To: Keith McConnell MS 623SS WMBT

N1 (101 060529 LPDR WM-10 (2)

SHEET 1 OF 1

ENGINEERING ORDER

Rockwell Hanford Operations
Richland, WA 99352

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PROJECT NO.	W.O./W.R. NO.	PROGRAM PHASE		BLDG. NO.	CEI	UCN	PRIORITY	RESPON. ENG.
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SYM	PART / DOCUMENT NO.	SHEET NO.	REV NO.	INDEX	NEXT ASSEMBLY PART NO.	DISPOSITION
	RSD-BWI-DP-016	1-16	A000		BWIP Data Package-Earthquake Swarms in the Hanford Region	

'87 APR -2 P12:03

ORG. CODE	PHONE	DATE
10110	6-2809	7/2/80
Geosciences A.C. Rohay		7/2/80
Geosciences S.M. Price		7/2/80
Geosciences		7/2/80
Scientific Tech.		7/2/80
S. Integrator M. [illegible]		7/18/80
Systems Integration R.N. Gurley		7/30/80
PRODUCTION SUPPORT		
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A-6400-072.1 (N-12-77)

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SUPPORTING DOCUMENT	Number RSD-BWI-DP-016	Rev. No.	Page 1 of 16
PROGRAM: Basalt Waste Isolation Project			
☐ CONTROL ☐ PROJECT Function Name:	Work Package No.		
Document Type: Data Package	Work Order No.		
Document Title: BWIP Data Package Earthquake Swarms in the Hanford Region	Original Release Date		
	Prepared by A. C. Rohay		Date 7/2/80
	Phone 6-2809	Room	Bldg. TAN / Area 700

Approvals

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Abstract

This data package contains a discussion of the character of earthquake swarms occurring in the Hanford region. The swarms have been detected over the past 10 years using a seismic monitoring network currently being operated by the University of Washington. The descriptive text is supplemented by two figures which summarize the locations, magnitudes, and time distribution of these earthquake swarms.

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BWIP DATA PACKAGE - EARTHQUAKE SWARMS IN THE HANFORD REGION

DATA SOURCE

Quarterly and annual reports on the seismicity of Eastern Washington are provided to the Department of Energy by the University of Washington. A seismograph network installed by the U.S. Geological Survey in 1969 has been operated since 1975 by the University of Washington. This network provides the raw data used to determine the earthquake parameters. A uniform redetermination of all earthquake locations and magnitudes was published in the University of Washington's 1979 Annual Report. Two figures from this report are included to summarize the earthquake swarm activity in the Hanford region. An additional source is a dissertation which studied in detail a swarm at Wooded Island in 1975. This study was included in the University of Washington's 1978 Annual Report.

DATA LIMITATIONS

Swarms of small earthquakes in Columbia River Basalt were discovered only after installation of a network of seismometers. Instrumental data are available for only the last ten years. The distribution of earthquakes during this time may not be representative of the distribution over the last hundred to thousand years. At the present time, the earthquake location threshold (for which all events can be located) is about 1.5 (M_L) in the immediate Hanford region, and is somewhat poorer, about 1.8 (M_L), in the whole of Eastern Washington. Thus, some of the events smaller than this value go unlocated. Swarm activity concentrated in the vicinity of Hanford does appear to be real, however, for the time period considered. Detailed studies of swarms using dense, temporary arrays have reduced the location thresholds to about magnitude 0 during their operation, usually for two to three month periods.

Location accuracy depends upon the size of the events, the distribution of the seismic stations, and the seismic velocity model used in the location computations. In general, the horizontal coordinates (epicenters) are accurate to better than two or three kilometers, while the depth of the events is less accurate and more dependent upon the velocity structure of the basalts. Hypocenters may be as much as 5 or more kilometers in error as a function as station distribution and data quality.

SYSTEMS INTEGRATION CONTACT

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Richland, Washington 99352

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Data Package: Earthquake Swarms in the Hanford Region

EARTHQUAKE SWARMS IN THE HANFORD REGION

Earthquake swarm activity is characterized by a spatial and temporal clustering of many small earthquakes with no outstanding single event. This type of earthquake sequence is typical of shallow events near the Hanford area, and indicates stress release on many small slip planes instead of a single main fault. The distribution of the best located earthquakes for the 1969-1979 instrumental period is plotted on the attached map (Figure 1). The events plotted are shallow, less than six kilometers deep. The regions of swarm activity have been enclosed in boxes. The temporal distribution is plotted on an accompanying figure (Figure 2) (the dots at the top of some of the histograms indicate an event greater than magnitude 3). The best example of swarm activity is located at Wooded Island, where swarms have occurred in 1969 and 1975. The earthquake sequence at Royal in 1973 appears to be a main-shock-aftershock sequence in contrast to the typical pattern of swarms in which a main shock can not be clearly defined.

Most of the swarm earthquakes are too small to allow calculation of the orientation of the possible slip planes. It is sometimes possible to select groups of events for such studies. The focal mechanisms of the swarm earthquakes indicate that they occur in response to gentle north-south compression but the direction of extension (vertical or east-west) seems to vary.

The events which occur in earthquake swarms are too small to be felt in most cases and would not be expected to damage structures. Their distribution may, however, indicate that fracturing is occurring in the basalt flows. Thus, the concentration of swarms on the northern flank of the Saddle Mountains indicates fracturing and deformation is occurring. This fracturing is likely to have hydrologic implications in terms of underground nuclear waste storage. As shown in Figure 1, the actual Hanford Site has large areas which have been free of swarm activity during the period of study.

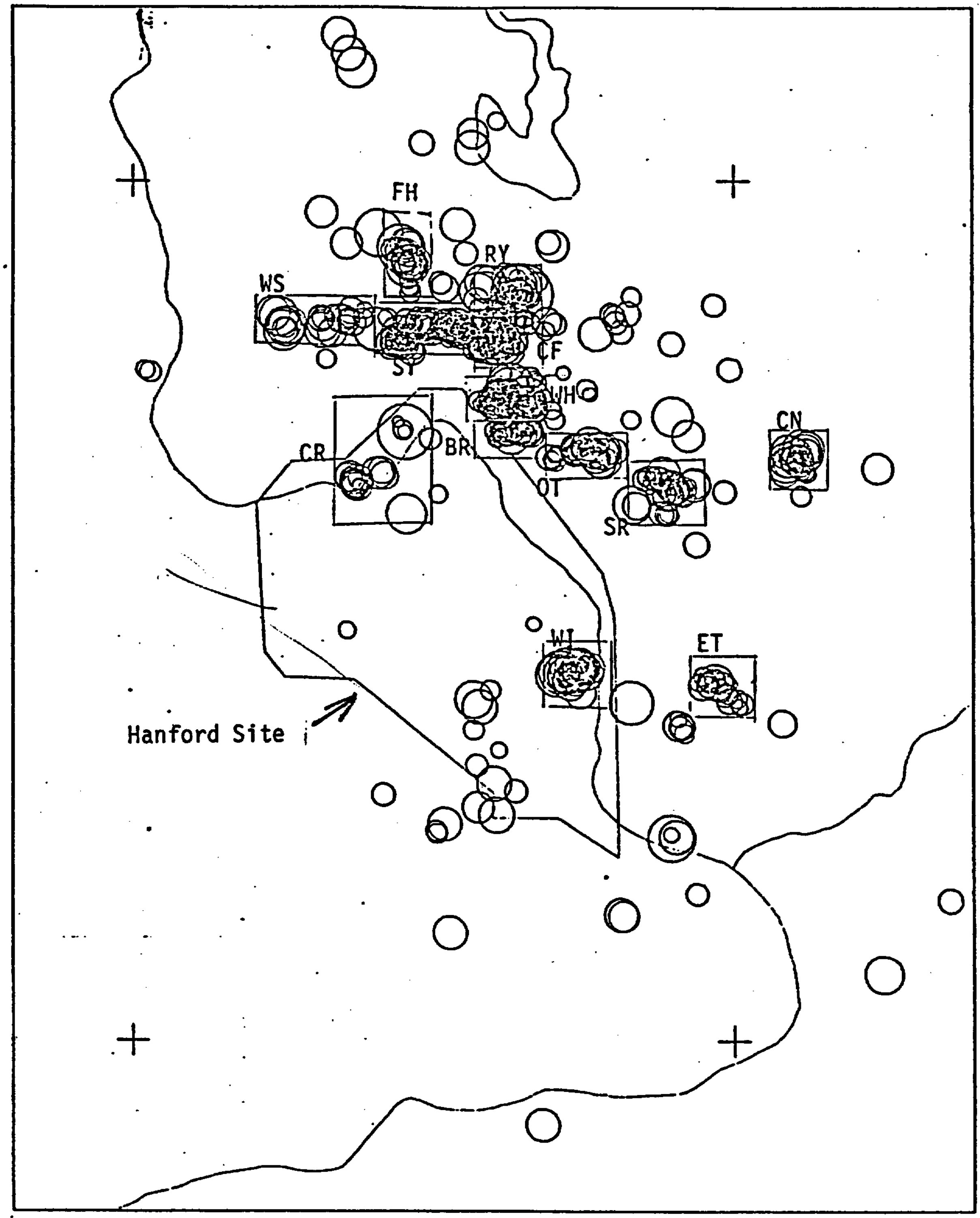
Also included as Attachment 2 and 3, are two previously prepared papers concerning earthquake swarm activity at Hanford. These papers contain information in addition to that discussed in the above paragraphs.

REFERENCES

Malone, S. D., Rothe, G. F., and Smith, S. W. (1975), Details of Micro-earthquake Swarms in the Columbia Basin, Washington, Bull. Seis. Soc. Am., V65, #4, pp. 855-864.

Malone, S. D., 1978, Annual Technical Report on Earthquake Monitoring of the Hanford Region, Eastern Washington.

Malone, S. D., 1979, Annual Technical Report on Earthquake Monitoring of the Hanford Region, Eastern Washington.



WELL LOCATED SHALLOW EARTHQUAKES 1969 - 1979
CENTER OF MAP IS 46.50 N 119.40 W

MAGNITUDE KEY ○ 0.0 ○ 1.5 ○ 3.0 ○ 4.5
(Richter Scale)

Figure 1. Locations of Earthquake Swarms

From: Malone, 1979

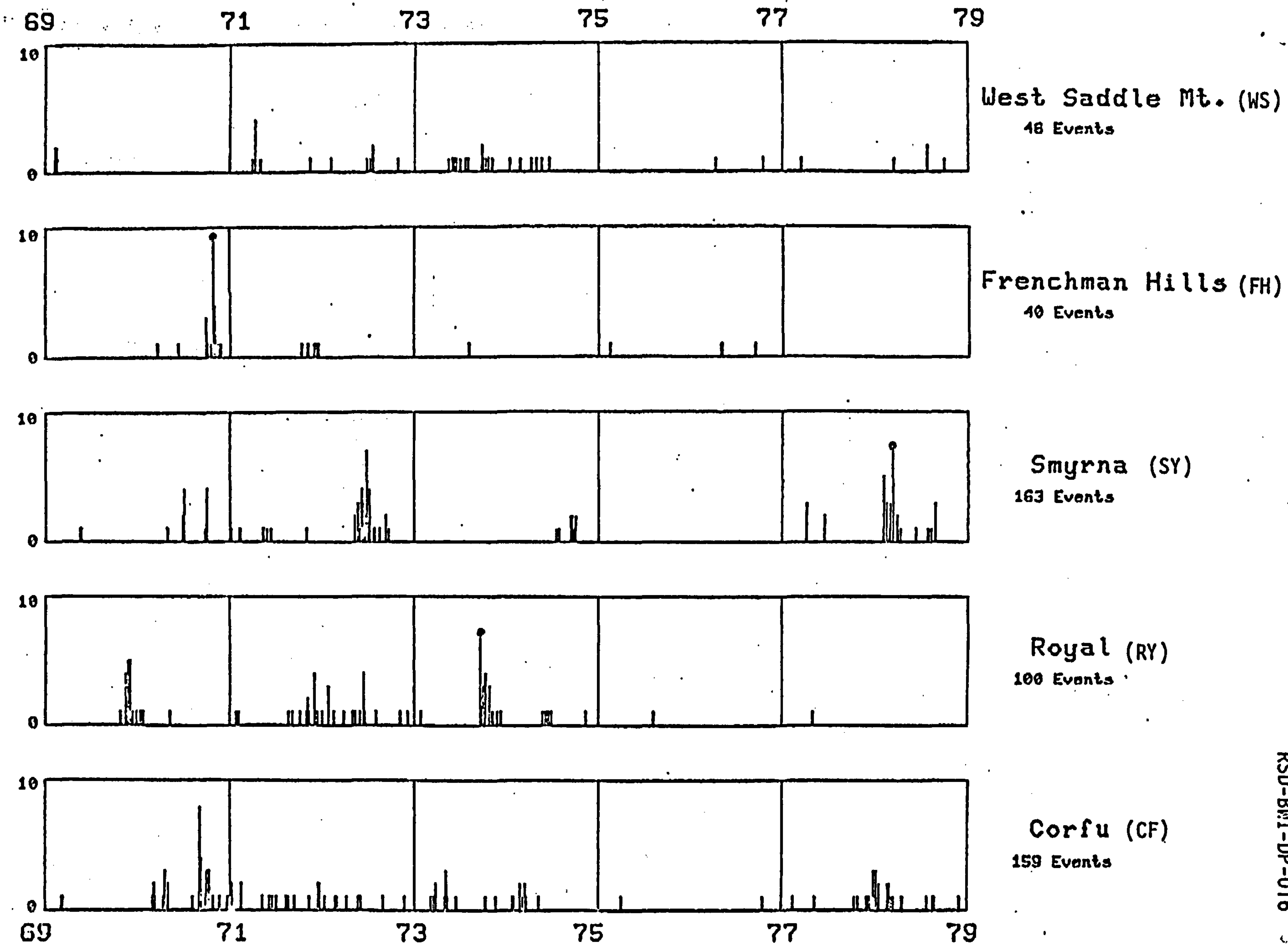


Figure 2. Temporal Clustering of Events Within Swarm Areas (See Figure 1 for locations.)

From: Malone, 1979

RSD-BWI-DP-016

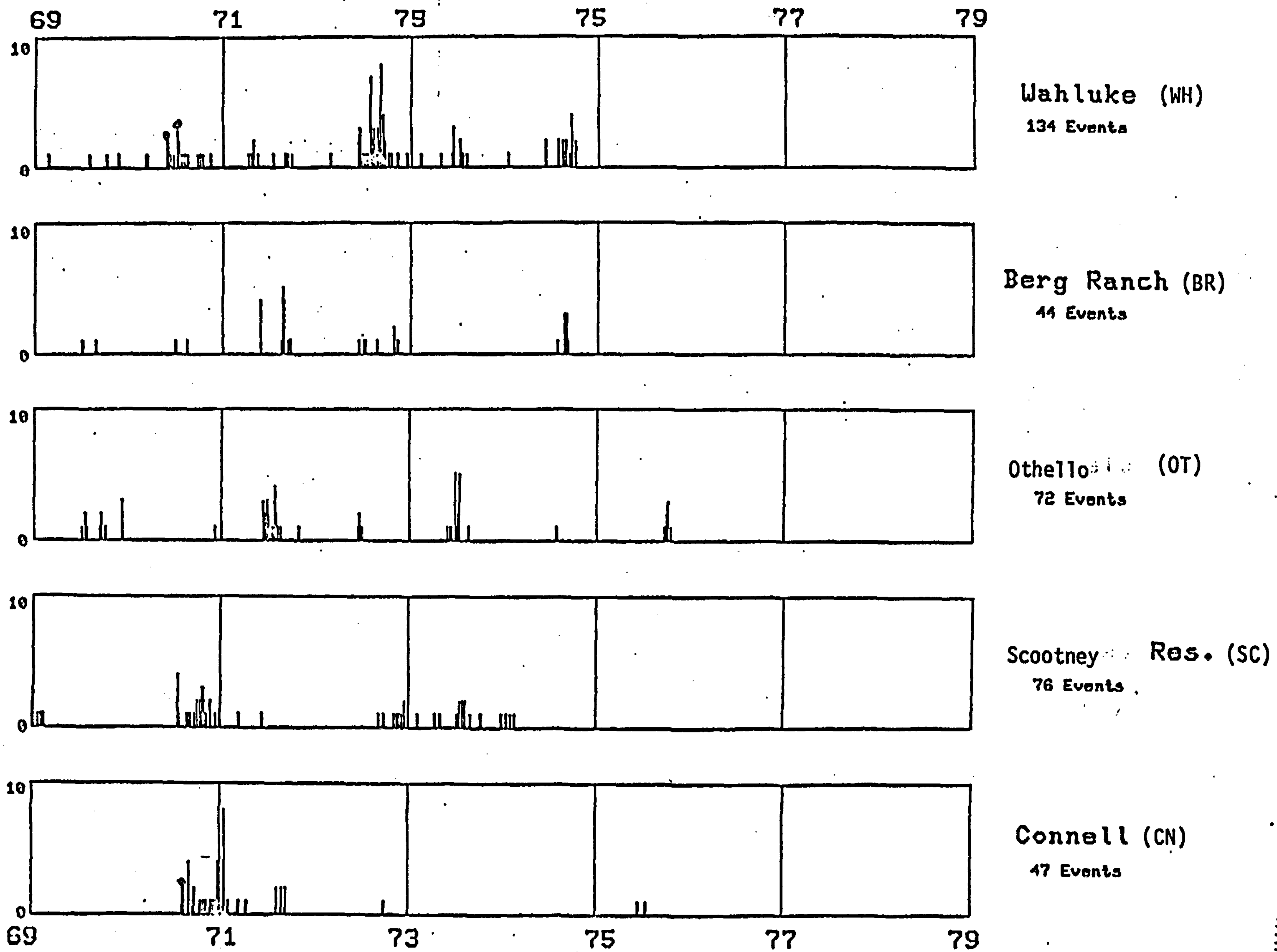


Figure 2. Continued

From: Malone, 1979

RSD-BWI-DP-016

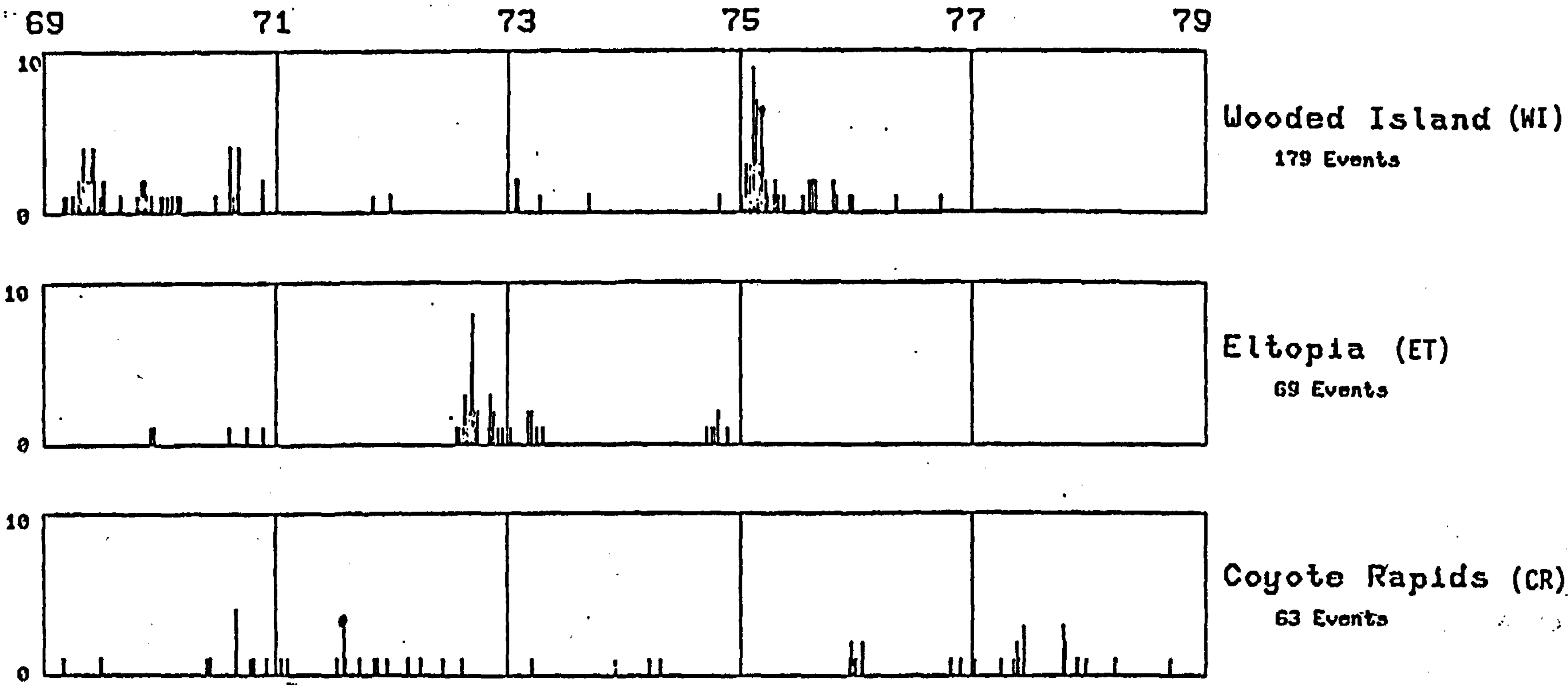


Figure 2. Continued

EARTHQUAKE SWARMS

Historical Background

Prior to the installation of the six station array in 1969 by the U.S. Geological Survey, earthquakes in eastern Washington and the area of the Hanford Site were monitored by a few seismographs of limited sensitivity located in Spokane, Seattle, Corvallis, and Victoria. The threshold for detection by such an array was about magnitude 4.5. With the exception of events large enough to be felt in non-instrumented areas, relatively few earthquakes were detected and even fewer were located with any precision. With such detection capabilities, few of the events recorded in the past 10 years by the eastern Washington network would have been detected, and almost none would have been located.

Based on a record of felt earthquakes, the area of eastern Washington is one of few earthquakes and relatively low seismic risk. The only exception to this observation would be a few moderate earthquakes that were felt at Corfu (November 1, 1918), Umatilla, Oregon (March 1892) and Milton-Freewater (July 15, 1936). These few events led Algermissen to place eastern Washington in a Zone 2 on his seismic risk map of the United States.

The Hanford/Eastern Washington Array

Under terms of an inter-agency agreement, the U.S. Geological Survey installed and operated a seismograph network from 1969 to 1975 when the responsibility of the net was transferred to the University of Washington. The initial six stations were deployed on and along the borders of the Hanford Site, but by 1972, there were 24 stations operating in southeastern Washington. When the network responsibility was assumed by the University of Washington, more stations were added bringing the total to about 36 in all of eastern Washington. There are currently about 40 stations operating throughout eastern Washington. The threshold for event detection and location in the area of the Hanford Site is about magnitude 1.5, although smaller events have been detected and located if they occur where they can be recorded by three or more stations. The threshold for detection and location for the remainder of eastern Washington is about magnitude 2. Events smaller than these thresholds may be recorded on one or two stations, but they can not be located and thus never appear in catalogs.

Seismicity of the Hanford Site 1969 to Present

The pattern of stress release is much better understood now than it was prior to 1969, but the collection of much additional data has also raised some perplexing problems. Earthquakes recorded in the area of southeastern Washington are all confined to the crust and indicate continued relief of stress at very low levels. To date, there is no obvious correlation of earthquakes with mapped geologic structure and no obvious alignment of earthquakes in planar zones that would suggest that relief of stress is concentrated along unmapped structures. Most earthquakes occur at very shallow depths (less than 5 km) in the area of the Hanford Site, but some do occur at depths up to about 28 km.

The occurrence of earthquakes in shallow swarms was one of the early significant discoveries by Mitch Pitt who ran the net for the U.S.G.S. Swarms are characterized by tens to thousands of small events that occur over a period of weeks to months at shallow depths in a very limited volume of rock (up to about 150 cubic kilometers of rock). Few events in a swarm will be larger than magnitude 2; many will be magnitudes less than one so that they can be detected but not accurately located. With few exceptions, there is no increase in numbers or size of events building up to a main shock and a subsequent dying away of activity after such an event. A swarm will begin and stress will continue to be relieved with no obvious pattern of numbers and sizes of earthquakes. Activity has been shown to migrate, but not in any systematic way. Swarm areas are generally elongate in an east-west direction. Reasonably accurate information on focal depths can only be obtained with station spacing that does not exceed focal depth.

Deployment of portable arrays during swarms at Wahluke, Royal Slope, Eltopia, Corfu, and Wooded Island indicate that most activity occurs at depths of three kilometers or less, and is apparently restricted to the basalt. The localities where swarms occur have been restricted over the first 10 years to areas along the north and south flanks of the Saddle Mountains and at Wooded Island. Several areas where swarms have been detected have been affected by such activity more than once in the 10 year period of record. In fact, swarm areas were thought to be rather well defined until recently when a new area was found along the Cold Creek Syncline near its intersection with the Olympic Wallowa Lineament.

Source Mechanisms

The source mechanism and the origin of the stress that is being relieved in swarms are not understood at present. Individual events are generally too small to get sufficient data that would allow the calculation of a focal mechanism solution for any single event. Therefore, using groups of similar records that presumably result from the same mechanism, composite focal mechanism solutions have been determined for several groups of similar events. There is no agreement as to the attitude of the slip plane suggesting that rupture is occurring on steeply dipping planes of several orientations, but generally oriented east-west and arising from a nearly north-south, nearly horizontally directed principal stress. Rothe, in his dissertation on the Wooded Island swarm, suggested that rupture was occurring in thick, competent basalt flows and that slip was occurring along columnar joints. Composite focal mechanism solutions for events in the Wooded Island swarm suggest rupture along nearly east-west planes that dip steeply to the north.

If Rothe's hypothesis is supported by further work, it has interesting ramification for the Basalt Waste Isolation Project. First, it suggests that stress accumulates to higher thresholds in thick competent flows than in thinner, more broken flows. Thus, thick competent flows would acquire a negative aspect in contrast to hydrologic aspects. Second, if the slip is taking place on columnar joints, these are limited in areal extent by the thickness of any flow. Since earthquake size is determined by the area of rupture, the size of earthquake that occurs in the basalt might be controlled by the maximum area of rupture and thus the maximum thickness of any flow. Since the basalt is jointed everywhere, the concentration of stress release by Rothe's mechanism is not a satisfactory explanation as it does not explain why stress release is concentrated and confined to small areas when all basalt is jointed.

The recurrence relation of earthquakes described by Richter is related to the source mechanism by which they arise. A frequently used plot in seismology relates earthquake magnitude to the log of the number of events of a given size ($\log N = a - bM$). The slope of such a line is referred to as the b value. Plots of earthquakes from elsewhere in the world suggest that tectonically produced earthquakes at and near plate boundaries are characterized by b values of about .75 to .90; non-tectonic events are characterized by b values greater than 1. Recurrence plots of swarm events in Columbia River Basalt reveal a b value greater than one, suggesting that they are similar to other swarm events in other areas that arise from unknown non-tectonic causes.

Data from the first ten years, and especially the first seven years, suggest that earthquake activity (i.e., total numbers of events) peaks in January and declines to a minimum in July. With due allowance for lag time, such a temporal cycle of activity suggests a relationship with irrigation as a possible cause of activity. Recent swarm activity has occurred in areas that are not irrigated and has begun at times when irrigation has been inoperative for several months. Increased load due to water, and/or increased pore pressure in shallow rocks may be a factor in microearthquake activity, but it does not appear to be the only causative factor. A relationship to lunar and solar generated earth tides has as yet to be pursued as a potential trigger for microearthquake activity.

Are Earthquake Swarms Restricted to the Hanford Site?

The sensitivity of the earthquake network at Hanford means that far more smaller events will be detected near Hanford than in other parts of the plateau. Some swarms have included events that are all below magnitude 2, and such swarms would probably only be detected in an area with close station spacing and high sensitivity. However, most swarms include events between magnitude 2 and 3; therefore, these swarms should be detected anywhere in the plateau. Ten years worth of data suggest that swarm activity is characteristic of the Hanford area, but not other areas of the plateau. If swarms in other areas of the plateau are restricted to very small events (maximum magnitude of 1 to 1.5), it is possible that such activity occurs and goes undetected because of network sensitivity.

Summary

Ten years worth of data suggest that swarms of temporally and spatially restricted small shallow earthquakes are characteristic of the Hanford area. Other events do occur at depths of 5 to 28 km, but more than 75% of the earthquakes occur in less than 5% of the area. The mechanism of the events is not understood, but the earthquakes do tend to occur in elongate east-west areas with slip on steeply dipping planes oriented nearly east-west and resulting from nearly horizontal north-south compression. With a threshold of detection and location of magnitude 1.5 events near Hanford in contrast to a threshold of magnitude 2 elsewhere in the plateau, many more small events near Hanford are recorded and located. Under such circumstances, it is possible that swarms of very small earthquakes could occur elsewhere in the plateau but go undetected. However, since most swarms include several events greater than magnitude 2, this possibility seems unlikely.

Since the mechanism of the swarm earthquakes is poorly understood, it is not possible at this time to say whether the conditions leading to microearthquakes at Hanford are duplicated at any other locality in the plateau.

Although the mechanism of swarms is not understood, there have been no events recorded in the 10 year history of the Hanford array that could not be accommodated by appropriate design techniques. The significance of the swarms as an indication of the potential for larger events over the design life of a repository remains to be determined.

ATTACHMENT 3

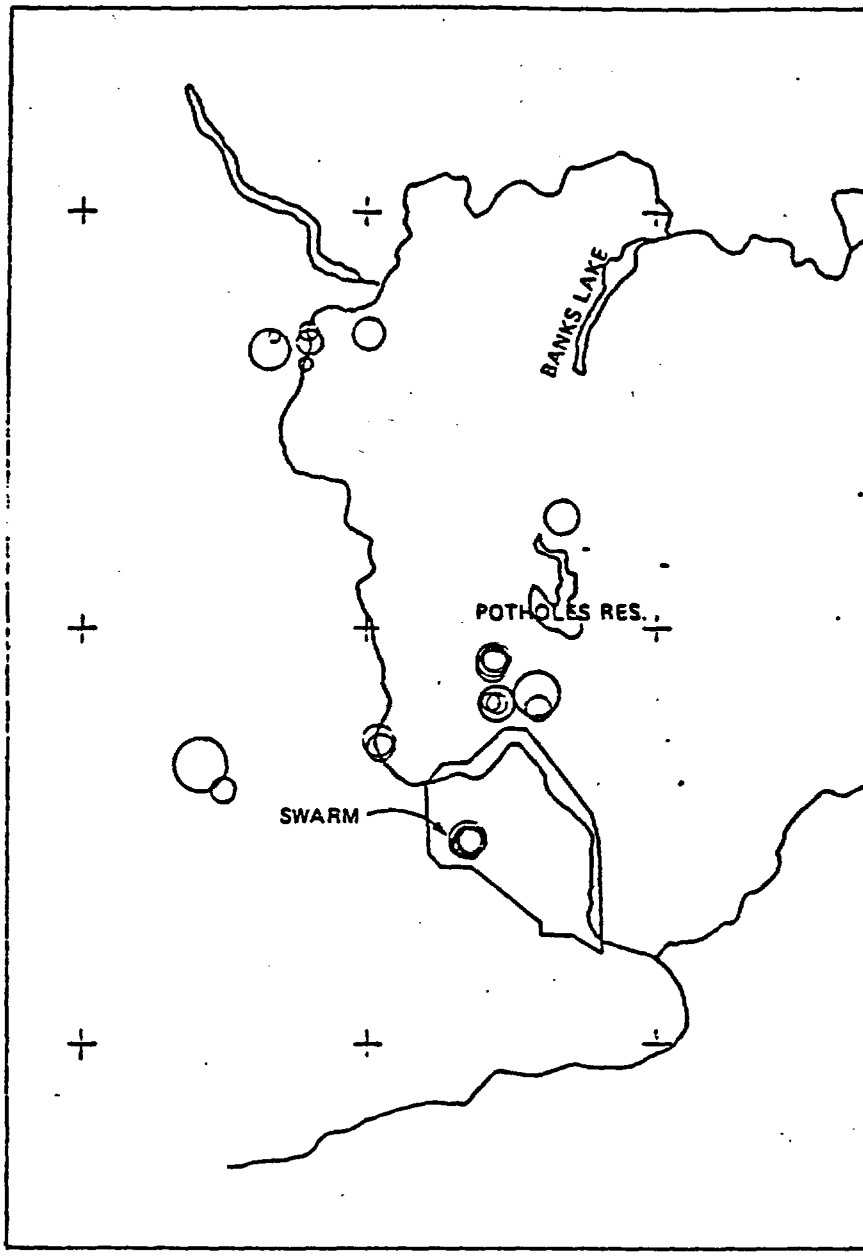
COLD CREEK EARTHQUAKE SWARM

A swarm of small earthquakes occured in the Cold Creek syncline area on 9/8/79. Seven events occured in a three hour period with the largest event (magnitude 2.4) followed by six smaller events (magnitudes 1.2 - 1.8). This region has not had any located earthquakes since two small events in late 1977 and early 1978. The recent swarm was preceded by events three days, one month, and two months earlier. A magnitude 2.1 event occured the following day, and another small earthquake occured one month later.

All of the events were located between 1.4 and 4.3 km depth. However, periodic studies of swarm activity using local arrays has indicated that the routine hypocenter locations are slightly biased to deeper locations. Spatially, the entire sequence is bound in a rectangular area 2 X 3.5 km, elongate in an east-west direction. The three hour swarm is contained in a much smaller region (1 km^2) in the center of the rectangle. The depths of these central events were on the average located deeper than those in the outlying regions. Activity apparently began in the outlying regions, migrated into the central region, and then migrated outward again.

Focal mechanism plots indicate that different events within this swarm produced differing polarities at individual station. This indicates some degree of variability in the planes of faulting. Consistent polarities at several stations indicate roughly north-south compression. The rest of the first motion data (which were variable) are best fit by nodal planes placed as close as possible to the take-off directions represented by the variable first motion data. Small random variations in the fault parameters could then explain the differences. The plotting of the data is itself dependent upon the location (especially the depth) and ultimately upon the velocity model. Consideration of these inaccuracies can also explain some of the inconsistencies in this data set.

The focal mechanisms determined consistently indicate a thrust mechanism. Extremal solutions can be produced with maximum compression near horizontal (plunge 10° to 30° south) oriented from north to north-west azimuths. Tension is near vertical, plunging 10° to 30° west. Possible slip surfaces inferred from the composite plot are either nearly horizontal (dipping 20^o to 30^o to the north or north-west), or near vertical (60^o to 70^o to the south or south-east), with the strike of the fault planes being east to north-east in either case. All the mechanisms are primarily thrust with with only minor right-lateral strike-slip components. The spatial distribution of the events is scattered, and does not help to determine which of the two general planes slip has occured on.

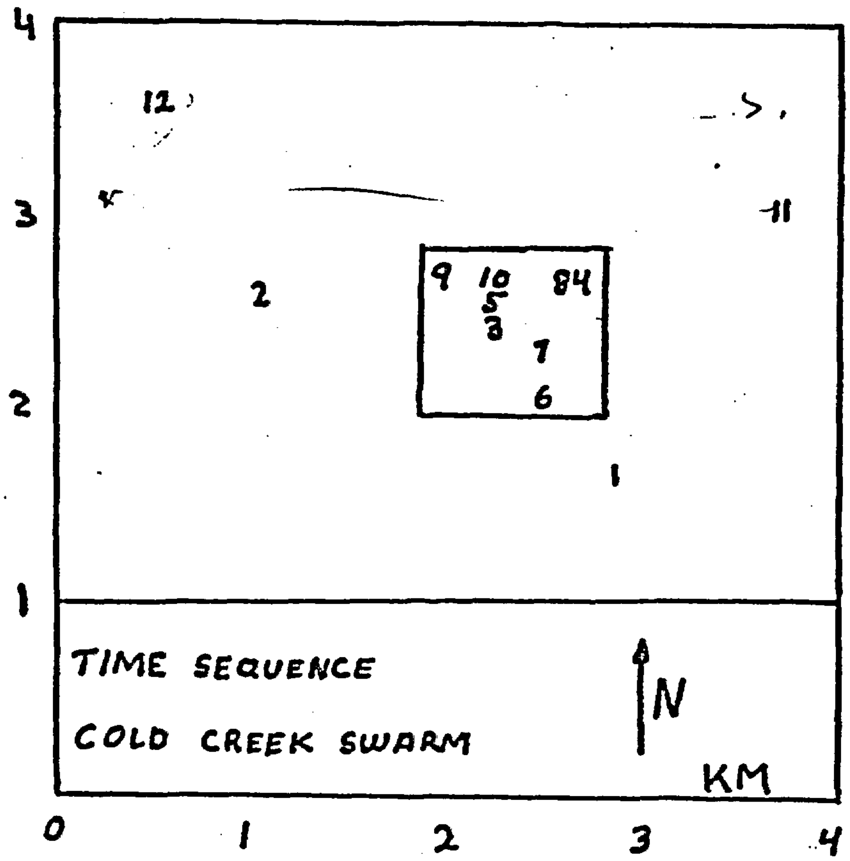


EASTERN WASHINGTON EARTHQUAKES JULY – SEPT. 1979 (AFTER MALONE' 1979c)
CENTER OF MAP IS 47.00 N 199.75W

MAGNITUDE KEY 0.0 1.3 2.7 4.0
(Richter Scale)

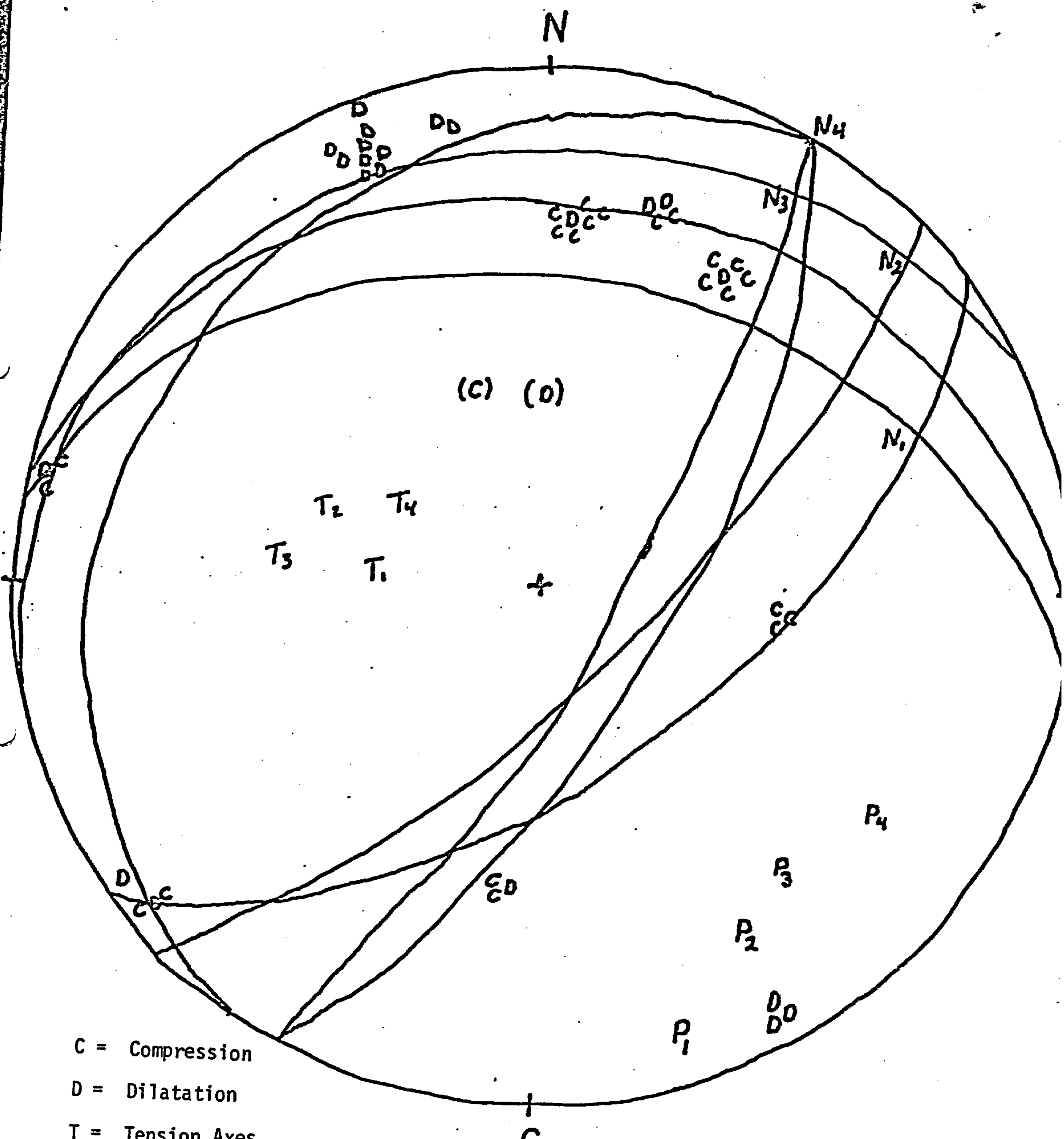
Project No. 13891C	WASHINGTON PUBLIC POWER SUPPLY SYSTEM	SHALLOW MICROEARTHQUAKE SWARM OF 2 AUGUST 1979	
Woodward-Clyde Consultants			

Number	DATE	DAY	TIME	LAT	LONG	DEPTH	MAG	#	Q	TYPE
1	7/ 8/79	189	[illegible]2:32.7	46-28.91	119-39.22	3.0	1.7	9	C	
2	8/ 2/79	214	740:35.0	46-29.41	119-37.83	3.0	1.1	7	C	
3	9/ 5/79	248	227:18.1	46-29.33	119-38.75	2.6	1.5	6	C	
4	9/ 8/79	251	621:59.4	46-29.45	119-39.07	2.8	2.4	10	B	
5	9/ 8/79	251	643: 1.8	46-29.34	119-38.66	4.3	1.2	6	B	
6	9/ 8/79	251	726:11.0	46-29.12	119-38.94	3.7	1.4	6	B	
7	9/ 8/79	251	845:33.7	46-29.26	119-38.92	3.3	1.8	9	B	
8	9/ 8/79	251	854:16.1	46-29.44	119-39.01	3.8	1.6	8	B	
9	9/ 8/79	251	855:25.8	46-29.46	119-38.57	3.2	1.3	6	B	
10	9/ 8/79	251	925:41.3	46-29.42	119-38.74	1.4	1.4	8	C	
11	9/ 9/79	252	15 1: 8.9	46-29.66	119-39.86	2.5	2.1	12	B	
12	11/ 4/79	308	1158:40.5	46-29.94	119-37.41	3.2	1.5	10	B	



Long plotted wrong

Locations and Magnitudes of Cold Creek Swarm Events



C = Compression

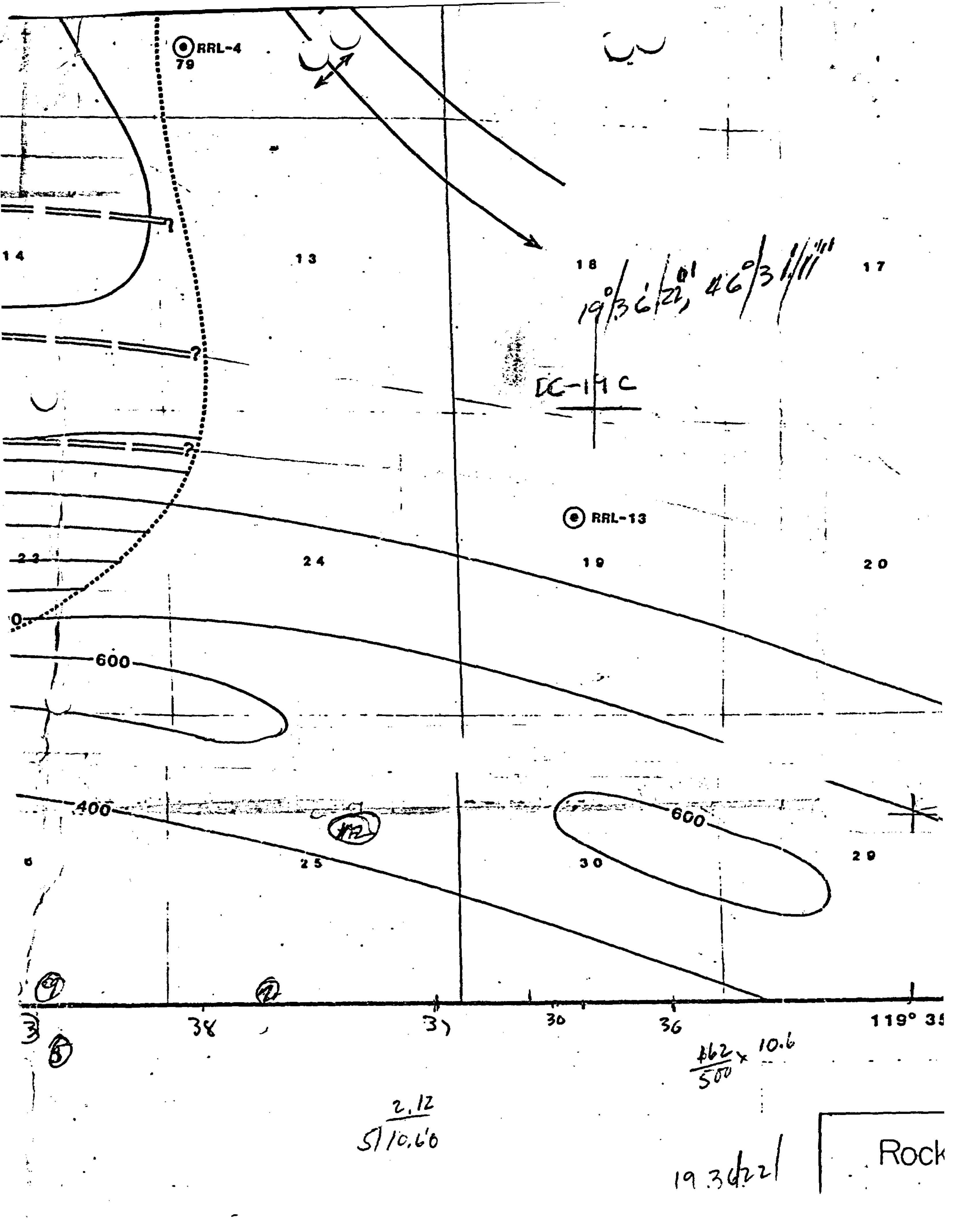
D = Dilatation

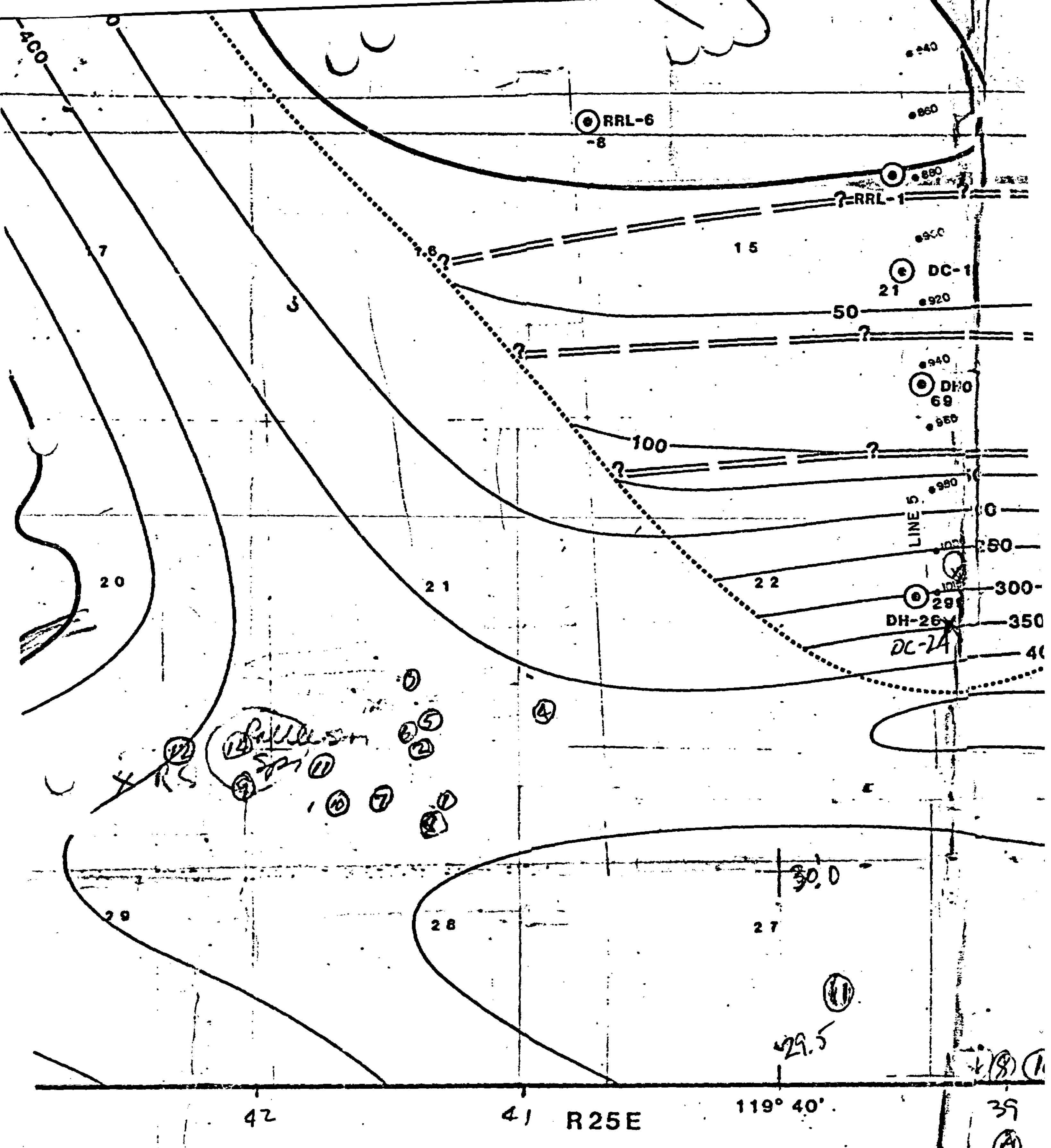
T = Tension Axes

P = Compression Axes

N = Intermediate Axes

Composite Fault Plane Solution for Cold Creek Swarm
(Lower Hemisphere Projection)


RRL-4
79
14
13
18
17
19°36'22", 46°31'11"
DC-19C
RRL-13
23
24
19
20
600
400
600
#12
25
30
29
38
37
30
36
119° 35
162/500 × 10.6
2.12
5/10.60
19.36/22/
Rock



Black Swarm 11/1985

Red Swarm 7/8/79 — 9/9/79

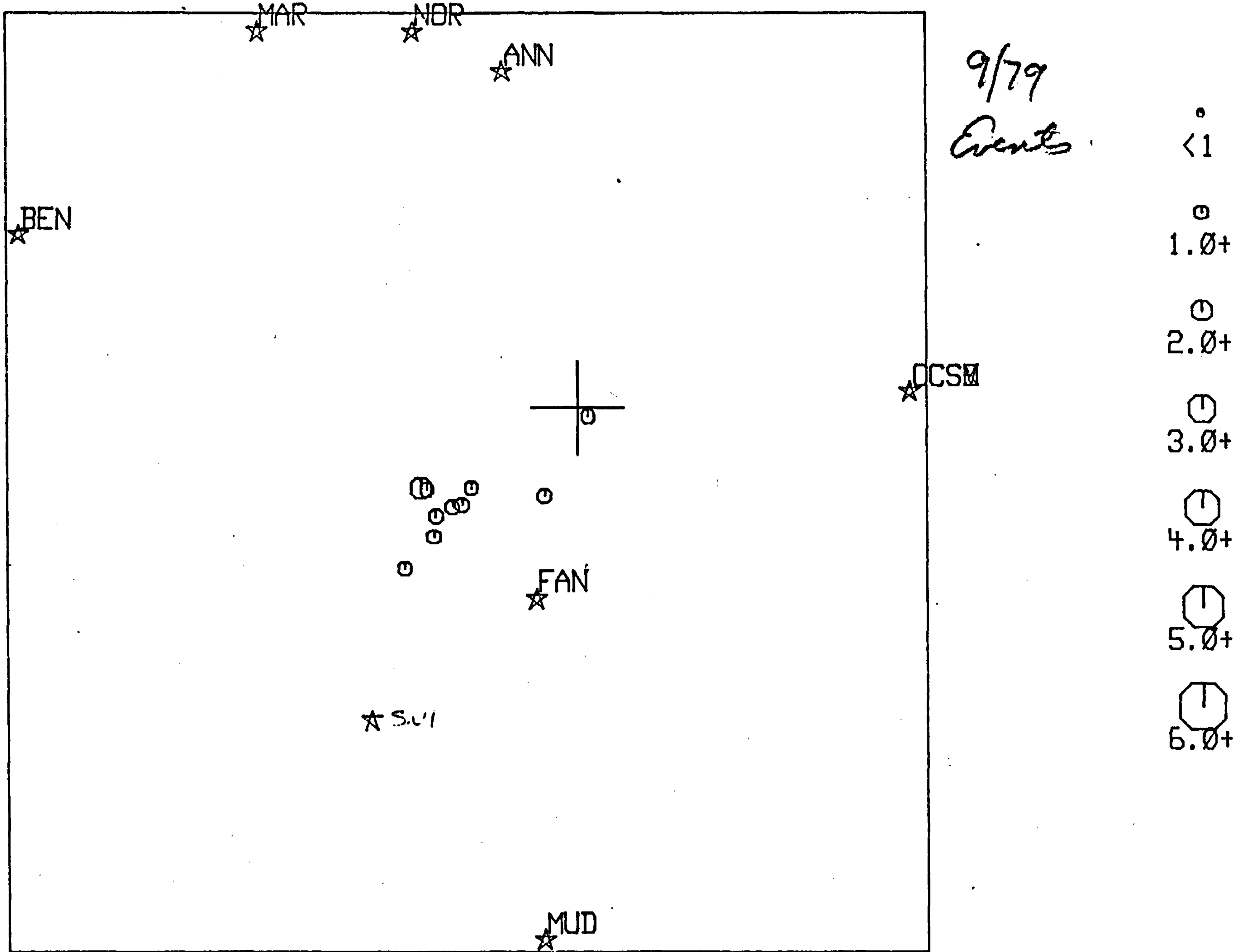
1.4 — 4.3 Km deep.

1.1 — 2.4 Mag

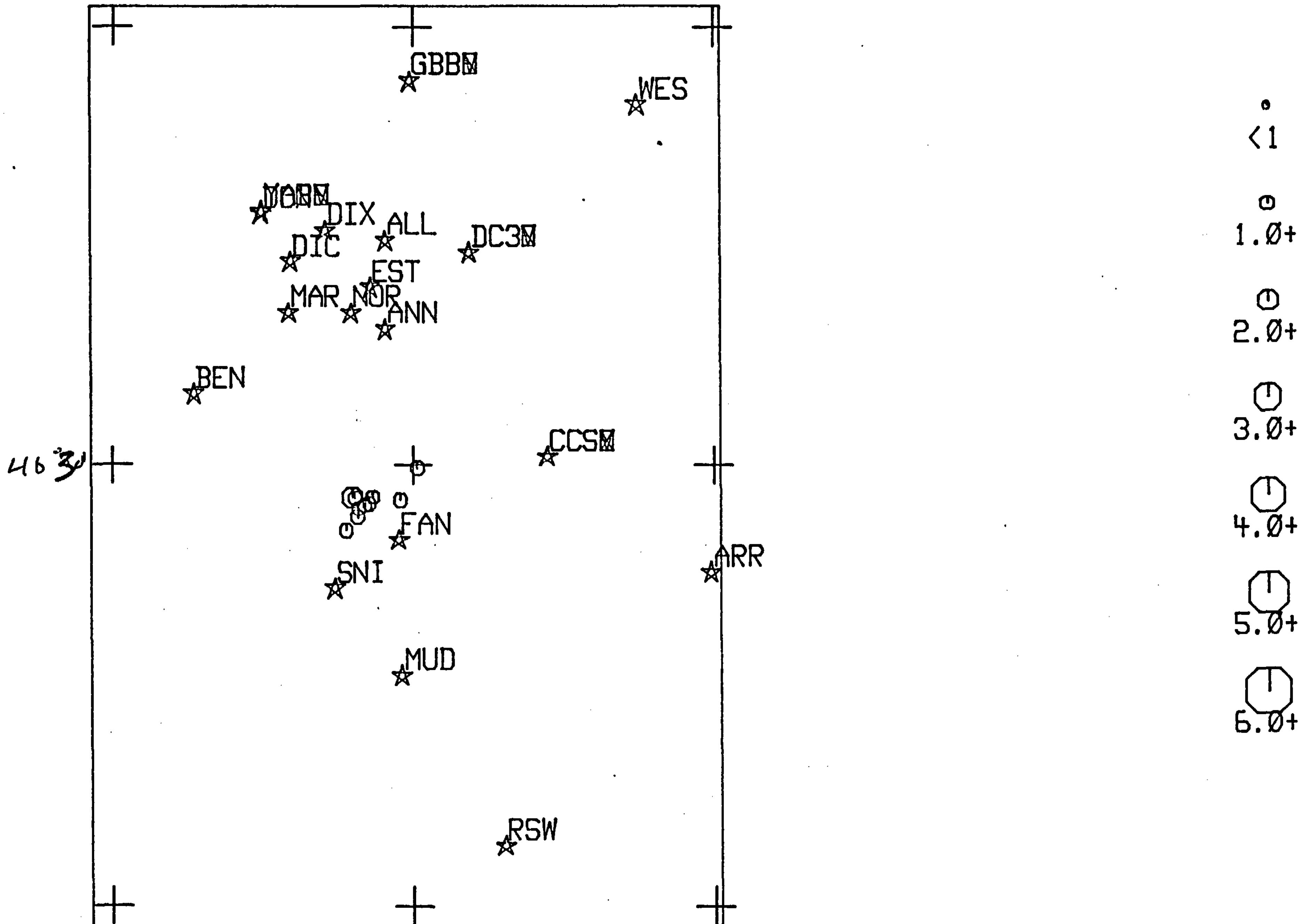
29.0

79

9/79
Events



Input command: M,N,P,D,R,S, or SPACE BAR



Input command: M,N,P,Q,R,S, or SPACE BAR faults are greater than 100 km (60 mi) long, and they cross the trends of several Yakima folds. Less numerous sinistral strike-slip wrench are also present. The wrench faults of regional extent appear to have developed contemporaneously with the Yakima folds and deformation along at least some of these features has continued into the Holocene. The reason for the apparent absence of these structures in the central portion of the Columbia Plateau (i.e., the Pasco Basin) is not known, nor is their role in the tectonic development of the Columbia Plateau. Studies are planned to address these uncertainties (Sections 8.3.1.2.2 and 8.3.1.2.4).

The reference repository location is within the Cold Creek syncline, which is one of the Yakima folds. It is the largest syncline in the Pasco Basin, with a width of over 10 km (6 mi). It is bounded on the north by the Umtanum Ridge-Gable Mountain structure and on the south by the Yakima Ridge. The Cold Creek syncline is asymmetric and relatively flat-bottomed; the center of the syncline is nearly flat except for small monoclinal flexures. The reference repository location is situated on and just north of the synclinal axis. Structure contours for several basalt horizons from the Grande Ronde Formation to the top of basalt indicate that the reference repository location is generally flat.

Deformation in the Columbia Plateau appears to be the result of north-south directed compression. This compression formed the Yakima folds and their associated faults and tectonic joints. Faulting, folding, and jointing were concentrated along the anticlinal crests during regional compression, with substantially less deformation occurring in the synclines. The gently dipping limbs of the anticlines contain widely spaced, discrete shear zones and faults that range from a few centimeters to 1 m (3.3 ft) wide. Zones of concentrated deformation tend to occur along the steeply dipping limbs of the anticlines. Paleomagnetic evidence for rotation within the basalts indicates that it is concentrated along the anticlinal axes, further suggesting that deformation is concentrated along anticlines. Seismologic evidence, geodetic data, and in situ stress measurements all indicate that the Columbia Plateau is currently within a predominantly north-south compressive stress regime. The implications of such a compressive stress regime, with respect to further deformation of the folds and faults, are not clearly understood. Studies are planned to address further these uncertainties (Sections 8.3.1.2.2 and 8.3.1.2.4).

Document in SCP Draft

1.8.1.4 Seismology of candidate area and site

An analysis of earthquake activity in the candidate area, including the site, is necessary to characterize the current tectonic setting, to provide information to evaluate earthquake risk to the repository and its performance, and to provide information for repository design.

The historical seismicity of the region (from about 1840) indicates that moderately strong earthquakes (i.e., magnitudes of six or greater) are infrequent in the Columbia Plateau. The region is better characterized as one of relatively continuous, low-level strain release, with small, shallow earthquake events. In contrast, the Puget Sound area to the west of the Cascade Range is characterized by moderate- to large-magnitude, relatively deep focus (greater than 10 km (6 mi)) earthquakes that have been common during the more than 150-yr historical record.

The majority of the historic earthquakes, located primarily from "felt" reports, that have occurred in the candidate area prior to 1969 have had intensities (MM) less than V and magnitudes less than 4.5. This seismicity has been concentrated around the northern, southern, and western parts of the Columbia Plateau. The largest earthquake known to have occurred within the Columbia Plateau was the July 16, 1936, Milton-Freewater, Oregon, earthquake. It had an estimated surface-wave magnitude of 5.7 to 5.8 and was located near Waitsburg, Washington, about 130 km (81 mi) east of the controlled area study zone. Fault plane solutions from aftershocks suggest that fault slip was consistent with the north-northeast-trending Hite fault; however, the trend of aftershocks lies to the west of the Hite fault. Because there is no clear association of the earthquake to the Hite fault, it may be associated with Rattlesnake-Wallula alignment or some as yet unmapped fault.

Since 1969, when the seismic network at the Hanford Site was initially installed, numerous earthquakes have been recorded in the Columbia Plateau. This instrumental seismicity is divided as follows into two general groups based on the nature and focal depths of the earthquakes:

- o Shallow microearthquake swarms and shallow individual events that are less than 5 km (3.1 mi) deep.
- o Deep individual events greater than 5 km (3.1 mi) depth.

Microearthquake swarms are the predominant type of seismic activity recorded in the Columbia Plateau. The microearthquake swarms contain from several to as many as 100 events, typically lasting a few days to several months and occuring in Columbia River basalt, whose volume is typically 2 by 5 km (1.2 by 3.1 mi) areally and 3 to 5 km (1.0 to 3.1 mi) deep. They contain earthquakes generally ranging from magnitude 1.0 to 3.5, but most events are less than 2.0. Linear east-west trends of the epicenter may be apparent within individual microearthquake swarms, while the entire swarm body is roughly oriented northwest-southeast. Although the microearthquake swarm bodies are roughly parallel to the structural trends within the Yakima Fold Belt, they cannot be related to individual mapped faults, and they are not concentrated on single planes but are rather diffuse in pattern. The microearthquake swarms often occur more than once in the same general area. The largest swarm-related earthquake (magnitude 4.4) occurred on December 20, 1973, on the Royal Slope about 40 km (25 mi) north of the controlled area study zone.

Earthquake swarm activity is concentrated in the central portion of the Columbia Plateau to the north and east of the controlled area study zone. The closest swarms to the controlled area study zone are at Wooded Island, 26 km (16 mi) east-southeast; Coyote Rapids, 8 km (5 mi) north; and Cold Creek, 5 to

8 km (3 to 5 mi) south. Microearthquake swarm activity appears to be generally confined to the Columbia River basalts (although infrequent swarm events may occur below the base of the basalts), and activity also appears to be spatially related to bedrock folds.

Deep, individual earthquakes occur generally below the base of the basalts to depths of about 30 km (19 mi). These deep events occur in a diffuse pattern and cannot be directly related to mapped surface structures. However, some clustering of deep earthquakes occurs below the Horse Heaven Hills (50 km (31 mi) south of the controlled area study zone) and there appears to be an increase in deep events below shallow swarm locations. There is currently uncertainty in the velocity model used to locate these earthquakes such that their vertical distribution is not precisely known. Studies to relocate these events using an improved velocity model are discussed in Section 8.3.1.2., in order to distinguish among deep and shallow earthquakes.

The instrumental (1969 through 1983) seismicity of the reference repository location (within about 10 km (6 mi)) is characterized primarily by two shallow microearthquake swarms and infrequent deep earthquakes that have occurred during two distinct time periods. The shallow microearthquake swarms include the Coyote Rapids swarm, located 8 km (5 mi) north of the controlled area study zone, and the Cold Creek swarm, located 5 to 8 km (3 to 5 mi) south of the controlled area study zone. The Coyote Rapids swarm includes 67 earthquakes at depths generally less than 2 km (1.2 mi) with the two largest events being magnitude 3.4 and ~~3.8.~~ The Cold Creek swarm includes 15 events from two periods of activity since ~~1979.~~ They have occurred at depths less than 5 km (3 mi) and the largest event was magnitude 2.4.

I believe these are the ones I've marked on the EMAX Map.

The deep earthquake activity of the reference repository location since 1969 has been limited to two periods containing few, small-magnitude events. The first period (November 1969) included four earthquakes with an apparent north-south trend through the reference repository location that occurred at depths of 3 to 10.3 km (1.6 to 6.4 mi) with magnitudes from 1.3 to 2.2. The second period (March to September 1971) included six events below the central northern border of the reference repository location. These occurred at depths of 6.5 to 8.0 km (4 to 5 mi) with magnitudes from 0.4 to 1.1.

The nature, characteristics, and mechanism of the shallow microearthquake swarm events and the deep seismicity are not well understood. Thus, the significance to the repository of particular events or series of swarms is uncertain. For these reasons, studies are planned to investigate the nature and mechanism of shallow and deep seismicity in the area of the repository (Section 8.3.1.2.4.3.3).

The current tectonic stress regime in the central Columbia Plateau, as derived from earthquake focal mechanism solutions and hydrofracturing measurements, indicates a predominance of north-south compression and vertical tension. This suggests that the majority of the current swarm-type tectonic deformation may be occurring on numerous high-angle reverse faults oriented roughly east-west rather than on single planes.

valley associated with Yakima Ridge

Previous work on the Hanford Site for the siting and licensing of commercial nuclear power plants has identified several Pasco Basin earthquake sources and their characteristics for use in seismic design. These studies provide a preliminary basis for the identification of earthquake sources, the estimation of source characteristics, the estimation of seismic hazard, and the development of estimates of ground motions for the repository. However, because of the differing nature of nuclear facilities (surface power plant versus surface and subsurface repository) and their differing time frames (100 yr versus 10,000 yr), the direct applicability to repository siting of the previous seismic hazard and design efforts for commercial reactors at the Hanford Site is uncertain. Therefore, further studies are planned in seismology (as well as structure and tectonics) to identify and characterize earthquake sources, study the differences of seismic wave transmission between the surface and subsurface, estimate vibratory ground motion, estimate the seismic hazard, and estimate the potential for induced seismicity affecting the candidate site (Sections 8.3.1.2.4.3.3, 8.3.1.2.2.3.2, 8.3.1.2.4.3.2, 8.3.1.2.4.3.4).

1.8.1.5 Long-term regional stability with respect to tectonic and geologic processes

A geologically stable area is one in which the present and projected future mechanisms and rates of geologic and tectonic processes are shown or interpreted not to pose a hazard to repository construction, operation, or long-term isolation. Primary geologic processes that may influence the assessment of geologic stability include tectonic, volcanic, and geomorphic processes. The assessment of their stability emphasizes the postclosure, long-term isolation period, considered to be the next 10,000 yr. The approach to such assessments is based on the investigatior, analysis, and interpretation of past and present geologic processes so that mechanisms and rates may be projected to the future. Models that describe the processes are developed to provide qualitative and (or) quantitative characteristics of the nature, mechanism, and rates of each process. The assessment of geologic and tectonic stability is important in characterizing the repository environment, assessing repository performance, and providing information used in repository design.

The assessment of tectonic stability is based on the development of one or more tectonic models. The tectonic model is a nonnumerical descriptive theory or concept that incorporates geological, geophysical, seismological, and geodetic data into a satisfactory explanation of the evolution of stress and strain in the earth's crust--in this case for the candidate area and candidate site. Thus, a tectonic model can be used to predict the character of future processes, such as preclosure vibratory ground motion and displacement and postclosure displacement or strain, that could affect the groundwater flow regime and, thus, potentially impact waste isolation.

The scales at which tectonic models exist to describe the candidate area and candidate site are for the Pacific Northwest, the Columbia Plateau, and