ISSN 1526-5757

25. PETROGENESIS OF THE GHOOSHCHI GRANITE BY K- AND Si-METASOMATISM OF DIORITES AND GABBROS, WESTERN AZERBAIJAN, IRAN

Pouran Behnia and Lorence G. Collins

January 13, 1998

Introduction

The Ghooshchi granite (Fig. 1) has been intruded as an anorogenic, A-type, within-plate granite in an area northwest of Uromiyeh Lake in western Azerbaijan in northwestern Iran (Jahangiri, 1990). The Precambrian crystalline basement in this area is a metamorphic complex consisting of schists and gneisses that have been intruded by gabbros and diorites (Fig. 1, Fig. 2, and Fig. 3). Granitoids of the area are grouped into five suites according to their mineralogy, texture, and exposed features. (1) Pink Ghooshchi granite, which is the largest mass, is characterized by granophyric and graphic textures. (2) Myrmekite-bearing granitic masses, hereafter called leucometasomatites, occur either as apophyse-like bodies in the gabbro or as marginal parts of the Ghooshchi granite (Fig. 2; Fig. 3). (3) Biotite granite occurs in the schists. (4) Two-mica granite is found in the gneisses. And (5) lensoidal granitic rocks are exposed in a phlogopite mine that contains abundant sphene, garnet, and calcite.

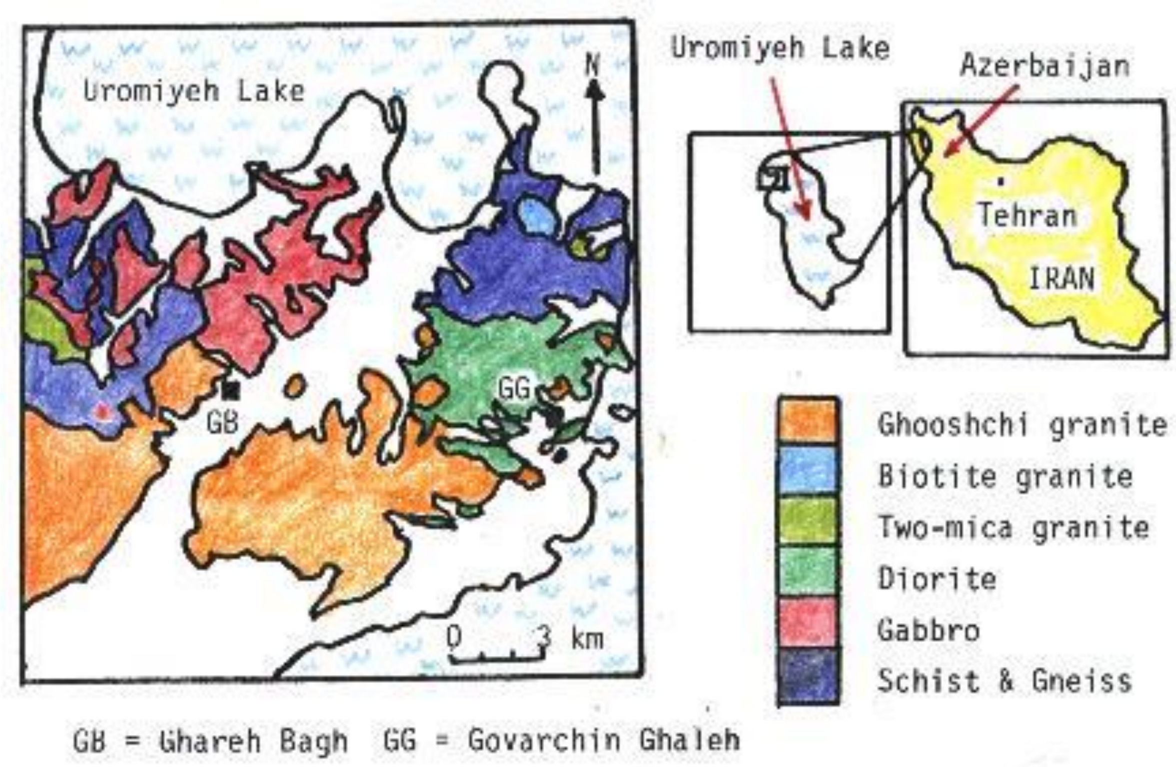

Fig. 1. Geologic map of Ghooshchi area (simplified and modified after Khodabandeh and Amini Fazl, 1991, but with the addition of the biotite granite).

Fig. 2. Apophyse-like body of leucometasomatite in contact with gabbro.

Fig. 3. Road-cut exposure near Govarchin Ghaleh, showing pink granite (right side), leucometasomatites (middle), and unaltered diorite or epidiorite (left side).

The gabbros are tholeiitic and metaluminous and are suggested to have been converted into alkalic through calc-alkalic compositions during Si- and K-metasomatism to form the transitional, apophyse-like bodies in the gabbros and in the marginal parts of the Ghooshchi granite. In that process the metasomatized rocks become potassic (with high-K contents, 7.50 wt. %) and range from metaluminous to peralkalic and mildly peraluminous (Behnia, 1995). Evidence to support the metasomatic relationships is provided in the following sections. Similar kinds of metasomatic relationships occur in the biotite and two-mica granites but are not discussed in this presentation.

Field relationships

Contacts between the Ghooshchi granite and the gabbros and diorites are poorly exposed, but in some places apophyse-like bodies of leucometasomatites extend into the gabbros. Locally, near the gabbro, mafic enclaves occur in the granite. In some places in the gabbros, light-colored felsic patches with no clear borders fade gradually into the gabbros. Although the apophyse-like appearance of the granitoids and the occurrence of mafic enclaves favor the intrusion of a granitic magma into the gabbros, the ghost-like felsic patches and transitional contacts suggest a replacement origin for the granitic rocks.

Thin section studies

*Feldspars and myrmekite***.**

Modal changes are shown in Table 1 for the transition from gabbro (samples 013 and 012) to monzonite (sample 011) to quartz monzonite (sample 010), and finally to leucometasomatite (sample 009). Plagioclase crystals in the primary gabbro are unbroken (Fig. 4), but in early stages of the transition, they become cataclastically fragmented into smaller parts (Fig. 5) or their albite lamellae are bent, causing the crystals to show strained extinction (Fig. 6). Microcline and myrmekite are absent in undeformed gabbro but progressively appear across the transition toward the leucometasomatite. The myrmekite appears first as rim myrmekite (Fig. 6) and then as wartlike myrmekite (Fig. 7). Microcracks occur in the deformed plagioclase crystals but never in the microcline or myrmekite.

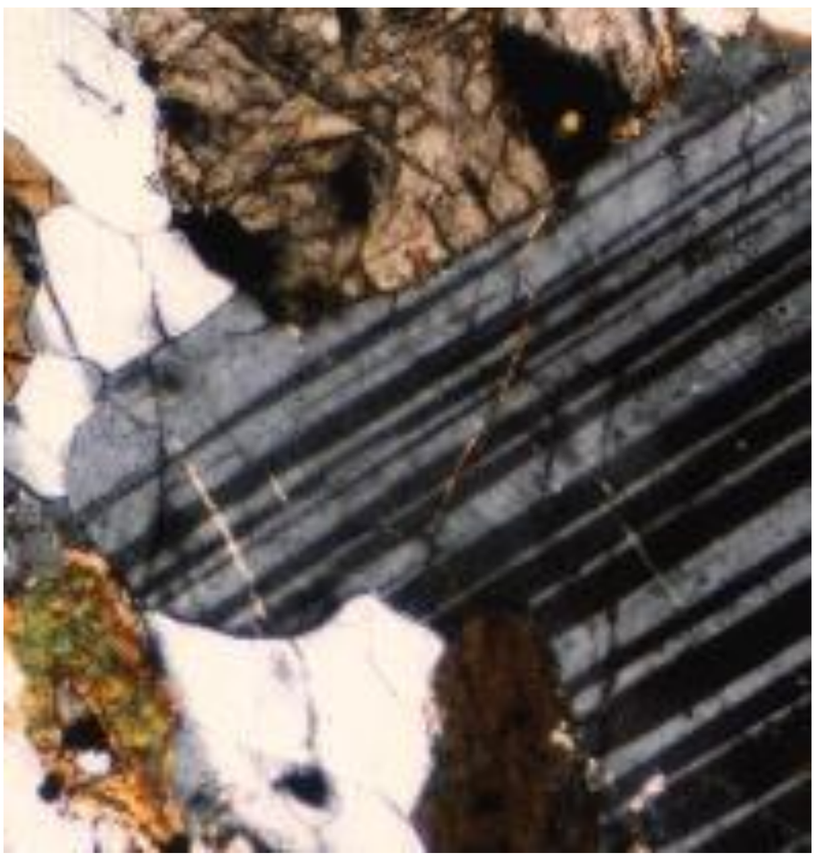

Fig. 4. An unchanged, albite-twinned plagioclase crystal in gabbro, sample 013. Pyroxene grains (gray, brown, green) border the plagioclase crystals.

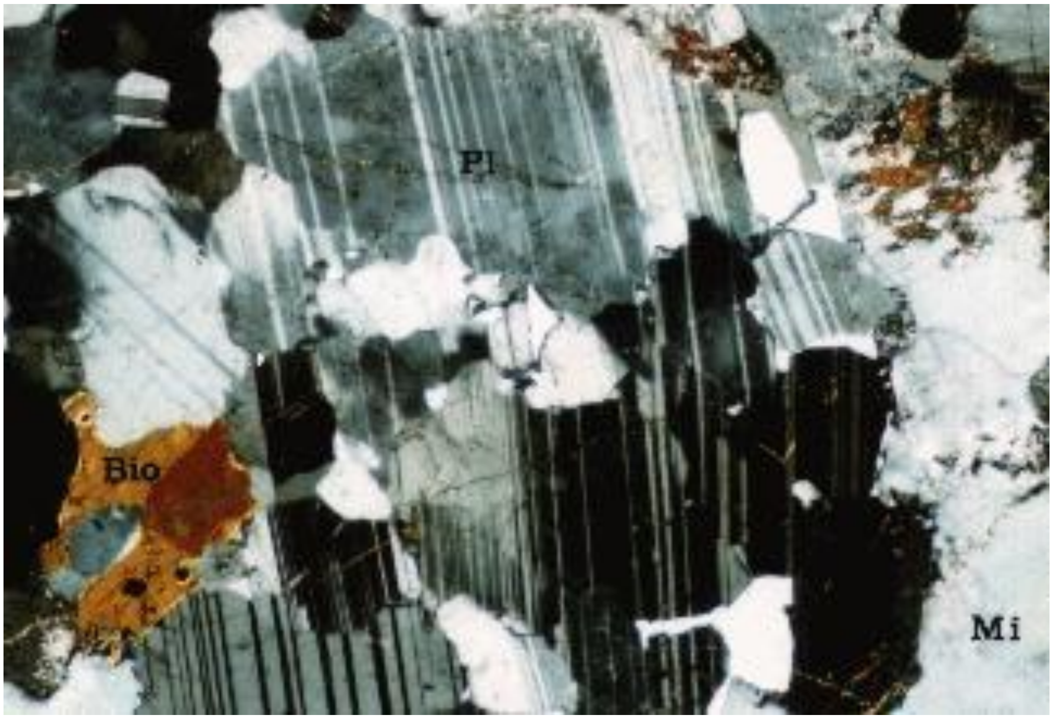

Fig. 5. Cataclastic texture, showing a large plagioclase grain broken into smaller parts in monzonite in early stages of replacement of gabbro in the transition zone. Microcline (Mi, light gray); biotite (Bio, brown).

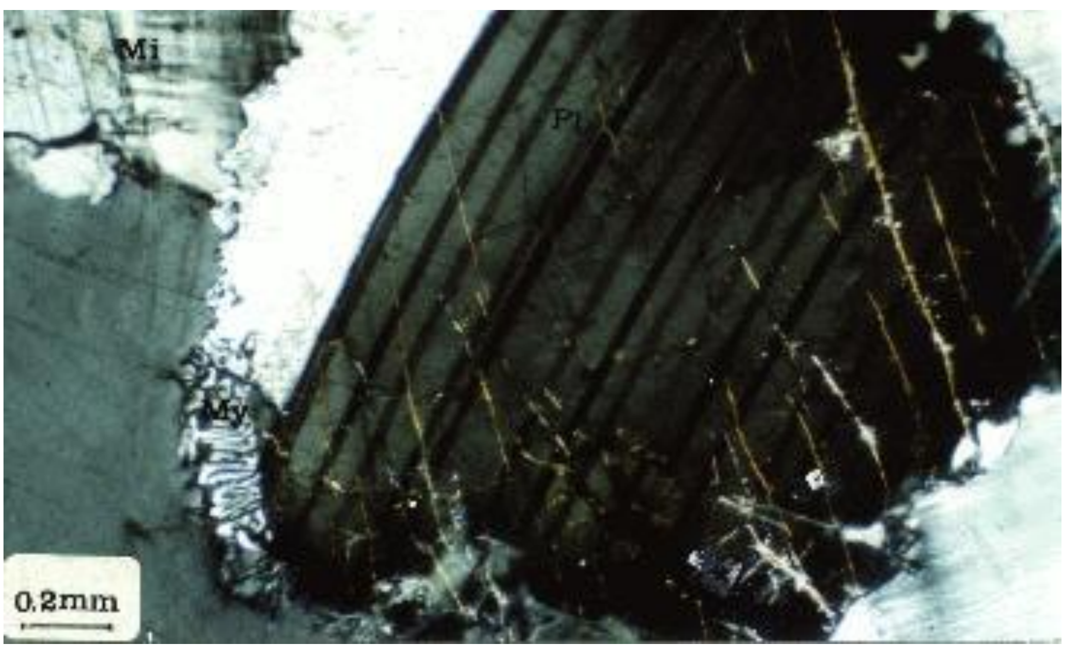

Fig. 6. A large crystal of plagioclase with bent albite-twin lamellae and strained extinction. Micro-cracks in the plagioclase do not extend into the surrounding microcline and myrmekite.

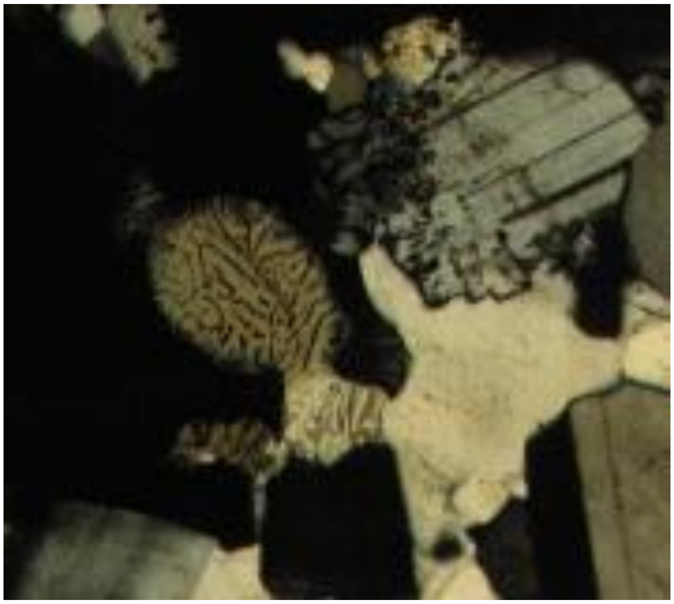

Fig. 7. Wartlike myrmekite (cream, center). K-feldspar (black).

Table 1. Modal compositions of the rocks in the transition zone from gabbro through monzonite and quartz monzonite to granite (leucometasomatite).

Minerals Sample	Qtz	K-feld	Plag	Myrm	Cpx	Opx	Amph	Bio	Opaq	Zr	Apa
Gabbro 013	0.6	0.4	70	-	15.8	4.2	-	2.5	5	<0.1	1.4
Gabbro 012	1.9	0.5	69	-	16	4.1	-	3.7	4.2	<0.1	0.6
Monz 011	2	49.6	34.7	3.2	2.2	-	1.3	5.4	1.4	<0.1	trace
Qz Monz 010	6.4	54.8	28.5	4.2	-	-	1.2	3.9	0.7	<0.1	-
Granite 009	26.5	59.3	4	8	-	-	-	1.6	0.6	<0.1	-

Qtz = quartz K-feld = K-feldspar Plag = plagioclase Cpx = clinopyroxene

Opx = orthopyroxene Myrm = myrmekite Amph = amphibole

Bio = biotite Opaq = opaques Apa = apatite

The first appearance of the K-feldspar (microcline) in the interiors of deformed plagioclase crystals, either forming irregular islands or filling interstices between broken plagioclase crystals (Fig. 8, Fig. 9, and Fig. 10). In more advanced stages of replacement these islands coalesce (Fig. 11) and increase in size until the volume of the microcline exceeds the volume of remnant plagioclase.

Fig. 8. Photomicrograph of a porphyroclast of albite-twinned plagioclase, broken into smaller pieces. Microcline (Alk F, black) has replaced the plagioclase along the borders of the fractures.

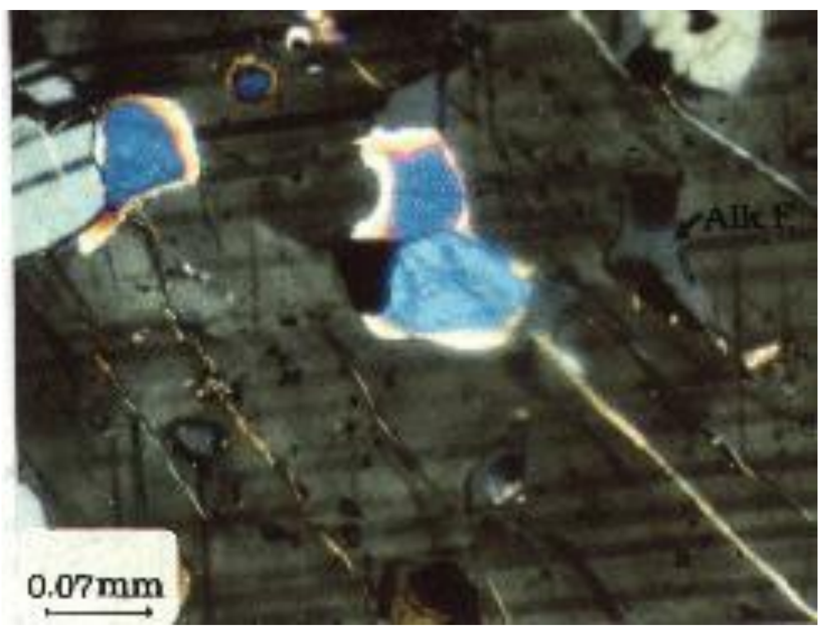

Fig. 9. Microcline (Alk F) patches, scattered as irregular islands within a plagioclase crystal in gabbro, sample 012. Bright colored grains are pyroxene.

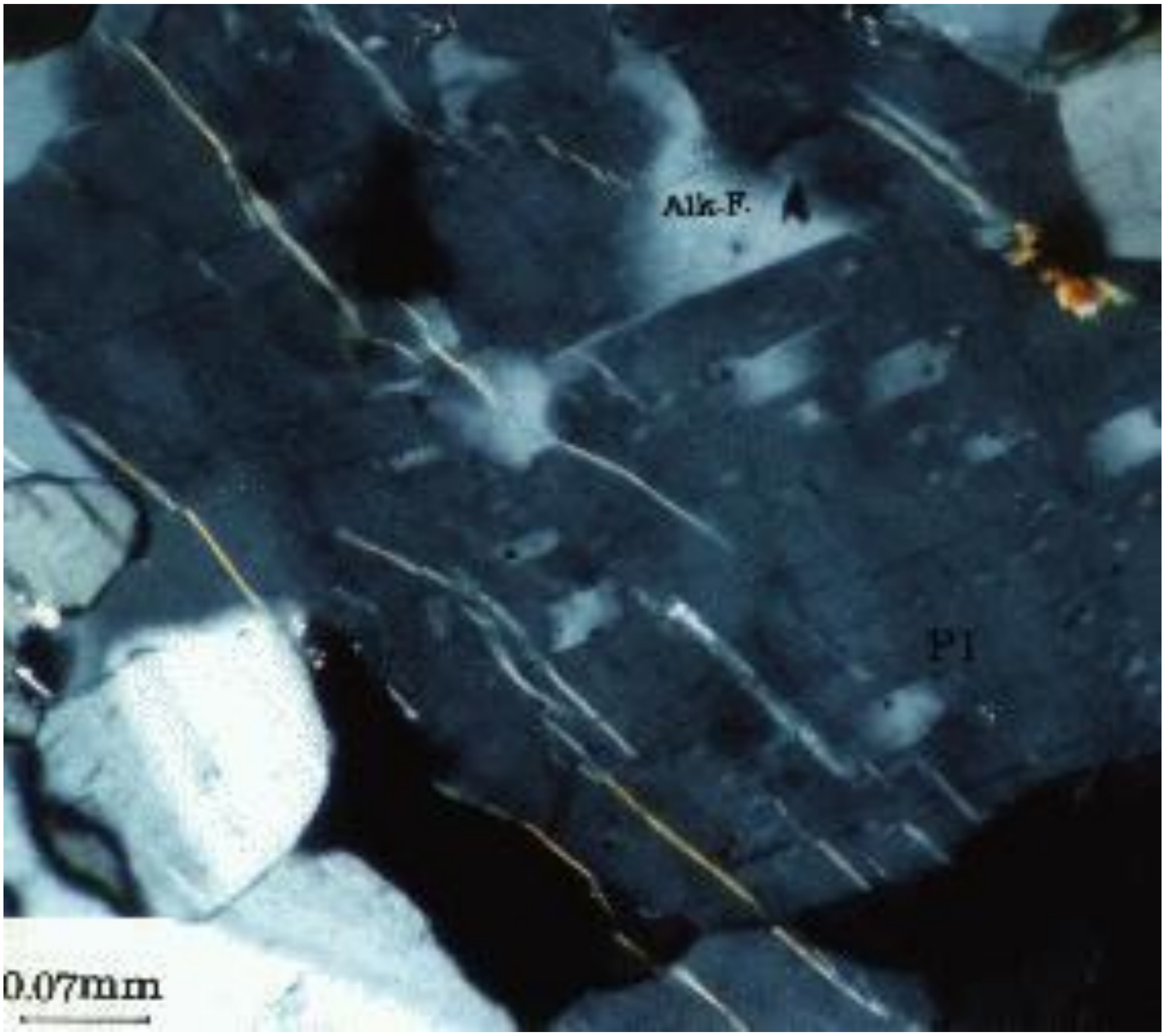

Fig. 10. Another plagioclase grain with microcline islands in gabbro, sample 012. Growth of microcline (Alk. F) is parallel to cleavage. Albite-twinned plagioclase is in lower right corner.

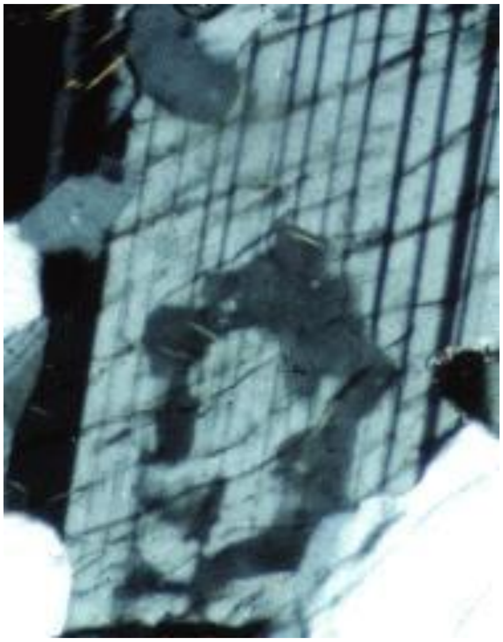

Fig. 11. larger and irregularly-shaped microcline (light gray) in an albite-twinned plagioclase crystal.

Where the microcline becomes coarse-grained, remnant plagioclase may occur as optically continuous islands in the microcline (Fig. 12 and Fig. 13).

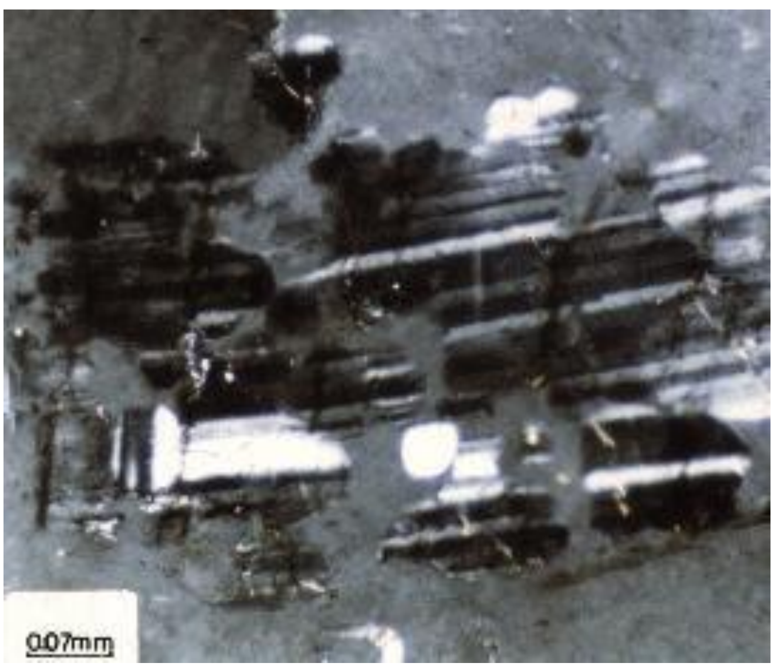

Fig. 12. Remnant plagioclase inclusions in microcline (light gray) with optically continuous island remnants of plagioclase.

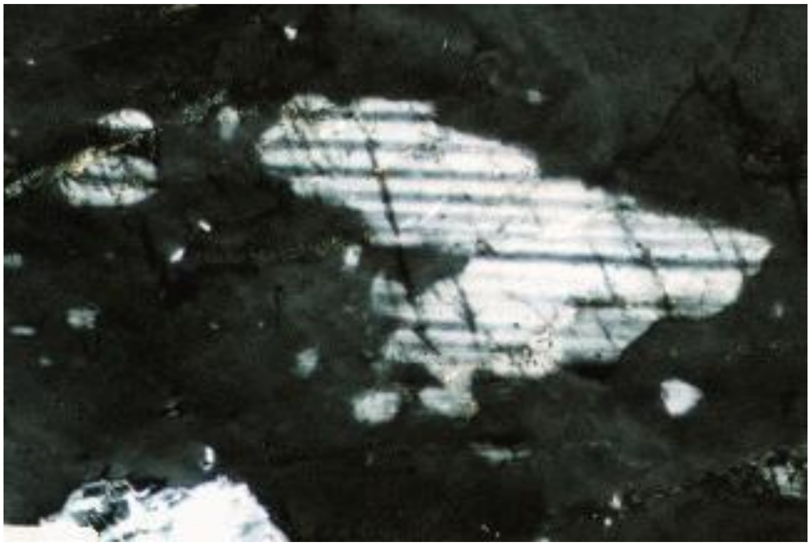

Fig. 13. Remnant plagioclase inclusion in microcline (dark gray) with optically continuous island remnants of albite-twinned plagioclase.

In still more advanced stages the microcline crystals grow to large size (as much as 10 mm) and surround remnants of myrmekite (Fig. 14) and/or contain relic quartz blebs of ghost myrmekite (Fig. 15; see http://www.csun.edu/~vcgeo005/Nr2Myrm.pdf and http://www.csun.edu/~vcgeo005/Nr3Myrm.pdf.

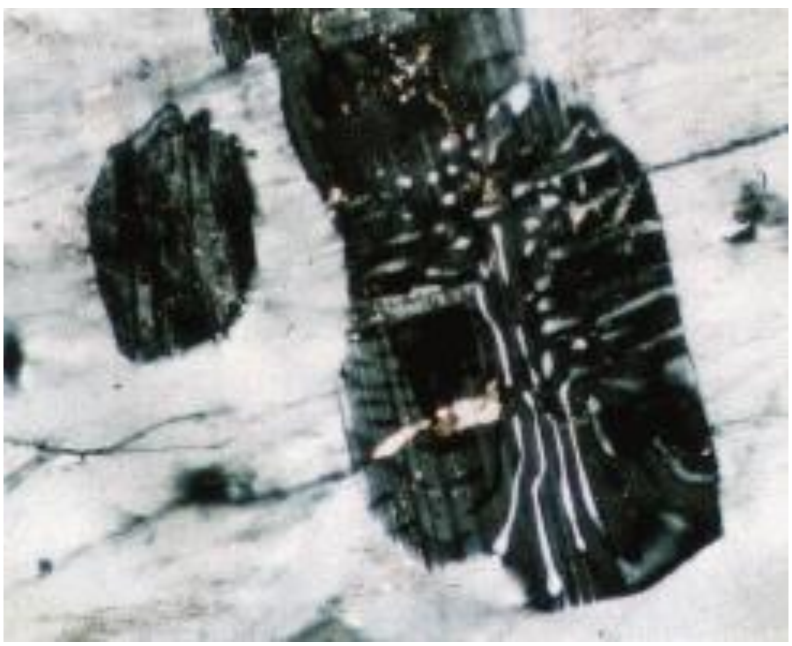

Fig. 14. Myrmekite surrounded by perthitic microcline (white). Plagioclase of the myrmekite still retains the original albite twinning of the former primary

plagioclase of the gabbro although the plagioclase is now more sodic in composition (Collins, 1988).

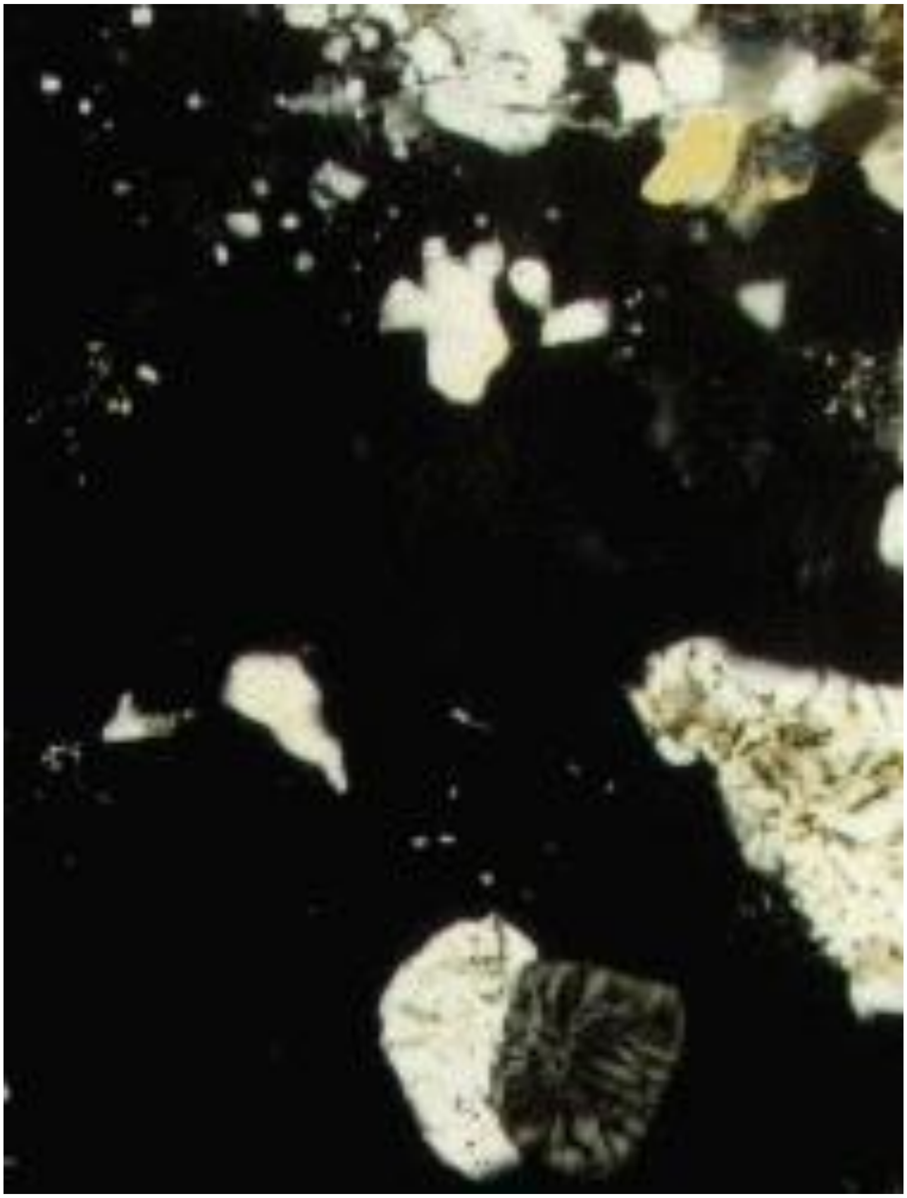

Fig. 15. Relic quartz blebs (white, ghost myrmekite) in microcline (black). Myrmekite islands in microcline (bottom; right).

In some places aggregates of broken plagioclase grains in the gabbro (Fig. 16) match the sizes of aggregate mosaics of myrmekite in the transition zone (Fig. 17), suggesting that such broken grains are converted to myrmekite in some places. This conversion is similar to the pattern observed in the transition between diorite and myrmekite-bearing granite at Temecula, California (Collins, 1988; Hunt et al., 1992; see http://www.csun.edu/~vcgeo005/Nr1Myrm.pdf, http://www.csun.edu/~vcgeo005/Nr2Myrm.pdf, and http://www.csun.edu/~vcgeo005/Nr3Myrm.pdf.

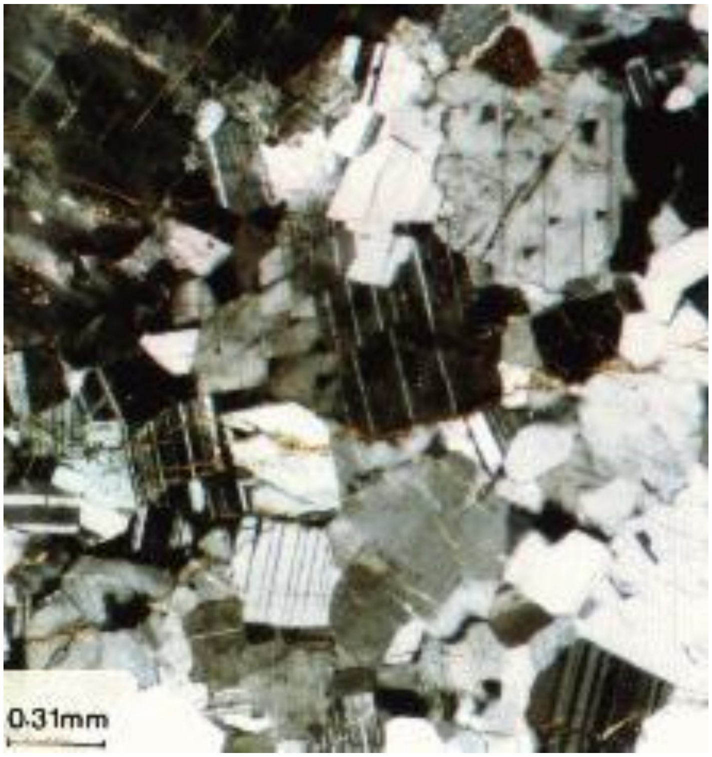

Fig. 16. Aggregate mosaic of tiny plagioclase crystals in gabbro, sample 011.

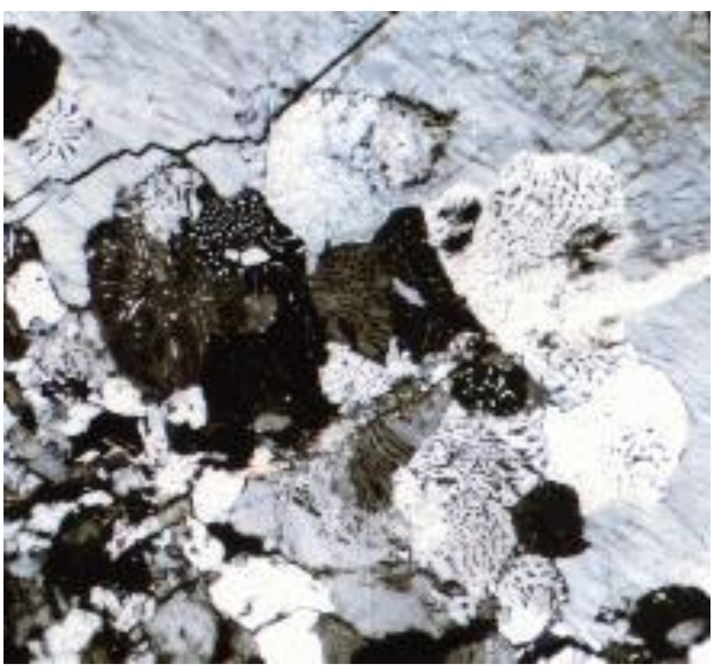

Fig. 17. In leucometasomatite, sample 009, myrmekite in some places occurs as an aggregate mosaic of similar size as to the grains shown in Fig. 16. Microcline (light gray, upper right).

In some places microcline replaces biotite, leaving remnant "leaves" projecting into the microcline (Fig. 18).

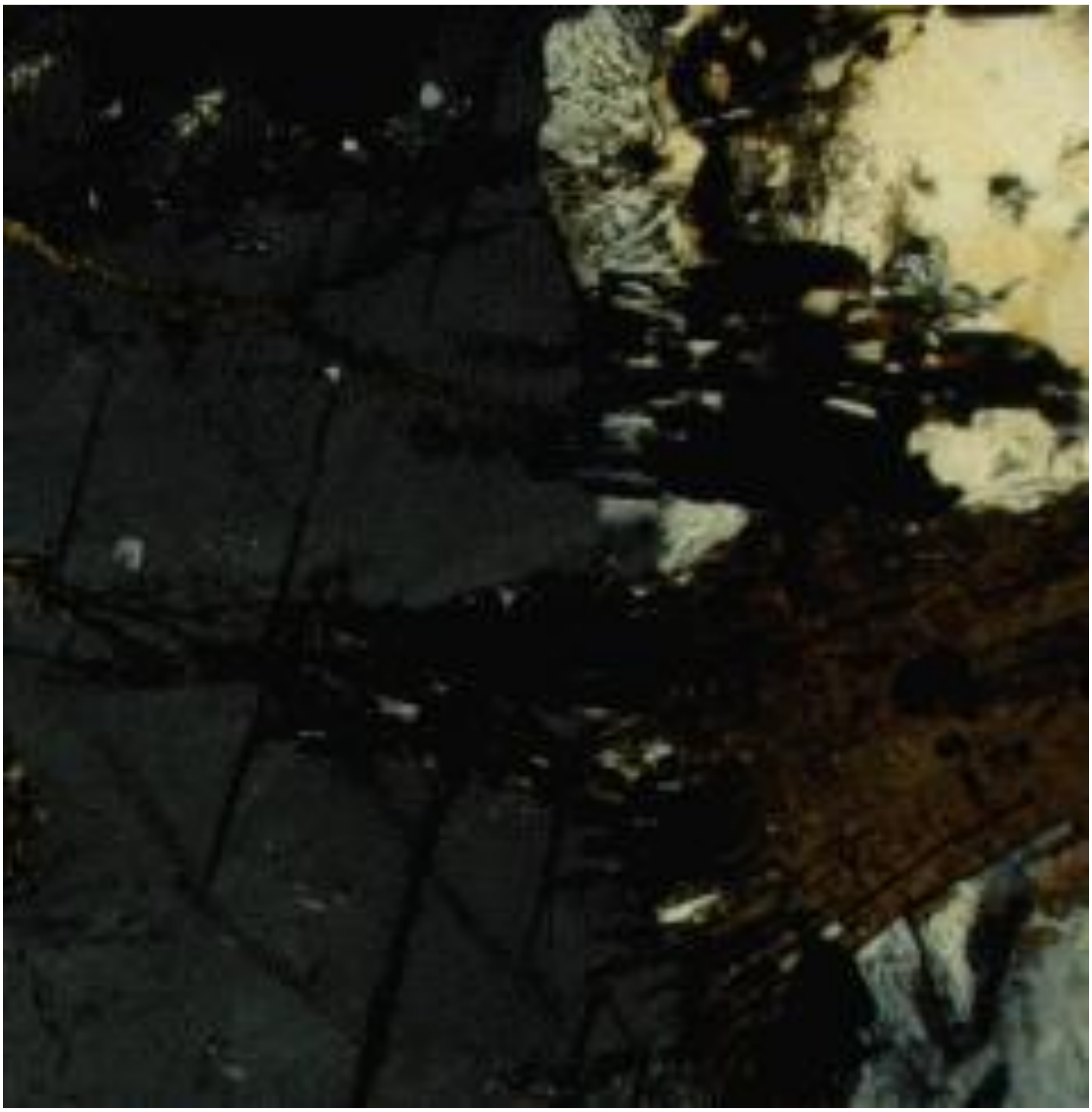

Fig. 18. Microcline (dark gray to black) replacing biotite (brown), leaving remnant "leaves" projecting into the microcline (center). Myrmekite (top). Plagioclase (cream, light gray; right side).

Also, microcline crystals may grow beyond their initial interior replacement of a deformed plagioclase crystal and engulf and replace adjacent ground-mass minerals as well. This is illustrated by a microcline crystal that has grown to enclose a former cataclastic shear zone with remnant angular-to-rounded quartz islands in the microcline, where similar quartz fragments project into a shear zone in the ground mass beyond the microcline crystal (Fig. 19). Significantly, the microcline is unsheared.

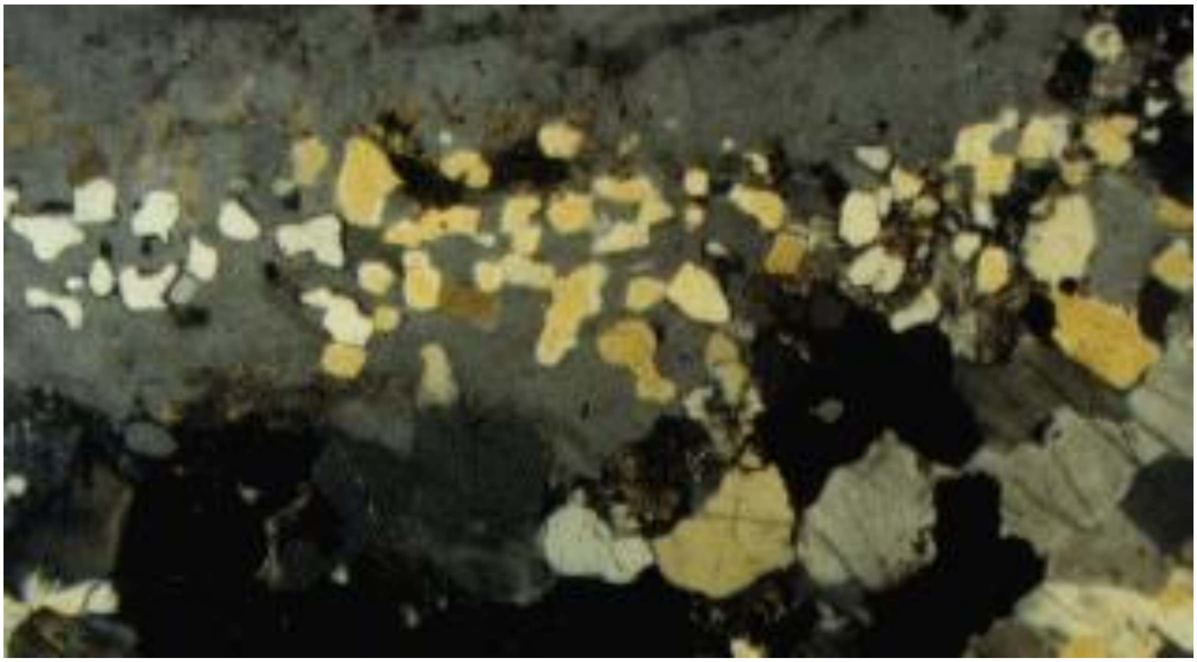

Fig. 19. Microcline (light gray; top) enclosing angular-to-rounded quartz fragments (white, cream) in a former shear zone which continues through the rock (right side). The microcline is not sheared but has replaced all other minerals except the quartz.

Ferromagnesian silicates and quartz.

Simultaneous with the progressive replacement of plagioclase in the transition from gabbro to leucometasomatite are progressive alterations of the ferromagnesian silicates. In gabbro, sample 013, pyroxene is unaltered (Fig. 20), but pyroxene crystals in gabbro, sample 012, in early stages of deformation, are altered to an amphibole or an unidentified brown mineral along fractures (Fig. 21).

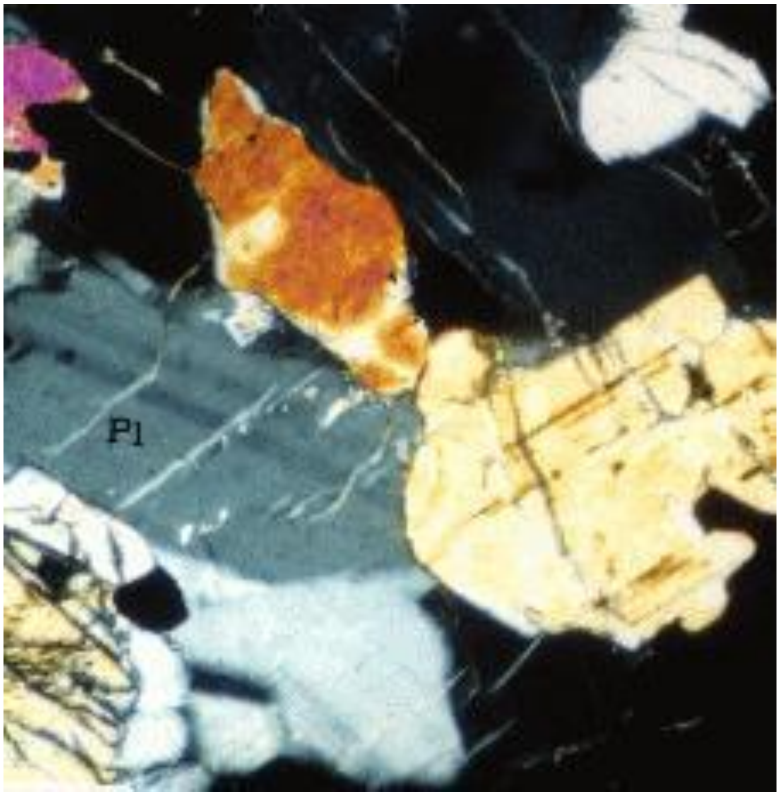

Fig. 20. Unchanged pyroxene crystals (cream, brown, pink) in gabbro, sample 013. Albite-twinned plagioclase (gray and black).

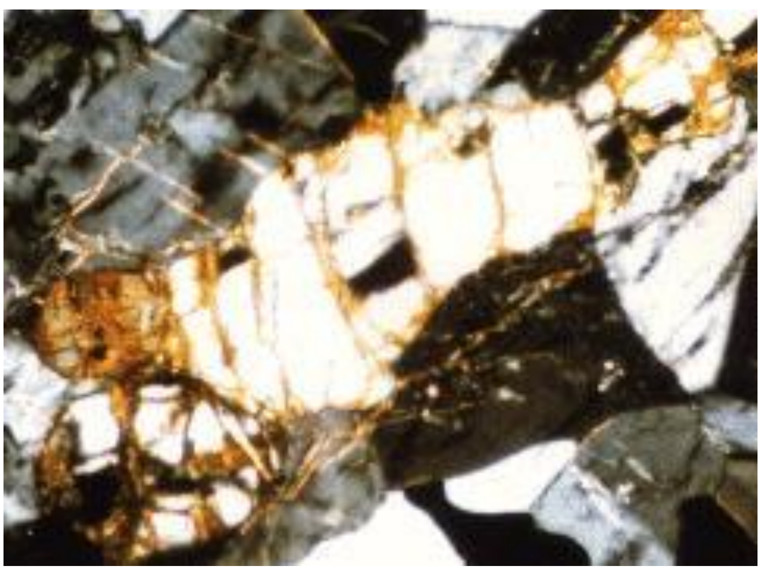

Fig. 21. Early stage of replacement of a pyroxene crystal (cream, center) in gabbro, sample 012, in which an unidentified brown mineral has formed along fractures. Plagioclase (gray, white) surrounds the pyroxene crystals. Iron oxides (black).

In the monzonite (sample 011), the alteration is more advanced, and biotite replaces the pyroxene crystals along fractures (Fig. 22). In final stages biotite completely or nearly completely replaces the pyroxene crystals, leaving an occasional island remnant in the biotite (Fig. 23). This replacement biotite tends to differ in appearance from primary biotite in the gabbro, which has a more uniform appearance, but also poikilitically encloses pyroxene crystals.

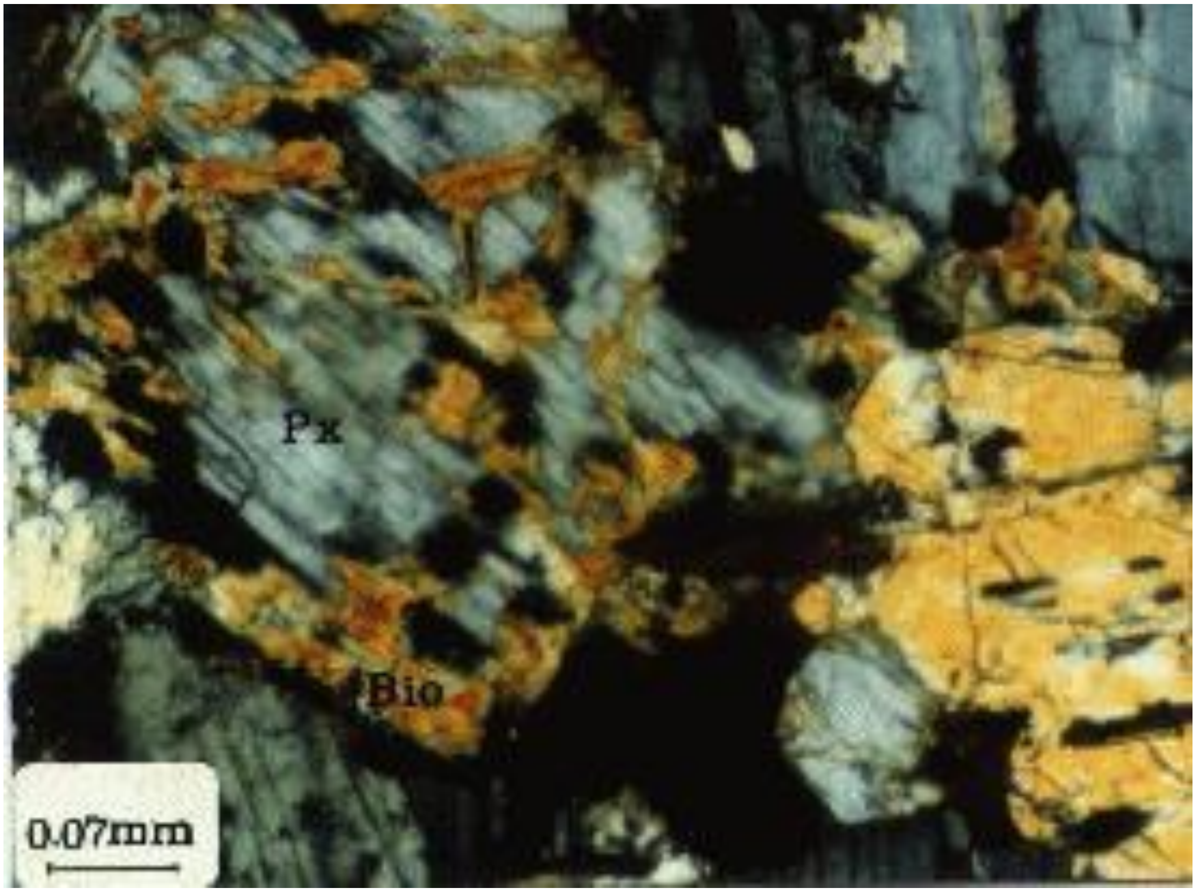

Fig. 22. Two crystals of pyroxene in gabbro, sample 012, in which the replacement is more advanced. Biotite (brown) has replaced the pyroxene (light gray) along fractures (left side). Plagioclase (gray) surrounds the pyroxene crystals).

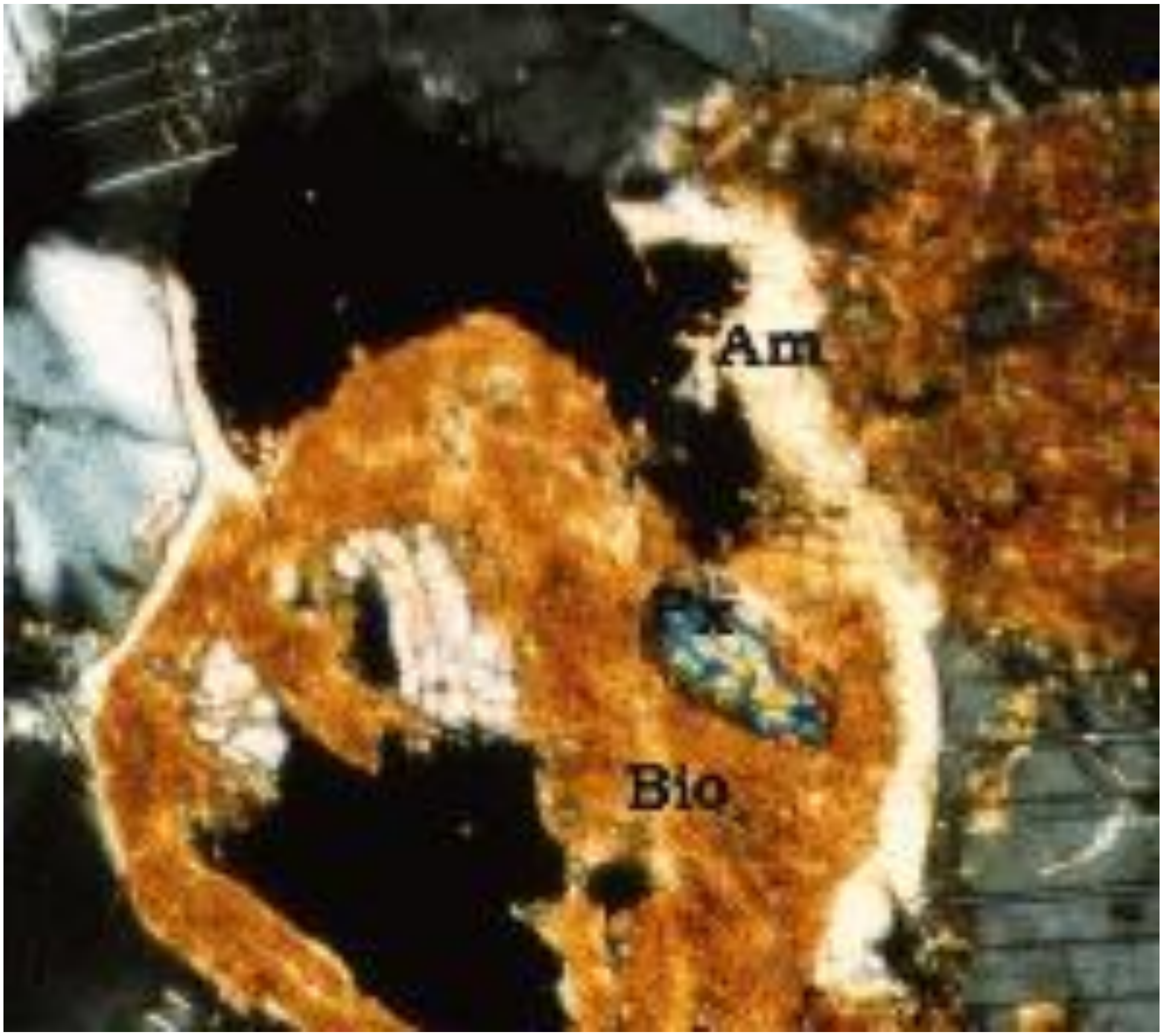

Fig. 23. In monzonite, sample 011, replacement of pyroxene by biotite has advanced to the point that only remnant islands of pyroxene green remain in the biotite (brown). Albite-twinned plagioclase (black and light gray) surround the biotite. Remnant amphibole (Am, brown) is also present.

In the quartz monzonite pyroxenes are absent, but some hornblende remains. In the granitic rocks, however, both biotite and hornblende show quartz sieve textures in intermediate stages of the transition zone (Fig. 24 and Fig. 25), suggesting that both are subsequently replaced by quartz. The biotite (primary and secondary), in particular, shows progressive replacement by quartz along cleavage directions. Quartz stringers and vermicules become thicker and thicker until only small remnants of biotite remain before totally disappearing in the quartz (Fig. 25 and Fig. 26). Apatite across the same transition is a relatively abundant accessory mineral (1.4 vol. %) in the gabbro, but gradually disappears to remain only as trace amounts in the leucometasomatite and the Ghooshchi granite.

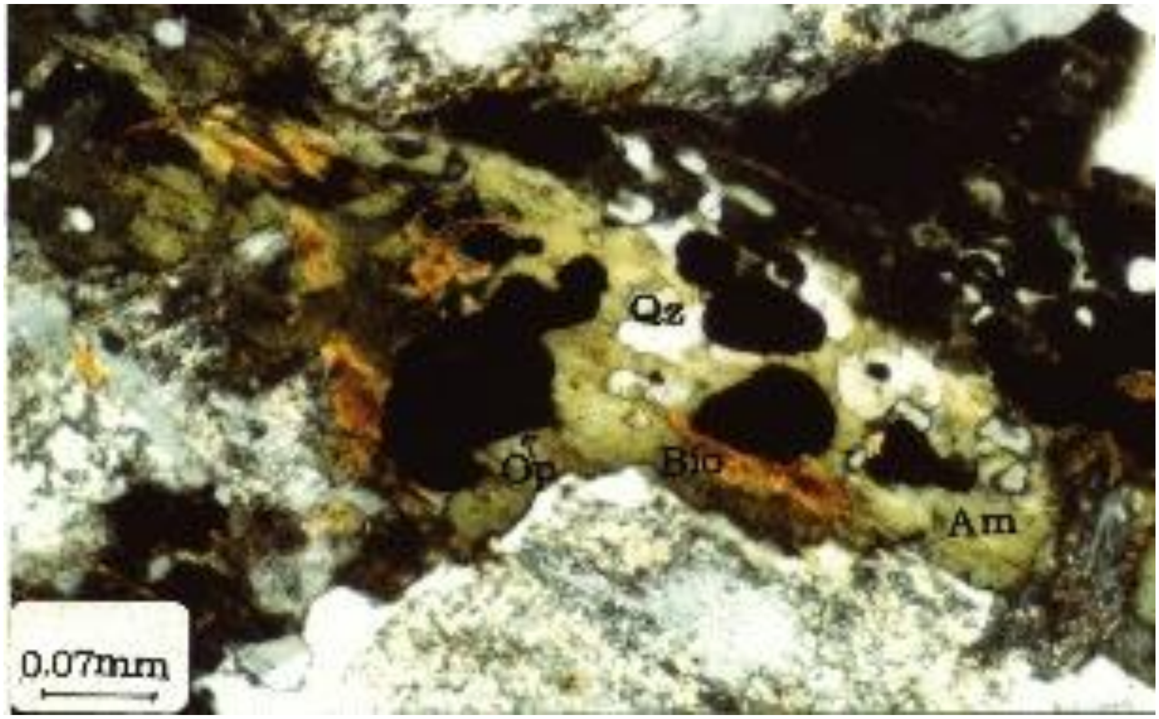

Fig. 24. Hornblende (greenish-brown) replaced by quartz (white) in a quartz sieve texture. Biotite (brown); plagioclase (white).

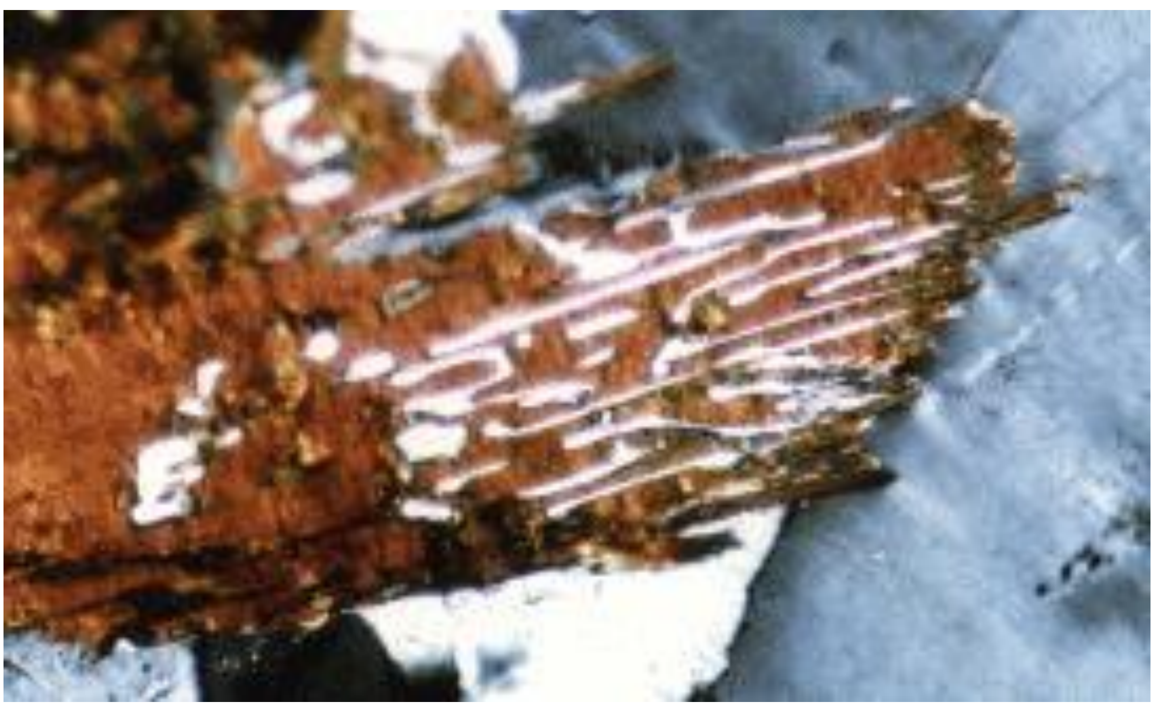

Fig. 25. Biotite (brown) replaced by quartz (white) along cleavage surfaces. Microcline (light gray) may also have replaced portions of the biotite (right side).

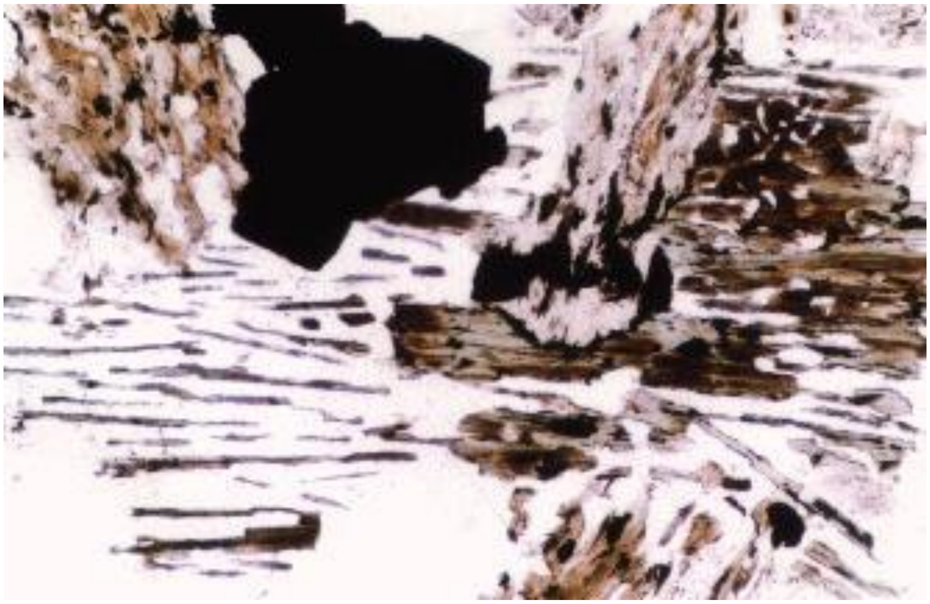

Fig. 26. More advanced stages of replacement of biotite by quartz. Remnant, needle-shaped biotite grains extend beyond the primary grain in the quartz (cross-polarized light). Iron oxide (black).

Chemical changes

Chemical data for major oxides and trace elements are shown in Table 2 for the transition zone from the gabbro into the apophyse-like leucometasomatite masses (Table 1) and also for the Ghooshchi granite. Across the transition, SiO_2 and K_2O increase as MgO, Fe_2O_3, CaO, TiO_2, and MnO decrease, correlating with the disappearance of the ferromagnesian silicates and progressive appearance of microcline and quartz. From samples 013 and 010, Na_2O increase and then decreases in sample 009. This pattern corresponds to the retention of some of the Na in recrystallized relatively-sodic plagioclase (Collins, 1988; Hunt et al., 1992). The trend for Al_2O_3 is somewhat irregular, first increasing and then decreasing. The early Al-increase occurs because the Al that is released from relatively-calcic plagioclase that is replaced by microcline is retained in biotite that replaces the pyroxenes (Fig. 18, Fig. 19, and Fig. 20). Later, as the biotite becomes replaced by quartz, the Al-content decreases. After an increase of P_2O_5 in gabbro, sample 012, a gradual decrease extends to the leucometasomatites and the Ghooshchi granite.

Table 2. Chemical analyses of major and trace elements in the transition rocks (Table 1) and the Ghooshchi granite.

Sample	013 gabbro	012 gabbro	011 monz	010 qtz monz	009 leucometasom	P19	P5
	Transition zone					**Ghooshchi granite**	
Wt. %							
SiO_2	62.00	65.50	64.90	68.70	75.50	77.20	77.00
TiO_2	1.40	0.98	0.42	0.32	0.16	0.15	0.06
Al_2O_3	10.90	11.50	14.90	13.50	10.50	9.70	10.60
Fe_2O_3 (t. Fe)	9.60	8.50	4.20	1.70	1.40	1.70	1.50
MgO	4.80	3.20	1.70	<0.20	<0.20	<0.20	<0.20
MnO	0.18	0.17	0.08	0.03	<0.01	<0.01	<0.01
CaO	7.50	5.60	4.20	3.10	0.78	<0.70	<0.70
Na_2O	1.90	2.60	3.60	4.40	4.00	4.20	4.30
K_2O	0.34	0.40	4.60	7.50	6.20	5.50	4.80
P_2O_5	0.26	0.34	0.15	0.05	<0.01	<0.01	<0.01
L.O.I.	0.22	0.04	0.38	0.12	0.30	0.26	1.00
ppm							
Cu	22	20	19	6	4	4	2
Mo	11	11	15	15	10	8	10
Pb	3	7	40	71	39	45	45
Zn	79	138	93	31	5	20	28
Ni	31	28	19	9	3	11	9
Co	52	43	47	23	46	46	53
Cr	69	43	34	9	13	<5	10
V	250	140	30	60	60	80	90
As	29	25	49	49	55	72	73
Ba	132	205	>1000		269	79	83
Rb	9	11	74	123	119	184	195
Sr	317	359	365	427	32	0	6
Nb	26	25	20	9	6	99	79
Th	4	8	10	17	10	44	39
U	12	7	21	14	14	24	20
Zr	178	303	687	225	173	405	232
Ga	13	13	12	14	17	23	43
Sc	20	12	6	<5	<5	<5	<5
Y	17	12	6	<5	<5	68	62

The trace elements Pb, Rb, and As follow the same trends as K_2O, whereas Cu, Ni, Sc, V, Y, and Nb have similar trends to those of MgO and Fe_2O_3. Enrichments of Pb and Rb occur because of their similar ionic sizes to that of the K ion, which allow them to be retained in the microcline and biotite. After decreasing toward the monzonite, V increases in quartz monzonite and granite. After an early increase, Zn decreases toward the granite, likely because Zn tends to concentrate in residual biotite. From gabbro toward quartz monzonite, Sr and Th increase and then decrease in granite. The Sr likely follows Ca, first being concentrated in residual Ca-bearing minerals, but then leaving the system with subtracted Ca. The elements Ba, Co, U, Ga, and Zr show no distinct trends.

Ghooshchi granite

The Ghooshchi granite has a rather large areal extent (Fig. 1), but its contacts with the sedimentary wall rocks are obscure, and the granite appears to be fault bounded. Because no contact metamorphism has been reported in the sedimentary wall rocks, the granite may have been intruded at relatively low temperatures. Although the myrmekite-bearing, apophyse-like leucometasomatites in the gabbros show distinct features of replacement, the Ghooshchi granite lacks these features. Granophyric and graphic textures and perthitic K-feldspar (orthoclase) with uniformly distributed albite lamellae provide evidence that this granite formed from a magma. Plots of chemical data for seven samples in the quartz-feldspar-water system (Winkler, 1976; in Behnia, 1995) suggest that these rocks crystallized in a temperature range of 700-760º C. In the field, the southern portion of the Ghooshchi granite has entirely magmatic characteristics. Northward is a broad border zone containing leucometasomatites within the granite, which is then bordered by a zone of gabbros with apophyse-like, transitional, leucometasomatite bodies (described in this presentation). Finally, there is a zone of gabbros and diorites which has less deformation and contains leucometasomatites. This zonal pattern supports the hypothesis that all the granitic rocks were formed by K- and Si-metasomatism of the gabbros with the aid of hydrous fluids. Gradations in Rb and Sr contents (Table 2) between all the rock types (gabbros and diorites to the metasomatic granitoids to the Ghooshchi granite) also lend support for this metasomatic hypothesis. This metasomatism, however, would have occurred prior to a sufficient rise in temperature to cause large portions of the metasomatized rocks to melt and subsequently recrystallize as the pink Ghooshchi granite.

Where did the elements subtracted during the metasomatism go?

Along the border of the Ghooshchi granite near Ghareh Bagh (Fig. 1) are phlogopite mines that have been mineralized. In these mineralized sites apatite, diopside, epidote, dravite, calcite, garnet, sphene, and soda-rich amphiboles are associated with phlogopite veins. Because such minerals contain the elements that would have been displaced by the K- and Si-metasomatism, perhaps the sites of these mines represent places where some of the displaced elements were deposited. More work needs to be done to support this hypothesis.

Conclusion

On the basis of field observation and microscopic and geochemical studies, an intensive metasomatism has overprinted deformed portions of the country rocks, especially the gabbros, transforming the parent rocks into felsic compositions. Cataclasis preceded the metasomatism, allowing the introduction of hydrothermal fluids into the parent rocks. K-metasomatism has converted relatively-calcic primary plagioclase into K-feldspar, myrmekite, and more sodic plagioclase as Si-metasomatism has replaced the ferromagnesian silicates by quartz. In these processes apophyse-like bodies within the gabbros, called leucometasomatites, were created. Similar metasomatic transitional stages occur in the biotite granite and two-mica granite and their host schists and gneisses but need further study and are not discussed here.

This study of the Ghooshchi granite terrane is significant because it supports the model in http://www.csun.edu/~vcgeo005/Nr24TwoStyles.pdf. That is, during subsolidus K-replacement of plagioclase in deformed gabbro and diorite, microcline and myrmekite are formed in leucometasomatites, but in the Ghooshchi granite that likely formed as the result of subsequent melting of the leucometasomatites, the K-feldspar has recrystallized as orthoclase that coexists with granophyric and graphic textures, but no myrmekite.

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