Metastable presence of Andalusite to partial melting conditions in migmatites of the Simin area, Hamadan, Iran

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Abstract
The metastable occurrence of a polymorph mineral in stability filed of other polymorphminerals is usual. Nevertheless in special conditions, the metastable occurrence of andalusite in partial melting conditions in migmatites is also probable. The mineral is seen in large sizes (about 30 cm tall). Partial melting has happened taken place to a temperature of 670 °C and andalusite has been metastable in this temperature One of the important factors in the metastable occurrence of andalusite in high temperatures is related to low entropy of polymorphic andalusite – sillimanite reaction. The occurrence of borons in the study area could increase the stability field of this mineral to a high temperature condition. Thus the large size of andalusite crystals along with mineral paragenesis intensified metastable occurrence of andalusite in partial melting field (higher temperature) of migmatites of the study area.

Discussion
All the three aluminosilicate's polymorphs exist in the migmatitic rocks in Simin area. The metastable resistance and persistence of the aluminosilicate minerals outside their stability field is notable (Kerrick 1990; White et al. 2003; Vernon et al. 1990). The minerals, usually can not grown in unstable conditions (Walther & Wood 1984), while they grow in suitable conditions (the field of stability of each mineral), they may remain beyond their stability field (metastability).
Basically, the reaction occurs, as with a change in either pressure or temperature, the quantity of Gibbs free energy of materials (G), changes too, although the quantity is different in various minerals. Thus, the collection of minerals that are in a balanced situation in similar conditions, after changing pressure or temperature has minimum free energy for along time. Such a state, entropy, that indicates the degree of disorder in the placement of material's atoms, shows how Gibbs free energy changes compared with temperature. Increasing the temperature, only the phase, having high entropy, remains. (Yardly 1989). However, when a polymorph changes to another, it needs a large amount of energy. Someworkers relate the same time metastable occurrence of andalusite in the field of sillimanite to low entropy of andalusite – sillimanite reaction (e.g. Walther & Wood 1984). Occasionally andalusite, existing in the pelitic's xenolites in grain boundaries and plan of cleavage changes to fibrolite and sillimanite, because of the heat of fluids and melts (Sesare et al. 2002). In some rocks, fibrolite develops in a separate phase of sillimanite (Hollistr 1969 a). Although, the latest is easier, andalusite changes first to fibrolite and then to sillimanite through polymorphic change, because of its low fibrolite's temperature compared to sillimanite's temperature, the change of andalusite to fibrolite can not be detected in the migmatitic rocks of Simin area (Sepahi et al. 2007).
The three polymorphs of aluminosilicate, existing in the same location, are not always synchronic Where each may has grown in a specific course of P_T_t metamorphism (Bucher & Frey 1994). How simply to be invoked to explain the occurrence of andalusite at conditions outside its stability range depends on whether the mode of aluminosilicate is increasing along the up-temperature part of the prograde path. It is likely that sillimanite has difficulty

uncleating. However, if the mode of aluminosilicates decreases along the up- temperature part of the prograde path, it is likely that sillimanite would appear in the sequence close to the reaction andalusite = sillimanite, unless sillimanite has difficulty uncleating. However, if the mode of aluminosilicate is decreasing along the same path, only the metastable persistence of andalusite in sillimanite field is required. Aluminosilicate mode contours are close to constant or decreasing until the muscovite + quartz breakdown reaction is reached where a small jump in aluminosilicate mode is predicted. Above this reaction, aluminosilicate modes decrease with rising temperatures, consequently with the exception of the muscovite + quartz breakdown reaction, aluminosilicate modes generally decrease with rising temperature. The muscovite + quartz breakdown reaction may occur in the andalusite field at pressures below about 2.5 K bar for the upper andalusite + sillimanite error limit. Below this pressure andalusite is the stable polymorph produced where the mode of aluminosilicate increases (White et al. 2003). Given the observation of metastable persistence of andalusite into the sillimanite stability field from several studies (Vernon et al. 1990; Greenfield et al. 1998), it is possible that sillimanite did not grow in these rocks until temperature at witch the kinetic barriers to this reaction had been over come and/or the mode of aluminosilicate began to increase (White et al. 2003).

Occurrence of andalusite in stability field of sillimanite reported in contact metamorphism and is called andalusite overstepping (Cesare et al. 2002). Overstepping grade varies between 50°C or 80°C (Larson & Sharp 2001) to 250°C (Cesare et al. 2002). On the basis of geothermobarometry results, the quantity of overstepping grad has reached 80°C in Hamedan area (Baharifar 2004). The reason of the problems is the occurrence of minor elements, such as the effect of Fe^{3+}, Mn^{3+} (Kerrick & Speer 1988). That is, if concentrated in aluminosilicates, it may shift the equilbiria in P-T space or change the field of stability in them (Kerrick & Speer 1988). In composition of aluminosilicates existing in the schists and the migmatites of the Hamedan area, some amount of Fe^{3+}, of which amount in andalusite is more than sillimanite (Sepahi et al. 2004). But the amount of impurity, here, is 0.5%. The existing 1.5% Fe^{3+}, can only dislocate the andalusite- sillimanite curve by 20°C (Holdaway & Mukhopadhyay 1993). Therefore, even if the above impurity has been effecting, it can not be the reason for overstepping.

Apparently, the longer is the period in which temperature is imposed to the rock, the longer will be the slope of overstepping. This cause, in contact metamorphism where the rate of heating is faster, is probable. But in migmatitic rocks that are formed in the regional metamorphism, provided that intrusion grouting is synchronous with migmatizaion, this can be applicable.

However the size of andalusite crystal and short time period between anatexis and recooling can play an important role in metastable occurrence of andalusite in stability field of sillimanite. So that the time needed for a big andalusite crystal to change in to sillimanite is very long time. Nevertheless this time seems not to be enough in the Simin area. Deficient change of andalusite to sillimanite and its metastability in margin of crystal, can confirm this cause.

Partial melting occurred at a temperature near andalusite - sillimanite univariant curve so that andalusite-, sillimanite- and andalusite-sillimanite-bearing migmatites alternate in the adjacent layers. The existence of tourmaline-rich aplites and pegmatites, and tourmalinites cutting through the medium-high grade metamorphic rocks, and occurrence of tourmaline in the country rocks confirm a possible boron-rich environment during and later to partial melting processes (e. g., Wolf and London 1997). In the boron-rich environments, the stability field of andalusite can be expanded to higher temperatures (Greenfield et al. 1998).

The typical assemblage of inter-layers of cordierite-migmatites (quartz-cordierite-andalusite-biotite-K-feldspar-spinel, Fig 1) can be stable at a temperature higher than ~600 ºC, and a maximum pressure of ~3 kbars (Tinkham et al. 2001). Considering the rapid decrease in the volume of biotite and partial replacement of andalusite porphyroblasts by cordierite-spinel symplectites in these rocks, the temperature could be higher than 650 ºC but andalusite persisted metastably into the sillimanite + melt field according to White et al. (2003) which is presented in the Fig. 2 and Fig. 3.

Conclusion

Affected by boron- rich environment, the stability field of andalusite has expended to higher temperature (field of sillimanite + melt in migmatites). The paragenesis of minerals in migmatites (quartz, cordierite, andalusite, biotite, K-feldspar, spinel) increases the field of andalusite stability to a temperature higher than 600 ºC. In addition, large size of andalusite crystal has made sillimanite nucleation hard to occur. Also short period between anatexis and recooling has decreased the time needed to change large andalusite crystals in to sillimanites, so that the change only occurred in margins and there were not enough time for the whole crystals to be changed into sillimanite.

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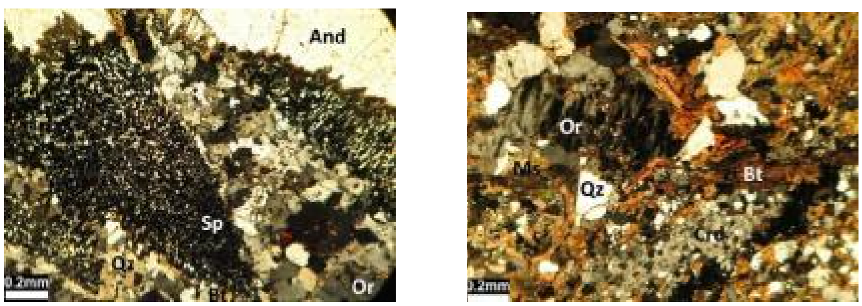

Fig. 1: collection of the minerals existing Mesosome of Migmatites (and= andalusite, bt= biotite, sp= spinel, qz= quartz, crd= cordierite, or= K-feldspar).

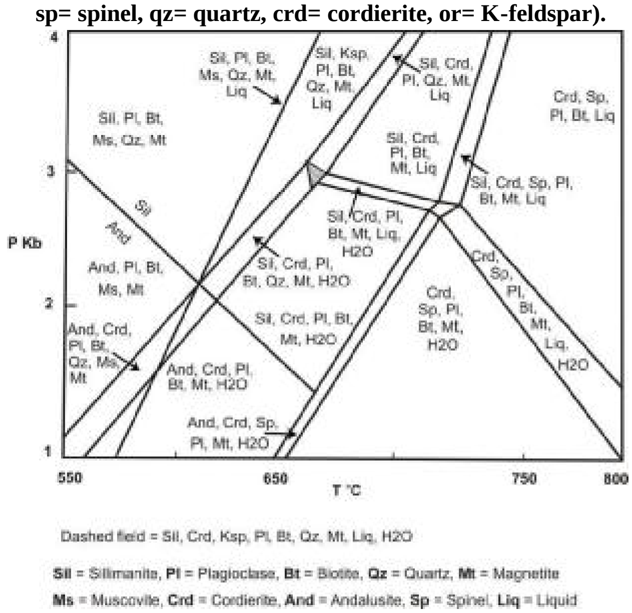

Fig. 2

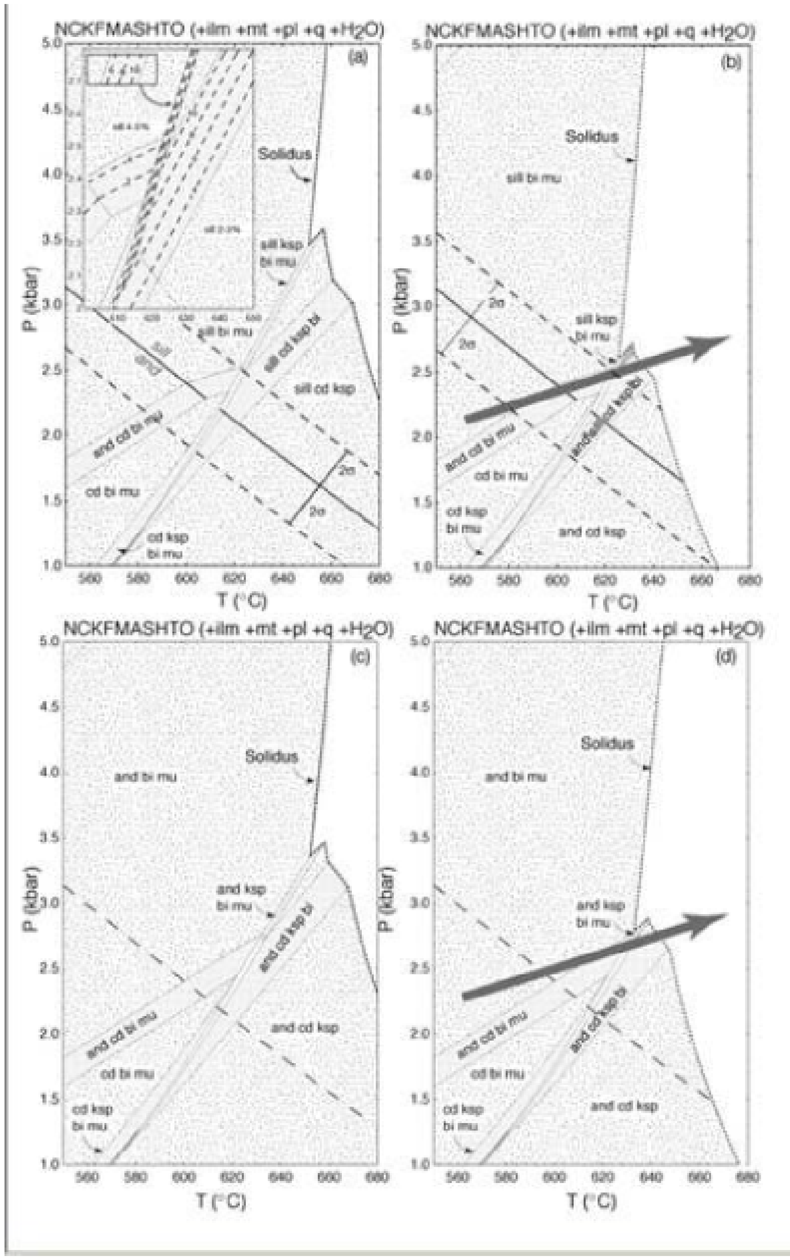

Fig. 3. ***P–T*** **pseudosections showing alternative subsolidus mineral assemblage relationships for the sample 1107pe composition. (a)** ***P–T*** **pseudosection for conditions of fluid in excess. Also shown are the 2σ error bars on the andalusite = sillimanite reaction. The inset shows calculated aluminosilicate mode contours for part of the diagram. (b) Semiquantitative** ***P–T*** **pseudosection showing the mineral relationships relative to a wet solidus depressed to lower temperatures because of the presence of boron. The position of the solidus is not calculated but is shifted to lower temperatures manually. Also shown are the 2σ error bars on the andalusite = sillimanite reaction. The grey arrow shows the position of a field gradient in** ***P–T*** **that is consistent with the petrographic observations assuming sillimanite replaces andalusite at the calculated reaction. (c)** ***P–T*** **pseudosection calculated assuming the metastable persistence of andalusite to temperatures above the calculated andalusite = sillimanite reaction. (d) Semiquantitative** ***P–T*** **pseudosection showing the mineral relationships relative to a wet solidus depressed to lower temperatures and the metastable persistence of andalusite. The grey arrow shows the position of a field gradient in** ***P–T*** **that is consistent with the petrographic observations assuming andalusite metastably persists beyond its calculated stability.**

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