

Mineralization of Nioborutile, Hercynite and Other Iron Oxides on Ultramafic Body, Carbonatite Complex of Tiruppattur, India

R. Ramasamy

Retired Deputy Director, Tamil Nadu State Department of Geology and Mining, Chennai, 600032, India

Abstract: Nioborutile, hercynite and other iron oxides are polygenetic. They occur together in carbonatite complex of Tiruppattur ($12^{\circ} 00'00''$ - $12^{\circ}30'00''$ N and $78^{\circ}25'00''$ - $78^{\circ}35'00''$ E). Silica oversaturated and undersaturated co-magmatic soda and pottassic rich syenites subjected to prolonged period of differentiation and fractionation are seen. The compositions of the syenites and iron oxides are varied from miaskitic $(Na+K)/Al < 1$ to agpaitic $(Na+K)/Al > 1$. Increasing of alkalis and volatiles, at very late magmatic stages, transition of mafic accessories and part of some alkali-rich feldsicc minerals into iron oxides are took place at agpaitic mineralization to accommodate silica-deficiency. Increasing constituents of alkalis and volatiles, subsequent crystallization of alkali feldsicc minerals, large quantity of silica is required to counteract silica deficiency and ultimately iron oxides are formed. At this condition, zircon, pyrochlore, rutile, nioborutile, ilmenite, ulvospinal and magnetite are formed. Residual Al, incompatible and REE are crystallized as hercynite and other Al rich REE bearing iron oxides.

Keywords: Carbonatite complex of Tirupattur, Apatite-magnetite rocks, Ultramafic, Nioborutile, Hercynite

1. INTRODUCTION

Iron oxide is polygenetic. It is ubiquitous primary and secondary accessory mineral in almost in all varieties of co-magmatic alkali syenites, carbonatites, ultrabasic and ultramafic rocks in carbonatite complex of Tiruppattur, ($12^{\circ} 00'00''$ - $12^{\circ}30'00''$ N and $78^{\circ}25'00''$ - $78^{\circ}35'00''$ E), Tamil Nadu [1-9] India. Occurrences of co-magmatic silica oversaturated and undersaturated syenites are unique feature of this complex. Heteromorphic transformation of olivine, pyroxene, amphibole and biotite into opaque iron oxides releasing silica into series of residual magmas are fractionated is a common feature. Iron oxides are emplaced along weak-planes present on ultramafic rock located in the SW of this complex (Fig. 1).

2. METHODOLOGY

Field works were carried out several times for Ph.D. research-work in the Presidency College, Chennai, between July 1967 and July 1973. After joining the Tamil Nadu State Geology Branch, Department of Industries, exploration and prospecting for vermiculite, sulphides, iron oxides and ultra-pottassic rocks were

carried out by the author in this area. Floats of iron oxide samples were collected on ultramafic rocks to estimate Al, incompatible-elements and REE contents. Thin sections of co-magmatic alkali syenites were studied. About 11+ 46 wet-gravimetric analyses of iron oxides were made. The alumina was determined by standard for wet-gravimetric analyzes. Spot analyses of 21 EDAX analyses were made on this samples in the Metallurgical and Material Science Laboratory, IITM by using high resolution scanning electron microscope. The results of trace elements ($\times 10^3$) were interpreted. Rittmann's norms [10] were calculated for major oxides.

3. FIELD AND PETROGRAPHIC STUDIES

Series of co-magmatic older soda rich and younger potash rich alkali syenites are emplaced in two adjacent structural basins in a sequential order respectively in north and south with magmatic continuity. Soda rich alkali syenites are imperceptly grade into younger porphyritic syenites towards center of the northern basin where porphyritic hornblende syenites further grade into coarse-grained augite-porphyritic syenite in the southern portion of this basin. Large phenocrysts ($7 \times 5 \times 2$ cm) of plate-like zoned oligoclase ($ab_{78}an_{22}\%$) carries two or more generation of early formed phenocrysts of oligoclase ($ab_{72}an_{28}\%$) orienting into different directions indicating low viscous state of younger syenite magma. Oscillatory zoning and twinning lamellae are seen in thin sections in such plates of oligoclase. All these syenites exhibit continuous optical and compositional zonings varying from margin to inward of the basin. Veins of acmite-magnetite-quartz rocks are seen at the core of the basin. An arc shaped carbonatite occurs at the contact of alkali syenites and ultramafic rocks NW of this Sevvattur Basin [3].

In the southern Jogippatti basin is composed of series of riebeckite-anorthoclase pegmatite and aplite showing myrolytic texture. Agpaitic texture is seen [11, 12, 13] with development of riebeckite at peripheral portions of feldspars. Most apaites exhibit poikilitic texture with zoned phenocryst of oligoclase. Irregular compositional zoning is exhibited among co-magmatic alkali syenites emplaced in this southern basin. Further south anorthoclase-garnet-syenite is exposed. Layers of wollastonite-sovite, wollastonite bearing pegmatite, scapolite-garnet-calcite aplite and wollastonite monomineralic rock are found. Very fine-grained silica undersaturated microcline-melanite

syenite and lamprophyric-shonkinite at peripheral portion of ultrabasics are seen. Small veins of anorthoclase, albitite, syenite porphyries and apatite-magnetite rocks occur on ultramafic rock as thin veins in this basin. Zircon syenite occurs as a small plug 2 km SW of Samalpatti village. Semi-precious zircon occurs as accessory mineral in the carbonatites of Sevvattur. Along axial planes of overturned doubly plunging ultramafic rocks, very small veins of sovite, ankerite carbonatites, barite and benstonite-carbonatite are seen adjacent to Onnakarai-Olaipatti villages. Ring dykes of carbonatite occur on riebeckite-syenite near Jogipatti village in this Basin [3, 4]. An arc shaped skarn rock is exposed at contact between alkali syenites and ultramafic rocks. Relicts of cossyrite and riebeckite are seen in some iron oxides. Thin veins of quartz, calcite, feldspars, riebeckite, acmite and apatite are seen along riebeckite-syenite weak planes of ultramafics and iron oxides. The ultramafic rock is transformed into biotite-amphibole-pyroxenite with specks of pyrite, pyrrhotite, bornite, chalcopyrite and native copper. Mineralization of these minerals is found along tightly folded fold-axial planes of skarn rocks. Monazite and galena are seen on albitite exposed adjacent to thin vein of ankerite-carbonatite breccias 100 m south of the skarn rock and 200m just west of Kanjanur Railway-gate. Large grain of galena over 10cm dimension is seen on a pegmatite of albitite.

Iron oxides are very fresh and heavy and exhibit metallic lusture and some of them have pitchy. Floats of iron oxides are strewn in significant volume 1 km south of Onnakarai-Olalipatti villages on ultramafics. Very late-stage mineralization of apatite-magnetite occurs as thin veins and diatremes along weak planes of ultramafic rocks 2 km SW of Onnakarai village. The size of iron oxides is widely varied from 10x7x5cm to >0.5x0.4x0.2cm. Very large grains of silicate perovskite up to 10x8x5cm occur at 1.5 km southwest of Kanjanur Railway-Gate. On the other hand SEM images show inequigranular well developed euhedral crystals ranging from 8x6x5µm to long platelets of 20x20x0.5µm. Prisms and plates of varying sizes (50x20x5µm) are also seen. The surface of such large grains shows pits and corrosive structures. Small prisms 10x0.2 µm are commonly found. Circular pits 3 µm with inner rims (0.05 µm) with cavities 20x10µm are developed along cleavage planes. Some cavities are partially filled with prisms and needles of riebeckite. Most of them are very small accessory minerals found as interstitial quartz with corroded periphery, prisms of riebeckite, feldspars, euhedral spinal, apatite and calcite are found in iron oxides as inclusions. The size of these inclusions varies from 2x2µm to 12x8µm. Most of iron oxides are platelets with thickness < 2µm. Some iron oxides have corroded outline indicating reaction between phenocrysts of iron oxides and residual magma. Under higher oxidation state, magnetite overgrows as euhedral martite. The

inclusions present in iron oxides appear to be revealed cooling history of alkali-magma and release silica to form silicate minerals or iron oxides. Some iron oxides are enriched with silica and alumina.

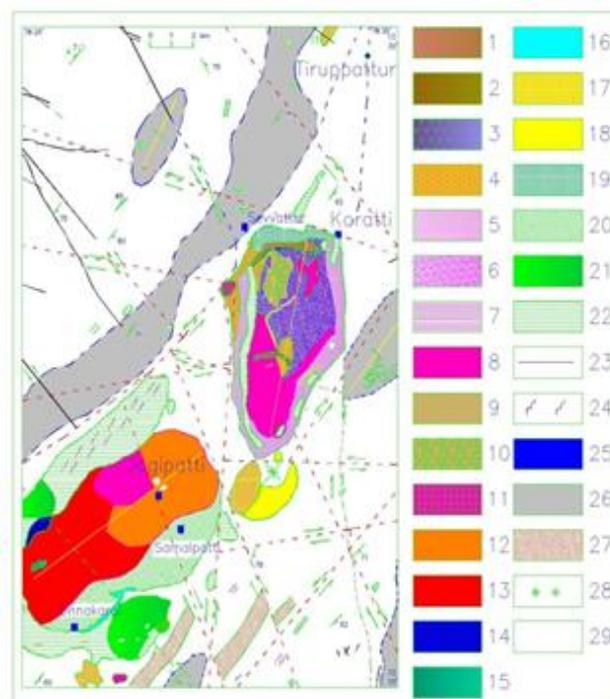


Fig.-1 Simplified Geological Map of carbonatite complex of Tiruppattur, Tamil Nadu
(after R. Ramasamy 1973 and 2012)

1 Carbonatite, 2 Shonkinite, 3. Vogesite, 4 Oligoclase, 5 Hornblende syenite, 6 Hornblende porphyritic syenite, 7 Augite syenite, 8 Porphyritic augite syenite, 9 Foliated syenite, 10 Foliated porphyritic syenite, 11 Hornblende biotite syenite, 12 Riebeckite syenite, 13 Garnetiferous syenite, 14 Microcline garnet syenite, 15 Wollastonite syenite, 16 Skarn, 17 Granite, 18 Granodiorite, 19 Biotite oligoclase pyroxenite, 20 Biotite pyroxenite, 21 Ultrabasic, 22 Ultramafic, 23 Dolerite, 24 Pegmatite-aplite, 25 Albitite, 26 Charnockite, 27 Pyroxene granulite, 28 Norite, 29 Granite gneiss. The syenites exhibit hypidiomorphic granular texture. Vogesite and shonkinite show panidiomorphic texture with euhedral grains of one or more generations of mafic and felsic minerals.

4. GEOCHEMICAL STUDIES

Wet-gravimetric chemical analyses are made for fine-grained iron oxide samples Table 1 and 2. The degree of oxidation ratio ($Fe^{III}/(Fe^{III} + Fe^{II} + Mn)$) ranges between 0 and 1 and the mean value is 0.66. They have very low concentration of MnO, MgO, CaO in these Iron oxides Quartz bearing iron oxides contain more proportions of calcite (88 wt %), apatite (48 wt.%) and other non-silicate minerals.

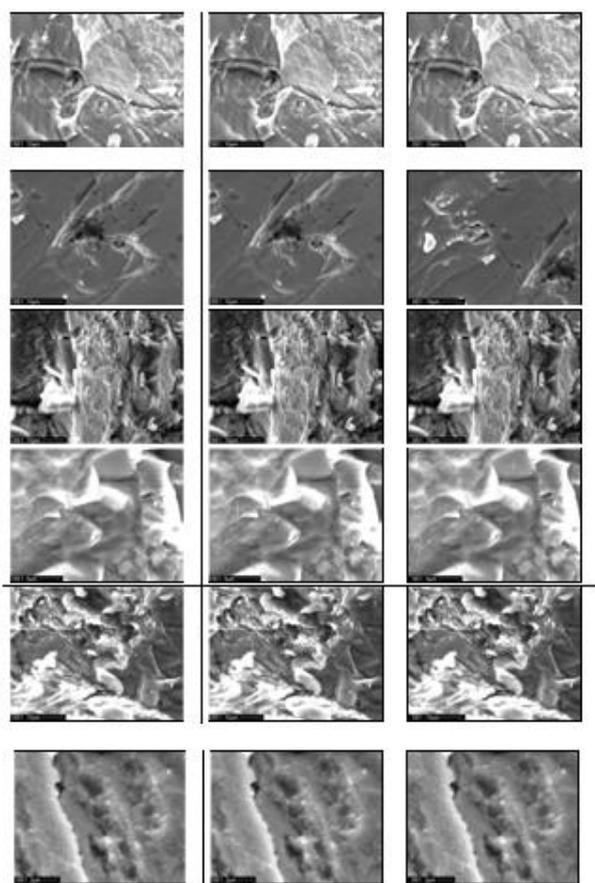


Fig. 2: Scanning Electron images of iron oxides from ultramafic complex Onnakarai-Olaipatti villages in the carbonatite complex of Tirupattur, Tamil Nadu. i) massive prism of iron oxides orient towards particular direction; ii) partially filled circular and elongated cavities orienting along smooth cleavage planes; iii) presence of pits and corrosion structures on the surface of an iron oxide prism. iv) branching-out iron oxides, skeletal, necking and cavernous form of iron oxides v) skeletal crystals are seen with plates and needles of iron oxides vi) irregularly corroded platelets of iron oxides (100x25x0.2 μm). Most of the images show very small quantities euhedral to subhedral crystals of silicate accessory minerals. Pits and cavities are seen on the surface of nioborutile. Quartz has been corroded at peripheral portions.

Table 3 shows no wide variations among Al and other trace elements between other iron oxides. K increases with decreasing of Na (Fig. 3). Spot analyses of EDAX of iron oxides have significant Nb, Zr and Dy. The trace elements ($\times 10^3$) show Sr exceeds over Ba; Zr over Nb; Rb over Pb; F over Cl; Co over Ni; Na over K; K over Ba and S over P (Table-3). Table 1-3 have both of silica rich and silica poor iron oxides but some of them are Fe^{III}, Fe^{II} Ti and P are enriched. Plots in the Fig:-3 show minimized irregularities of positive linear trends towards the course of differentiation and fractionation. Negative linear correlation between K and Na with a turning point of saturation moves towards positive

linear correlation (Table 2 and Fig. 4). Na+K vs Ca show negative correlation, Ca depletes with increase of Na+K. (Fe+Mn+Ti) values decreases against Si. Iron oxides increase with decrease of Si. Silica and alumina are enriched in some iron oxides. Some iron oxides have higher content of ferric oxides. Pottassic feldspars, albite and riebeckite occur as inclusions. From Rittmann's norm [10] it is known that certain iron oxides have normative olivine, nepheline and leucite but no such minerals are found in thin sections of host rocks or iron oxides. Positive linear correlations are found between Na+K and Al; Mn and Fe^{II}; K and Na; P and Ti and CO₂ and P₂O₅ are seen. Negative correlations are seen with some limitation at some turning points (Fig:-4) of saturations. In Table 3, positive linear variations of V vs Cr and (Nb+Ta) vs (Zr+Hf) are found Fig.5. Some trace elements magnified to 10³ V, Cr; LREE, (Fig. 5) initially increase with Dy but deplete downwards after attaining certain stages of saturation Fig. 3, 4 and 5. Similar pattern is seen between K against Na. Negative correlation exist between (Na+K) vs Si; Ca vs Mg; Fe vs Mg and others show scattered distribution. Very late formed apatite- magnetite is mineralized (Table-1-3) on ultramafic rocks. Increase of (Na+K)/Al against Si are caused crystallization of alkali-feldsicc minerals and nioborutile like iron oxides from agpaite residual magmas (12). Circular or semi-circular feature indicates reversal of agpaite ratios with enrichment of Al after some turning point of saturation relative to (Na+K)/Al against Si. Extraction of Al and REE cause subsequent crystallization of hercynite (Fig.6).

The EDAX analyses show that most iron oxides are enriched with high contents of ($\times 10^3$) Nb, Zr, Dy, Y, Pb, Sr, Sc, Rb, Cr, V, Ni and Co. The composition and ionic structure of nioborutile on the basis of 2 O atoms is highly exceeds in ion over 1 in tetrahedral sites.

Table 1:- Wet-gravimetric chemical composition of Iron oxides and their inclusions from carbonatite complex of Tirupattur, Tamil Nadu, India.

	Wet Gravimetric Analysis of Iron oxides											
	12	21	47	451	450	4921	4921	4921	4921	4921	4921	4921
SiO2	10.25	26.14	61.27	42.22	1.95	0.10	0.87	27.95	0.05	0.12	0.02	0.50
Al2O3	0.07	0.07	0.17	1.26	6.55	0.18	0.88	0.81	0.18	0.06	0.76	
Fe2O3	27.59	49.64	23.11	22.05	2.74	67.45	65.60	16.29	0.00	0.00	0.00	56.51
FeO	27.82	10.22	1.20	1.59	1.95	22.51	21.88	7.21	0.00	0.00	0.00	14.85
MnO	0.46	0.02	0.01	0.04	0.07	0.29	0.59	0.79	0.00	0.00	0.00	0.51
MgO	0.01	0.01	0.01	0.00	1.28	0.25	0.89	6.42	1.24	1.55	0.76	
CaO	11.15	0.01	1.06	14.30	29.22	1.05	2.07	19.26	36.55	24.64	6.95	
Na2O	0.71	0.16	0.01	1.97	0.45	0.00	0.17	4.08	0.20	0.92	0.15	
K2O	0.24	0.17	1.06	0.28	0.29	0.00	0.51	0.28	0.00	0.00	0.44	
TiO2	1.57	0.22	0.01	1.27	9.50	0.08	0.00	0.61	0.00	0.00	12.77	
SnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
SrO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	1.55	0.00	
P2O5	0.04	0.14	0.24	7.27	25.82	0.00	0.00	0.21	40.46	41.05	0.00	
CO2	0.00	0.00	1.28	2.46	0.00	0.00	0.00	15.29	0.00	0.00	0.00	
SO3	0.00	0.00	0.10	1.67	0.00	0.00	0.00	0.22	0.00	0.00	0.80	
F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
H2O	0.00	0.00	0.29	0.24	0.25	0.00	0.52	0.26	0.00	0.00	0.00	
On the basis of 2 O atoms												
Si	5.442	8.891	11.826	8.477	0.416	0.029	0.259	5.246	0.011	0.048	0.142	
Al	0.012	0.010	0.020	0.157	0.274	0.022	0.165	0.200	0.025	0.028	0.125	
Fe3	5.562	2.299	4.700	2.257	0.429	14.867	14.680	2.468	0.000	0.000	12.024	
Fe2	8.506	1.917	0.191	0.416	0.248	5.512	5.441	1.707	0.000	0.000	4.456	
Mn	0.105	0.004	0.002	0.007	0.012	0.096	0.149	0.122	0.000	0.000	0.122	
Mg	0.004	0.002	0.002	0.002	0.429	0.109	0.292	1.900	0.489	0.492	0.321	
Ca	2.212	0.002	0.204	2.120	8.945	0.228	2.568	4.292	12.978	12.485	2.104	
Na	0.270	0.069	0.004	0.746	0.184	0.000	0.099	1.207	0.126	0.282	0.280	
K	0.117	0.048	0.285	0.025	0.026	0.000	0.192	0.071	0.000	0.000	0.159	
Ti	0.217	0.255	0.001	0.226	1.520	1.779	0.000	0.290	0.000	0.000	2.927	
Nb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Sr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.101	0.192	0.000	
P	0.009	0.026	0.034	1.224	6.455	0.000	0.000	0.206	7.224	7.412	0.000	
CO2	0.000	0.000	0.262	0.685	0.000	0.000	0.000	4.268	0.000	0.000	0.000	
SO3	0.000	0.000	0.024	0.248	0.000	0.000	0.000	0.424	0.000	0.000	0.169	
F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
H2O	0.000	0.000	0.467	0.217	0.220	0.000	1.057	0.461	0.000	0.000	0.000	

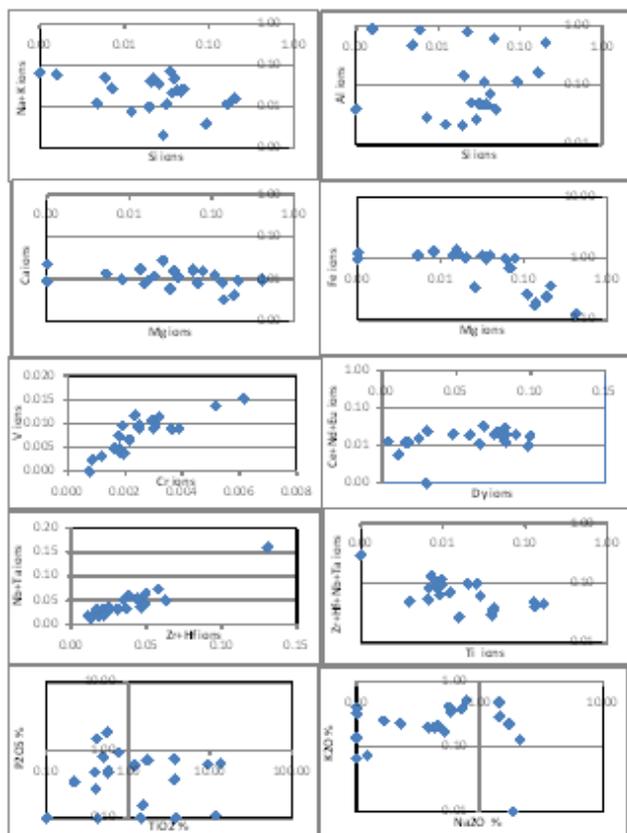


Fig. 5. Bi-variant distribution of chemical components determined by EDAX analyses.

Formation of alkali-feldspars relatively requires more silica than foidal minerals. A circular trend (Fig. 6) is seen in the EDAX analyses. Apatitic textures [13, 14] present in some ultra pottassic rocks (Fig.7) are other evidences.

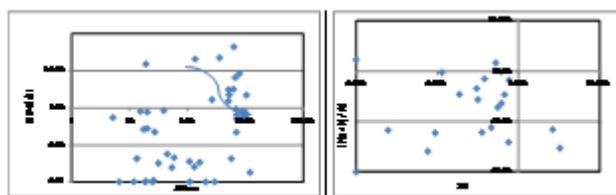


Fig. 6:- (Na+K)/Al plotted against Si both for the iron oxides analyzed (11+46) for wet gravimetric analyses and for 21 EDAX analyses show enrichment of (Na+K)/Al against Si and a trend moves from miaskitic to apgaitic stage and then a reversal trend by enrichment of Al ions during late stages of residual magmatic fractionation.

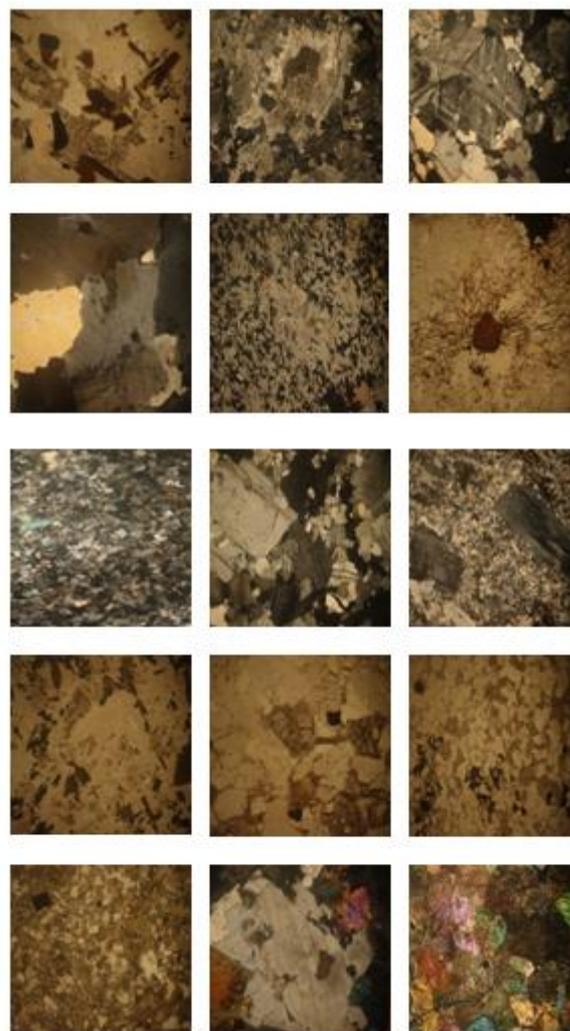


Fig. 7. Some syenites and syenite porphyries showing apgaitic texture by development of mafic minerals after feldsic minerals [12]. 1 hornblende-biotite syenite, 2 oligoclase porphyritic syenite, 3 oligoclase in augite-syenite porphyry showing 3 or more generations magmatic orientation and crystallization, 4 hornblende-quartz-syenite 5 albitite showing expansion cracks by development of Na-pyrochlore, 6 biotite-oligoclase, 7 aegirine syenite, 8. quartz rich aegirine syenite, 9 syenite porphyry, 10 porphyritic feldspar surrounded by biotite flakes, 11 coarse-grained garnet anorthoclase syenite, 12 microcline-melanite syenite, 13 melanite-biotite syenite 14 sanidine clouded with iron oxides in shonkinite, 15 clinopyroxene clouded with dusts of iron oxides in a pyroxenite emplaced in ultramafic rock. Some of these rocks indicate that mafic minerals formed at interspatial places of alkali feldspars revealing apgaitic texture.

5. DISCUSSION

According to Heinrich viscous miaskitic $(Na+K)/Al < 1$ rock has [11] more volatiles than low viscous agpaite rock $(Na+K)/Al > 1$. The state of release of volatiles depends up on temperature, pressure, magmatic structure, closed or open system of magmatic fluids and other physical and chemical conditions. Series of residual miaskitic magmas after enrichment of (Na+K) and Si during the course of differentiation and fractionation [12-17] transit into agpaite magmas releasing volatiles. Unlike Bowen's reaction series [16], residual agpaite magma starts with initial crystallization of feldspar minerals [12] and subsequent crystallization of mafic minerals which form at [12] interstitial spaces of (agpaite texture) feldspar minerals. Large quantity of silica is required to form sufficient alkali feldspars [17] and foidal minerals to account for released out excessive alkalis at late stages of magmatic differentiation and fractionation. Therefore mafic minerals and some feldspar minerals are directly converted into iron oxides [17].

The extraction of Al, incompatible and REE from agpaite residual magma, the trend moves again into miaskitic. At this stage, iron oxides incorporate more quantities of Al, REE and incompatible elements. The early formed euhedral, subhedral, opaque iron dusts in mineral grains and their peripheral concentrations [9] and very late formed overgrowths of martite are polygenetic. Formation of nioborutile is just earlier than hercynite (Fig. 6). Alkalis and silica increase during the course on normal differentiation and fractionation [16]. Agpaite factor $\{(Na+K)/Al\} > 1$ controlled by Si depends up on rate of cooling, physicochemical character, viscosity of fractionated residual magma and its volatile content. Increasing enrichment of alkalis relative to silica all mafic minerals and some feldspar minerals transform into iron oxides [17, 18].

The equilibrium of common minerals present in silica saturated norm [10] shows state of stability of subsolidus minerals and the composition of magmatic fluid from which various minerals crystallized. The following table indicates release of silica to residual magma:

Leucite = 1 Orthoclase - 1 Quartz
 Nepheline = 1 Albite - 2 Quartz
 Kalsilite = 1 Orthoclase - 2 Quartz
 Jadeite = 1 Albite - 1 Quartz
 Tschermakite = 1 Anorthite - 1 Quartz
 Tschermakite = 4 Anorthite + 3 Hypersthene - 2 Quartz
 Pargasite = 2 Albite + 2 Anorthite + 4 Hypersthene - 6 Quartz
 1 Hastingite = 2 Albite + 1 Anorthite + 3 Wollastonite + 5 Hy - 9 Quartz
 1 Edenite = 2 Albite + 4 Wollastonite + 5 Hypersthene - 6 Quartz
 Acmite = 1 Sodasilite + 1 Hematite
 Arfvedsonite = 1 Albite + 2 Acmite + 1 Wollastonite + 2.5 Hy - 2 Qz
 Kataphorite = 3 Albite + 1 Acmite + 2 Wollastonite + 4 Hy - 1 Qz

Other hand, silica is absorbed during transformation alkali-mafic minerals from the magma. The reaction of all these saturated mineral composition might have been reversible under suitable PTX conditions. Therefore compositions of subsolidus mineral grains may widely vary.

Diopside = 1 Wollastonite + 1 Edenite
 Hedenbergite = 1 Wollastonite + 1 Ferrosilite
 Actinolite = 4 Wollastonite + 5 Hypersthene + 2 Quartz
 Hornblende = 2 Anorthite + 2 Wollastonite + 4 Hypersthene
 Riebeckite = 4 Acmite + 3 Hypersthene + 2 Quartz
 Cossyrite = 2 Sodasilite + 2 Ilmenite + 7 Ferrosilite + 2 Quartz
 Arfvedsonite = 1 Acmite + 1 Sodasilite + 4 Hypersthene + 2 Quartz
 Kataphorite = 1 Albite + 1 Acmite + 1 Sodasilite + 2 Wo + 4 Hy + 2 Qz

The following equations indicate formation of opaque minerals which release significant amount of silica to meet silica deficiency of residual magmas enriched in alkalis and volatiles to form feldspar minerals and iron oxides.

Spinel = 1 Enstatite + 1 Sillimanite - 2 Quartz
 Pleonaste = 1 Hypersthene + 1 Sillimanite - 2 Quartz
 Hercynite = 1 Ferrosilite + 1 Sillimanite - 2 Quartz
 Hercynite = 1 Hematite + 1 Sillimanite - 1 Quartz
 Ulvospinel = 1 Magnetite + 2 Ilmenite
 Magnetite = 1 Ferrosilite + 1 Hematite - 1 Quartz
 Ilmenite = 1 Ferrosilite + 1 Rutile - 1 Quartz
 Rutile = 1 Ilmenite - 1 Fe (OH)₂
 Nioborutile = 1 Rutile + Nb₂O₅
 Nioborutile = 1 Rutile + 1 Ferrosilite - 1 Quartz
 Perovskite = 1 Wollastonite + 1 Ilmenite - 1 Ferrosilite
 Sphene = 1 Wollastonite + 1 Ilmenite + 1 Quartz - 1 Ferrosilite
 Garnet = 3 Ferrosilite + 1 Sillimanite - 1 Quartz

Two or more generations of opaque iron dusts are seen in feldspar, clinopyroxene and ankerite respectively in some, syenite, ultramafic and ankerite-carbonatite. The very common saturated accessory minerals combine to form rather complex iron oxide minerals to compensate silica deficiency in the residual magma. The incompatible elements enriched residual magma finally deposits nioborutile, apatite, monazite and hercynite. The chemical analyses of series of residual alkaline layers vary from early miaskitic into agpaite and then to again miaskitic residual magmatic series.

6. CONCLUSION

Iron oxides from differentiated and fractionated series of co-magmatic series of silica oversaturated and undersaturated alkali syenites in the carbonatite complex of Tiruppattur, India are polygenetic. During the course of magmatic differentiation, the residual magma transits from miaskitic to agpaite and then again to miaskitic forming characteristic rocks and

minerals. The excessive enrichment of alkalis and volatiles at the very late-staged residual magma completely is transformed all mafic minerals and part of some felsic minerals into iron oxides [17]. The iron oxides are emplaced as veins and diatremes on the ultramafic rock. Mineralization of nioborutile is earlier than hercynite incorporating more quantity of Al, incompatible and REE

ACKNOWLEDGEMENT

The author gratefully thanks to Mr. T. Ragavaiyya, Senior Technician in the Laboratory of Material Sciences, IITM, Chennai-36 for his co-operation during the course of Laboratory investigation.

List Item – 1 Article with 8 pages

List Item – 2. Seven figures

List Item – 3 18 References

List Item - 4 Author's bibliography with photo

REFERENCES

- [1] I. S. Borodin, V. Gopal, V. M. Maralev, V. Subramanian, Precambrian carbonatites of Tamil Nadu, South India, Journal of the Geological Society of India, v. 12, pp.101-112, 1973
- [2] R. Ramasamy, Geology of the area South west of Tiruppattur, Madras State (Tamil Nadu), India, Ph.D., Thesis, pp226, University of Madras, 1973
- [3] R. Ramasamy, Structure and tectonics of carbonatite complex of Tiruppattur, Tamil Nadu In: Bhattacharya, A.K. (Ed.) Current Trends in Geology, IV Indian Geological Congress, Today and Tomorrows Publishers, New Delhi, pp. 119-136, 1982
- [4] R. Ramasamy, Crystallization, fractionation and solidification of co-magmatic alkaline series sequentially emplaced in carbonatite complex of Tiruppattur, Tamil Nadu, India, Book on Crystallization- Science and Technology, Edrs Marcello Rubens, Barsi Andreetta, ISBN, pp. 535-564, 12th Sept. 2012, INTECH, Austria.
- [5] S. Saravanan, S. and Ramasamy A magnesioriebeckite from Samalpatti area, Tamil Nadu, India, Mineralogical Magazine, v. 38, pp. 376-377, 1971
- [6] S. Saravanan, S. and R. Ramasamy, Geochemistry and petrogenesis of shonkinite and associated alkaline rocks of Tiruppattur carbonatite complex, Tamil Nadu, Journal of the Geological Society of India, v. 46, pp. 235-243, 1995.
- [7] R. Ramasamy, Icelandsparr ocelli from skarn rock of Garigaipalli area, Tamil Nadu, v.52, (17) Sept., pp.808-811, 1983
- [8] R. Ramasamy, S.P. Subramanian, and R. Sundaravadivelu, R. Compositional variations of olivine in shonkinite and its associate ultrabasic rock from the carbonatite complex of Tiruppattur,

Tamil Nadu, Current Science, v. 99, (10) pp. 1428-1433, 2010.

- [9] R. Ramasamy, R., L.G. Gwalani, and S.P. Subramanian, A note on the occurrence and formation of magnetite in the carbonatites of Sevvattur, North Arcot district, Tamil Nadu, Southern India Journal of Asian Earth Sciences, v. 19, pp 297-304, 2001.
- [10] A. Rittmann, *Stable Mineral Assemblages of Igneous Rocks*, Springer-Verlag, Berlin, 264p, 1973.
- [11] E. Wm. Heinrich, *The Geology of Carbonatites*, Rand McNally, Chicago, by C.E. Tilley, 601pp, 1967.
- [12] E. Wm Heinrich, *Microscopic Petrography*, Mc Craw Hill, New York, 296p.1956.
- [13] Tom Andersen and Marlina Eburg, The miaskitic-to-agpaitic transition in peralkaline nepheline syenite (white foyaite) from the Pilanesberg Complex, South Africa, Chemical Geology v. 54, p.20, Aug, 2016
- [14] Michael A.W. Marks, Kai Hettmann, Julian Schilling, B. Ronald Frost, Gregor Markl, Factors for the transition from Miaskitic to Agpaitic Phase Assemblages, Journal of Petrology, v. 52, (3) pp. 439-455, Mar. 2011
- [15] M.A.A.W. Marks and A. G. Markid, Global review on agpaitic rocks, Earth-Science Reviews. V. 173, pp229-258, Oct, 2017.
- [16] N.L. Bowen, *The Evolution of the Igneous rocks*, Oxford University Press, 1928.
- [17] K. Yagi, Petrochemical studies on the alkaline rocks of the Morotu District, Sakhalin, GSA Bull, v. 64, pp. 769-810 1953
- [18] Ian S.E. Carmichael, F.J. Turner, J. Verhoogen, Mc Graw Hill, New York, 739p., 1974.

AUTHORS' BIOGRAPHIES



Ph.D. Univ. Madras 1974, PDF Geochim in MSU, Russia 77-80. Petrologist in DGM 74-2000, Project Consultant in DOE & CE IITM 2008-15,