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Important carbonatite–alkaline/alkaline complexes and related mineral resources in the world

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1. Distribution

More than 500 carbonatite–alkaline/alkaline complexes are distributed in the world. Main concentrated areas of the complexes are East African rift zones, northern Scandinavia–Kola peninsula, eastern Canada and southern Brazil as seen in Figure 1. The distribution is restricted interior and marginal regions of continents and structurally controlled by assumed deep fractures. The East African rift valley is one of the typical examples.

The carbonatites are generally associated with ultramafic and/or alkaline rocks, but in some cases occur as isolated dykes, cylindrical intrusives and volcanic cones. Along with the East African rifts, many effusive carbonatites and alkaline rocks are observable. The Oldoinyo Lengai carbonatite, Tanzania, famous for the eruption in 1960, consists mainly of tuffs, agglomerates and lava flows of Na-rich carbonatites with ijolites, nepheline syenites and phonolite flows (DAWSON, 1966).

Carbonatites representing more deeper part of them are recognized in the northern Scandinavia–Kola peninsula, the eastern Canada, the southern Brazil and the other regions and mostly associated with alkaline and mafic to ultramafic rock suites such as ijolite, melteigite, jacupirangite, pyroxenite, peridotite and so on.

The ages of carbonatite–alkaline/alkaline complexes mostly determined by K–Ar method vary from Archean to Recent time, and each group of the complexes is closely related to their regional structural events. Canadian carbonatites were divided into four groups; middle and upper Proterozoics, Paleozoics and Cretaceous. The Paleozoic carbonatites are related to the St. Lawrence rift system associated with the Atlantic Ocean opening (PERRAULT and MANKER, 1981). In the southern Brazil, two groups of lower and upper Cretaceous have intruded into Precambrian basements surrounding the Parana basin. The carbonatites with similar ages are distributed at the opposite side, Angola and Namibia. Those are intimately associated with break off of the Gondwana continents (MARSH, 1972; HERZ, 1977). In Kola peninsula three groups of alkaline/carbonatite–alkaline complexes are recognized; middle Proterozoic, lower to middle Paleozoic and upper Paleozoic. Almost all the complexes are related to northwest–southeast trending Kandalaksha graben and east–west trending deep fractures (VARTIAINEN and PAARMA, 1979).

2. Mineral resources related to carbonatite–alkaline/alkaline complexes

Important mineral resources such as niobium, rare earth and phosphorus are associated with carbonatite and alkaline complexes and have been developed in many countries (Table 1). Their mineral reserves calsssified by their formation age are shown in Fig. 2. Copper, uranium and zirconium have been produced in

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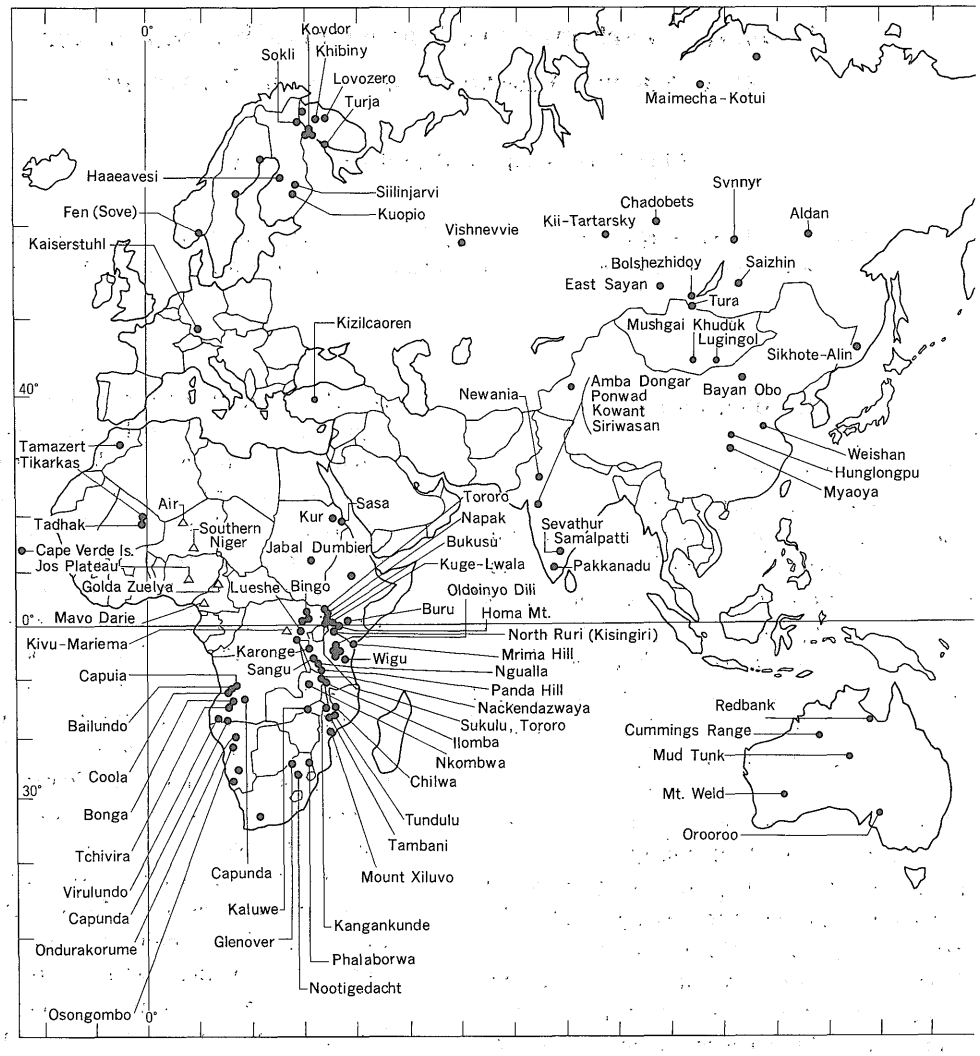

Fig. 1 Distribution map of main alkaline-

significant amounts from some complexes; Phalaborwa, South Africa; Kovdor, Kola, USSR and others. Industrial minerals such as fluorite, limestone and vermiculite have been mined in India, Brazil and some African countries. Furthermore, titanium and strontium have been studied for the developments in Brazil and Malawi.

Niobium: Niobium ores have been produced mostly from the carbonatites in Brazil and Canada, and a little amount of niobium are from tin slugs and tantalum ores. Niobium ore reserves of Araxa, Tapira and Catalao carbonatites in the southern Brazil, hold about 83 percent of those in the world. Recently Seis Lagos carbonatite complex in Amazonas state, Brazil has been reported as the biggest Nb-ore reserves in the world (2898 mill.t., 2.81% Nb_2O_5, Pena, 1989).

Rare Earth: About 66 percent of rare earth production comes from carbonatite complexes, mainly Mountain Pass, USA, and Baiyun (Bayan) Obo, China. Bastnaesite and monazite, main rare-earth minerals in those carbonatites,

carbonatite/alkaline complexes in the world.

are rich in light rare-earth elements. Total ore reserves of the two ore deposits are estimated about 40 million tons in RE_2O_3 content and beyond 80 percent of the total world reserves. Furthermore, some alkaline complexes in the Kola peninsula have a great potentiality of rare earth as a byproduct from apatite concentrate.

Phosphorus: Most of carbonatite-alkaline complexes contain a great quantity of apatite and some of them have contributed to fertilizer industries. USSR, Brazil and Africans are main producing countries and the total world apatite ore sererves are estimated about 822 million tons in P_2O_5 contents. Khibiny, the largest alkaline complex in USSR has about 500 million tons in P_2O_5 contents. It has produced around 15 million tons per annum (NOTHOLT, 1979) and at present might have held 18 million tons of apatite concentration.

Other resources: Zirconium, especially baddeleyite, is a important resource and have been recovered as one of accessory minerals in Phalaborwa and Kovdor complexes. Anatase, a secondary titanium mineral is associated with

Table 1 Mineral resources related carbonatite complexes.

Name of complex	Lithology	Type of carbonatite	Age(Ma)	Commodity	RSRV(mil.t)	Ore grade(%)		Reference
Araxa(Barreiro), Brazil	glimmerite,phoscolite	beforsite, sovite	91	niobium	465	2.48	Nb_2O_5	Filho, et al.,1984
				phosphorus	460	15.01	P_2O_5	Pena,1989
				rare earth	0.8	13.5	RE_2O_3	
				barium	463	20.67	$BaSO_4$	
Tapira, Brazil	pyroxenite, peridotite, syenite	sovite	70	niobium	180	0.67	Nb_2O_5	Rodrigues&Lima,1984
				titanium	95	17.68	TiO_2	Berbert,1984
				phosphorus	921	8.32	P_2O_5	Pena,1989
Salitre I, Brazil	peridotite,pyroxenite,tra -chyte,foyaite,glimmerite	sovite	83	titanium	84	23.28	TiO_2	Rodrigues&Lima,1984 Berbert,1984
Salitre II, Brazil	dunite,peridotite,pxnite, tinguite,glimmerite	sovite	79	titanium	92	13.0	TiO_2	Rodrigues&Lima,1984
Serra Negra, Brazil	dunite,peridotite,pxnite, tinguite,glimmerite	sovite	65	titanium	200	27.63	TiO_2	Rodrigues&Lima,1984 Berbert,1984
Catalao I, Brazil	peridotite,glimmerite phoscolite	beforsite	83	niobium	15.7	1.61	Nb_2O_5	Baecker,1983
				phosphorus	306	7.96	P_2O_5	Rodrigues&Lima,1984
				titanium	6	19.90	TiO_2	Hirano et al,1987
				rare earth	2	12.2	RE_2O_3	
Catalao II, Brazil	glimmerite,phoscolite	sovite	-	niobium	2	2.18	Nb_2O_5	Baecker,1983 Rodrigues&Lima,1984
Morro do Engenho, Brazil	dunite,peridotiote, nepheline syenite	calcitic	Cretaceous	nickel	70	1.27	Ni	Rodrigues&Lima,1984
Jacupiranga, Brazil	peridotite,pyroxinite, nepheline syenite	sovite,beforsite	130	phosphorus	89	6.15	P_2O_5	Rodrugues&Lima,1984
				nickel	3	1.39	Ni	Hirano et al,1987
Juquia (Morro do Serrote), Brazil	pyroxenite,peridotite, pulaskite,syenite	beforsite	127	phosphorus	2	16.0	P_2O_5	Born,1971 Rodrigues&Lima,1984
Ipanema, Brazil	glimmerite,pyroxenite, pulaskite	sovite	123	phosphorus	117	6.73	P_2O_5	Rodrigues&Lima,1984
Anitapolis, Brazil	pxnite,urtite,syenite, melteigite,glimmerite	sovite	129	phosphorus				Rodrigues&Lima,1984
				residual	53	8.20	P_2O_5	
				primary	206	4.00	P_2O_5	

Table 1 (continued)

Name of complex	Lithology	Type of carbonatite	Age(Ma)	Commodity	RSRV(mil.t)	Ore grade(%)	Reference
Barra do Itapirapua Brazil		beforsite	-	rare earth phosphorus	- -	0.94 RE_2O_3 2.49 P_2O_5	Cordeiro & Oliveira, 1984
Mato Preto, Brazil	phonolite	sovite,beforsite	67	fluorine	2.8	58.0 CaF_2	Loureiro & Tavares, 1983
Pocos de Caldas, Brazil	tinguite,phonolite, nepheline syenite	-	53-87	zirconium rare earth	0.2 6	65-70 ZrO_2 5.0 RE_2O_3	Ulbrich & Gomes,1981 DNPM,1979
Seis Lagos, Brazil	syenite	ferrocarbonatite, beforsite	-	niobium rare earth	2898 -	2.81 Nb_2O_5 1.50 RE_2O_3	Rodrigues&Lima,1984 Pena,1989
Oka, Canada	melteigite,ijolite, urtite,okaite	sovite	122	niobium rare earth	122 122	0.45 Nb_2O_5 0.2 RE_2O_3	Currie,1976 Perrault&Manker,1981
St.Honore, Canada	ijolite,urtite, nepheline syenite	sovite,dolomitic -ankeritic carb.	560	niobium	16	0.69 Nb_2O_5	Currie,1976 Perrault&Manker,1981
James Bay(Argor), Canada	pyroxenite	dolomitic carb.	1655	niobium phosphorus	62.5 62.5	0.52 Nb_2O_5 3-10 P_2O_5	Stockford,1972 Currie,1976
Manitou Islands, Canada	syenite,alkali pyroxenite	carbonatite dyke	568	niobium uranium	1.9 3.0	0.86 Nb_2O_5 0.041 U_3O_8	Dawson,1966 Currie,1976
Lackner Lake, Canada	ijolite,malignite nepheline syenite	carbonatite	1090	phosphorus niobium	10 10	19.5 P_2O_5 0.23 Nb_2O_5	Hodder,1981 Currie,1976
Nemegosenda Lake, Canada	nepheline syenite,	calcitic carb.	1010	niobium	20	0.47 Nb_2O_5	Currie,1976
Mountain Pass, USA	shonkinite,syenite	calcitic,dolomitic-ankeritic carb.	1440	rare earth	100	5.0 RE_2O_3	Adams & Staatz,1973 Olson et al.,1954
Iron Hill, USA	ijolite,pyroxenite	carbonatite	520-580	niobium	40	0.25 Nb_2O_5	Roskill,1983
Kizilcaoren,Turkey	phonolite,trachyte	carbonatite	24	rare earth fluorine	0.3 0.3	2.5 RE_2O_3 37.4 CaF_2	Kayabal,1986 Morteani & Satir,1989
Amba Dongar, India	nephelinite,phonolite	ankeritic carb.	37.5-76	fluorine rare earth	116 -	30.0 CaF_2 3 RE_2O_3	Viladkar,1981
Baiyun (Bayan) Obo, China	alkaligabbro, trachyte	dolomitic carb.	1400	rare earth iron niobium	35 1150 0.78 as Nb basis	as RE_2O_3 basis 33-35 Fe	Sun Hong-ru,1983 Argall,1980

Table 1 (continued)

Name of complex	Lithology	Type of carbonatite	Age(Ma)	Commodity	RSRV(mil.t)	Ore grade(%)	Reference
Miaoya,China	syenite	sovite,ankeritic cb.	271	niobium	15	0.25 Nb_2O_5	Li, 1980
Mushugay-Khuduk, Mongol	K-rich alkaline rocks	apatite-magnetite carb.	L.Jr-E.Cr	rare earth	370	1.6 RE_2O_3	Vakhrushev et al.,1980 Kavalenko et al.,1981
Lugingol, Mongol	K-rich alkaline rocks	carbonatite	L.Jr-E.Cr	rare earth	-	-	ditto.
Phalaborwa, S.Africa	pyroxenite,phoscolite	sovite	2047	copper zirconium	315 -	0.69 Cu 0.15 ZrO_2	Coetzee,1976 PMCLMGMS,1976
Grenover, S.Africa	only fenetization	beforsite,sovite	1300	phosphorus niobium	10 -	20-32 P_2O_5 0.68 Nb_2O_5	Carter&Bennett,1973
Dorowa, Zimbabwe	syenite,phonolite	sovite	200	phosphorus	67	6.5 P_2O_5	Carter&Bennett,1973
Shawa, Zimbabwe	dunite,ijolite	beforsite>>magnesite	201	vermiculite	-	-	Johnson,1966 Nicolayson,et al.1962
Okorusu, Namibia	foyaite,urtite,syenite	sovite		fluorine	7-10	35.0 CaF_2	Deans,1966
Ondurukurume, Namibia	foyaite,syenite	sovite, beforsite		niobium	8	0.3 Nb_2O_5	MacCall,1963 Deans,1966
Bonga, Angola		carbonatite		niobium	824	0.48 Nb_2O_5	Pena,1989
Natache,Tundul, Malawi	neph-syenite,syenite, feldspathic agglomer.	sovite,sideritic carb.	133	phosphorus	1.25	15.0 P_2O_5	Carter&Bennett,1973
Chilwa Isl.,Malawi	fenitic syenite, feldspathic breccia	sideritic,ankeritic carb. sovite	136	niobium	3-5	0.32-1.51 Nb_2O_5	Carter&Bennet,1973 Deans,1966
Kangankunde,Malawi	fenitization only	sovite,ankeritic carb.	125	rare earth strontium	0.325 0.325	4.7 RE_2O_3 17.9 $SrCO_3$	Carter&Bennett,1973
Ilomba Hill,Malawi	foyaite,ijolite, syenite	sovite,dolomitic carb.	490-508	niobium uranium	0.1 -	0.3 Nb_2O_5 0.05 U_3O_8	Carter&Bennet,1973 Bloomfield,et al1981
Panda Hill,Tanzania	fenetization only	sovite,dolomitic carb.	116	niobium	300	0.3 Nb_2O_5	Fick et al.,1959
Sukulu, Uganda	ijolite,neph-syenite	sovite,ferruginous carb.	24-26	phosphorus niobium	200 200	13.0 P_2O_5 0.23 Nb_2O_5	Deans,1966 Reedman,1984

Table 1 (continued)

Name of complex	Lithology	Type of carbonatite	Age(Ma)	Commodity	RSRV(mil.t)	Ore grade(%)		Reference
Bukusu, Tororo, Uganda			16-32	niobium	70	0.25	Nb_2O_5	Bloomfield,1973 Pena,1989
Bingo,Zaire		dolomitic carbonatite		niobium	7	2.86	Nb_2O_5	Roskill, 1983
Lueshe, Zaire	cancrinite syenite	sovite,rauhaugite	516-635	niobium	30	1.34	Nb_2O_5	Maravic&Morteani,80
Mrima Hill,Kenya	nepheline syenite	sovite,dolomitic carb.		niobium	50	0.7	Nb_2O_5	MacCall, 1963
				rare earth	6	5.0	RE_2O_3	Deans,1966
Kaiserstuhl, Germany	limburgite,phonolite, nephelinite	sovite	18-66	niobium	0.8	0.5	Nb_2O_5	Wimmenauer,1974
Kodal,Norway	syenite	carbonatite	-	phosphorus	70	6.0	P_2O_5	Notholt,1979
Sove(Fen),Norway	nephelinite,ijolite, melteigite,alnoite	sovite,rauhaugite	565-590	niobium	61	0.2	Nb_2O_5	Heinrich,1966 Roskill,1983
Sokli,Finland	peridotite,pyroxenite	phoscolite,sovite	334-378	phosphorus	50	19.0	P_2O_5	Notholt,1979
				niobium	-	-		Vartiainen,1980
Siilinjarvi,Finland	glimmerite	phoscolite,sovite	1785-2530	phosphorus	465	4.0	P_2O_5	Notholt,1979
Khibiny,USSR	ijolite,melteigite, urtite,neph-syenite	-	L.C-E.P	phosphorus with REE	2700	18.0	P_2O_5	Notholt,1979
Kovdor,USSR	melteigite,ijolite, pyroxenite,dunite	small carbonatite vein	370	phosphorus	708	6.6	P_2O_5	Notholt,1979
				iron	708	50	T.Fe	
Synnyr(Oshrkov), USSR		-	-	phosphorus with REE	500	4.0-4.5	P_2O_5	Notholt,1979
Motzfeldt,Greenland	syenite	-	1300	niobium	80	0.4-1.0	Nb_2O_5	Pena,1989

Mineral resources associated with carbonatite-alkaline/alkaline complexes in the world

Niobium	103 million tons(Nb_2O_5)
Phosphorus	822 million tons(P_2O_5)
Rare earth	47 million tons(RE_2O_3)
Titanium	105 million tons(TiO_2)
Fluorine	40 million tons(CaF_2)

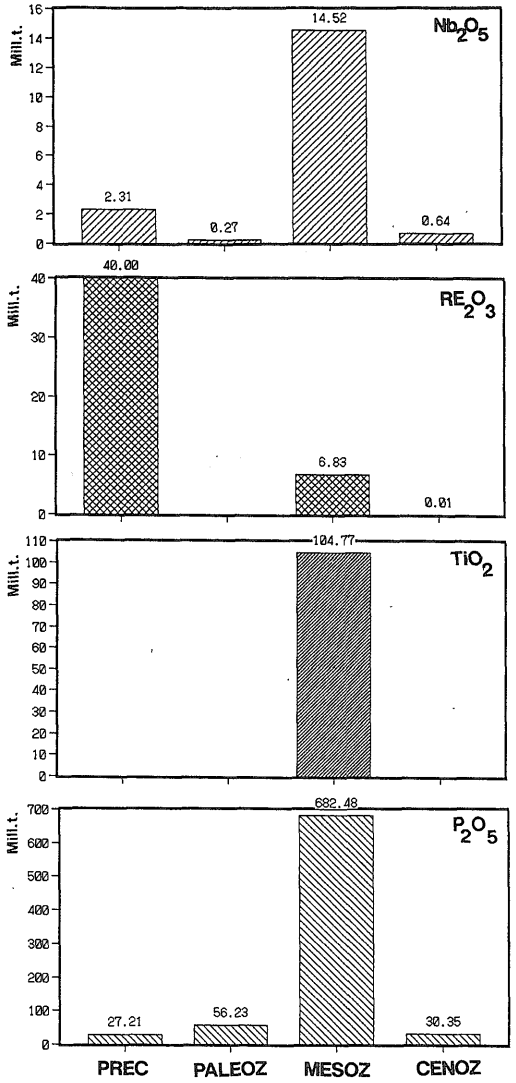

Fig. 2 Carbonatite-related mineral reserves in the world. Reserves are calculated based on the data shown in Table 1. A Nb-ore reserve of Seis Lagos, Amazonas state in Brazil is omtted from this figure because of the unknown age of the carbonatite intrusion.

Brazilian carbonatites and recently its recovering technology has been developed by Tapira Mine.

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世界の主要カーボナタイト–アルカリ複合岩体とそれに伴う鉱物資源

神谷雅晴・平野英雄

要　旨

世界の主要カーボナタイトの岩相，固結年代，およびそれに伴う鉱物資源を一覧表としてまとめ，それぞれの位置を図示した．カーボナタイトに伴う鉱物資源のうち，ニオブ，レアアース，チタン，リンは地域分布ばかりでなく，形成時代にも著しい偏在性が存在することを示した．

（受付：1990年3月27日；受理：1990年9月1日）