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Pyroxene-sövite in Amba Dongar Carbonatite-alkalic Complex, Gujarat

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ABSTRACT

The present paper for the first times gives details of pyroxene-sövites of Amba Dongar and discusses significance of these pyroxenes in evolution of carbonatite magma in Amba Dongar. Calciocarbonatite (sövite) forms the major mass of carbonatite in Amba Dongar complex. It shows large variation in texture and mineral composition and has complex evolutionary history. Three types of compositional variations are observed in sövite samples, (1) monomineralic sövites are coarse grained with 99% calcite, (2) sövites with abundant apatite, barite, pyrochlore, magnetite and zirconolite and (3) silico-sövite with of clinopyroxene and phlogopite. In the crystallization history of various sövite types, silico-sövite seems to have crystallized as an earlier phase and was later caught up in major sövite mass. Both, phlogopite-sövite and pyroxene-sövite are coarse grained and exhibit hypidiomorphic texture. Phlogopite is strongly zoned with Mg-rich core to Fe-rich rims. Pyroxenes also exhibit zoning with decrease in Ca and Mg and increase in Fe and Na from core to rim. In general composition of clinopyroxene varies from diopsidic to aegirine-augite. Pyroxene-sövites show good concentration of Ba, Sr, Nb and LREE. Elevated concentrations of LREE are found in two aegirine-sövites.

INTRODUCTION

Brögger (1921) introduced the term silicocarbonatite which was used later by many carbonatite petrologists (e.g von Ekermann, 1948, Pecora, 1962, Heinrich, 1966, Chakhmouradian and Mitchell, 2003 etc). Saether (1957) used the term "pyroxene-sövite" for silico-carbonatites. Silicate minerals in carbonatites are not uncommon (e.g. Chakhmouradian and Mitchell, 2003, Andersen, 1988, Kresten, 1979, Hogarth, 1989, Viladkar, 2000, Gittins et al, 2005, Chakrabarty et al 2009, Reguir et al, 2009,) however, their origin has been debatable; either primary or by wall rock assimilation. Occurrence of phlogopite micas in sövite and alvikites in Amba Dongar and its significance in differentiation of carbonatite was first described by Viladkar (2000). Pyroxene-sövites have not been described so far and thus the present paper, for the first time, gives mineralogical data on pyroxenes in different sövites xenoliths and their significance in the evolution of sövite in Amba Dongar. In general the compositions of pyroxenes from these sövite xenoliths vary from diopsidic to aegirine-augite.

FIELD RELATIONS

Amba Dongar carbonatite diatreme, situated in the western part of the Deccan basalt province is the most explored complex by geologists and geochemists from different parts of the world. Sövite is the predominant type of carbonatite found in a ring structure which has been built by several pulses of carbonatite intrusions (Viladkar and Wimmenauer, 1992). There is large variation in mineralogy of sövite from different part of the ring dike. Sövite exposure in the northern part (Fig. 1) of the ring dike is extensively explored for fluorspar mineralization and with progressive mining, during last 50 years, deeper parts of sövite were exposed. Both phlogopite-sövite and pyroxene-sövite were not exposed at present level of erosion but many xenoliths of these rocks were encountered at these deeper levels during mining operations, and also in a tunnel driven through the sövite exposure during mining for fluorite. The size of the pyroxene-sövite xenoliths, which were collected and included in this work, is small, in majority of cases not more than 10 cm (except for one which is recently exposed and measuring more than 2 meters across). Similar types of silico-sövites were noticed in deeper sections of some boreholes in the mining area. Phlogopite-sövites were described earlier by Viladkar (2000) while present paper for the first time discusses details of pyroxene-sövite.

PETROGRAPHY

In thin sections, pyroxene-sövite is coarse grained, hypidiomorphic with pyroxene (diopsidic or aegirine-augite) and calcite as major minerals (Fig. 2). Pyroxenes occurring in different xenoliths, show euhedral form, never broken, and not resorbed, as one might expect that they would be if they were of xenocrystic in origin. Usually, they

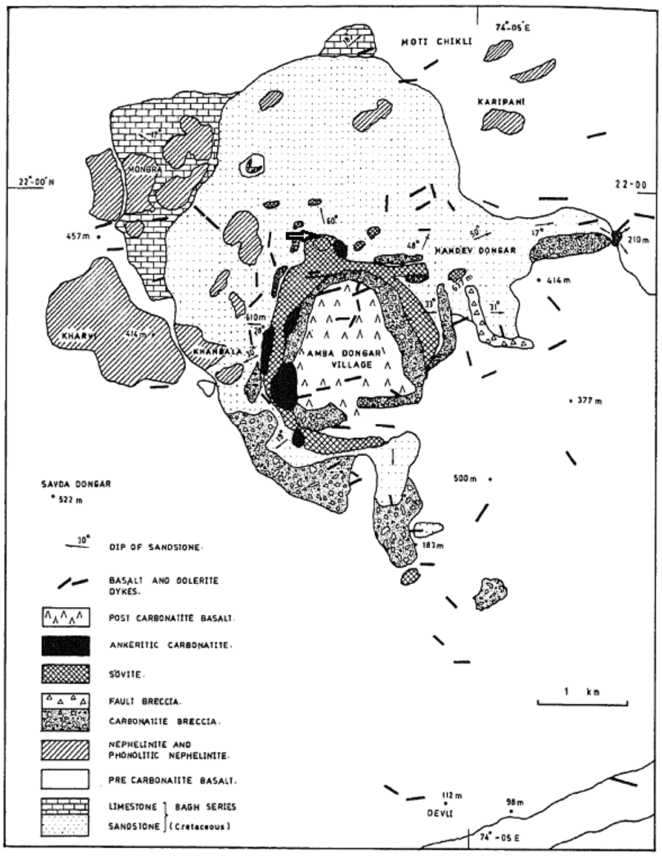

Fig.1. Geological map of Amba Dongar and surrounding area (Viladkar, 1981). Arrow in the northernmost part of ring dike points to sample locations.

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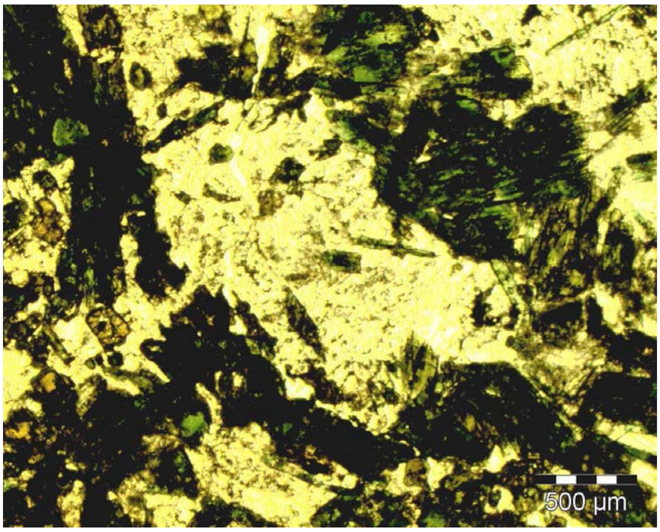

Fig.2. Pyroxene-sövite with predominant Aegirine + Calcite

occur both as segregation of grains and independent crystals in carbonatitic calcitic base. However, in one case there is evidence of pyroxene being a cumulate and this pyroxene was later shattered when caught up in sövitic magma, and shattered individual crystals appear to have been surrounded by calcite. These pyroxenes are diopsidic and show evolution trend towards Fe^2 (Fig. 4 and 5). In remaining xenoliths pyroxene is mainly aegirine-augite to aegirine which shows faint pleochroism and also exhibit very complex zoning (Fig. 3). These strongly zoned pyroxenes display a relatively long crystallization history. There are no other silicates minerals present along with pyroxenes. Had these been xenoliths /xenocrysts of alkaline rocks of Amba Dongar complex (nephelinite-phonolite), there would have been at least nepheline and melanite along with pyroxenes. So the possibility of these as xenoliths of alkaline rocks is ruled out. Textural evidence is also in favour of the fact that these pyroxene phenocrysts crystallized before the surrounding carbonate in sövitic magma, in which they were suspended. All pyroxenes appear to have crystallized in equilibrium with sövite. Accessory minerals include magnetite (mainly along with aegirine-augite, and aegirine), apatite, pyrochlore, and sporadically monazite and bastanaesite. The BSE image of zoned pyroxene is shown in Fig.3. In a strongly zoned phenocryst there is decrease in Ca, Mg and sharp increase in Fe, Na towards the rim. Increase in Na during crystallization of these pyroxenes results in development of aegirine-augite rim. Zoning in some is quite complicated and shows fluctuation in concentration of some elements like, Ca, Ti, Na and Fe.

PYROXENE MINERAL CHEMISTRY

Pyroxenes were analysed on the Joel Superprobe JXA_8200 microprobe with accelerating voltage of 15 kV and beam current 10 nA, at the Max-Planck Institute for Chemistry (MPI), Mainz, Germany.

290 grains of pyroxenes from different xenoliths were analysed on the microprobe. Representative analyses of pyroxenes from these xenoliths are given in Tables 1, 2 and 3. Compositional variation in pyroxenes from different xenolith is observed when plotted (Figs. 4 and 5). The most primitive pyroxene compositions are from a xenolith which appears to be a cumulate. All others show pyroxene evolution towards Fe and Na-rich composition. In zoned crystals core composition is diopsidic and rim is aegirine augite.

DISCUSSION

Silicosövite seems to be common in many carbonatite complexes and the different views regarding their origin are discussed by Andersen (1988), Chakhmouradian and Zaitsev (2002), Chakhmouradian and Mitchell (2003) and others. The role of silica activity in carbonatite magma is discussed in detail by Barker (2001). However, the aim of this paper is not to discuss the origin of silico-carbonatites in general. The discussion is restricted mainly to the evolution of pyroxene-sövites of Amba Dongar.

For the origin of such rocks in Amba Dongar all petrographic evidence points to the primary nature of silicate minerals and they are not formed due to wall rock reaction.

Composition of pyroxenes from different xenoliths varies from diopsidic to aegirine augite, with initial trend towards Fe^2 end of the triangle. The diopsidic pyroxene ($Wo_{38\text{-}41}$, $En_{44\text{-}53}$, and $Fs_{15\text{-}8}$) occurs mainly as cumulate and also in cores of strongly zoned aegirine-augite. Some diopsides from cumulate contain high Al_2O_3 (up to 7.5%). This could be an indication of their having crystallized at much higher

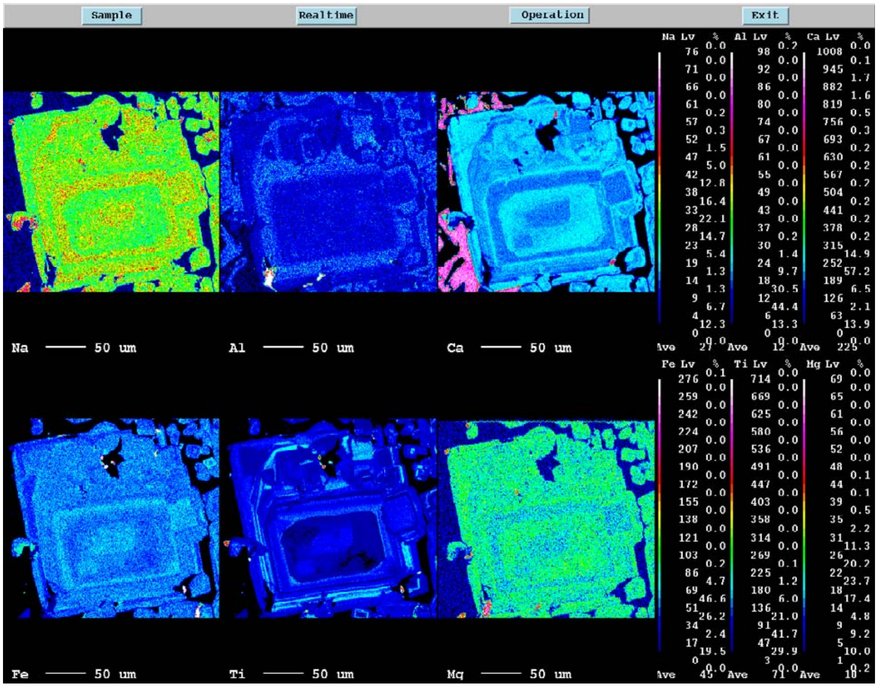

Fig.3. BSE image of strongly zoned aegirine-augite in pyroxene-sövite

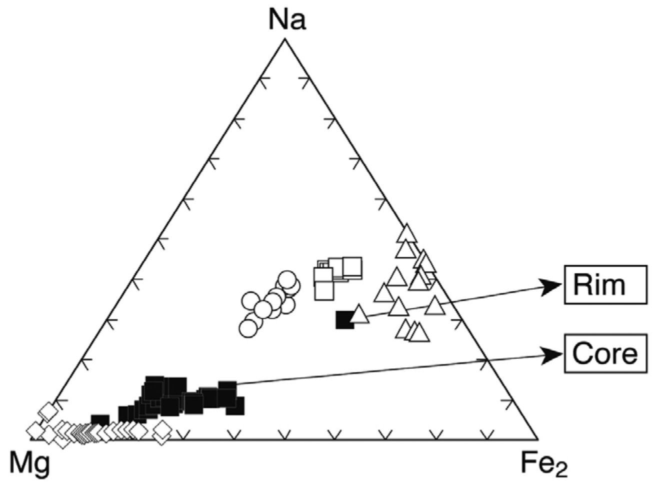

Fig.4. Plot of pyroxenes on Mg-Fe^2-Na (Mol%), Open triangle- AD/ 7/2005, filled square-AD/7/H, diamond - AD/10/2005, circle - 6/AD/ 2005, open square - Pyroxene-sövite (2004).

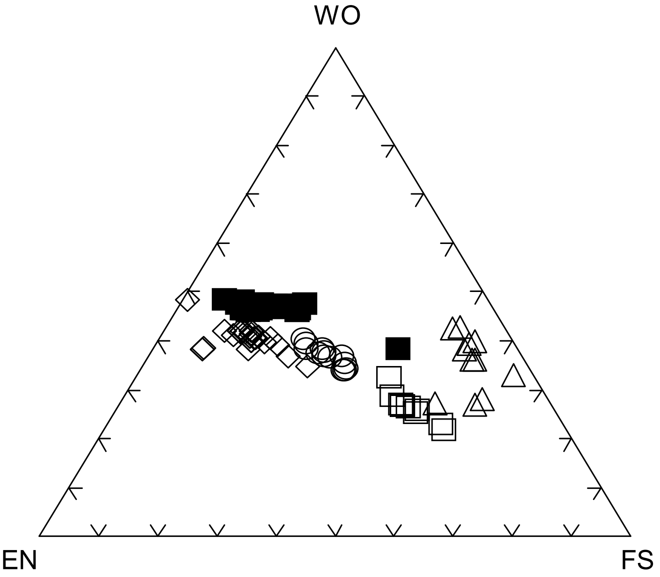

Fig.5. Plot of same pyroxenes (Mol %) on En-Wo-Fs. Symbols: same as in Fig.4.

pressure. This is consistent with their early origin at depth. Diopsidic pyroxene phenocrysts appear to have crystallized at early stage of the history of crystallization of sövitic magma, in which they were engulfed. Later generation pyroxene (Wo_{40-33}, En_{31-35} and Fs_{34-24}) shows trend towards Fe and Na enrichment and seems to have crystallized in later pulse of the sövitic magma. Crystallization path of different pyroxenes is depicted in Figs. 4 and 5. Zoned crystals can be used to show chemical and fo_2 changes in the sövitic magma during its evolution. Core of such pyroxene is diopsidic while the rim composition shows enrichment in Fe and Na. This reflects on progressive depletion in Mg and Ca and increase in Fe and Na with crystallization. Similar trend of Mg depletion and Fe enrichment during successive crystallization trend was shown in micas in sövites of Amba Dongar (Viladkar, 2000). This suggests a change from early reducing to later oxidizing conditions during pyroxene crystallization in the sövitic magma with falling temperature of crystallization and the general trend of pyroxene crystallization is towards Na and Fe enrichment and not towards hedenbergite component. It may be mentioned here that the pyroxene-sövites mostly occur as xenoliths in major mass of sövite and their original mineralogy has been modified

Table 1. Representative analyses of diopsidic pyroxene from pyroxene-sovite

SiO_2	51.14	51.10	51.68	50.56	51.98	51.59	51.71
TiO_2	0.49	0.51	0.85	0.82	0.81	0.96	0.94
Al_2O_3	7.44	7.52	2.22	2.39	2.23	2.03	2.60
FeO	4.91	4.87	9.03	16.68	8.22	10.23	9.31
MnO	0.13	0.08	0.20	0.37	0.20	0.23	0.21
MgO	17.35	17.48	15.14	12.31	16.00	14.96	15.53
CaO	17.70	17.49	20.63	16.81	20.56	20.00	20.09
Na_2O	0.81	0.89	0.19	0.14	0.22	0.21	0.20
K_2O	0.00	0.00	0.00	0.03	0.01	0.00	0.02
Total	**99.97**	**99.94**	**99.94**	**100.11**	**100.23**	**100.21**	**100.61**
Si	1.845	1.841	1.919	1.927	1.915	1.918	1.906
Ti	0.013	0.014	0.024	0.024	0.022	0.027	0.026
Al	0.316	0.319	0.097	0.107	0.097	0.089	0.113
Fe^3	0.024	0.033	0.030	0.003	0.045	0.037	0.039
Fe(ii)	0.124	0.114	0.250	0.529	0.209	0.282	0.248
Mn	0.004	0.002	0.006	0.012	0.006	0.007	0.007
Mg	0.933	0.939	0.838	0.700	0.879	0.829	0.853
Ca	0.684	0.675	0.821	0.687	0.812	0.797	0.793
Na	0.057	0.062	0.014	0.010	0.016	0.015	0.014
K	0.000	0.000	0.000	0.001	0.000	0.000	0.001

Table 2. Representative analyses of aegirine-agutie

	C	R					
SiO_2	52.42	53.47	54.26	54.02	53.92	53.52	54.17
TiO_2	0.02	1.03	0.56	0.65	1.47	1.43	0.67
Al_2O_3	0.08	0.79	0.34	0.53	0.46	0.33	0.83
FeO	15.00	20.25	14.09	14.80	15.30	16.01	15.30
MnO	1.49	0.31	0.60	0.62	0.80	0.70	0.33
MgO	9.61	5.18	9.16	8.71	7.81	7.80	8.37
CaO	16.20	7.95	15.04	15.31	13.38	13.16	13.54
Na_2O	2.13	9.54	6.01	5.56	6.67	6.91	6.93
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**96.95**	**98.52**	**100.06**	**100.20**	**99.81**	**99.86**	**100.14**
Si	2.05	1.98	2.00	2.00	2.00	1.98	1.99
Ti	0.00	0.29	0.02	0.02	0.04	0.04	0.02
Al	0.00	0.03	0.01	0.02	0.02	0.01	0.04
Fe(ii)	0.43	0.62	0.43	0.46	0.47	0.50	0.47
Mn	0.05	0.02	0.02	0.02	0.03	0.02	0.01
Mg	0.56	0.29	0.50	0.48	0.43	0.43	0.46
Ca	0.68	0.32	0.59	0.61	0.53	0.52	0.53
Na	0.16	0.69	0.42	0.40	0.48	0.50	0.49
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3. Represntative analyses aegirine from pyroxene-sovite

SiO_2	51.89	52.22	52.21	52.65
TiO_2	0.01	0.12	0.04	0.16
Al_2O_3	0.04	0.30	0.07	0.10
Cr_2O_3	0.00	0.00	0.01	0.02
FeO	30.02	27.86	30.40	31.01
MnO	0.90	1.03	0.39	0.24
MgO	0.03	0.65	0.00	0.05
CaO	6.05	5.11	5.19	0.59
Na_2O	10.20	11.44	10.82	14.23
K_2O	0.00	0.02	0.00	0.00
Total	**99.13**	**98.76**	**99.13**	**99.05**
Si	2.13	2.13	2.14	2.16
Al	0.13	0.15	0.14	0.16
Fe(iii)	0.77	0.86	0.80	1.09
Ti	0.00	0.00	0.00	0.00
Fe(ii)	0.19	0.02	0.17	-0.12
Mn	0.03	0.04	0.01	0.01
Mg	0.00	0.04	0.00	0.00
Ca	0.27	0.22	0.23	0.03
Na	0.81	0.91	0.86	1.13
K	0.00	0.00	0.00	0.00

Table 4. Silico sovites of Amba Dongar

	1	2	3	4	5	6
SiO_2	6.33	24.57	10.36	2.09	4.13	32.04
TiO_2	0.05	0.01	0.05	0.05	0.07	0.34
Al_2O_3	0.03	0.02	-	-	0.06	4.02
Fe_2O_3	3.38	2.93	4.80	1.90	4.37	5.54
FeO	-	-	-	-	-	-
MnO	0.38	0.47	0.61	0.48	0.83	0.35
MgO	0.22	0.31	0.29	0.13	2.19	5.37
CaO	49.59	39.14	47.89	51.39	46.67	26.65
Na_2O	0.01	1.02	-	-	0.02	2.05
K_2O	0.01	-	2.01	-	0.01	1.68
P_2O_5	0.09	0.06	0.17	1.32	1.79	0.75
CO_2	36.30	31.00	32.00	40.00	37.00	19.00
Total	**96.39**	**99.53**	**98.18**	**97.36**	**97.14**	**97.80**
Ba	6481.00	6176.00	10781.00	3783.00	7765.00	6603.00
Sr	3251.00	2374.00	2700.00	3550.00	2978.00	4876.00
Y	130.00	93.00	168.00	203.00	183.00	37.00
Zr	116.00	49.00	107.00	63.00	135.00	644.00
Nb	2169.00	-	1155.00	1528.00	881.00	1006.00
Th	20.00	7.00	12.00	20.00	65.00	36.00
U	-	1.00	-	-	-	10.00
V	105.00	33.00	119.00	74.00	191.00	244.00
La	1701.00	1250.00	2270.00	385.00	2198.00	1450.00
Ce	3173.00	2533.00	4773.00	738.00	7765.00	3382.00
Pr	-	-	-	-	-	-
Nd	1110.00	1147.00	2127.00	316.00	1134.00	1229.00
Sm	-	95.00	166.00	25.80	-	114.00
Eu	-	23.51	43.20	6.51	-	23.10
Gd	-	-	-	-	-	-
Tb	-	8.63	15.80	3.12	-	13.20
Dy	-	-	-	-	-	-
Ho	-	-	-	-	-	-
Er	-	-	-	-	-	-
Tm	-	-	-	-	-	-
Yb	-	6.47	10.60	3.90	-	8.37
Lu	-	1.00	1.30	0.66	-	0.93

due to their entrapment in the sövitic magma. The compositional changes seen are over printed on the xenoliths besides inherited.

The recent publication of Reguir et al. (2012) document compilation pyroxene evolutionary trend from several carbonatites (e.g. Aley, Murun, Eden Lake, Alnö, Oka, Afrikanda, etc) and showed the similar aegirine enrichment trend in pyroxenes. In case of Amba Dongar, all petrographic and mineral chemistry evidence clearly shows that in the crystallization history of pyroxene-sövites, the diopsidic pyroxene has crystallized first, and subsequent crystallization under high fo_2 conditions resulted in crystallization of aegirine-augite and aegirine enrichment.

There has to be enough Mg and Si in the parental sövitic magma for crystallization of Mg-rich pyroxenes. That the sövite at Amba Dongar was initially more magnesian is evident from the presence of Mg-rich mica and periclase bearing sövite (Viladkar and Wimmenauer, 1992, Viladkar, 2000).

Five samples of pyroxene-sövite were analysed for major, trace and rare earth elements and results are tabulated in Table 4. All samples are characterised by high Ba, Sr, Nb and LREE. Among all samples aegirine-augite-sövite has fairly high concentration of these elements. The chondrite normalized distribution patters of these rocks are shown in Fig.6. In general, enrichment of trace and REE is more in aegirine-sövite.

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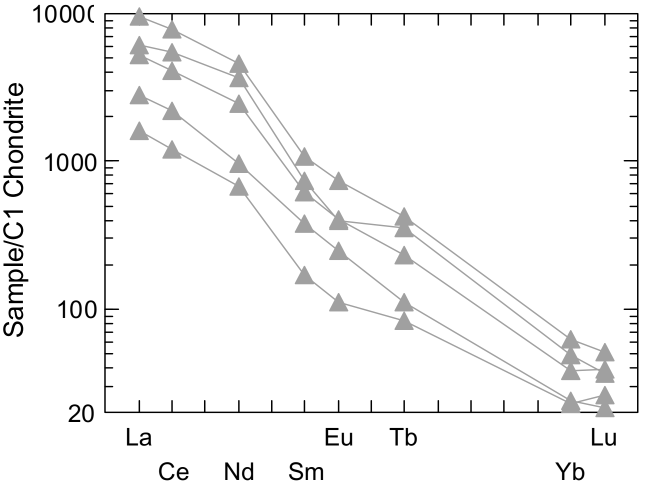

Fig.6. Chondrite normalized distribution patterns in pyroxene-sövite

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