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GEOLOGICAL SURVEY

Borehole gravity meter surveys in drill holes USW G-3, UE-25p#1 and UE-25c#1, Yucca Mountain Area, Nevada

by

D. L. Healey, F. G. Clutsom and D. A. Glover

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CONTENTS

ILLUSTRATIONS

TABLES

Borehole gravity meter surveys in drill holes USW G-3, UE-25p#1 and UE-25c#1, Yucca Mountain Area, Nevada

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ABSTRACT

The borehole gravity meter (BHGM) measures a larger volume of rock than conventional logging tools and provides an independent measurement of the in situ bulk density. Drill holes USW G-3, UE-25p#1, and UE-25c#1 were logged with the BHGM and free-air gradient (FAG) measurements were made at UE-25p#1 and UE-25c#1. The BHGM data in these two holes was reduced using the measured FAG values. Windy conditions prevented measuring a FAG at USW G-3 and these data were reduced using the assumed "normal" value of 0.3086 mGal/m. At UE-25p#1 and UE-25c#1, respectively, the measured FAG values are 1.8 and 0.97 percent higher and the calculated densities are 0.07 and 0.04 mg/m^3 higher than values calculated using the "normal" value. These calculated differences in density are not insignificant and indicate the need to measure the FAG at each logged hole. The interval densities calculated from the three BHGM surveys are presented herein.

INTRODUCTION

The Yucca Mountain site, located in the southwestern quadrant of the Nevada Test Site (fig. 1) is being investigated for its suitability as a repository for high-level nuclear waste. As part of this continuing study, borehole gravity meter surveys were conducted in drill holes USW G-3, UE-25p#1, and UE-25c#1 (shown in fig. 1) during November 1983 by the U.S. Geological Survey (USGS). These holes were logged in cooperation with the U.S. Department of Energy (DOE) as part of the Nevada Nuclear Waste Storage Investigations (NNWSI). Drill hole USW H-1 was also logged with the borehole gravity meter as part of this investigation, but at an earlier date (Robbins, Schmoker, and Hester, 1982).

LaCoste and Romberg slim hole borehole gravity meter (BHGM) BH-6 was used to log each of the four holes logged to date at Yucca Mountain.

Purpose of Study

The primary objective of these three drill hole surveys was to measure the in situ bulk densities of the lithostratigraphic units penetrated by drill holes USW G-3, UE-25p#1, and UE-25c#1. The interpretation of these data will focus on geologic structure adjacent to the borehole.

Accurate density determinations require data that are not significantly affected by casing, drill-hole rugosity, or drilling induced conditions. The borehole gravity meter (BHGM) is primarily a density logging tool. However, the BHGM has a very large radius of investigation compared with conventional logging tools (McCulloch, 1966, p. 4). Therefore, a BHGM survey provides an independant measure of the in situ bulk density of the rocks surrounding the

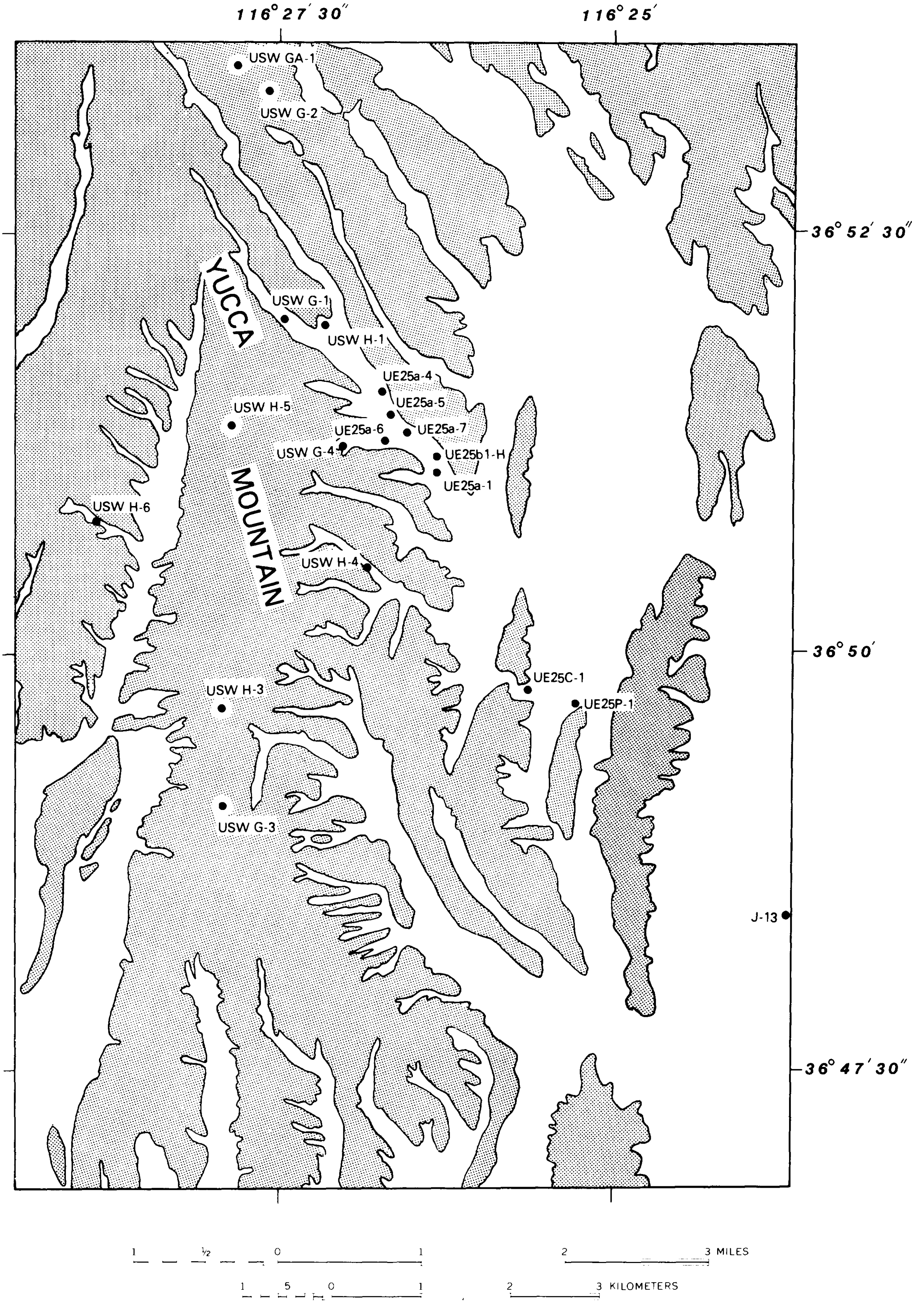

Figure 1.--Index map of the Yucca Mountain area showing the locations of drill holes USW G-3, UE-25p#1, and UE-25c#1.

drill hole. A better understanding of the subsurface rock properties and structure can be gained from an integrated study of the data from conventional logs and (or) cores and the BHGM data.

Acknowledgements

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REDUCTION PROCEDURES

Numerous references concerning the fundamentals of BHGM logging and data interpretation have been published. A selected listing of reports that cover work done at, or adjacent to, the Nevada Test Site include: Robbins, 1980; Robbins, Schmoker, and Hester, 1982; Schmoker and Kososki, 1978; Kososki, Robbins, and Schmoker, 1978, and Healey, 1970.

The in situ bulk density in megagrams per cubic meter (mg/m^3) between two points, vertically separated, in a drill hole (assuming near horizontal beds) is given by

$$\rho_b = \frac{F - \Delta g/\Delta z}{0.02556} \qquad 1)$$

Where F is the free-air gradient (FAG) of gravity in mGals/ft, Δg is the measured difference in gravity, corrected for the effect of adjacent terrain, Earth tides and instrument drift, between two points, Δz is the vertical distance separating the two points.

The BHGM observations are corrected for the effects of Earth tides, instrument drift and terrain. The BHGM reduction program BHGRAV.77, written by A. Cogbill, LANL, calculates the effects of Earth tides and instrument drift and applies appropriate corrections to the gravity data. The terrain correction, determined for each observation point downhole, is carried out to a radial distance of 21.944 km. The inner zone compartment elevations (through zone H, Hammer, 1939) are determined by hand from topographic maps and from sketches of the drill site. Digitized topography (digitized at 30 second intervals of latitude and longitude) is utilized by the reduction program to carry the terrain correction out to the specified radial distance from the drill hole.

The corrections for instrument drift are calculated from the replicate observations made at base stations (repeated stations) downhole.

Free-air gradients

An inspection of equation 1 shows that the free-air gradient (FAG) has a direct effect on the calculated interval density. Experience in Yucca Flat and on Pahute and Rainier Mesas has shown that the measured FAG can vary from the assumed "normal" value of 0.3086 mGal/m by plus or minus (±) several percentage points (Healey, 1970, p. B61; Schmoker and Kososki, 1978; Robbins, Schmoker, and Hester, 1982, p. 9, 11, 14, 16; and Healey, 1984, (written comm.).

Changing the FAG causes a shift in the calculated interval densities. If we were only concerned with relative differences between points down hole this shift would not matter. However, we are concerned with the true bulk density which necessitates measuring the FAG, if at all possible.
The FAG is determined from the following relationship.

$$F = \frac{\Delta g + TC}{\Delta H} \qquad 2)$$

where F = FAG; Δg is the difference in gravity (mGal) measured on the ground and at some point above the ground; TC is the difference in the terrain correction between the two points, and ; ΔH is the vertical distance separating the two points.

At Yucca Mountain there are no elevated structures on which to measure the FAG. Also, several attempts to measure the FAG on the "Monkey board" of the REECO Ideco 525 drill rig were unsuccessful due to excessive vibrations (operator movement, wind, generators, etc.). The inability to measure the FAG in areas lacking elevated structures (Yucca Flat and now Yucca Mountain) has long been a problem.

Over an extended period of time, several schemes to circumvent this problem have been proposed and each has been discarded as inadequate.

Briefly, these schemes considered building a platform on the tines of a large fork lift, the use of a boom truck, and planting a tall telephone pole. Only the boom truck was field tested and it proved to be far from stable.

Recently we found that the Bureau of Land Management (BLM) has a truck-mounted, hydraulically-hoisted survey tower used in timbered areas. The tower is designed as a tower within a tower. The inner tower is independant of the outer (free-standing) and has a raised pedestal on which to set the gravity meter. The operator stands on the outer tower which prevents his movement from being transmitted to the inner tower. Preliminary testing indicated that during periods of little wind, and if the inner tower was guyed, gravity observations could be obtained on top of the tower.

Arrangement~~s were~~ completed with BLM to take the truck to the Nevada Test Site (NTS) for field testing. Using the tower gravity observations were made 34.8 feet (10.61 m) above the ground at drill holes UE-25p#1 and UE-25c#1. Windy conditions prevented gravity observations at USW G-3. This height is considered as minimal for the measurement of the FAG. Therefore, at least four observations were taken on the ground (bottom) and three observations on the tower (top) at each site. These observations were then averaged to obtain the Δg values shown on table 1. At USW G-3 the "normal" value of 0.3086 mGal/m (0.09406 mGal/ft) for the FAG was assumed. The calculated FAG at UE-25p#1 is 1.8 percent and that at UE-25c#1 is 0.97 percent higher than the "normal" value assumed at USW G-3. At the earliest opportunity we plan to return to USW G-3 and again try to measure a FAG there. Table 1 lists the results obtained from the FAG measurements at Yucca mountain.

STRATIGRAPHY

The major lithostratigraphic units penetrated in drill holes USW G-3, UE-25p#1, and UE-25c#1 are shown as simplified stratigraphic columns on tables 2, 3, and 4, respectively.

INTERVAL DENSITIES

The in situ interval bulk densities calculated from the BHGM data are shown on tables 5, 6, and 7. The input parameters, depth in feet and meters, and the relative gravity (in mGals) are listed in columns 2, 3, and 4. Columns 5, 6, and 7 list the calculated values for the vertical gradient (mGal/m), the interval density (mg/m^3) and average density (mg/m^3).

The data for USW G-3, UE-25p#1, and UE-25c#1 are shown in tables 5, 6, and 7, respectively.

Table 1--Summary of data obtained from Free-air gradient measurements at Yucca Mountain, Nevada Test Site

Drill Hole	Coordinates Nevada State	Elev. ground (ft) (m)	Measured values ΔH (ft) (m)	Δg (mGal)	Gravity value (top) (bottom)	Terrain correction (top) (bottom)	Corrected Δg (mGal)	Calculated FAG (mGal/m) (mGal/ft)
USW G-3	N.752,780 E.558,483	4856 1480.11	34.77 10.60	----	(assumed "normal" value)			0.3086 0.09406
UE-25p#1	N.756,171 E.571,485	3654 113.74	34.8 10.61	3.054	3274.759 3277.813	0.537 0.819	3.336	0.3146 0.09586
UE-25c#1	N.757,095 E.569,768	3708 1130.20	34.8 10.61	3.163	3270.913 3274.076	0.625 0.767	3.305	0.3116 0.09497

Table 2.--Summary of major lithostratigraphic units and contacts in drill hole USW G-3 (from Scott and Castellanos, written comm., 1982)

Stratigraphy	Depth of interval meters (feet)	Thickness of interval meters (feet)
Paintbrush Tuff		
Tiva Canyon Member	0-114 (0-374)	114 (374)
Bedded tuff	114-129 (374-424)	15 (50)
Paintbrush Tuff--cont.		
Topopah Spring Member	129-428 (424-1404)	299 (980)
Bedded tuff	428-431 (1404-1414)	3 (10)
Tuffaceous beds of Calico Hills	431-459 (1414-1506)	28 (92)
Bedded tuff	459-475 (1506-1558)	16 (52)
Crater Flat Tuff		
Prow Pass Member	475-608 (1558-1995)	133 (437)
Bedded tuff	608-613 (1995-2011)	5 (16)
Crater Flat Tuff--cont.		
Bullfrog Member	613-796 (2011-2612)	183 (601)
Bedded tuff	796-800 (2612-2625)	4 (13)
Crater Flat Tuff--cont.		
Tram Member	800-1173 (2625-3848)	373 (1223)
Bedded tuff	1173-1182 (3848-3878)	9 (30)
Lithic Ridge Tuff	1182-1458 (3878-4783)	276 (905)
Bedded tuff	1458-1488 (4783-4882)	30 (99)
Older tuffs	1488-1533 (4882-5031)	45 (149)

Table 3--Preliminary summary of major lithostratigraphic units and contacts in drill hole UE-25p#1 (from M. D. Carr, written comm., 1983)

Stratigraphy	Depth of interval meters (feet)	Thickness of interval meters (feet)
Alluvium	0-39 (0-128)	39 (128)
---unconformity---		
Timber Mountain Tuff		
Ranier Mesa Member	39-52 (128-170)	13 (42)
---unconformity---		
Bedded tuff	52-55 (170-180)	3 (10)
Paintbrush Tuff		
Tiva Canyon Member	55-81 (180-267)	26 (87)
---fault---		
Topopah Spring Member	81-381 (267-1250)	300 (983)
Tuffaceous beds of Calico Hills	381-422 (1250-1385)	41 (135)
Bedded tuff	422-436 (1385-1430)	14 (45)
Crater Flat Tuff		
Prow Pass Member	436-546 (1430-1792)	110 (362)
Bedded tuff	546-558 (1792-1830)	12 (38)
Crater Flat Tuff--cont.		
Bullfrog Member	558-683 (1830-2240)	125 (410)
Bedded tuff	683-690 (2240-2265)	7 (15)
Crater Flat Tuff--cont.		
Tram Member	690-873 (2265-2863)	183 (598)
---fault---		
Lithic Ridge Tuff	873-1063 (2865-3488)	190 (623)
Bedded tuff	1063-1067 (3488-3502)	4 (14)
Older tuff		
Unit A	1067-1100 (3502-3610)	33 (108)
Unit C	1100-1138 (3610-3733)	38 (123)
Conglomerate	1138-1172 (3733-3844)	34 (111)
Older tuff		
Calcified tuff	1172-1204 (3844-3950)	32 (106)
Tuff of Yucca Flat	1204-1244 (3950-4080)	40 (130)
---fault---		
Lone Mountain Dolomite	1244-1667 (4080-5470)	433 (1390)
Roberts Mountain Formation	1667-1805 (5470-5923)	128 (453)

Table 4.--Preliminary summary of major lithostratigraphic units and contacts in drill hole UE-25c#1 (from R. W. Spengler, written comm., 1984)

Stratigraphy	Depth of interval (meters)	(feet)	Thickness of interval (meters)	(feet)
Paintbrush Tuff				
Tiva Canyon Member	0-93	0-305	93	305
Bedded tuff	93-96	305-315	3	10
Paintbrush Tuff--cont.				
Topopah Spring Member	96-406	315-1332	310	1017
Rhyolite Lavas & Tuffs of Calico Hills	406-516	1332-1692	110	360
Crater Flat Tuff				
Prow Pass Member	516-646	1692-2119	130	427
Bedded tuff	646-656	2119-2153	10	34
Crater Flat Tuff--cont.				
Bullfrog Member	656-821	2153-2695	165	542
Bedded tuff	821-828	2695-2716	7	21
Tram Member	828-914	2716-3000	86	284

Table 5.--Summary of borehole gravity data showing calculated interval and average densities in drill hole USW G-3. Free-air gradient used= 0.3086 mGal/m (see table 1)

Count	Depth (ft)	Depth (m)	Gravity mGal	Gradient mGal/m	Interval Density (mg/m^3)	Average Density (mg/m^3)
1	50.00	15.24	0.000	---------	Indefinite	----------
2	123.00	37.49	2.346	0.10543	2.423	2.423
3	134.00	40.84	2.715	0.11005	2.368	2.416
4	216.00	65.84	5.409	0.10780	2.395	2.406
5	234.00	71.32	6.027	0.11257	2.338	2.399
6	365.00	111.25	10.542	0.11310	2.332	2.371
7	425.00	129.54	13.787	0.17740	1.565	2.242
8	504.00	153.62	16.773	0.12400	2.202	2.235
9	520.00	158.50	17.429	0.13458	2.076	2.230
10	540.00	164.59	18.284	0.14028	2.008	2.221
11	568.00	173.13	19.489	0.14119	1.997	2.208
12	680.00	207.26	24.476	0.14608	1.938	2.160
13	796.00	242.62	28.506	0.11400	2.321	2.185
14	830.00	252.98	29.666	0.11186	2.347	2.192
15	930.00	283.46	33.648	0.13065	2.122	2.184
16	1007.00	306.93	36.410	0.11770	2.277	2.192
17	1048.00	319.43	37.914	0.12032	2.246	2.194
18	1120.00	341.38	40.503	0.11800	2.273	2.199
19	1184.00	360.88	42.632	0.10910	2.379	2.210
20	1272.00	387.71	45.576	0.10976	2.372	2.221
21	1324.00	403.56	47.901	0.14672	1.931	2.209
22	1504.00	458.42	57.803	0.18048	1.528	2.125
23	1530.00	466.34	59.052	0.15761	1.801	2.119
24	1557.00	474.57	60.333	0.15562	1.825	2.114
25	1582.00	482.19	61.700	0.17940	1.541	2.105
26	1612.00	491.34	63.246	0.16906	1.664	2.096
27	1654.00	504.14	65.323	0.16227	1.745	2.087
28	1682.00	512.67	66.635	0.15375	1.847	2.083
29	1712.00	521.82	67.987	0.14781	1.918	2.080
30	1730.00	527.30	68.675	0.12556	2.183	2.081
31	1812.00	552.30	72.657	0.15929	1.781	2.067
32	2021.00	616.00	82.044	0.14736	1.923	2.052
33	2054.00	626.06	83.641	0.15871	1.788	2.047
34	2109.00	642.82	85.922	0.13606	2.058	2.048
35	2140.00	652.27	86.958	0.10966	2.373	2.053
36	2185.00	665.99	88.602	0.11989	2.251	2.057

Table 6.--Summary of borehole gravity data showing calculated interval and average densities in drill hole UE-25P#1. Free-air gradient used= 0.3146 mGal/m. (see Table 1)

Count	Depth (ft)	Depth (m)	Gravity mGal	Gradient mGal/m	Interval Density (mg/m^3)	Average Density (mg/m^3)
1	90.00	27.43	0.000	-----	Indefinite	-----
2	148.00	45.11	3.136	0.17737	1.636	1.636
3	160.00	48.77	3.698	0.15365	1.919	1.685
4	177.00	53.95	4.633	0.18055	1.598	1.668
5	200.00	60.96	5.831	0.17084	1.714	1.678
6	211.00	64.31	6.349	0.15472	1.906	1.698
7	229.00	69.80	7.219	0.15851	1.861	1.719
8	248.00	75.59	8.013	0.13708	2.117	1.767
9	264.00	80.47	8.739	0.14879	1.977	1.787
10	283.00	86.26	9.467	0.12576	2.252	1.832
11	332.00	101.19	11.421	0.13084	2.191	1.905
12	400.00	121.92	14.216	0.13484	2.144	1.957
13	495.00	150.88	18.299	0.14101	2.070	1.984
14	640.00	195.07	23.539	0.11857	2.338	2.077
15	725.00	220.98	27.193	0.14102	2.070	2.076
16	792.00	241.40	29.985	0.13672	2.121	2.080
17	928.00	282.85	35.396	0.13056	2.195	2.099
18	999.00	304.50	38.035	0.12195	2.297	2.114
19	1094.00	333.45	41.364	0.11496	2.381	2.140
20	1129.00	344.12	42.582	0.11413	2.391	2.148
21	1194.00	363.93	45.054	0.12478	2.263	2.155
22	1210.00	368.81	45.601	0.11213	2.414	2.159
23	1400.00	426.72	54.013	0.14526	2.019	2.138
24	1550.00	472.44	59.967	0.13024	2.198	2.145
25	1635.00	498.35	62.935	0.11454	2.386	2.158
26	1672.00	509.63	64.358	0.12624	2.246	2.160
27	1728.00	526.69	66.670	0.13543	2.137	2.159
28	1803.00	549.55	69.759	0.13511	2.140	2.158
29	1830.00	557.78	70.881	0.13636	2.125	2.158
30	1857.00	566.01	71.955	0.13057	2.194	2.158
31	1907.00	581.25	73.813	0.12191	2.298	2.162
32	1955.00	595.88	75.458	0.11242	2.411	2.169
33	2062.00	628.50	79.162	0.11359	2.397	2.181
34	2125.00	647.70	81.444	0.11882	2.335	2.186
35	2163.00	659.28	82.894	0.12516	2.259	2.187
36	2346.00	715.06	90.179	0.13061	2.194	2.188
37	2578.00	785.77	98.655	0.11986	2.322	2.200
38	2594.00	790.65	99.209	0.11365	2.396	2.201
39	2635.00	803.15	100.697	0.11900	2.332	2.203
40	2885.00	879.35	109.834	0.11992	2.321	2.214
41	3080.00	938.78	117.210	0.12410	2.272	2.218
42	3120.00	950.98	118.663	0.11917	2.330	2.219
43	3296.00	1004.62	125.034	0.11875	2.335	2.226
44	3377.00	1029.31	127.789	0.11162	2.420	2.230
45	3504.00	1068.02	132.506	0.12184	2.299	2.233
46	3586.00	1093.01	135.298	0.11172	2.419	2.237

Table 6. cont.--Summary of borehole gravity data showing calculated interval and average densities in drill hole UE-25p#1. Free-air gradient used= 0.3146 mGal/m. (see Table 1)

Count	Depth (ft)	Depth (m)	Gravity mGal	Gradient mGal/m	Interval Density (mg/m^3)	Average Density (mg/m^3)
47	3614.00	1101.55	136.321	0.11989	2.322	2.238
48	3730.00	1136.90	140.263	0.11147	2.422	2.244
49	3842.00	1171.04	143.528	0.09566	2.611	2.255
50	3910.00	1191.77	145.723	0.10588	2.489	2.259
51	3920.00	1194.82	146.054	0.10870	2.455	2.260
52	3930.00	1197.86	146.423	0.12100	2.309	2.260
53	3940.00	1200.91	146.756	0.10916	2.450	2.260
54	3950.00	1203.96	147.065	0.10151	2.541	2.261
55	3960.00	1207.01	147.367	0.09915	2.569	2.262
56	3970.00	1210.06	147.663	0.09706	2.594	2.263
57	3980.00	1213.10	147.964	0.09860	2.576	2.263
58	3990.00	1216.15	148.231	0.08773	2.705	2.264
59	4000.00	1219.20	148.469	0.07797	2.822	2.266
60	4025.00	1226.82	149.191	0.09475	2.622	2.268
61	4040.00	1231.39	149.626	0.09510	2.617	2.269
62	4067.00	1239.62	150.371	0.09056	2.672	2.272
63	4082.00	1244.19	150.819	0.09796	2.583	2.273
64	4280.00	1304.54	156.165	0.08858	2.695	2.293
65	4974.00	1516.08	174.051	0.08456	2.743	2.357
66	5052.00	1539.85	176.027	0.08312	2.760	2.364
67	5075.00	1546.86	176.608	0.08287	2.763	2.365
68	5880.00	1792.22	196.291	0.08022	2.795	2.425

Table 7.--Summary of borehole gravity data showing calculated interval and average densities in drill hole UE-25c#1. Free-air gradient used= 0.3116 mGal/m. (see Table 1)

Count	Depth (ft)	Depth (m)	Gravity mGal	Gradient mGal/m	Interval Density (mg/m^3)	Average Density (mg/m^3)
1	65.00	19.81	0.000	-----	Indefinite	-----
2	98.00	29.87	1.124	0.11173	2.384	2.384
3	184.00	56.08	4.269	0.12000	2.285	2.313
4	265.00	80.77	7.377	0.12586	2.215	2.273
5	292.00	89.00	8.871	0.18155	1.551	2.187
6	321.00	97.84	10.604	0.19610	1.378	2.096
7	342.00	104.24	11.489	0.13824	2.068	2.094
8	365.00	111.25	12.404	0.13049	2.160	2.099
9	422.00	128.63	14.627	0.12796	2.190	2.113
10	468.00	142.65	16.627	0.14269	2.015	2.102
11	584.00	178.00	21.898	0.14909	1.938	2.065
12	623.00	189.89	23.391	0.12554	2.219	2.076
13	723.00	220.37	26.976	0.11764	2.313	2.112
14	829.00	525.68	31.325	0.13458	2.111	2.112
15	852.00	259.69	32.212	0.12654	2.207	2.115
16	1000.00	304.80	38.282	0.13457	2.111	2.114
17	1050.00	320.04	40.140	0.12192	2.262	2.122
18	1074.00	327.36	40.955	0.11138	2.388	2.128
19	1116.00	340.16	42.334	0.10776	2.431	2.140
20	1292.00	393.80	48.604	0.11687	2.323	2.166
21	1342.00	409.04	50.573	0.12924	2.175	2.167
22	1402.00	427.33	53.314	0.14988	1.929	2.156
23	1582.00	482.19	61.406	0.14749	1.957	2.133
24	1648.00	502.31	64.283	0.14299	2.011	2.127
25	1787.00	544.68	69.865	0.13176	2.145	2.129
26	1860.00	566.93	72.381	0.11307	2.368	2.139
27	1978.00	602.89	77.034	0.12936	2.174	2.141
28	2155.00	656.84	84.468	0.13779	2.073	2.135
29	2234.00	680.92	87.441	0.12349	2.244	2.139
30	2266.00	690.68	88.583	0.11704	2.321	2.142
31	2298.00	700.43	89.664	0.11085	2.394	2.145
32	2412.00	735.18	93.453	0.10906	2.416	2.158
33	2446.00	745.54	94.596	0.11025	2.402	2.162
34	2484.00	757.12	95.934	0.11553	2.339	2.165
35	2528.00	770.53	97.523	0.11850	2.303	2.167
36	2550.00	777.24	98.362	0.12508	2.225	2.168
37	2690.00	819.91	103.922	0.13029	2.163	2.167
38	2766.00	843.08	106.733	0.12137	2.269	2.170
39	2955.00	900.68	113.356	0.11497	2.345	2.182

Drill hole USW G-3

Drill hole USW G-3 was logged with the BHGM on November 16-17, 1983. A total of 48 gravity observations were made between depths of 15.24 and 665.99 m. A total of 36 stations had been established after replicate readings were adjusted to a single value at each base station.

On April 12-13, 1984, an attempt was made to measure the FAG at this site using the BLM truck. Windy conditions at this exposed site on the ridge of Yucca Mountain prevented us from getting useable readings. Because of this the USW G-3 data were reduced using the "normal" value of 0.3086 mGal/m for the FAG. A computer plot of the USW G-3 interval densities is shown in figure 2 (in pocket).

Drill hole UE-25p#1

Drill hole UE-25p#1 was logged on November 18-19, 1983. A total of 91 gravity observations were made between depths of 27.43 m and 1972.22 m in this hole. It was not possible to obtain an observation shallower than 27.43 m because of windy conditions. After the replicate readings at the base stations were adjusted to a single value at each base, 68 stations had been established.

The FAG was measured at UE-25p#1 on April 13, 1984. The measured value of 0.3146 mGal/m was then used to calculate the interval densities shown in table 6. As mentioned previously, this FAG is 1.8 percent higher than the assumed "normal" value. Using this FAG in the density calculations results in interval density values that are 0.07 mg/m^3 higher than would be calculated from the normal value. Although 0.07 mg/m^3 is a relatively small error in density, approximately 2 percent for most rocks, it is on the order of the difference in density between dolomite and limestone, limestone and sandstone, or a zeolitized tuff and a non-zeolitized tuff. Also, porosities calculated from densities which are in error by 0.07 mg/m^3, are in error by about 5 percent.

Detailed gravity observations between 1191.77 m (3910 ft) and 1244.19 m (4082 ft) were made to study a fault that was penetrated by the drilling. This zone was unstable and could not be logged open hole. The only accurate and reliable data that was obtained in this interval was gravity and gamma ray. The gradational transition from Tertiary tuff to Silurian dolmomite is plainly seen in fig. 3 (in pocket) which is a computer plot of the UE-25p#1 interval densities. Lower density values at 1244 m corresponds to the fault itself. Lower density values at the top of the gradational transition zone 1195-1199 m may be a secondary related fault, and is a permeable porous zone that is evident in a core through this interval (verbal communication M.D. Carr, 1984). The resul s of this fault study will be included in the planned interpretation report of the BHGM data.

Drill Hole UE-25c#1

Drill hole UE-25c#1 was logged on November 20-21, 1983. A total of 48 gravity observations were made between depths of 19.81 and 900.68 m in this drill hole. It was not possible to obtain gravity observations shallower than 19.81 m (65 ft) because of windy conditions. A total of 39 stations had been established after replicate readings at the base stations were adjusted to a single value at each base.

The FAG was measured on April 13, 1984. The measured value of 0.3116 mGal/m was then used to calculate the interval densities shown in table 7. This measured FAG is 0.97 percent higher than the "normal" value, and results in interval densities that are 0.04 mg/m^3 higher than would be calculated from the "normal" FAG. This is a significant difference, and if the incorrect value was used in tonnage calculations for mining purposes an error of about 2 percent could result. A computer plot of the UE-25c#1 interval densities is shown in fig. 4 (in pocket).

CONCLUSIONS AND RECOMMENDATIONS

(1) BHGM surveys at Yucca Mountain provide excellent density data. The measured gravity values do, however, need to be reduced using a FAG measured at, or near, each logged hole.

(2) Additional holes at Yucca Mountain should be logged with the BHGM, especially those holes close to the proposed shaft and repository.

(3) A pilot hole at the shaft site should be considered. If drilled, BHGM and gamma-gamma logs should be made. From these logs an accurate overburden density could be determined for mining purposes.

(4) Structure adjacent to a drill hole may be evaluated by comparing BHGM and gamma-gamma density logs. Good correlation between BHGM and gamma-gamma densities can be interpreted to indicate a lack of structure adjacent to the drill hole. Conversely, poor correlation can be interpreted to indicate the presence of structure (faulting, horst, graben, etc.).

(5) The BHGM is a useful tool and should be fully utilized to help resolve the problems that remain regarding the structural setting of Yucca Mountain.

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