TECHNICAL REPORT

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2. Purpose

This report describes the seismicity and earthquake monitoring activities within the Yucca Mountain region during fiscal year 2004 (FY2004 - October 1, 2003, through September 30, 2004) based on operation of the Southern Great Basin Digital Seismic Network (SGBDSN). Network practices and earthquake monitoring conducted at the Nevada Seismological Laboratory (NSL) under DOE directives for prior fiscal years are covered in similar yearly reports (see references). Real-time systems, including regional data telemetry and data management at NSL, provide for the automatic determination of earthquake locations and magnitudes and notification of important earthquakes in the region to UNR staff and DOE management. All waveform and meta-data, including automatic locations, phase arrival information, and analyst reviewed information, are managed through a relational database system allowing quick and reliable evaluation and analysis of ongoing earthquake activity near Yucca Mountain. This network, which contains weak-motion and strong-motion instrumentation, addresses the seismic hazard of the Yucca Mountain area by providing accurate earthquake magnitudes for earthquake recurrence estimates, spatial hypocentral control to very low magnitudes for identifying and assessing active faults and verifying tectonic models, true ground motions over the complete range of expected earthquake amplitudes for developing predictive models, and earthquake source information for characterizing active faulting.

3. Quality Assurance

This report is prepared under QAP-3.4, Rev. 5 of the NSHE Quality Assurance Program. Data was collected and developed using all other applicable procedures of that program. Unless explicitly stated, all data presentations of this report are qualified. No conclusions of this report are based on unqualified data.

4. Introduction (Abstract)

The Nevada Seismological Laboratory operated a 30-station monitoring network within a ring of approximately 50 km radius around Yucca Mountain during FY2004. This year showed the second-lowest seismic moment rate in the NTS and Yucca Mountain region for any fiscal year reporting period since prior to the 1992 M 5.6 Little Skull Mountain (LSM) earthquake. A total of 2180 earthquakes were located for FY2004. The largest event during FY2004 was M 2.99 and there were only 12 earthquakes greater than M 2.00. This is the second year since the LSM event that no M ≥ 3.00 earthquake was recorded within 65 km of Yucca Mountain. (FY2003 was the first.)

For FY2004, focal mechanisms were developed for 24 earthquakes. These focal mechanisms show predominantly strike-slip motion with a tension axis oriented WNW-ESE.

Four earthquakes in FY2004 were within 10 km of Yucca Mountain, all having M < 0. A total of 31 earthquakes have occurred in this immediate zone around Yucca Mountain since the digital network operations started in October 1995.

Activity in the Death Valley area was monitored by several analog stations still maintained in conjunction with the Yucca Mountain monitoring. There is continuing aftershock activity in the zone of the 1993 M 6.1 Eureka Valley and 1999 M 5.6 Scotty’s Junction earthquakes. Overall, the seismicity level of the Death Valley area is significantly greater than that in the vicinity of Yucca Mountain.

5. Methods and Materials

5.1 Station Description

As of September 30, 2004 the Southern Great Basin Digital Seismic Network (SGBDSN) included 29 digital seismograph stations. Station locations are Q data and are listed in Appendix 1. Two additional stations (ECO and YFT) were installed by Sandia National Laboratories (SNL) but are considered effectively part of the SGBDSN, with all normal QA procedures applied to them. Another station, AL5, is located at Alcove 5 in the ESF and is also considered effectively part of the network. These three stations are integrated into the SGBDSN telemetry system, and data are transmitted and processed in the same way as for all other SGBDSN sites. Some stations of the former analog monitoring network (Southern Great Basin Seismic Network – SGBSN) have been maintained outside the SGBDSN to aid primarily in the seismic characterization of the Death Valley area. A map of a larger area showing the analog (SGBSN) stations along with the digital (SGBDSN) stations is shown in Figure 1. Data from analog stations were used to determine focal mechanisms and to aid in the location of events. All digital stations except ECO, YFT , and AL5 use Geotech S-13 seismometers. Stations ECO and YFT are configured with Geotech GS-13 seismometers. The AL5 station within Alcove 5 of the Exploratory Studies Facility (ESF) uses a Mark Products three-component L4 seismometer. Neither the GS-13 nor Mark Products seismometers are used in magnitude computations. Also, no analog station data are used to calculate earthquake magnitudes. Ten digital sites are equipped with strong-motion instrumentation (see Appendix 1). Supplemental 16-bit A/D cards were added to onsite recorders in order to handle the output from RefTek Model 133-05 accelerometers. Data from these strong-motion sites are available in near-real-time and recorded and archived along with all SGBDSN data.

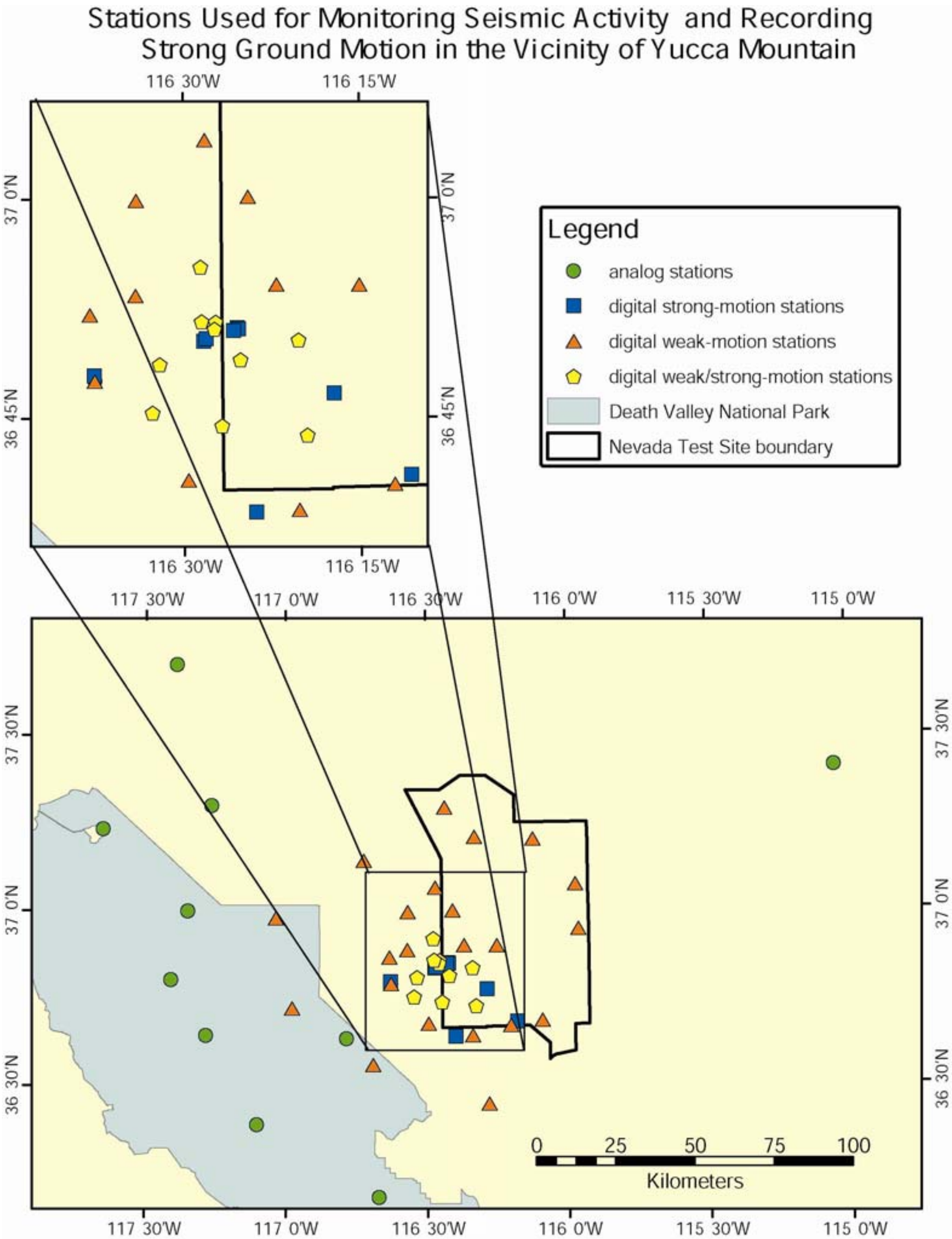

Figure 1. Locations of Yucca Mountain area seismic stations. (Q data sources: DID # 012DV.010, DID # 006DV.005, and DID # 023DV.001)

The S-13 seismometers/recorders produce 6.43 counts per nm/s on the flat portion of the velocity response; the nominal corner frequency is at 1.0 Hz, and the damping is a nominal 0.7. Monthly system checks ensure that there is only a maximum ±10% deviation for any particular instrument from the nominal response. System check pulses were analyzed to show that none of the instruments drifted outside of this range. Sensors of the analog stations have a similar free period and damping coefficient, but are not checked periodically. The SGBDSN S-13 response falls off at 40 Hz due to anti-aliasing filters in the DAS (Digital Acquisition System) units recording at 100 sps (samples per second). The S-13's, as configured with the DAS units, can clip at short distances (< 10 km) for M > 3 earthquakes.

5.2 Data Collection Method

The field data acquisition systems are described in von Seggern and Smith (1997). During the time period covered by this report, two data streams were in effect at all stations except ECO and YFT: 1) a 20-sps, 3-component, continuous data stream and 2) a 100-sps, 3-component, triggered data stream. Stations ECO and YFT only had the triggered stream. The former was enabled with a "continuous" trigger specification, which creates contiguous trigger windows of 30 minutes duration each. The latter was controlled by an "event" trigger specification with the following parameters:

short-term average (STA) length	0.4 seconds
long-term average (LTA) length	10.0 seconds
STA/LTA trigger threshold	3.5
pre-trigger record length	30 seconds
total record length	150 seconds
channels included in trigger	Z, N, E
threshold exceeded by at least *n* channels	1

A third data stream has been added for the 10 stations equipped with accelerometers. This stream is "cross-triggered" from the 100-sps seismometer stream described above, and the data are also recorded at 100 sps. The manner of data collection at the NSL was previously described in von Seggern and Smith (1997). Raw data are archived in large 24-hour files (one per station) that contain all original data packets sent from the field acquisition units. Such files are termed "refraw" files, and the actual file names end with this term. We call the set of these files the "upstream" recording, and it is archived on DVD media. These DVDs are submitted to the YMP Records Processing Center, as in all prior years, as a raw data record.

On January 1, 2000, a major transition to the Antelope (BRTT, Inc.) seismic processing system was made (von Seggern et al., 2000). This transition for the entire NSL network incorporated recording and processing of seismic data from the SGBDSN. The SGBDSN data, directed to files as described above, are also transmitted in near-real-time to the Antelope system where it is then available for review and analysis with the seismic data processing tools of the Antelope system. In automating some seismic network operations through Antelope, additional data processing measures are incorporated in the data flow. These introduce potential failure points in the data collection process if we rely exclusively on the Antelope system for a final data archive. Archival procedures are in place to put the data on DVD's in Antelope format as a "downstream" dataset. Depending on the use of the data, retrieval from one or the other (upstream or downstream) of the archived datasets is possible. The upstream archival dataset, although more complete, can often be more difficult to use than the downstream dataset. In addition to storing waveform data, Antelope also stores various parametric data in tables, collectively called Datascope (Quinlan, 1998).

5.3 Downtime and Problems

The reliable collection of data is subject to the following problems:

* seismometer malfunction or failure
* DAS malfunction or failure
* radio transmission interference
* telemetry interference or failure
* hardware failure at the central recording site
* software failure at the central recording site

Except for seismometer malfunction and some types of DAS malfunction, the nature of these problems is that no data are recorded rather than data are corrupted. The case of corrupt data is covered by writing appropriate Non-Conformance Reports. No NCR-reportable malfunctions occurred in FY2004. Sensor/recorder performance is controlled by procedures in IPR-001 ("Operation of the Yucca Mountain Seismic Network"). In this fiscal year of operation, various examples of all of the above types of problems occurred. A more accurate, station-specific, method of tracking downtime from the upstream recording was

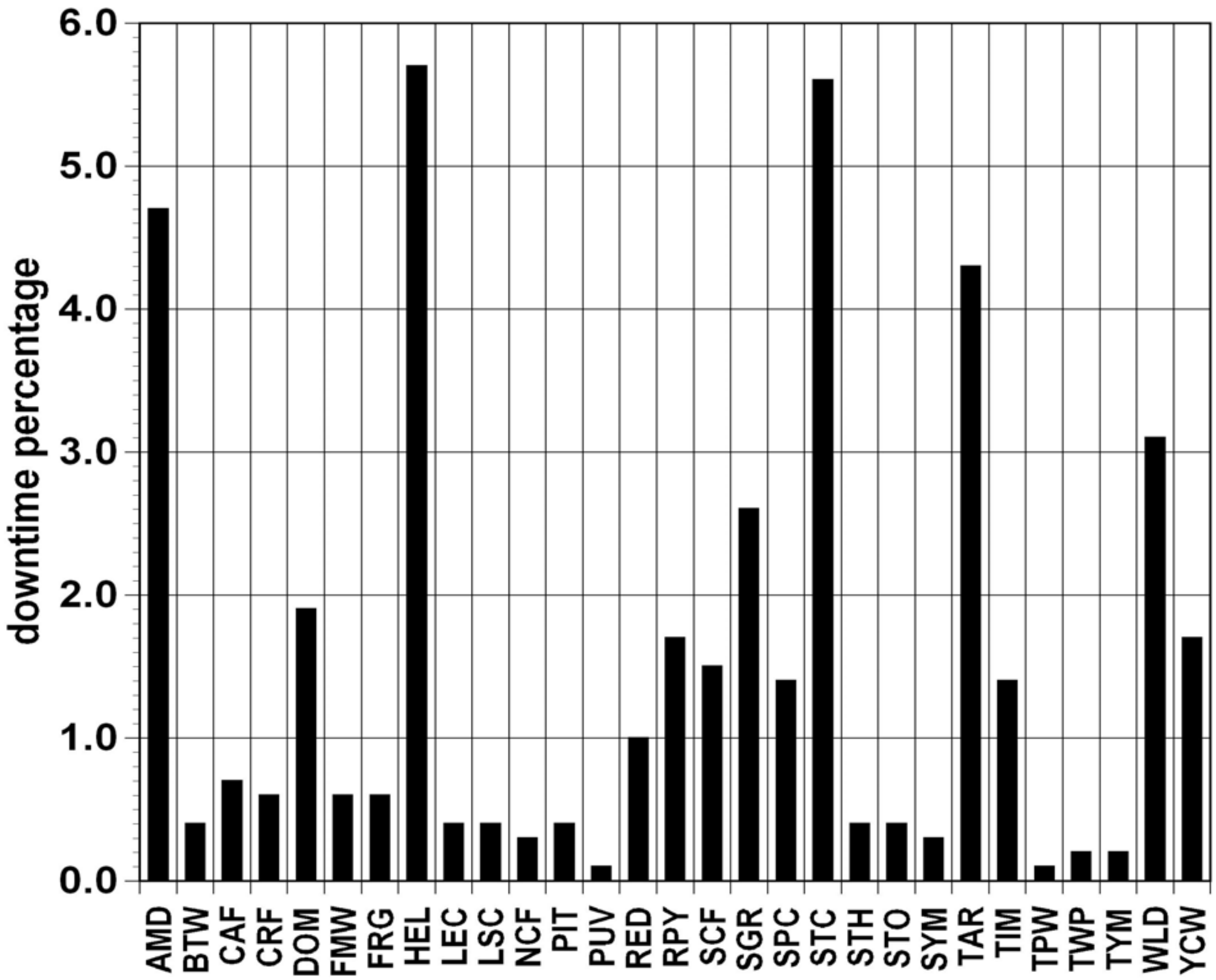

Figure 2. Downtime of the individual stations of the SGBDSN during FY2004.

devised for this report. It is based on querying the Datascope table called "reno.wfdisc" for recorded time intervals for each station. (These Datascope tables are in the daily Antelope directories /data/yyyy/jjj on the YMP computing system at the NSL, where yyyy = year and jjj = julian day. Data in these tables are 'unqualified'.) Downtime for any given station is simply the total span of time minus the total of these time intervals for that station. Figure 2 is a summary of the downtime for each station within the SGBDSN. (The SNL stations ECO and YFT are run in triggered mode only and so are not represented here.) This figure shows that the downtime was under 3% for all stations except five: AMD, HEL, STC, TAR, and WLD. The least downtime, at station PUV or TWP, is approximately 0.1%. The 0.1% is then interpreted as the upper bound of the network-wide downtime, that is, when all stations were not recorded.

The downtime inferred from gaps in recording does not exactly represent when data are unrecoverable. The upstream recording to refraw files, as discussed above, is actually more complete due to the fact that Antelope software failures would further add to the outage as seen in the Antelope archive of data. Data from the refraw files are fully recoverable and, in fact, can be replayed through the Antelope system in a non-real-time mode. We have had occasion to do this, with satisfactory results. The decision to replay the refraw data is made on the length of the "hole" in the Antelope archive and the appearance of any significant earthquakes in that time period. If problems, such as telemetry failure, affect both the upstream and downstream archives, then recovery is generally not possible. An exception is when the outage has short duration (~ 15 to 30 minutes) because the data are saved in a FIFO (first-in, first-out) memory in the DAS units until transmission can be restored. We are not aware of any events with M > 2 falling in the 0.1% of overall downtime for FY2004. Most of the downtime in Figure 2 relates to times where only one station or only a part of the network was down. Single-station downtimes only marginally impact the ability to locate events within the network. Multi-station downtimes have greater impact on this ability; but, even with a few stations operative, events of M > 1 within the SGBDSN can usually be located accurately.

5.4 Daily Processing

The daily processing routine was fully described in von Seggern and Smith (2001) for FY2000 and has not changed since. The preliminary processing is done with the Antelope system of BRTT, Inc., and the preliminary event locations and magnitudes are kept in the Datascope database (Quinlan, 1998). Waveforms are excerpted for these events and kept online with the database.

The last step in preliminary analysis is for the events to be checked and initialed on record sheets called the "Yucca Mountain Seismic Event Sheet." These sheets are made by subsetting the Antelope database for events within 65 km of Yucca Mountain (specifically, the station RPY). Events are reviewed according to IPR-002 ("Determining the Location of Earthquakes Recorded by the Yucca Mountain Seismic Network") and initialed by professional staff on the record sheets. In this process events may be relocated and magnitudes recomputed; the revised information is captured in the database. This is still not the "final" qualified data. Also at this time, a review is made on classification of events other than local earthquakes (for instance, blasts).

5.5 Finalizing the Earthquake Catalog

The final locations and magnitudes for the FY2004 earthquakes were obtained according to UCCSN procedures IPR-002 and IPR-003 ("Determining the Magnitude of Earthquakes Recorded by the Yucca Mountain Seismic Network"). The location program specified in IPR-002 is HYPOINVERSE, V1.0 (STN # 10080-1.0), originally developed by Klein (1989). The magnitude program specified in IPR-003 is MLCALC, V3.0 (STN # UCCSN-04-014), which was internally developed and implements the local magnitude calculation of Richter (1935); this magnitude is widely termed “M_L”. Again, we note that non-SGBDSN arrivals may be used in the locations, depending on seismological judgment. This enables us to improve the locations of events around the fringe of the SGBDSN. With regard to final magnitudes, we emphasize that only S-13 SGBDSN waveforms are used, as required by IPR-003.

The preliminary earthquake catalog for FY2004, as residing in the Datascope database, contained a total of 2247 earthquakes. The procedure for computing final locations prescribes that the arrival times and preliminary locations be extracted from the Datascope tables and reformatted for input to the program HYPOINVERSE, V1.0 (STN # 10080-1.0); this was done with the program DB2PHS, V2.0 (STN # UCCSN-04-017). The procedure requires that a single velocity model be used for the entire suite of earthquakes; this model, called the “moonhof” velocity model (Hoffman and Mooney, 1984), has the following structure:

Depth to Top of Layer (km)	P velocity (km/s)
0.0	3.00
1.0	6.00
25.0	6.35
30.0	6.60
35.0	7.80

Note that the velocity of the second layer in IPR-002 is given as 5.85 km/s, not 6.00 km/s. This alteration crept into the velocity model and has affected all SGBDSN locations since the start of operations in October 1995. A Non-Conformance Report (NCR # UNR-03-0011) was filed and has been closed. This NCR contains an impact analysis which states that the result of this error on locations is insignificant, and we intend to continue to use the “erroneous” 5.85 km/s. S-wave velocities are computed from P-wave velocities using a Poisson ratio of 0.25.

HYPOINVERSE was run in batch mode with the altered velocity model. A few hypocenters were eliminated because they had four or less arrivals. At this point, events with large azimuthal gaps (>300°) and with large horizontal error (> 5 km for one sigma) were culled out for review.

Events just west of the LSM area were also reviewed because several of them were considered unreliable. This unreliability was due to the fact that, for many of these events, the only observing stations were LSC, FMW, STH, and CAF (3 or 4 of them), which are nearly in a linear configuration. This review criterion eliminated several events. The procedure then calls for removing arrivals having residuals greater than 0.3 seconds. The program was rerun with these removed, and many additional events could not be located because the number of acceptable arrivals fell below five. Through all these criteria, 67 events were removed from the original 2247, less than 3%. Comparable culling was done on the data for previous years. None of the removed events had a magnitude larger than 2.0. A total of 2180 events then remained in the final catalog. The final magnitudes (M_L) were then computed according to IPR-003. The final hypocenter and magnitude catalog for FY2004 was then submitted as dataset DID # 006DV.011.

Note that the HYPOINVERSE output format includes error bars (+/- one standard deviation) for the horizontal (*erh*) and vertical (*erz*) precision of the hypocenters. These errors, indicative of the location quality, are considerable in some cases (on the order of several km) and are generally greater for *erz* values than for *erh* ones. The errors for the FY2004 catalog are comparable to those in prior years.

The hypocenter results here must be weighed in relation to the assumptions (mostly programmatic) used in producing the final locations. One of these assumptions was that the earth can be represented by a homogeneous, plane-layered velocity model. This implies the use of a single 1-D velocity model for the entire network region. This “1-D earth” assumption has been inherent in all reporting since the start of Yucca Mountain seismic monitoring in 1978. We regard this assumption as satisfactory for the intended primary uses of the data. Further refinement of hypocenters through a 3-D velocity model and through advanced relative location algorithms is beyond the scope of this report but may be important for future work in understanding details of faulting and tectonics in the Yucca Mountain vicinity.

Station corrections are often used with a 1-D velocity model to improve locations; but we chose to not utilize them. This too has been true for all the earthquake catalogs produced since the start of seismic monitoring in the Yucca Mountain region. Again, ignoring such first-order terms is satisfactory for the intended primary uses of the data. We now have a large enough dataset to compute these terms but expect that they will be highly azimuthal and distance dependent: a sign of significant 3-D velocity heterogeneity. When 3-D location programs are applied to the hypocenters produced here, the station effects will be automatically and accurately accounted for.

Aside from the location precision indicated by the *erh* and *erz* values, there is the question of accuracy. Especially for events near the fringe of the SGBDSN network on the west side, the addition of analog readings, if available, should have improved both location precision and accuracy in nearly every case. However, it is important to note that, even with excellent station coverage in both distance and azimuth, locations can be significantly off. The non-proliferation explosion (NPE) of September 22, 1993, was recorded by the entire analog network and had excellently timed arrivals; but its computed location, with depth constrained to the known 0.4 km, was off by approximately 2 km horizontally (von Seggern and dePolo, 1994). The 95% confidence ellipse around the computed epicenter had a semi-major axis of only 0.5 km and thus failed to cover the true location. This inaccuracy is due to the significant 3-D velocity variations in the southern Great Basin that are not accounted for in routine location with a 1-D plane-layered velocity model.

6. Assumptions

In examining spatial distributions of seismicity, one must keep in mind that earthquake hypocenters always have accuracy errors. Each hypocenter has its own errors based on the station configuration and the velocity model used. The mean value of the horizontal error for the FY2004 (DID #006DV011) is roughly 0.25 km. The vertical mean error is larger by several times, but not relevant to map views of seismicity as presented here. So, although individual epicenter locations must be viewed with caution, the overall patterns of seismicity, as seen on length scales of 1 to 10 km or more, are fairly well represented even considering the individual epicenters errors. Another assumption in viewing seismicity is that the network threshold of detection is constant all across the monitoring region. This is seldom, if ever, true and is not true for the SGBDSN. More earthquakes appear in some areas of the maps simply because the threshold is lower for these parts. High or low apparent seismicity may simply be a factor of the detection threshold. Interestingly there may be areas of the maps having very low relative network thresholds but still showing a paucity of events; an important example is the area immediately around Yucca Mountain. Spatially varying threshold for the SGBDSN is computed and shown in von Seggern (2004). We have demonstrated in section 5.3 that the station downtime is sufficiently low that no significant bias is introduced into the seismicity maps for FY2004 due to incomplete recording.

7. Discussion

7.1 FY2004 Overall Seismicity

A total of 2180 earthquakes in FY2004 were located within 65 km of the Yucca Mountain repository area, as measured from station RPY in the repository block. Figure 3 is a plot of FY2004 earthquake locations within the 65 km radius. Figure 4 essentially repeats the plotting of FY2004 epicenters, but now on shaded topographic relief. There were only 12 earthquakes with M > 2 during FY2004. The largest event during FY2004, M 2.99 on 4/26/2004, occurred on the northeast side of the Funeral Mountains approximately 42 km SSW of station RPY. Since 1992 the LSM aftershock zone has been the most prominent feature of the seismicity of the NTS region, and Figure 3 shows that this continues to be true with the large cluster of events at LSM approximately 20-25 km southeast of Yucca Mountain. LSM area activity has been covered in numerous yearly seismicity reports (see references). Of the FY2004 M > 2 earthquakes, two occurred (Figure 3 and 4) in a zone southwest of the LSM aftershock zone. This, and the presence of several M > 1 earthquakes, suggests a possible propagation of stress in this direction from the main aftershock zone.

Overall, the earthquake distribution in Figure 3 is diffuse within the network, with a few clusters indicating repeated activity. Some notable clusters of larger events lie beyond the margins; for instance, the cluster to the east in the Ranger Mountains and the cluster to the southwest in the Amargosa Range. The activity of FY2004 in Figure 3 can be compared to that of the previous eight years of monitoring with the SGBDSN as shown in Figure 5. Symbol sizes for earthquakes in Figure 5 have not been scaled to magnitude in order to simply show the distribution of seismicity.

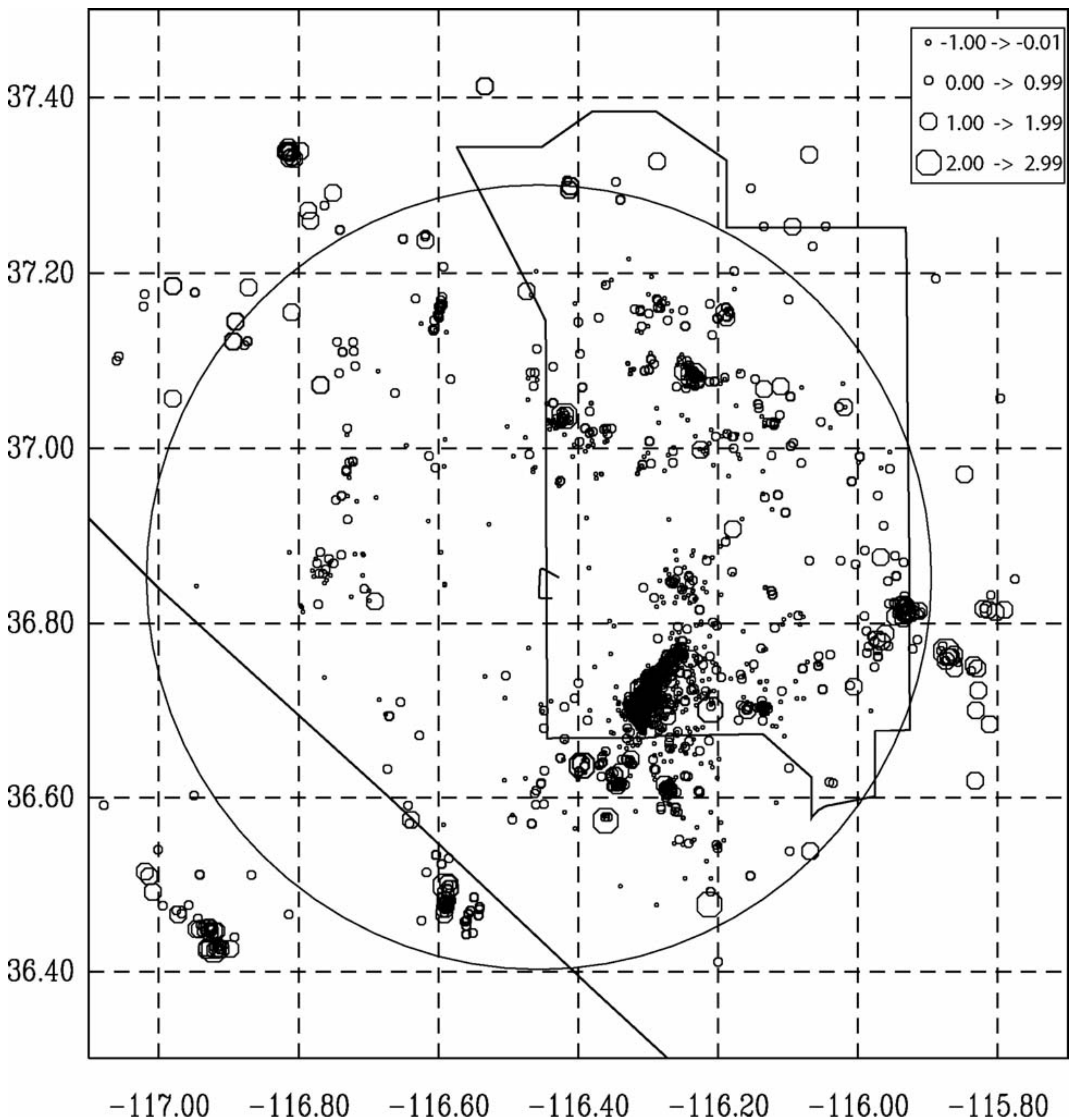

Figure 3. Seismicity within 65 km of station RPY for FY2004. The ring shown is a 50-km radius around station RPY. (Q data from DID # 006DV.011)

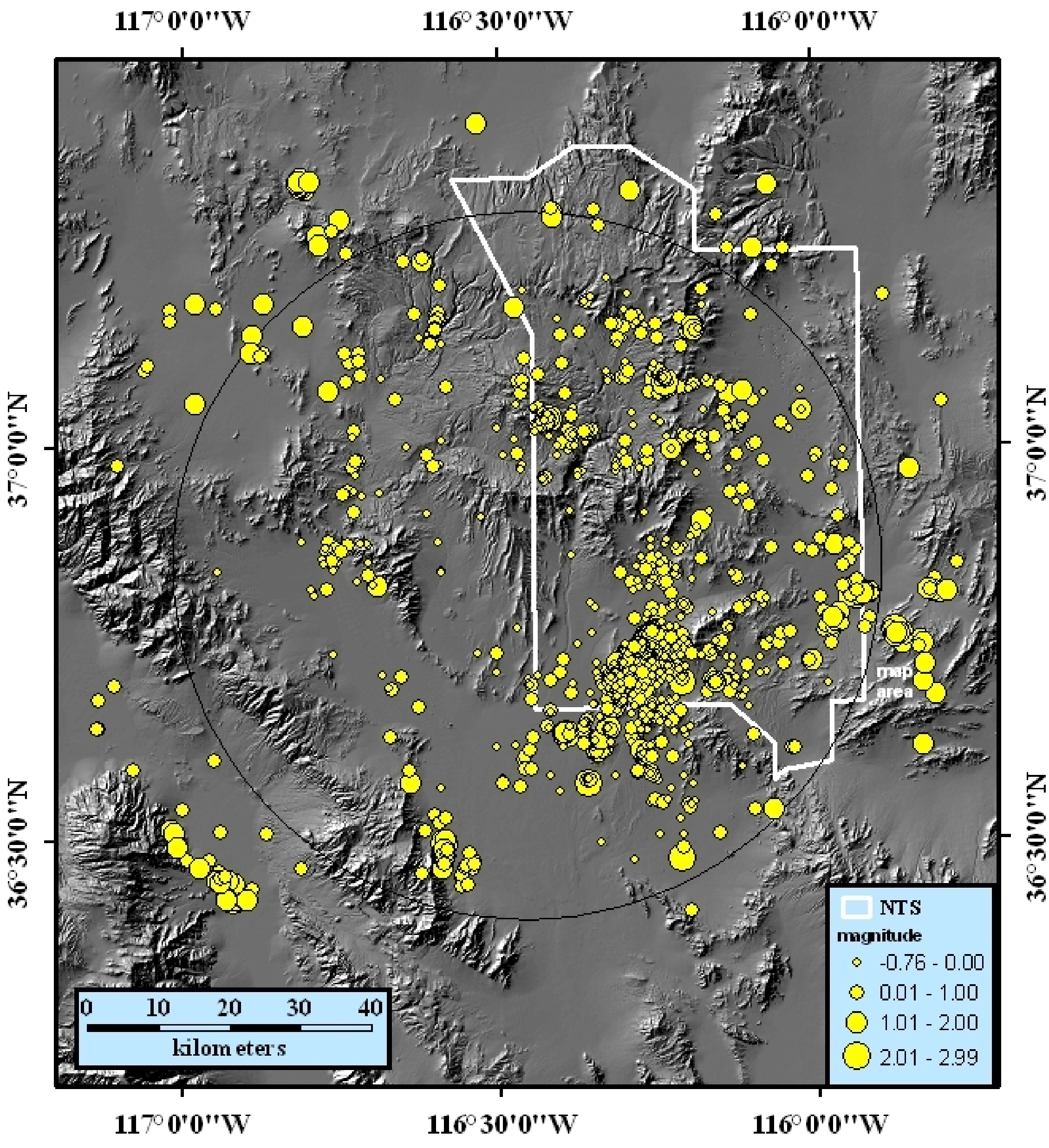

Figure 4. Seismicity within 65 km of station RPY for FY2004 on shaded topographic relief. The ring shown is a 50-km radius around station RPY. (Q data from DID # 006DV.011)

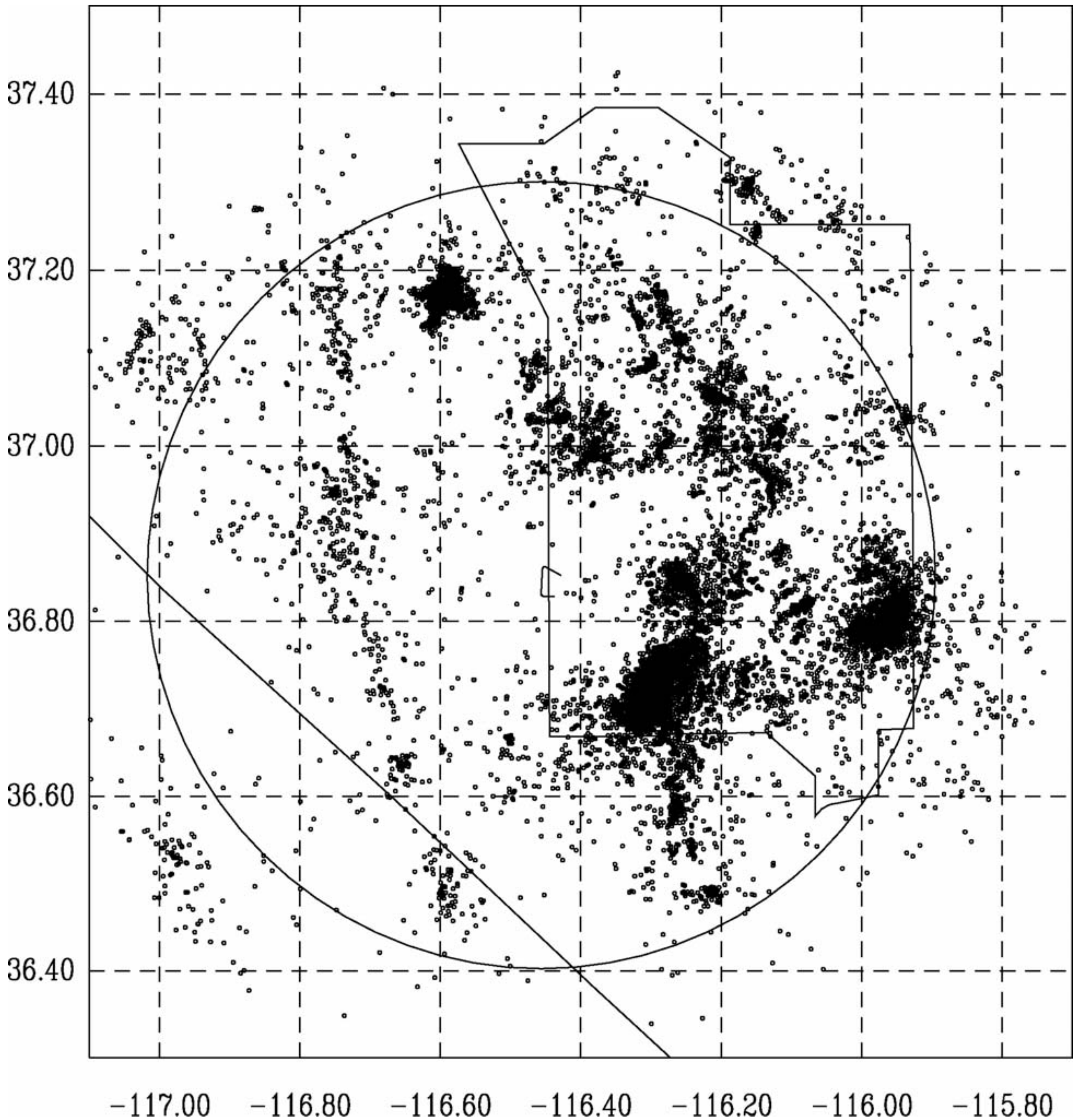

Figure 5. Seismicity within 65 km of station RPY for FY1996-2003. The ring shown is a 50-km radius around station RPY. All epicenters are plotted with identical symbols, regardless of magnitude. (Q data from DID # 006DV.001 and DID # 006DV.004)

The cumulative magnitude curve for the seismicity of FY2004 is plotted in Figure 6 along with that for the previous eight years. The number of events in the previous years has been divided by eight in order to show a comparative curve on the basis of annual seismicity. The two curves have very similar slopes ("b-value" in $\log_{10}N = a - bM$) for $-0.2 < M < 1.9$. Below M ~ -0.2, both curves turn over and flatten, indicating the threshold of detection and location for the SGBDSN network (von Seggern, 2004). Above M ~ 2.0, the FY2004 data shows a deficiency of larger events relative to the long-term seismicity rate. This is, however, expected in examining only one year of data without any significant earthquakes. Smith and von Seggern (2005) show that the long-term trend of seismic activity, as measured by moment rates, has been decreasing in the SGBDSN monitoring area since the LSM earthquake of 1992. This largely explains the downward offset ("a-value" in $\log_{10}N = a - bM$) in the 2005 level of activity even at small M compared to the annual value set by the previous eight years. This offset is approximately 0.2 on the $\log_{10}$ scale of Figure 6, or a factor of approximately 1.5 in absolute count of events.

7.2 Focal Mechanisms

The determination of focal mechanisms for earthquakes in the SGBDSN FY2004 catalog was done in a manner closely following that reported in von Seggern and Smith (1997) using observed P-wave polarities. The actual program used for determining focal mechanisms is FPFIT, V1.0 (STN 10083-1.0), originally developed by Reasenberg and Oppenheimer (1985). The procedure for obtaining focal mechanisms is controlled by IPR-003, R4. Data from the seismicity catalog (DID # 006.DV011) was the starting point of developing the focal mechanisms for FY2004.

We have combined data from the analog stations (see Figure 1) with that from the SGBDSN digital network to obtain improved datasets for determination of focal mechanisms. Note that the number of analog stations that are available in the southern Great Basin is small. Since 01/01/2000 when we began processing all data through Antelope, combining data from the two networks is simply automatic because both networks are processed together.

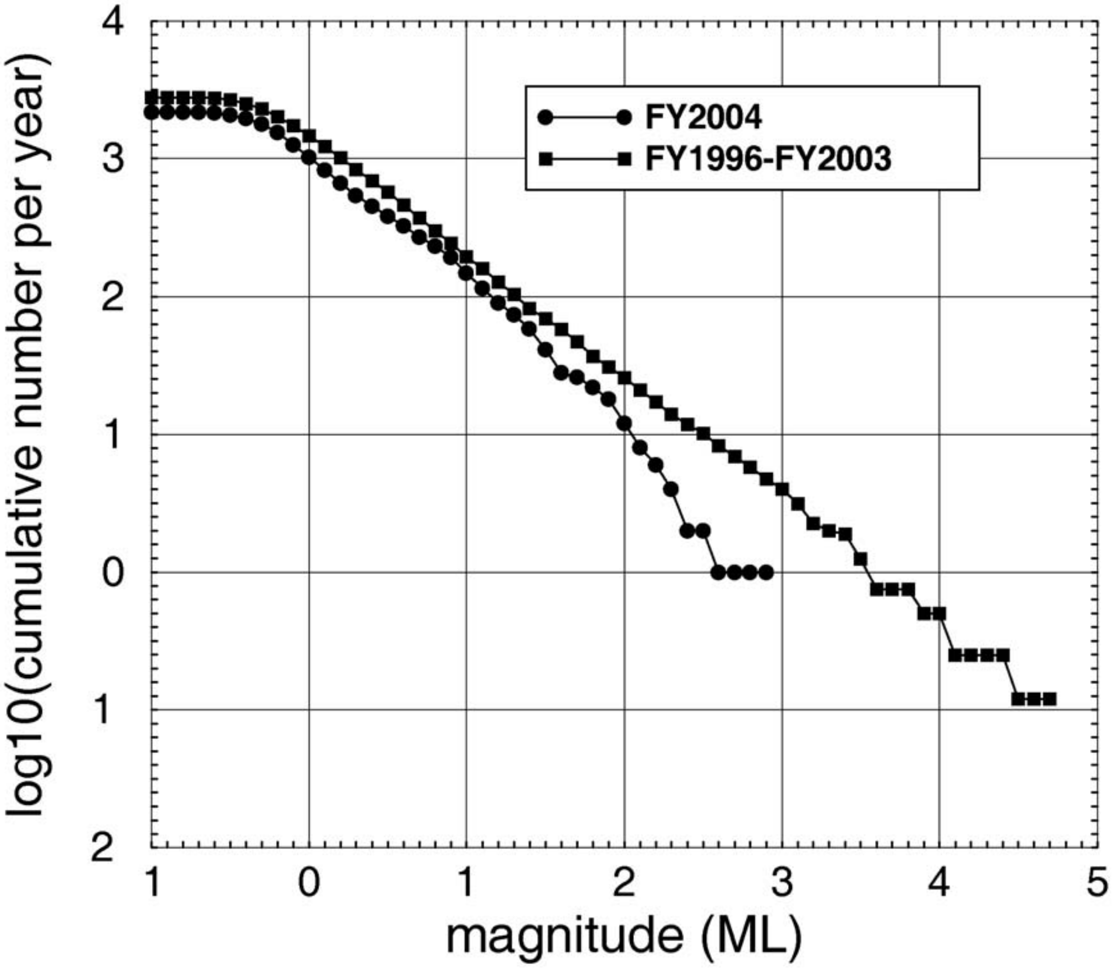

Figure 6. Cumulative recurrence curves for magnitudes in the FY2004 catalog (Q data taken from DID # 006DV.011) and in the FY1996-2003 catalog (Q data taken from DID # 006DV.001 and DID # 006DV.004).

Due to the concentration of events in the LSM area after the 6/29/1992 M 5.6 event, it was decided to not develop focal mechanisms for events in this area. A very large number of focal mechanisms already exist for this area (von Seggern et al., 2001), and any further information developed from the FY2004 data would be mostly redundant. Excluding the LSM area then, a preliminary list of 79 events was made by searching the final FY2004 catalog for events larger than M = 1 with greater than 15 stations associated to them. The input data for FPFIT, including the first motions, were taken from the HYPOINVERSE “arc” output. Before running FPFIT though, a thorough review of all first motions was done because the initial first motions are computer-generated. In this review roughly a quarter of the first motions were changed. Also, some first motions at additional stations, not initially picked, were found to be clear and thus useful in the solutions. Changes and additions were hand-entered into the “arc” file. A few events (22) were found to have insufficient data or to not have a large enough azimuthal range of data to provide reliable focal mechanisms, and these events were removed.

Program FPFIT was run on the data of the remaining 57 events. Details describing the methodology of this program are given in von Seggern and Smith (1997). After an initial run of FPFIT, not all mechanisms were well defined. Most of the events showing multiple solutions were rejected. However, in a few cases it was reasonable to prefer one solution over the other(s). For instance, where only one of the multiple solutions was tectonically viable (for instance, no near-horizontal fault plane), this solution was accepted. Another situation in which one solution might be objectively preferred over the others is when one or more critical stations with clear first motions agree with only one of the solutions. A few discrepant first motions were reviewed and changed if thought to be wrong, and a final run of FPFIT was made.

Table 1 lists the 24 acceptable, first-motion, focal-mechanism solutions for FY2004. Event solutions are tabulated in a modified FPFIT format in order to fall within the page size. Corresponding lower hemisphere graphical representations and first-motion polarities are shown in Figure 7. The solutions correspond well with those of previous years, with tension axes to the northwest-southeast at generally low plunge angles and pressure axes aligned with WNW-ESE but distributed over a much larger range of plunge angles. These are primarily strike-slip with no pure normal-faulting events. Focal mechanism solutions for previous years have been compiled in yearly YM seismicity reports (see references).

Table 1

Focal Mechanisms for FY2004 (Q data taken from DID # 006DV.012, with "Mag" data taken from #006DV.011)

Date	OT	Mag	#P	gap	near	rms	eh	ez	str	dp	rk	erft	#fm	s	d	r
20031005	143644	1.49	31	217	2.0	0.13	0.4	0.7	255	75	170	0.00	18	15	35	30
20031005	165200	1.48	30	204	2.0	0.14	0.5	1.0	70	70	150	0.21	17	30	20	30
20031012	061545	1.47	29	182	9.0	0.11	0.4	1.6	85	60	-160	0.33	22	30	43	50
20031021	102938	1.59	39	56	5.0	0.11	0.2	0.9	135	70	-30	0.03	28	13	35	25
20031105	072935	1.76	27	229	15.0	0.09	0.5	2.0	160	55	-30	0.06	19	35	45	40
20031106	061121	1.11	31	122	16.0	0.16	0.5	15.4	80	70	-160	0.00	21	20	63	80
20031205	050659	1.00	39	87	10.0	0.14	0.3	14.6	95	55	-170	0.00	17	23	33	25
20031213	085206	1.37	32	199	8.0	0.10	0.4	0.7	90	90	160	0.00	18	25	53	60
20040107	104322	1.33	39	83	14.0	0.12	0.3	1.3	275	75	-160	0.11	17	18	28	40
20040118	121912	1.89	23	194	23.0	0.08	0.5	1.7	95	60	-160	0.08	24	20	45	60
20040120	095658	1.07	27	68	7.0	0.14	0.4	8.0	70	90	180	0.06	18	8	63	80
20040126	112353	1.07	27	194	23.0	0.08	0.4	1.2	275	85	-150	0.00	16	18	30	50
20040201	045445	2.07	44	107	4.0	0.13	0.3	0.5	85	35	-160	0.12	31	15	18	15
20040206	224252	1.27	28	108	4.0	0.09	0.3	0.5	215	60	40	0.00	15	15	13	10
20040426	232659	2.99	26	115	11.0	0.08	0.3	1.1	355	80	0	0.34	31	30	45	45
20040427	005616	1.33	34	213	13.0	0.10	0.4	1.2	245	85	160	0.14	23	25	50	70
20040427	010716	1.88	38	164	13.0	0.11	0.4	1.2	355	75	-10	0.03	30	8	25	20
20040427	055203	1.41	37	94	12.0	0.12	0.3	1.5	230	75	160	0.07	27	23	45	70
20040501	223602	1.76	31	91	12.0	0.11	0.3	1.1	260	85	170	0.25	19	90	45	40
20040628	125912	1.54	26	196	18.0	0.11	0.6	1.6	355	85	0	0.04	24	15	53	40
20040825	155429	1.55	32	72	5.0	0.12	0.4	0.7	65	40	170	0.06	23	28	30	40
20040904	083747	1.50	25	124	14.0	0.09	0.3	1.2	50	80	-160	0.07	16	5	15	30
20040918	051705	1.81	26	245	14.0	0.09	0.5	1.0	160	85	10	0.20	19	8	35	30
20040921	062802	1.16	30	115	15.0	0.14	0.6	4.0	140	65	-30	0.18	15	10	30	50

Date: event date (yyyymmdd)
OT: event time in UTC
Mag: magnitude (ML)
#P: number of P-wave picks
gap: location gap
near: nearest station
rms: root-mean-square residual of station travel time residual
eh: horizontal error in the location
ez: vertical error in the location
str: strike of one of the fault planes
dp: dip of one of the fault planes
rk: rake of one of the fault planes
erft: overall error in fit
#fm: number of P-waves used in the solution
s: error in strike
d: error in dip
r: error in rake
Note: strike (str), dip (dp), rake (rk) are Aki & Richards (2002) convention

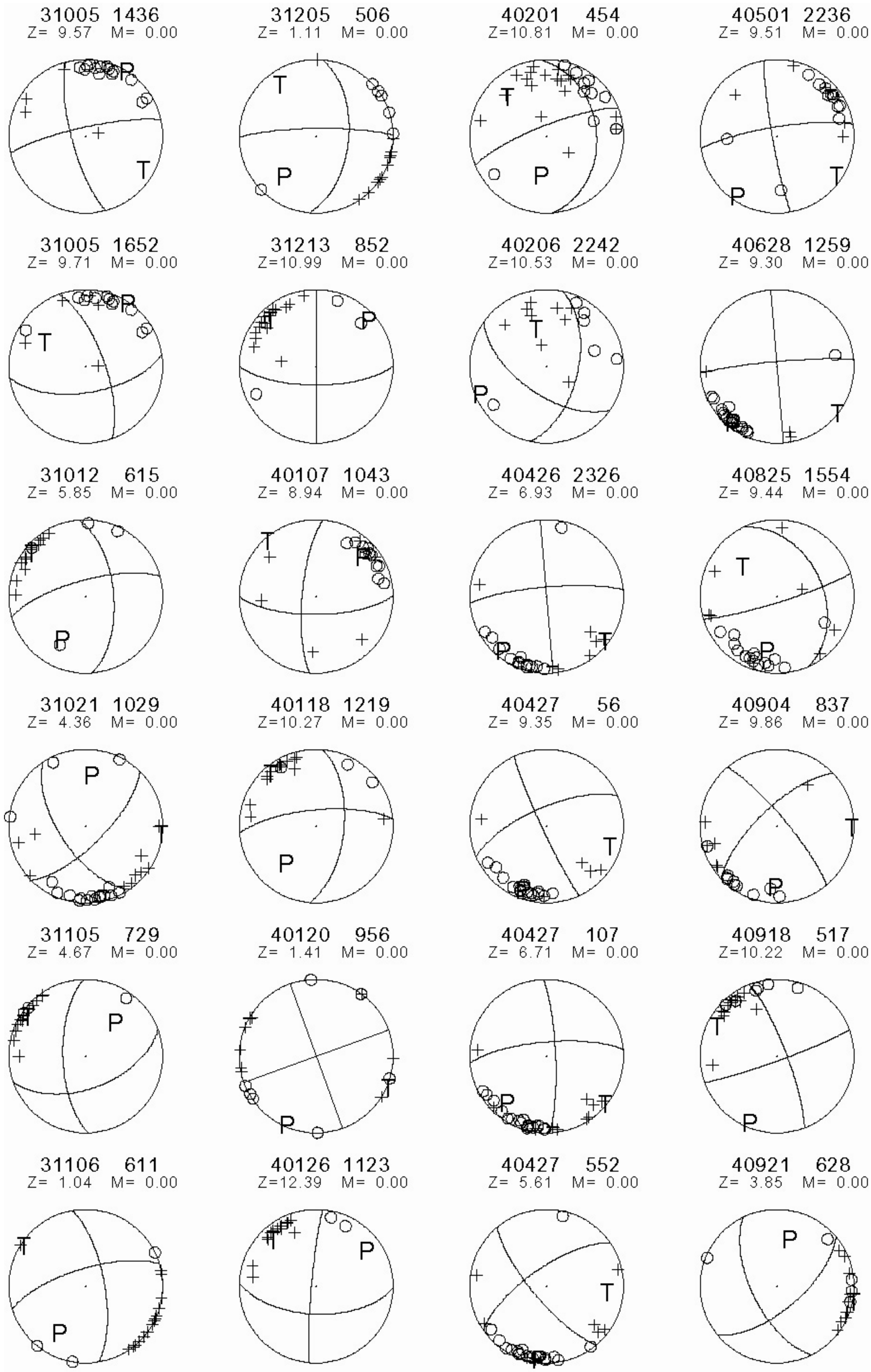

Figure 7. Lower hemisphere of focal mechanisms for FY2004. (Q data from DID # 006DV.012)

7.3 Seismicity Near Yucca Mountain

A search of the catalog epicenters within a 10-km radius of Yucca Mountain (specifically from the location of station RPY: 36.8515, -116.4563) was made as in previous seismicity reports. Four earthquakes fell within this area in FY2004 as listed in Table 2.

Table 2

Earthquake Activity Near Yucca Mountain in FY2004 (Q data from DID # 006DV.011)

date	origin time	lat		lon		depth	ML
	UTC	deg	min	deg	min	(km)	
01/31/2004	04:32:04.58	36	55.24	116	23.30	2.91	-0.21
04/24/2004	10:31:59.35	36	46.30	116	28.27	2.20	-0.22
06/26/2004	10:19:44.13	36	54.81	116	31.66	10.90	-0.25
09/25/2004	05:09:41.09	36	51.81	116	23.08	1.16	-0.35

Catalogs for previous years (FY1996 – FY2003) were searched with the same criterion and added to those of Table 2 to produce a nine-year list of 31 earthquakes within 10 km of RPY. The 31 epicenters are displayed in Figure 8 on shaded topography of the Yucca Mountain area. Note that there are no events with $M_L > 1.0$. Also, there is no pronounced clustering of the events into any particular zone of activity.

A cumulative recurrence curve of all 31 Yucca Mountain events (FY1996 – FY2004) is shown in Figure 9. This figure shows that the threshold of detection and location of events near Yucca Mountain lies at roughly M -0.3. The slope of the recurrence curve ("b-value" in $\log_{10}N = a - bM$) cannot be reliably determined from such a small dataset. Crudely, one sees that the rate of earthquakes with M > 0 is below one per year within 10 km of Yucca Mountain because the plot covers nine years of monitoring.

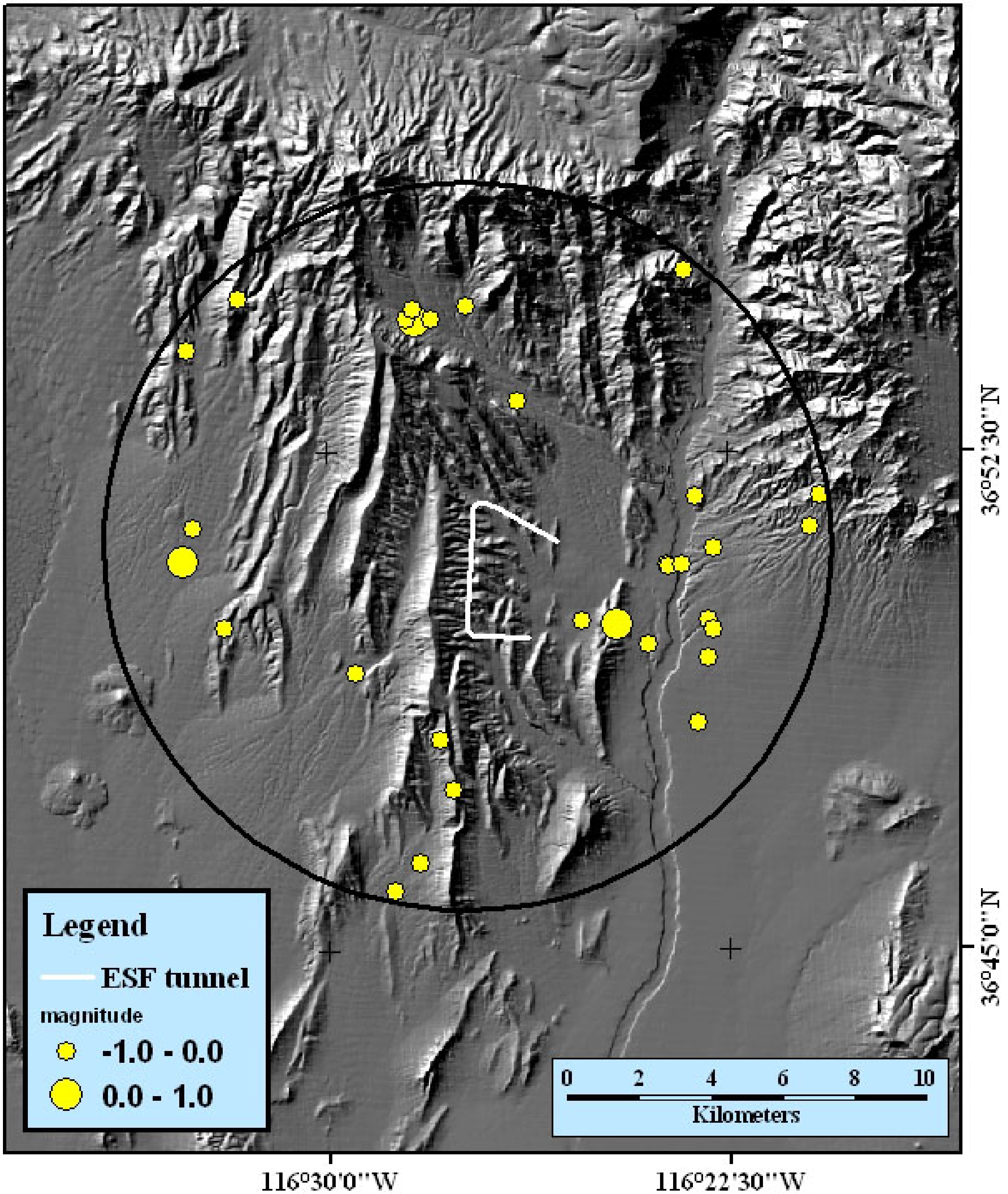

Figure 8. Earthquakes in FY1996-2004 occurring within 10 km of station RPY, which lies above the ESF tunnel. (Q data taken from DID # 006DV.001, 006DV.004, and 006.DV.011)

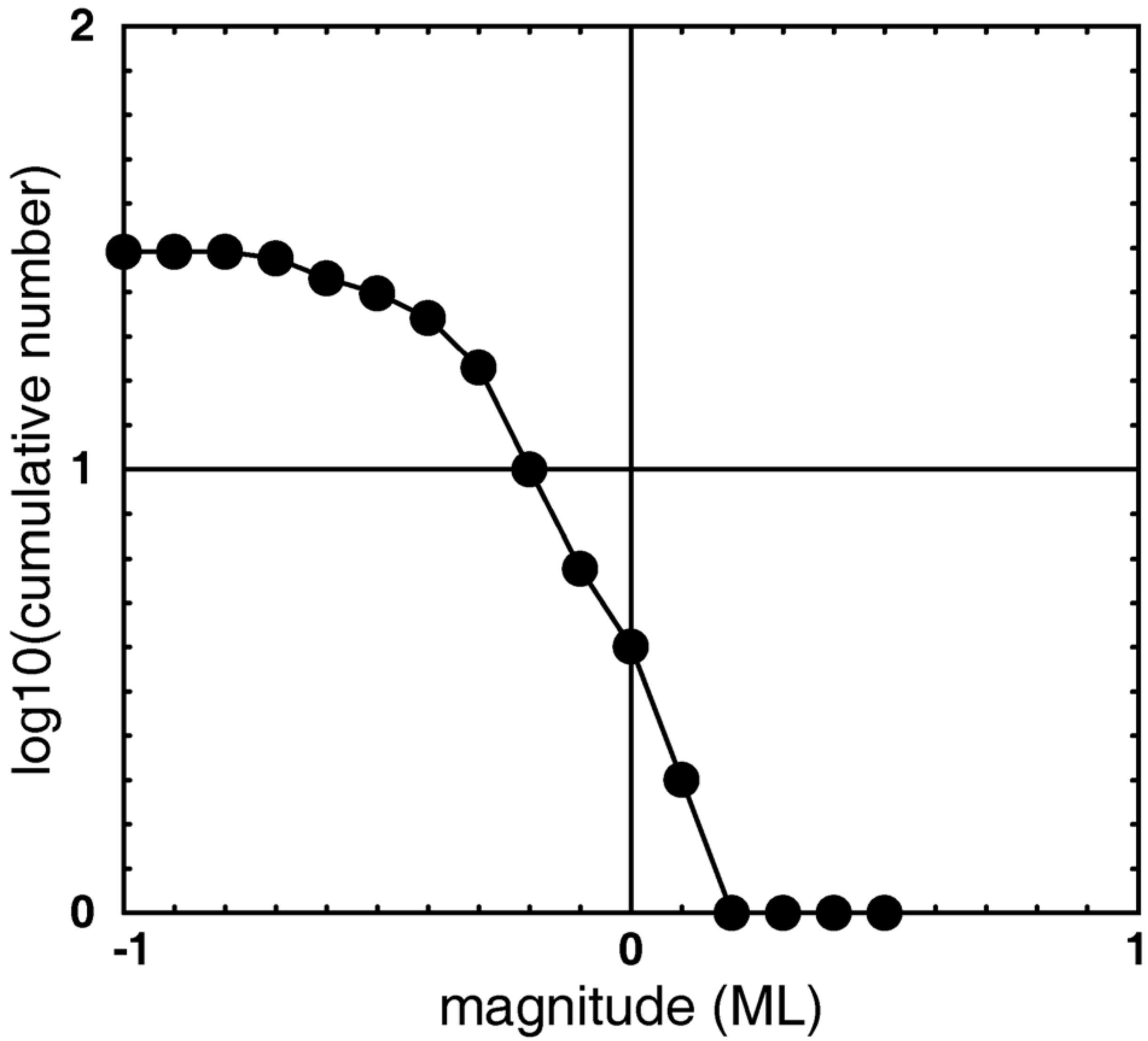

Figure 9. Recurrence curve for earthquakes in FY1996-2004 occurring within 10 km of station RPY, which lies above the ESF tunnel. (Q data taken from DID # 006.DV.001, 006DV.004, and 006DV.011)

7.4 Seismicity in the Death Valley Area

Earthquakes in the Death Valley region had been reported by the USGS (Harmsen 1994, and references therein) from 1978 through September 1992. In October 1992 NSL took over the seismic monitoring task for the Yucca Mountain Project. The record of seismicity in Death Valley has been somewhat non-uniform since 1992 because of the transition from the analog network to the site-specific digital network in late 1995. The analog stations in Death Valley

National Park were retained after this transition though. We only began to again treat Death Valley seismicity in the FY2000 and subsequent seismicity reports (see references); this report discusses the seismicity for FY2004 only.

In January 2000 NSL combined its digital and analog stations into a single system, called Antelope, for data collection and analysis, as discussed earlier in this report. Event location was notably improved in the Death Valley region in routine analysis due to the availability of the Yucca Mountain digital stations. In addition, it was now possible to compute Richter local magnitudes for most events in this region. We have created an Antelope-derived non-Q catalog (DID # 006DV.010) for FY2004 for the southern Great Basin, including the Death Valley region. (This catalog was derived from the Antelope “reno” tables in the directory /data/2003 and /data/2004.) Local magnitude M_L was used if available; in those few cases where only duration magnitude was available, we converted it to local magnitude using the relationship given in von Seggern and Smith (1997):

$$M_L = -1.24 + 1.31M_D$$

The Death Valley earthquake epicenters are shown in Figure 10 on a shaded digital elevation map so that the relation of seismic activity to geologic features can be more easily seen. Within the current boundary of the park as shown, the largest event in FY2004 was the M 4.2 event on 12/20/2003 in the northern part of DVNP. This event is in the aftershock zone of the 1993 M 6.1 Eureka Valley earthquake.

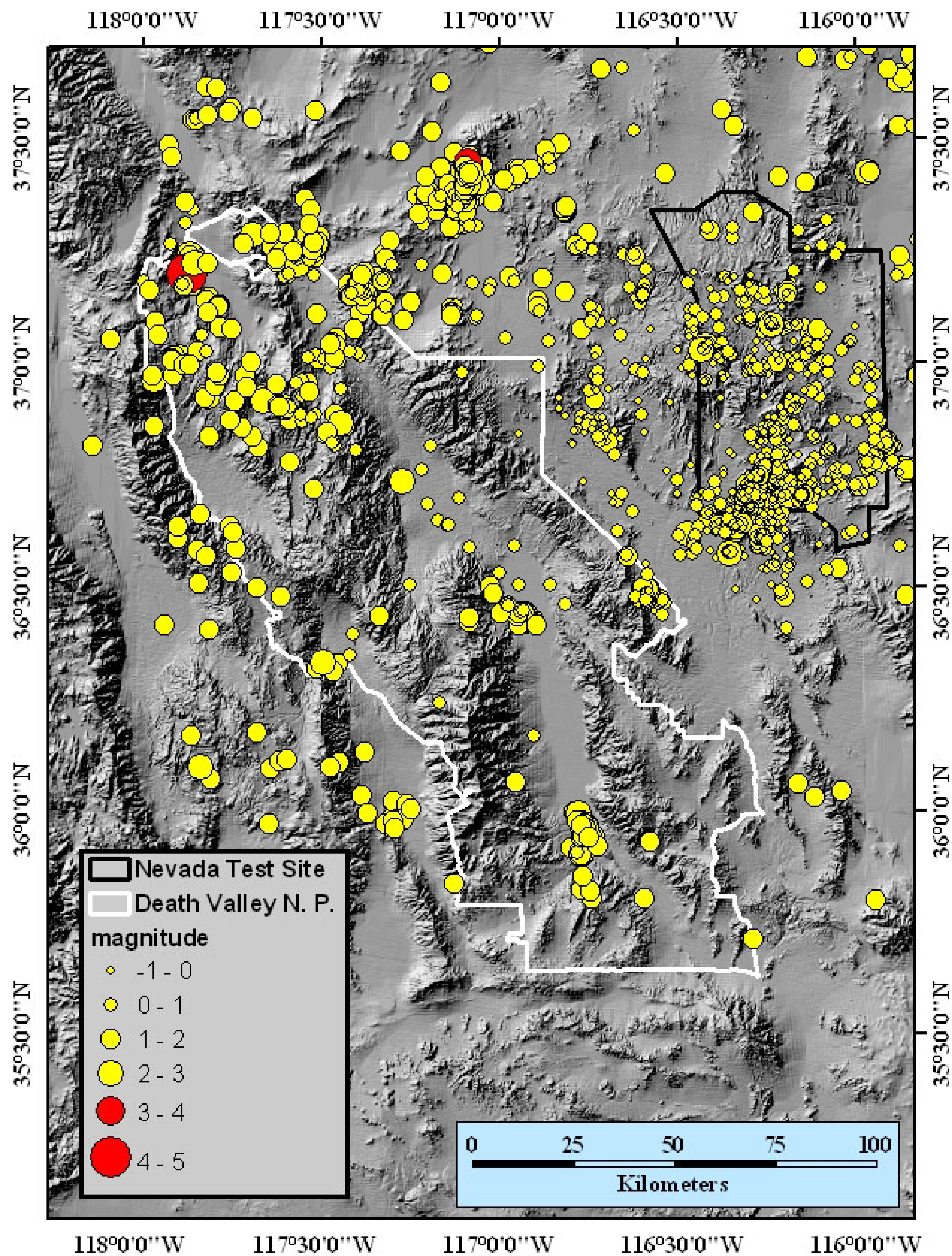

Figure 10. Seismicity in the area of Death Valley National Park for FY2004. (non-Q data from 006DV.010 – not to be used for quality-affecting work)

Overall, the seismic activity in DVNP and its immediate surroundings is higher than within the area of the SGBDSN itself to the east of the park. Even though the threshold of detection and location of earthquakes clearly increases west of the SGBDSN due to the sparser coverage and lower S/N (signal-to-noise) ratios of the analog stations, Figure 10 shows that many more events of a given magnitude above M 1 occur in the DVNP area than the Yucca Mountain area. Based on fault-slip rates, strain rates may be as much as 400 times greater in the Death Valley region than near Yucca Mountain. One notable feature in the current seismicity is the continuing aftershock activity related to the 1993 Eureka Valley M 6.1 earthquake and, to the northeast, also to the 1999 Scotty's Junction M 5.6 earthquake which occurred at approximately 37.4°N, 117.1°W (von Seggern et al., 2001).

7.5 Conclusions

FY2004 had the second-lowest level of seismic activity since the NSL began network operations in the vicinity of Yucca Mountain in late 1992. Only FY2003 showed a lower level of activity, and then only slightly. Following a region-wide increase in seismic activity for roughly three years in the Yucca Mountain area after the 1992 M 5.6 LSM earthquake and a subsequent decline in activity over roughly the past nine years, the region appears to be returning to pre-LSM earthquake activity rates.

A total of 2180 earthquakes were located within 65 km of station RPY, which is over the ESF, in FY2004. No particularly new or interesting sequences were within the FY2004 compiled catalog; the seismicity generally overlaid that of previous years. The largest event in FY2004 had an M_L of 2.99, and the recurrence curve for FY2004 earthquakes tracked that of eight previous years well (FY1996-FY2003), although showing a lower count of activity than the average of the previous years by approximately a factor of 1.5. Among the FY2004 earthquakes not in the aftershock zone of the 1992 LSM earthquake, 24 provided reliable focal mechanisms. These mechanisms reflected those of previous years in their orientations and add to the cumulative evidence of a WNW-ESE tensional domain in the Yucca Mountain vicinity.

Four small earthquakes (all with $M_L < 0$) were located within 10 km of station RPY in FY2004. When added to the 27 earthquakes in that region for the previous eight years to form a recurrence curve, it is seen that: 1) only three earthquakes with $M > 0$ have occurred in this area immediately around the repository in nine years, 2) the rate of earthquakes in this area is only slightly more than three per year, and 3) the threshold for complete detection and location of earthquakes in this area is roughly M_L -0.3.

8. Inputs and References

8.1 Inputs

(Q unless otherwise stated)

DID 006.DV001
DID 006DV.004
DID 006DV.005
DID 006DV.009 (non-Q)
DID 006DV.010 (non-Q)
DID 006DV.011
DID 006DV.012
DID 012DV.010
DID 023DV.001

8.2 References

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9. Appendices

(on following pages)

Appendix 1

Locations and Descriptions for the SGBDSN and Strong-Motion Sites
Q data – DID # 012DV.010 and 006DV.005

Permanent Network Monitoring Sites

code	station name and area	latitude north	longitude west	elevation km	on date	seismometer	strong motion+
AL5*	Alcove 5, ESF	36.8596	116.4547	1.0660	1998252	Mark Prod. L4	y
AMD	Amargosa Desert, BLM	36.4526	116.2809	0.7560	1997115	Geotech S-13	n
BTW	Beatty Wash, NAFB	36.9978	116.5665	1.3910	1995230	Geotech S-13	n
CAF	Calico Fan, NTS	36.8391	116.3377	1.1100	1995034	Geotech S-13	y
CRF	Crater Flat, BLM	36.8118	116.5340	1.0320	1995165	Geotech S-13	y
DOM	Dome Mountain, NTS	37.0021	116.4086	1.7110	1995333	Geotech S-13	n
ECO*	Echo Peak, NTS	37.2108	116.3296	2.2320	1999197	Geotech GS-13	n
FMW	Forty Mile Wash, NTS	36.9021	116.3688	1.1460	1995165	Geotech S-13	n
FRG	Fran Ridge, NTS	36.8169	116.4195	1.1550	1995165	Geotech S-13	y
HEL	Hell'sGate, Death Valley NP	36.7246	116.9750	0.7470	2002175	Geotech S-13	n
LEC	Lee's Camp, Death Valley NP	36.5627	116.6896	1.1130	2002057	Geotech S-13	n
LSC	Little Skull Cliff, NTS	36.7307	116.3255	1.2380	1995034	Geotech S-13	y
NCF	North Crater Flat	36.8899	116.5682	1.1510	1995034	Geotech S-13	n
PUV	Plutonium Valley, NTS	36.9494	115.9633	1.2530	1995258	Geotech S-13	n
PIT	Cinder Pit, BLM	36.6798	115.4937	0.0850	2000334	Geotech S-13	n
RED	Red Mountain, NTS	36.6895	116.0930	1.1430	1996037	Geotech S-13	n
RPY	Repository, NTS	36.8515	116.4563	1.3010	1996038	Geotech S-13	y
SCF	South Crater Flat, BLM	36.7568	116.5440	0.9090	1995034	Geotech S-13	y
SGR	South Grapevine, DVNP	36.9805	117.0327	1.5600	1998127	Geotech S-13	n
SPC	Specter Range, NTS	36.6746	116.2030	1.0640	1996075	Geotech S-13	n
STC	Silent Canyon, NTS	37.2939	116.4358	1.9600	1995209	Geotech S-13	n
STH	Stripped Hills, NTS	37.6457	116.3375	1.0500	2000179	Geotech S-13	n
STO	Solitario Canyon, BLM	36.8603	116.4742	1.3590	1995165	Geotech S-13	y
SYM	South Yucca Mountain, NTS	36.7416	116.4460	0.9950	1995034	Geotech S-13	y
TAR	Tarantula Canyon, BLM	36.8680	116.6322	1.2310	1996023	Geotech S-13	n
TIM	Timber Mountain, NAFB	37.0667	116.4694	1.8710	1996143	Geotech S-13	n
TPW	Topopah Wash, NTS	36.9016	116.2519	1.5730	1995258	Geotech S-13	n
TWP	Twin Peaks, NTS	37.2047	116.1234	1.5760	1995205	Geotech S-13	n
TYM	Thirsty Mountain, NAFB	37.1441	116.7208	1.4570	1996275	Geotech S-13	n
WLD	Wildcat Mountain, BLM	36.7927	116.6257	0.9300	1995193	Geotech S-13	n
YCW	Yucca Wash, NTS	36.9224	116.4756	1.4980	1996032	Geotech S-13	y
YFT*	Yucca Flat, NTS	37.0762	115.9735	1.3540	1999197	Geotech GS-13	n

+ "y" indicates that a RefTek 133-05 strong-motion instrument has been added at the site
* station is not officially part of the SGBDSN

Management Units:

BLM	Bureau of Land Management
DVNP	Death Valley National Park
NTS	Nevada Test Site, DOE
NAFB	Nellis Air Force Base

Independent Strong-Motion Sites

code	station name and area	latitude north	longitude west	elevation km
SPRS	Specter Range Strong Motion	36.6882	116.1772	1.071
LWLS	Lathrop Wells Strong Motion	36.6445	116.3976	0.825
SYMS	Side Yucca Mountain Strong Motion	36.8377	116.4723	1.328
WCTS	Wildcat Canyon Strong Motion	36.7929	116.6256	0.966
MDVS	Midway Valley Strong Motion	36.8519	116.4214	1.112
BYMS	Bottom of Yucca Mountain	36.8393	116.4767	1.251
TYMS	Top Yucca Mountain Strong Motion	36.8394	116.4675	1.506
FOCS	FOC Strong Motion	36.7779	116.2867	1.042
EXHS	Exile Hill Strong Motion	36.8495	116.4294	1.178

Appendix 2

Events Identified and Located as Blasts in FY2004
Non-Q data (DID # 006DV.009)

date	hh:mm:ss.ttt	latitude	longitude	magnitude
12/06/2003	18:04:37.625	37.0098	-116.7759	0.85
12/14/2003	20:47:29.121	36.9937	-116.7805	0.32
01/14/2004	07:20:32.391	37.0991	-116.0340	1.25
04/14/2004	18:12:45.152	37.0021	-116.5799	0.06
04/24/2004	17:40:20.145	36.9982	-116.7772	1.03
04/26/2004	22:39:17.675	36.9730	-116.7269	0.89
06/21/2004	13:24:46.810	37.0045	-116.7867	0.16
08/31/2004	18:32:20.381	37.0367	-116.7521	0.50