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Complete analytical data
for samples of the Big Timber stock,
Crazy Mountains, Montana

by

Edward A. du Bray¹

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¹ Denver, Colorado

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INTRODUCTION

The Eocene Big Timber stock in the Crazy Mountains of south-central Montana is an 8- by 13-km (in plan view), compositionally and texturally diverse composite intrusion with a well developed radial dike swarm. The stock is hosted by sedimentary rocks of the Paleocene Fort Union Formation. A sharp intrusive contact separates the two principal phases of the stock: fine-grained quartz monzodiorite and medium-grained diorite and gabbro (Streckeisen, 1973). Differentiation-related (E.A. du Bray, unpub. data, 1995) major oxide abundance variation within the stock is extensive and spatially nonsystematic. Abundances of most trace elements were not strongly influenced by magma reservoir differentiation.

The geology of the stock was mapped by du Bray and others (1993). Derivative studies concerning the petrogenesis of the stock and its associated radial dike swarm are in progress. The purpose of this report is to present geochemical data obtained for samples collected during geologic mapping and to make the data available for petrogenetic study of the stock. Major oxide and trace element compositional variation with the Big Timber stock is documented by analytical data for a set of 69 samples; 49 samples of the diorite and gabbro phase (table 1), 17 samples of the quartz monzodiorite phase (table 2), and 3 samples of the quenched phase (table 3) were analyzed. Sample sites are shown in du Bray and others (1993). A subset of 17 samples, representative of the stock's full range of compositional variation, was selected for instrumental neutron activation analysis (table 4). Major oxide and trace element abundances have also been determined for about 50 samples of the dike swarm (A.B. Wilson, unpub. data, 1995).

ANALYTICAL METHODS

All geochemical analyses were performed in analytical laboratories of the U.S. Geological Survey in Denver, Colo. Major oxide analyses were performed (analysts, D.F. Siems and J.S. Mee) using X-ray fluorescence techniques (Taggart and others, 1987). Fe^{2+} :total iron as Fe^{2+} ratios were adjusted to 0.90 and major oxide abundances recalculated to 100 percent, volatile free. Rb, Sr, Y, Zr, Nb, and Ba abundances were determined (by E.A. du Bray) by energy-dispersive X-ray fluorescence spectroscopy (Elsass and du Bray, 1982; Yager and Quick, 1992) using ^{109}Cd and ^{241}Am radio-isotope excitation sources. Additional trace element abundances (table 4) in the 17-sample subset were determined (analyst, J.N. Grossman) using techniques described by Baedecker and McKown (1987).

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Geologic mapping and sample collection for this study were conducted by E.A. du Bray, J.E. Elliott, A.B. Wilson, B.S. Van Gosen, and L.A. Rosenberg during 1992 as part of a mineral resource assessment of the Custer and Gallatin National Forests. U.S. Geological Survey analysts are thanked for their input. A constructive review by M.I. Toth is much appreciated.

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Table 1.--Composition of samples of the diorite and gabbro phase of the Big Timber stock, Crazy Mountains, Montana. [Major oxide data in weight percent, trace element data in parts per million. Ferrous iron/total iron as FeO adjusted to 0.9 and abundances normalized to 100 percent, volatile free]

Sample	202300	202302	202307	202309	202311	202313	202315	202316	202317	202318
SiO ₂	49.25	53.79	50.37	47.54	50.13	51.33	53.29	50.79	53.42	54.25
Al ₂ O ₃	14.10	15.00	16.48	11.17	12.89	10.69	16.95	16.83	17.81	17.17
Fe ₂ O ₃	1.28	0.99	1.10	1.52	1.27	1.22	1.07	1.18	0.94	0.98
FeO	10.34	7.99	8.90	12.34	10.27	9.90	8.68	9.58	7.58	7.92
MgO	8.98	6.57	6.04	12.70	9.51	11.51	4.32	5.63	4.32	4.36
CaO	9.04	7.50	9.20	10.26	8.94	9.39	6.99	8.96	7.53	7.52
Na ₂ O	2.61	3.53	3.39	1.64	2.64	2.30	3.75	3.37	3.63	3.72
K ₂ O	1.62	2.44	1.59	0.94	1.44	1.46	2.44	1.15	2.36	1.85
TiO ₂	2.07	1.58	1.93	1.50	2.09	1.61	1.75	1.82	1.69	1.58
P ₂ O ₅	0.50	0.45	0.85	0.20	0.60	0.41	0.63	0.55	0.60	0.51
MnO	0.19	0.14	0.14	0.18	0.20	0.19	0.14	0.14	0.13	0.15
Rb	27	62	27	21	36	37	49	26	56	45
Sr	1199	827	1157	635	737	667	1111	1034	1185	1073
Y	26	27	29	12	28	35	26	26	36	22
Zr	62	140	41	54	48	76	104	51	85	66
Nb	27	21	16	9	21	21	19	13	17	18
Ba	1466	1216	807	526	928	836	2099	696	2189	1078
Sample	202320	202324	202325	202326	202327	202330	202331	202333	202334	202335
SiO ₂	47.01	53.50	57.04	55.05	56.66	52.67	54.77	54.96	50.23	51.97
Al ₂ O ₃	13.80	15.74	17.61	16.82	16.23	14.24	19.17	14.48	13.30	13.76
Fe ₂ O ₃	1.56	1.02	0.77	0.96	0.88	1.01	0.82	1.10	1.58	1.19
FeO	12.66	8.30	6.23	7.78	7.09	8.14	6.62	8.92	12.76	9.66
MgO	9.17	6.08	4.25	4.41	4.58	9.26	3.62	6.14	7.96	7.99
CaO	9.17	7.83	7.10	6.92	6.50	8.37	7.34	7.18	7.72	8.82
Na ₂ O	2.45	3.41	3.63	3.73	3.97	3.00	4.27	3.21	2.50	2.97
K ₂ O	1.07	1.99	1.76	2.49	2.29	1.80	1.52	2.09	1.51	1.57
TiO ₂	2.53	1.44	1.17	1.27	1.17	1.02	1.15	1.40	1.84	1.57
P ₂ O ₅	0.40	0.49	0.31	0.42	0.47	0.34	0.58	0.37	0.38	0.34
MnO	0.18	0.19	0.12	0.14	0.15	0.16	0.12	0.16	0.21	0.17
Rb	24	37	28	56	42	30	26	42	25	31
Sr	659	1198	1087	967	1057	847	1385	683	711	626
Y	27	19	16	28	22	25	23	25	14	24
Zr	61	67	92	97	77	55	34	118	62	101
Nb	16	16	15	17	11	7	15	10	12	13
Ba	597	1851	1325	1443	1336	1151	1357	1076	878	797
Sample	202336	202400	202504	202505	202509	202511	202512	202609	202612	202613
SiO ₂	56.78	50.28	51.61	53.09	56.50	55.45	54.27	50.66	50.65	55.62
Al ₂ O ₃	17.43	17.88	16.69	17.39	15.88	19.30	17.24	18.08	18.04	17.83
Fe ₂ O ₃	0.86	1.15	1.12	1.07	0.86	0.76	0.92	1.09	1.06	0.94
FeO	6.96	9.35	9.04	8.65	6.99	6.13	7.47	8.85	8.58	7.58
MgO	3.23	4.91	5.44	4.21	5.04	2.67	4.23	4.59	4.81	3.35
CaO	6.29	8.83	8.30	7.52	6.49	7.52	7.42	9.09	9.17	6.63
Na ₂ O	3.94	3.41	3.40	3.59	3.83	3.97	3.87	3.34	3.40	3.95
K ₂ O	2.33	1.61	1.63	1.88	2.65	2.30	2.32	1.51	1.61	2.10
TiO ₂	1.51	1.68	2.01	1.86	1.21	1.28	1.59	1.97	1.89	1.41
P ₂ O ₅	0.53	0.73	0.62	0.59	0.44	0.53	0.53	0.70	0.65	0.47
MnO	0.13	0.16	0.14	0.15	0.11	0.11	0.14	0.12	0.13	0.13
Rb	44	23	37	45	64	64	50	31	27	44
Sr	924	1127	1083	932	842	1254	917	1222	1123	980
Y	31	28	25	28	25	25	19	27	24	17
Zr	87	56	62	80	149	64	95	86	57	121
Nb	24	13	21	16	23	16	13	14	15	15
Ba	1241	1162	874	1030	1248	1443	1340	893	865	1476

Table 1.--(Continued)

Sample	202614	202615	202616	202708	202710	202711	202715	202716	202720	202721
SiO ₂	54.41	55.10	58.37	53.88	53.30	50.33	53.60	52.84	48.69	47.39
Al ₂ O ₃	17.69	19.22	17.01	18.33	15.35	17.87	17.83	16.24	9.21	14.21
Fe ₂ O ₃	0.94	0.78	0.78	0.87	0.95	1.22	0.91	1.09	1.65	1.43
FeO	7.59	6.34	6.30	7.05	7.73	9.84	7.40	8.82	13.36	11.59
MgO	4.09	2.71	3.18	3.25	6.53	4.46	3.73	5.66	14.27	10.35
CaO	7.40	6.49	5.60	7.48	7.51	8.12	7.69	7.87	9.14	10.35
Na ₂ O	3.85	5.16	4.06	4.39	3.58	3.40	4.12	3.45	1.35	2.08
K ₂ O	1.90	2.27	2.88	1.91	2.56	1.78	1.94	1.80	0.62	0.86
TiO ₂	1.47	1.17	1.20	1.91	1.80	1.93	1.89	1.54	1.26	1.29
P ₂ O ₅	0.51	0.63	0.48	0.78	0.55	0.89	0.77	0.50	0.18	0.25
MnO	0.14	0.13	0.12	0.13	0.14	0.17	0.12	0.16	0.26	0.19
Rb	57	62	38	40	44	45	39	34	12	28
Sr	1011	829	1845	1327	896	945	1327	993	533	914
Y	27	19	29	31	31	30	29	29	17	20
Zr	68	110	70	55	79	84	76	91	31	29
Nb	13	19	16	24	28	12	21	21	8	9
Ba	1117	1526	2563	1260	1166	908	1072	1011	542	504
Sample	202722	202723	202727	202728	202729	202730	202731	202732	202733	
SiO ₂	51.87	56.09	45.93	55.43	55.40	56.09	52.45	50.48	55.71	
Al ₂ O ₃	17.53	18.15	12.05	18.10	18.06	16.68	17.62	14.34	15.17	
Fe ₂ O ₃	1.03	0.83	1.64	0.86	0.84	0.91	0.94	1.15	0.89	
FeO	8.34	6.71	13.26	6.98	6.82	7.34	7.61	9.32	7.22	
MgO	5.57	2.80	8.85	3.35	3.62	4.14	5.78	9.48	6.43	
CaO	8.15	6.23	11.33	7.03	7.09	6.42	8.82	9.22	7.52	
Na ₂ O	3.76	4.59	2.55	4.45	4.00	3.80	3.68	2.65	3.49	
K ₂ O	1.76	2.62	1.17	1.85	2.17	2.68	0.91	1.41	1.88	
TiO ₂	1.33	1.21	2.15	1.31	1.38	1.34	1.53	1.35	1.12	
P ₂ O ₅	0.50	0.62	0.84	0.52	0.49	0.48	0.44	0.41	0.43	
MnO	0.15	0.14	0.22	0.11	0.12	0.13	0.23	0.18	0.14	
Rb	20	64	21	36	38	58	28	28	35	
Sr	1003	1309	1139	1021	1114	886	825	829	1004	
Y	28	26	33	27	21	32	22	19	26	
Zr	96	122	50	40	85	86	94	69	76	
Nb	13	25	15	12	15	16	18	10	11	
Ba	1651	2015	799	1234	1626	1390	552	799	1118	

Table 2.--Composition of samples of the quartz monzodiorite phase of the Big Timber stock, Crazy Mountains, Montana. [Major oxide data in weight percent, trace element data in parts per million. Ferrous iron/total iron as FeO adjusted to 0.9 and abundances normalized to 100 percent, volatile free]

Sample	202301	202303	202304	202305	202312	202314	202321*	202322*	202329	202608
SiO ₂	67.27	70.35	66.56	58.77	59.47	58.98	57.89	58.65	60.03	58.45
Al ₂ O ₃	15.65	14.83	15.55	17.08	17.14	16.88	17.32	17.44	17.57	16.89
Fe ₂ O ₃	0.38	0.31	0.39	0.73	0.69	0.74	0.82	0.77	0.66	0.70
FeO	3.08	2.51	3.18	5.92	5.62	5.95	6.65	6.28	5.35	5.68
MgO	1.63	1.36	2.17	2.74	2.63	2.94	2.82	2.63	2.06	3.66
CaO	2.92	1.80	3.23	5.47	5.19	5.14	5.66	5.24	4.89	5.28
Na ₂ O	4.57	4.68	4.61	4.23	4.23	4.44	3.96	4.18	4.69	4.49
K ₂ O	3.56	3.55	3.34	3.07	3.10	3.04	2.89	3.00	3.07	2.90
TiO ₂	0.66	0.41	0.67	1.34	1.28	1.32	1.38	1.22	1.07	1.40
P ₂ O ₅	0.22	0.15	0.22	0.52	0.52	0.45	0.48	0.46	0.52	0.44
MnO	0.06	0.05	0.06	0.12	0.12	0.12	0.12	0.12	0.09	0.10
Rb	83	57	65	65	59	55	63	59	54	61
Sr	701	890	899	1070	1025	924	881	849	985	864
Y	13	10	17	23	23	31	21	27	23	21
Zr	173	116	152	134	150	161	191	178	164	214
Nb	23	16	18	20	23	27	21	17	21	26
Ba	2065	2828	1991	1724	1648	1612	1520	1503	1822	1578
Sample	202610	202700	202702	202706	202709	202713	202719			
SiO ₂	64.21	66.57	67.19	57.34	60.03	56.45	56.95			
Al ₂ O ₃	16.00	15.42	15.40	16.53	16.03	15.82	16.71			
Fe ₂ O ₃	0.49	0.40	0.37	0.78	0.67	0.83	0.84			
FeO	3.97	3.27	3.00	6.30	5.41	6.69	6.82			
MgO	2.21	2.23	2.09	4.04	3.71	5.27	3.51			
CaO	3.81	3.12	3.06	5.89	4.95	6.34	6.19			
Na ₂ O	4.53	4.61	4.65	3.88	4.35	3.89	3.91			
K ₂ O	3.51	3.39	3.40	3.24	3.14	2.77	3.04			
TiO ₂	0.92	0.67	0.60	1.43	1.19	1.40	1.40			
P ₂ O ₅	0.29	0.25	0.20	0.45	0.42	0.42	0.48			
MnO	0.07	0.06	0.05	0.12	0.10	0.14	0.14			
Rb	69	60	62	72	75	79	80			
Sr	765	885	907	842	833	785	753			
Y	18	15	11	22	28	22	22			
Zr	173	135	135	166	138	121	165			
Nb	17	16	18	27	25	19	18			
Ba	1850	2116	2206	1312	1639	1138	1257			

* Campfire Lake mass (du Bray and others, 1993).

Table 3.--Composition of samples of the quenched phase of the Big Timber stock, Crazy Mountains, Montana.

[Major oxide data in weight percent, trace element data in parts per million. Ferrous iron/total iron as FeO adjusted to 0.9 and abundances normalized to 100 percent, volatile free]

Sample	202319	202323	202507
SiO ₂	56.57	57.56	61.18
Al ₂ O ₃	17.84	16.54	17.39
Fe ₂ O ₃	0.77	0.81	0.62
FeO	6.27	6.58	5.04
MgO	3.06	3.58	1.92
CaO	6.33	5.90	4.55
Na ₂ O	4.32	3.99	4.34
K ₂ O	2.73	3.08	3.52
TiO ₂	1.44	1.34	0.93
P ₂ O ₅	0.53	0.49	0.42
MnO	0.13	0.13	0.08
Rb	55	69	78
Sr	948	905	783
Y	30	27	25
Zr	209	199	216
Nb	27	33	21
Ba	1707	1614	1628

Table 4.--Instrumental neutron activation analyses, in parts per million, for selected samples of the Big Timber stock, Montana.

[Samples listed in order of increasing iron content. bdl, below detection limit]

Sample	202303	202304	202610	202709	202305	202706	202336	202713	202733
Sc	3.59	6.45	7.67	12.0	11.5	15.3	12.7	16.9	20.5
Cr	42.1	71.8	36.8	133	17.0	126	9.9	180	268
Co	5.52	11.7	13.8	22.5	16.6	23.8	20.9	26.9	32.2
Ni	22	32	25	66	bdl	47	bdl	77	100
Zn	34	42	39	60	77	63	83	68	91
Sb	0.110	0.060	bdl	0.130	0.092	0.180	0.094	0.180	0.099
Cs	0.48	0.90	1.00	2.30	1.20	1.30	1.40	1.40	1.20
La	38.8	49.7	52.3	54.4	64.5	42.9	47.2	42.3	43.4
Ce	59.5	78.3	81.5	93.6	118	78.3	84.2	74.1	79.4
Nd	21	25	27	35	48	32	36	31	35
Sm	2.89	3.88	4.65	6.27	8.19	6.35	6.69	6.28	6.24
Eu	0.750	0.996	1.20	1.530	1.990	1.660	1.83	1.64	1.63
Tb	0.210	0.340	0.420	0.580	0.744	0.630	0.674	0.654	0.640
Yb	0.42	0.87	1.10	1.40	2.00	1.60	1.70	1.70	1.70
Lu	0.071	0.120	0.160	0.190	0.260	0.230	0.240	0.230	0.220
Hf	3.89	4.7	5.18	4.47	4.90	5.67	3.34	4.97	3.07
Ta	0.865	1.44	1.42	1.46	1.60	1.68	1.14	1.47	0.790
Th	10.1	11.3	9.15	6.71	9.82	7.56	8.07	8.43	6.29
U	1.6	2.1	1.4	1.3	1.7	1.2	1.4	1.6	1.3
Sample	202614	202324	202716	202504	202316	202300	202309	202727	
Sc	20.8	20	21.2	21.4	25.0	25.1	31.5	36.5	
Cr	37.1	139	95.5	101.0	54.8	287	486	125	
Co	30.9	31.8	35.0	35.2	39.4	50.9	74.0	53.5	
Ni	bdl	73	44	48	34	120	210	66	
Zn	69	110	94	98	88	113	98	130	
Sb	0.200	0.140	0.120	0.10	0.092	bdl	bdl	0.190	
Cs	1.80	1.20	1.30	0.89	1.10	0.89	1.10	0.57	
La	42.7	42.2	45.7	38.5	29.5	48.4	19.5	50.7	
Ce	79.2	79.2	89.3	76.3	58.5	98.9	38.9	108.0	
Nd	35	35	41	37	29	47.3	19	61	
Sm	6.89	6.67	8.15	7.79	6.51	8.73	4.13	12.4	
Eu	1.76	1.87	2.08	2.14	1.75	2.17	1.13	2.78	
Tb	0.710	0.690	0.860	0.825	0.713	0.767	0.440	1.08	
Yb	2.1	1.6	2.4	1.9	1.5	1.8	1.0	2.5	
Lu	0.27	0.26	0.33	0.27	0.21	0.25	0.15	0.32	
Hf	3.09	3.02	3.54	3.11	2.53	2.70	1.90	2.97	
Ta	0.973	0.800	1.10	1.20	0.800	1.47	0.490	0.820	
Th	7.42	5.95	4.67	4.87	3.94	3.75	2.40	4.31	
U	1.50	1.00	0.86	0.93	0.59	0.76	0.46	1.00	