CHAPTER 6
GENESIS OF STEATITE MINERALIZATION

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6.4 GENESIS OF STEATITE MINERALIZATION:

6.5 SUMMARY

In this chapter, the events leading to steatite mineralization in the study area is described, beginning with evolution of the host rocks. Due to complexity of metamorphism in the area (original metamorphism overprinted by contact metasomatism), rigorous treatment of mineralogical data defining phase relationship was not possible. Therefore determination of paragenetic sequences of alteration, for the most part is based on petrographic observations supplemented by mineralogical data. The nature of fluids responsible for mineralization is deciphered based on fluid inclusion and stable carbon and oxygen isotope data of carbonates in the talcified rocks.

6.1 EVOLUTION OF THE TERRAIN

The Bageshapura area contains steatite mineralization that is spatially associated with iron formations and clay deposits. This
association is unique in terms of geological evolution of the terrain. Previous work in the area is lacking and the present investigation therefore throws light on geological aspects of steatite mineralization in the area.

The gneisses with relict patches of sialic (quartzitic), mafic (chlorite -biotite-hornblende) together with subordinate layers and inclusions of bedded amphibolites forms the basement rocks in the study area. The age of these gneisses is presumed to be 3.2 to 3.4 b.y. in the absence of radiometric age determinations. During the period between 3.2-3.0 b.y., the adjacent Kalyadi area witnessed widespread rifting according to Ravindra (1989) into which ultramafic volcanicalstic material along with H$_2$S, iron (BIF-I) and copper deposited in the deepening basins.

Trondhjemetic gneisses were emplaced in the above rock formations c. 3.0 b.y. marking the end phase of M1 metamorphism in the area. Some of the ultrabasic intrusive (chlorite-actinolite rocks) were probably emplaced during 3.0 to 2.8 b.y, followed by a phase of quiescence representing the unconformity between the Sargur group (Kalyadi formation) and Dharwar supergroup (Bageshapura formation).

The period between 2.8 - 2.7 b.y was dominated by compressive forces and development of NNW- trending rifts in the Bageshapura and the adjacent Kalyadi regions. The rifts in the Bageshapura area witnessed eruption of amygdular basalts, culminating in the deposition of oxide facies iron formations (BIF -II). Metamorphism of the Bageshapura (and Kalyadi) formations around 2.6 b.y (at pressures 2 to 3 Kb and temperatures of 400 - 450° C) was possibly accompanied by emplacement of ultramafic rocks in the area. This was followed by an event of
feldspathisation and emplacement of Arasikere - Banavar granite c.2.6 b.y ago (Venkatasubramaniyam and Naryanswamy, 1974) with attendant hydrous fluids related to the emplacement of Desani granite.

Steatite mineralization in the Bageshapura area post-dates the above events. Decisive criteria for the formation of steatites in the study area is discussed under the following headings:- (1) Geological constraints of talc formation and (2) Nature of solutions responsible for steatite mineralization.

6.3 GEOLOGICAL CONSTRAINTS ON TALC FORMATION.

Formation of steatite is largely dependant on the availability of sufficient Mg, which may be derived from low-grade metamorphism / hydrothermal alteration of ultramafic / mafic rocks and by contact and regional metamorphism of siliceous dolomites. The possible reactions involved in the formation of steatite are the same as those applicable to talc, since talc is one of the components of steatite.

Availability of Al, Ca or K in the precursor rock governs the formation of other minerals associated with talc, since steatite is invariably associated with other minerals. Abundance of Al in the parent rock results in the formation of chlorite, profusion of Ca leads to the formation of tremolite and that of K results in the formation of phlogopite. Metasomatism with attendant high Si activity favours the formation of talc. Silica may be derived from the adjacent quartz-bearing rocks or by hydrothermal solutions.
According to Hess (1933), the mineral succession in the formation of massive steatite from ultramafic rocks is: hornblende, actinolite, chlorite, talc and carbonate in the order of decreasing temperature. During the course of metasomatism of the rocks, in cases where the alteration is arrested due to withdrawal of solution from the contact of ultramafic rocks, then one of the intermediate members of the above series may be present. During steatitization, the original olivine / pyroxene of the ultramafic rocks is first replaced by hornblende (in the presence of sufficient alumina) or actinolite (in case of deficiency of alumina). Further decrease in temperature and presence of sufficient alumina results in the whole rock being transformed into a chlorite-rich mass. In majority of the cases however, talc and carbonate would have formed sufficiently so that the end product is a steatite with relics of chlorite + carbonate. In many cases, it is found that chlorite is developed from alteration of ultramafic rocks and not serpentine, as is the case in the present study area. This feature may be attributed to the availability of iron and alumina in the ultramafic, which favours formation of chlorite rather than serpentine. Therefore the composition of the host rock rather than temperature and pressure, governs the formation of either serpentine or chlorite.

Steatite / talc deposits form from ultramafic rocks by alterations involving little chemical transfer, since the chemical composition of the primary rocks is relatively similar to the steatite. The texture of the rocks affected by steatitization in the area indicates constant volume alteration, since the original fabric of the parent rocks are faithfully preserved. No cracks in the rocks or distortion fabric are visible around patches of talcified minerals. The common talc / steatite forming reactions from minerals of the ultramafic rocks are:
\[2\text{Mg}_2\text{Si}_4\text{O}_8 + 2\text{H}_2\text{O} = \text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + \text{MgO}\.\]

Olivine \hspace{1cm} \text{Serpentine}

\[\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + \text{SiO}_2 = \text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_4 + \text{H}_2\text{O}\]

Serpentine \hspace{1cm} \text{Talc}

\[2\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + 3\text{CO}_2 = \text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2 + \text{Mg CO}_3 + \text{H}_2\text{O}\]

Serpentine \hspace{1cm} \text{Talc}

\[\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2 + 4\text{CO}_2 = \text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2 + 2\text{CaMg(CO}_3) + 4\text{SiO}_2\]

Tremolite \hspace{1cm} \text{Talc}

It appears that elements were neither introduced nor extracted in important amounts, but rather that they have been redistributed within the limited volume of the rock under consideration. Mg was either derived locally from the surrounding rocks or it was introduced from an external source. Mafic dykes, amphibolites, gneisses and ultramafic bodies are potential sources of Mg.

Steatite formation occurs only in association with ultramafic rocks and therefore there is no need to postulate Mg-transport on a larger scale. If Mg is supplied along the veins, then talc formation should have been independent of lithology of the host rocks. It is pertinent to note that steatite mineralization in the Bageshapura area is spatially associated with altered gneisses, the latter in the form of clay deposits constitutes economic concentrations and being mined. This situation is comparable to the talc deposits of Rabenwald in Eastern Alps described by Prochaska (1989); wherein talc is associated with hydrothermally altered gneisses.
termed "leucophyllite"). However the talc deposits of Rabenwald form part of the alpine nappe, in contrast to the steatite mineralization in the Bageshapura area, which is hosted in ultramafics in a Archaean craton (layered complex). It may be contended that the event responsible for alteration of the gneisses in the study area was identical with the talc-forming process, but possibly additional Mg was necessary for steatite formation.

Steatite formation is due to ingress of (Mg-rich) hydrothermal fluids, related to intrusion of the Desani granite, reacting with the constituent minerals (actinolite, chlorite and carbonate) of the host rocks. In deposits where acid intrusives are spatially associated with the ultramafics, as in the present study area, certain other minerals develop in addition to steatite the most common mineral being biotite or its hydrated equivalent - vermiculite. Both these varieties of mica are present in the Bageshapura area. It is contended that potassium for the formation of vermiculite was derived from the acid intrusive and Mg came from the host ultramafic rocks.

Mineral assemblages in metamorphic rocks, near to, but not affected by steatite formation record peak metamorphic temperature of about 400-450°C and pressure of about 2 to 3 Kb (Ravindra 1989). The observed Steatite mineralization is not compatible with this condition of P-T, and it is therefore concluded that steatite formation in the study area occurred at a lower temperature and post-dates the peak period of metamorphism. It may be conjectured that steatite formation began with the hydrothermal alteration of ferromagnesian constituents leading to the development of chlorites on a sufficient large scale.
Possible sources of hydrothermal fluids for the metasomatism was the emplacement of the Desani granite in the area. However there is no strong alteration observed near the granite - ultramafic contacts at the present level exposed by erosion. Steatitization (talcification) is pervasive through the whole ultramafic rocks and there is no control other than the fabric of the rock itself.

6.3 NATURE OF MINERALIZING SOLUTIONS RESPONSIBLE FOR STEATITE MINERALIZATION

6.3.1 Fluid inclusion studies: Fluid inclusion studies on the quartz grains adjacent to talc-chlorite ores have been used to decipher the nature of the mineralizing fluids of talc deposits. In the present study, fluids inclusions in the quartz grains of late quartzo-feldspathic veins post dating granite were considered as associated with steatite mineralization. Hence the data of these fluid inclusions have been used to constrain the nature of mineralizing solutions. Fluid inclusion studies suggest that steatite mineralization in the study area is controlled by the CO$_2$ - poor and H$_2$O-rich fluid influx associated with emplacement of quartzo-feldspathic veins. The range of temperature deciphered from temperature of homogenization of quartz veins in talcified ultramafics is 123°C – 235°C. Further, trails of secondary inclusions are indicative of tectonic activity concomitant with acidic intrusion in the study area, which may have promoted the migration of hydrothermal solutions.

Since dolomite is absent in the ultramafics of the study area and its presence is noticed only with the spatially associated talc, it may be
conjectured that both dolomite and talc have comparable mode of genesis. Talc having formed by the activity of hydrothermal fluids, the same may be the attributed to the formation of dolomite. Hence, the carbon and oxygen isotope data of dolomites are considered to evaluate the nature of hydrothermal fluids involved in the formation of talc in steatite. The density values of 0.996- 1.010 g/cc obtained for the fluids and relatively moderate salinity values indicate that the fluids for steatite mineralization were derived from acid intrusive rocks. The presence of low density CO₂ (0.875-0.793 g/cc) and low to moderate salinity 11 to 14 wt% NaCl equiv. aqueous inclusions suggest unmixing of these inclusions. The range of temperature deciphered from temperature of homogenization of quartz grains of quartzo-felspathic veins associated with talcified ultramafics is 123°C – 235°C. This temperature range is consistent with talc mineralization originating from hydrothermal activity.

6.3.2 Stable isotope studies: Stable carbon and oxygen isotope ratios were determined for the carbonates associated with talc, at the University of Massachusetts, U.S.A., by the conventional techniques of McCrea (1950). Since dolomite and talc are products of alteration from the same fluids in the Bageshappura area and therefore dolomite has been used as an index to decipher the possible source and temperature of steatite mineralization in the Bageshappura area. The results of the stable isotope investigation is tabulated in Table 6.1.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>δ¹³C PDB  °/oo</th>
<th>δ¹⁸O SMOW °/oo</th>
</tr>
</thead>
<tbody>
<tr>
<td>PK 301- JADGHATTA</td>
<td>- 4.96</td>
<td>8.96</td>
</tr>
<tr>
<td>PK 302- JADGHATTA</td>
<td>-5.99</td>
<td>8.85</td>
</tr>
<tr>
<td>PK 303- KARGUNDA</td>
<td>- 5.50</td>
<td>7.87</td>
</tr>
</tbody>
</table>

TABLE 6.1: Stable isotope data of dolomite associated with talc steatites.
Based on the composition of fluid inclusions described earlier (Chapter 4), the hydrothermal fluids involved in the formation of talc and minor/traces of dolomite in the study area are H\textsubscript{2}O- and CO\textsubscript{2}- rich. Further, the narrow variation of \(\delta^{13}\)C values (-3 to -5 °/oo) of dolomites is indicative of a single source of carbon, both H\textsubscript{2}O and CO\textsubscript{2} having derived from a magmatogenic hydrothermal source (Schandl & Wicks, 1993).

Oxygen isotope data of carbonates places constraints on the temperature and/or isotopic composition of the talc-forming fluids. If the carbonate forming fluid was modern meteoric water with \(\delta^{18}\)O values of -20 to 0 °/oo, then the temperature of formation of the carbonate would be substantially lower. For reasonable temperature of 100 to 300° C the fluids must posses \(\delta^{18}\)O values greater than -10°/oo. A water-rich fluid in excess (high fluid to rock ratio) has the capacity to change \(\delta^{18}\)O of the carbonate because of the large quantity of oxygen in the fluid relative to the quantity of oxygen. In the study area, carbonate (dolomite) associated with talc mineralization have yielded \(\delta^{18}\)O values around 8°/oo, which is consistent with \(\delta^{18}\)O values of 7.5 to 8.0 °/oo, reported for Muamsa granite by Shin et al., (2003).

The \(\delta_{13}\) C and \(\delta_{18}\) O values of dolomites of the Bageshapura area, plotted in the diagram of Schroll (2002) (Fig. 6.1), indicates a hydrothermal source.
Fig. 6.1 δ¹³C and δ¹⁸O data of carbonates of the study area plotted in the diagram of Schroll (2002).
6.2 GENESIS OF STEATITE MINERALIZATION:

The above results lead to the conclusion that steatite/talc mineralization in the Bageshapura area resulted from the activity of hydrothermal solutions on chlorite-actinolite schists; the latter owes it origin to the regional metamorphism of ultramafic-mafic rocks in the area. Hydrothermal solutions also caused talcification of some ultramafic-mafic rocks in the study area. The hydrothermal solutions were CO₂- and H₂O-rich solutions, whose ingress into the mafic/ultramafic rocks resulted in their conversion into steatite/talc.

6.5 SUMMARY

1. The gneisses with relict patches of sialic (quartzitic), mafic (chlorite -biotite-hornblende) together with subordinate layers and inclusions of bedded amphibolites forms the basement rocks in the study area. The age of these gneisses is presumed to be 3.2 to 3.4 b.y.

2. Trondhjemetic gneisses were emplaced in the above rock formations c. 3.0 b.y. marking the end phase of M1 metamorphism in the area.

3. The period between 2.8 - 2.7 b.y was dominated by compressive forces and development of NNW- trending rifts in the Bageshapura area.
4. This was followed by an event of emplacement of Arasikere – Banavara-Desani granite c. 2.6 b.y ago with attendant hydrothermal activity.

5. Steatite mineralization in the Bageshapura area post-dates the above events.

6. Steatite/talc deposits formed from ultramafic/mafic rocks by alteration involving little chemical transfer. Elements were neither introduced nor extracted in important amounts, but rather that they have been redistributed within the limited volume of the rock under consideration. Mg for the formation of dolomite and talc were derived locally from the protoliths. Steatite formation occurs only in association with ultramafic rocks and therefore there is no need to postulate Mg-transport on a large scale. Ca needed for the formation of minor amounts of dolomite was derived from chlorite-tremolite-actinolite schist.

7. Source of hydrothermal fluids for the metasomatism of meta-ultramafic/mafic rocks can be attributed to the event of Desani granite emplacement.

8. The narrow variation of $\delta^{13}$C of carbonates associated with steatite mineralization indicates that the metasomatic fluids were derived from a single source.

9. $\delta^{18}$O value of 8°/oo obtained for the dolomites associated with steatite mineralization is consistent with the values reported for steatite/talc deposits originating from the hydrothermal alteration of ultramafic/mafic source rocks.