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Trace Metals and Major and Rare Earth Elements in Cuttings from Five High-Temperature Wells in the Northwest Region of The Geysers, California, Vapor-Dominated Geothermal System

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INTRODUCTION

Temperatures within the main vapor-dominated steam reservoir at The Geysers geothermal field generally are in the range 238°C to 244°C. A few deep wells in the northwestern part of the field have penetrated beneath this reservoir into a second vapor-dominated reservoir where temperatures are >315°C, while vapor pressure remains nearly constant at about 35.9 bars (Walters et al., 1992). Vapor-dominated reservoirs generally are thought to operate like heat pipes in which steam formed near the base of the system convects upward (along with other gases, such as CO_2 and H_2S), while liquid that has condensed from steam near the top of the reservoir counterflows downward (White et al., 1971). To the extent that this steam condensate carries H_2S in solution, it may dissolve gold from the surrounding rock during the counterflow. Re-evaporation of the down-flowing condensate and precipitation of dissolved material might occur at the base of the upper reservoir where there is a relatively sharp increase in temperature while vapor pressure remains nearly constant. In addition, brine that once was present throughout the system (Moore, 1992) may have deposited a variety of ore minerals when and where boiling was vigorous during the transition from previous hot water-dominated to present-day vapor-dominated conditions. The investigation reported here was a geochemical reconnaissance survey looking for evidence of accumulation of Au and other metals in the transition zone between the two reservoirs. The petrology of the cuttings was not examined as part of the investigation.

SAMPLES ANALYZED

A total of 51 samples from 5 wells that penetrated the high-temperature reservoir in the northwestern part of The Geysers field (Table 1) were analyzed. These wells all bottomed in metasediments of the Franciscan assemblage. Individual samples were composites of cuttings from 3 m intervals obtained during rotary air drilling. The samples were cleaned with a magnet to remove possible contamination from the steel drill rods and well casings, although some contamination from high-temperature grease, drilling components, and oxidized steel (e.g., Pb, Mo, Cr, Ni, W, Cu) is unavoidable (see Table 2 for possible sources of contaminants). The depths at which samples were selected for analyses were chosen to span the likely transition region between the main reservoir and the high-temperature reservoir. A total of 48 elements were analyzed for each sample; 29 by instrumental neutron activation analysis (INAA), and 19 by inductively coupled plasma emission spectrometry (ICP) after total digestion of the cuttings. Table 3 shows the elements that were analyzed, the analytical method, and the detection limits.

Table 4 shows the analytical results for Au and selected chalcophile elements, Table 5 for rock-forming elements, Table 6 for the rare earth elements (REE), and Table 7 for other elements present in trace amounts.

No significant Au anomaly was detected in any of the composite cuttings samples that we analyzed (Fig. 1). From a resource perspective, none of the chalcophile metals are present in significant concentrations. Values of As as a function of distance from the top of the high-temperature reservoir (HTR) are erratic, with the highest values above the HTR interspersed with generally low values (Fig. 2). The highest values of Sb are near the top of the HTR (Fig. 3). Anomalously high values of Cu and Zn clearly correlate with the top of the HTR in cuttings from the Prati 37 well, but do not show this correlation in the Prati 25 and Prati State 31 wells (Figs. 4 and 5). Pb is relatively enriched in a zone below the top of the HTR in the Prati State 31 and Prati 37 wells, but not in well Prati 25 (Fig. 6). The highest concentrations of Cu, Pb, and Zn all were found in cuttings obtained from a depth of 8400 ft (2560 m) in the Prati 37 well, or about 300 ft (90 m) below the estimated depth of the top of the HTR (Table 3). This sample also contained the highest concentration of W, Ni, and Co (Table 6).

There is little variation in U or V relative to the top of the HTR (Fig. 7). Other trace metals exhibit a variety of distributions, some showing enrichment at or below the top of the HTR in cuttings from some wells and not in others (Figs. 8–12). The highest concentrations of Cr and Mo were found in cuttings from 8600 ft (2620 m) deep in the Prati State 31 well, along with a relatively high concentration of Mn (Table 6).

CONCLUSIONS

We found no evidence that a sizable disseminated Au deposit might be forming in response to present hydrothermal activity near the bottom of the lower-temperature vapor-dominated steam reservoir in the northwestern part of The Geysers where there is a sharp increase in temperature from about 240°C to >315°C. It is possible that vein-type Au deposits might be present that were not intersected by the five wells that we sampled, or that such deposits were intersected by the wells, but missed by us because of the relatively wide spacing of our samples. The absolute concentrations of chalcophile elements and other trace metals are relatively low, but some anomalies do occur. It is impossible to say at this time whether the distribution of these elements is related mainly to contamination of the cutting during drilling, to the present vapor-dominated hydrothermal activity, or to the previous hot water-dominated system that once was present (Moore, 1992). However, the generally higher values at or below the top of the HTR suggests that this horizon has played a role in concentrating these elements.

Acknowledgments

We wish to thank the Central California Power Agency (CCPA) for making available the cuttings which we analyzed, and for granting permission to publish the results. Data on the high-temperature wells was generously provided by Mark A. Walters. Funding for J.N. Moore was provided by the Department of Energy under contract DE-AC07-90ID12929. The manuscript received constructive reviews by L.J.P. Muffler and J.B. Lowenstern.

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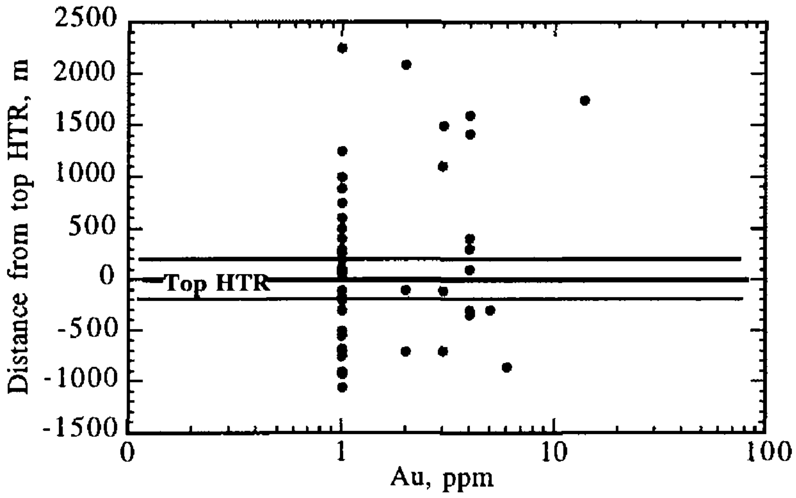

Figure 1. The distribution of Au in cuttings from the transition region between ≈240°C and >315°C vapor-dominated reservoirs in five wells in the northwest region of The Geysers steam field relative to the estimated distance above or below the top of the high-temperature reservoir (line labeled Top HTR with 200-ft error band). All of the samples containing <2 ppb Au are arbitrarily plotted at 1 ppb Au in order to show the number and distribution of samples analyzed.

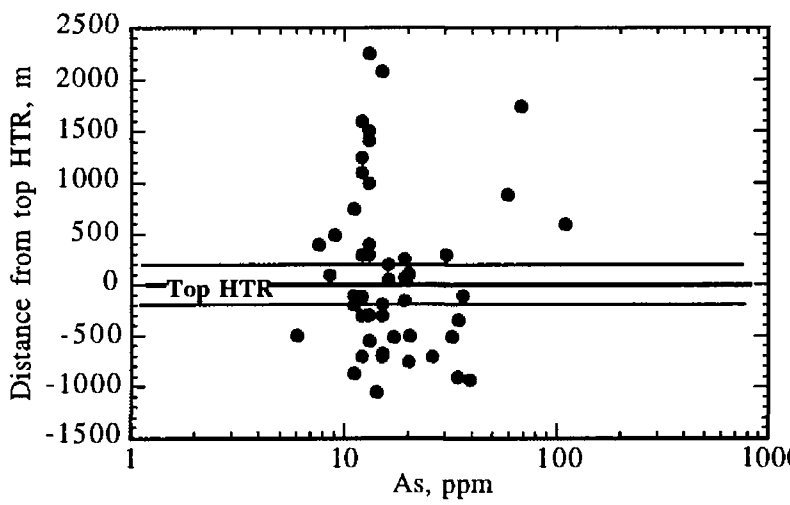

Figure 2. The distribution of As in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in five wells in the north-west region of The Geysers steam field relative to the estimated distance above or below the top of the high-temperature reservoir.

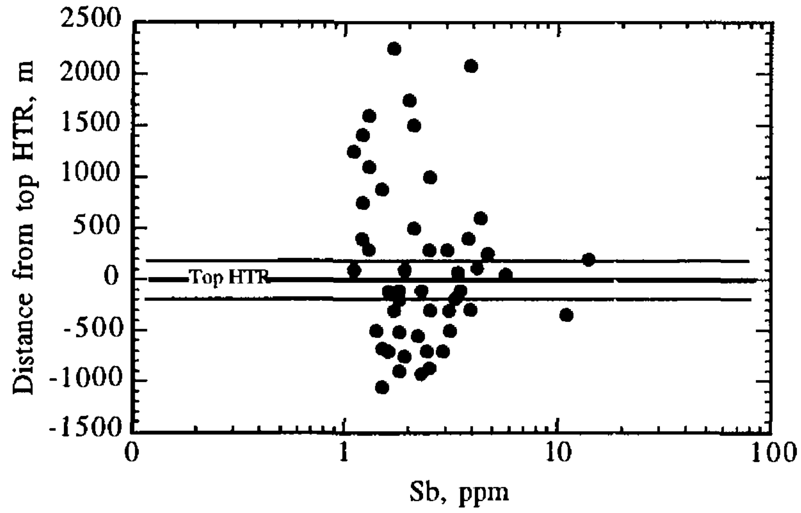

Figure 3. The distribution of Sb in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in five wells in the northwest region of The Geysers steam field relative to the estimated distance above or below the top of the high-temperature reservoir.

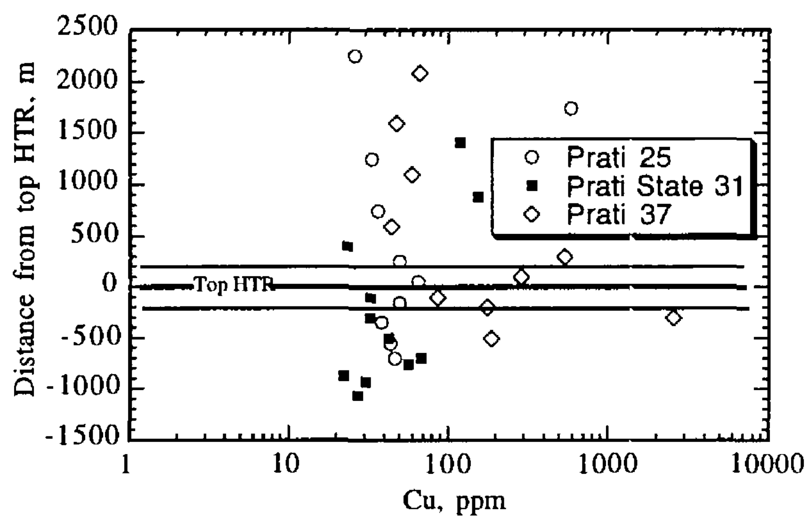

Figure 4. The distribution of Cu in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in the Prati 25 and 37 wells and Prati State 31 well in the northwest region of The Geysers steam field relative to the estimated distance above or below the high-temperature reservoir.

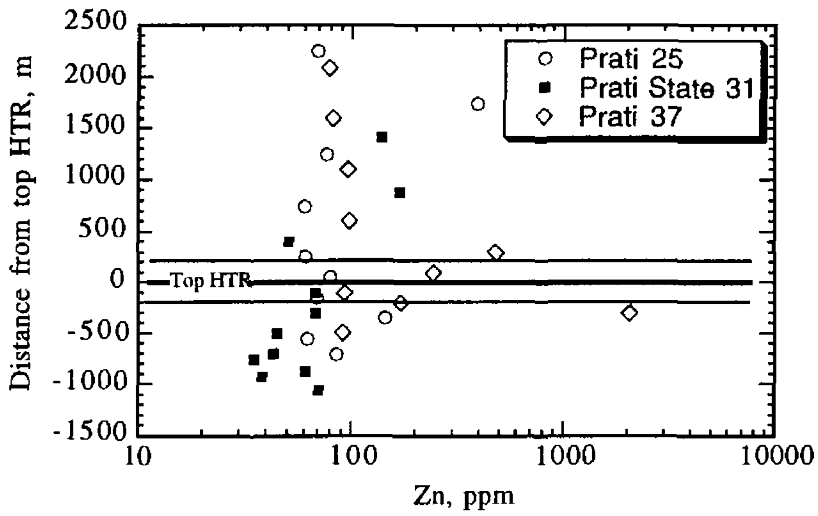

Figure 5. The distribution of Zn in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in the Prati 25 and 37 wells and Prati State 31 well in the northwest region of The Geysers steam field relative to the estimated distance above or below the high-temperature reservoir.

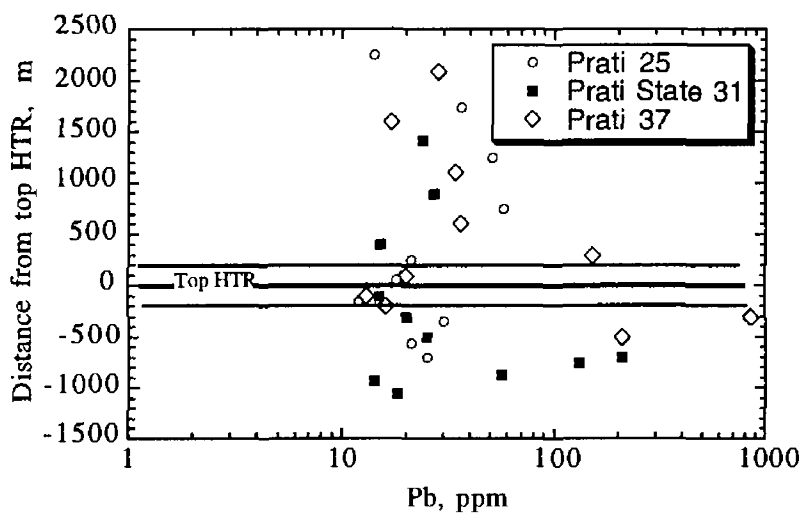

Figure 6. The distribution of Pb in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in the Prati 25 and 37 wells and Prati State 31 well in the northwest region of The Geysers steam field relative to the estimated distance above or below the high-temperature reservoir.

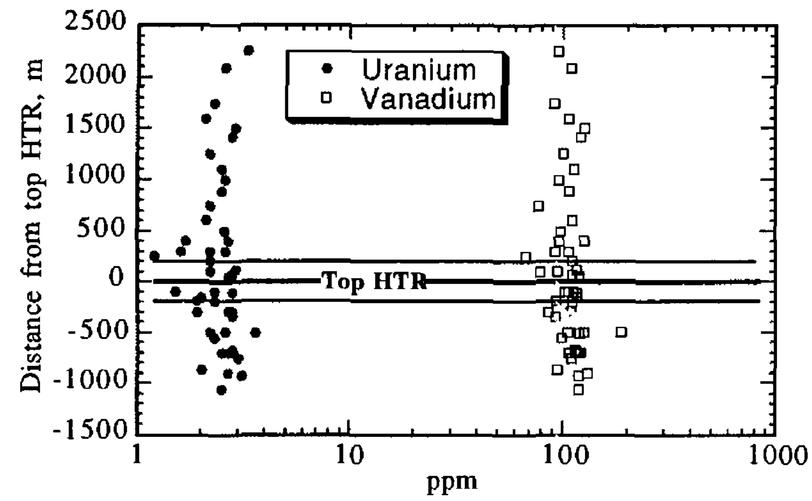

Figure 7. The distribution cf U and V in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in five wells in the northwest region of The Geysers steam field relative to the estimated distance above or below the high-temperature reservoir.

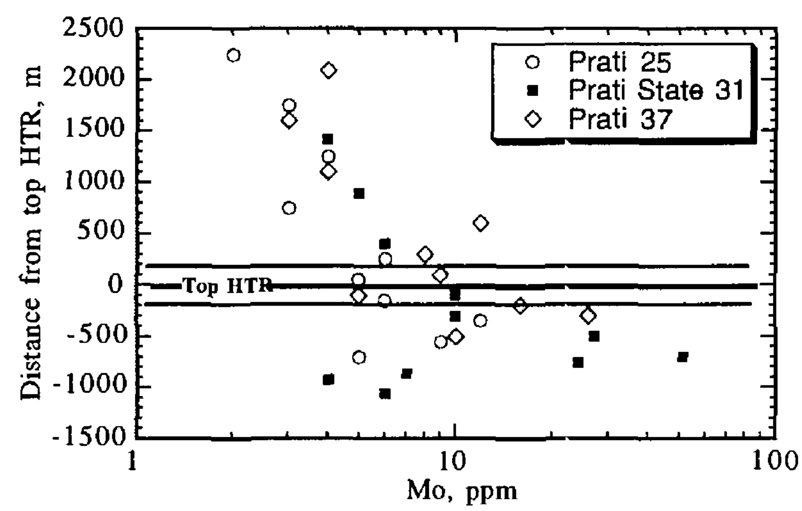

Figure 8. The distribution of Mo in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in the Prati 25 and 37 wells and Prati State 31 well in the northwest region of The Geysers steam field relative to the estimated distance above or below the high-temperature reservoir.

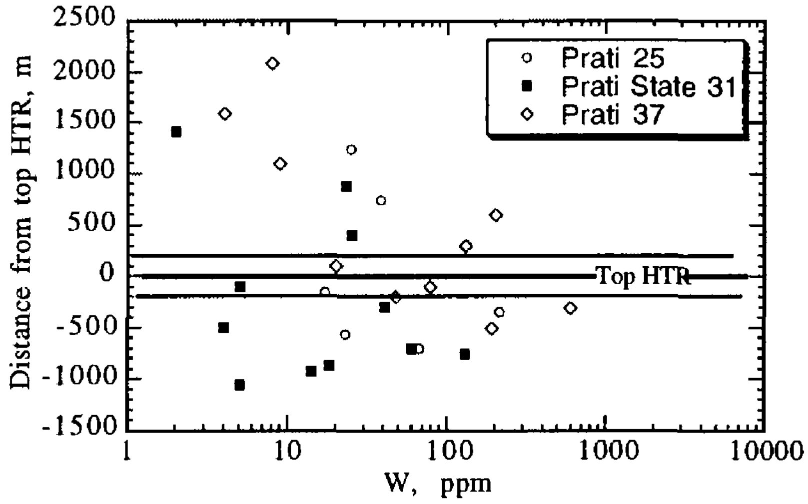

Figure 9. The distribution of W in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in the Prati 25 and 37 wells and Prati State 31 well wells in the northwest region of The Geysers steam field relative to the estimated distance above or below the high-temperature reservoir.

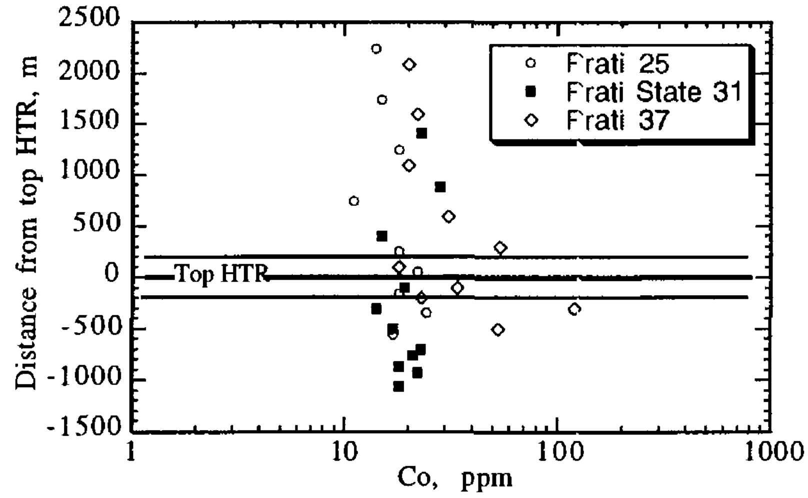

Figure 11. The distribution of Co in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in the Prati 25 and 37 wells and Prati State 31 well in the northwest region of The Geysers steam field relative to the estimated distance above or below the high-temperature reservoir.

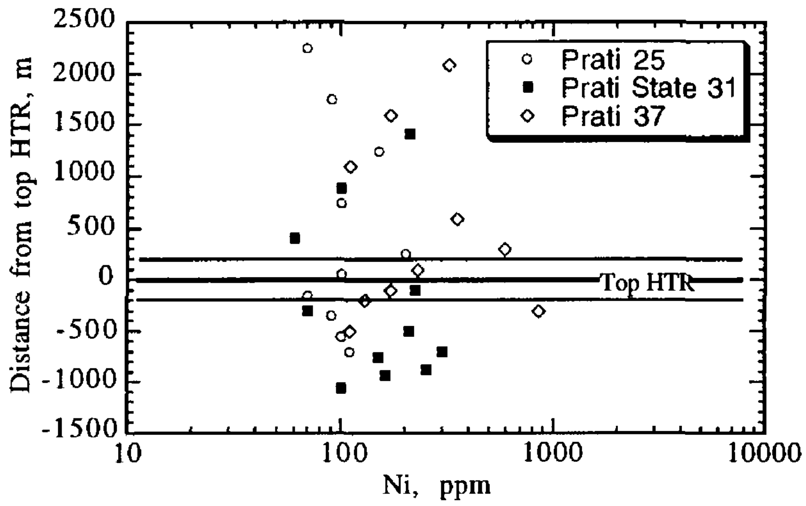

Figure 10. The distribution of Ni in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in the Prati 25 and 37 wells and Prati State 31 well in the northwest region of The Geysers steam field relative to the estimated distance above or below the high-temperature reservoir.

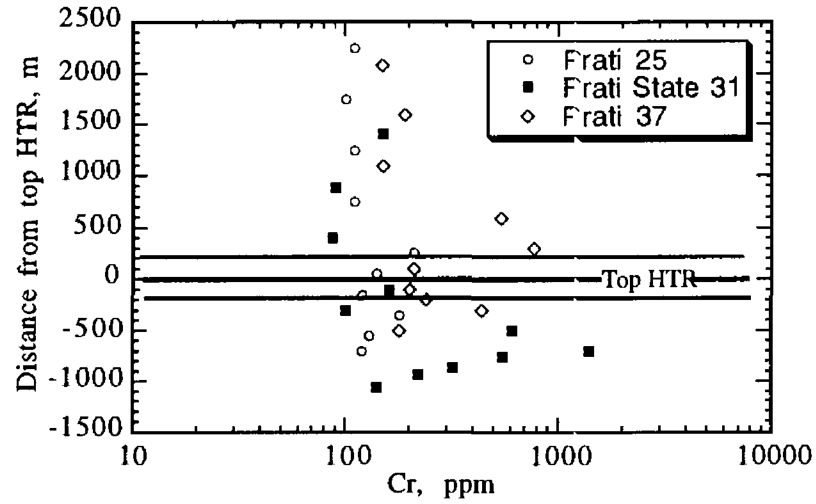

Figure 12. The distribution of Cr in cuttings from the transition region between the ≈240°C and >315°C vapor-dominated reservoirs in the Prati 25 and 37 wells and Prati State 31 well in the northwest region of The Geysers steam field relative to the estimated distance above or below the high-temperature reservoir.

Table 1. Ground elevations (GE) of wells, measured depths to high-temperature reservoir (MD-HTR), elevation of the top of the HTR relative to sea level (HTR-SL), and elevation of the top of the hornfels relative to sea level (HRN-SL). Data from Walters et al. (1992).

Well	(GE) ft (m)	(MD-HTR) ft (m)	(HTR-SL) ft (m)	(HRN-SL) ft (m)
Prati 5	2553 (778)	8470 (2502)	–5768 (–1758)	–5579 (–1701)
Prati 25	2347 (716)	8280 (2524)	–5770 (–1759)	–6197 (–1889)
Prati State 31	2116 (645)	7940 (2420)	–5598 (–1706)	–5893 (–1797)
Prati 32	2116 (645)	8375 (2553)	–6178 (–1883)	–6302 (–1921)
Prati 37	1901 (580)	8130 (2479)	–6110 (–1862)	–6206 (–1892)

Table 2. Chemistry of common metallic and metal-bearing contaminants in cuttings. [From Hulen and Sibbett, 1982.]

Contaminant	Source	Elements Present
Steel (and rust)	Drill pipe, drill collars, bits, subs, reamers, stabilizers, casing, miscellaneous surface components	Fe, Mo, Cr, Ni, V, S
Tungsten carbide	Bits, stabilizers, reamers, hole openers	W
Thread compounds and other greases	Tool joints, etc.	Pb, Zn, Mo, Cu, Li, Al
Monel metal	Non-magnetic drill collars	Cu, Ni
Cast aluminum, lead iron; iron filings	Drillable metal components of downhole cementing assemblies	Al, Pb; Fe (Al and Fe may be alloyed with or contaminated by minor amounts of other metals)
Paint	Painted components of the drilling system	(Examples) Blue: Cu, Co, Sn Red: Cd, Fe White: Pb, Zn, Ti

Table 3. Detection limits of elements analyzed

INAA Portion					
Element		**Element**		**Element**	
Au	2 ppb	Hf	1 ppm	Se	3 ppm
As	0.5 ppm	Hg	1 ppm	Sm	0.1 ppm
Ba	50 ppm	Ir	5 ppb	Sn	100 ppm
Br	0.5 ppm	La	0.5 ppm	Ta	0.5 ppm
Ce	3 ppm	Lu	0.05 ppm	Th	0.2 ppm
Co	1 ppm	Na	0.01 wt%	Tb	0.5 ppm
Cr	5 ppm	Nd	5 ppm	U	0.5 ppm
Cs	1 ppm	Rb	5 ppm	W	1 ppm
Eu	0.2 ppm	Sb	0.1 ppm	Tb	0.2 ppm
Fe	0.01 wt%	Sc	0.1 ppm		

Total Digestion – ICP Portion					
Element		**Element**		**Element**	
Ag	0.4 ppm	K	0.01 wt%	Sr	1 ppm
Al	0.01 wt %	Mg	0.01 wt%	Ti	0.01 wt%
Be	2 ppm	Mn	1 ppm	V	2 ppm
Bi	5 ppm	Mo	1 ppm	Y	2 ppm
Ca	0.01 wt %	Ni	1 ppm	Zn	1 ppm
Cd	0.5 ppm	P	0.001 wt%		
Cu	1 ppm	Pb	5 ppm		

Table 4. Analytical results for Au and selected chalcophile elements

Well	Measured depth (ft)	Measured depth (m)	Distance above or below HTR (ft)	Distance above or below HTR (m)	Au (ppb)	As (ppm)	Sb (ppm)	Se (ppm)	Hg (ppm)	Bi (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Ag (ppm)	Cd (ppm)
PRATI 5	7000	2134	1470	448	3	13	2.1	<3	<1	<5	62	109	26	<0.4	0.8
PRATI 5	7500	2286	970	296	<2	13	2.5	<3	<1	<5	45	67	52	<0.4	<0.5
PRATI 5	8000	2438	470	143	<2	9	2.1	<3	<1	8	129	129	27	<0.4	<0.5
PRATI 5	8200	2499	270	82	<2	13	2.5	4	<1	7	546	465	73	<0.4	<0.5
PRATI 5	8400	2560	70	21	<2	20	1.9	<3	<1	<5	34	67	64	<0.4	<0.5
PRATI 5	8600	2621	–130	–40	<2	36	3.5	<3	<1	<5	40	69	18	<0.4	<0.5
PRATI 5	8800	2682	–330	–101	5	12	1.7	<3	<1	<5	17	24	11	<0.4	<0.5
PRATI 5	9000	2743	–530	–162	<2	20	1.4	<3	<1	<5	200	169	7	<0.4	<0.5
PRATI 5	9200	2804	–730	–223	<2	12	2.9	<3	<1	<5	227	181	25	<0.4	<0.5
PRATI 5	9400	2865	–930	–283	<2	34	1.8	<3	<1	<5	36	22	11	<0.4	<0.5
PRATI 25	6000	1829	2280	695	<2	13	1.7	<3	<1	<5	26	69	14	<0.4	<0.5
PRATI 25	6500	1981	1780	543	14	68	2	<3	<1	<5	580	392	36	<0.4	<0.5
PRATI 25	7000	2134	1280	390	<2	12	1.1	<3	<1	<5	33	77	51	<0.4	<0.5
PRATI 25	7500	2286	780	238	<2	11	1.2	<3	<1	8	36	60	57	<0.4	<0.5
PRATI 25	8000	2438	280	85	<2	19	4.7	<3	<1	<5	49	61	21	<0.4	<0.5
PRATI 25	8200	2499	80	24	<2	16	5.7	<3	<1	<5	64	80	18	<0.4	<0.5
PRATI 25	8400	2560	–120	–37	<2	19	3.4	<3	<1	<5	49	69	12	<0.4	<0.5
PRATI 25	8600	2621	–320	–98	4	34	11	<3	<1	<5	38	144	30	<0.4	0.5
PRATI 25	8800	2682	–520	–158	<2	13	2.2	<3	<1	6	43	62	21	<0.4	<0.5
PRATI 25	8950	2728	–670	–204	2	15	1.6	<3	<1	<5	46	85	25	<0.4	<0.5
PRATI STATE 31	6480	1975	1460	445	4	13	1.2	<3	<1	<5	119	139	24	<0.4	<0.5
PRATI STATE 31	7010	2137	930	283	<2	58	1.5	<3	<1	<5	153	169	27	<0.4	<0.5
PRATI STATE 31	7500	2286	440	134	4	8	1.2	<3	<1	<5	23	51	15	<0.4	<0.5
PRATI STATE 31	8000	2438	–60	–18	2	11	1.8	<3	<1	<5	32	68	15	<0.4	<0.5
PRATI STATE 31	8200	2499	–260	–79	<2	13	3.1	<3	<1	6	32	68	20	<0.4	<0.5
PRATI STATE 31	8400	2560	–460	–140	<2	32	3.1	<3	<1	<5	42	45	25	<0.4	<0.5
PRATI STATE 31	8600	2621	–660	–201	3	26	2.4	<3	<1	<5	67	43	206	<0.4	<0.5
PRATI STATE 31	8650	2637	–710	–216	<2	20	1.9	<3	<1	<5	56	35	130	<0.4	<0.5
PRATI STATE 31	8770	2673	–830	–253	6	11	2.5	<3	<1	<5	22	60	56	<0.4	0.6
PRATI STATE 31	8830	2691	–890	–271	<2	39	2.3	<3	<1	<5	30	38	14	<0.4	<0.5
PRATI STATE 31	8960	2731	–1020	–311	<2	14	1.5	<3	<1	<5	27	71	18	<0.4	<0.5
PRATI 32	8000	2438	375	114	<2	13	3.8	<3	<1	<5	47	78	15	<0.4	<0.5
PRATI 32	8100	2469	275	84	4	30	3	<3	<1	<5	60	96	39	0.5	<0.5
PRATI 32	8200	2499	175	53	<2	16	14	<3	<1	<5	32	78	13	<0.4	0.6
PRATI 32	8290	2527	85	26	<2	20	4.2	<3	<1	<5	81	94	73	–0.4	<0.5
PRATI 32	8330	2539	45	14	<2	19	3.4	<3	<1	<5	59	85	22	–0.4	<0.5
PRATI 32	8510	2594	–135	–41	3	12	1.6	<3	<1	<5	70	102	19	0.4	<0.5
PRATI 32	8590	2618	–215	–66	<2	15	3.3	<3	<1	7	76	97	44	2.1	<0.5
PRATI 32	8690	2649	–315	–96	<2	13	3.9	<3	<1	<5	46	69	25	0.6	<0.5
PRATI 32	8910	2716	–535	–163	<2	17	1.8	<3	<1	6	58	100	23	<0.4	<0.5
PRATI 32	9080	2768	–705	–215	<2	15	1.5	<3	<1	<5	55	85	29	0.4	<0.5
PRATI 37	6010	1832	2120	646	2	15	3.9	<3	<1	<5	66	78	28	0.4	<0.5
PRATI 37	6500	1981	1630	497	4	12	1.3	<3	<1	<5	47	82	17	<0.4	<0.5
PRATI 37	7000	2134	1130	344	3	12	1.3	<3	<1	6	59	96	34	0.4	<0.5
PRATI 37	7500	2286	630	192	<2	110	4.3	<3	<1	<5	44	98	36	0.4	<0.5
PRATI 37	7800	2377	330	101	<2	12	1.3	<3	<1	6	529	480	151	0.5	<0.5
PRATI 37	8000	2438	130	40	4	9	1.1	<3	<1	<5	282	242	20	<0.4	<0.5
PRATI 37	8200	2499	–70	–21	<2	11	2.3	<3	<1	<5	85	93	13	0.4	<0.5
PRATI 37	8300	2530	–170	–52	<2	11	1.8	<3	<1	6	175	170	16	0.4	<0.5
PRATI 37	8400	2560	–270	–82	4	15	2.5	<3	<1	<5	2515	2051	851	0.4	<0.5
PRATI 37	8600	2621	–470	–143	<2	6	1.4	<3	<1	<5	185	91	209	<0.4	<0.5

Table 5. Analytical results for selected rock-forming elements

Well	Measured depth (ft)	Measured depth (m)	Distance above or below HTR (ft)	Distance above or below HTR (m)	Fe (wt%)	Mg (wt%)	Ti (wt%)	Al (wt%)	Na (wt%)	K (wt%)	Ca (wt%)	P (wt%)	Na/K
PRATI 5	7000	2134	1470	448	5.40	1.57	0.37	8.39	0.76	2.21	1.69	0.093	0.34
PRATI 5	7500	2286	970	296	4.06	1.21	0.35	7.80	2.41	1.21	2.41	0.058	1.99
PRATI 5	8000	2438	470	143	4.02	1.19	0.36	7.65	2.07	1.60	2.12	0.056	1.29
PRATI 5	8200	2499	270	82	3.85	1.16	0.38	7.94	2.32	1.38	2.64	0.053	1.68
PRATI 5	8400	2560	70	21	4.20	1.27	0.34	7.86	1.97	1.32	3.41	0.058	1.49
PRATI 5	8600	2621	−130	−40	4.59	3.67	0.37	7.35	1.89	1.11	2.57	0.054	1.70
PRATI 5	8800	2682	−330	−101	3.57	1.36	0.40	7.62	3.84	0.68	2.76	0.051	5.65
PRATI 5	9000	2743	−530	−162	3.89	1.99	0.40	7.68	4.24	0.87	2.73	0.051	4.87
PRATI 5	9200	2804	−730	−223	3.86	1.71	0.42	7.36	3.62	0.45	2.80	0.044	8.04
PRATI 5	9400	2865	−930	−283	3.86	1.85	0.50	8.42	3.22	1.39	2.72	0.059	2.32
PRATI 25	6000	1829	2280	695	3.64	1.26	0.26	6.39	1.98	1.08	4.66	0.058	1.83
PRATI 25	6500	1981	1780	543	3.98	1.32	0.32	7.30	2.08	1.37	1.59	0.069	1.52
PRATI 25	7000	2134	1280	390	4.09	1.33	0.36	7.64	2.37	1.29	1.46	0.066	1.84
PRATI 25	7500	2286	780	238	2.40	0.87	0.33	6.46	2.48	1.03	1.63	0.052	2.41
PRATI 25	8000	2438	280	85	3.32	2.71	0.21	5.60	1.41	1.30	2.88	0.045	1.08
PRATI 25	8200	2499	80	24	5.70	2.07	0.33	8.23	1.88	1.50	2.21	0.075	1.25
PRATI 25	8400	2560	−120	−37	5.62	1.85	0.32	8.91	1.82	1.53	2.98	0.074	1.19
PRATI 25	8600	2621	−320	−98	4.95	1.58	0.27	6.98	1.26	0.85	7.43	0.083	1.48
PRATI 25	8800	2682	−520	−158	4.64	1.80	0.30	7.91	2.05	1.39	2.40	0.07	1.47
PRATI 25	8950	2728	−670	−204	5.41	1.79	0.34	8.57	1.52	1.71	2.49	0.086	0.89
PRATI STATE 31	6480	1975	1460	445	5.28	2.06	0.22	8.34	1.53	1.58	1.39	0.085	0.97
PRATI STATE 31	7010	2137	930	283	4.69	1.48	0.34	8.27	2.24	1.58	1.63	0.092	1.42
PRATI STATE 31	7500	2286	440	134	3.12	1.31	0.36	7.37	2.81	1.07	1.94	0.044	2.63
PRATI STATE 31	8000	2438	−60	−18	4.79	2.40	0.32	7.99	2.16	1.48	1.95	0.075	1.46
PRATI STATE 31	8200	2499	−260	−79	3.79	1.33	0.33	8.68	2.67	1.70	2.84	0.047	1.57
PRATI STATE 31	8400	2560	−460	−140	4.44	1.53	0.36	8.07	1.98	1.51	2.78	0.073	1.31
PRATI STATE 31	8600	2621	−660	−201	4.94	1.39	0.41	7.73	2.26	1.29	2.61	0.058	1.75
PRATI STATE 31	8650	2637	−710	−216	4.98	1.63	0.41	8.23	2.21	1.58	1.95	0.07	1.40
PRATI STATE 31	8770	2673	−830	−253	3.85	2.94	0.37	7.43	1.77	1.27	2.97	0.061	1.39
PRATI STATE 31	8830	2691	−890	−271	4.87	2.59	0.42	8.73	2.01	1.81	2.63	0.079	1.11
PRATI STATE 31	8960	2731	−1020	−311	5.13	2.02	0.41	9.44	2.16	1.87	2.28	0.096	1.16
PRATI 32	8000	2438	375	114	5.27	1.71	0.35	8.54	1.34	2.24	2.33	0.09	0.60
PRATI 32	8100	2469	275	84	5.00	2.77	0.32	7.68	1.60	1.46	2.94	0.071	1.10
PRATI 32	8200	2499	175	53	4.62	1.48	0.38	7.61	1.81	1.12	4.61	0.044	1.62
PRATI 32	8290	2527	85	26	4.94	1.79	0.41	8.13	2.24	1.29	2.71	0.064	1.74
PRATI 32	8330	2539	45	14	4.82	1.71	0.40	7.91	2.35	1.27	2.48	0.059	1.85
PRATI 32	8510	2594	−135	−41	4.83	1.57	0.38	8.06	2.04	1.77	2.05	0.08	1.15
PRATI 32	8590	2618	−215	−66	4.95	1.34	0.31	6.61	3.00	1.01	2.49	0.054	2.97
PRATI 32	8690	2649	−315	−96	4.10	1.54	0.37	8.21	2.10	1.56	2.62	0.078	1.35
PRATI 32	8910	2716	−535	−163	4.84	1.49	0.38	8.02	2.80	1.57	1.75	0.09	1.78
PRATI 32	9080	2768	−705	−215	5.19	1.91	0.38	7.94	2.52	1.53	2.16	0.072	1.65
PRATI 37	6010	1832	2120	646	4.57	2.31	0.35	7.77	2.03	1.83	1.90	0.071	1.11
PRATI 37	6500	1981	1630	497	4.50	2.57	0.34	7.60	1.76	1.56	1.68	0.071	1.13
PRATI 37	7000	2134	1130	344	4.62	1.95	0.34	8.03	1.72	1.60	1.96	0.077	1.08
PRATI 37	7500	2286	630	192	5.22	3.69	0.35	7.47	1.51	1.38	3.40	0.066	1.09
PRATI 37	7800	2377	330	101	4.64	5.77	0.29	5.84	1.49	0.75	3.65	0.051	1.99
PRATI 37	8000	2438	130	40	3.48	1.93	0.32	6.75	1.66	1.56	1.83	0.051	1.06
PRATI 37	8200	2499	−70	−21	5.16	3.21	0.36	7.83	1.68	1.62	2.18	0.074	1.04
PRATI 37	8300	2530	−170	−52	4.56	1.41	0.40	7.98	1.82	1.93	1.96	0.072	0.94
PRATI 37	8400	2560	−270	−82	4.69	1.68	0.41	7.81	1.85	1.82	2.18	0.07	1.02
PRATI 37	8600	2621	−470	−143	6.74	3.73	0.46	7.57	3.51	0.40	4.56	0.064	8.78

Table 6. Analytical results for rare earth (REE) elements

Well	Measured depth (ft)	Measured depth (m)	Distance above or below HTR (ft)	Distance above or below HTR (m)	La (ppm)	Ce (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Tb (ppm)	Yb (ppm)	Lu (ppm)
PRATI 5	7000	2134	1470	448	27.3	60	26	5.0	1.3	0.9	2.8	0.44
PRATI 5	7500	2286	970	296	29.8	60	26	4.6	1.3	<0.5	2.2	0.36
PRATI 5	8000	2438	470	143	29.5	61	28	4.4	1.3	0.7	2.3	0.37
PRATI 5	8200	2499	270	82	29.7	60	30	4.7	1.3	0.9	2.3	0.42
PRATI 5	8400	2560	70	21	25.0	50	26	4.2	1.1	0.9	2.1	0.34
PRATI 5	8600	2621	–130	–40	16.8	38	18	3.6	0.9	0.8	2.0	0.34
PRATI 5	8800	2682	–330	–101	16.6	35	17	3.5	0.9	0.8	1.9	0.31
PRATI 5	9000	2743	–530	–62	15.9	35	18	3.7	1.0	0.6	2.0	0.34
PRATI 5	9200	2804	–730	–223	20.8	43	20	4.0	1.0	0.6	2.1	0.38
PRATI 5	9400	2865	–930	–283	19.4	43	20	4.2	1.1	<0.5	2.4	0.36
PRATI 25	6000	1829	2280	695	22.7	44	18	3.4	0.9	<0.5	1.7	0.3
PRATI 25	6500	1981	1780	543	21.3	39	15	3.6	1.1	0.7	1.8	0.29
PRATI 25	7000	2134	1280	390	35.2	66	32	4.9	1.3	<0.5	2.1	0.33
PRATI 25	7500	2286	780	238	31.5	59	27	4.4	1.3	0.6	1.8	0.34
PRATI 25	8000	2438	280	85	11.2	26	10	2.3	0.6	<0.5	1.3	0.21
PRATI 25	8200	2499	80	24	24.4	57	28	5.4	1.5	0.8	2.8	0.45
PRATI 25	8400	2560	–120	–37	22.3	49	26	4.8	1.4	<0.5	2.3	0.38
PRATI 25	8600	2621	–320	–98	26.8	52	21	3.9	1.2	0.8	2.2	0.39
PRATI 25	8800	2682	–520	–158	21.5	48	18	4.3	1.3	0.7	2.1	0.36
PRATI 25	8950	2728	–670	–204	23.9	53	24	4.7	1.4	0.9	2.5	0.42
PRATI STATE 31	6480	1975	1460	445	21.7	49	25	4.4	1.2	0.9	2.3	0.42
PRATI STATE 31	7010	2137	930	283	28.4	62	29	4.9	1.3	0.9	2.2	0.35
PRATI STATE 31	7500	2286	440	134	19.8	37	20	3.9	1.1	0.6	1.8	0.28
PRATI STATE 31	8000	2438	–60	–18	25.1	49	21	4.1	1.0	0.8	2.0	0.35
PRATI STATE 31	8200	2499	–260	–79	34.5	64	27	5.0	1.3	<0.5	2.0	0.35
PRATI STATE 31	8400	2560	–460	–140	23.8	50	19	4.4	1.2	0.7	2.2	0.39
PRATI STATE 31	8600	2621	–660	–201	28.9	57	25	4.9	1.3	0.9	2.5	0.41
PRATI STATE 31	8650	2637	–710	–216	27.2	56	23	5.0	1.3	<0.5	2.6	0.42
PRATI STATE 31	8770	2673	–830	–253	21.7	42	18	3.9	1.0	0.6	2.0	0.32
PRATI STATE 31	8830	2691	–890	–271	23.2	53	23	4.6	1.2	<0.5	2.6	0.4
PRATI STATE 31	8960	2731	–1020	–311	24.8	53	24	4.9	1.4	<0.5	2.4	0.44
PRATI 32	8000	2438	375	114	26.5	56	31	5.1	1.5	0.9	2.5	0.4
PRATI 32	8100	2469	275	84	22.1	50	24	4.3	1.2	0.8	2.2	0.38
PRATI 32	8200	2499	175	53	21.2	43	20	4.1	1.2	0.6	2.1	0.36
PRATI 32	8290	2527	85	26	21.7	44	25	4.5	1.3	<0.5	2.3	0.39
PRATI 32	8330	2539	45	14	20.5	44	21	4.1	1.2	0.8	2.3	0.38
PRATI 32	8510	2594	–135	–41	26.9	57	24	4.8	1.3	0.9	2.4	0.4
PRATI 32	8590	2618	–215	–66	18.5	37	18	3.3	0.9	<0.5	1.7	0.28
PRATI 32	8690	2649	–315	–96	23.4	47	19	4.2	1.0	0.6	2.1	0.34
PRATI 32	8910	2716	–535	–163	23.2	50	21	4.4	1.0	0.9	2.3	0.4
PRATI 32	9080	2768	–705	–15	22.4	47	18	4.2	1.1	0.6	2.3	0.34
PRATI 37	6010	1832	2120	646	17.8	39	17	3.8	1.1	<0.5	2.4	0.36
PRATI 37	6500	1981	1630	497	21.5	46	21	4.0	1.1	0.8	2.2	0.34
PRATI 37	7000	2134	1130	344	23.7	52	21	4.5	1.2	0.9	2.3	0.42
PRATI 37	7500	2286	630	192	19.8	44	18	4.0	1.2	0.7	2.4	0.38
PRATI 37	7800	2377	330	101	16.1	39	16	3.3	1.0	0.8	2.0	0.33
PRATI 37	8000	2438	130	40	23.3	52	24	3.7	1.1	<0.5	1.9	0.3
PRATI 37	8200	2499	–70	–21	18.4	43	18	3.8	1.1	0.6	2.2	0.38
PRATI 37	8300	2530	–170	–52	26.3	57	26	4.6	1.4	<0.5	2.4	0.35
PRATI 37	8400	2560	–270	–82	24.4	51	21	4.2	1.3	1.0	2.7	0.39
PRATI 37	8600	2621	–470	–143	12.6	32	19	4.1	1.5	0.9	2.5	0.37

Table 7. Analytical results for other selected elements present in trace amounts

	Measured depth (ft)	Measured depth (m)	Distance above or below HTR (ft)	Distance above or below HTR (m)	Rb	Cs	Be	Sr	Sc	Y	Th	V	Ta	Cr	Mo	W	U	Mn	Co	Ir	Ni	Sn	Br
					(in parts per million)																		
PRATI 5	7000	2134	1470	448	94	10	<2	292	19	17	8.5	127	1.3	130	7	12	2.9	636	20	<5	82	<100	1.9
PRATI 5	7500	2286	970	296	57	3	<2	273	15	17	7.7	96	<0.5	230	15	18	2.6	766	17	<5	76	<100	<0.5
PRATI 5	8000	2438	470	143	81	5	<2	310	15	17	8.1	99	2.8	180	11	62	2.6	680	21	<5	90	<100	1.8
PRATI 5	8200	2499	270	82	56	3	<2	299	14	18	7.4	92	2.6	200	16	66	2.6	1113	26	<5	204	<100	<0.5
PRATI 5	8400	2560	70	21	65	5	<2	338	14	17	7.5	95	<0.5	120	8	11	2.2	2754	16	<5	66	<100	1.4
PRATI 5	8600	2621	–130	–40	83	9	<2	337	18	16	5.7	106	<0.5	350	10	13	2.3	692	23	<5	241	<100	<0.5
PRATI 5	8800	2682	–330	–101	45	4	<2	261	16	17	4.9	108	<0.5	110	4	3	1.9	562	13	<5	49	<100	1.7
PRATI 5	9000	2743	–530	–162	64	7	<2	223	22	17	5.8	125	<0.5	120	7	5	2.6	325	16	<5	131	<100	<0.5
PRATI 5	9200	2804	–730	–223	<15	5	<2	272	20	17	6.9	117	<0.5	240	11	21	2.8	560	19	<5	128	<100	<0.5
PRATI 5	9400	2865	–930	–283	85	10	<2	265	20	14	8.6	131	1	210	11	36	2.7	351	15	<5	138	<100	<0.5
PRATI 25	6000	1829	2280	695	55	4	<2	217	11	13	6.3	95	1.1	110	2	–1	3.3	511	14	<5	57	<100	<0.5
PRATI 25	6500	1981	1780	543	60	4	<2	188	13	14	6.3	91	<0.5	100	3	–1	2.3	593	15	<5	63	<100	1
PRATI 25	7000	2134	1280	390	59	3	<2	243	14	17	8	100	1.6	110	4	25	2.2	670	18	<5	107	<100	<0.5
PRATI 25	7500	2286	780	238	46	2	<2	261	11	17	6.3	77	0.6	110	3	38	2.2	531	11	<5	50	<100	<0.5
PRATI 25	8000	2438	280	85	51	3	<2	358	12	10	3.4	67	<0.5	210	6	–1	1.2	671	18	<5	174	<100	<0.5
PRATI 25	8200	2499	80	24	55	5	<2	268	21	20	7.6	119	<0.5	140	5	–1	2.7	1170	22	<5	84	<100	<0.5
PRATI 25	8400	2560	–120	–37	54	5	<2	311	19	16	6.7	117	<0.5	120	6	17	2	1034	18	<5	72	<100	1.7
PRATI 25	8600	2621	–320	–98	48	2	<2	320	13	18	6.5	92	2.2	180	12	210	2.8	2967	24	<5	93	<100	<0.5
PRATI 25	8800	2682	–520	–158	69	4	<2	286	15	14	6.5	99	<0.5	130	9	23	2.3	881	17	<5	80	<100	2.1
PRATI 25	8950	2728	–670	–204	76	5	<2	453	19	14	7.6	121	<0.5	120	5	67	2.7	970	23	<5	87	<100	2.6
PRATI STATE 31	6480	1975	1460	445	79	5	<2	224	18	13	7.6	122	<0.5	150	4	2	2.8	811	23	<5	101	<100	2.6
PRATI STATE 31	7010	2137	930	283	67	5	<2	269	15	16	6.4	106	<0.5	90	5	23	2.5	1180	28	<5	82	<100	<0.5
PRATI STATE 31	7500	2286	440	134	55	2	<2	172	14	13	4.7	97	<0.5	87	6	25	1.7	530	15	<5	38	<100	<0.5
PRATI STATE 31	8000	2438	–60	–18	100	6	<2	261	16	13	6.1	102	1	160	10	5	1.5	690	19	<5	106	<100	<0.5
PRATI STATE 31	8200	2499	–260	–79	92	5	<2	280	15	18	8.9	85	0.9	100	10	40	2.7	869	14	<5	55	<100	<0.5
PRATI STATE 31	8400	2560	–460	–140	95	6	<2	340	14	18	7.2	105	0.9	610	27	4	2.2	1859	17	<5	183	<100	<0.5
PRATI STATE 31	8600	2621	–660	–201	92	6	<2	302	16	18	7.9	106	1.5	1400	51	60	2.5	2951	23	<5	252	<100	<0.5
PRATI STATE 31	8650	2637	–710	–216	89	8	<2	262	18	17	8	109	1.3	550	24	130	3	1199	21	<5	133	<100	<0.5
PRATI STATE 31	8770	2673	–830	–253	62	4	<2	259	15	16	6.2	95	0.9	320	7	18	2	1125	18	<5	171	<100	<0.5
PRATI STATE 31	8830	2691	–890	–271	120	10	<2	286	19	14	7.8	119	<0.5	220	4	14	3.1	751	22	<5	136	<100	<0.5
PRATI STATE 31	8960	2731	–1020	–311	82	7	<2	275	19	11	8	119	<0.5	140	6	5	2.5	869	18	<5	63	<100	<0.5
PRATI 32	8000	2438	375	114	75	4	<2	308	19	18	7.9	125	<0.5	120	4	5	2.7	869	20	<5	69	<100	<0.5
PRATI 32	8100	2469	275	84	86	5	<2	312	17	16	6.9	107	<0.5	440	9	7	2.2	921	27	<5	183	<100	1.9
PRATI 32	8200	2499	175	53	42	<1	<2	400	17	17	5.2	111	0.6	150	6	4	2.2	1626	15	<5	86	<100	1.7
PRATI 32	8290	2527	85	26	49	4	<2	286	18	16	6.6	116	0.6	160	10	29	2.9	829	22	<5	154	<100	1.9
PRATI 32	8330	2539	45	14	73	4	<2	290	17	16	6.1	111	1.4	130	11	41	2.8	793	22	<5	109	<100	2
PRATI 32	8510	2594	–135	–41	65	5	<2	250	16	16	7.5	116	0.8	240	13	43	2.8	928	24	<5	97	<100	<0.5
PRATI 32	8590	2618	–215	–66	50	3	<2	239	12	12	5.3	93	1.3	220	24	200	1.9	847	49	<5	88	<100	<0.5
PRATI 32	8690	2649	–315	–96	71	4	<2	355	15	14	7.1	110	0.8	160	5	39	2.7	996	22	<5	62	<100	1.8
PRATI 32	8910	2716	–535	–163	72	5	<2	297	16	11	8.1	119	<0.5	110	10	62	3.6	697	25	<5	65	<100	3.5
PRATI 32	9080	2768	–705	–215	73	4	<2	266	17	12	6.8	114	<0.5	260	14	97	2.8	906	31	<5	101	<100	3.3
PRATI 37	6010	1832	2120	646	90	8	<2	202	17	13	6.3	108	<0.5	150	4	8	2.6	610	20	<5	105	<100	<0.5
PRATI 37	6500	1981	1630	497	59	7	<2	242	16	13	6.2	106	<0.5	190	3	4	2.1	682	22	<5	141	<100	2.1
PRATI 37	7000	2134	1130	344	92	5	<2	264	17	14	7.6	113	<0.5	150	4	9	2.5	776	20	<5	95	<100	1.6
PRATI 37	7500	2286	630	192	66	4	<2	470	19	17	5.6	111	<0.5	540	12	200	2.1	1668	31	<5	290	<100	<0.5
PRATI 37	7800	2377	330	101	31	2	<2	300	18	13	5.1	92	3	770	8	130	1.6	934	54	<5	569	<100	0.7
PRATI 37	8000	2438	130	40	62	4	<2	171	12	13	6.3	78	1.3	210	9	20	2.2	608	18	<5	181	<100	<0.5
PRATI 37	8200	2499	–70	–21	56	4	<2	307	18	13	5.8	112	1	200	<5	78	2.3	918	34	<5	156	<100	<0.5
PRATI 37	8300	2530	–170	–52	73	6	<2	239	15	13	8.1	111	<0.5	240	16	47	2.3	774	23	<5	123	<100	<0.5
PRATI 37	8400	2560	–270	–82	81	6	<2	310	16	12	7.5	110	12	440	26	590	2.8	854	120	<5	729	<100	<0.5
PRATI 37	8600	2621	–470	–143	20	2	<2	482	26	22	2.1	185	5	180	10	190	<0.5	1114	53	<5	94	<100	<0.5