Zeitschrift: Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie

Band: 70 (1990)

Heft: 2

Artikel: Quartz textures in dioritic rocks of hybrid origin

Autor: Bussy, François / Ayrton, Stephen

DOI: https://doi.org/10.5169/seals-53615

SCHWEIZ. MINERAL. PETROGR. MITT. 70, 223–235, 1990

Quartz textures in dioritic rocks of hybrid origin

by *François Bussy*[1,2] *and Stephen Ayrton*[1]

Abstract

Quartz in diorites and tonalites characteristically occurs in three textural forms:

a) Interstitial to feldspars (and other minerals). This is the dominant relationship, and poses the problem of the crystallization sequence involving these two minerals. Fractional crystallization does not allow the production of a residual liquid of SiO_2 composition. Some feldspars must therefore have crystallized with the quartz – in what proportions and with what composition must be determined – which means that this sort of geometry, i.e. the interstitial occurrence of a mineral against the crystal faces of another, does not mean that they are not involved, at least partially, in a cotectic relationship.

A remarkable, seldom described, and unexplained texture is the relatively common occurrence of "ophitic" quartz, where round or sub-hexagonal domains of interstitial quartz incorporate laths of plagioclase (and other minerals). This feature occurs in situations where magmas of contrasting composition coexisted and most probably mixed, for instance in mafic microgranular enclaves incorporated in granitic rocks (Mont-Blanc granite, Fully anatectic granodiorite, Western Alps; M. Capanne granite, Italy). Mixing has, according to this view, led to intermediate compositions with the establishment of thermal equilibration between the still-crystallizing mafic enclaves and acidic host. The last stages of crystallization were completed at a low rate of nucleation, allowing the development of large poikilitic quartz crystals enclosing laths of plagioclase, the marginal zones of which are coeval with the quartz.

b) Quartz also occurs as "ocelli", very commonly in tonalitic enclaves (within granitoids) or in larger masses. Although these have been considered to be early, high pressure precipitates, there is again very good evidence for magma mixing, and for the incorporation of quartz xenocrysts from a crystallizing acidic magma into a more mafic liquid. These quartz crystals are invariably rounded, even embayed, and are either rimmed with ferromagnesian minerals (biotite and/or hornblende), or not. The nature of the ferromagnesian minerals, as well as the presence and the width of the rim depend, to a large extent, on the characteristics of the host material at time of incorporation.The rim may protect the quartz from further corrosion, but in any case some silicic liquid must be available and these mini-magmas could also crystallize in the form of interstitial quartz. The previous texture may be combined with this one to form interstitial patches of quartz spreading out from the quartz ocelli. In these occurrences, it can be clearly seen that the ocelli have an outer rim in optical continuity with the central part, but distinguishable from the latter mainly through the presence of abundant long apatite needles. Both ocelli and "ophitic" quartz exist in certain basalts, lamprophyres and appinites as well.

c) Quartz, as well as feldspars, may also form interstitial patches directly projecting from host granitoid into mafic dioritic enclave. This suggests that granitic liquid was capable of penetrating the enclave to some degree, which may be partly enhanced by the development of a porous texture in the crystallizing enclave, due to some 10% reduction in volume.

In conclusion, a number of features concerning the texture of quartz in diorites and tonalites are related to situations in which the mixing of magmas very likely occurred. The intermediate compositions may in fact be at least partly due to the mixing of two liquids of contrasting composition.

Keywords: quartz, ocelli, ophitic texture, diorites, hybrids.

1. Introduction

Quartz plays an essential role in many rocks of dioritic composition. Tonalites, microgranular enclaves in granitoids, lamprophyres and appinites commonly contain quartz in one form or another. Certain textures appear in contexts involving the mingling and mixing of magmas,

[1] Institut de Minéralogie et Pétrographie, Université de Lausanne-BFSH2, CH-1015 Lausanne.
[2] Present address: Earth Sciences Dept, University of Leeds, GB-Leeds LS2 9JT.

i.e. hybridization. In this respect, the argument will be extended to basalts with quartz "drops", most probably xenocrysts.

Here, we discuss a very common feature, the famous quartz "ocelli" and also quartz as an interstitial phase. In the latter instance, oikocrysts of quartz, in a quasi-ophitic arrangement, enclose feldspar laths and other minerals. This very particular, although quite widespread texture is conspicuous in the microgranular enclaves of many granitoids. Another texture involves the development of interstitial quartz at the contact between granitoid and microgranular enclave. These textures are not mutually exclusive. On the contrary, they often coexist, and, again, this always seems to occur when mafic and felsic rocks are intimately associated with good evidence, otherwise, of magmatic exchange.

2. The quartz ocelli

The characteristics of the quartz ocelli will be considered in their various environments, i.e. basic to intermediate plutonic, hypabyssal or volcanic rocks, followed by the question of their origin itself.

2.1. DESCRIPTION

2.1.1. Plutonic context

Quartz ocelli in plutonic rocks systematically exhibit the same textural profile, whatever the occurrence. Variations are a function of the mineralogy and grain-size of the host rock. Typically, they are rounded, ellipsoidal or spherical, a few millimetres in diameter, generally formed of a single quartz grain *(core)* rimmed by a millimetric corona of ferromagnesian minerals *(rim)*.

The core is often subdivided into sub-grains, even if the rock has not undergone any apparent deformation; this subdivision is related to a web of criss-crossing curviplanar fractures, reminiscent of the fracture pattern in thermally shocked crystals (Fig. 4). The microfractures are generally filled with carbonate and/or alkali feldspar, occasionally zeolites (BARRIÈRE, 1977). In a given occurrence, there is a tendency towards an average size which is close to that of the quartz grains in the host granitoid, where the ocelli are incorporated into enclaves or in associated dioritic-gabbroic masses (cf. Figs 1 + 2). While the ocelli have an overall rounded shape, rectangular or hexagonal subhedral forms also occur (BUSSY, 1989) and embayments are common. CLOCCHIATTI (1975) stressed the difficulty in distinguishing embayments due to the corrosion of quartz crystals from open, skeletal growth forms. The constantly smooth edges of the subhedral crystals of the ocelli strongly support resorption, in variable degrees, of initially euhedral crystals.

The cores of the ocelli contain some inclusions, distinct from the filling of embayments which may, depending on the orientation of the section, appear to be within the quartz. In the ocelli of the microgranular enclaves of the M. Capanne granite (Elba Island, Italy, BUSSY, 1989), the included minerals are biotites, zircons and apatites, whose habits are different from those of the crystals in the matrix, but identical, on the other hand, to those of the crystals within the host granite. Fluid inclusions are always present, and often very abundant. They constitute alignments or dense, planar swarms of hundreds of individual inclusions. BARRIÈRE (1977) mentions analyses suggesting low temperature crystallization or recrystallization, with H_2O and CO_2 immiscibility.

The ferromagnesian rim of the ocelli is their most striking characteristic. The mineral composition generally recalls that of the host rock (Figs 3 + 5); it therefore contains pyroxene and/or amphibole and/or biotite depending on whether the rock is a gabbro, a diorite, a tonalite or even a granodiorite (e.g. BARRIÈRE, 1977). A notable exception is mentioned by SATO (1975) in a volcanic context, with development of Ca-rich clinopyroxene coronas in orthopyroxene-bearing andesites. Some K-feldspar is generally associated with these ferromagnesian minerals; it may form an independent zone between the quartz core and the rim (BARRIÈRE, op. cit.) or poikilitic areas within the corona or outside it (e.g. BUSSY, 1989). The pyroxene and amphibole crystals in the innermost part of the corona are often in radial disposition with euhedral shapes, but tangential arrangements are common. In a given rock, rimmed ocelli may coexist with rimless ones. This situation is particularly notable in microgranular enclaves, where the rimless ocelli frequently exhibit a zonal structure: a central inclusion-poor or inclusion-free zone is rimmed by a zone, in optical continuity with the latter, filled with inclusions, long apatite needles being conspicuous. Towards the matrix, these inclusions (all the matrix minerals are represented) become progressively more abundant, and there is a progressive transition to the latter, in which quartz is interstitial and poikilitic. The quartz ocelli are thus seen to extend into the matrix. The contact between the two zones is virtually invisible, but the first appearance of the apatite gives an idea of its geometry, irregular and curviplanar, exceptionally subhedral.

As mentioned in the introduction, *the occurrence* of ocelli in the plutonic context is systematically related to situations in which acid and basic rocks coexist, with indications of more or less pronounced mixing and/or mingling. The main evidence is the abundance in granitoids of mafic microgranular enclaves, sometimes attaining the dimension of a small stock (see the numerous articles on the subject, e.g. VERNON, 1983, REID et al., 1983; FROST and MAHOOD, 1987; BARBARIN, 1988; BUSSY, 1989; ZORPI et al., 1989) and the presence within the enclaves of large corroded crystals, whose nature, size and composition are identical to those of the crystals in the host granite, and which must be considered to be xenocrysts derived from the granitoid, mechanically incorporated and partially dissolved in the hotter magma of the enclaves. The best demonstration of this process is given by the large, corroded alkali-feldspar megacrysts, sometimes rimmed with plagioclase in a rapakivi association (e.g. HIBBARD, 1981; VERNON, 1986), within gabbroic or tonalitic rocks whose matrix shows no sign of this mineral (Fig. 1).

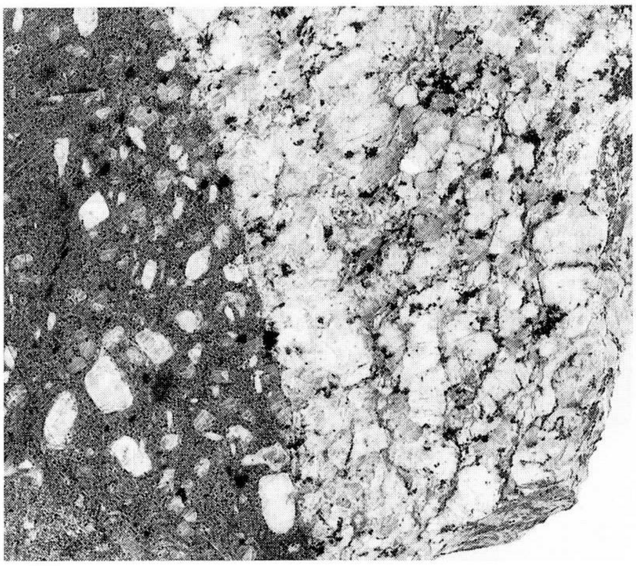

Fig.1 Sample of typical Mont-Blanc granite in contact with a microgranular, dioritic enclave. Quartz crystals and feldspar megacrysts are concentrated near the granite, some crystals actually straddling the contact. Both species are identical to the quartz and feldspar within the granite. Some of the quartz crystals are, however, rimmed (the classic "ocelli"), the alkali feldspars are rounded and generally mantled with sodic plagioclase (rapakivi texture), and the plagioclases are often sieved ("patchy zoning"). Biotites as well are to some extent derived directly from the granitic system through mechanical mixing. Width of sample: 18 cm.

In a given rock, the quartz ocelli are distributed in a more or less uniform manner, but tend to be concentrated towards the granitic component, as in Fig. 1, with certain crystals even straddling the granite-mafic enclave contact. The ocelli are clearly more abundant in rocks of intermediate composition, but they appear in gabbros as well as in granites. Fig. 2 shows a well-rimmed quartz within an off-shoot of the Ploumanac'h granite

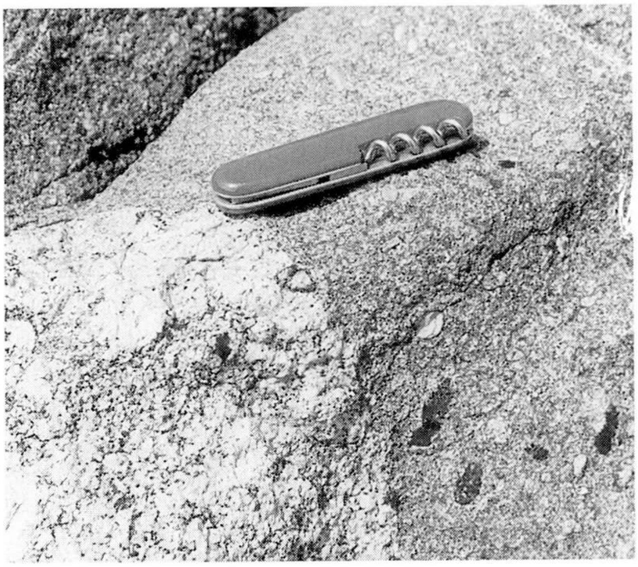

Fig. 2 Quartz ocelli in gabbro and granite, Ploumanac'h massif (Ste Anne), Brittany. This occurrence shows that the ocelli are not to be found exclusively in the mafic-intermediate rock-types, but also in granitoids. In the opinion of the authors, this suggests that mechanical mixing may cause "to-and-fro' exchange", which may partly explain complex zoning in the large plagioclase feldspars.

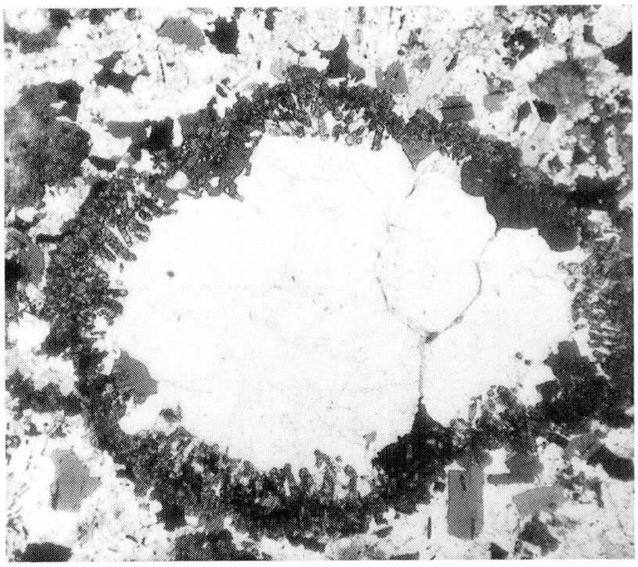

Fig. 3 Quartz ocellus in gabbro from the Ploumanac'h massif (Ste Anne), Brittany. The ferromagnesian rim is largely formed of euhedral pyroxene crystals in radial disposition. Diameter of ocellus: 6 mm.

complex. This is not as rare as it might seem. Close inspection of certain granites reveals the existence of many rimmed quartz grains.

2.1.2. Volcanic context

Quartz ocelli in certain basalts and andesites, e.g. from the British Tertiary Province (McGregor, 1965), the Permian lavas of Exeter (Tidmarsh, 1932), or from the Tertiary Shikoku (Japan) volcanic Province (Sato, 1975), are virtually identical to those of plutonic rocks. The same forms, sizes, internal structures, fracture patterns and ferromagnesian rims are present. Pyroxenes, generally augite, again form a radial pattern around the quartz grains, sometimes with sanidine. A notable difference is the common presence of Na- and K-rich glass (Sato, op. cit.) within the corona. Carbonate again appears, often with some abundance in the rim.

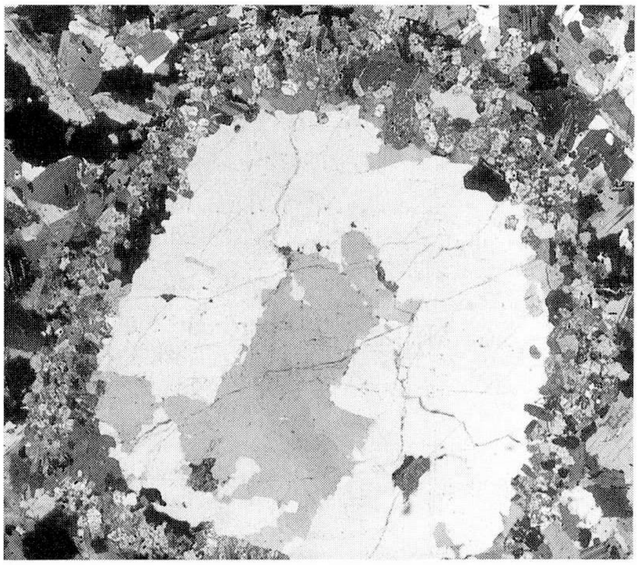

Fig. 4 Quartz ocellus in gabbro from the Ploumamac'h massif, with the typical fracture pattern probably due to thermal shock. The microfractures are filled with carbonate + feldspar, occasionally zeolites. Diameter of ocellus: 5 mm. Crossed polars.

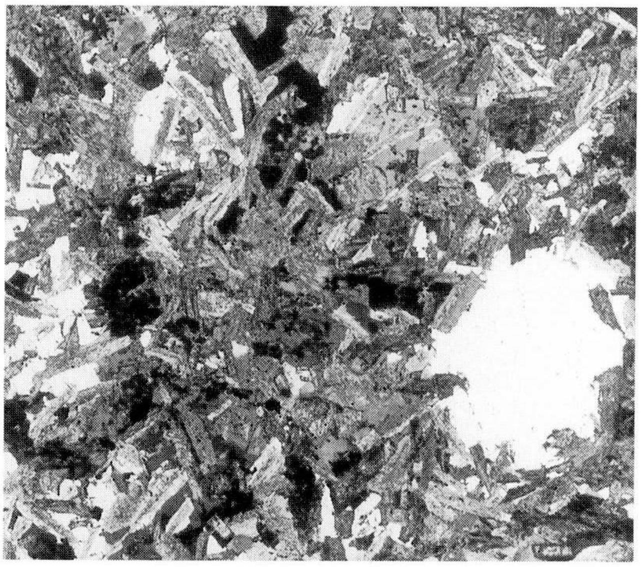

Fig. 5 Quartz ocellus with a hornblende-rich rim and interstitial, "ophitic" quartz patches in Neuntelstein tonalite (Vosges). The ocellus is 2 mm across. Crossed polars.

2.1.3. Hypabyssal context

Lamprophyres, in the widest sense, also contain ocelli absolutely identical with the ones described above (Fig. 6). A particular feature is the common abundance of carbonate in the rim. It is worthy of note that it is the ocelli in micaceous lamprophyres that prompted Rosenbusch (1887) to introduce the term for the first time.

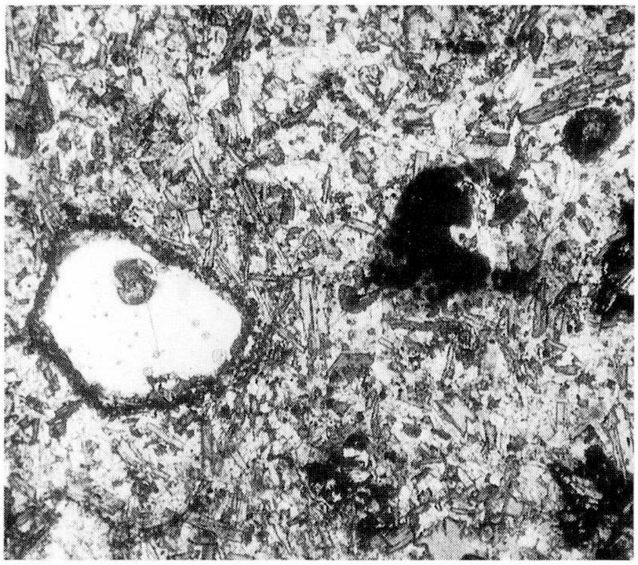

Fig. 6 Quartz ocellus in lamprophyre (Noirmont, Jersey, Channel Islands). Note the euhedral form of the quartz crystal. Diameter: 1 mm.

2.2. ORIGIN OF THE QUARTZ OCELLI

2.2.1. Volcanic context

Most authors consider the quartz ocelli in basalts to be xenocrysts (see Hatch et al., 1952, p. 300, for example). The main points for that view are:

a) the presence in these lavas of xenoliths of granite, sandstone or quartzite, exhibiting all stages of disintegration into independent crystals, notably quartz, whose size decreases progressively with distance from the xenolith, until their disappearance when completely dissolved (e.g. Tidmarsh, op. cit.; Sato, op. cit.). Tidmarsh even identified fibrous sillimanite in the core of an ocellus rimmed with pyroxene, indicating a xenolithic, crustal origin for this quartz grain.

b) the presence of glass around the ocelli, suggesting partial fusion due to thermal disequilibrium of quartz xenocrysts incorporated into basaltic magma, rather than resorption of phenocrysts through a drop in pressure. In this respect, the fracture pattern commonly observed in the ocelli could be the expression of differential expansion due to thermal shock (TIDMARSH, op. cit.). The ferromagnesian corona is thus interpreted as a reaction zone due to the local coexistence of a siliceous liquid with the surrounding basalt (SATO, 1975). Chemical diffusion and exchange occurs, controlled by the two-liquid partitioning coefficients leading to uphill enrichment of Na and K in the siliceous liquid (WATSON, 1982). The radial orientation of the pyroxenes of the corona is logical in this context, as their growth develops normal to the diffusion front. The internal margin of the corona corresponds therefore to the limit reached by centripetal fusion, just as Tidmarsh had suggested (TIDMARSH, op. cit.).

A phenocrystalline origin for the ocelli in certain lavas has been proposed in situations where contamination and/or mixing with an acid component is not visible in the outcrop. Thus, NICHOLLS et al. (1971) postulate early crystallization of quartz at depth and at high pressure (> 20 kb) on the basis of thermodynamic calculations in order to explain the presence of quartz in tholeiitic basalts related to island arcs in an oceanic environment. Experimental evidence, however, does not seem to allow fractionation of early quartz, at or near the liquidus, in systems with less than ca 65% SiO_2 (cf. HUANG and WYLLIE, 1986). Also, garnet should appear at or near the liquidus in a wide spectrum of SiO_2 %, and garnet is very rare indeed in the rocks which contain the quartz ocelli. Moreover, subduction situations, even in the oceanic realm, do not exclude the presence of a volcanic component with phenocrystic quartz (e.g. calc-alkaline quartz-andesites, dacites), which could contaminate tholeiitic basalts. To the best of our knowledge, ocelli never occur in purely oceanic basalts with which no acid rocks are associated.

2.2.2. Plutonic context

Here, genetic interpretations are more varied (see review in BARRIÈRE, 1977):

a) hybridization of basic rocks through metasomatism related to the proximity of granites. Blastic growth of quartz ocelli seems improbable, as their cores are not poikilitic and lack inclusions of minerals seen in the matrix, in particular acicular apatite. Considering the poikilitic nature of the quartz in the matrix, developed during the magmatic stage (see chapter 3), it is difficult to imagine how fluids (?) could subsequently dissolve, eliminate and possibly recrystallize considerable parts of the matrix to form pools of quartz without including relics. On top of that, in certain basic rocks, particularly the microgranular enclaves, the matrix exhibits a flow texture, with deflection around the ocelli demonstrating that the latter were already present in the magmatic stage.

b) hydrothermal pseudomorphic replacement of early minerals by quartz; this mechanism is just as improbable as the preceding one. Apart from the fact that there are no clearly established examples of pseudomorphic development of pure quartz, it is difficult to visualize what the original mineral could be. The hexagonal shape of certain ocelli speaks for direct crystallization.

c) cavity filling; a point often made in favour of this hypothesis is the radial disposition and the euhedral habit of the ferromagnesian minerals of the corona at the contact with the quartz core of the ocelli, which could indeed suggest early, free, centripetal growth, followed by late infilling of the cavity by pure quartz. While this mechanism does occur in certain specific situations, notably in very fluid-rich alkaline environments, where the cavities are incompletely filled (PLATEVŒT, oral comm., 1988), it cannot be extrapolated to the general case. A number of observations go against it, as, once again, the shape of the ocelli: how to explain hexagonal or rectangular cavities? Also, why are the ocelli in rocks with fluidal texture not elongated like the bubbles in lava flows? Preliminary cathodoluminescence analyses by RAMSEYER (University of Bern) have moreover revealed in certain ocelli a zonal structure characteristic of centrifugal growth of a phenocryst rather than the centripetal filling of a cavity (Fig. 7). Finally, the radial growth of the ferromagnesian minerals is perfectly explained within the frame of crystallization controlled by chemical diffusion in the siliceous liquid enveloping the partially fused quartz grains.

d) Immiscibility; it is possible that unmixing of a silicate liquid could form the minerals that rim the ocelli on one hand, and the quartz core on the other. While this mechanism is conceivable for ocelli with a well developed corona, it does not explain the formation of rimless ocelli, as mechanisms involving immiscibility do not lead to the development of a purely siliceous liquid (e.g. PHILPOTTS, 1976, 1982 and oral comm., 1985).

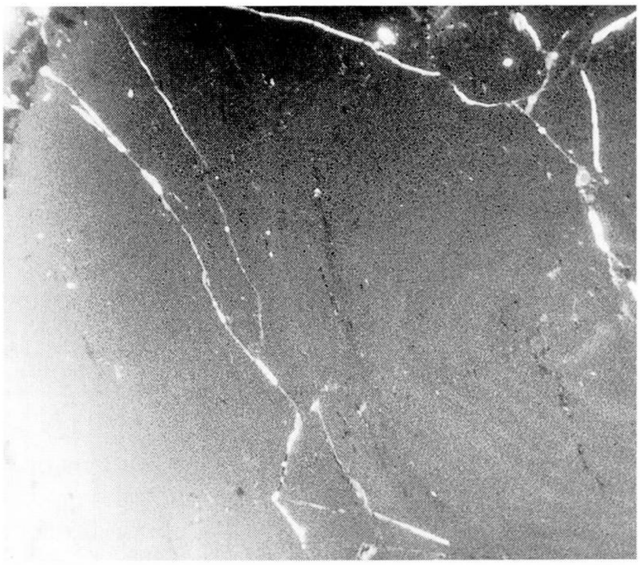

Fig. 7 Cathodoluminescence picture of a quartz xenocryst (5–6 mm across) from a microgranular, dioritic enclave in the Mont-Blanc granite. Euhedral zones suggest growth in a high-temperature magmatic environment. The exact nature of the zoning is not yet known. Analysis by Karl Ramseyer, University of Bern.

e) Pre-existing crystals of quartz; the review presented above and the textural observations in paragraph 2.1. strongly indicate that the ocelli of plutonic rocks are pre-existing crystals variably resorbed/fused in a magma with which they were in disequilibrium. Given the fact that these ocelli systematically appear in contexts of magma mixing, a conclusion based on independent evidence, we consider that they represent xenocrysts mechanically introduced into basic magmas and derived in general, but not exclusively, from the associated acid magmas. This hypothesis is the one that best integrates all the preceding observations. The virtual identity in texture between ocelli in plutonites and in volcanites, where their xenocrystic nature is firmly established, points to a single, common post-incorporation evolution in both settings. This evolution may be summarized as follows: mixing between a mafic magma and an acid liquid in which quartz phenocrysts and other mineral species of "granitic" character are suspended leads to their incorporation in the resulting hybrid melt, which is hotter and less evolved than the liquid from which they are derived. Thermal disequilibrium is the consequence, leading to fracturation and partial dissolution. The siliceous liquid thus formed does not mix easily with the surrounding magma. A process of selective interdiffusion ensues allowing preferential crystallization of ferromagnesian minerals and K-feldspar. With decrease in temperature, the system reaches the stability field of quartz which crystallizes preferentially in crystallographic continuity with pre-existing ocelli, trapping an increasing number of crystals of the matrix, as the latter crystallizes.

In the basic rock suite at Ploumanac'h, BARRIÈRE (1977) observed that ocelli are rare – with a poorly developed corona – in the dioritic members relative to the gabbroic ones. It is tempting to explain this feature as being due to insufficient armouring of the quartz, contrary to the ocelli in the gabbros. This might suggest that depending on the rate at which the gabbroic magma solidifies, ocelli may survive or not. At low levels of the crust, or if the temperature is maintained through successive injections of magmas, the quartz may have more time to be completely fused and redistributed, and with other xenocrystic species (K-feldspar, biotite, . . .) succumbing to a similar destiny, a more or less homogeneous dioritic hybrid liquid could consequently form.

Certain basic ocelli-bearing rocks apparently contain no other xenocrystic mineral species. In reality, patchy zoned feldspars, interpreted as partially dissolved xenocrysts (BUSSY, 1989b), are always present. As for K-feldspar and biotite, they may have been absent from the acid magma at time of mixing, or they may have been more efficiently dissolved than the quartz, as it is to be observed in granitic xenoliths undergoing disintegration in basic surroundings (e.g. in the micromonzodioritic dikes cutting the Mont-Blanc granite, Western Alps).

There remain a number of points to be clarified, amongst which are the presence of carbonates and zeolites, filling cracks and sometimes occurring in the centre of the ocelli. Rather than considering that the whole (quartz, feldspar, carbonates, zeolites, etc. . . .) constitutes a cavity filling, it may be that the process has evolved normally, well below solidus conditions, and that carbonates and zeolites have followed the fracture pattern to the centre of the grain, where intersection of these fractures may provide a somewhat larger space. The origin of the carbonate is enigmatic, and the presence of CO_2 inclusions (at least in the ocelli analysed from Ploumanac'h) intriguing. Could the former be produced from the latter due to decrepitation at time of immersion of the quartz into the hotter medium? Another possible explanation may be that, not only do Na, K and H_2O diffuse preferentially in the siliceous melt surrounding the ocelli undergoing partial fusion (SATO, 1975), but also CO_2. It would therefore be concentrated at an early stage around the ocelli and enhance the formation of carbonate.

2.2.3. Hypabyssal context

The "xenocryst" hypothesis may be extended to the ocelli in hypabyssal rocks, notably lamprophyres, given the textural similarities between them and the ocelli in both plutonic and volcanic rocks, and also the fact that many lamprophyres are equally related to situations in which acid and basic rocks coexist. The abundance of carbonate around the ocelli of the lamprophyres would simply express the high fluid content and the particular richness in CO_2 of these magmas.

3. The ophitic quartz texture

In certain ocelli-bearing rocks, the quartz of the matrix forms irregular poikilitic patches, either rounded or elongate, discontinuous, whose size is clearly larger than that of the other matrix minerals, which they contain in the form of numerous inclusions (Figs 8 + 9). The concentration of the latter is often such that only optical continuity indicates that a number of apparently independent quartz domains actually belong to a single quartz grain. The term "ophitic quartz texture", or simply "ophitic quartz", will be applied to this particular development of quartz in the matrix, as it greatly resembles pyroxene oikocrysts in ophitic dolerites. This texture is mainly observed in the dark microgranular enclaves of granitoids, but other occurrences have been mentioned, for instance in the basalts with quartz ocelli from the British Tertiary Province, and in light-coloured acid enclaves in granites from the same region (EMELEUS, 1970, and oral comm., 1987). WIEBE (oral comm., 1990) mentions "ophitic quartz" in layered cumulate dioritic rocks, and in some fine-grained anorthosites in the Nain complex. In basalts, the presence of poikilitic quartz is related to that of the ocelli. In fact, the texture is often developed around the ocelli themselves, from which the poikilitic quartz extends. The source of the interstitial quartz is doubtless to be found in the partial or total fusion of the ocelli and possibly in the presence of a quartz-normative liquid, introduced with the quartz xenocrysts. The poikilitic quartz pools in the acid enclaves contain mainly inclusions of euhedral alkali feldspars, occasionally in radial disposition. EMELEUS (1970) considers these enclaves to be fragments of pre-existing rocks which reacted with their environment, but the precise mechanism involved is not described.

Several authors have mentioned poikilitic quartz in dark microgranular enclaves (e.g. PABST, 1928; DIDIER, 1964). While VERNON (1983) considers it as doubtless magmatic, most have related it to a process of secondary silicification of the enclaves due to the host granitic magma, notably through infiltration of felsic liquid (NOCKOLDS, 1939; OTTO, 1974). Views are therefore varied, but there has been no attempt to explain the fundamental mechanism leading to this particular texture. We propose here a new interpretation based on the study of the microgranular enclaves of the M. Capanne granite, which takes into account the specific relationship between this texture and the enclaves, and more generally, situations of magma mingling and mixing.

3.1. DESCRIPTION

The texture of the matrix of the microgranular enclaves of the M. Capanne granite varies with their modal composition (Fig. 10). To tonalitic, granodioritic and granodioritic-granitic compositions correspond respectively doleritic (s.l.), ophitic quartz and microgranular textures. The quartz content (relative to the sum quartz + feldspar) of the ophitic enclaves is equal to or slightly lower than that of the other textural types. This ophitic texture cannot therefore be due to preferential silicification of the enclaves in which it forms.

Typically, an enclave with ophitic quartz contains, apart from xenocrysts derived from the granite: (a) plagioclase (about 50% vol.), always in stubby euhedral laths, less than 1 mm in length, locally in mutual contact, with albite and/or Carlsbad twinning, strongly zoned with compositions ranging from An_{50} (core) to An_{20} (edge); (b) brown-red biotite (15-20%) in small euhedral flakes from 0.1 to 0.3 mm; (c) irregular poikilitic quartz patches (17–25%) reaching 4 to 6 mm, with inclusions that are neither oriented nor in zonal disposition; (d) alkali feldspars (10–20%), either in small (up to 1 mm) independent interstitial anhedral crystals with rare inclusions, or in patches up to 1–2 mm, rounded, irregular and poikilitic like the quartz; (e) numerous accessory minerals, mainly long, hollow needles of apatite.

In enclaves where both quartz and K-feldspar are poikilitic, biotite and plagioclase, which form the frame of the matrix, are distributed in an homogeneous and isotropic manner, the interstitial space being occupied by big irregular touching oikocrysts of quartz and K-feldspar. In the more common situation, only the quartz is poikilitic but does not fill all the interstitial space of the matrix in a regular manner; the oikocrysts form quartz patches in which the concentration of plagioclase and biotite crystals is often lower than that of the surrounding matrix. Outside the oikocrysts, the plagioclase laths are locally in contact and form a doleritic texture, occasionally fluidal near the margins of the enclave. With decrease in the number of poikilitic quartz patches, one may observe all the intermediate steps leading to a purely doleritic texture in which quartz forms interstitial grains. The plagioclase laths included in the quartz oikocrysts are subhedral with more or less irregular to finely cuspate edges (Fig. 12), like their counterparts contained within the pyroxene oikocrysts of ophitic dolerites. When they are only partly included, they sometimes are wedge-shaped with the point enclosed in the quartz. In the common situation where ocelli are present, poikilitic quartz preferentially develops around them, just as in ocelli-bearing basalts (see Figs 8 + 9, as well as Fig. 11 for comparison).

3.2. ORIGIN OF THE OPHITIC QUARTZ TEXTURE

3.2.1. Constraints on genetic models

In the M. Capanne situation, any genetic interpretation must take into account the following observations and deductions. The development of the ophitic quartz texture is: (1) specifically related to microgranular enclaves; (2) strictly limited to enclaves with subhedral laths of plagioclase; (3) a function of the chemical composition of the enclave; (4) preferential around quartz ocelli. On the other hand, it is independent: (5) of the shape and size of the enclave; (6) of its porphyrocryst content and of the nature of the latter; (7) of the position of the enclave in the granitic massif (enclaves with ophitic quartz texture may even lie near to enclaves with different texture); (8) of the quartz content of the matrix of

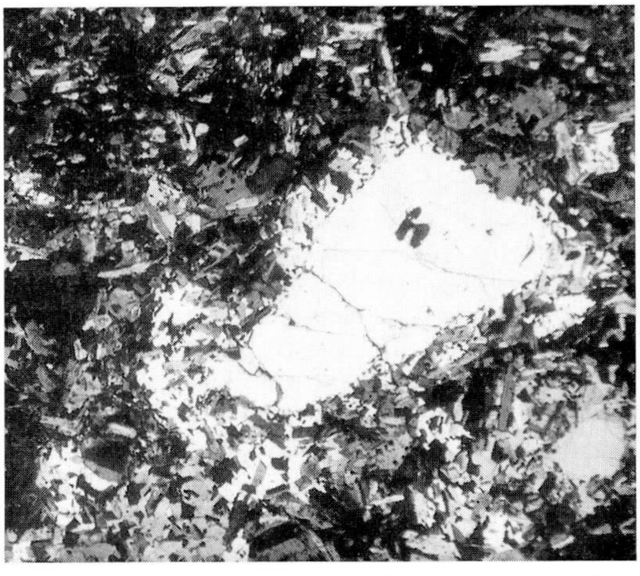

Fig. 8 Development of poikilitic quartz around a quartz ocellus in an enclave from the M. Capanne granite. Dimension of the quartz ocellus: ca 5 mm. Crossed polars.

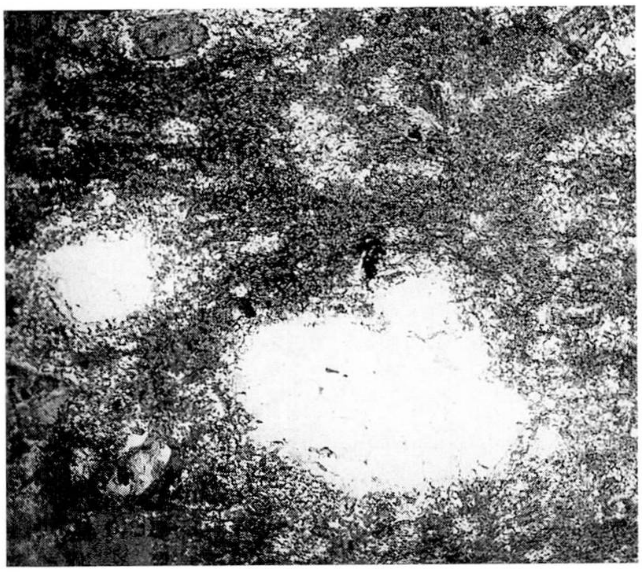

Fig. 9 Quartz ocellus in enclave from the Mont-Blanc granite. Note the development of poikilitic quartz within the matrix, in optical continuity with the central quartz grain. Diameter: ca 4 mm. Crossed polars.

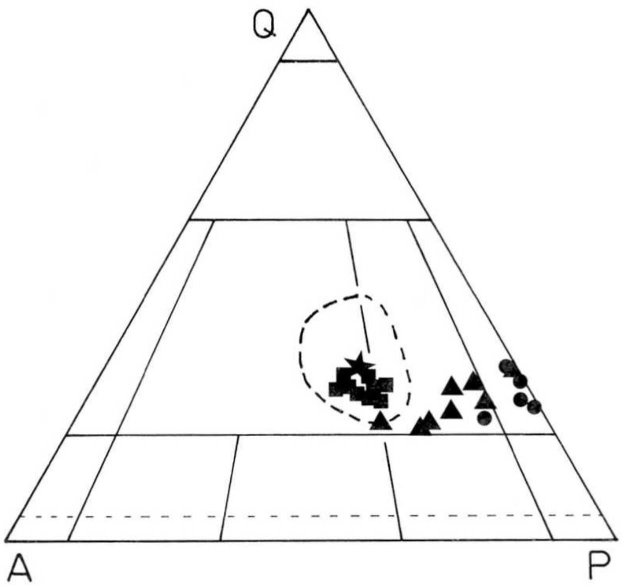

Fig. 10 Modal analyses of the M. Capanne granite and its microgranular enclaves in the QAP Streckeisen diagram (1974). Symbols: microgranular enclaves with doleritic (= circles), microgranular (= squares), and ophitic quartz (= triangles) texture; star and area limited by broken line = average and granite field according to Waldeck (1977).

the enclave up to a point (< 25%); there is often less quartz in the ophitic enclaves than in enclaves with doleritic texture. (9) Where quartz oikocrysts are in a domain of the matrix with fluidal texture, the surrounding crystals are deflected (Fig. 13) while the included crystals are unoriented. (10) Where plagioclase and biotite show a general equant development in the matrix, they are *not* deflected near the contacts with quartz oikocrysts. (11) Very fine and fragile apatite needles straddle the contacts between poikilitic quartz and its plagioclase inclusions or between poikilitic quartz and any crystal of the surrounding matrix, without being broken.

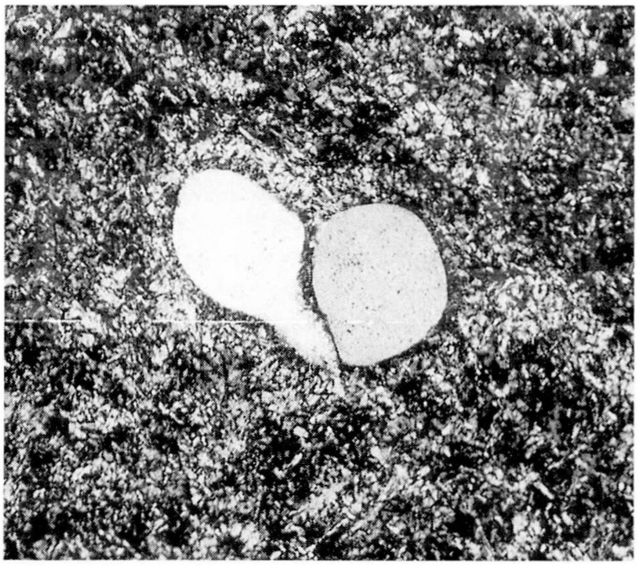

Fig. 11 Quartz phenocryst in a microgranite from the Aiguilles Rouges massif, Evionnaz, Valais (Switzerland). The rounded form is considered to be due to magmatic resorption, as euhedral shapes exist (inclusions within feldspar phenocrysts). This may be due either to pressure decrease or temperature increase (or a combination of both). The released silica forms a fuzzy rim around the phenocryst, and in optical continuity with the latter. The same feature is seen around certain rimless quartz ocelli (see Figs 9 + 10). There too, any available liquid silica crystallizes on the surface of the quartz grain. Diameter of phenocryst: 1 mm. Crossed polars.

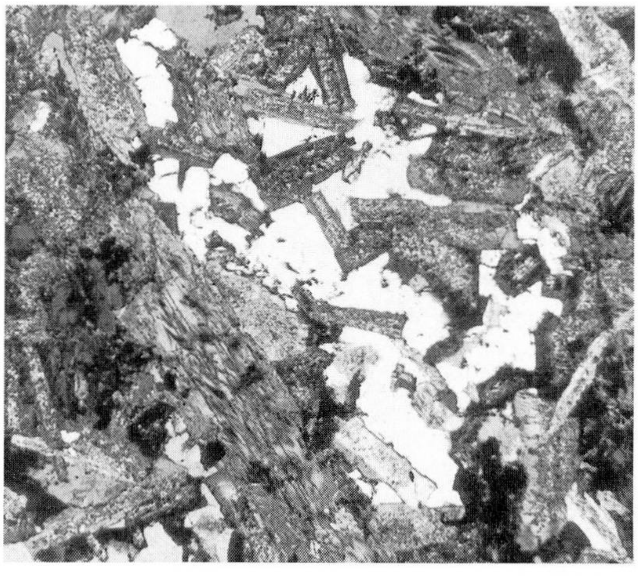

Fig. 12 Interstitial quartz in Neuntelstein tonalite (Vosges). Note the cuspate feldspar/quartz contact, possibly due to cotectic crystallization. Field of view: ca 5 mm. Crossed polars.

Fig. 13 Texture of microgranular enclave from the M. Capanne granite (Elba Island, Italy). The matrix has a fluidal texture deflected by a quartz oikocryst. Crossed polars. Diameter of quartz oikocryst: 2 mm. Crossed polars.

Taken as a whole, these observations are incompatible with a metasomatic origin of the quartz oikocrysts through blastic growth in a solid medium. Apart from the difficulty in visualizing what material the quartz might have replaced, as its inclusions are subhedral and without trace of corrosion, this hypothesis is incapable of explaining observations (2), (3) and (9). Moreover, there is no reason why quartz forming metasomatically in a regular plagioclase network should contain inclusions clearly more spaced out than the surrounding laths, as is often observed. Against a "force of crystallization" separating the plagioclase crystals, one can oppose observations (10) and especially (11), which indicates that the oikocrysts exerted no constraint on their inclusions during their growth.

An origin through secondary coalescence of independent, interstitial quartz grains catalysed by the circulation of fluids emanating from the granite encounters the same objections (2), (3) and (9). Also, it would necessitate abnormal local concentrations of primary quartz grains – which have never been observed – corresponding to the inclusion-poor poikilocrysts; finally, no outline defined by minute impurities is visible in the oikocrysts.

Consequently, only crystallization in a magmatic environment (s. l.) can be considered. Observation (9) is critical in this respect; it demonstrates that the quartz oikocrysts are earlier than the development of the fluidal texture, formed while the enclave was still liquid, or at least plastic.

3.2.2. Origin in the magmatic context

The poikilitic development of crystals in the magmatic context, in particular in intercumulate disposition, is conceivably the result, according to WAGER et al. (1960), of the coalescence in situ and growth of a multitude of nuclei dispersed in the interstitial liquid. In reality, it is probable that a high rate of nucleation will produce, for quartz, a large number of small independent grains (SWANSON, 1977), and that the small number of oikocrysts is due to a very low rate of nucleation with a high growth rate (SWANSON, op. cit.).

These particular conditions may be fulfilled in the case of microgranular enclaves, during formation through dispersion of a relatively mafic, hot hybrid liquid with few suspended crystals, in a colder granitic mass. Indeed, these mafic blobs are submitted to a rapid decrease in temperature with undercooling, leading to a high rate of nucleation of plagioclase and biotite. A large number of small crystals will grow simultaneously in the whole mass of the enclave, which will soon reach the temperature of the host granitic melt. In certain favourable circumstances, this *equilibrium temperature* of the system will be very near that at which quartz precipitates in these enclaves. Consequently, quartz will not be affected by undercooling in the latter, and will nucleate at a slow rate. If, moreover, quartz ocelli or small grains of quartz have been introduced mechanically, through mixing with the granitic magma, they may act as nuclei for the rapid growth of quartz, as soon as its crystallization temperature is reached, but this growth will be irregular and poikilitic as the enclave is already filled with numerous crystals of plagioclase and biotite. The irregular contact of the plagioclase crystals within the quartz oikocrysts and the wedge-shaped form of some of them are interpreted as the result of cotectic quartz-plagioclase crystallization, which will continue to the solidus of the enclave, around 700 °C according to BUSCH and OTTO (1980).

Figure 14a illustrates the case of a magma of granodioritic composition with 3 weight-% H_2O at 2 kb, similar to that of the enclaves with ophitic texture in the M. Capanne granite. Clearly, if the temperature of the granitic component – which is the equilibrium temperature of the system – was about 700° to 720 °C at time of mingling (independently estimated), quartz was hardly affected by the undercooling of the magma of the enclaves.

The specific conditions leading to the development of ophitic quartz texture depend on the combination of several factors, namely initial composition, temperature, pressure and fluid content of the two coexisting magmas. At M. Capanne, the absence of poikilitic quartz in the tonalitic enclaves with doleritic texture and granitic enclaves with microgranular texture is mainly related to the chemistry of these rocks. According to WHITNEY (1975), the temperature at which quartz appears in a tonalitic liquid at 2 kb and 3–4% H_2O is above 800 °C (Fig. 14b) (at these water contents, the temperature of crystallization of quartz is virtually independent of the presence or the absence of biotite, which allows use of the diagram in Fig. 14b, as a reasonable approximation). The enclaves will be rapidly equilibrated at about 720 °C, which means that strong undercooling and a high rate of nucleation will lead to numerous small interstitial grains. At the other end of the spectrum, the enclaves of granitic composition crystallize rapidly with formation of the classic microgranular texture of hypabyssal acid rocks. In other words, there is a "compositional window" in which the ophitic quartz texture may develop.

The proposed model takes all the mentioned constraints into account and very specifically the relationship between this texture and the enclaves. We consider that it may be extended to enclaves from other granitic massifs in which the texture appears on fulfillment of the condition that the equilibrium temperature between granite and enclaves is near that of the precipitation of quartz in the magma of the enclaves.

In certain microgranular enclaves of the M. Capanne and Mont-Blanc granites, sphene and occasionally ilmenite exhibit a poikilitic development similar to that of quartz, but on a smaller scale. It is possible that conditions of crystallization similar to those in which the ophitic quartz appears existed for these minerals, as well as for the poikilitic alkali feldspar described at the beginning of this section.

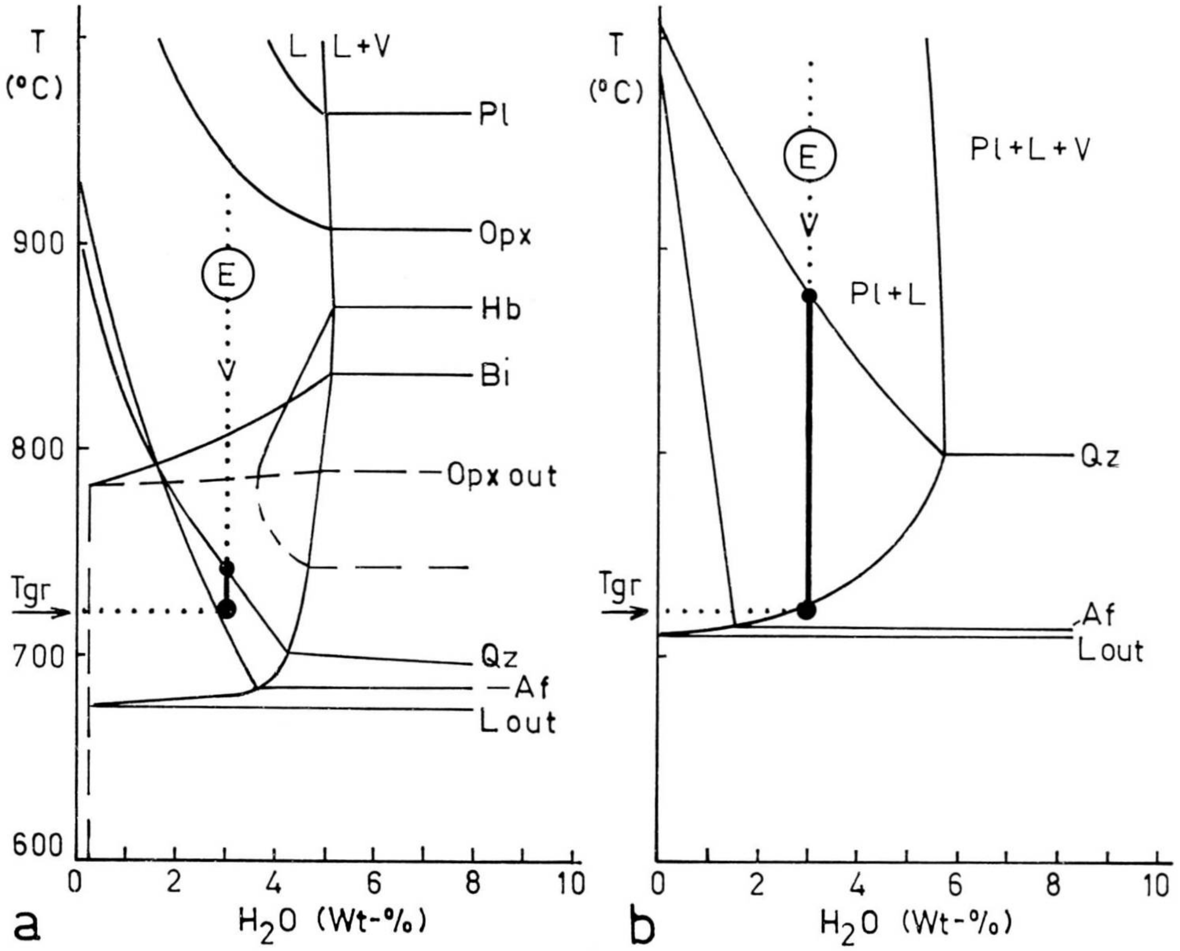

Fig. 14 Phase diagrams. a) temperature (T) versus H_2O in weight % at 2 kb for a synthetic granodiorite, according to NANEY (1983); b) same as a) for an iron – and magnesium – free synthetic tonalite, according to WHITNEY (1975). The thick vertical line indicates the amount of undercooling (ΔT) for quartz in enclave magma (E) containing 3 weight % H_2O at time of rapid crystallization in contact with a granitic magma at temperature Tgr. Symbols: L = liquid, V = vapor, Opx = orthopyroxene, Hb = hornblende, Bi = biotite, Qz = quartz, Af = alkali feldspar.

4. Quartz textures at granite-enclave contacts

A third kind of texture involving quartz in intermediate compositions, although akin to the ophitic type, may indicate yet another mechanism in a situation of hybridization. Specifically, the contact between a granitoid and its microgranular enclaves often exhibits an area of interstitial ophitic quartz in the latter, in optical continuity with a quartz grain within the granitoid. The impression is that of a liquid (feldspar shows the same relationship) partly crystallizing in the granitic domain, and partly within the enclave. The entire field occupied by quartz in optical continuity has much the same dimension and form as the quartz grains, moreover often subhedral, in the granitoid (Fig. 15).

A possible explanation may be that liquid from the granitic system has been able to penetrate the enclave undergoing (rapid) crystallization. The volume of the mafic blob must be reduced, in the course of solidification, by some

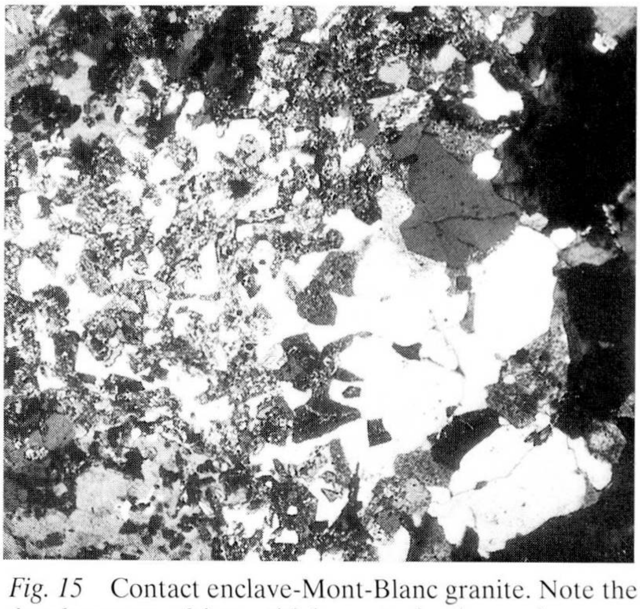

Fig. 15 Contact enclave-Mont-Blanc granite. Note the development of interstitial quartz in the enclave matrix, in optical continuity with quartz in the granite. Feldspar areas are also shared by enclave and host granite. Field of view: ca 8 mm. Crossed polars.

10%, and the enclave must therefore become spongy or porous. Liquid from the host granitic system would penetrate, and indeed would probably be sucked into the lower-pressure enclave system. Such a process of filtration has been discussed in some detail by PETERSEN (1987) who has drawn attention to the mechanism of "solidification contraction", and to its potential importance in magmatic differentiation.

5. Conclusions

Quartz ocelli and ophitic quartz in tonalites, microgranular enclaves, lamprophyres and appinites and even in quartz basalts, are different expressions of mixing mechanisms involving basic and acid crystallizing systems. The quartz ocelli are shown to be xenocrysts introduced mechanically into the more basic environment from the acid system. The remarkable development of quartz oikocrysts, very much like the ophitic pyroxenes of dolerites, is apparently related to a specific composition which may be attained through hybridization (not excluding other possible mechanisms). In this compositional "window", quartz has a much lower rate of nucleation relative to the other mineral species, and therefore forms large, often subhedral domains enclosing feldspar laths and ferromagnesian crystals. In these circumstances, quartz may grow on whatever ocelli happen to be present. Some of the interstitial quartz, however, especially in the rim-zone of the ocelli, may be derived from the ocelli themselves, whose outline clearly attests marginal fusion/corrosion.

Acknowledgements

We express our thanks to the Fondation Herbette and to the Fondation du 450e Anniversaire (Université de Lausanne) who kindly financed the organization of the symposium on diorites held in Lausanne, September 22–23, 1989. We also thank Dr H. Emeleus (Durham University) for his comments on "ophitic" quartz, and for some thin sections of rocks from the British Tertiary Province, and Dr K. Ramseyer (University of Bern) for the cathodoluminescence analysis of ocelli, and useful comments.

References

BARBARIN, B. (1988): Field evidence for successive mixing and mingling between the Piolard diorite and the Saint-Julien-La-Vêtre monzogranite (Nord-Forez, Massif Central, France). Canad. J. Earth Sci. 25, 49–59.

BARRIÈRE, M. (1977): Le complexe de Ploumanac'h, massif armoricain. Thèse de doctorat, Université de Brest, 291 p.

BUSCH, W. and OTTO, J. (1980): Endogenic inclusions in granites of the Black Forest, Germany. N. Jb. Miner. Mh., 6, 269–282.

BUSSY, F. (1989a): Pétrogenèse des enclaves microgrenues associées aux granitoïdes calco-alcalins: exemple des massifs varisques du Mont-Blanc (Alpes occidentales) et miocène du Monte Capanne (Ile d'Elbe, Italie). Thèse de doctorat, Université de Lausanne, 309 p.

BUSSY, F. (1989b): The origin through resorption of patchy-zoned plagioclases in a plutonic mixing environment: the case of the Monte Capanne granite (Elba Island, Italy). Abstr. EUG V, Strasbourg, France.

CLOCCHIATTI, R. (1975): Les inclusions vitreuses des cristaux de quartz, étude optique, thermo-optique et chimique, applications géologiques. Mém. Soc. geol. France, LIV/122, 1–96.

DIDIER, J. (1964): Etude pétrographique des enclaves de quelques granites du Massif Central français. Ann. Fac. Sci. Clermont-Ferrand 23, 254 p.

EMELEUS, C.H. (1970): Acid inclusions in the porphyritic granophyre ring dyke, Slieve Gullion, Co. Armagh. Irish nat. J. 16/11, 322–325.

FROST, T.P. and MAHOOD, G.A. (1987): Field, chemical and physical constraints on mafic-felsic magma interactions in the Lamarch granodiorite, Sierra Nevada, California. Bull. geol. Soc. Amer. 99, 272–291.

HATCH, F.H., WELLS, A.K. and WELLS, M.K. (1952): The petrology of igneous rocks. Thomas Murby and Co, London, 469 p.

HUANG, W.L. and WYLLIE, P.J. (1986): Phase relationships of gabbro-tonalite-granite-water at 15 kbar with applications to differenciation and anatexis. Amer. Mineralogist 71, 301–316.

HIBBARD, M.J. (1981): The magma mixing origin of mantled feldspars. Contrib. Mineral. Petrol. 76, 158–170.

MCGREGOR, M. (1965): Excursion guide to the geology of Arran. Geol. Soc. Glasgow, 192 p.

NANEY, M.T. (1983): Phase equilibria of rock-forming ferromagnesian silicates in granitic systems. Amer. J. Sci. 283, 993–1033.

NICHOLLS, J., CARMICHAEL, I.S.E. and STORMER, J.C. (1971): Silica activity and P_{total} in igneous rocks. Contrib. Mineral. Petrol. 33, 1–20.

NOCKOLDS, S.R. (1939): Some theoretical aspects of contamination in acid magmas. J. Geol. 41, 561–589.

OTTO, J. (1974): Die Einschlüsse im Granit von Oberkirch (Nordschwarzwald). Ber. Naturf. Ges. Freiburg/Br. 64, 83–174.

PABST, A. (1928): Observations on inclusions in the granitic rocks of the Sierra Nevada. Bull. Dep. geol. Sci. Univ. California 17/10, 137–155.

PETERSON, J.S. (1987): Solidification contraction: another approach to cumulus processes and the origin of igneous layering. In: I. Parsons (ed), "Origin of igneous layering" (NATO-ASW). D. Reidel Publishing Co, 505–526.

REID, J.B., Jr., EVANS, O.C. and FATES, D.G., (1983): Magma mixing in granitic rocks of the central Sierra Nevada, California. Earth and Planetary Sci. Lett., 66, 243–261.

ROSENBUSCH, H. (1887): Mikroskopische Physiographie der Mineralien und Gesteine. II. Massige Gesteine. Stuttgart, 877 p.

SATO, H. (1975): Diffusion coronas around quartz xenocrysts in andesite and basalt from Tertiary volcanic region in NE Shikoku, Japan. Contrib. Mineral. Petrol. 50, 49–64.

SWANSON, S.E. (1977): Relation of nucleation and crystal-growth rate to the development of granitic textures. Amer. Mineralogist 62, 966–978.

TIDMARSH, W.G. (1932): The Permian lavas of Devon. Quat. Jour. Geol. Soc., 88, 712–773.

VERNON, R.H. (1983): Restite, xenoliths and microgranitoid enclaves in granites. J. Proc. roy. Soc. New South Wales 116, 77–103.

VERNON, R.H. (1986): K-feldspar megacrysts in granites – phenocrysts not porphyroblasts. Earth Sci. Rev. 23: 1–63.

WAGER, L.R., BROWN, G.M. and WADSWORTH, N.J. (1960): Types of igneous cumulates. J. Petrol. 1: 73–85.

WALDECK, H. (1977): Die Insel Elba – Mineralogie, Geologie, Geographie, Kulturgeschichte. Sammlung Geologischer Führer, 64, Gebrüder Bornt.

WATSON, E.B. (1982): Basalt contamination by continental crust: some experiments and models. Contrib. Mineral. Petrol. 80: 73–87.

WHITNEY, J.A. (1975): The effects of pressure, temperature and XH_2O on phase assemblage in four synthetic rock compositions. J. Geol. 83, 1–31.

ZORPI, M.J., COULON, C., ORSINI, J.B. and COCIRTA, C. (1989): Magma mingling, zoning and emplacement in calc-alkaline granitoid plutons. Tectonophysics 157, 315–329.

Manuscript received January 30, 1990; revised manuscript accepted May 3, 1990.