ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/264233801

Petrological and Geochemical Criteria for Tectonic Environment of the Chukchi Segment in Okhotsk-Chukchi Volcanic Belt

Article *in* Russian Journal of Pacific Geology · January 2000

CITATIONS
0

READS
28

1 author:

Vladimir Fyodorovich Polin
Far East Geological Institute
30 PUBLICATIONS **79** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project

«Вулкано-плутонизм мезозойско-кайнозойских границ плит на Северо-Востоке Азии: петрологические, геохронологические и изотопно-геохимические аспекты» View project

All content following this page was uploaded by Vladimir Fyodorovich Polin on 26 July 2014.

The user has requested enhancement of the downloaded file.

Geol. of Pac. Ocean, 2000, Vol. 16, pp. 607-642
Reprints available directly from the Publisher
Photocopying permitted by license only

©2000 OPA (Overseas Publishers Association) N.V.
Published by license under
the Harwood Academic Publishers imprint,
part of the Gordon and Breach Publishing Group
Printed in Singapore

Petrological and Geochemical Criteria for Tectonic Enviroment of the Chukchi Segment in Okhotsk-Chukchi Volcanic Belt

V.F.POLIN* and E.J.MOLL-STALCUP**

* *Far East Geological Institute, Far East Branch, Russian Academy of Sciences, Vladivostok*

** *U. S. Geological Survey, Reston*

Received July 29, 1996

Comprehensive petrological and geochemical studies of Albian, Late Senonian and Paleogene volcanogenic basalt-bearing formations of the Chukchi segment of the Okhotsk-Chukchi volcanic belt (CS OCVB) were carried out using new evidence on REE and rare-element geochemistry. Essential discrepancies in petrogeochemical and petrological and mineralogical parameters were revealed between Cretaceous and Paleogene rocks comparable in basicity.
Cretaceous volcanites display features typical of rocks from island arcs and active continental margins. Paleogene assemblages are similar to rocks of margin continental rifts (trachybasalts) and typical of intraplate associations (comendites, alkali granites). Paleogene basalts show signs of relationship with intraplate Neogene-Quaternary Bering Sea basalts, but differ from them in lesser "primitivity" and lower contents of thermophyle elements (Ni, Co, Cr). The evidence obtained testifies that the Cretaceous and Paleogene basalt-bearing formations of the CS OCVB developed in different geodynamic environments. Volcanite composition of the Cretaceous stages of belt development shows them to have formed in active continental margin conditions. Paleogene volcanism reflects the situation of tectonic extension (or transform margin) to show numerous evidence of the initial stages of continental rift magmatism. The process of rift origin discontinued in its early stage, probably because a new Benioff zone originated to the east of the OCVB. Appearance of volcanogenic rocks of the intraplate geochemical type in the area of the OCVB in Paleogene is indicative of geodynamic regime changes in this region at Cretaceous-Paleogene boundary.

INTRODUCTION

During formation of Okhotsk-Chukchi volcanic belt (OCVB), mass manifestations of basalt magmatism took place in Early Cretaceous, Late Cretaceous and Paleogene [2-6,8,17,31,33, etc.]. The last outflows of basaltoids took place in Neogene-Quaternary time in dissociation with belt volcanism

[1,19,22,23 etc.]. This work is based on novel factual material on the geochemistry of rare and rare-earth elements in basalt-bearing formations, including contrasting ones from the Chukchi segment of OCVB in Cretaceous and Paleogene time.

As shown by OCVB contributors, belt basaltoids of different age have a number of common geochemical peculiarities in composition, being as they are essentially regional. At the same time, they have an even greater set of characteristics distinguishing rocks close in basicity and those of different age and basalt-bearing formations [3,12,14,24,25,28,33, etc.]. The latter circumstance served as a chance to try to reconstruct the geodynamic conditions of the Okhotsk-Chukchi volcanogenic formation, stemming from the rock compositions of these formations.

The present authors tackled the problem by using as examples volcanic structures of the East Chukchi Zone (ECZ), Central Chukchi Zone (CCZ) and Anadyr Sector (AS) of the Okhotsk-Chukchi volcanic belt (Fig. 1).

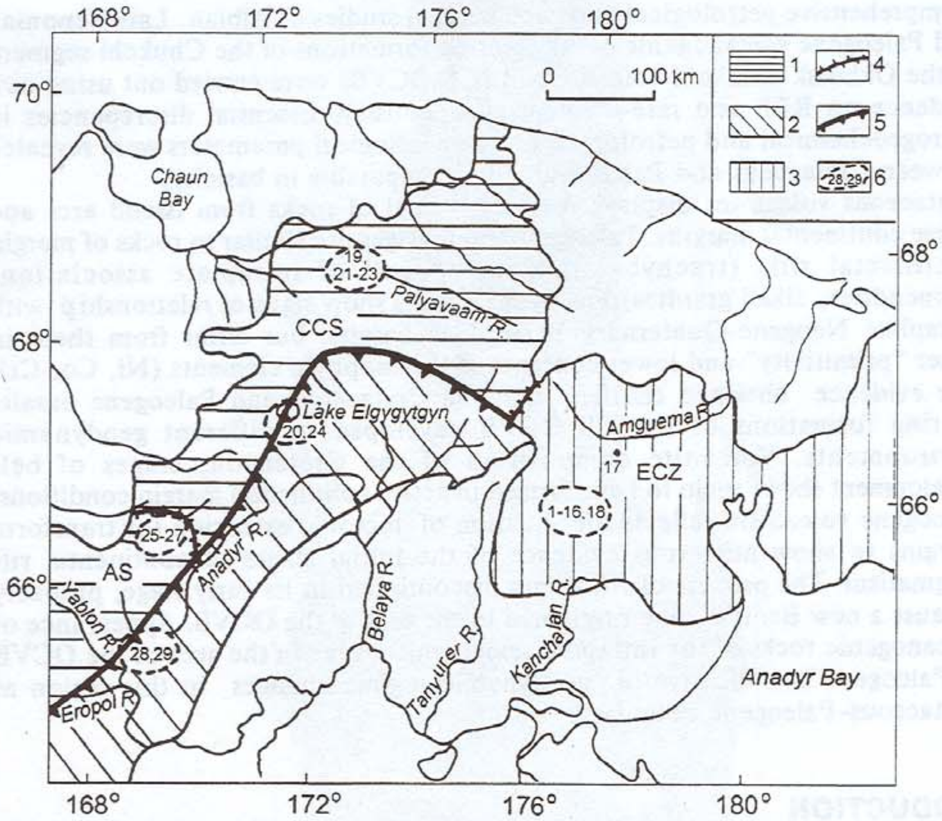

Fig.1 Sketch map of sampling of different-age basalt-bearing formations of CS OCVB. Okhotsk-Chukchi volcanogenic velt (modified from [3]): 1 - outer zone, 2 - inner zone, 3 - flank zone; 4 - sector and zone boundaries of volcanogenic belt: East Chukchi zone (ECZ), Central Chukchi (CCS) and Anadyr (AS) sectors; 5 - boundary between outer and inner zones of volcanogenic belt; 6 - outlines of sampling sites (numbers encircled indicate sample numbers in Table 1).

GEOLOGIC AND TECTONIC POSITION OF THE STUDY FORMATIONS

Numerous work [2-5, 7, 14, 17, 24, 25, 28, 31, 33, 34, etc.] have been devoted to the description of the geological and structural position, petrographical and chemical compositions of OCVB, including basalt-bearing ones. Hence, we will provide only brief information for the reader to understand our research.

OCVB is part of the structure of the planetary character - Chukotka-Cathaysian system of margin-continental volcanic belts stretching along Eastern margin of the Asian continent for more than 8000 km [3, 5, 7, 20, 21, 33, 46 etc.]. A number of blocks and zones (sectors, fragments according to a terminology of different authors) is assigned to the belt in accord with structural, tectonic and composition zonation. The zonation is subdivided into longitudinal and transversal and stipulated, on the one hand, by heterogeneity of structures of belt foundation, and on the other, by the mode of geodynamic motion of various blocks along faults. Appearance of transversal zonation with regard to belt extension is its "external" ("rear", subcontinental) and "internal" ("frontal", suboceanic) zone; the boundary between them coincides with the boundary of continental and transition crust types during the volcanogene formation [2, 5, 34, etc.]. Besides, there are distinctions in composition and assigment of formations depending on belt foundation constitution. Similar zonation allows to distinguish separate sectors, or fragments of OCVB, adequate to particular geoblocks of the northeast margin of the Asian continent (ancient massives, various zones of folded areas). The rear and frontal zones of the volcanic belt are divided by a system of pulled-together sinistral strike-slip faults corresponding athrough deep fault [32]. In relation to this boudary, the constitution and basement thickness, rock compositions and OCVB formations change along with the nature of their volcanic structures. The rear zone is located on a thick granite metamorphic crust; the frontal zone is formed on crust characterizaed by transition from oceanic to continental crust [34, etc]. The so-called belt "flank" zones (East Chukchi and West Okhotsk) are superimposed on hard crystalline massives with pre-Rhiphean continental crust and have no lengthwise zonation and composition, sequence and formation close to the rear zone [3].

Basaltic rock strata assigned to belt strata proper formed in three stages, each marking the beginning of a specific cycle of OCVB tectono-magmatic activity. The first stage includes basaltoids in the composition of Early Cretaceous formations: "amphibole and pyroxene andesites and andesibasalts", and "high-alumina basalts and andesibasalts" [3], whose allocation is defined by structural features of the basement and system of depth faults.

Second stage Late Cretaceous basaltoids were assigned to volcanic centers of focal volcanism. This stage is characterized by formation of two-pyroxene andesite and andesibasalt [3], and also by contrast trachybasalt-trachyrhyolite series and basalt-andesibasalt formation [23, 24, etc.] The basalt-andesibasalt members of Late Cretaceous formations are represented by less volumetric strata than the more widespread Early Cretaceous members. The subvolcanic facies is composded of small-size bodies of gabbro, monzodiorite, trachyandesite, and latite. According to different authors, the age of Late Cretaceous, basalt-bearing formations is Cenomanian, Cenomanian-Turonian, Turonian-Senonian, Senonian, and Maastrichtian-Danian [3, 17, 31,33, etc.].

The third Paleogene stage is represented by volcanic formations composing volcanic plateaus, as well as ring caldera complexes localized along faults. With regard to composition, they are assigned to basalt, basalt-trachybasalt and bimodal trachybasalt-trachydacite formations containing pantellirites, comendites and alkali granites [3, 24, 25, etc.]. In the first two formations, the basalts, trachybasalts, andesibasalts and trachyandesibasalts are dominant. Trachybasalts and trachydacites are prevalent in bimodal formations, while trachyandesibasalts, trachyandesites, trachyrhyolites, trachites, pantellirites, comendites and alkali granites are present in lesser amounts.

Paleogene basic rocks are almost entirely represented by effusives. Small-sized hypabyssal bodies of subalkali olivine gabbro are extremely rare occurrences, while trachyandesites and trachydacites are abundant both in effusive and extrusive dike occurrences. Subvolcanic and hypabyssal derivations (dikes, stocks, domes) are more acidic in the composition.

The K-Ar age of late stage (52.5-66.0 Ma) basaltoids shows their Danian-Eocene origin. The phytostratigraphic characteristics of these formations are absent; hence, their age at geologil prospecting was conditionally accepted as Senonian or Paleocene, and as Late Cretaceous on the last map legends. Palynologic definitions [16] showed the rock age to be post-Paleocene.

A more detailed geological, petrographic and geochemical characteristic of basalt-bearing complexes mentioned above was reported in the works of V.F. Belyi [2-6, etc.], V. G. Sakhno and V. F. Polin [25], V. F. Polin [24, etc.] and others. Given below are the main specifics of REE distribution data, for which with regard to given regions relevant data has been cited for the first time. Given the REE content and in particular, relations between some of them are reckoned as properties for solving the problems of rock genesis and geodynamic characteristic of the region, their behavior in basalt-bearing formations of different age presents special interest.

ANALYTICAL METHODS

Basalt-bearing formations were characterized by examining 82 formation samples. Chemical analysis of rocks was performed by classical method in the laboratories of Far East Geological Institute (FEGI), Russian Academy of Sciences (RAS), Vladivostok. X-ray fluorescent analysis (XRF, see Table 1) results for Ba, Rb, Sr, Zr, Y and Nb in representative formation samples were made in Analytical Laboratory, U. S. Geological Survey, Dever, and at Geological Institute, RAS, Analytical Center, Moscow* ; neutron-activation analyses of other rare elements were performed in Analytical Laboratory, U.S. Geological Survey, Reston and at Geological Institute, RAS, Analytical Center, Moscow. In addition, the Co, Ni and Cr contents were determined by quantitative method involving plasma photometry at FEGI, RAS (Index "PP"). The definition error for rare elements was about 5%, except for Gd, Tb and Tm analysis, the accuracy of whose determination was ±10%. The accuracy of quantitative spectrum analysis also equaled ±10%.

The analyses of 29 representative samples of Cretaceous and Paleogene basalt-bearing formations of CS in OCVB are given in Table 1, and their brief geological and petrographic characteristics in Table 2.

RESULTS

Geochemistry of Rare Earth Elements

The composition of REE-spectrums researched is normalized to the chondrite composition [40], and their normalized trends (spider plots) are shown in Fig. 2.

Using the plots, it can be seen that all rocks are enriched in REE, and their contents correlate with alkalinity, but in basalts - with titanium contents as well. REE distribution have high differentiated character in basalts of all examined complexes (Table 1, Figs 2,3). The deviation from this tendency in moderate differentiation was observed only in low titanium basalts of Early Cretaceous Salamikhinsky suite (for example, ПН-69-713, Table 1).

Compositions of Paleogene basalts are slightly more enriched with light REE than compositions of Early and Late Cretaceous basalts. As for heavy REE, they are equivalent to Cretaceous rocks. High titanium trachybasalts** distinguished by higher contents of virtually all REE compose the special group.

---

*Samples analyzed at Analytical Center of Geological Institute, RAS, Moscow are indicated in Table 1 by asterisk.

**Remarkable feature of the rocks of Paleogene bimodal formation is the presence of moderate and high titanium basalts in the same geological section (1.3-1.9 and 2.1-2.8% TiO_2, respectively).

Table 1 Representative compositions of basalt-bearing formations of CS OCVB (major elements, %, trace elements, ppm).

Region	East Chukotka sector of OCVB								
Age	Albian		Senonian			Paleocene-Eocene			
Sample	PN-37-312	PN-46-431	PN-27-243	PN-19-176	PN-27-245	PN-35-305	PN-31-270*	IL-3-13*	IL-3-14
Component	1	2	3	4	5	6	7	8	9
SiO_2	47.31	49.68	52.75	53.90	59.65	48.32	48.34	47.60	51.99
TiO_2	1.54	1.53	1.02	1.19	0.87	1.90	1.73	2.79	2.07
Al_2O_3	19.75	17.76	17.92	17.15	17.28	17.60	16.96	16.79	18.00
Fe_2O_3	4.86	4.12	2.94	4.16	3.15	4.46	3.45	6.29	5.21
FeO	4.35	5.23	5.36	3.49	2.74	4.96	6,26	5.58	4.28
MnO	0.21	0.18	0.15	0.19	0.14	0.14	0.16	0.22	0.13
MgO	4.01	4.94	4.97	3.97	2.46	6.70	8.02	4.87	3.18
CaO	10.71	8.55	7.86	7.02	4.98	8.40	6.28	6.74	7.29
Na_2O	2.94	3.56	3.35	2.94	4.19	3.34	3.34	3.92	3.76
K_2O	0.79	1.19	0.74	2.16	1.78	0.77	1.09	1.50	1.21
P_2O_5	0.47	0.66	0.48	0.47	0.37	0.42	0.56	0.95	0.66
H_2O^-	0.86	1.12	0.58	0.99	0.96	1.43	0.11	0.90	0.82
H_2O^+	1.04	1.44	1.65	2.39	1.08	1.18	1.62	1.40	0.98
CO_2	1.20	0.01	0.01	0.10	0.02	0.01			0.01
Total	100.04	99.97	99.78	100.12	99.67	99.63	99.92	99.55	99.59
Nb (XRF)	< 10	< 10	< 10	< 10	< 10	< 10	4.7	17	18
Rb (XRF)	13	22	19	27	39	12	16	11	19
Rb	13.7	16.3	17.2	27	34.2	5.75			9.59

Sr (XRF)	860	1600	670	660	600	630	840	640	730
Sr	972	1780	708	762	627	619			795
Ba (XRF)	360	890	455	830	650	315	410	420	540
Ba	372	874	451	789	644	329			519
Cs	0.78	0.511	1.75	1.13	3.1	0.22			0.39
Zr (XRF)	104	166	140	275	194	126	190	320	295
Zr	128	137	144	248	182	138			256
La	17.80	31.30	17.20	29.00	23.30	13.60	24	34	29.50
Ce	44.2	75.3	41	66.6	54.5	34.40	56	66	74.20
Nd	25.9	38.2	22.9	33.3	30.2	21.00	29	37	42.50
Sm	5.9	7.02	5.14	6.83	6.69	4.88	6.6	8.9	9.19
Eu	1.79	1.92	1.5	1.58	1.82	1.57	2.3	2.6	2.31
Gd	5.33	5.27	4.35	5.87	5.95	4.40			8.00
Tb	0.706	0.689	0.607	0.742	0.816	0.65	0.97	1.4	1.11
Tm	n.d.	0.307	0.294	0.355	0.482	n.d.			0.50
Yb	1.84	1.82	1.85	2.16	2.57	1.81	2.4	3.2	2.96
Lu	0.267	0.285	0.277	0.319	0.39	0.28	0.33	0.48	0.42
Y (XRF)	15	13	18	18	31	19	25	38	36
Hf	2.65	3.79	3.07	6.27	4.68	2.91	3,00	6,00	5.79
Ta	0.215	0.421	0.301	0.53	0.452	0.33	0.50	1.0	0.89
Th	1.72	2.45	2.24	7.79	4.18	0.74	0.94	2.6	2.39
U	0.541	0.672	0.897	2.61	1.52	0.35	0.29	0.59	0.92
Sc	28.6	22.6	22.2	19.3	15.9	23.4			19.90
Cr	28.6	17.8	71.2	93.1	7.54	149.00			22.20
Cr (PP)	42	16	70	190	11	100	180	9	15
Co	26.5	24.8	24.5	20.5	10.4	33.4			24.30

Table 1 (continued).

Region	East Chukotka sector of OCVB								
Age	Albian		Senonian			Paleocene-Eocene			
Sample	PN-37-312	PN-46-431	PN-27-243	PN-19-176	PN-27-245	PN-35-305	PN-31-270*	IL-3-13*	IL-3-14
Component	1	2	3	4	5	6	7	8	9
Co (PP)	37	20	25	31	10	34	39	31	27
Ni	22.5	21	49.7	52.1	< 5.6	100			31.20
Ni (PP)	49	26	72	83	14	140	130	20	35
Zn	22.5	78.7	92.4	84	93.2	89.6	72	120	111
As	n.d.	2.96	n.d.	0.832	4.54	n.d.			1.55
Sb	n.d.	n.d.	n.d.	0.202	0.205	n.d.			n.d.
Au	<0.10	<0.55	<1.6	<0.72	<2.0	<1.0			<1.1
Eu/Eu*	0.96	0.93	0.95	0.74	0.86	1.02			0.81
Th/Ta	8.0	5.83	7.47	14.7	9.24	2.24	1.88	2.6	2.68
La/Ta	82.8	74.3	57.1	54.7	51.5	41.2	48	34	33.1
La/Yb	9.7	17.2	9.3	13.4	9.1	7.5	10.0	10.6	10.0
Zr/Nb (XRF)	>10.4	>16.6	>14.0	>27.5	>19.4	>12.6	40.4	18.8	16.4
Ba/La	20.9	27.9	26.2	27.2	27.6	24.2	17.1	12.4	17.6
Ba/Nb (XRF)	>36..0	>89.0	>45.5	>83.0	>65.0	>31.5	87.2	24.7	30.0
Ba/Sr	0.38	0.49	0.64	1.04	1.03	0.53	0.49	0.66	0.65

Region	East Chukotka sector of OCVB								
Age	Paleocene-Eocene								
Sample	IL-3-17	IL- 2-8	PN-44-422	PN-50-473	IL- 1-8	PN-50-471	PN-29-263	PN-201-1515*	PN-28-251*
Component	10	11	12	13	14	15	16	17	18
SiO_2	58.05	63.40	66.35	68.80	72.20	73.90	71.30	74.96	73.35
TiO_2	0.68	0.98	0.90	0.39	0.17	0.16	0.16	0.28	0.16
Al_2O_3	18.49	17.27	14.78	14.90	13.13	13.23	14.49	10.60	14.09
Fe_2O_3	2.17	4.90	1.97	1.67	1.61	0.78	1.40	2.75	0.95
FeO	3.63	0.83	1.84	0.96	0.82	0.65	1.48	1.35	1.48
MnO	0.09	0.02	0.12	0.04	0.09	0.06	0.07	0.08	0.07
MgO	3.15	0.56	0.86	1.05	0.52	0.30	0.10	0.04	0.10
CaO	6.23	2.11	2.15	2.77	1.85	0.70	0.49	0.43	0.70
Na_2O	4.39	4.60	5.99	3.90	4.21	4.15	5.41	4.16	4.19
K_2O	1.05	3.75	3.10	2.90	3.84	3.70	4.20	4.51	4.11
P_2O_5	0.43	0.40	0.22	0.12	0.09	0.06	0.08	0.02	0.07
H_2O^-	0.25	0.43	0.39	1.00	0.06	0.21	0.05	0.14	0.07
H_2O^+	0.93	0.54	1.02	0.65	2.09	1.62	0.28	0.22	0.44
CO_2	0.01	0.01	0.01	0.01	0.01	0.01	0.01		
Total	99.55	99.80	99.70	99.16	100.69	99.53	99.52	99.54	99.78
Nb (XRF)	12	15	< 10	< 10	< 10	12	49	39	9.5
Rb (XRF)	41	84	55	48	50	69	88	160	110
Rb	42.1	83.2	55.2	44	47.6	62.5	95		

Table 1 (continued).

Region	East Chukotka sector of OCVB								
Age	Paleocene-Eocene								
Sample	IL-3-17	IL- 2-8	PN-44-422	PN-50-473	IL- 1-8	PN-50-471	PN-29-263	PN-201-1515*	PN-28-251*
Component	10	11	12	13	14	15	16	17	18
Sr (XRF)	760	530	275	720	180	79	< 10	1.8	71
Sr	798	532	260	722	163	63.5	< 17		
Ba (XRF)	640	760	850	700	640	730	48	10	1100
Ba	618	793	805	714	643	722	32.4		
Cs	1.33	0.989	1.25	1.37	0.427	0.854	1.12		
Zr (XRF)	225	495	285	148	150	106	890	960	220
Zr	190	435	243	136	n.d.	108	754		
La	25.80	41.4	26.80	21.90	22.60	23.50	65.80	38.00	36.00
Ce	54.20	109	60.10	40.80	44.2	47.1	136	93	65
Nd	24.80	40.9	28.50	16.90	16.5	15.6	55.5	48	33
Sm	4.86	8.28	6.41	3.11	2.84	2.64	10.4	8.40	7.10
Eu	1.37	1.84	1.85	0.72	0.502	0.359	0.515	0.54	1.10
Gd	4.15	7.05	5.63	2.28	2.12	2.25	9.17		
Tb	0.59	1.02	0.84	0.32	0.303	0.313	1.39	2.20	0.93
Tm	0.30	0.529	0.52	n.d.	0.195	n.d.	0.985		
Yb	1.76	3.24	3.40	1.07	1.23	1.31	6.41	8.60	3.90
Lu	0.25	0.453	0.49	0.16	0.185	0.19	0.934	1.30	0.68
Y (XRF)	21	41	30	11	15	19	68	97	39

Hf	4.40	10.4	6.58	3.54	3.94	3.41	19.6		
Ta	0.58	1.31	0.65	0.48	0.749	1.04	3.45		
Th	3.14	8.78	4.85	5.21	5.87	7.36	10.4	3,50	
U	1.00	2.88	1.74	1.73	2.06	1.31	1.8	10,0	
Sc	13.50	9.79	17.40	4.44	2.19	2.37	1.08		
Cr	27.70	3.17	n.d.	5.93	1.52	1.58	1.3		
Cr (PP)	42	7	5	14	6	<1	3	<1	12
Co	16.80	7.12	2.23	4.99	1.29	0.59	0.068		
Co (PP)	24	14	3	8	4	1	1	1	2
Ni	21.10	n.d.	< 3.4	n.d.	< 2.8	2.9	6.7		
Ni (PP)	68	14	8	24	7	2	2	1	11
Zn	69.30	43.80	115.00	40.60	29.4	23.7	151	175	41
As	2.58	4.22	9.91	1.73	0.956	n.d.	1.18		
Sb	n.d.	0.349	0.67	0.46	0.404	n.d.	0.252		
Au	< 1.9	< 0.18	< 0.41	< 0.96	< 0.73	< 0.89	2.1		
Eu/Eu*	0.91	0.72	0.92	0.79	0.60	0.44	0.16		
Th/Ta	5.41	6.7	7.46	10.85	7.84	7.01	3.01		
La/Ta	44.5	31.6	41.2	45.6	30.2	22.4	19.1		
La/Yb	14.7	12.8	7.9	20.5	18.4	17.9	10.3	4.4	9.2
Zr/Nb (XRF)	18.8	33	>28.5	>14.8	>15.0	8.8	18.2	24.6	23.2
Ba/La	24.0	19.2	30.0	32.6	28.4	30.7	0.49	0.26	30.6
Ba/Nb (XRF)	53.3	50.7	>85.0	>70.0	> 64.0	60.8	0.98	0.26	115.8
Ba/Sr	0.77	1.49	3.10	0.99	3.94	11.37	> 1.90	5.6	15.5

Region	Central Chukotka sector						Anadyr sector				
Age	Senonian					Paleogene	Albian			Senonian	
Sample	PN-8-76	ЭЛ-3-20	PN-17-156	PN-8-75	PN-9-91	ЭН-1-1	PN-69-713	PN-70-723	PN-69-711	PN-84-908	PN-87-945
Component	19	20	21	22	23	24	25	26	27	28	29
SiO_2	51.20	52.96	54.76	59.65	62.90	51.70	53.49	55.26	59.10	49.70	54.63
TiO_2	1.00	0.85	1.16	0.92	0.63	1.08	1.06	1.05	0.28	1.17	1.39
Al_2O_3	17.00	16.64	16.53	17.15	15.21	16.66	16.85	17.73	17.80	19.96	17.69
Fe_2O_3	3.54	2.72	1.72	3.50	1.79	4.60	2.72	3.69	3.72	4.08	4.14
FeO	4.40	4.94	6.41	2.48	2.94	3.92	6.68	4.61	2.17	5.45	4.15
MnO	0.14	0.14	0.19	0.09	0.10	0.15	0.17	0.22	0.05	0.17	0.18
MgO	5.77	5.12	4.90	2.04	1.89	4.95	4.74	3.61	2.42	4.16	2.72
CaO	9.51	8.22	7.97	5.47	4.40	8.14	8.07	6.43	4.38	9.77	6.43
Na_2O	2.82	2.16	2.53	2.70	3.00	3.00	2.07	3.64	2.79	2.94	4.33
K_2O	1.32	1.62	2.00	2.79	1.60	2.00	1.70	1.88	3.03	0.62	2.83
P_2O_5	0.32	0.38	0.37	0.29	0.17	0.50	0.32	0.46	0.22	0.33	0.56
H_2O^-	1.80	0.99	0.62	0.72	0.50	1.53	1.03	0.64	1.38	1.29	0.88
H_2O^+	0.84	2.34	0.49	1.06	4.64	1.48	0.74	0.25	1.10	0.01	0.09
CO_2	0.02	0.98	0.28	0.61	0.01	0.02	0.04	0.02	1.10	0.02	0.32
Total	99.68	100.06	99.93	99.47	99.78	99.73	99.68	99.49	99.54	99.67	100.34
Nb (РФМ)	<10	<10	<10	<10	<10	<10	<10	10	<10	<10	<10
Rb(XRF)	38	42	65	97	134	38	38	46	82	12	32
Rb	38.90	40.80	70.40	103.00	126.00	34.70	44.90	45.80	82.90	6.36	33.60
Sr (XRF)	500	350	480	435	450	910	490	550	380	720	650

Sr	479	368	516	484	436	951	556	581	396	764	704
Ba (XRF)	350	550	650	760	800	620	380	510	670	325	670
Ba	320	576	655	749	761	651	384	482	678	328	687
Cs	0.27	3.02	2.24	3.19	17.30	0.59	0.49	0.60	2.72	0.39	0.38
Zr (XRF)	150	88	184	205	230	152	95	134	166	90	205
Zr	132	90	187	209	216	145	83	137	190	95	217
La	20.40	12.40	27.50	33.10	36.40	25.10	12.20	17.40	19.40	12.60	31.20
Ce	46.00	25.40	60.90	69.90	78.30	59.80	28.60	40.60	44.30	29.90	73.30
Nd	23	13.90	30.10	30.80	33.20	32.60	16.10	21.50	22.30	18.80	39.60
Sm	4.71	3.25	5.96	6.44	6.66	6.87	4.09	5.15	4.82	4.76	9.09
Eu	1.51	1.03	1.55	1.46	1.12	1.71	1.25	1.43	1.07	1.44	2.48
Gd	4.30	3.50	5.40	5.21	5.64	5.32	4.32	5.06	4.65	4.37	7.89
Tb	0.57	0.51	0.77	0.79	0.81	0.62	0.67	0.71	0.65	0.58	1.14
Tm	0.30	0.32	0.40	0.45	0.45	0.26	n.d.	0.42	n.d.	0.30	0.56
Yb	1.86	1.97	2.54	2.75	2.79	1.55	2.39	2.72	2.41	1.095	3.47
Lu	0.26	0.30	0.40	0.40	0.41	0.23	0.35	0.38	0.36	0.30	0.51
Y (XRF)	22	22	22	27	31	18	23	31	21	24	32
Hf	3.33	2.11	4.30	5.11	5.67	3.46	2.55	3.21	4.38	2.00	4.73
Ta	0.52	0.32	0.67	0.76	0.82	0.33	0.30	0.40	0.48	0.19	0.48
Th	4.15	3.15	6.99	10.60	14.20	4.25	2.14	2.69	6.16	1.42	3.47
U	1.15	1.31	1.92	2.89	4.16	1.52	0.85	1.06	2.51	0.47	1.10
Sc	24.40	29.60	25.50	17.30	12.80	22.70	28.90	20.20	19.500	30.60	21.40
Cr	176	110	214	20.90	23.00	132.00	83.40	16.6	21.30	18.40	20.00
Cr (PP)	180	90		34	25	115	69	34	24	13	15
Co	23.30	23.20	20.00	10.60	7.17	28.40	29.00	21.80	10.20	27.50	14.20
Co (PP)	27	27		12	8	25	25	18	8	40	12

Table 1 (continued).

Region	Central Chukotka sector						Anadyr sector				
Age	Senonian					Paleogene	Albian			Senonian	
Sample	PN-8-76	ЭЛ-3-20	PN-17-156	PN-8-75	PN-9-91	ЭН-1-1	PN-69-713	PN-70-723	PN-69-711	PN-84-908	PN-87-945
Component	19	20	21	22	23	24	25	26	27	28	29
Ni	18.10	17.00	14.00	13.00	<7.3	58.90	21.00	21.00	12.00	26.00	<11
Ni (PP)	34	19		13	14	87	21	21	12	26	10
Zn	94.20	77.30	90.30	78.20	71.50	95.10	89.80	88.30	67.40	111.00	111.00
As	0.79	8.11	25.30	5.58	11.30	1.75	0.89	n.d.	5.28	4.78	n.d.
Sb	n.d.	0.67	0.22	0.90	0.54	0.11	n.d.	n.d.	0,98	n.d.	n.d.
Au	<0.03	<1.2	<0.35	n.d.	<0.03	<0.03	<1.8	<1.3	<0.94	<0.56	<0.48
Eu/Eu*	1.01	0.93	0.82	0.75	0.54	0.83	0.90	0.85	0.68	0.95	0.88
Th/Ta	8.0	9.8	10.4	14.0	17.3	12.9	7.1	6.70	12.80	7.47	7.23
La/Ta	39.2	38.8	41.0	43.6	44.4	76.1	40.7	43.5	40.4	66.3	64.9
La/Yb	11.0	6.3	10.8	12.0	13.0	16.2	5.1	6.4	8.0	11.5	9.0
Zr/Nb	>15.0	>8.8	>18.4	>20.5	>23.0	>15.2	>0.5	13.4	>16.6	>9.0	>20.5
Ba/La	15.7	46.4	23.8	22.6	20.9	25.9	31.5	27.7	35.0	26.0	22.0
Ba/Nb (XRF)	>35.0	>55.0	>65.0	>76.0	>80.0	>62.0	>38.0	51.0	>67.0	>32.5	>67.0
Ba/Sr	0.67	1.56	1.27	1.55	1.75	0.68	0.69	0.83	1.71	0.43	0.98

Table 2 Geological and petrographical characteristic of representative rocks of basalt-bearing formations of CS OCVB.

No.*	Rock type and location	Complex; formation	Phenocrysts	Texture
1.	basalt; Razdol'naya R.	Varenaisky; Early Cretaceous	Pl, Cpx, Ol, Mt	Megaporphyry; microdoleritic with micropoikilitic
2.	trachybasalt Mutnaya R.	basalt-andesibasaltic	Pl, Ol, Cpx	Microglomeroporphyry, micropoikilophitic
3.	basalt, Kytepnayvaam R.	Medvedgensky (Ekitikinsky); Late Cretaceous	Pl, Cpx, Ol	Glomeroporphyry; microdoleritic with micropoikilophitic
4.	trachyandesitbasalt; Kytepnayvaam R.	trachyandesitic (trachyandesibasaltic-trachyrhyolitic contrasting)	Pl, Opx, Cpx, Mt	Seriate megaporphyry porphyry; hyalopilitic
5.	trachyandesite; Kytepnayvaam R.		Pl, Opx, Cpx, Hb	Glomeroporphyry and seriate porphyry; hyaline to microlitic
6.	trachybasalt; Valunisty Cr.	Tnekveemsky (Nunligansky, Tanyurersky); Paleogene	Pl, Ol	Microporphyry; intersertal with micropoikilitic
7.	trachybasalt; Mt. Vysokaya	trachybasalt-trachydacite-komendite-alkali granitic	Pl, Ol, Q (rare, xenocryst)	Seriate porphyry; intersertal
8.	trachybasalt; Kuropatach'ya R. basin		Pl (rare), Ol (rare)	Microporphyry; micropoikilophitic
9.	trachybasalt; Kuropatach'ya R. basin		Pl, Ol, Mt, Il	Megaporphyry; intersertal with microophitic
10.	trachyandesite; Kuropatach'ya R. basin		Pl, Ol, Cpx	Glomeroporphyry; hyalopilitic
11.	trachydacite; Stoybishchnoye Lake		Pl, Bi, Hb (?), Mt	Porphyry; microlitic to hyalopilitic
12.	trachydacite; Golubaya R. basin		Pl, Opx, Cpx, Mt	Glomeroporphyry; pilotaxitic
13.	rhyodacite; Il'myneyveem R.		Pl, Hb, Bi, Mt	Nevaditic; hyalopilitic
14.	trachyrhyolite; Gachgagyrgyvaam R.		Pl, Bi, Cpx, Mt	Seriate porphyry; microlitic with axiolitic; zeolitization

Table 2 (continued).

No.*	Rock type and location	Complex; formation	Phenocrysts	Texture
15.	trachyrhyolite; Il'myneyveem R.		Q, Bi, Pl, Mt	Glomeroporphyry; allotriomorphic granular
16.	comendite; Korotkaya R.		Anort	Seriate microporphyroid; microhypidiomorphic granular: Hed, Arf, Aeg- Aug, Q, Fsp, Engm
17.	comendite; Mt Greben		San, Q, Arf	Megaporphyry; microhypidiomorphic granular with granophyric
18.	alkali granite; Volch'ya R.		Q, Fsp, Pl (rare), Arf (rare.), Mt (rare)	Porphyroid granophyric
19.	basalt; Kookvyn R.	Koekvun'sky; Late Cretaceous andesibasalt–andesitic	Pl, Opx, Cpx	Seriate porphyry; microlitic
20.	andesibasalt; El'gygytgyn Lake		Pl, Opx, Cpx, Mt	Microporphyry; intersertal
21.	andesibasalt; Kookvyn R.		Pl, Cpx, Opx (?), Mt	Microporphyry; intersertal
22.	andesite; Kookvyn R.		Pl, Opx, Cpx, Mt, Q (xenocryst)	Nevaditic glomeroporphyry; hyalopilitic
23.	Ignimbrite of andesitic dacite Kookvyn R. eutaxitic		Pl, Opx, Cpx, Bi, Mt, Il	Pyroclastic, pseudofluidal; ignimbrite-ashy
24.	trachybasalt; Mechekrinnetveem R.	Emivansky; Paleogene (?); trachyandesibasaltic	Pl, Opx, Cpx, Ol, Mt	Microporphyry; microdoleritic with trachybasalt-intersertal sanidine
25.	basaltic andesite; Mechkereva R.	Salamakhinsky; Early Cretaceous basalt - andesibasaltic—andesitic	Pl, Cpx,	Microporphyry; intersertal
26.	basaltic andesite; Mechkereva R.		Pl, Opx, Mt	Porphyry; microdoleritic
27.	andesite; Mechkereva R.	Vilkovsky; the same	Pl, Opx, Cpx, Mt	Seriate porphyry; microlitic

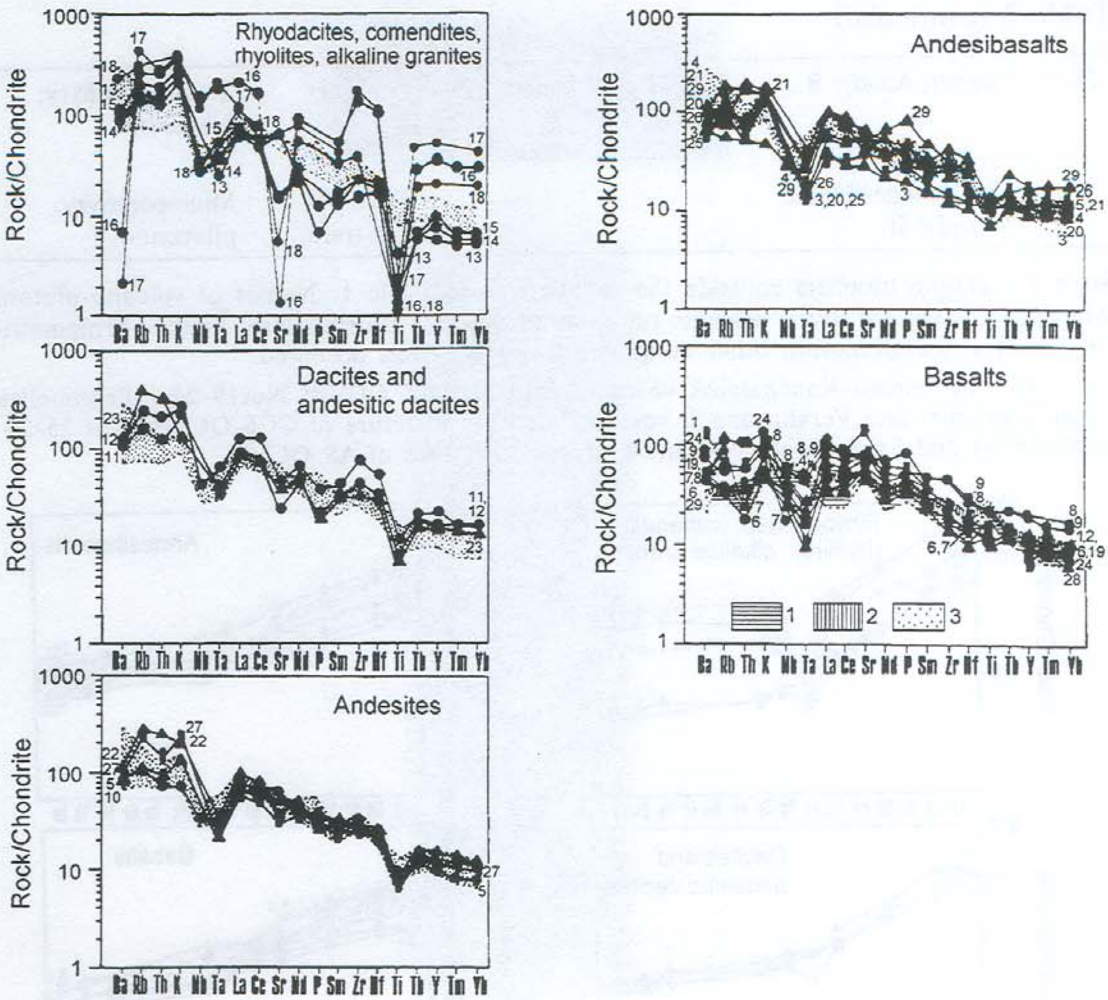

Fig. 3 Spider plots of rare and incompatible elements normalized to the chondrite composition [50], for the rocks of basalt-bearing formations of CS OCVB.

1-3 - the fields of different in age volcanic rocks of Yukon-Kuskokvim region of Alaska (E.J.Moll-Stalcup, unpublished data): 1 - basalts of Neogene-Quaternary Bering volcanic province, 2 - basalts of Paleogene volcanic field of Nukluk, volcanic belt of Mts. Kuskokvim. Other symbols as in Fig. 2.

Trachyandesites, trachydacites and trachyrhyolites from basalt-bearing formations are notably more enriched in REE, and also have still greater ratio of light REE to heavy ones in comparison with basic rocks. In particular, the means of La/Yb is about 6-10 for basalts and trachybasalts, 8-15 for trachyandesibasalts and trachyandesites, and 18-21 for most acidic rocks. At the same time, the enrichment factor of the rare-earth spectrum by light lanthanides in trachydacites of Paleogene contrast formation is close to the one in trachyandesibasalts and trachyandesites of the same formation. Comendites of the contrast formation are distinguished by sharp relative enrichments of practically all REE spectrum. Thus, it is rather indicative that comendites represent the only rock type with clearly pronounced europium anomaly. Paleogene alkali granites have an intermediate position between comendites and trachyrhyolites of the same age on the spider plots.

On the whole, REE distribution in most examined rocks is typical for calc-alcaline and subalkaline series. These derivations are distinguished by high total REE (predominantly, at the expense of light lanthanides), direct correlation of total REE and alkalinity, regular lowering values normalized to chondrite of the element contents, in accordance with increase of their serial number. Geochemical specificity of calc-alkaline and subalkaline basaltoids and andesites (quite often - and moderately silicic rocks) of CS OCVB is related to absence of europium minimum in it, something that distinguishes these rocks from derivations comparable in basicity with formations of ensyalic island arcs.

An interesting property of Eu behavior in studied acid rocks is the negative correlation of the europium anomaly with CaO contents observed in some samples. Possible causes of this phenomenon are examined below in discussion of results.

Geochemistry of Incompatible Elements

Contents of incompatible elements were normalized to the chondrite composition in accord with [52] (Fig. 3). Elements on this type of spider plot are located by increasing degree of compatibility with mantle rocks, from left to right, according to Norry and Fitton [45]. In the figures, with the purpose of matching, spider models of incompatible element distributions in Alaska* volcanic rocks: Late Cretaceous suprasubductional andesite rocks, Paleogene intraplate and Neogene-Quaternary - “typical intraplate” basalts are represented.

It is apparent from the diagrams that all intraplate basaltoids of Alaska have characteristic peaks on Nb and Ta, which, as follows from [45], are typical of continental and oceanic provinces of alkali basalts. On the contrary, in Late Cretaceous volcanics of Yukon-Kuskokvim region of Alaska, no less than in all Early and Late Cretaceous basaltoids of the CS OCVB, clear negative anomalies on Nb and Ta are observed, and only Paleogene high titanium trachybasalts of CS OCVB (for example, IL - 3-13, IL - 3-14 from Table 1) are characterised by peak contents of these elements. The model of incompatible element distributions in these rocks is rather similar to those

---

*E.J. Moll-Stalcup, unpublished data of Cretaceous and Neogene-Quaternary volcanic rocks of Kuskokvim volcanic belt [44] and volcanic area of Yukon river basin. As to some Russian researchers opinion [21, 33, 46, etc.] and ours, Cretaceous rocks of Kuskokvim Mountains belong to possible prolongation of OCVB on West Alaska. There are other views about its nature [5, etc.].

for Paleogene and Neogene-Quaternary intraplate basaltoids of Alaska. Paleogene moderate titanium basalts of CS OCVB, besides Nb and Ta depletion, differ from intraplate basalts of Alaska by relative enrichment of the most incompatible elements: Rb, Ba and K (this is characteristic for high titanium trachybasalts). The spectrums of moderately and feeblly incompatible elements in all basalts of CS OCVB either are a little bit more enriched, or are in equivalent to the spectrums of Paleogene and Neogene-Quaternary basalts of volcanic belts and zones of Alaska.

A comparison of andesitic and acidic rocks shows, on the one hand, a similarity of distribution models of the majority of moderately and feebly incompatible elements (except for Sr, Ti and P) in suprasubductional volcanoes of Alaska and, on the other, most of those close to them in basicity rocks of basalt-bearing formations CS (except alkali rocks). Contents of the most incompatible elements (except for Ba) of CS OCVB essentially exceed those in Alaska rocks.

A comparison (according to SiO_2 contents) of basalt-bearing formations of CS OCVB different in age and basisity demonstrates a particular similarity of distribution models therein of incompatible elements. However, there are some features that should be emphasized.

1. The contents of most incompatible elements (from Ba up to Ce, see Fig. 3) is considerably increased from basic rocks, through andesitic and moderately acidic ones, up to the most acidic rocks, respectively.

2. The spider models for Paleogene basalts and trachybasalts differ from models for Early and Late Cretaceous basaltoids (in comparable on SiO_2 samples) by smaller negative anomalies on Nb and Ta; in high titanium Paleogene trachybasalts, as it was already mentioned, this negative anomaly usually misses.

3. Paleogene comendites are sharply distinguished among all types of the examined rocks with the extremely low Ba contents (2-7 times exceeding the chondritic one), high positive peaks on Nb, Ta, Zr, Hf, and profound negative anomalies on Ti, P and Sr.

4. Deplication on Ti, P and Sr, though not so sharply expressed as in comendites, is a characteristic feature of the majority acidic and moderately - acidic rocks of the basalt-bearing formations of CS OCVB.

5. On the contrary, the basic rocks (especially, Paleogene rocks), are characterized by the positive anomaly on Sr and P, and slightly smaller in respect to Ti.

DISCUSSION OF RESULTS

The analytical data in Table 1 and the spider plots of rare-earth and incompatible elements show that Early and Late Cretaceous rocks of

CS OCVB, as well as Late Cretaceous volcanics of Alaska are characterized by so-called "suprasubductional" geochemical features. These are: Large Ion Lithophils (LIL) and light REE enrichments compared with high energy field elements of (including, heavy REE), negative Nb-Ta anomalies, moderate and low concentrations of Ti, P and Zr, at heightened and high values of Zr/Nb, Ba/La, La/Ta, Th/Nb and K/Nb. The current idea is that such compositions can be formed due to: a) contamination of "a mantle wedge" above the subduction zone by H_2O-SiO_2 alkali fluids ascending from dehydrated oceanic plate, or b) as a result of repeatedly melting basalts, with extraction of incompatible elements [27], or c) partial melting of amphibolites [39].

Most Paleogene basalts and trachybasalts show such compositional features, which are characteristic of Cretaceous basaltoids as well. They are the enrichment by high incompatible and light REE elements, and less by feebly incompatible and compatible elements. However, these features in rocks of Paleogene formations are exhibited in milder form than in Cretaceous. Normalized graphs of Paleogene high Ti trachybasalts have peak values of Nb and Ta contents, relatively alkali and light REE. The same rocks are characterized by low values of the reference-point ratios: Zr/Nb, Th/Nb, K/Nb, Ba/La, La/Ta at high contents of Zr, Nb, Ta, La, that is in the complex they reveal typical features of intraplate lavas [15,43,49,52]. High concentrations of Zr, P and Ti, high values Ni/Co and Zr/Y are present also in all Paleogene basalts and trachybasalts; this is significant in distinguishing them from "suprasubductional" lavas to make them close to rocks of continental rifts. However, as it will be shown further below, on an absolute level of typical elements, the majority of Paleogene basaltoids can nonetheless be compared not with representative of intraplate volcanics but only with lavas of marginal continental rifts.

The acidic alkali rocks of Paleogene trachybasalt-trachydacite formation are completely similar to acidic magmatic rocks of typical intraplate bimodal associations [35, 36]. The andesitic and moderately acidic derivations of Paleogene are intermediately positioned between intraplate and suprasubductional ones (judging by some peculiarities); on the other hand, they are similar to suprasubductional rocks.

The most convincing reasons for the afore-mentioned supposition about the "subductional" origin of Cretaceous basalt-bearing formations of CS OCVB and rifting Paleogene formations were confirmed by the positions of the figurative points of their rocks in the discrimination diagrams shown below.

Wood's Th-Hf-Ta diagram [53] is highly indicative in this respect, representing, as the author suggests, discontinuity in the lithosphere, yet one not depending on variations of rock compositions stipulated by degree of partial melting or fractionation processes. In this diagram (Fig. 4), figurative points of basalts of Cretaceous formations are plotted in a field of typical suprasubductional derivations ("compression field"). Their position is compounded by a model showing the origin of basalts from initially depleted mantle source subsequently enriched "with subduction component". The points of Paleogene basaltoids are allocated close to the trend of the enriched mantle source of intraplate enviroment and tension zone and disposed in fields of basalts of spreading zones and margin continental rifts. A similar situation is observed in the TiO_2-Zr (Fig. 5) and Ti/Cr-Ni (Fig. 6) diagrams. The majority of the examined samples of Cretaceous basalt-bearing formations are allocated on the mentioned diagrams in fields of lava of volcanic arcs, that is suprasubductional ones. Most of the points of Paleogene origin are found in the fields either in intraplate rocks or rocks from spreading zones.

The correlations of Th, Ta and La concentrations, widely used as a criterion for magmatic series, typomorphic for specific situations, also emphasize that

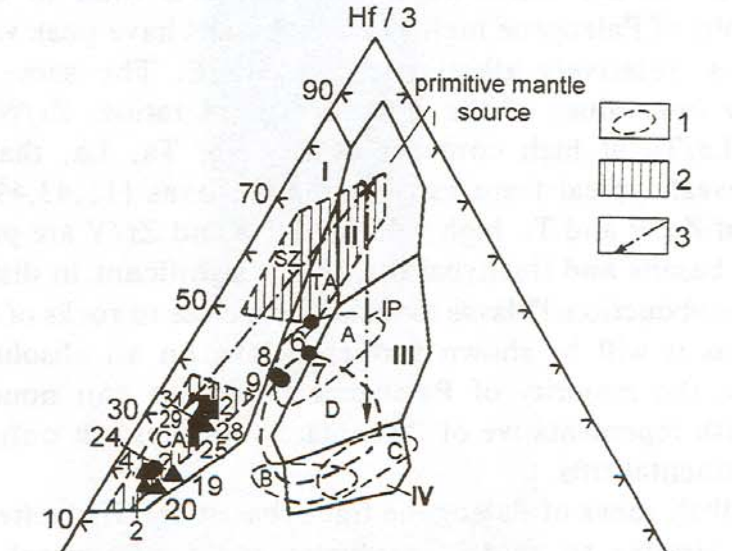

Fig. 4 The Th-Hf-Ta classification of Cretaceous and Paleogene basaltic rocks of Chukotka.

1 - the fields of basalt contents from different regions [8], A - margin continental rift of Rio Grande; B - basalts of marginal sea - Oki-Dogo I., Japan; C - Cenozoic subalkaline and alkaline basalts of Mongolia and Zabaykalie; D - Late Cenozoic intraplate basalts of Kamchatka. 2 - the fields of basalt contents from different settings; CA - compresion area; TA - tension area. 3 - enrichment trends of moderate depleted mantle: IP - in intraplate setting; SZ - over subduction zone. I-IV - the fields of basalt contents from different geodynamical setting: I - volcanic arcs, II - mid-oceanic ridges, III - mid-oceanic ridges and intraplate settings, IV - intraplate settings. 2 - from [18, v.3], 3, I-IV - from [53]. Other symbols as in Fig. 2.

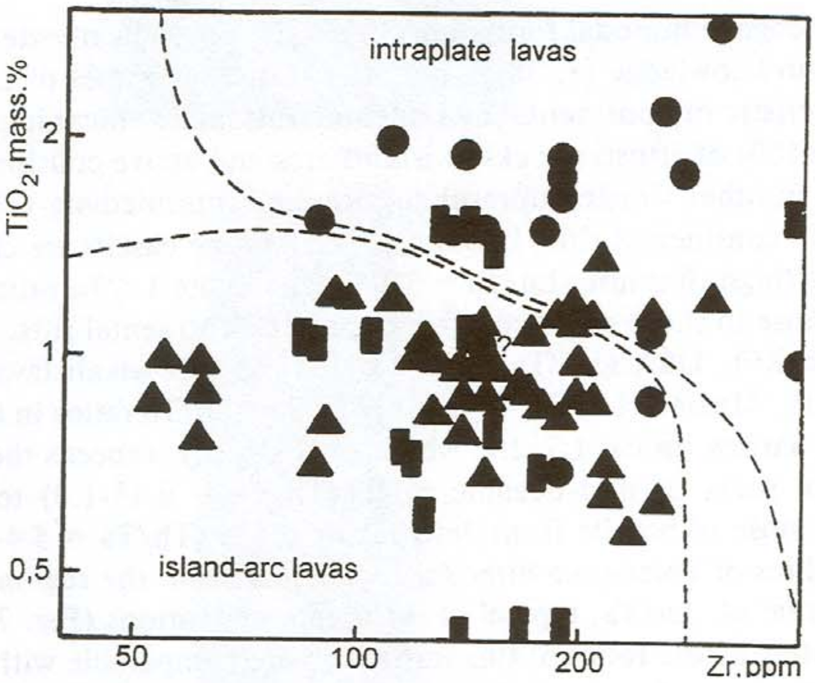

Fig. 5 The TiO_2-Zr discrimination diagram, [49]. Other symbols as in Fig. 2.

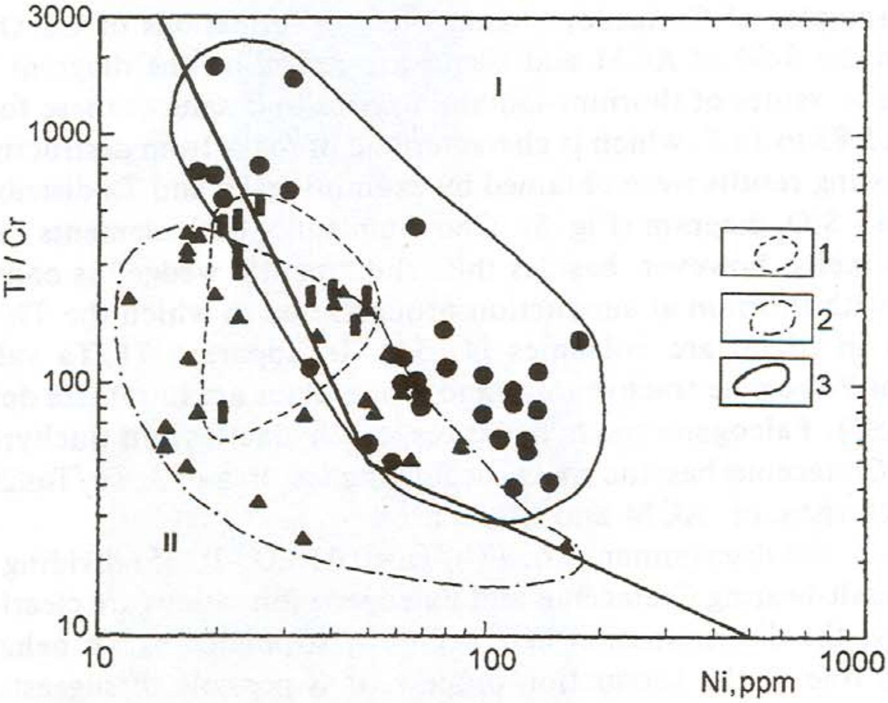

Fig. 6 The Ti/Cr-Ni diagram for Cretaceous and Paleogene basalts of Chukotka segment of OCVB.

I-II - fields of basalt contents from different geodynamical situations, according to L. Bekkaluva, etc. [18, v.6]: I - spreading zones in oceans and marginal seas, II - island arcs. 1-3 - the fields of the rocks of basalt-bearing formations of CS OCVB: 1 - Early Cretaceous; 2 - Late Cretaceous; 3 - Paleogene. Other symbols as in Fig. 2.

rocks of Paleogene bimodal formations belong to products of extension zones. It is common knowledge [8, 38, 41, etc.] that the low values of La/Ta (< 20) are characteristic of continental and oceanic intraplate volcanics, high values (25≤La/Ta≤100) of effusive rocks of island arcs and active continental margin (ACM), or in other words, suprasubduction and intermediate values of lavas from margin continental rifts. In our case, Paleogene basalts are characterized by Ta ratios (high titanium: La/Ta = 33-34; moderate La/Ta ratios = 41-48), which are close to those of basalts from margin continental rifts: tholeiites of Rio Grande Rift, USA (La/Ta = 15-35) [38] or calc-alkali lavas of Tepic-Zacoalco Rift, Mexico (La/Ta = 17-56) [41]. The Th/Ta ratios in these basalts vary within narrow limits: 1.7-2.7, which only slightly exceeds the interval of variations in rocks of mid-oceanic ridge (Th/Ta = 0.45-1.3) to essentially differ from those of basalts from destructive zones (Th/Ta = 5.4-21) [47].

Comendites of Paleogene bimodal formation from the region are similar in value to that of La/Ta, typical of intraplate derivations (Fig. 7); andesitic and moderately acidic rocks of this formation are comparable with near-basic ones, Cretaceous volcanic rocks (suprasubductional) from basalt-bearing formations.

Lava samples of Cretaceous basalt-bearing formations of CS OCVB are located in the field of ACM and island arc rocks, on the diagram "La-Ta" (Fig. 7). The values of thorium-tantalum ratios in basalts of these formations vary from 5.83 to 14.7, which is characteristic of rocks from destructive zones.

Interesting results were obtained by examining Th and Ta distribution on the Th/Ta - SiO_2 diagram (Fig. 8). Geochemically, both elements can enrich intraplate melts; however, besides this, the "mantle wedge" is considerably enriched with thorium at subduction process, due to which the Th/Ta ratio is highest in island arc volcanics [47,54]. In apparent Th/Ta values, the majority of Paleogene trachybasalts and comendites are intraplate derivations (1≤Th/Ta≤3), Paleogene trachyandesites, trachydacites and trachyrhyolites, as well as Cretaceous basaltic rocks, occupying an area of 3<Th/Ta≤25 values, are characteristic of ACM and island arcs.

In Fig. 8, the discriminant line ($Th/Ta=0.41SiO_2-16.35$) dividing fields of rocks of basalt-bearing Cretaceous and Paleogene formations are clearly visible. Apparently, the discrimination here is chiefly stipulated by Th behaviour. In view of its role in the subduction process, it is possible to suggest that the above-said discriminant line divides fields of rocks from different sources, namely those that had undergone and not undergone deep (high-grade) metasomatism, i.e. suprasubduction and intraplate development in origin. Furthermore, it is obviously possible, with accumulation of sufficient information, to use the afore-mentioned discriminant for dividing rocks of suprasubduction and postsubduction origin with all OCVB limits.

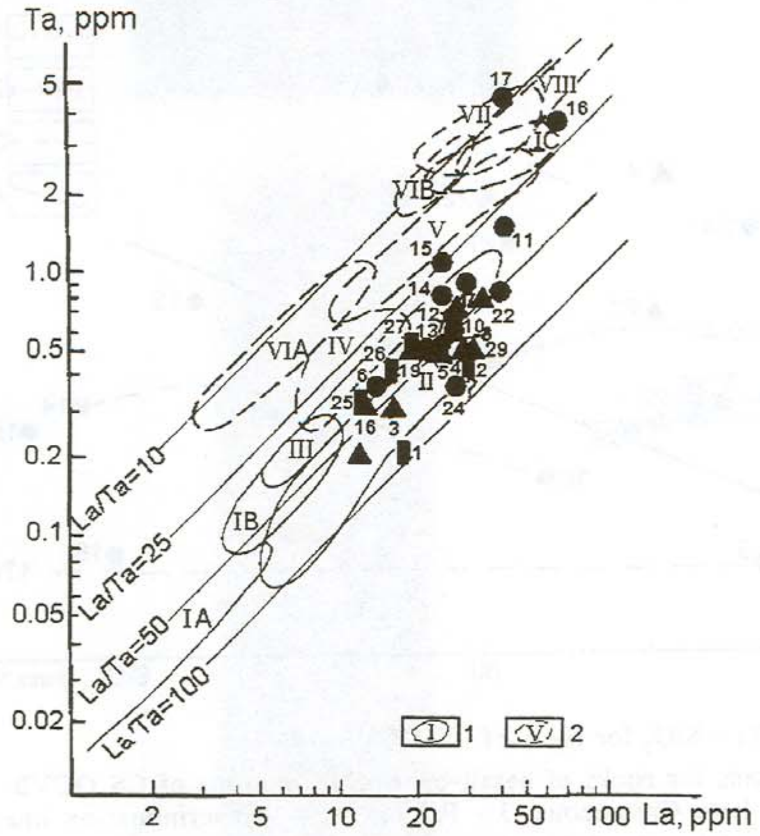

Fig. 7 Ta and La relation in rocks of basalt and bimodal series of Chukotka and other regions.

1-2 - the fields of rocks, according to [8]: 1 - island arcs and active continental margins, 2 - within-plate associations. Abbreviation inside contours: I - Japan: A - tholeiitic basaltic andesite series, B - high aluminous basaltic dacite series, C - trachybasalt-trachyte-rhyolite series of Oki-Dogo I.; II - calc-alkaline basalt-rhyolite series of south Chile; III - calc-alkaline basalt-rhyolite series of Santorin I.; IV - basalts of Rio Grande rift; V - alkali olivine-basalt-trachyte-rhyolite series of Sardinia I.; VI - basalts of Hawaii-Emperor ridge: A - tholeiitic, B - alkaline; VII - subalkali and alkali basalts of Mongolia and Zabaykalie; VIII - alkali olivine-basalt-trachyte-pantellerite series of East Africa rift. Other symbols as in Fig. 2.

The thorium-tantalum ratio also allows to make conclusions about the quality and nature of types of initial melt sources [8]. Basing on the closeness of Th/Ta values in rocks of Cretaceous formations of CS OCVB, one may suspect that they had certain close types of sources enriched at subduction processes. Conversely, with 3-5 times smaller values of this parameter in comendites and in the majority of examined Paleocene basalts testify to their obviously diverse source feebly enriched with thorium. At the same time, the chydacite-trachyrhyolite assemblage of Paleogene bimodal formation shows

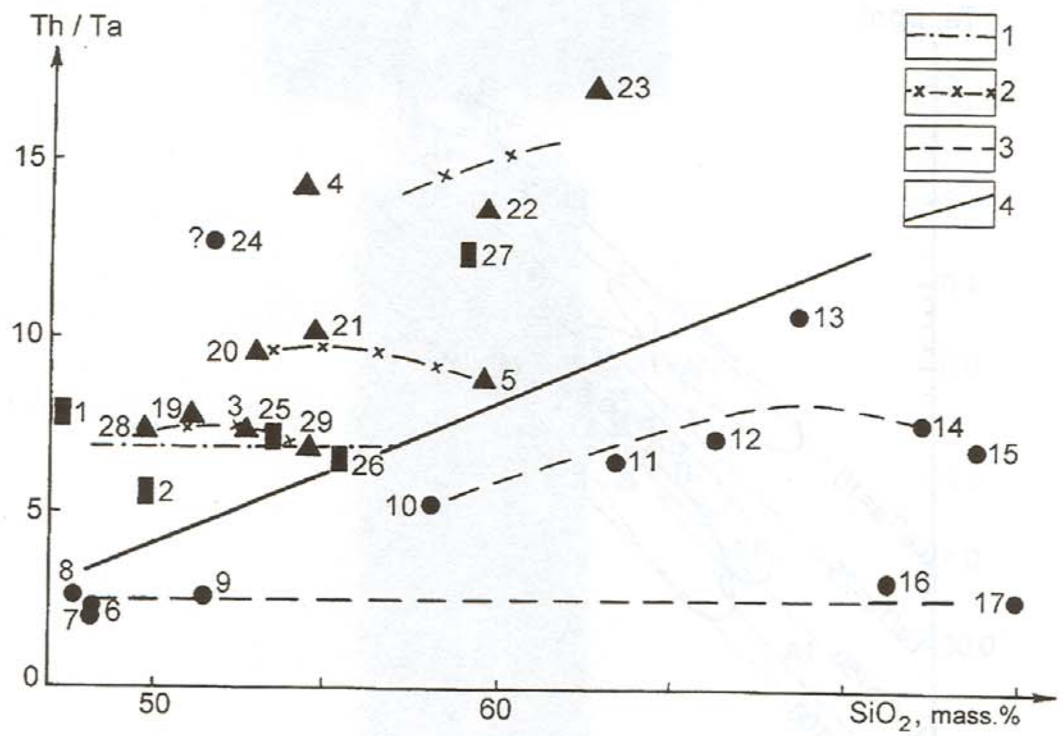

Fig. 8 The Th/Ta - SiO_2 for rocks of CS OCVB.

1-3 - Th/Ta trends for rocks of basalt-bearing formations of CS OCVB: 1 - Early Cretaceous, 2 - Late Cretaceous, 3 - Paleogene. 4 - discrimination line: Th/Ta = $0.41SiO_2$-16.35 dividing the fields of Cretaceous and Paleogene rocks. Other symbols as in Fig. 2.

similiarity with Cretaceous derivations as the source type (enriched with thorium). Possibly, this fact is indicative of the heterogeneity of the rock source in the given association.

Knowledge of the behavior of Th and Ta would be highly important for understanding the features of petrogenesis shown in so-called "diagrams of Th-Ta identification process"* (Fig. 9). In these diagrams, points of three samples of Paleogene basalts and two of comendites show a trend close to the line of assimilation-fractional crystallization of basic melt of derivate of intraplate source. The rock compositions of Paleogene trachydacite-trachyrhyolite series contrast formation show a trend close to that of assimilation of fractional crystallization, but already of trachyandesitic melt. Stemming from the diagram, the basic and andesite - moderately acidic melt formations

---

*Use of this type of diagram is based on the ratio of more incompartible element to less incompartible that remains constant or increases weakly under melt fractionation in closed system but relatively quick decrease under growth of partial melting source [37, 42].

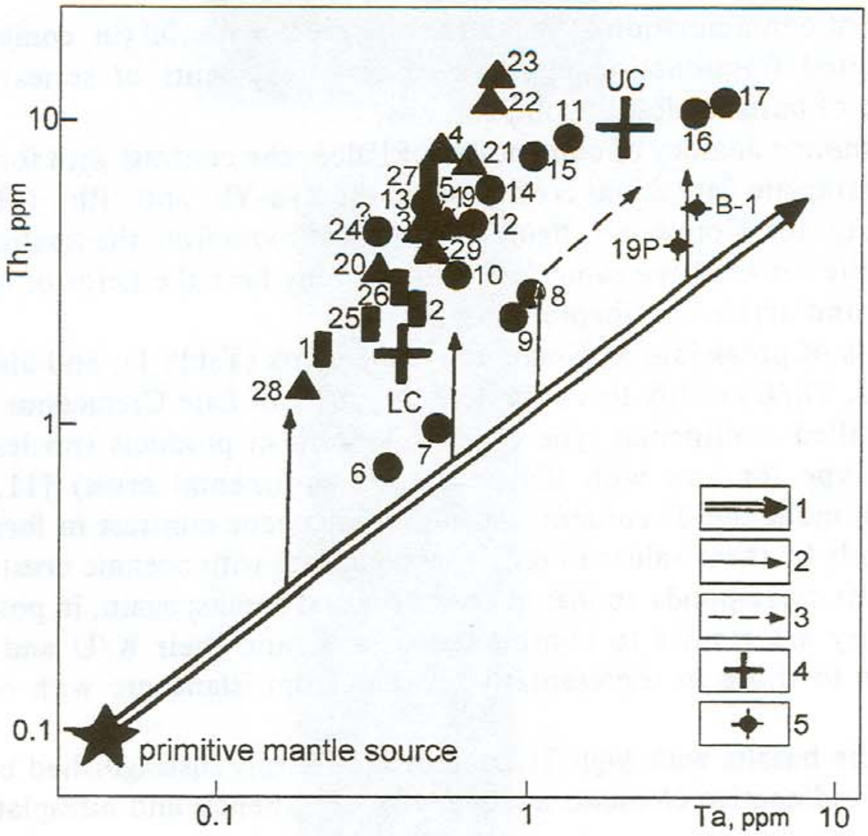

Fig. 9 The Th-Ta diagram of process identification.
1 - variations of within-plate source; 2 - source variations connected with subduction; 3 - assimilation-fractional crystallization trend; 4 - Bulk Earth: LC - lower crust, UC - upper crust, 5 - alkali basalts of Andes. (1-3 - [54]; 4,5 - [51]). Other symbols as in Fig. 2.

depend on belt foundation constitution. Similar zonation allows to distinguish separate sectors or OC fragments influencing crust material on the composition of their initial melts.The genesis of the comendites is ambiguously treated in the given diagram. On the one hand, they can be considered as high-grade differentiates (or liquants) of basalt magma, close in composition to the basalts associated with them, and on the other as a thorium-enriched product with small degree of of partial melting of intraplate source similar to that of some types of alkali basalts, for example Andes-type [47] (see Fig. 9). This assumption is also confirmed by extremely low Ba concentration in the comendites. The apparent closeness of Th/Ta values to those in Paleogene basalts and comendites (show the unity of their magma source), no less than the anomalously high contents of zirconium in the comandites apparently correspond to both variants.

The distribution of figurative points of Cretaceous basaltoids* in the diagram conform to the subduction-bound genesis of their primary basalt melts, and to subsequent contamination of the latter with crust matterial (in combination with restricted fractionation over rather short segments of series) till to appearance of basic-andesitic compositions.

The complete analogy of comendites of Paleogene contrast with formation of typical intraplate derivations is observed in the "Ta-Yb" and "Rb - (Yb+Ta)" diagrams (Fig. 10). Conversely, figurative points of rocks from the trachydacite-trachyrhyolite series of the same formation occupy here the fields of rocks of island arcs and active continental margins.

Contents of potassium and radioactive elements (Table 1), and also their ratios (K/U, Th/U) testify to a complete similarity of Late Cretaceous basalts to the so-called continental type of basic volcanism products (no less than island arc type for arcs with the developed continental crust) [11, etc.]. Basalts with moderate Ti contents dating to Paleocene contrast in formation approximately by these values to rocks of island arcs with oceanic crust. Their REE contents corresponds to that in oceanic island basalts; again, in potassium contents they are similar to continental basalts, and their K/U and Th/U values close to those in representative basalts from island arc with oceanic crust.

Paleogene basalts with high Ti content are sharply distinguished by high contents of radioactive elements adequate for continental and intraplate type volcanism.

In K/U values, Early Cretaceous basalts occupy an intermediate position between Late Cretaceous and Paleogene ones, but they are similar to Late Cretaceous basalts with respect to other parameters examined above.

In finalizing the discussion of results, we pay attention to the question of the origin of the negative correlation, indicated in the previous chapter, between values of europium anomaly with CaO contents. By solving this issue, we shed light on the origin of acidic alkali rocks of bimodal formation.

---

*Early and Late Cretaceous trachyandesite and trachybasaltic andesite samples occupy a special position on Th diagrams. They have petrographical signs of crust assimilation (PN-8-75 from Koekvunsk structure of CCS contains small inclusions of "resorpted" xenogenous quartz) and potassium metasomatism influence with Th and K supply (PN-19-176 sampled on a flank of "Valunistoe" (ECZ) ore field has no visual metosomatic signs). Obviously, such samples can not be taken as the principle for correct petrogenetic conclusions. The question about high Th content in Paleogene (?) basalt sample from Mechekrinnetveemsk basalt field (CCS) (it is showed with "?" mark on the diagrams) remains unsolved. This sample on Th diagrams plots "suprasubduction" volcanic fields due to high Th content. It is close to the "suprasubduction" volcanics because of relatively low TiO_2 (about 1 mass.%) and high La/Ta (76). These facts as well as recently obtained Late Cretaceous age of the basalts sampled at Enmivaam and Mechekrinnetveem river basins lead to the conclusion about the basalt mentioned area belong to Late Cretaceous (suprasubduction) formation instead of Paleogene (postsubduction) one. Notably, Maastrichtian-Danian age of Enmivaam suite has been early indicated by N.I. Filatova [33].

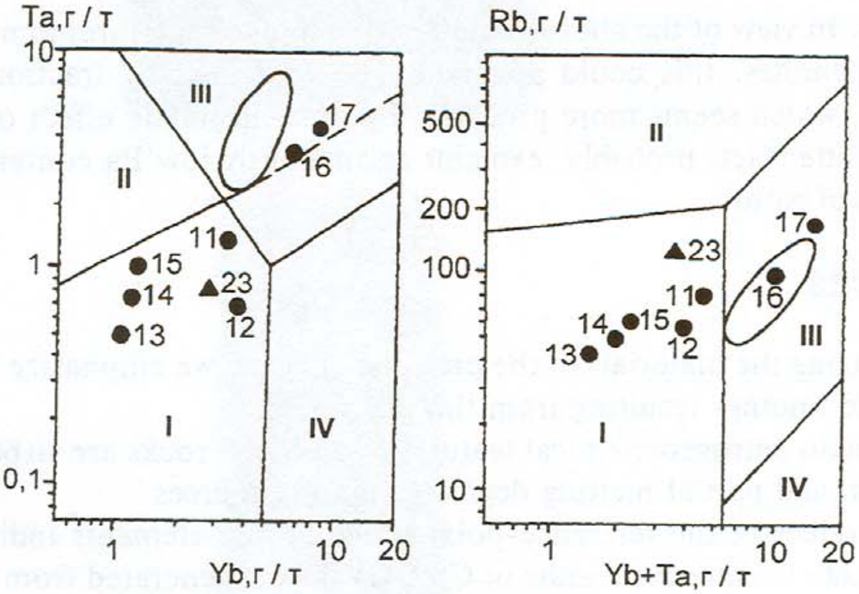

Fig. 10 The discrimination diagrams for granites [48] showing the fields I - island arc granites, II - collisional granites, III - within-plate granites, IV - ocean-ridge granites. The contour - the field of alkali-olivine-basalt-trachyte-comendite series of Kamchatka [8]. Other symbols as in Fig. 2.

This phenomenon could apparently not be explained without examining the causes of europium anomalies in general. It has now become generally acceptable to link europium minimum to plagioclase fractionation from a melt or with magma melting from material with residual plagioclase paragenesis ("gabbroid mantle"). At the same time, as some contributors justly note, this explanation seems highly improbable because these hypothetical plagioclase remainders were not detected anywhere by anybody. Basing on experimental data, V.A. Zharikov proposed an explanation of this phenomenon [10], which seems to us more substantiated than "the plagioclase mechanism". The distribution of trivalent europium is essentially similar to the behavior of representative lanthanides; divalent europium behaves as an element similar to alkali-earth elements. In case of rise in acidity (for example with effect of post-magmatic acid fluids), there is a shift of oxidizing-reduction reactions in the more reduced forms. Thus, europium passes in the divalent form, readily taken out by a fluid from a melt. In this situation it would appear that the behaviour of earth metal oxides, primarily CaO, connected with divalent Eu by ratios of isomorphism, as will be shown by appearance of negative correlation between the Ca contents and value of europium minimum. In that situation, when Eu remains in a melt in the tetravalent form (in absence of metasomatic effect of acid fluids or with high oxygen fugacity), europium minimum will be absent. Absolute Eu contents in a rock would in any case be logically explained by presence therein of composition of the main mineral-concentrator, plagioclase. In view of the above-mentioned fact of abrupt europium anomaly in the comendites, this could apparently be explained by fractionation of feldspar or, which seems more probable, by post-magmatic effect of an acid fluid. The latter fact, probably, explains anomalously low Ba contents in the comendites of barium.

INFERENCES

In summarizing the materials of the previous chapter, we emphasize the main petrogenetic findings resulting from this discussion.

1. The main petrogeochemical features of all basalt rocks are stipulated by composition and partial melting degree of mantle sources.

2. The values of the reference-point ratios of rare elements indicate that Early and Late Cretaceous basalts of CS OCVB were generated from depleted mantle variously contaminated by "subduction component".

3. The same relations for Paleogene basic rocks testify to their fusion, or from a less depleted source or at a smaller degree of partial melting. With the first supposition, the values of such relevant petrochemical characteristics, as alkalinity, femic index and titanium index of these rocks are in poor agreement [14, 24, 33, etc.]. The subalkaline character and high femic index of Paleogene basaltoids, with their simultaneously high alumina index testify to the fusion of their initial melts at much reduced water activity (and boosted carbonic acid activity) of equilibrium fluid in conditions of basic melts fusion in Cretaceous time. The high titanium and melanocratic indices of Paleogene basalts and trachybasalts are likewise indicative of the large depths of derivation of basalt magmas in Paleogene in comparison with Cretaceous.

4. Basic rocks of Paleogene contrast in formation of CS OCVB in the composition and time of manifestation to occupy an intermediate position between suprasubductional Early and Late Cretaceous basalts of the same structure, on the one hand, and intraplate Neogene-Quaternary basaltoids of Bering volcanic province [19], on the other. This allows to assume that the basalts of Paleogene formations of CS OCVB originated from melts in a composition similar to Bering province basalts, but slightly transformed by interaction with crust material heated by prior magmatic processes or those resulting at the greater degree of source melting.

5. Petrochemical and mineralogical parameters of volcanics of Paleogene basalt-andesibasaltic and contrast formations of CS OCVB are not compounded with the idea about them being accessory to a uniform number of calc-alkaline type formations of active continental margin. In rock composition, Paleogene basaltic and bimodal magmatism is closer to rift intraplate magmatism than to ACM or island arc magmatism. M.N. Zakharov *et al.* made a similar

conclusion earlier for Paleogene basaltoids of Okhotsk member of OCVB [12].

6. High-alumina basites and mesites (semi-basic rocks) of Cretaceous and Paleogene basalt-bearing formations of CS OCVB are not interlinked by fractional differentiation ratios, and are products of independent melts. This is proven by the nature of REE spectra and incompatible elements; by absence in both type rocks of any significant europium minimum; by absence of correlations for titanium and zirconium; by difference of Th/Ta values and other reference-point ratios of trace elements, and also by a number of other factors discussed earlier by the present author [24].

7. Essential mineralogical and geochemical distinction between trachyandesite-trachyrhyolite and comendite - alkaline granite associations from Paleogene contrast in formation to testify to radical distinctions in their petrogenesis. A subalkaline acidic association was probably formed at close interaction of basalt melts (transition and intraplate geochemical types) with crust material, probably, by "paratectonic process" (on [9]). The comendites and the alkali granites can be considered or as high-grade differentiates of trachybasalt magma, or as products of low degree of mantle source melting, something common with the trachybasalts.

CONCLUSION

A geochemical study of different-age basalt-bearing formations of CS OCVB has shown them to be generated in various geodynamic conditions.

In composition of volcanic rocks of Cretaceous stages of volcanic belt generation, apparently conditions of active continental margin were displayed. This conclusion agrees with available tectonic reconstruction, according to which [13, 21] in Early Cretaceous time, probably, as a result of disclosure of the Northern Atlantic, continental plates of North America and Northeast Asia became active. Their movement, as well as the prolonged movement of Kula plate resulted in the folding and origination of dipping at low angle zones of Benioff along a newly generated continental margin. During this regime of dominating compression*, basalt-bearing OCVB formations formed in Early Cretaceous. The source of magma at that time was, judging by the composition of products, located in the mantle upper horizons, within limits of the so-called "mantle wedge".

---

*However, this does not exclude the presence of expansion zones alternating with compression zones along lateral. Possibly, the variation of basalt composition in the formation can be explained by this fact.

In Late Cretaceous, according to geological data, the compression still existed [13, etc.], but its extent and duration in OCVB were greater due to the assumed approximation to Benioff zone of a section of oceanic crust with abnormal constitution [33]. Apparently, as a result caused by that period, basalt melts had even more distinct features of suprasubduction derivations than in Early Cretaceous.

Obviously, on the boundary of the Late Cretaceous - Paleogene subduction had completely stopped due to abrupt modification of mutual movement of continental and oceanic plates [30,32 etc.] from frontal (thrust-underthrust) to relative - parallel (strike-slip). The boundary of the plates that dips at low angle in the subduction period is replaced at this time by subvertical, probably of transform type. Generated as a result of even smaller amplitude, but abrupt shift dislocations (or motions along transform faults) the near-shift structure of the extension [29, 32, etc.] as a result could could have been rather deep, as shown in [29]. Thus, in the field of progressing depth pre-shift magmatic chambers could have developed filled pulsewise during the entire period of active compression [29].

Clearly, it could be that as a result of pre-shift rifting mechanism in Early Paleocene there was a "jump" of a magma generation zone from a mantle wedge field to a mantle asthenosphere zone. In our view, the reality of such rift origin was confirmed by the local character of apparent manifestations of Paleogene basalt, one displaying magmatism in Okhotsk-Chukotka volcanic belt. Significantly, some OCVB contributors treated this fact as evidence of accessory Paleogene volcanism to "dissipated-type rift volcanism", as exemplified by Okhotsk member [12].

We associate the occurrence in Paleogene of limited OCVB of bimodal formation (remarkably advanced exclusively within limits of blocks with thick continental crust) with possible delay of basalt magmas coming from an asthenosphere source heated up by prior suprasubduction magmatism in a crust by accumulating said magmas in crust chambers and accompanying scale of "paratectic" processes (as understood by Dobretsov *et al.* [9]), probably with insignificant role of fractionation. The combination of the paratectic processes and fractionation is explained by origination of bimodal trachyandesite - trachyrhyolite association. For most alkali acidic rocks of this formation their derivation continues during low-degree partial melting of the mantle or with differentiation or basalt melt liquation. Nor does available geochemical evidence in the majority of works (excluding that for Ba contents) contradict the hypothesis of fractional - crystallizing origin of comendites from basalt melt, with a possible subsequent filtration, pressing of alcaline acidic residual fluid.

In structures of dominating extension, long-lived delays of basalt magmas apparently did not occur due to the essentially monomodal basalt series.

Thus, the obtained geochemical materials basically conform quite well with earlier assumptions by E.G. Peskov and M.M. Migovich [22,23] about Paleogene volcanism of OCVB as being essentially of rift origin.

In our view, the presented material does not contradict the conclusion that the stage of Paleocene volcanism marks a transition from the subduction stage of OCVB development to intraplate or riftogenic one. In the wide time gap between Paleogene and Neogene-Quaternary volcanism, Paleogene marginal continental rifting within OCVB bounds, had apparently remained incomplete due to joining to the Asian continent of the Okhotsk-Sea and Koryak blocks [13] and owing to development of a new thick (powerful) Benioff zone in Eocene-Oligocene time eastward from OCVB [33]. From this position, Bering Neogene-Quaternary volcanism is represented by an analog of "dissipated"-type riftogenic volcanism associated with magmas[12, 22, 33]. Further geological and petrological studies of rift formations of marginal-continental type would allow to develop a more unambiguous interpretation of their origin.

The most important conclusion resulting from an analysis of the material contained in this paper is that not all volcanic stratas referring to OCVB are part of the continental margin (in the "suprasubduction" belt sense. Paleogene subduction rock testifies to sharp change in melt source forming the volcanic belt, which shows in sharp alteration of the geodynamic condition in the region for a short period of time on the Cretaceous-Paleogene boundary.

The authors are very grateful to V.G. Sakhno, A.I. Khanchuk, V.P. Utkin, Yu.A. Martinov, S.O. Maksimov, B.L. Zalishchak, and P.L. Nevolin for their fruitful discussions and consultations, and also V.G. Sudzelovskaya, V.G. Sazonov and FEGI staff for helping technically design the manuscript.

The authors extend their special gratitude to M.L. Gelman for the detailed analysis and constructive criticism he provided in reviewing this paper. The majority of his remarks and suggestions were taken into account in the final version.

The paper was completed with the financial support of the Russian Basic Research Foundation, Grant N 98-05-65326.

REFERENCES

1. Akinin, V.V., Apt, Yu.E., Belaya, B.V., Belyi, V.F. and Luskin A.D., in: *Kontinental'nyi paleogen i neogen Severo-Vostoka SSSR Vyp. 1* (Continental Paleogene and Neogene of the North-East USSR) (Magadan, 1988): N 1: 13-23.
2. Belyi, V. F., *Stratigrafiya i structury Okhotsko-Chukotskogo vulkanicheskogo poyasa* (Stratigraphy and structures of Okhotsk-Chukotka volcanic belt) (Moscow: Nauka, 1977).

3. Belyi, V.F., *Formatsii i tektonika Okhotsko-Chukotskogo vulkanicheskogo poyasa* (Formations and tectonics of Okhotsk-Chukotka volcanic belt) (Moskow: Nauka, 1978).
4. Belyi, V.F., *Geologiya Okhotsko-Chukotskogo vulkanicheskogo poyasa* (Geology of Okhotsk-Chukotka volcanic belt) (Magadan, 1994).
5. Belyi, V. F., *Tikhookeanskaya geologiya* N 5: 3-19 (1996).
6. Belyi, V.F. and Tilman, S.M., *Geotectonika* N 2: 83-84 (1966).
7. *Vulkanicheskiye poyasa Vostoka Azii* (Volcanic belts of East Asia) (Moscow: Nauka, 1984).
8 *Geokhimicheskaya tipizatsiya magmaticheskikh i metamorficheskikh porod Kamchatki* (Geochemical typization of magmatic and metamorphic rocks of Kamchatka) (Novosibirsk, 1990).
9. Dobretsov, N.L., Andreev, G.I., Gordienko, I.V. *et al., Geologiya i geophizika* N 12: 22-31 (1982).
10. Zharikov, V.A. *Vestnik Moskovskogo Univer. Ser. geol.* 4: 3-12 (1996).
11. Zhitkov, A.S., *Okeanologiya* **30**, N 5: 809-814 (1990).
12. Zakharov, M.N., Konusova, V.V. and Smirnova, E.B., *Geochimiya vulkanitov tipichnikh geodinamicheskikh obstanovok* (Geochemistry of volcanites from typical geodynamic settings) (Novosibirsk, 1986): 133-148.
13. Zonenshain, L.P., Kuzmin, M.I. and Natapov, L.Sh., *Tektonika litosfernikh plit territorii SSSR, Tom 2* (Tectonics of lithosphere plates on USSR territory) (Moscow: Nedra, V. 2, 1990).
14. Kotlyar, I.N., Belyi, V.F. and Milov, A.P., *Petrokhimiya magmaticheskikh formatsiy Okhotsko-Chukotskogo vulkanogennogo poyasa* (Petrochemistry of magmatic formations of Okhotsk-Chukotka volcanic belt) (Moscow: Nauka, 1981).
15. Kuzmin, M.I., *Geokhimiya fanerozoiskikh magmaticheskikh porod i geodinamicheskiye usloviya ikh formirovaniya v podvidgnikh poyasakh* (Geochemistry of Phanerozoic magmatic rocks and geodynamic conditions of their origin in the mobile belts: dissertation) (Irkutsk, 1981).
16. Kundyshev, A.S. and Verkhovskaya, N.B., *Doklady AN SSSR* **279**: 706-708 (1984).
17. Lebedev, E.P., *Stratigraphiya i vozrast Okhotsko-Chukotskogo vulkanicheskogo poyasa* (Stratigraphy and the age of Okhotsk-Chukotka volcanic belt) (Moscow: Nauka, 1987).
18. *Magmaticheskiye gornie porodi, v 6 tomakh* (T.3: Osnovnie porodi, 1985; T.5: Ultraosnovnie porodi, 1988; T.6: Evolutsiya magmatizma v istorii Zemli, 1987) (Magmatic rocks, in 6 volumes (V.3: Basic rocks, 1985; V.5: Ultrabasic rocks, 1988; V.6: Magmatism evolution of Earth history, 1987)) (Moscow: Nauka, 1985-1988).
19. Moll-Stalkup, E.J. *Tikhookeanskaya geologiya* N 14: 60-70 (1995).
20. Nagibina, M.S., in: *Vulkanicheskie i vulkano-plutonicheskie formatsii. Trudy II volcanolog. soveshch.*(Volcanic and intrusive formations) (Moscow: Nauka, 1966): 241-248.
21. Parfenov, L.M., *Kontinentalniye okraini i ostrovniye dugi mezozoid Severo-vostoka Azii* (Continenantal margins and island arcs of Mesozoides of North-East Asia) (Novosibirsk: Nauka, 1984).
22. Peskov, E.G., *Geotektonika* N 2: 76-85 (1984).
23. Peskov, E.G. and Migovich, I.M. *Geologiya i geofizika* N2: 11-18 (1980).
24. Polin, V.F., *Petrologiya kontrastnoy serii Amguemo-Kanchalanskogo vulkanicheskogo polya Chukotki* (Petrology of the contrast series of Amguemo-Kanchalansk volcanic area of Chukotka) (Vladivostok: DVO AN SSSR, 1990).
25. Sakhno, V.G. and Polin, V.F., in: *Vulkanicheskie poyasa Vostoka Azii. Geologiya i*

metallogeniya (East Asia volcanic belts. Geology and metallogeny) (Moscow, 1989): 248-260.
26. Sidorov, A.A., Berman, Y.S. and Naybrodin, V.I., *Sov. geologiya* N8: 77-85 (1970).
27. Sonders, A.D. and Tarni, Dj., in: *Geologiya okrainnikh basseynov* (Geology of marginal basins) (Moscow, 1987): 102-133.
28. Speranskaya, I.M., in: *Petrokhimicheskiye osobennosti molodogo vulkanizma* (Petrochemical features of recent volcanism) (Moscow, 1963): 115-136.
29. Tevelev, Al.V. and Tevelev, Ark.V., *Doklady RAN* **346**: 653-655 (1996).
30. Ueda, S., *Noviy vzglyad na Zemlyu* (New view on Earth) (Moscow: Mir, 1980).
31. Umitbayev, R.B. *Okhotsko-Chaunskaya metallogenicheskaya provintsiya (stroeniye, rudonostnost', analogi)* (Okhotsk-Chaun metallogenic province (composition, ore content, analogy)) (Moscow: Nauka, 1986).
32. Utkin, V.P., in: *Vulkanicheskie poyasa Vostoka Azii* (East Asia volcanic belts) (Moscow, 1984): 328-352.
33. Filatova, N.I., *Periokeanicheskiye vulkanogenniye poyasa* (Perioceanic volcanogenic belts) (Moscow: Nedra, 1988).
34. Shilo, N.A., Vashchilov, N.A. and Migovich, I.M., *Geologiya i geophizika* N 2: 12-17 (1979).
35. Yarmolyuk, V.V., *Verkhnepaleozoyskiye vulkanogenniye assotsiatsii i strukturno - petrologicheskiye osobennosti ikh razvitiya* (Upper Paleozoic volcanogenic associations and structural-petrological features of their development) (Moscow: Nauka, 1978).
36. Yarmolyuk, V.V. and Kovalenko, V.I., *Riftogenniy magmatizm aktivnikh kontinental'nikh okrain i ego rudonostnost'* (Rift magmatism and ore content of active continental margins) (Moscow: Nauka, 1991).
37. Allegre, C.J. and Minster, J.F., *Earth and Planet. Sci. Let.* **38**: 1-25 (1978).
38. Dungan, M.A., Lindstrom, M.M., McMillan, N.J., *et al., J. Geophys. Res.* **91**, N B6: 5999-6028 (1986).
39. Gill, J.B., *Orogenic andesites and plate tectonics* (New York: Spinger-Verlag., 1981).
40. Haskin, L.A., Haskin, M.A., Frey, F.A. and Wildman, T.R., in: *Origin and distribution of the elements.* 1 (Ed.L.H.Ahrens) (Pergamon, 1981): 889-911.
41. Luhr, J.F., Alan, J.F., Carmichael, I.S.E., Nelson, S.A. and Hasenaka, T., J. *Geophys. Res.* **94**, N B4: 4515-4530 (1989).
42. Minster, J.F. and Allegre, C.J., *Contrib. Mineral. and Petrol.* **68**: 37-52 (1978).
43. McDonough, W.F., McCulloch, M.T. and Sun, S.S., *Geochim. et Cosmochim. Acta* **49**, N 5: 2051-2067 (1985).
44. Moll-Stalcup, E.J., in: *The Geology of Alaska: Boulder, Colorado, Geological Society of America. The Geology of North America* (Plafker G., and Berg H.C., eds.) G-1:589-619 (1994).
45. Norry, M.J. and Fitton, J.G., in: *Continental basalts and mantle xenoliths: Cheshire, England* (Hawkesworth C.T. and Norry M.T., eds.) (Shiva Publishing, Ltd., 1983): 5-19.
46. Parfenov, L.M., Voinova, I.P., Natal'in, B.A. and Semenov, D.F., *J.Phys. Earth.* **26**: suppl. S503-S525 (1978).
47. Pearce, J.A., in: *Andesites: orogenic andesites and related rocks* (ed. R.S.Thorpe) (Chichester: John Wiley, 1982): 525-548.
48. Pearce, J.A., Harris, N.B.W. and Tindle, A.G., *J. Petrol.* **25**: 956-983 (1984).
49. Pearce, J.A. and Norry, M.J., *Contrib. Mineral, and Petrol.* **69**, N 1:33-47 (1979).
50. Thompson, R.N., Morrison, M.A., Hendry, G.L. and Parry, S.J., *Phil. Trans. Roy. Soc. London*, ser. A. 310: 549-590 (1984).

51. Thorpe, R.S., Francis, P.W. and O'Callaghan, L. *Phil. Trans. Roy. Soc. London*, ser. A. **310**: 675 -692 (1984).
52. Vukadinovic, D. and Nicholls, I.A. *Geochim. Et Cosmochim. Acta* **53**: 2349-2363 (1989).
53. Wood, D.A., *Earth. Planet. Sci. Lett.* **50**, N 1: 11-30 (1980).
54. Wood, D.A., Joron, J.L. and Treuil, M., *Earth. Planet. Sci. Lett.* **45**, N 2: 326-336 (1979).

Translated by A. V. Gryebennikov

View publication stats