to a structure comprising hundreds of thousands of individual sub-millimetre crystals of quartz by any mechanism of growth from a liquid. It is therefore suggested that the plates developed along fractures which formed during the dehydration of a silica gel according to the following mechanism.

Following its injection into a cavity in the country rock, the silica gel would begin to cool, dehydrate and subsequently contract. In a similar way to the formation of columnar joint patterns in basaltic lava flows, the contraction would result in individual 'cells' which would contract as separate units. Within each of these cells fractures would have developed in response to the contraction. It is interesting that all the plates which subsequently developed along these fractures are perfectly planar with no evidence of curvature, so the fracturing behaviour of the gel must be different to that of other non-crystalline solid materials such as glass in which conchoidal fractures would be expected. The fractures would have provided pathways for the ingress of aqueous solutions (perhaps containing hematite in suspension) and promoted the crystallisation of thin central zones of randomly orientated quartz crystals. Once a central zone was formed, the quartz would act as a nucleation centre for the recrystallisation of the remaining silica gel and quartz crystals grew orthogonally from the central zone, their orientation being controlled by the simultaneous growth of many crystals outwards from the same plane. However as quartz has a higher density than the silica gel, there would be further contraction towards the crystallisation centres, ultimately resulting in the development of vugs. During the recrystallisation of the quartz between two central zones any hematite present in the gel could not be incorporated in the crystalline quartz and would be pushed ahead of the growing crystals (Sweetman, 1988). This accounts for the concentration of hematite on the surface of quartz crystals lining the vugs and along the line where two rows of orthogonal crystals meet. The central position of the contact of the two sets of quartz crystals from adjacent central zones indicates simultaneous equal growth away from the two central zones, and the cross-cutting relationships indicate that all the central zones formed prior to the growth of the orthogonal quartz. The overall reduction in volume resulting from the crystallisation of the gel would account for the abundance of the vugs, and the average density of the whole rock (2.48 g $cm^{-3}$) may give an indication of the anhydrous density of the original gel.

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# Staurolite from a metabasite and its paragenesis

THIS study deals with the gedrite–staurolite assemblage from a metabasite (amphibolite) in the Vinjamuru area (Lat 14°50′ and Long 79°35′) of the Nellore granite–greenstone terrain of S. India. The rocks of the study area have been classified into an older Vinjamuru schist complex and a younger Udayagiri Group (Vasudevan *et al.*, 1977). Metapelites (quartz–mica–

plagioclase–staurolite–garnet–kyanite schists), partly migmatised due to the injection of quartzo-feldspathic material, are the oldest rocks and these are followed by quartzites, dolomites and amphibolites. The Udayagiri Group is made up of metarhyolites, carbonate rocks, quartzites, meta-andesites and metadacites. A NNW–SSE trending shear zone, proved to be a thrust by DSS studies (Kaila *et al.*, 1979), traverses the study area; it brought the rocks of Vinjamuru Group into juxtaposition with the Udayagiri Group (Vasudevan *et al.*, 1977). The rocks in the vicinity of the shear zone have been subjected to retrogression and the hornblende is partially replaced by chlorite.

Amphibolites occur in schistose and massive varieties and are generally composed of hornblende, plagioclase, orthoclase, opaques ± garnet, and have an igneous parentage [Moeen and Babu, 1988). They are intrusive bodies and in the well sections, located at SE of Vinjamuru Taluq office, it has been observed that the amphibolites are intruded into the dolomite, resulting in contact metamorphism. The contact is characterised by the development of tremolite–diopside–dolomite rock. In other localities, where amphibolites are associated with quartzites, thin layers of amphibolites occur in quartzites. Towards the west of Nandigunta (Lat 14°50′45″ and Long 79°32′30″), an amphibolite essentially made up of gedrite is exposed. It runs for about 150 metres in a NW–SE direction and the contact with the hornblende schists is not exposed. In this area, the contact between the hornblende schists and the overlying metarhyolites is well exposed. When traced towards the amphibolite–metarhyolite contact, the hornblende schist becomes richer in biotite and poorer in hornblende, indicating an interaction between rhyolite lava and the amphibolite. The petrography provides evidence of the conversion of hornblende to biotite.

The gedrite-bearing amphibolites are essentially made up of gedrite plus staurolite, which is absent in other amphibolites, and minor amounts of biotite, garnet and occasionally plagioclase. Hornblende is sparse in amount and few needles of sillimanite occur and they seem to be released from gedrite.

Gedrite occurs as columnar aggregates with feeble pleochroism and parallel extinction. Staurolite appears as subidioblastic grains coexisting with gedrite, biotite and garnet. Gedrite–staurolite and gedrite–biotite–staurolite are the most commonly observed assemblages. Staurolite also occurs as inclusions in garnet. Inclusions of quartz, biotite and opaques are

**Table 1. Electron probe analyses of staurolites and gedrite**

| | Staurolite | | Gedrite |
|---|---|---|---|
| | RS 91 | RS 112 | |
| $SiO_2$ | 28.70 | 27.65 | 44.54 |
| $TiO_2$ | 00.49 | 00.46 | 00.13 |
| $Al_2O_3$ | 52.38 | 54.47 | 16.49 |
| FeO | 13.28 | 12.94 | 19.71 |
| MnO | 00.14 | 00.13 | 00.29 |
| MgO | 03.06 | 02.56 | 15.56 |
| CaO | 00.02 | 00.01 | 00.49 |
| $Na_2O$ | 00.02 | 00.01 | 01.81 |
| $K_2O$ | 00.05 | 00.04 | 00.04 |
| $Cr_2O_3$ | 00.04 | 00.04 | 00.03 |
| BaO | 00.05 | 00.04 | 00.04 |
| Total | 98.23 | 98.35 | 99.13 |
| | 44(0) | 44(0) | 22(0) |
| Si | 7.561 | 7.277 | 6.096 |
| Al(4) | 16.299 | 16.900 | 1.904 |
| Al(6) | | | 0.759 |
| Ti | 0.097 | 0.090 | 0.013 |
| Fe | 2.931 | 2.849 | 2.256 |
| Mn | 0.032 | 0.029 | 0.034 |
| Mg | 1.204 | 1.004 | 3.174 |
| Ca | 0.005 | 0.003 | 0.072 |
| Na | 0.009 | 0.003 | 0.480 |
| K | 0.016 | 0.013 | 0.003 |
| Cr | 0.010 | 0.009 | 0.003 |
| Ba | 0.005 | 0.005 | 0.002 |
| $X_{Mg}$ | 0.291 | 0.260 | - |
| T | - | - | 8.000 |
| C | - | - | 5.000 |
| B | - | - | 1.788 |
| A | - | - | 0.003 |

**Table 2. XRF analysis of the host rocks**

| | RS 91 | RS 112 |
|---|---|---|
| $SiO_2$ | 49.09 | 59.12 |
| $TiO_2$ | 01.40 | 01.20 |
| $Al_2O_3$ | 12.90 | 17.62 |
| $Fe_2O_3$ | 02.52 | 04.82 |
| FeO | 17.48 | 07.98 |
| MnO | 00.34 | 00.08 |
| MgO | 14.11 | 04.60 |
| CaO | 00.45 | 00.40 |
| $Na_2O$ | 01.10 | 01.50 |
| $K_2O$ | 00.50 | 03.14 |
| $P_2O_5$ | 00.13 | 00.07 |
| Total | 100.02 | 100.53 |

common in staurolite and twinning is well developed. Biotite occurs both as the product of prograde metamorphism and as an alteration product of gedrite. The former coexists with gedrite, staurolite, biotite, and garnet, and also as inclusions in them. Garnet occurs as well developed porhyroblasts with sieve structure carrying the inclusions of staurolite and biotite.

Staurolite in the metapelite occurs as perfect idioblasts in association with micas, garnet, plagioclase and quartz.

The staurolites are Fe-rich (Table 1). Since the metapelite (RS 112) is aluminous and siliceous (Table 2) its composition is favourable for the development of staurolite as mentioned by Grew and Sandiford (1984). In the case of metabasite (RS 91), the highly augmented FeO and MgO contents favour the development of ferromagnesium minerals. The impoverishment of Ca not only causes the development of gedrite at the expense of hornblende but also limits the formation of plagioclase. Similarly, the poor $K_2O$ content inhibits the growth of K-feldspar. Hence the available Al, at the expense of feldspars, and high Fe, Mg contents favour the growth of staurolite.

The composition of RS 91 is unusual and does not correspond to any of the basaltic rocks. Since they are intrusive bodies, it can be presumed that they are intruded into the pelitic rocks (now represented by metapelite) resulting in mixing of pelite with basic magma. The band of gedrite-bearing amphibolite can be interpreted as the portion rich in the pelite component and this explains the smaller areal extent of the rock. Further, the present mineral assemblage is in contrast with the Hbl + Pl + Ky (or Cor) + St + Ru assemblage reported by Gibson (1978) in a pure metabasite. The low $X_{Mg}$ value of the staurolite indicates that it has formed at usual metamorphic conditions as Mg rich rocks yield Mg-staurolites at high $P$ and $T$ conditions (Masaki and Qijia, 1988).

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