa	MPa		+ degrees above horizontal - degrees below horizontal
Principal stresses				
	(+, compression)			
S_1 (minimum)	+1.4	±0.5	N. 49° W.	+22°
S_2 (maximum)	+11.7	±0.8	N. 59° E.	+37°
S_3 (intermediate)	+5.8	±0.4	N. 18° E.	-45°
Normal stress components in X, Y, Z (east, north, vertical) coordinate system				
	(+, compression)			
σ_x	+6.4	±0.5	East	Horizontal
σ_y	+5.1	±0.3	North	Horizontal
σ_z	+7.4	±0.3	---	Vertical
Shear stress components in X, Y, Z coordinate system[1/]				
τ_{xy}	+3.5	±0.3	---	---
τ_{yz}	+0.5	±0.2	---	---
τ_{zx}	+3.6	±0.8	---	---

[1/] Positive or negative sign on shear stress magnitude indicates direction of shear stress with respect to X, Y, Z coordinate system.

Table 6.--State of stress determined in U12n.10 B structures drift (USBM overcore method)

[---, not applicable]

	Stress magnitude	Standard deviation	Bearing	Inclination
	MPa	MPa		+ degrees above horizontal - degrees below horizontal
Principal stresses				
	(+, compression)			
S_1 (minimum)	+3.8	±0.7	N. 2° E.	+22°
S_2 (maximum)	+7.0	±1.0	N. 84° W.	-9°
S_3 (intermediate)	+6.1	±0.7	N. 27° E.	-66°
Normal stress components in X, Y, Z (east, north, vertical) coordinate system				
	(+, compression)			
σ_x	+7.0	±1.0	East	Horizontal
σ_y	+4.1	±0.7	North	Horizontal
σ_z	+5.8	±0.6	---	Vertical
Shear stress components in X, Y, Z coordinate system[1/]				
τ_{xy}	-0.2	±0.8	---	---
τ_{yz}	-0.8	±0.5	---	---
τ_{zx}	+0.1	±0.6	---	---

[1/] Positive or negative sign on shear stress magnitude indicates direction of shear stress with respect to X, Y, Z coordinate system.

Table 7.--State of stress determined at U12n.10A working point (USBM overcore method)
[---, not applicable]

	Stress magnitude	Standard deviation	Bearing	Inclination
	MPa	MPa		+ degrees above horizontal - degrees below horizontal
		Principal stresses		
	(+, compression)			
S_1 (minimum)	+5.7	±0.7	N. 59° W.	+50°
S_2 (maximum)	+8.6	±0.4	N. 53° E.	+17°
S_3 (intermediate)	+6.2	±0.4	N. 25° W.	-34°
	Normal stress components in X, Y, Z (east, north, vertical) coordinate system			
	(+, compression)			
σ_x	+7.4	±0.7	East	Horizontal
σ_y	+6.9	±0.7	North	Horizontal
σ_z	+6.1	±0.4	---	Vertical
		Shear stress components in X, Y, Z coordinate system 1/		
τ_{xy}	+1.1	±0.4	---	---
τ_{yz}	+0.3	±0.4	---	---
τ_{zx}	+0.8	±0.4	---	---

1/ Positive or negative sign on shear stress magnitude indicates direction of shear stress with respect to X, Y, Z coordinate system.

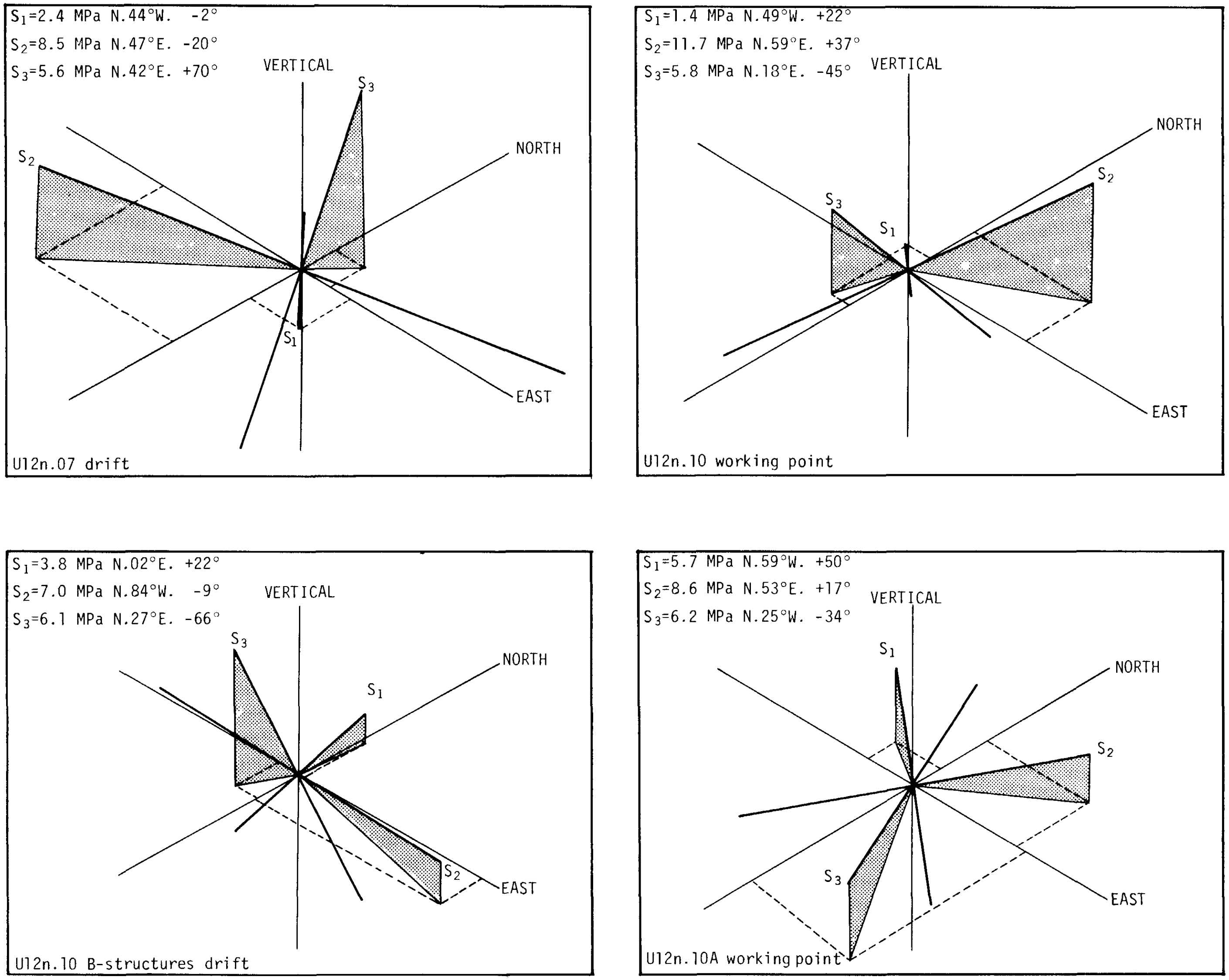


Figure 10.--Graphical representations of principal stresses determined in U12n tunnel complex.

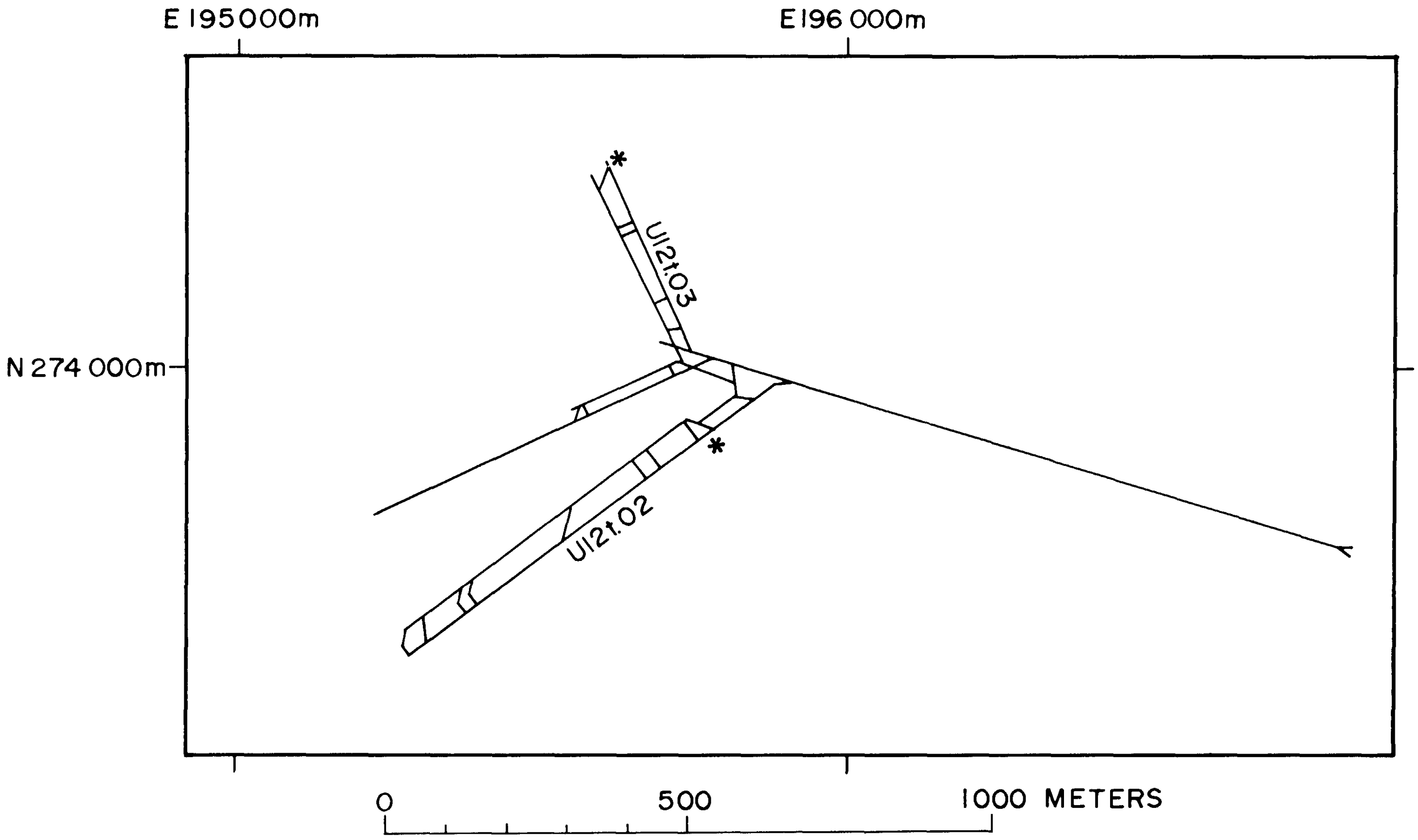
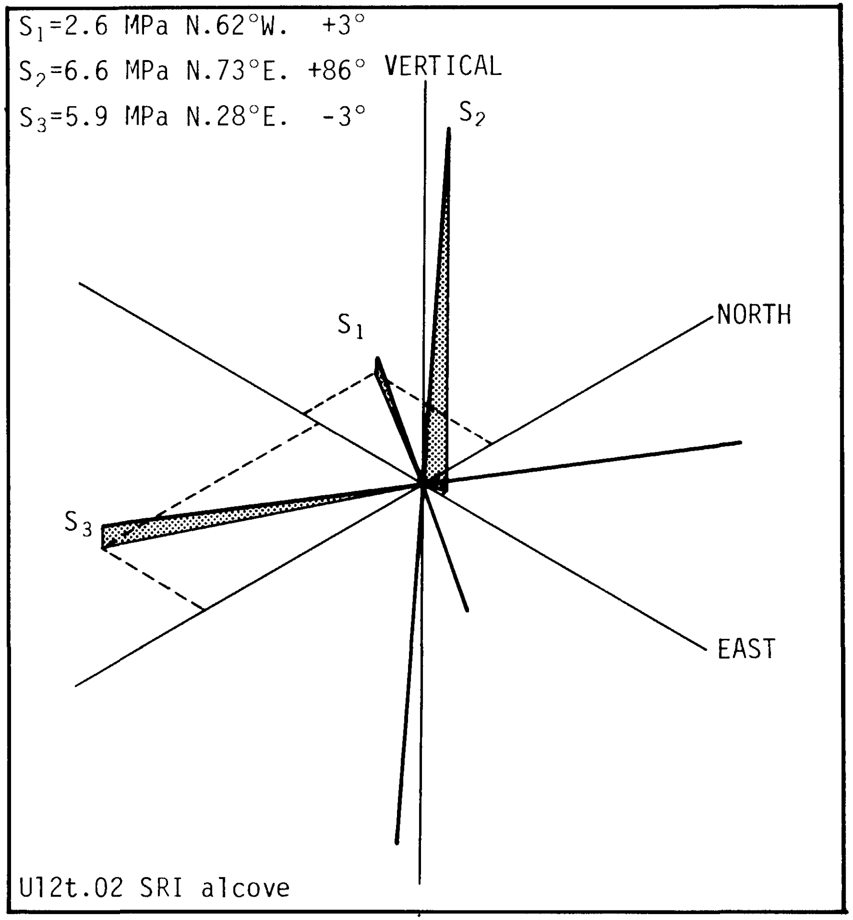


Figure 11.--Locations of stress determinations (*) in U12t tunnel complex.

Table 8.--State of stress determined at U12t.03 working point (USBM overcore method)
[---, not applicable]

	Stress magnitude	Standard deviation	Bearing	Inclination
	MPa	MPa		+ degrees above horizontal - degrees below horizontal
Principal stresses				
	(+, compression)			
S_1 (minimum)	+4.3	±1.0	N. 37° W.	+31°
S_2 (maximum)	+8.1	±0.8	N. 33° E.	-29°
S_3 (intermediate)	+5.2	±0.9	N. 89° E.	+45°
Normal stress components in X, Y, Z (east, north, vertical) coordinate system				
	(+, compression)			
σ_x	+5.6	±0.8	East	Horizontal
σ_y	+6.3	±0.8	North	Horizontal
σ_z	+5.6	±0.8	---	Vertical
Shear stress components in X, Y, Z coordinate system[1/]				
τ_{xy}	+1.3	±0.5	---	---
τ_{yz}	-1.4	±0.7	---	---
τ_{zx}	-0.4	±0.6	---	---

[1/]Positive or negative sign on shear stress magnitude indicates direction of shear stress with respect to X, Y, Z coordinate system.



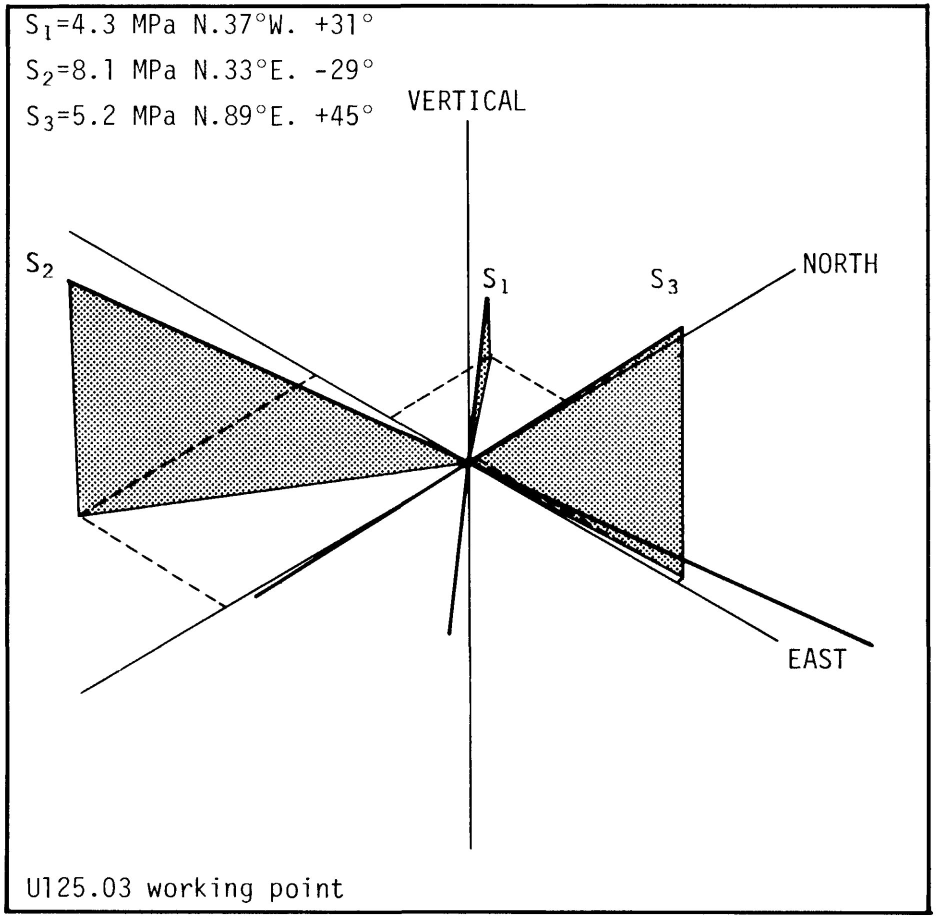


Figure 12.--Graphical representations of principal stresses determined in U12t tunnel complex.

Table 9.--State of stress determined in U12t.02 SRI alcove (USBM overcore method)
[---, not applicable]

	Stress magnitude	Standard deviation	Bearing	Inclination
	MPa	MPa		+ degrees above horizontal - degrees below horizontal
Principal stresses				
	(+, compression)			
S_1 (minimum)	+2.6	±0.5	N. 62° W.	+3°
S_2 (maximum)	+6.6	±0.5	N. 73° E.	+86°
S_3 (intermediate)	+5.9	±0.4	N. 28° E.	-3°
Normal stress components in X, Y, Z (east, north, vertical) coordinate system				
	(+, compression)			
σ_x	+3.3	±0.4	East	Horizontal
σ_y	+5.2	±0.4	North	Horizontal
σ_z	+6.6	±0.5	---	Vertical
Shear stress components in X, Y, Z coordinate system[1/]				
τ_{xy}	+1.4	±0.3	---	---
τ_{yz}	-0.1	±0.5	---	---
τ_{zx}	+0.2	±0.5	---	---

[1/] Positive or negative sign on shear stress magnitude indicates direction of shear stress with respect to X, Y, Z coordinate system.

SUMMARY OF RESULTS

Results of the stress determinations indicate a generally consistent pattern of relatively high northeast-southwest-trending stress and relatively low northwest-southeast-trending stress within Rainier and Aqueduct Mesas (table 10). This pattern is very obvious when the principal stresses are resolved into maximum and minimum horizontal stress components (fig. 13). The pattern is consistent with estimates of the regional stresses in the NTS area. Carr (1974) cited considerable geologic and geophysical evidence, including earthquake focal-plane solutions, from which he estimated the direction of maximum horizontal compressive stress for the region to be about N. 40° E.-S. 40° W. The plot of horizontal secondary principal stresses on figure 13 suggests that the topography of the mesas to some degree controls the orientation of the stresses. Because the topographic edges of the mesas offer the least horizontal confinement, the minimum stress axes tend to aline roughly normal to the boundary of the mesas, producing local modifications in stress orientation.

As is often the case with stress determinations made relatively near the Earth's surface, the maximum horizontal stress magnitudes in Rainier and Aqueduct Mesas are approximately equal to, but often greater than, the vertical stress magnitude (McGarr and Gay, 1978). This situation is sometimes explained as resulting from residual or thermal stresses, or the process of denudation in which large amounts of overburden have been removed, thus locking in relatively high horizontal stresses. Neither residual stresses nor denudation would seem to apply to Rainier and Aqueduct Mesas. The mechanical and physical properties of the tuff are not conducive to retention of high-magnitude residual stresses arising at the time of deposition of the rocks. Large-scale erosion or denudation has not occurred. The stresses in Rainier and Aqueduct Mesas appear to be largely tectonic in origin, and probably reflect the regional stress pattern at depth. Local variations in magnitude and orientation occur in the regional pattern, owing to the topographic configuration of the mesas, the location above the average regional elevation, and the influence of local geologic features at individual measurement locations.

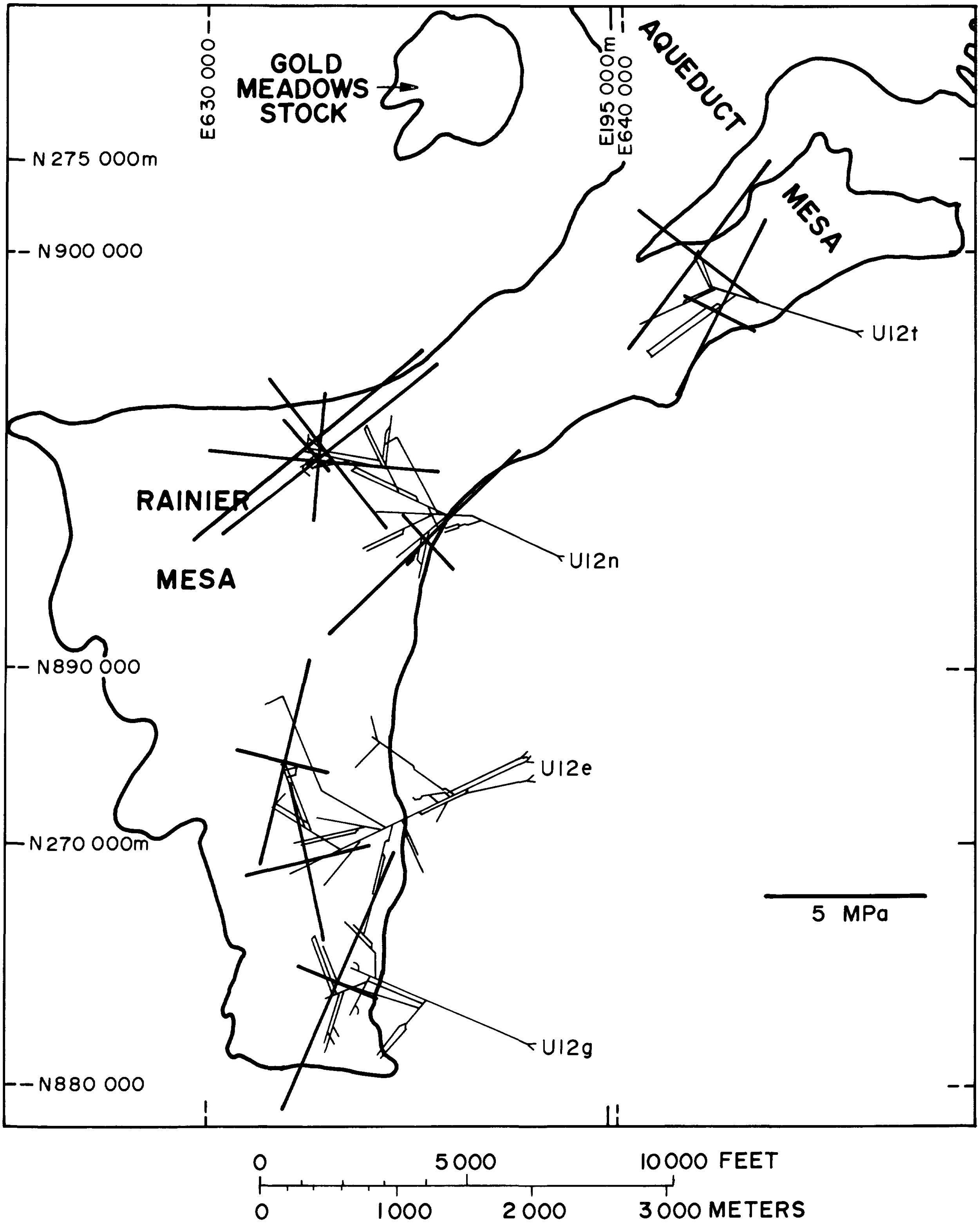


Figure 13.--Horizontal secondary principal stresses at nine locations in Rainier and Aqueduct Mesas.

Table 10.--Principal stresses determined at nine locations in Rainier and Aqueduct Mesas (USBM overcore method)

Tunnel	Depth (m)	Maximum MPz	Intermediate MPz	Minimum MPz	Bearing of maximum	Inclination	Bearing of minimum	Inclination
U12n.07	381	8.5	5.7	2.4	N. 47° E.	-20°	N. 44° W.	-2°
U12t.02	428	6.6	5.9	2.6	[1] N. 74° E.	+86°	N. 62° W.	+3°
U12gMDBP	442	8.5	6.8	2.6	N. 21° E.	+2°	N. 68° W.	-7°
U12e.18	383	6.9	6.0	2.8	N. 4° E.	-40°	N. 75° W.	+12°
U12e.06	408	6.6	4.7	3.7	[2] N. 51° W.	-64°	S. 88° W.	+20°
U12t.03	328	8.1	5.2	4.3	N. 33° E.	-29°	N. 37° W.	+31°
U12n.10	398	11.7	5.8	1.4	N. 59° E.	+37°	N. 49° W.	+22°
U12n.10 B Drift	393	7.0	6.1	3.8	S. 84° E.	+9°	N. 2° E.	+22°
U12n.10A2	388	8.6	6.2	5.7	N. 53° E.	+17°	N. 59° W.	+50°

[1] N. 28° E. -3°
[2] N. 4° E. +16°
Intermediate principal stress orientation.

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