Occurrence of melanite garnet in syenite and ijolite–melteigite rocks of Samchampi–Samteran alkaline complex, Mikir Hills, Northeastern India

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The Samchampi–Samteran alkaline complex constitutes a part of the ultramafic–mafic–alkaline–carbonatite complexes of Shillong Plateau and Mikir Hills and represents one of the differentiation centres of Sylhet Trap magmatism which manifests the initiation of Kerguelen plume activities on the Indian subcontinent. A detailed petrographic study reveals that Ti-rich andradite garnets occur in syenite and ijolite–melteigite rocks of the Samchampi–Samteran alkaline complex, Mikir Hills, northeastern India. The Ti-rich garnets have formed at the expense of clinopyroxene in both syenite and ijolite–melteigite rocks due to alkali metasomatic reactions between earlier formed mafic mineral and late-stage fluids. Distinct mineral–chemical characters supported by electron microprobe data classify the Ti-rich andradite garnets as melanite. Melanite garnets from the Samchampi–Samteran alkaline complex are chemically akin to those from different alkaline complexes from India and abroad, and their unique compositional parameters clearly reflect the effects of alkali metasomatism on the mineral paragenesis of an alkaline complex like Samchampi–Samteran.

Keywords: Andradite garnets, ijolite–melteigite, melanite, syenite.

TITANIUM-bearing garnets enriched in andradite ($Ca_3Fe^{3+}_2$-Si_3O_{12}), schorlomite ($Ca_3Ti_2[Al > Fe^{3+}_2]_2SiO_{12}$) or melanite ($Ca_3Ti_2[Al < Fe^{3+}_2]_2SiO_{12}$) molecules typically occur in a wide variety of alkaline igneous rocks[1–3], especially in those with a high degree of silica undersaturation. The characteristic occurrences of Ti-rich garnets include syenites[4], nepheline syenites[5], ijolite–melteigites[6] and carbonatites[4]. The Ti-rich garnets in undersaturated alkaline igneous rocks may have their origin related to alkali metasomatism and magmatism of carbonatitic affinity[7,8]. The rare and unusual occurrences of these Ti-rich garnets and the fact that they contain Ti, a cation not normally present in garnets, have prompted studies of their petrography, mineral chemistry and zoning patterns in detail[3,9]. This communication reports the occurrences of Ti-rich melanite garnet in syenite and ijolite–melteigite rocks of the Samchampi–Samteran alkaline complex, Mikir Hills, northeastern India. Petrography and mineral–chemical features of the studied melanite garnets have been discussed in order to constrain the mineral paragenesis and derive some implications on their overall genetic association.

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The Shillong Plateau and Mikir Hills of northeastern India host ultramafic–mafic–alkaline–carbonatite complexes which represent various differentiated complexes of Sylhet Traps (a part of the Bengal–Sylhet–Rajmahal flood basalts)[10,11]. The Sylhet Trap magmatism, in turn, has been interpreted to be coeval with the Kerguelen plume activity on the Indian subcontinent in the *c*. 120–100 Ma time window[12–14]. The Samchampi (26°13′N, 93°18′E)–Samteran (26°11′N, 93°25′E) alkaline complex is one such differentiation centres related to Sylhet Traps and occurs as a near-circular plug-like intrusion within the Precambrian granite gneisses of Mikir Hills in the Karbi Anglong District, Assam, northeastern India. The geological map of Samchampi–Samteran alkaline complex is given in Figure 1. This intrusive complex comprises a broad compositional lithospectrum, including syenite, ijolite–melteigite, alkali pyroxenite, alkali gabbro, nepheline syenite and carbonatite. Syenite constitutes the dominant lithomember of the complex within which the ijolite–melteigite suite of rocks has been emplaced with an arcuate outcrop pattern (Figure 1). Field observations record a sharp contact between syenite and ijolite–melteigite rocks. Alkali pyroxenite and alkali gabbro occur as inliers within the ijolite–melteigite suite. In the field, lumpy vanadium-bearing titaniferous magnetite ore bodies are exposed as isolated intrusives within the syenite host rocks (Figure 1). Dykes and dykelets of nepheline syenite and carbonatite occur as later intrusives cutting across the syenite and ijolite–melteigite rocks. Their spatial relationship suggests that they represent the youngest intrusive lithomember of the complex.

Petrographically, syenites are coarse-grained and mainly consist of K-feldspar, amphibole, clinopyroxene, plagioclase and carbonates. Biotite, sphene, apatite and magnetite occur as accessory minerals. In some syenite samples garnet is present as a major constituent and at places garnet contains inclusion of apatite (Figure 2 *a*). In sample SAJ 4A (syenite), clinopyroxene grains occur as inclusion within garnet, suggesting the earlier origin of clinopyroxene and replacement of clinopyroxene by garnet, possibly due to metasomatic reactions. Syenites show an overall hypidiomorphic granular texture with local development of perthitic intergrowths. Ijolite–melteigite rocks are coarse-grained and hypidiomorphic granular. Nepheline and clinopyroxene represent the essential mineralogy of these rocks, whereas in some samples, biotite, garnet and carbonates are present as major constituents.

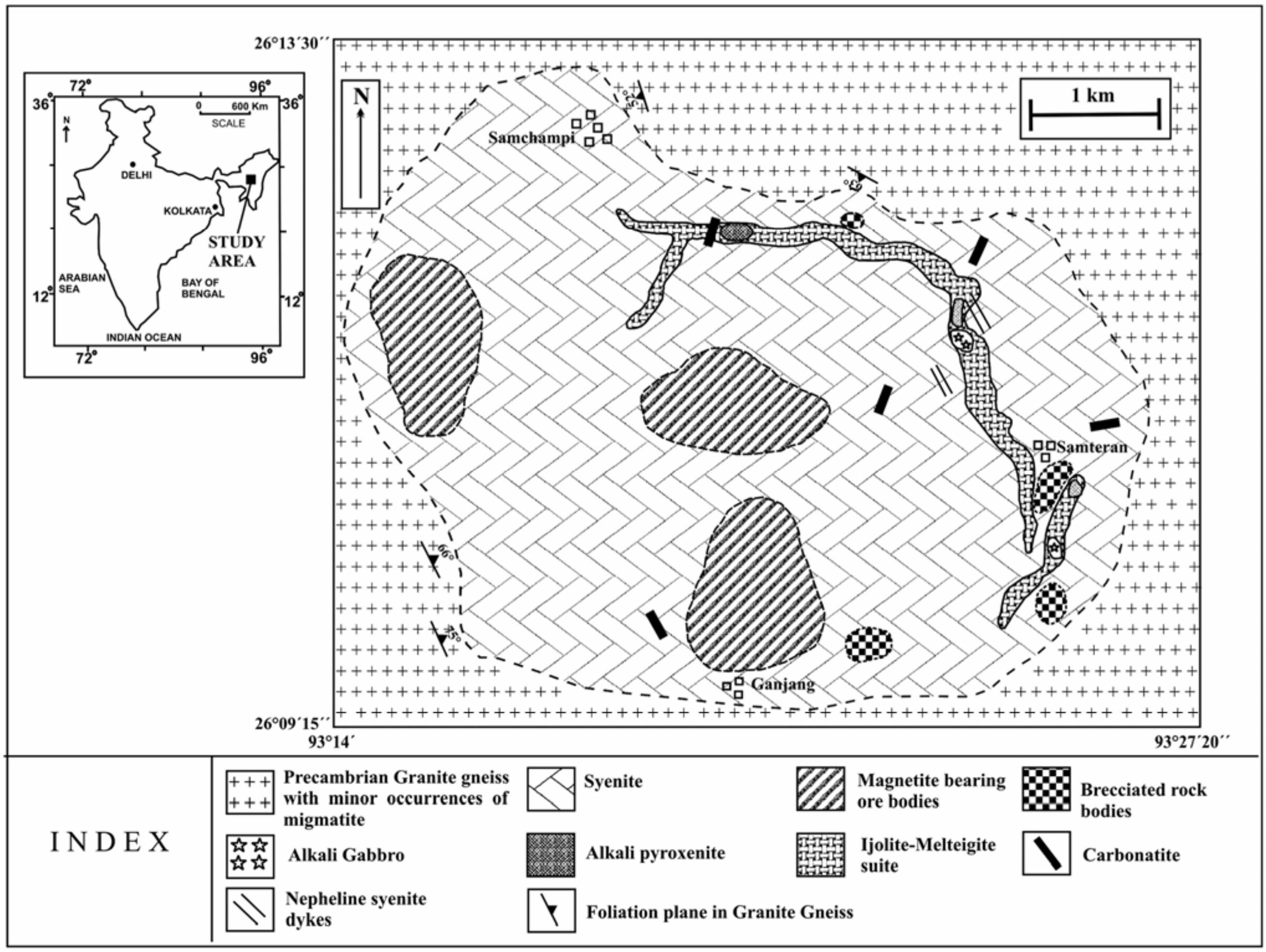

Figure 1. Geological map of Samchampi–Samteran ultramafic–mafic–alkaline–carbonatite complex. Inset map shows location of the study area.

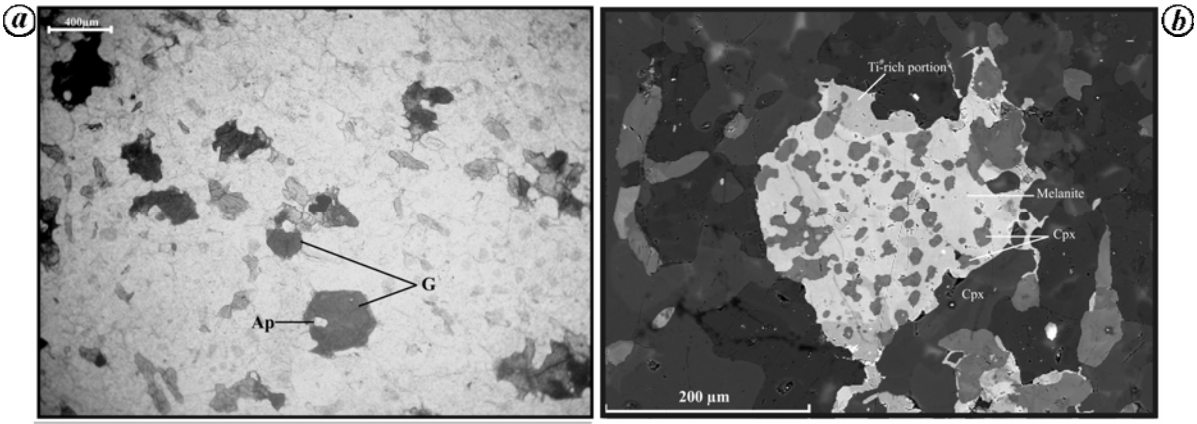

Figure 2. ***a***, Photomicrograph showing inclusion of apatite (Ap) within melanite (G). ***b***, Back scattered electron image showing the darker, Ti-rich portion of melanite garnet grain in syenite.

Subordinate amounts of K-feldspar, sphene, apatite and magnetite represent the accessory mineral phases. Petrographic observations of some ijolite–melteigite samples reveal distinct development of garnet at the expense of clinopyroxene. Alkali pyroxenites are dominantly composed of aegirine and aegirine–augite, whereas K-feldspar, nepheline, biotite, sphene, apatite and magnetite are present in subordinate amounts. The alkali pyroxenites generally show hypidiomorphic granular texture, but in places, cumulus texture has developed locally where

Table 1. Petrographic summary of constituent rock types of Samchampi–Samteran alkaline complex

Rock type	Mineral composition: Essential minerals	Mineral composition: Accessory minerals	Texture
Alkali pyroxenite	Clinopyroxene	K-feldspar, nepheline, biotite, sphene, apatite and magnetite	Hypidiomorphic granular
Alkali gabbro	Clinopyroxene, K-feldspar, and nepheline	Sphene, apatite, carbonate and magnetite	Poikilitic
Melteigite	Clinopyroxene and nepheline with biotite, melanite and carbonate	Sphene, apatite and magnetite	Hypidiomorphic granular
Ijolite	Clinopyroxene and nepheline with biotite, melanite and carbonate	Sphene, apatite and magnetite	Hypidiomorphic granular
Syenite	K-feldspar, melanite, amphibole, plagioclase and carbonate	Biotite, sphene, apatite and magnetite	Hypidiomorphic granular
Vanadium-bearing titaniferous ore bodies	Magnetite	Hematite	Locally developed box-work type intergrowth texture
Nepheline syenite	K-feldspar and nepheline	Biotite, sphene, apatite and magnetite	Hypidiomorphic granular
Carbonatite	Calcite, clinopyroxene biotite and apatite	–	Sovite

clinopyroxene occurs as cumulates and nepheline occupies the intervening spaces as the intercumulus phase. Alkali gabbro rocks contain K-feldspar, clinopyroxene and nepheline as essential mineral constituents. Sphene, apatite, carbonates and magnetite represent accessory phases. Nepheline syenites are coarse-grained, hypidiomorphic granular and essentially composed of K-feldspar and nepheline. Clinopyroxene occurs as the major mafic constituent and accessory minerals include biotite, sphene, apatite and magnetite. Carbonate minerals represent the principal mineral composition of carbonatites. Clinopyroxene and biotite occur as mafic constituents. In some carbonatite samples, apatite is present in significant proportions. The studied carbonatites are mainly sovitic with a coarse-grained, hypidiomorphic granular textural pattern. Vanadium-bearing titaniferous magnetite ore bodies are dominantly composed of magnetite associated with hematite. Pronounced effects of martitization are evident where magnetite has been oxidized and replaced by hematite, which occurs as lamellae. Box-work type intergrowth textural pattern has been observed in martitized grains[15]. A petrographic summary of constituent rock types of the Samchampi–Samteran alkaline complex is presented in Table 1.

Quantitative chemical analyses of melanite garnets from syenite and melteigite of the Samchampi–Samteran alkaline complex have been undertaken at the Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, USA. The major element compositions of melanite garnets were analysed by wavelength dispersive spectrometry (WDS) on a JEOL JXA-733 electron probe micro analyser with computer control. A fully focused beam operating with beam energy of 15 keV and a probe current of 300 nA were used. Typical counting times were 20–40 s and 1σ standard deviations of the counts were 0.5–1%. Synthetic and natural standards were used during the analyses[16].

Representative compositions of garnet from syenite (SAJ 4A) and melteigite (SAJ 17) of the Samchampi–Samteran alkaline complex are given in Table 2. The electron microprobe data of the analysed garnets depict a prominent enrichment in CaO (ranging from 31.52 to 32.08 wt%) with lesser amounts of Al_2O_3 (ranging from 0.67 to 2.7 wt%) and Cr_2O_3 (ranging from 0.04 to 0.09 wt%). Most strikingly, the Samchampi–Samteran garnets contain significant proportions of TiO_2, ranging from 3.62 to 12.88 wt%, which reveals a unique compositional character. Variations in the concentration of Ti (refs 3, 5) have been observed in the presently studied melanite garnets where the outer portion of a melanite grain gives a darker shade indicating higher Ti concentration than the lighter, low Ti inner portion (Figure 2 *b*). The Na_2O and $FeO^{(t)}$ contents of syenite (SAJ 4A) are greater than those of melteigite (SAJ 17), whereas melteigite (SAJ 17) is characterized by higher amounts of MgO, TiO_2 and Al_2O_3 than those of syenite (SAJ 4A) (Figure 3). MgO content of the analysed garnets systematically increases with TiO_2 and MnO content reaches a value of 0.6 wt%.

The electron microprobe analysis (EPMA) data of the Samchampi–Samteran garnets suggest a composition rich in andradite components (Table 2). The analysed garnet compositions are projected onto the spessartine + pyrope – Ti-andradite – grossular system, where the compositional range corresponds to Ti-andradite (Figure 4 *a*)[3,17]. According to Deer *et al.*[18], Ti-rich andradite garnets can be further classified into melanite and schorlomite, depending on whether Fe^{3+} or Ti predominates in the octahedral site, placing the limit approximately at 15 wt% TiO_2. Considering the classification parameters,

Table 2. Electron microprobe analysis data of garnet

Sample	SAJ 17	SAJ 4A			
Analysis					
Rock type	M	←	S		→
SiO_2	28.03	32.64	33.79	32.09	32.29
TiO_2	12.88	3.62	4.06	7.10	6.66
Al_2O_3	2.67	1.31	1.55	0.67	0.71
Cr_2O_3	0.07	0.08	0.04	0.10	0.08
FeO	0.90	–	0.67	1.83	1.63
Fe_2O_3	20.37	27.62	26.22	24.83	25.37
MnO	0.60	0.60	0.54	0.55	0.58
MgO	1.15	0.15	0.21	0.24	0.21
CaO	31.91	32.08	32.21	31.53	31.52
Na_2O	0.14	0.21	0.26	0.33	0.35
Total	98.71	98.31	99.55	99.27	99.40
Formula on the basis of 24 oxygen atoms					
TSi	4.788	5.601	5.706	5.477	5.503
TAl	0.536	0.264	0.294	0.134	0.142
Sum_T	5.325	5.865	6	5.611	5.645
Al^{VI}	–	–	0.014	–	–
Fe^3	2.616	3.563	3.328	3.186	3.25
Ti	1.655	0.467	0.516	0.912	0.854
Cr	0.009	0.011	0.006	0.013	0.01
Sum_A	4	4	4	4	4
Fe^2	0.129	–	0.094	0.261	0.232
Mg	0.292	0.039	0.052	0.061	0.054
Mn	0.086	0.087	0.078	0.079	0.084
Ca	5.840	5.898	5.827	5.766	5.755
Na	0.048	0.070	0.085	0.111	0.116
Sum_B	6.396	6.094	6.136	6.278	6.241
Sum_cat	16	16	16	16	16
And	82.75	95.52	91.38	95.58	95.51
Gross	9.01	1.94	6.10	1.22	1.48
Pyrope	6.15	0.69	0.95	1.22	1.06
Spess	1.82	1.55	1.42	1.59	1.64
Uvaro	0.28	0.30	0.16	0.39	0.31
XCagnt	0.920	0.979	0.963	0.935	0.940
XFegnt	0.020	–	0.016	0.042	0.038
XMggnt	0.046	0.006	0.009	0.010	0.009
Fe_Mggnt	0.442	–	1.808	4.279	4.296

M, Melteigite; S, Syenite.

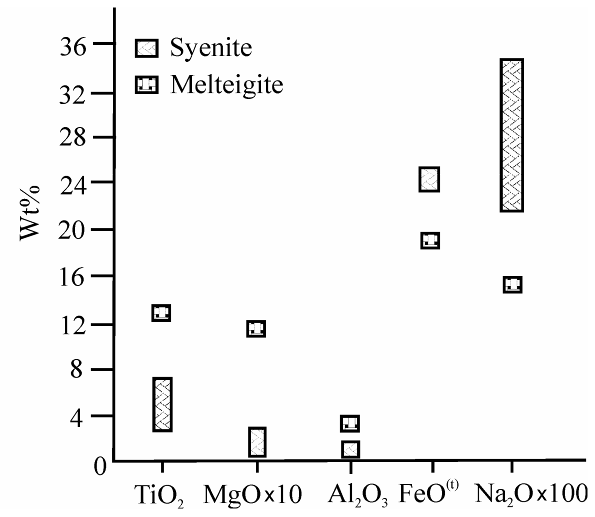

Figure 3. Compositional range of garnets from syenite and melteigite in terms of TiO_2, MgO, Al_2O_3, $FeO^{(t)}$ and Na_2O contents.

the studied Ti-andradites from the Samchampi–Samteran alkaline complex can be designated as melanite with a maximum 12.88 wt% TiO_2 (i.e. TiO_2 content less than 15 wt%, $Fe^{3+} > Ti$, $Al < Fe^{3+}$)[18–20] in all the analysed samples (Table 2). When the garnet compositions are referred to the TiO_2 (wt%) versus Fe_2O_3 (wt%) diagram (Figure 4 *b*)[21], all the data plots fall below the 15 wt% TiO_2 line and occupy the field of melanite. The compositional range of Samchampi–Samteran garnets is very much correlatable with that of garnets from well-studied alkaline complexes of the world like Sung Valley[22], Amba Dongar[20], Magnet Cove, Arkansas[23] and Alberta, Canada[24] (Figure 4).

Ti-rich garnets can form over a wide range of temperatures and pressures and particularly, in alkaline rocks, they appear to reflect complex, late-stage metasomatic reactions of earlier formed mafic minerals with alkali-rich fluids[3,20]. This phenomenon is consistent with the

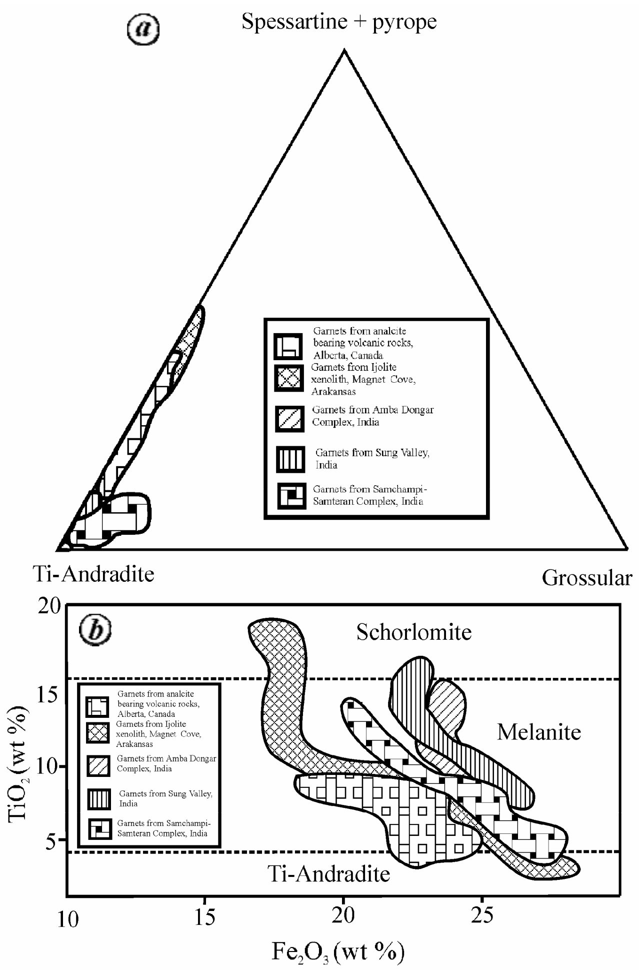

Figure 4. ***a***, Diagram showing the compositional field of garnet from Samchampi–Samteran in spessartine + pyrope – Ti–andradite – grossular system[3]. The compositional range of Samchampi–Samteran garnets has been compared with that of garnets from other alkaline complexes. The plots corresponding to garnets from the Amba Dongar complex, India have got clustered near the apex of Ti–andradite. ***b***, TiO_2 versus Fe_2O_3 diagram showing the fields of schorlomite, melanite and Ti-andradite. The compositional range of the studied garnets falls in the melanite field. Respective compositional fields of garnets from other alkaline complexes have also been shown.

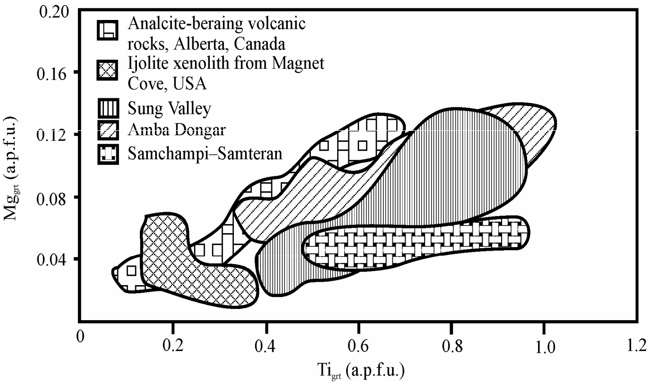

Figure 5. Mg_{grt} (a.p.f.u.) versus Ti_{grt} (a.p.f.u.) diagram showing the respective compositional fields of garnet from Sung Valley (India), Amba Dongar (India), Magnet Cove (USA), Alberta (Canada) and Samchampi–Samteran (present study).

petrographic observations of the Ti-rich Samchampi–Samteran garnets which depict that the garnets have formed at the expense of clinopyroxene as a result of fluid-driven metasomatic alterations. Evaluation of EPMA data characterizes the garnets as Ti-rich andradite and their chemical parameters classify them as melanite. These melanite garnets are calcic and represent an overall composition ranging from $And_{82.75}Gr_9Py_6Sp_{1.82}Uv_{0.28}$ to $And_{95.58}Gr_{1.22}Py_{1.22}Sp_{1.59}Uv_{0.40}$. Mg_{grt} (a.p.f.u.) versus Ti_{grt} (a.p.f.u.) relations (Figure 5) suggest that the melanite garnets from syenite and melteigite of Samchampi–Samteran alkaline complex are compositionally akin to those from Sung Valley ijolites[22]; melilite-free nephelinites of Amba Dongar, northern Deccan[23]; metasomatized ijolites of Magnet Cove, Arkansas[24], and alkaline igneous rocks from Alberta, Canada[3]. Characteristically, the garnets from both the alkaline complexes of Samchampi–Samteran and Sung Valley are titania-rich with prominent andradite component and involve complex substitution $Ti^4Fe^3 \leftrightarrow Ti^4Al^3$ in appropriate crystal sites, thereby yielding the melanite variety[24,25]. Thus, the occurrence of Ti-rich melanite garnets in the syenite and ijolite–melteigite rocks and their petrographic and mineral–chemical study point towards the role of a fluid-enriched milieu in the magmatic history of the Samchampi–Samteran alkaline complex and the effects of alkali metasomatism on its mineral paragenesis.

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Effect of *Tribulus terrestris* on monosex production in *Poecilia latipinna*

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***Tribulus terrestris* (*Tt*) is a traditionally known, non-toxic aphrodisiac herb for effecting maleness. It would help develop an eco-friendly method to masculinize the fish, *Poecilia latipinna*, because males have higher commercial value. A dose-dependent masculinization occurs on administration of *Tt*, which improved male ratio. All groups of *Tt*-treated fish also exhibited notable growth acceleration.**

Keywords: Masculinization, *Poecilia latipinna*, sex reversal, *Tribulus terrestris* hormones.

TRIBULUS TERRESTRIS (*Tt*; Zygophyllaceae) is a ground-spreading herb, widely distributed in China, Japan, Korea, the western part of Asia, the southern part of Europe, and Africa. It is a common plant known to elevate the testosterone levels in humans and animals. In humans, it has been used to treat impotence and has been found to increase testosterone levels and improve athletic performance as well[1–6]. It contains a number of different substances, including steroidal saponins. Protodioscin, the most dominant saponin in *Tt*, is considered to be the main substance responsible for increasing testosterone production[7].

The sex ratio of *Poecilia* fish has great significance in aquaculture because uncontrolled reproduction of this group in production ponds is one of the most serious limitations in *Poecilia* culture. Males grow faster than females[8,9]. Therefore, the maintenance and breeding of male populations have generated interest in terms of commercial applications. *Poecilia* fish can be masculinized by direct synthetic hormonal treatment that is efficient and straightforward[10–12]. However, synthetic hormones are more expensive than local plant extracts; also their administration in fish is time-consuming and labour-intensive and requires expertise. Further, synthetic hormones accumulate in the sediment water and aquatic biota[13,14]. There is no report on the accumulation of protodioscin in the sediment water or on the toxicity of *Tt* in fish. An alternate technique for commercially producing all-male fish populations would be to use plant extracts. Therefore, the present study was undertaken to investigate the effect of *Tt* on sex reversal to produce all-male population and enhance growth rate in *Poecilia latipinna*.

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