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The origin of the flecked gneiss of Liuguzhuang (Qianan block, east Hebei, P.R. China)

by G.L. Chen¹, W. Johannes², M. Schliestedt² and Y.Q. Lan³

Abstract

The flecked gneiss of Liuguzhuang shows well developed leucosome and mesosome, but no melanosome. It looks like a migmatite with flecks. The predominant mafic mineral in the leucosome is garnet, with little biotite present. The garnets are specially located in the centre of the leucosomes. By contrast biotite is the only mafic mineral in the mesosome.

Petrographic and microprobe analyses indicate that the leucosomes of the Liuguzhuang flecked gneiss were not formed by partial melting, but by the metamorphic reaction: biotite + sillimanite + quartz = almandine + K-feldspar + H₂O. Partial melting presumably did not occur in the rock, because the grain size of quartz, K-feldspar and sillimanite in the leucosome and the mesosome are very similar, and the orientation of the minerals in both lithologies are the same.

Keywords: Flecked gneiss, metapelite, migmatite, mass balance, Qianan block, China.

Introduction

MEHNERT (1968) defined "migmatite" as follows: "A migmatite is a megascopically composite rock consisting of two or more petrographically different parts, one of which is the country rock, generally in a more or less metamorphic stage, the other is of pegmatitic, aplitic, granitic or generally plutonic appearance."

To avoid any implications as to whether it did form from a melt, a body of this material is descriptively called a leucosome, after Mehnert. The leucosome is a body of pale-coloured, quartzofeldspathic or feldspathic lithology of a migmatite. Generally there are other parts which look like ordinary metamorphic rocks, e.g. pelitic schist or dioritic gneiss. HENKES and JOHANNES (1981) introduced the term mesosome for the lat-

ter. Sometimes there is another body spatially separating the leucosome from the mesosome. This is called melanosome; it is dark-coloured, rich in mafic minerals and complementary to leucosome.

According to the other works (HENKES and JOHANNES, 1983; GUPTA and JOHANNES, 1983; JOHANNES, 1985; GUPTA and JOHANNES, 1986; JOHANNES, 1988), the main textural dissimilarities between leucosome and mesosome are:

a) The grain size of minerals in leucosome is usually larger than that in mesosome.

b) The mineral orientation is generally very good in the mesosome, but not developed in the leucosome.

The origin and development of stromatic migmatites has been studied in detail by MEHNERT (1968) and JOHANNES and GUPTA (1982). Two ma-

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for models for the formation of such migmatites have been proposed. MEHNERT (1968) postulated that the protolith of a stromatic migmatite is homogeneous, and represented by the mesosome. The neosome (leucosome + melanosome) formed from the mesosome. In contrast, the model of GUPTA and JOHANNES (1982) and JOHANNES (1988) explain the formation of stromatic migmatites through the almost isochemical partial melting of paragneiss layers of different compositions.

Recently, a relatively rare migmatite type – flecked gneiss (as defined by ASHWORTH, 1985) has been studied in detail by TRUMBULL (1988). The term "flecked gneiss" describes a texture composed of centimetre-sized subspherical segregations of leucocratic minerals cored by dark clots of mafic minerals (TRUMBULL, 1988). Two models for the formation of the "flecked gneiss" have been proposed. One of them explains the flecked gneiss in terms of partial melting (LAPPIN and HOLLISTER, 1988); the other proposes that the fleck was formed by metamorphic segregation (FISHER, 1973; CHENHALL et al., 1980; TRUMBULL, 1988).

The Liuguzhuang flecked gneiss has many similarities with stromatic migmatite, but it also has some differences. It is similar to flecked gneiss and shows no evidence of partial melting. The purpose of this paper is to describe the properties, the origin and the development of the Liuguzhuang flecked gneiss.

Geological setting

The flecked gneiss area of Liuguzhuang is situated within the so-called "Qianan block" in east Hebei, China. The Qianan block consists mainly of Archean metamorphic rocks of amphibolite and granulite facies. The protolith is interpreted to consist of basic volcanic rocks, intermediate to acidic tuffs and siliceous ferruginous rocks characterized by polycyclic volcanic sedimentation (LAN YUQI and SHI XINGMING, 1984). The age of metamorphism is dated between 2400–2730 Ma (SUN JIANSU, 1982). The metamorphic grade increases from amphibolite facies in the south to granulite facies in the north. Migmatization is well developed in the area, and broadly coincided with the main or final stage of granulite facies metamorphism (ZHOU YUWEN, 1982). The intensity of the migmatization increases from south to north, which is in agreement with the change of the metamorphic grade in the area.

The Liuguzhuang flecked gneiss occurs as a layer which strikes northeast-southwest, and dips to the N.W. (Fig. 1). It parallels the gneissosity of

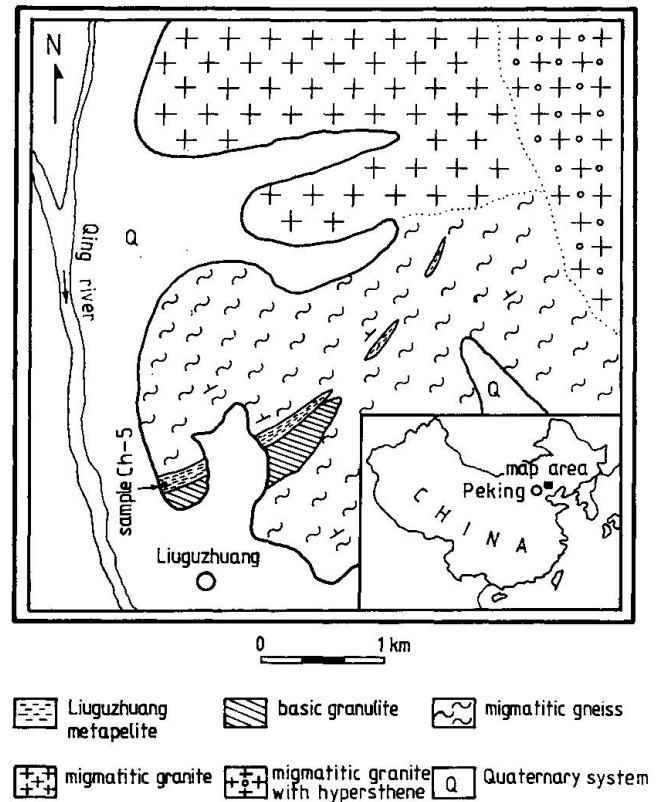


Fig. 1 Simplified geological map of Liuguzhuang area.

the country rock. The layer is about 35 metres wide in the southwest and tapers towards the northeast until it becomes discontinuous, and disappears in migmatitic granite.

Petrographic description of the metapelite

The Liuguzhuang flecked gneiss consists of two petrographically different parts (mesosome and leucosome). The leucosome is pale yellow and usually occurs as bands, lenses or irregular forms in the grey-black mesosome. Figure 2 illustrates the relationship between mesosome and leucosome.

MESOSOME

The mesosomes show a well developed foliation due to the preferred orientation of biotite and sillimanite as well as some quartz and feldspar. The bands of the mesosomes are irregular and vary generally from 0.5 to 1.0 cm in width.

Dominant minerals in the mesosome are quartz, plagioclase, K-feldspar, biotite and sillimanite, a little rutile and muscovite (Tab. 1). Its fabric and the relationships among the minerals

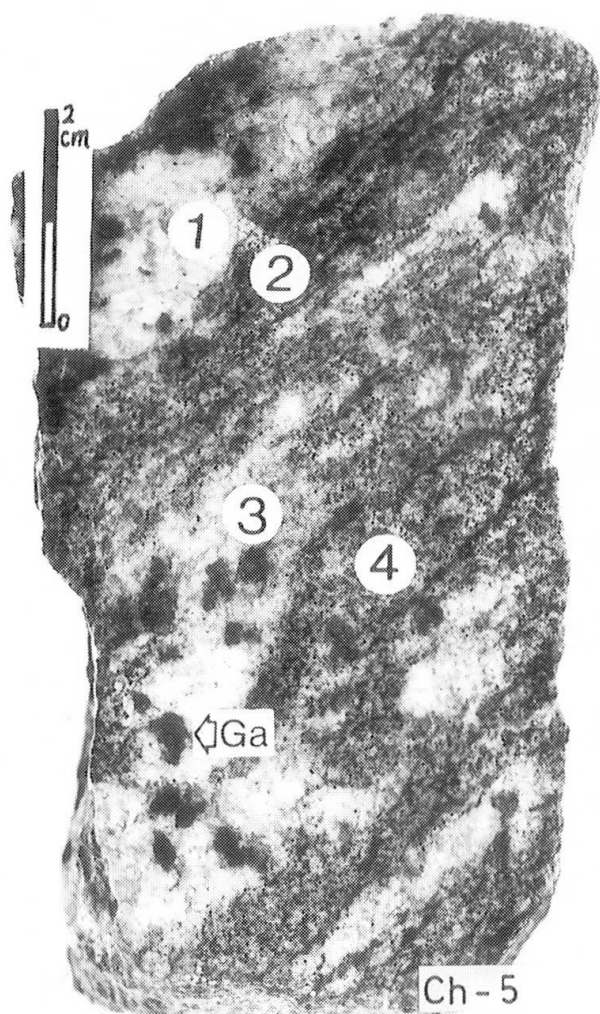


Fig. 2 Sample photograph of Liuguzhuang metapelite. Ga, garnet; 1 and 3, leucosomes; 2 and 4, mesosomes.

are given in figures 3 a and b. The mesosome shows granular lepidoblastic texture and well developed gneissic structure. The grain size of the minerals typically varies from 0.2 to 0.5 mm, although sillimanite can be up to 5.0 mm in length.

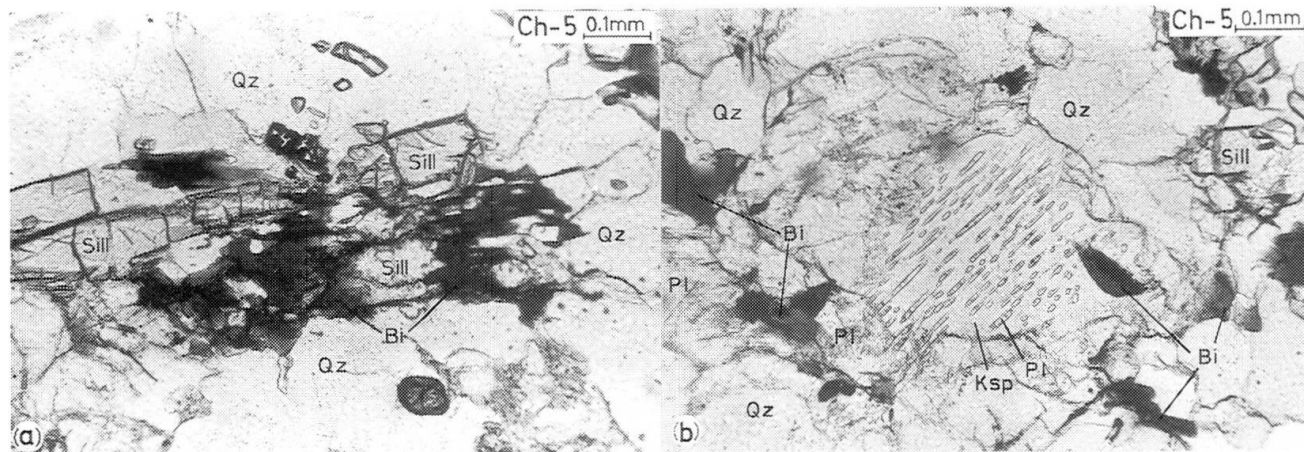


Fig. 3 Microscope photographs of mesosome. (a) mineral relationships among Bi (biotite), Sill (sillimanite) and Qz (quartz); (b) exsolution of Pl (plagioclase) in Ksp (K-feldspar).

Biotite is typically pleochroic from yellow to brown, and plagioclase exsolution occurs in all K-feldspars (Fig. 3b).

LEUCOSOME

The leucosome occurs as discontinuous 0.5–1.0 cm wide bands, lenses and islands in the mesosome. Dominant minerals are K-feldspar, quartz, plagioclase, garnet and sillimanite, with little biotite, rutile and muscovite (Tab. 1).

Figures 4 a and b shows fabric properties and relationships among the minerals. The leucosomes have porphyroblastic texture. The porphyroblasts are garnet, which have a grain size of 0.3–5.0 mm. The groundmass shows granoblastic texture and consists mainly of K-feldspar, quartz, plagioclase and sillimanite as well as some biotite, rutile and muscovite. The grain size of quartz and plagioclase is 0.2–0.5 mm. The K-feldspar is between 0.2–3.0 mm, and sillimanite can be between 0.2–1.0 mm in length.

The garnet is irregular and poikiloblastic, including quartz, sillimanite and biotite. The sillimanite included in garnet is of variable size and has a strong preferred orientation (Fig. 4a).

The included sillimanite is oriented similarly to that of the leucosome matrix, and also to that of the sillimanite in the mesosome.

Biotite in the leucosome occurs in three different ways: (i) included in garnet; (ii) bordering and in contact with garnet, and (iii) in the matrix.

Quartz and K-feldspar alternate adjacent to garnet (Fig. 4b).

Plagioclase exsolution occurs in all K-feldspars, and is similar to that observed in mesosome.

According to the relationships between the minerals described above, it is clear that the garnet is formed later than quartz, biotite and silli-

Tab. 1 Modal mineral composition.

	Qz	Pl	K-Feld	Bi	Ga	Sill	Mus	Rut
Leucosome 1	26	19	46	0.2	6	2.4	+	+
Mesosome 2	35	34	18	8.4	no	5	+	+
Leucosome 3	28	18	37	0.3	14	2.2	+	+
Mesosome 4	37	37	17	9	no	5	+	+

Qz, quartz; Pl, plagioclase; K-Feld, K-feldspar; Bi, biotite; Ga, garnet; Sill, sillimanite; Rut, rutile; Mus, muscovite; no, not observed; +, <0.1%.

manite. On this basis the following mineral reaction is considered to have occurred during the granulite facies metamorphism:

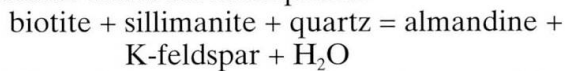


Figure 5 shows a comparison of compositional and fabric relationships between leucosome and mesosome. The following important features can be observed in the figure 5:

1. Orientation of the minerals occurs not only in the mesosome but also in the leucosome, and the direction of the orientation is the same in both.

2. The minerals quartz, plagioclase and sillimanite in both leucosome and mesosome have similar grain size, but some of the K-feldspar in the leucosome has larger grain size than those in the mesosome.

3. There is no melanosome between leucosome and mesosome, the boundary between them being gradational.

The similar fabric in leucosome and mesosome indicates that partial melting did not occur in the rock during the granulite facies metamorphism, and thus, the leucosome in Liuguzhuang metapelite did not result from partial melting.

Mineral chemistry

The compositions of biotite, which occurs in four textural associations in the rock, have been analysed by electron microprobe (see Tab. 2 and Fig. 6). Garnet, plagioclase and K-feldspar have also been analysed.

BIOTITE

The biotite of Leu-1 occurs as an inclusion in garnet; however, because it is surrounded by quartz, the biotite is not in contact with the garnet. The two biotites of Leu-2 and Leu-3 are in contact with the garnet rim, and the biotite of Leu-4 occurs in the matrix of the leucosome. The biotite of Mes-5 occurs in the mesosome. Figure 6 compares the composition of the four types of biotite.

Biotites Leu-4 and Mes-5 have similar composition, but are quite different from Leu-1, 2, 3.

The two biotites Leu-2 and Leu-3 have similar composition, but they have slightly more Mg and less Fe than Leu-1. The three biotites Leu-1, Leu-2 and Leu-3 are much lower in Fe and higher in Mg than the biotites Leu-4 and Mes-5.

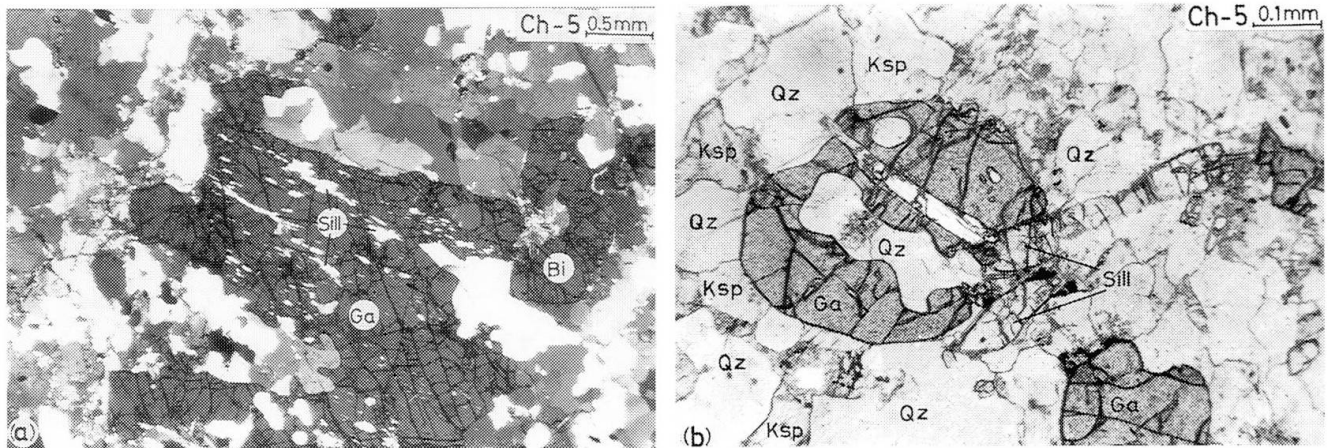


Fig. 4 Microscope photographs of leucosome. (a) orientation of relicts of Sill (sillimanite) in Ga (garnet); (b) mineral relationships among Ga, Sill, Qz and Ksp. Qz and Ksp, which are alternative to each other.

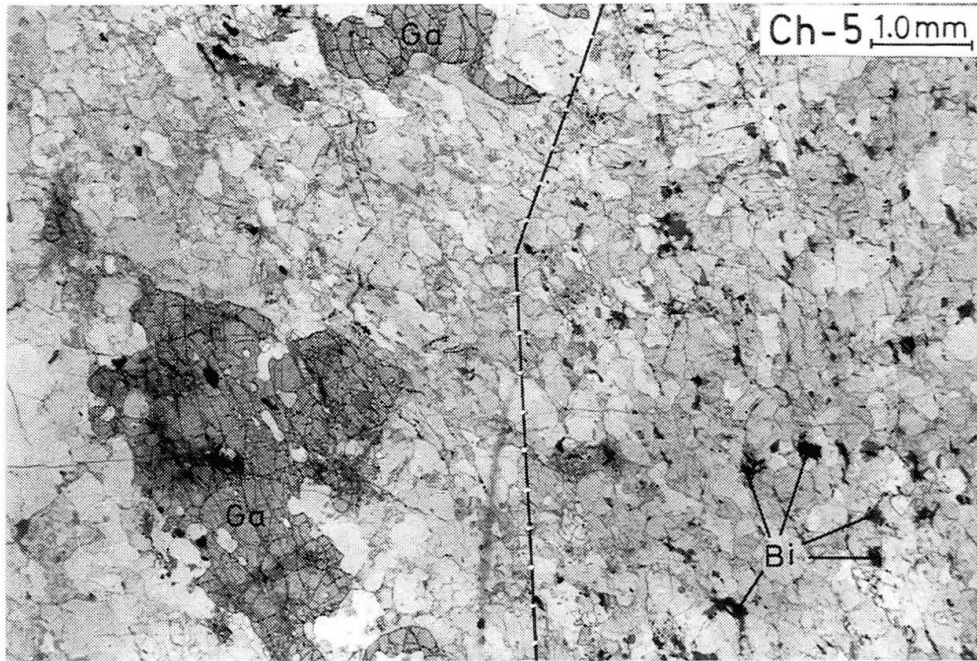


Fig. 5 Relationship between leucosome (left part) and mesosome (right part). Ga, garnet; Bi, biotite.

The differences in the biotite composition can be interpreted in the following way. On textural grounds it was shown above that the reaction $Bi + Sil + 2 Qz = Alm + Ksp + H_2O$ occurred in the rock during metamorphism. In this reaction, garnet forms at the expense of biotite. The Fe/Mg ratio in the garnet of the Liuguzhuang metapelite is between 1.35–1.45 (see Tab. 2). Thus the garnet needs more Fe than Mg from biotite during the metamorphic reaction, and consequently the remaining biotite has more Mg and less Fe than the initial biotite. The biotites of Leu-1, Leu-2 and Leu-3, for example, are richer in Mg and have lower Fe compared to biotites Leu-4 and Mes-5 (Fig. 6).

Because the biotites Leu-2 and Leu-3 are in contact with garnet, diffusion of elements between the two phases would modify their composition during cooling. The biotite Leu-1 is not in contact with garnet, and the speed of the diffusion of elements between the two phases after the metamorphic peak may be estimated slower than that between biotite and garnet which are in contact. For this reason, the composition of the biotite Leu-1 is somewhat different from that of the two biotites of Leu-2 and Leu-3.

FELDSPAR

Plagioclase compositions have been determined in profiles across sample Ch-5 over a distance of

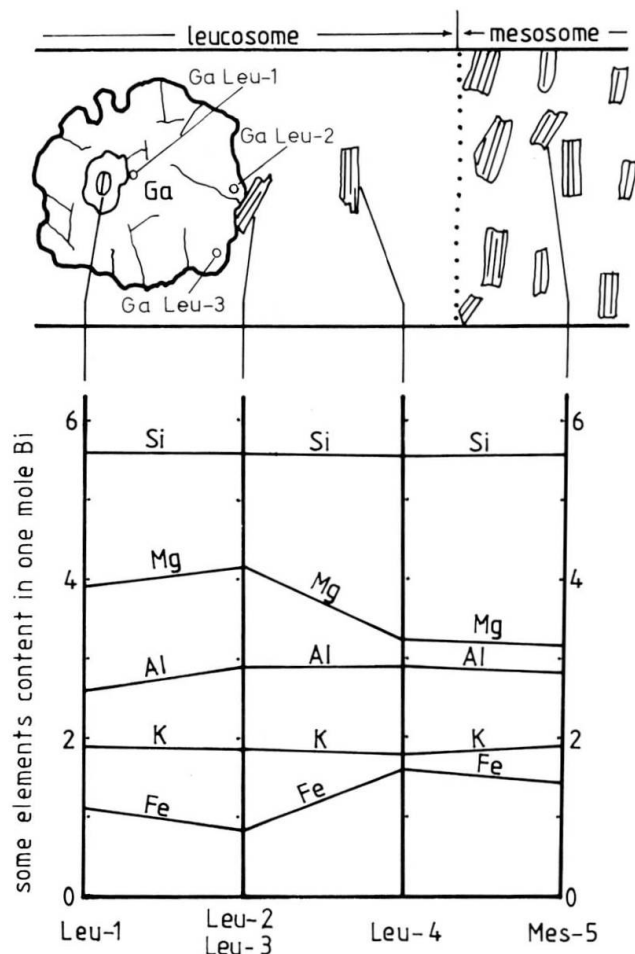


Fig. 6 Comparison of major element contents in biotites from different parts of the leucosome and mesosome.

Tab. 2 Microprobe analyses of garnets and biotite

	Ga-Leu1	Ga-Leu2	Ga-Leu3		Bi-Leu1	Bi-Leu2	Bi-Leu3	Bi-Leu4	Bi-Mes5
	Core	Rim	Rim						
SiO ₂	39.67	39.37	39.90	SiO ₂	38.63	39.05	39.05	37.49	36.66
TiO ₂	0.12	0.01	0.00	TiO ₂	4.33	2.33	2.48	3.27	4.72
Al ₂ O ₃	22.38	22.48	22.54	Al ₂ O ₃	15.01	16.65	16.44	16.59	15.53
Cr ₂ O ₃	0.00	0.02	0.02	Cr ₂ O ₃	0.00	0.00	0.01	0.01	0.02
Fe ₂ O ₃	0.43	0.61	0.06	MgO	18.02	19.32	19.17	14.38	13.88
MgO	11.06	10.70	10.91	CaO	0.02	0.06	0.05	0.02	0.05
CaO	0.90	0.81	0.82	MnO	0.00	0.01	0.01	0.02	0.05
MnO	0.44	0.45	0.45	FeO	9.24	6.83	7.07	13.74	13.98
FeO	26.44	27.29	26.80	BaO	0.02	0.03	0.01	0.01	0.02
Total	101.43	101.74	101.50	Na ₂ O	0.07	0.02	0.08	0.05	0.04
				K ₂ O	10.11	10.18	9.98	9.33	9.73
				Total	95.45	94.48	94.35	94.91	94.68
Cation O = 24				Cation O = 22					
Si	5.97	5.93	6.00	Si	5.612	5.647	5.656	5.565	5.501
Ti	0.01	0.00	0.00	Ti	0.473	0.253	0.270	0.365	0.533
Al	3.97	3.99	3.99	Al	2.570	2.838	2.806	2.902	2.746
Cr	0.00	0.00	0.00	Cr	0.000	0.000	0.001	0.001	0.002
Fe ³⁺	0.05	0.07	0.01	Mg	3.902	4.164	4.138	3.182	3.104
Mg	2.48	2.40	2.44	Ca	0.003	0.009	0.008	0.003	0.008
Ca	0.15	0.13	0.13	Mn	0.000	0.001	0.001	0.003	0.006
Mn	0.06	0.06	0.06	Fe	1.123	0.826	0.856	1.706	1.754
Fe ²⁺	3.33	3.44	3.37	Ba	0.001	0.002	0.001	0.001	0.001
Total	16.01		16.00	Na	0.020	0.006	0.022	0.014	0.012
UV:	0.00	0.06	0.06	K	1.874	1.878	1.844	1.767	1.862
AD:	1.54	1.75	0.17	Total	15.577	15.623	15.604	15.509	15.530
GR:	0.87	0.41	2.03						
AL:	55.37	56.99	56.09						
SP:	0.93	0.95	0.95						
PY:	41.28	39.83	40.70						

Bi, biotite; Leu, in leucosome; Mes, in mesosome

Ga, garnet

2 cm (Fig. 7). The plagioclases in both leucosome and mesosome have very similar anorthite content approximately An₂₀. The variation of the An-content is very small (only 0.01–0.05). The exsolved plagioclase in K-feldspar have very similar compositions (Tab. 3) as those in figure 7.

K-feldspars in both leucosome and mesosome have similar compositions (Tab. 3).

GARNET

The compositions of garnet core are very similar as those of garnet rim (Tab. 2).

Discussion and conclusion

Partial melting is thought to have played an important part in the origin and development of stromatic migmatites (MEHNERT, 1968; GUPTA and JOHANNES, 1982; JOHANNES, 1988). The leuco-

somes of stromatic migmatite resulted from partial melting of compositionally favourable lithologies.

No partial melting occurred in Liuguzhuang flecked gneiss, so what was the reason for the formation of the leucosomes in Liuguzhuang flecked gneiss? To find the answer, the following questions must be answered:

1. Is the Liuguzhuang metapelite a migmatite?

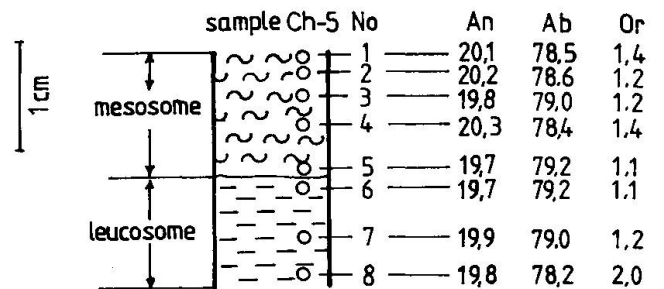


Fig. 7 Plagioclase compositions in profiles across the leucosome and mesosome of the sample Ch-5.

Tab. 3 Compositions of K-feldspars and plagioclase exsolutions.

	Leu-1		Leu-2		Mes-1	
	K-Feld	Pl	K-Feld	Pl	K-Feld	Pl
SiO ₂	64.83	65.30	65.33	64.17	64.99	64.24
Al ₂ O ₃	18.87	23.44	18.91	23.75	19.02	23.57
CaO	0.05	4.13	0.09	4.42	0.07	4.33
Na ₂ O	0.98	8.71	1.36	9.68	1.45	9.08
K ₂ O	15.11	0.14	14.73	0.21	14.83	0.69
Total	99.84	101.72	100.42	102.23	100.36	101.91
Cation O = 8						
Si	2.987	2.824	2.988	2.781	2.979	2.793
Al	1.025	1.195	1.019	1.213	1.027	1.208
Ca	0.002	0.191	0.004	0.205	0.003	0.202
Na	0.088	0.730	0.121	0.813	0.129	0.765
R	0.888	0.008	0.860	0.012	0.867	0.038
Total	4.989	4.948	4.992	5.025	5.006	5.005
An	0.25	20.59	0.45	19.92	0.34	20.06
Ab	8.95	78.58	12.25	78.95	12.89	76.13
Or	90.80	0.83	87.30	1.13	86.76	3.81

K-Feld. K-feldspar; Pl. plagioclase;
Leu-. in leucosome; Mes-. in mesosome

2. Why are all the garnets only in leucosomes, and not in mesosomes?

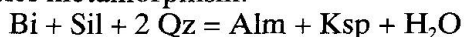
The Liuguzhuang flecked gneiss looks like a stromatic migmatite. It consists of two petrographically different parts, one of which has properties very similar to those of the mesosome defined by HENKES and JOHANNES (1981). This part is called mesosome in this paper, and the other part is called leucosome. The leucosome of Liuguzhuang flecked gneiss differs from the leucosome of a typical stromatic migmatite. The differences are:

a) The grain size of the felsic minerals are similar in the leucosome and the mesosome.

b) Mineral orientation is present not only in the mesosome, but also in the leucosome.

c) Garnets are fairly abundant and are generally located in the central part of the leucosomes. There is no garnet in the mesosome. Therefore, the Liuguzhuang flecked gneiss is not a stromatic migmatite, it is a flecked gneiss.

It has been argued above that the following reaction occurred in the rock during granulite facies metamorphism:



A mass balance calculation of the reaction is required to understand why garnet is present only in the leucosome. The following model reaction was calculated from mineral data for Bi of Mes-5,

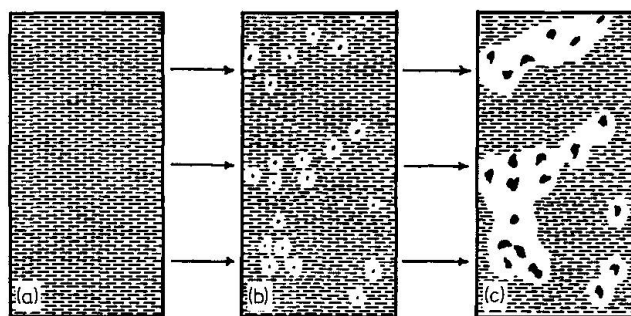
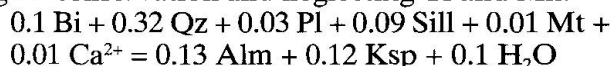


Fig. 8 A model of the evolution of Liuguzhuang metapelite. (a) paragneiss; (b) flecky gneiss, garnets begin to crystallize during metamorphism; (c) stromatic gneiss, the fleck chain one another with growth of the garnets.

Ga of Leu-2, Pl of No. 2 and Ksp of Leu-1, assuming Al conservation and neglecting Ti and Mn:



From this reaction it can be seen that the formation of almandine consumes much biotite and quartz. The potassium from the consumed biotite forms much K-feldspar. Adjacent to garnet K-feldspar therefore appears at the expense of biotite and the leucosome is formed. This also explains why garnet is distributed only in the center of the leucosomes and why the mineral volumes between leucosome and mesosome are different (Tab. 1).

Figure 8 shows the suggested model for the formation of a flecked gneiss. Before the reaction $\text{Bi} + \text{Sill} + 2 \text{Qz} = \text{Alm} + \text{Ksp} + \text{H}_2\text{O}$ occurred, the Liuguzhuang flecked gneiss was homogeneous (Fig. 8a) and had an uniform mineral assemblage and a fabric similar to the mesosome. The garnet began to crystallize in the rock with increasing temperature, and at the same time the biotite around the garnet began to disappear, so the flecked gneiss formed. As the garnets grew the flecks appeared (Fig. 8b) and became larger until they became chained to one another (Fig. 8c).

Acknowledgements

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