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10. DISTRIBUTION OF Au AND Pd IN BASALTS AND DIABASES IN HOLE 504B, LEGS 69 AND 140[1]

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ABSTRACT

Au contents have been determined in 77 samples of basalts and sheeted diabase dikes. Pd has been evaluated in 39 of the samples. The mean amount of Au is 3 parts per billion (ppb), fluctuating from 0.4 to 10 ppb. Au contents appear to be independent in type and intensity of alteration as well as with depth sub-bottom, although in the lower part of Hole 504B, 1900–2000 mbsf, Au contents are markedly decreased (mean: 1.1 ppb) and show a distinct correlation with a decrease in Zn contents. Pd contents vary from 2 to 360 ppb (mean: 37 ppb) Pd is higher in basalts (53.7 ppb) and lower in diabase dikes (30 ppb), especially in moderately or strongly altered ones (12.5 ppb).

INTRODUCTION

We have undertaken studies to find out contents and distributions of gold and palladium in diabase dikes and basalts from Hole 504B. Toward this end we have used the main part of Pertsev's collection of samples from Deep Sea Drilling Project Leg 69 and Ocean Drilling Program (ODP) Leg 140 as well as the whole collection (12 samples) received by Korobeynikov from Leg 140.

To date we have made 77 determinations of Au content and 39 of Pd.

One of the purposes of the investigation is to compare the noble metal contents in the upper part of the ocean basement — that is, basalt pillow lavas and flows — with those in sheeted diabase dikes. In addition, we addressed other problems, such as dependence of the element distribution upon the depth, type, or intensity of alteration and on some geochemical features of rock units. We have compared the Au and Pd contents measured in our samples to shipboard geochemical data characterizing the petrologic units from which we obtained our samples (Cann, Langseth, Honnorez, Von Herzen, White, et al., 1983; Dick, Erzinger, Stokking, et al., 1992).

ANALYTICAL METHODS

Au and Pd contents have been determined by the polarographic and the inversion-voltampermetric methods (Kolpakova et al., 1970, 1991) in the Tomsk Polytechnic University, analyst G.A. Novikova.

Au content was estimated from charges of 1 g by the method of film polarography with build-up on the graphite electrode. The sensitivity of the method is 0.01 ppb; reproducibility is 90% with control by internal and external standards. Differences of results in parallel runs are usually within the 12%–40% level and are mostly due to the distribution dispersion of gold in a sample. Extraction of Au was conducted twice by the ethyl- or diethyl-ether from water solutions of HBr.

The Pd contents have been determined by the method of inversion volt-ampermetry with the carbon-past electrode. The method permits us to evaluate Pt-group element contents in charges 1–50 g in compositional intervals from 1 ppb to several percent (by weight). The reproducibility of the method reaches 80%–90% (Kolpakova et al., 1986).

RESULTS AND DISCUSSION

The Au and Pd contents are presented in Table 1 and Figure 1, along with sample depths, alteration peculiarities, and geochemical features of corresponding petrological units. Both basalts and diabase dikes have moderately low mean contents of gold (3.3 and 2.7 ppb, respectively). The distribution of the gold in the samples, however, is not uniform. In basalts, relatively low values (1–0.5 ppb) were found in samples from 442, 474, 482, 483, and 485 mbsf. Higher concentrations, 4.5–6 ppb, were noted at 283, 287, 430, 463, 477, and 484 mbsf. We have detected no differences in Au content between pillow edges and their interior. The samples of basalts showing noticeable oxidative alteration ($n = 13$) give almost the same mean for gold (3.2 ppb) as the samples ($n = 17$) with only reductive or neutral oxidation (3.3 ppb).

The intensity of basalt alteration does not have a detectable influence on the Au distribution. Eleven mostly unaltered basalt samples have 3.2 ppb, whereas 19 specimens that are moderately or strongly replaced by secondary minerals give 3.3 ppb.

In sheeted dikes recovered during Legs 137 and 140, three intervals are characterized by different mean amounts of gold, as shown in Table 2. Here, too, alteration has no significant influence on gold contents in spite of the change in types of secondary mineral assemblages from clay minerals in the upper (basalt) part to greenschist minerals in the lower (dike) part. The weakly altered rocks ($n = 23$) have 2.5 ppb, and moderately or strongly replaced ones ($n = 24$) contain 2.9 ppb. The highest Au concentration (10 ppb) appears to be associated with a higher than usual pyrite content in the sample (Sample 140-504B-202R-1, Piece 1).

The considerably lower Au contents in the lower part of the hole (mean 1.1 ppb) seem to correlate with the noticeable decrease in Zn contents found by the shipboard investigation (Dick, Erzinger, Stokking, et al., 1992), possibly due to increased leaching of metals in that part of the hydrothermal cell.

On the whole, the distribution of gold recovered in Hole 504B from ocean basement generally follows a log-normal low: A/S_A (ratio of skewness to variance of skewness) = 3.38 and E/S_E (ratio of excess to variance of excess) = 4.94. The mean Au content (3 ppb) compares well with basalts and diabases of other regions (Korobeynikov, 1988).

The mean amount of Pd in our samples is 37 ppb ($n = 39$). Pd distribution in the basement recovered in Hole 504B, however, is not uniform. Pd amounts in basalts range from 4 to 120 ppb (Table 1) with a mean of 53.7 ppb ($n = 10$). In diabase dikes, Pd content ranges from 2 to 360 ppb ($n = 28$) with a mean of 30 ppb. The reason for the especially high Pd concentration (360 ppb) in a sample of rather fresh diabase (Sample 137-504B-173R-2, 14–16 cm, Piece 2) is not yet clear. All samples of diabase ($n = 28$) display a mean of 30 ppb. If we exclude the specimen with especially high Pd ($n = 27$), we get only 17.7 ppb. Weakly altered or fresh diabases show 56.8 ppb ($n = 11$) or

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Table 1. Au and Pd contents and some geochemical characteristics of samples from Hole 504B.

Core, section, interval (cm)	Piece	Unit	Depth (mbsf)	Alteration		Au (ppb)	Pd (ppb)	Mg^*	CaO/Na_2O (wt)	Zr/Y (wt)	TiO_2/Cr (wt)	Zn (ppm)
				Intensity	Type							
Leg 69, Hole 504B												
4-2, 2–17	291	2A	282	S	R	4.2		0.63	7.06	1.78	18.1	65
4-2, 18–20	292	2A	284	W	Ox	5.4		0.65	6.12	2.26	20.6	53
4-3, 94–96	320	2A	285	W	R	3.3					20.6	62
4-4, 82–85	336	2A	287	M	R	4.6		0.62	6.98	2.18	20.6	6.8
4-5, 75–77	352	2A	289	M	Ox	4.2	60	0.62	7.74	2.04	20.6	66
6-2, 95–97	422	2B	306.7	M	Ox	4.0		0.66	6.29	2.26	24.4	81.7
6-2, 120–122	424	2B	307.1	M	Ox	3.0	4	0.65	6.15	2.17	22.1	81
7-2, 103–105	464	2C	312	M	Ox	3.6	50	0.63	5.75	2.04	23.0	67
8-1, 87–90	524	2D	317	M	Ox	3.1	20	0.67	5.90	2.09	22.8	69
15-1, 72–75	898	3C	379	M	R	2.7	6	0.64	6.73	1.89	32.6	60
15-4, 65–67	934	3C	381	W	R	3.6		0.65	6.74	1.89		
16-2, 27–29	976	3C	385	M	Ox	2.0		0.63	6.73	2.00	27.2	85
16-4, 52–54	1008	4	390	M	Ox	3.6	120	0.67	5.72	2.40	27.2	115
17-2, 72–75	1062	4	395	W	R	3.3	100	0.67	6.02	2.37	19.1	73
19-2, 108–112	1149	6	410	S	Ox	2.5		0.61	6.29	1.97	19.4	64
21-2, 47–54	1203	9	422	W	R	3.9		0.66	7.41	1.64	18.0	70
21-2, 115–117	1214	10	423	W	R	3.4	91	0.65	6.70	1.68	22.6	
21-3, 146–148	1236	11	425	M	Ox	3.3		0.68	6.24	1.91	19.5	62
21-4, 98–102	1251	14	429	W	R	3.0		0.66	7.29	1.64	18.0	61
21-5, 8–11	1259	14	430	W	R	6.0		0.66	7.29	1.64	18.0	61
23-1, 115–117	1326	16	447	M	Ox	3.0		0.65	6.82	1.72	26.8	71
24-1, 88–90	1343	16	449	M	Ox	3.0		0.65	6.82	1.72	21.0	56
25-2, 108–111	1436	17	462	W	Ox	0.9		0.64	6.20	2.07	29.2	83
26-1, 3–6	1447	17	463	M	R	4.8		0.66	5.65	1.72	30.5	69
27-2, 60–63	1485	17	474	W	R	0.9		0.63	4.91	2.36	29.2	83
28-1, 30–36	1490	18	477	S	R	4.9		0.65	6.81	1.42	34.2	71
28-2, 50–58	1508	19	481	S	R	5.2		0.61	5.65	2.45	24.6	68
28-3, 87–89	1533	19	482	W	R	1.0	4	0.65	5.71	1.89	31.0	151
28-4, 12–15	1541	19	483	M	R	0.7	120	0.65	5.71	1.89	31.0	76
29-1, 21–23	1561	20	485	S	R	0.5	16	0.63	6.75	2.05	31.2	76
Leg 137, Hole 504B												
173R-2, 14–16	2	194	1576	W	R	1.5	360	0.62	9.91	1.82	36.8	
176R-1, 74–76	14	X	1596	W	R	2.3	36					
Leg 140, Hole 504B												
186R-1, 103–105	14B	213	1630	S	R	3.2	3	0.67	8.08	2.29	26.3	43.2
189R-1, 132–135	26	218	1652	W	R	3.6	12	0.61	7.26	1.83	41.0	63.7
191R-1, 91–93	13	218	1670	W	R	2.7		0.66	7.24	1.76	18.9	54.4
192R-1, 34–36	10	218	1674	M	R	1.0		0.62	6.66	1.83	35.5	70.7
194R-1, 50–52	9	220	1685	W	R	2.0		0.65	7.25	1.76	23.8	57.6
197R-1, 108–111	26	222	1704	M	R	6.0	20	0.67	7.38	1.80	21.7	56.2
197R-2, 14–16	2	223	1712	W	R	1.2		0.67	7.13	1.74	21.3	56.5
200R-1, 116–118	20	227	1730	W	R	4.2	36	0.69	7.25	2.04	16.8	52.6
200R-1, 128–130	21	227	1731	W	R	3.2	66	0.69	7.25	2.04	16.8	52.6
200R-2, 79–81	10	227	1732	W	R	3.0		0.70	7.35	2.03	16.8	49.6
200R-2, 95–97	12	227	1733	W	R	4.8	36	0.70	7.35	2.03	16.8	49.6
200R-3, 90–92	14	227	1734	W	R	2.2	20	0.69	7.39	2.06	18.6	64.3
200R-4, 50–53	13	227	1735	M	R	4.3	7	0.63	6.32	2.07	22.7	62.0
202R-1, 1–4	1	229	1747	S	R	10.0	10	0.66	7.25	1.76	22.2	53.3
202R-1, 16–18	4	229	1748	W	R	1.5		0.66	7.25	1.76	22.2	53.3
203R-1, 57–59	15	232	1756	M	R	2.5	6	0.67	7.53	2.37	25.5	37.0
204R-1, 20–23	5	232	1757	S	R	2.7	5	0.67	7.58	2.34	24.5	46.8
204R-1, 44–46	11	232	1757.5	M	R	2.0	10	0.67	7.58	2.34	24.5	46.8
205R-1, 35–37	6	232	1759	M	R	2.7		0.68	8.00	2.35	26.0	56.5
205R-1, 40–43	7	232	1759.2	W	Ox	4.7	4	0.68	8.00	2.35	26.0	56.5
206R-1, 32–34	8	235	1764	W	R	1.6		0.68	7.52	1.98	17.0	51.5
208R-1, 57–59	14	239	1780	W	R	1.0		0.66	7.57	1.92	19.1	57.6
209R-1, 30–31	5	240	1788	M	R	2.7	2	0.64	6.34	1.76	9.3	60.7
209R-1, 42–44	6	240	1788.2	S	R	1.0	5	0.64	6.34	1.76	9.3	61.0
209R-2, 127–130	20	240	1790	S	R	3.9	12	0.69	7.42	1.91	15.8	43.8
211R-1, 54–56	12	241	1800	S	R	3.4		0.66	7.08	1.75	21.6	46.9
212R-1, 55–57	16	241	1807	W	R	2.7		0.66	7.15	1.75	21.4	48.8
213R-1, 10–13	3	242	1813	M	R	4.5	7	0.60	6.68	1.96	67.6	36.8
213R-1, 100–102	24	243	1818	W	R	4.0		0.62	6.30	1.96	39.2	68.9
214R-1, 18–21	4	244	1819	S	R	3.2	60	0.68	7.00	1.75	11.2	39.3
214R-2, 23–25	6	244	1821	S	R	2.7	17	0.71	7.08	1.72	18.0	34.6
215R-1, 53–55	14	244	1825	W	R	1.7	12	0.66	7.27	1.76	21.4	43.9
219R-1, 13–15	4	250	1865	M	R	2.5	11					
220R-1, 10–13	3	252	1866	W	R	4.2	13	0.66	7.11	1.78	20.9	55.9
221R-1, 26–28	8	254	1879	M	R	4.0	28	0.67	8.26	2.49	40.7	35.9
222R-1, 19–21	1D	254	1885	M	R	2.9		0.63	6.29			
226R-1, 45–48	10	260	1922	M	R	0.9	3	0.67	7.22	1.79	22.0	39.3
226R-2, 17–20	2	260	1924	M	R	2.0		0.66	7.01	1.83	24.5	39.7
227R-1, 59–61	8A	260	1930	W	R	0.5		0.67	7.17	1.80	20.9	36.9
228R-1, 60–62	14	262	1942	W	R	0.9		0.68	6.85	1.77	21.3	49.2
229R-1, 14–16	5	264	1950	W	R	0.3						
230R-2, 1–3	1A	265	1953	M	R	0.4		0.67	7.59	1.97		22.9
232R-1, 12–14	3	265	1958	M	R	1.3	7					23.0
235R-1, 8–10	3	267	1980	W	R	1.0						
237R-1, 3–5	2	269	1990	W	R	0.6	30	0.65	6.89	1.90		35.9

Notes: Mg^* = Molar ratio MgO/(MgO + FeO); FeO is considered as $0.9*Fe_{total}$. Alteration intensity: M = moderate, S = strong, W = weak. Alteration type: Ox = oxidized, R = reduced or neutral.

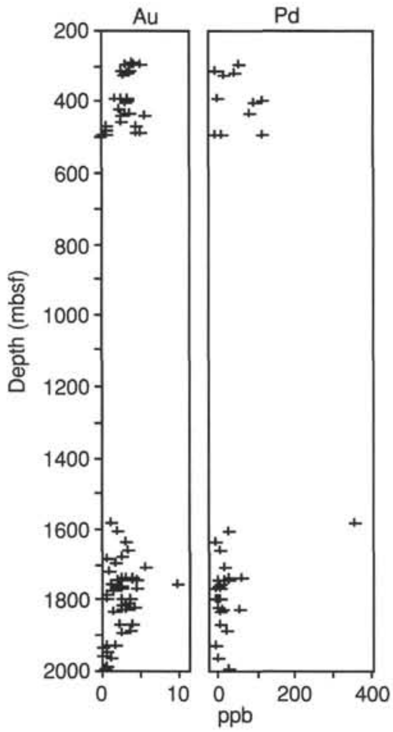

Figure 1. Au and Pd distribution in studied intervals of Hole 504B.

26.5 ppb (n = 10), respectively. Strongly and moderately altered diabases demonstrate markedly lower Pd content of 12.5 ppb (n = 17).

The correlation analysis among Au content, depth (D), Mg^*, CaO/Na_2O, Zr/Y, TiO_2/Cr, and Zn in the rocks of the basement studied (Table 3) demonstrates the absence of stable correlations between Au contents and the other parameters. A very weak positive correlation seems to exist between Au and TiO_2/Cr: $r_{Au-TiO_2/Cr} = +0.03$. D, Zn, and Mg^* show unstable negative relations with Au contents: $r_{Au-D} = -0.114$; $r_{Au-Zn} = -0.102$; $r_{Au-Mg^*} = -0.016$. There is a negative correlation between Mg^* and TiO_2/Cr ($r = -0.478$).

Factor analysis of Au content and the other characteristics shows positive values for Au (0.935) and Zr/Y (0.254).

SUMMARY

Au contents in the rocks studied range from 0.4 to 10 ppb and demonstrate a rather stable mean of about 3 ppb in much the same way as analogous rocks of other regions.

The data on Au distribution allow us to suggest that Au contents in basalts and diabase dikes of Hole 504B do not depend on depth or on type and intensity of alteration, as the Mg^* and TiO_2/Cr values of the rocks have only weak tendencies toward negative and positive correlations with gold.

Relatively higher values of Au content (5–10 ppb) appear to be induced by higher secondary pyrite concentrations.

Table 2. Mean amounts of Au in sheeted dikes from Legs 137/140.

Depth (mbsf)	n	Mean (ppb)	Standard deviation
1576–1712	9	2.6	1.46
1730–1879	29	3.2	1.69
1885–1990	10	1.1	0.77

The low Au contents in the lower part of Hole 504B drilled during Leg 140 (1900–2000 mbsf) seem to be paragenetically connected with low Zn contents there, possibly due to more intense leaching in that part of the convective hydrothermal system.

Pd contents generally are much higher (mean 36 ppb). Their values range between 2 and 360 ppb. Higher concentration of Pd in basalts and much lower concentrations in altered diabases seem to have developed because of greenschist alteration of the diabases.

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* Abbreviations for names of organizations and publications in ODP reference lists follow the style given in *Chemical Abstracts Service Source Index* (published by American Chemical Society).

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Table 3. Statistical analysis of the variables from Table 1.

Depth (mbsf)	Mean of each variable					
	Mg^*	CaO/Na_2O	Zr/Y	Au	TiO_2/Cr	Zn
282	0.63	7.06	1.78	4.2	18.1	65
283	0.65	6.12	2.26	5.4	20.6	53
287	0.62	6.98	2.18	4.6	20.6	6.8
289	0.62	7.74	2.04	4.2	20.6	66
306.7	0.66	6.29	2.26	4.0	24.4	81.7
307.1	0.65	6.15	2.17	3.0	22.1	81
312	0.63	5.75	2.04	3.6	23.0	67
317	0.67	5.90	2.09	3.1	22.8	69
379	0.64	6.73	1.89	2.7	32.6	60
385	0.63	6.73	2.00	2.0	27.2	85
390	0.67	5.72	2.40	3.6	27.2	115
395	0.67	6.02	2.37	3.3	19.1	73
410	0.61	6.29	1.97	2.5	19.4	64
422	0.66	7.41	1.64	3.9	18.0	70
425	0.68	6.24	1.91	3.3	19.5	62
429	0.66	7.29	1.64	3.0	18.0	61
430	0.66	7.29	1.64	6.0	18.2	61
447	0.65	6.82	1.72	3.0	26.8	71
449	0.65	6.82	1.72	3.0	21.0	56
462	0.64	6.20	2.07	0.9	29.2	83
463	0.66	5.65	1.72	4.8	30.5	69
474	0.63	4.91	2.36	0.9	29.2	83
477	0.65	6.81	1.42	4.9	34.2	71
481	0.61	5.65	2.45	5.2	24.6	68
482	0.65	5.71	1.89	1.0	31.0	151
483	0.65	5.71	1.89	0.7	31.0	76
485	0.63	6.75	2.05	0.5	31.2	76
1630	0.67	8.08	2.29	3.2	26.3	43.2
1652	0.61	7.26	1.83	3.6	41.0	63.7
1670	0.66	7.24	1.76	2.7	18.9	54.4
1674	0.62	6.66	1.83	1.0	35.5	70.7
1685	0.65	7.25	1.76	2.0	23.8	57.6
1704	0.67	7.38	1.80	6.0	21.7	56.2
1712	0.67	7.13	1.74	1.2	21.3	56.5
1730	0.69	7.25	2.04	4.2	16.8	52.6
1731	0.69	7.25	2.04	3.2	16.8	52.6
1732	0.70	7.35	2.03	3.0	16.6	49.6
1733	0.70	7.35	2.03	4.8	16.6	49.6
1734	0.69	7.39	2.06	2.2	18.6	64.3
1735	0.63	6.32	2.07	4.3	22.7	62.0
1747	0.66	7.25	1.76	10.0	22.2	53.3
1748	0.66	7.25	1.76	1.5	22.2	53.3
1756	0.67	7.53	2.37	2.5	25.5	37.0
1757	0.67	7.58	2.34	2.7	24.5	46.8
1757.5	0.67	7.58	2.34	2.0	24.5	46.8
1759	0.68	8.00	2.35	2.7	26.0	56.5

Depth (mbsf)	Mean of each variable					
	Mg^*	CaO/Na_2O	Zr/Y	Au	TiO_2/Cr	Zn
1759.2	0.68	8.00	2.35	4.7	26.0	56.5
1754	0.68	7.52	1.98	1.6	17.0	51.5
1780	0.66	7.57	1.92	1.0	19.1	57.6
1788	0.64	6.34	1.76	2.7	9.3	60.7
1788.2	0.64	6.34	1.76	1.0	9.3	61.0
1790	0.69	7.42	1.91	3.9	15.8	43.8
1800	0.66	7.08	1.75	3.4	21.6	46.9
1807	0.66	7.15	1.75	2.7	21.4	48.8
1813	0.60	6.68	1.96	4.5	67.6	36.8
1818	0.62	6.30	1.96	4.0	39.2	68.9
1819	0.68	7.00	1.75	3.2	11.2	39.3
1821	0.71	7.08	1.72	2.7	18.0	34.6
1825	0.66	7.27	1.76	1.7	21.4	43.9
1866	0.66	7.11	1.78	4.2	20.9	55.9
1879	0.67	8.26	2.49	4.0	40.7	35.9
1922	0.67	7.22	1.79	0.9	22.0	39.3
1924	0.66	7.01	1.83	2.0	24.5	39.7
1930	0.67	7.17	1.80	0.5	20.9	36.9
1942	0.68	6.85	1.77	0.9	21.3	49.2
			Average			
	0.66	7.07	1.96	3.07	23.82	60.60
			Standard deviation			
	0.00	2.69	0.06	2.73	73.00	341.93
			A/S_A			
	−0.271	5.758	0.458	1.027	2.263	2.072
			E/S_E			
	−0.385	39.74	−0.687	3.003	8.981	7.666
			$A/(6/N)^{0.5}$			
	−0.890	18.952	1.506	3.380	7.449	6.819
			$E/(24/N)^{0.5}$			
	0.634	64.798	−1.130	4.942	14.781	2.616

Table 3 (continued).

	Depth (mbsf)	Matrix of correlation					
		Mg^*	CaO/Na_2O	Zr/Y	Au	TiO_2/Cr	Zn
Depth	1.000	0.396	1.103	−0.099	−0.114	−0.049	−0.630
Mg^*	0.396	1.000	−0.057	0.012	−0.016	−0.478	−0.324
CaO/Na_2	0.103	−0.057	1.000	−0.024	0.001	−0.115	−0.232
Zr/Y	−0.099	0.012	−0.024	1.000	0.032	0.158	0.108
Au	−0.114	−0.016	0.001	0.032	1.00	0.030	−0.102
TiO_2/Cr	−0.049	−0.478	−0.115	0.158	0.030	1.000	0.127
Zn	−0.630	−0.324	−0.232	0.108	−0.102	0.127	1.000