

Metamorphic conditions of the aureole rocks from Dhunaghat area, Kumaun Lesser Himalaya

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In Dhunaghat area of Kumaun Lesser Himalaya, Precambrian greenschist metapelites of the Almora Group show evidence of contact metamorphism caused by intrusion of the hot Cambrian Champawat Granitoids plutonic body. Mineral assemblages indicate hornblende-hornfels facies conditions of contact metamorphism. Temperatures between 600 and 650°C and pressures around 3 kb are suggested for the contact metamorphism.

THE Lesser Himalayan thrust nappes comprising metamorphics represent isolated remnants of a thrust sheet extending from the Great Himalayan Central Crystallines to the present nappes. These nappes are intruded by Cambro-Ordovician granites at many places all along the Himalayan arc. We have identified contact metamorphic effects of one of these granites and describe in this paper the petrography, mineral paragenesis, time-relationship and approximate P-T conditions of this metamorphism.

The Dhunaghat area in the Kumaun Lesser Himalaya (Figure 1) in part exposes the phyllites, schists and gneisses of the polyphasedly deformed Precambrian Almora Group¹. The country rocks are intruded by the Cambrian Champawat Granitoids (CCG) dated at 560 ± 20 Ma (ref. 2). Medium-grade metasediments of the Saryu Formation associated with high-grade Almora granite gneisses dated to be 1865 ± 60 Ma old² and the low-grade metasediments of the Gumalikhet Formation flank the southern and the northern boundary of the CCG plutonic body respectively (Figure 1). CCG compositionally range from granite to granodiorite. It is foliated near the margins and porphyritic towards the core. Metasediments, enveloping the CCG, exhibit contact metamorphism as evidenced by thin section studies. The maximum width of Dhunaghat contact aureole is about 1 km.

The hitherto unknown contact aureole adjacent to CCG has been marked on the basis of hornfelsic texture and mineralogical composition. The spots in hornfels (Figure 2a) comprise randomly oriented porphyroblasts of muscovite, chlorite, chloritoid and quartz. The regional schistosity-S has been superimposed by C-surfaces which developed during the forceful intrusion of the CCG. Hornfelsic texture overprints both S- and the C-surfaces. The characteristic minerals developed during contact

metamorphism are chloritoid, andalusite, fibrolite, chlorite, muscovite, biotite and quartz.

The presence of chloritoid in the contact metamorphic rocks of Kumaun Lesser Himalaya is not described by earlier workers. We recognize two types of chloritoids. Anhedral earlier chloritoid-I occurs with inclusions of quartz and diffused twin lamellae (Figure 2b). The later recrystallized chloritoid-II is characterized by well-developed lepidoblasts with sharply defined twin planes (Figure 2c). Randomly oriented chloritoid-II overprints both the S- and the C-surfaces. Andalusite occurs as coarse columnar aggregates (Figure 2d), and is pleochroic from rose-red to pale green. Andalusite is associated with quartz and chlorite. Sporadic fibrolite occurs as radiating aggregates (Figure 2e) and at places occurs in intimate association with biotite. Biotite occurs as randomly oriented medium-sized flakes in the matrix and contains inclusions of quartz. It is partly altered to chlorite. Muscovite occurs as random small flakes and is associated with fibrolite and K-feldspar. Fine chlorite flakes are oriented at varied angles and define the hornfelsic texture (Figure 2f). Quartz occurs as sub-rounded to rounded inclusions in biotite, andalusite and chloritoid, as well as medium sized grains in the matrix as recrystallization product.

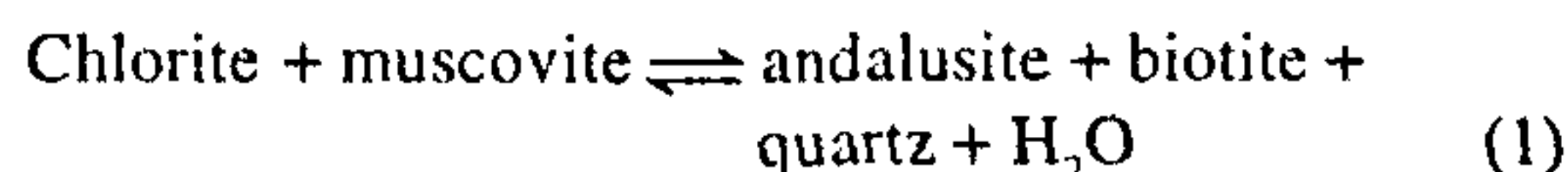
In thin sections, development of C-surfaces is observed at low magnifications, while at higher magnifications randomly oriented fine mica flakes that overprint the C-surfaces define the hornfelsic texture.

The metamorphic conditions of contact metamorphic rocks from the Dhunaghat area are discussed below on the basis of stable mineral parageneses. The important contact metamorphic assemblages are:

1. Quartz-biotite-muscovite-andalusite-fibrolite \pm chlorite (inner zone)
2. Quartz-biotite-muscovite-andalusite \pm chlorite (middle zone)
3. Quartz-muscovite-chloritoid-andalusite \pm chlorite \pm biotite (middle zone)
4. Quartz-muscovite-chloritoid-magnetite \pm haematite (outer zone)

The mineral assemblages suggest hornblende-hornfels facies conditions of contact metamorphism³.

The formation of fibrolite in the assemblage no. 1 has been attributed to the andalusite \rightleftharpoons sillimanite (fibrolite) polymorphic transformation. The mineral assemblage no. 2 is attributed to the following reaction:



In the quartz-muscovite-chloritoid-andalusite \pm chlorite \pm biotite assemblage, the chloritoid has developed by the following reactions:

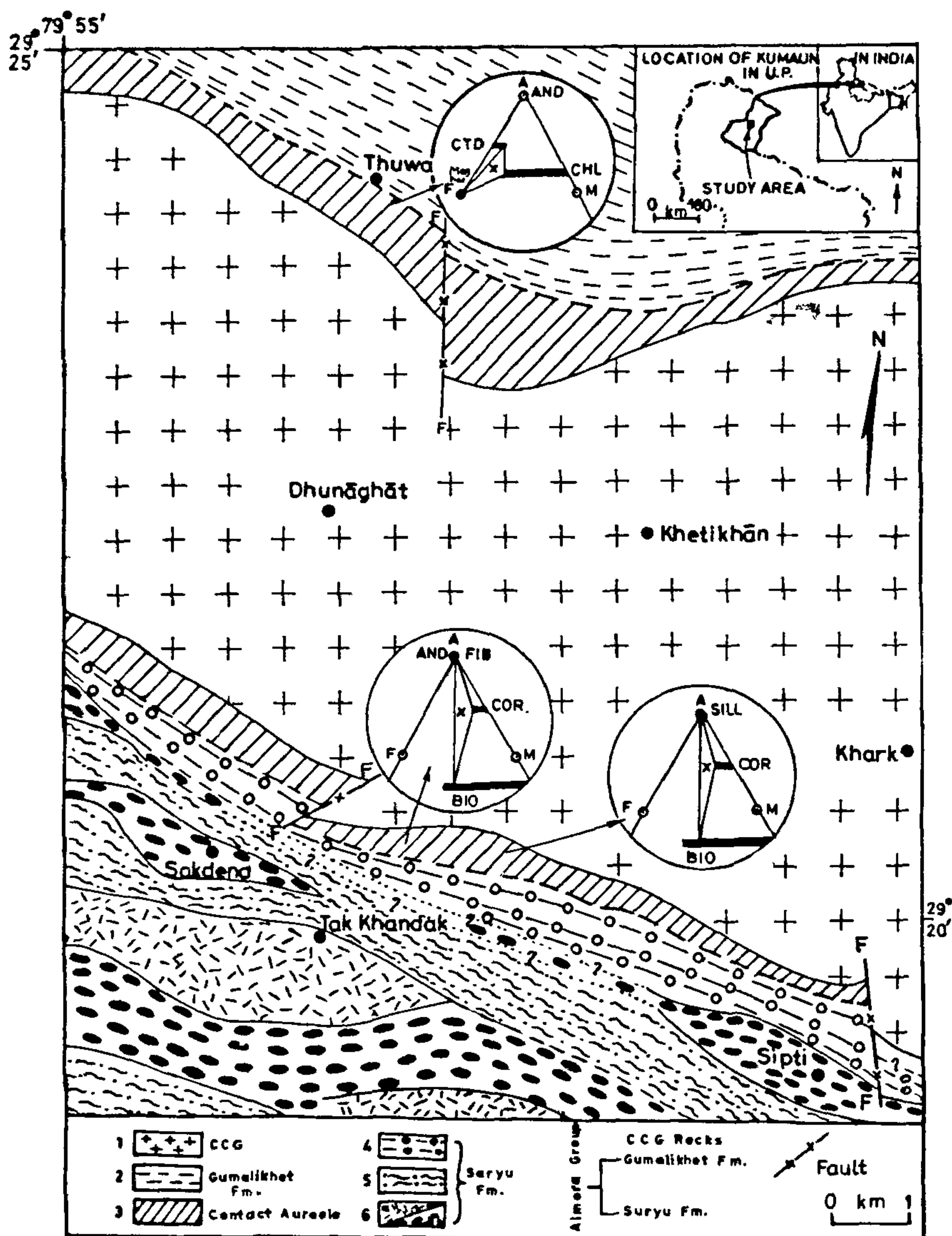
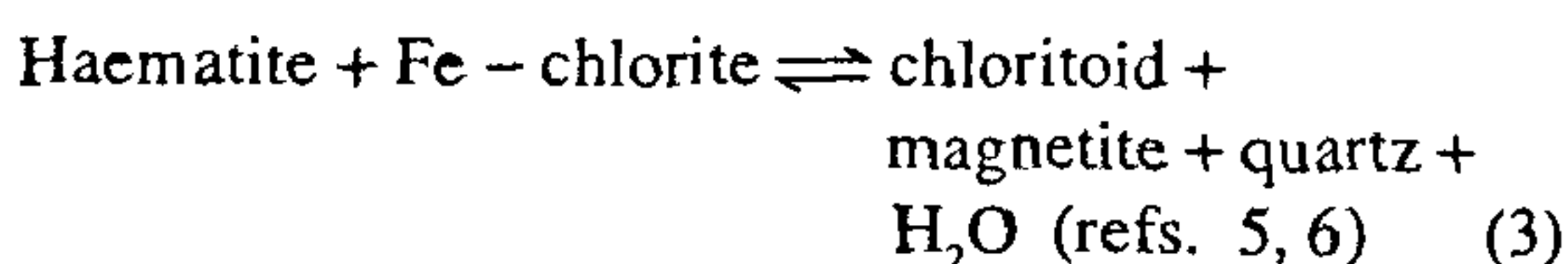
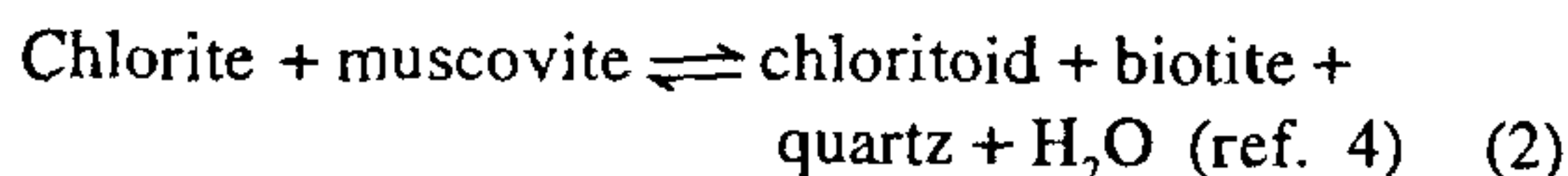
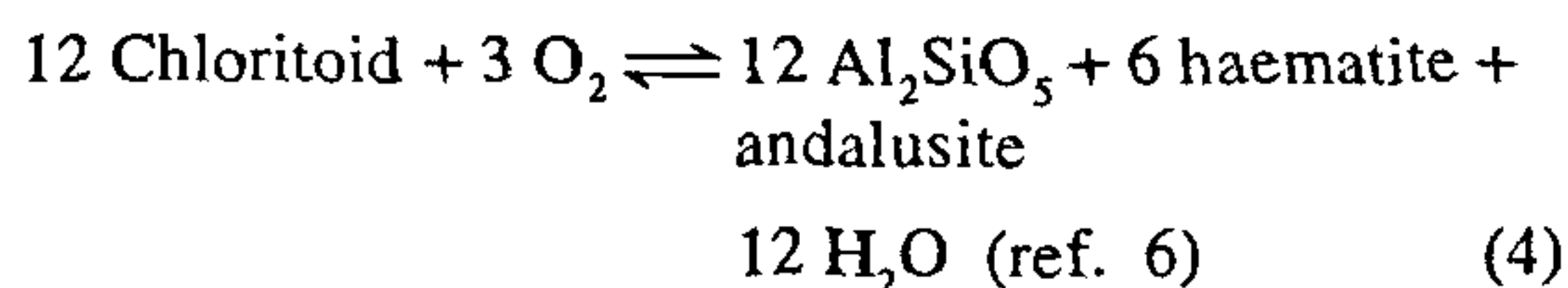


Figure 1. Map showing the location of study area and aureole of Cambro-Ordovician Champawat Granitoid (CCG) pluton in the Dhunaghat area. 1 = CCG, 2 = metapelites of the Gumalikhet Formation, 3 = contact aureole, 4 = mylonitized garnet ± cordierite mica-schist intercalated with quartzites, 5 = garnet ± cordierite mica-schists intercalated with micaceous quartzites, 6a = crudely foliated Almora granites, and 6b = cordierite-sillimanite bearing Almora granite gneisses.



The formation of andalusite associated with haematite is attributed to the reaction:



This reaction has been succeeded by reaction (3) during the regressive phase of contact metamorphism, which is corroborated petrographically as the andalusite crystals are enclosed in chloritoid porphyroblasts.

The outermost hornfelses around the CCG exhibit the

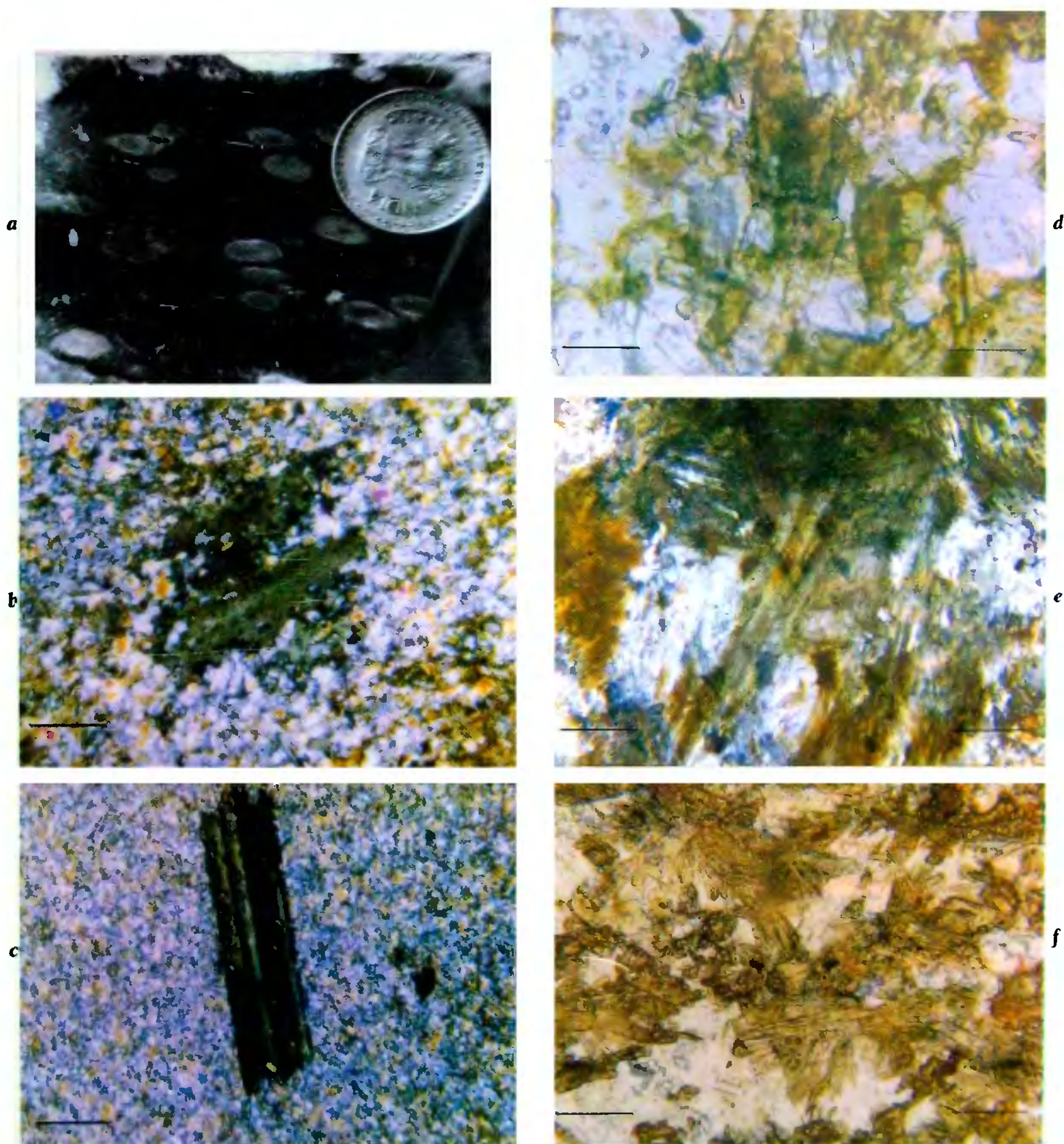
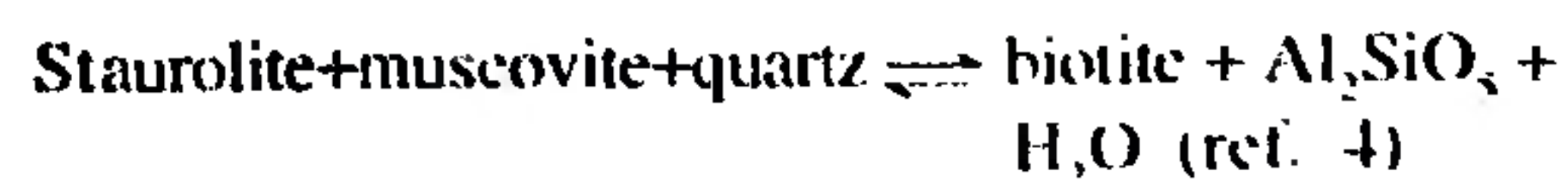


Figure 2. *a*, Handspecimen showing the spotted hornfelsic texture in the phyllitic rocks of Dhunaghat area. *b*, Photomicrograph showing anhedral chloritoid-I with inclusions of quartz and diffused twin lamellae. Bar = 0.25 mm; *c*, Photomicrograph showing well-developed lepidoblasts with sharp twin lamellae chloritoid-II. Notice that the chloritoid-II overprints the C-foliation. Bar = 0.25 mm; *d*, Photomicrograph showing columnar andalusite in the phyllitic rocks of the study area. Bar = 0.08 mm; *e*, Photomicrograph showing the development of fibrolite in the aureole rocks of the Dhunaghat area. Bar = 0.08 mm; *f*, Photomicrograph showing characteristic hornfelsic texture defined by randomly oriented chlorite.

development of the assemblage chlorite–chloritoid–muscovite–quartz \pm biotite showing hornfelsic texture. The assemblage implies that the reaction (2) has occurred.

We also note the reaction



to have occurred during the contact metamorphism. The

reaction has been investigated by Hoschek⁴ and the following P-T conditions have been suggested:

675 ± 15°C at 5.5 kbar
575 ± 15°C at 2 kbar.

Although this reaction suggests that the temperature of 575°C was certainly exceeded, it is not possible to estimate the pressures in light of Salje's⁷ work casting doubts on the andalusite/sillimanite boundary.

As muscovite + quartz is still stable in the contact metamorphic assemblages of the highest grade, it is concluded that the temperatures were below the muscovite + quartz breakdown curve, viz. <680°C at 3.5 kbar.

Estimation of pressure is not possible using intersection of the curve staurolite + muscovite ⇌ biotite + andalusite + H₂O and the andalusite/sillimanite boundary of Holdaway⁸ as Holdaway used prismatic sillimanite for the determination of this boundary, while the rocks from the Dhunaghat area contain fibrolitic sillimanite.

The three curves, viz., S_1 , S_3 and f as determined by Salje⁷ are shown in Figure 3. The andalusite/fibrolite boundary determined by Salje is the f curve. It is interesting that for assemblages of the contact metamorphism neither the muscovite + quartz stability curve nor the minimum melting curve has been crossed while the rocks contain fibrolitic sillimanite. In any case the f curve determined by Salje⁷ has not been crossed. Petrographic observations for the P-T regime of contact metamorphism are shown in Figure 3. A compromise has been made for the Salje's andalusite/fibrolite boundary, in the light of the observation⁹ that the growth of natural fibrolites in preferred orientation on particular substrates extends the stability field of fibrolite towards that of prismatic sillimanite or that the kinetic factors favour fibrolite growth. Further, the absence of almandine garnet constrains pressure for the hornfelsic rocks below 4 kbar.

On the basis of the foregoing discussion pressure around 3 kbar and temperatures between 600 and 650°C are deduced for the contact metamorphism (see dotted trapezium in Figure 3).

The well preserved contact metamorphic signatures, viz. the hornfelsic texture, fresh andalusite crystals and chloritoid-II lepidoblasts, overprint the regional schistosity in the contact aureole rocks formed by the 560 ± 20 Ma old intrusion of the CCG. These unobliterated imprints suggest that the dominant regional metamorphism affecting the country rocks in Almora

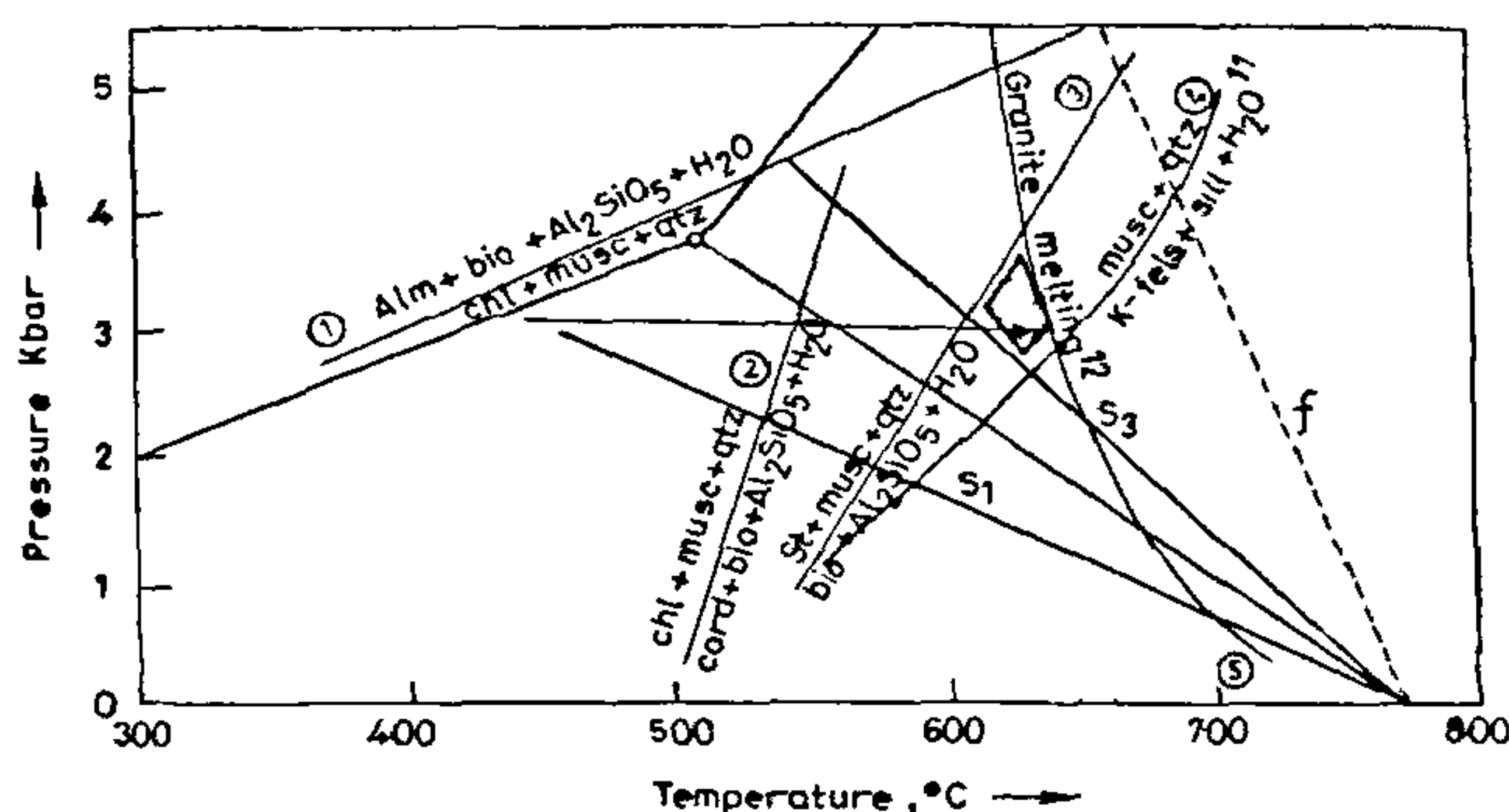


Figure 3. Inferred contact metamorphic conditions (trapezium with dots) of the aureole rocks from Dhunaghat area. The Al-silicate phase boundaries of Holdaway⁸ and the boundary between prismatic sillimanite-fibrolite and andalusite after Salje⁷ are indicated by S_1 to S_3 and f curves. The muscovite + quartz stability curve¹¹ and the curve for the beginning of melting¹² are also shown.

Nappe was older than the Cambrian contact metamorphism. This observation is at variance with the opinion of many workers (Pecher¹⁰ and others) who note that the central crystallines and their equivalents were dominantly affected by Tertiary metamorphism.

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