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Fluids in granitic environment

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ABSTRACT. — Fluids play an essential role for mass and heat transfer in granitic bodies, and their surroundings, at any time after their emplacement. Recent combined stable isotope and fluid inclusion studies have largely improved the knowledge on the characteristics of such fluids, and on the processes controlling the fluid production and circulation. Thus, different fluids can be identified, and roughly described as follows: 1) magmatic water, unmixed from the late stage melt; 2) early (metamorphic) fluids, generated in the surrounding rocks during the early stage of the granite emplacement; 3) late external fluids (of any origin but mainly of meteoric derivation), circulating as a consequence of either pluton cooling, or any reheating (HHP granites, new magmatic intrusion,...).

The long-lived and multistaged fluid circulation in cooled granites has usually overprinted the earliest fluids. This late hydrothermal activity caused also a significant disturbance of the mineralogical and geochemical features of the granite, and is responsible for a great part of the element (especially those of metallogenic interest) transfers.

Key words: fluids, hydrothermal activity, fluid inclusion, subsolidus alteration, granite.

RÉSUMÉ. — Les phases fluides jouent un role essentiel dans les tranferts de masse et de chaleur dans les granites, et leur environnement, dans l'ensemble des stades suivant leur intrusion. Les récents travaux en géochimie des isotopes stables et les études des inclusions fluides ont largement amélioré la connaissance des caractéristiques de ces fluides et des mécanismes contrôlant leur production et leur circulation. Différents types de fluides ont ainsi été identifiés, et peuvent brièvement être décrits ainsi: 1) les eaux magmatiques expulsées par le magma 2) les fluides précoces (d'origine métamorphique) produits dans les séries encaissantes lors de l'intrusion 3) les fluides tardifs, externes aux granites (d'origines diverses mais le plus souvent météoriques) qui ont circulé à la faveur de flux anormaux de chaleur d'origine diverse.

Le caractère polyphasé et de longue durée de ces circulations de fluides après le refroidissement du granite explique les difficultés d'observation des témoins des circulations précoces qui sont largement occultés par les effets de ces circulations tardives. Celles-ci causent de plus des perturbations significatives des caractéristiques minéralogiques et géochimiques des granites, et sont responsables d'une grande part des transferts d'éléments (et notamment ceux d'intérêt métallogénique).

Mots clés: fluides, activité hydrothermale, inclusion fluide, alteration subsolidus, granite.

Introduction

The spatial relationships between various kinds of mineralization and granites have been known for a long time. This feature has focused interest onto the source, the nature and the behaviour of the fluids associated with granitic intrusions. More recently, combined

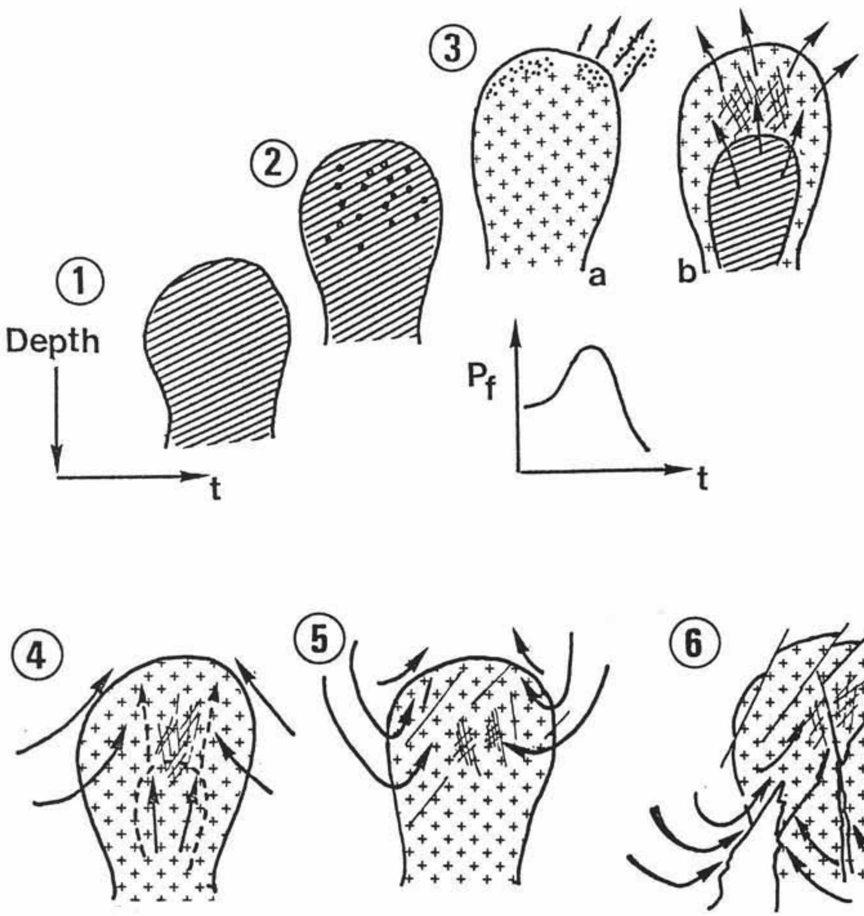

Fig. 1. — Schematic representation of the main stage of fluid production or circulation within or around a granite pluton. 1) magma intrusion; 2) unmixing of a fluid phase from the magma; 3) a- crystallization of silicate phases from the unmixed fluid; b- hydraulic fracturing of the crystallized zones of the pluton; 4) early interaction between granitic rocks or magma with external fluids; 5) convective fluid circulation created by the thermal anomaly due to the pluton emplacement; 6) late hydrothermal activity related to «external» heat sources.

stable isotope and fluid inclusion studies have greatly improved the knowledge of fluid production and circulation within granites and their surrounding rocks. In an increasing number of case, it is possible to determine the source of the fluids and their P-V-T-X characteristics all over the granite history.

Fluid generation in shallow granitic intrusions and subsequent fluid-granite interactions are summarized in Figure 1 (1). As extensively discussed by BURNHAM (1967, 1979) and BURNHAM and OHMOTO (1980), the crystallization of anhydrous minerals from an initially water-undersaturated magma finally results in water saturation of the residual silicate melt. Then, an aqueous phase, which may still coexist with the melt and the crystals, unmixes from the magma (second, or retrograde, boiling). This aqueous phase may leave the granite, yielding or not crystallization of silicate phases in the surroundings (hydrothermal pegmatites) (Fig. 1[3a]). However, if the roof is impervious, an overpressure builds up, until opening of preexisting joints (such as cooling joints) or even hydraulic fracturing (PHILLIPS 1973; BURNHAM 1979) (Fig. 1[3b]). Both cases are common, but the latter one is of major interest in ore deposition in granitic environments (Sn, W, Mo, Cu). Soon after its separation from the granitic magma, the aqueous phase may unmix into a brine and a vapor, and may react with the solid granite, especially in the cases of the hydraulic fracturing mentioned above.

As early as this stage, external fluids may enter the system and interact with magmatic fluids and solid granite (TAYLOR, 1977; 1978) Fig. 1(4): deep fluids of metamorphic origin, derived from the thermal aureole of the granitic intrusion, and later fluids of more external derivation (i.e. meteoric fluids). A full convective cycle is thus created (Fig. 1(5)).

After the main pluton has cooled down, with a resulting weakening of the related hydrothermal circulation, further fluid-granite interaction may be kept up by a renewal of magmatic activity, or even by the heat production produced by the radioactive decay in the granite (HHP granites, FEHN et al., 1978; FEHN, 1985) (Fig. 1(6)).

In this paper, we intend to exemplify some of these different stages of fluid-rock interaction in high-level intrusions of granitic parentage. The relationships between magmatic generation and the hydrothermal stages, as well as the consequences of fluid circulation on the granite mineralogy and geochemistry will be emphasized. We will largely rely upon the studies made by the E.N.S.G., C.R.P.G. and CREGU teams at Nancy.

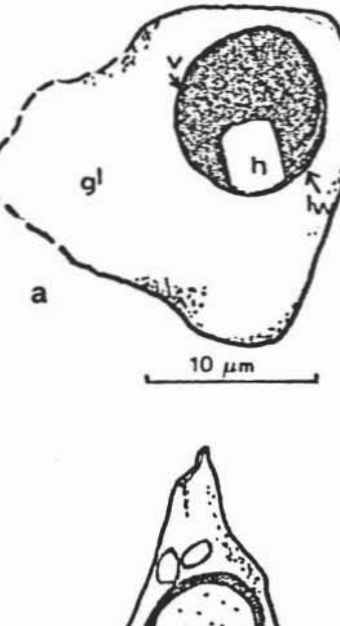

Fig. 2. — a) Inclusion in quartz exhibiting four phases: glass (gl), a halite cube (h), a vapor (v) and a liquid phase (lw); these phases resulted from the trapping of an hydrous silicate melt coexisting with immiscible globules of a highly saline aqueous fluid (figure drawn from a photograph in ROEDDER and COOMBS, 1969); b) Inclusions from the Volynia pegmatites, with a liquid, a vapor phase and numerous crystals (partly silicates).

Main stages of fluid production and circulation in granitic environments

1. Magmatic stage

a. Direct observation of fluid-magma unmixing is possible, in glassy inclusions resulting from melt entrapment at the time of crystallization of magmatic minerals (CLOCCHIATTI, 1975; SOBOLEV and KOSTYUK, 1975; ROEDDER, 1979). However, such evidence is rare in granitic rocks, for the following reasons:

- small size of the inclusions, which makes difficult their observation;
- frequent melt recrystallization inside the inclusions, when microcracks are sufficiently abundant to allow fluids to circulate within the host crystals;
- lack of good trap for melts such as olivine or pyroxene crystals which do not recrystallize as easily as quartz does.

However, ROEDDER and COOMBS (1967) were able to observe melt-related fluids in the subvolcanic granites from Ascension Island. They describe three main types of inclusions in quartz and feldspars: glass + vapour, liquid + vapour + halite, and CO_2-rich inclusions. Some inclusions, as shown in figure 2a, result from the heterogeneous entrapment of a melt and an immiscible globule of highly saline aqueous solution which nucleated a halite cube during cooling. The occurrence, in the same crystals, of both melt inclusions, brine inclusions, and intermediate compositions between these two extremes, is a strong argument for the unmixing of a brine from a H_2O-alkali chloride saturated silicate melt.

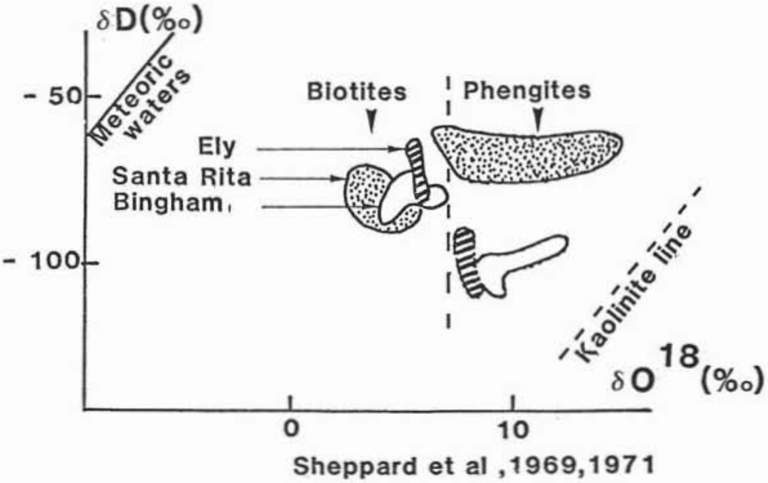

Fig. 3. — δD-δ^{18}O diagram applied to biotites and phengites from different Cu-porphyry copper deposits (Ely, Santa Rita, Bingham) modified from SHEPPARD et al., 1969, 1971.

Similarly, NAUMOV et al., (1977), and ZAKHARCHENKO (1971, 1976) described recrystallized melt and brine inclusions in quartz from the Volynia pegmatites. Figure 2b shows an example of such an inclusion, with a liquid, a vapor bubble and numerous crystals of various salts and silicates. In this case, it has been suggested that the observed inclusions record a continuous transition from the magmatic stage to the hydrothermal one. This interpretation has been criticized (WEISBROD, 1981). Moreover, experimental data on hydrous melts (TUTTLE and BOWEN, 1958; BURNHAM, 1979) do not support this continuous transition model, as immiscibility gaps are systematically present in such systems.

b. Most generally, direct observation of the fluid-melt separation is very rare. Yet, the unmixed fluids may be observed and studied, especially in highly differenciated cupolas, which generate fluids strongly enriched in volatiles (F, B, Li,...). Some examples are presented below.

(i). Quartz-tourmaline rocks which occur as cupolas or pipes within the granitic apices of Cornwall (HALLS et al., 1977; CHAROY, 1979), or as subvolcanic breccias associated with the quartz-latite stocks of bolivian tin porphyries (GRANT et al., 1977). As demonstrated by fluid-inclusion studies, these rocks result from the crystallization of very highly saline B-rich fluids at temperatures in the range 600°-700°C, i.e. to magmatic temperatures; these fluids are therefore interpreted as unmixed from a B-rich granitic magma. Further evidence for this interpretation is given: 1) by the close association of quartz-tourmaline rocks with tourmaline-bearing granites, as in Cornwall (CHAROY, 1979); 2) by the light stable isotope data for the Bolivian occurrences, which are in favor of a magmatic origin for the B-rich fluids (GRANT et al., 1980).

(ii). Early brines and vapors observed in fluid inclusions from the Cu- and Mo-porphyries. These are mostly aqueous, with very high K/Na ratios, and record very high trapping temperatures, in the range 550°-800°C (ROEDDER, 1971; MOORE and NASH, 1974; CHIVAS and WILKINS, 1977; ETMINAN, 1977; EASTOE, 1978; RAMBOZ, 1979; DENIS et al., 1980; REYNOLDS and

BEANE, 1985; see also LAGACHE and WEISBROD, 1977). They are usually interpreted as magmatic fluids.

These fluids are responsible for early hydrothermal alteration (potassic alteration). This alteration develops along microcracks and joints channelizing the K-rich brines. It is not rare, in Cu-porphyries, to observe late magmatic veins crosscutting early potassic joints, which are in turn crosscut by a new generation of joint-controlled alteration of the same kind (KIRKHAM, 1971). These geometrical relationships demonstrate the close temporal relationships between magmatic activity and circulation of the early brines. Stable isotope data for hydrothermal biotites produced by potassic alteration indicate indeed a magmatic origin for the related fluid (SHEPPARD et al., 1971) (Fig. 3).

In the porphyry environment, fluid pressure commonly exceeded the pressure necessary for the rocks to fracture, resulting in the all-over hydraulic brecciation so typical of Cu- an Mo-porphyries. As a consequence of the pressure drop, the magmatic saline fluid unmixed in turn into a very highly saline brine and a low salinity-low density vapor, as clearly indicated from fluid inclusion studies in porphyries (ROEDDER, 1971; MOORE and NASH, 1974; CHIVAS and WILKINS, 1977; ETMINAN, 1977; EASTOE, 1978; RAMBOZ, 1979; DENIS et al., 1980; REYNOLDS and BEANE, 1985). These brines are often metal-enriched, as shown for instance by RAMBOZ (1979) in the South Tintic Cu-porphyry, in which the K-rich aqueous fluids transported an average of 2000 ppm Cu (Fig. 4).

(iii). A very similar situation is encountered at Echassières (French Massif Central), in a Li-F-albite late hercynian granite. Fluid inclusions in magmatic topaz (AÏSSA et al., 1987), record generation and circulation of early fluids. The earliest fluid is a brine (≈ 25 wt% eq. NaCl) with a high content in lithium chloride, as indicated by the extremely low eutectic temperature (around —70°C). It is trapped at temperatures of 560°-600°C, which match the solidus temperature of 570°C experimentally determined by PICHAVANT et al. (1987) for the Li-F-albite granite. It can thus safely be deduced that this early saline fluid is the result of an unmixing process from an H_2O-F-Li rich melt. From detailed studies (AÏSSA et al., 1987), pressure evolution can be reconstructed: unmixing of the early brine from the residual melt yields an increase of pressure above the lithostatic value, followed by a rapid pressure drop from lithostatic to hydrostatic values. This induced the boiling of the early brine yielding more and more saline brines, together with less and less saline vapours (Fig. 5). The similarity with

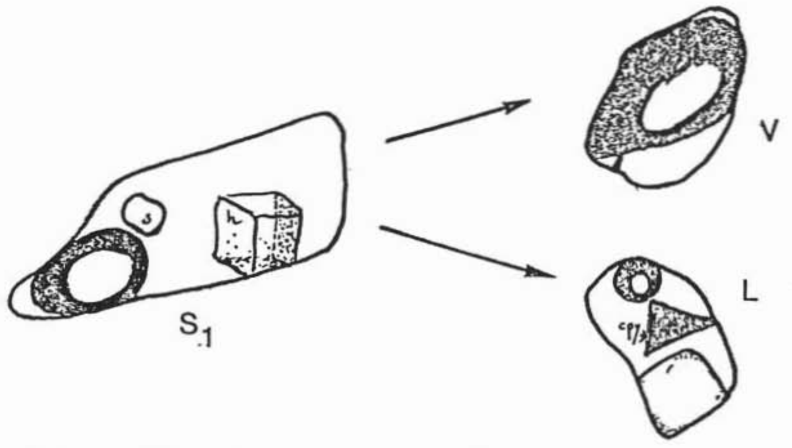

Fig. 4. — Schematic features of fluid inclusions representative of the main fluids encountered in porphyry copper deposits: S1, the early brine (with sylvite and halite as daughter minerals), and L and V, respectively the liquid (with a tetrahedral crystal of chalcopyrite) and the vapor issued from the boiling of S1. (Figure drawn from WEISBROD, 1981).

the porphyry environment is obvious, except for hydraulic fracturing, which apparently has not occurred (or to a very limited extent) in the Li-F-albite granite of Echassières.

b. *Every time* a magmatic fluid can be observed, it is followed in apparent continuity by circulation of less saline fluids with lower trapping temperatures, correlated with a change in the characteristics of hydrothermal alteration.

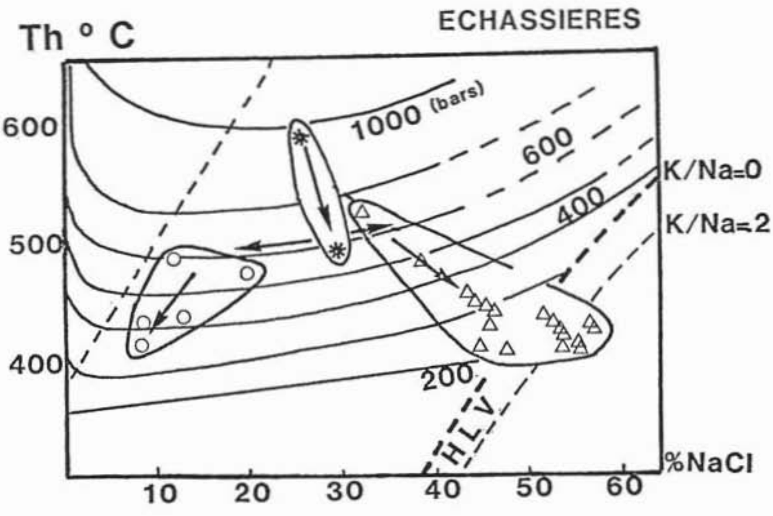

Fig. 5. — Th (homogenization temperature)-salinity (in eq. weight % NaCl) diagram applied to the microthermometric results obtained in fluid inclusions from the Echassière topazes. Arrays give schematic evolution trends of the fluid composition during the unmixing of a vapor and a liquid phase from the early brine.

2. Early interactions with external fluids

a. *It is not uncommon* to observe early interaction between granitic magma and an external fluid:

— in the porphyry environment, such as at Bingham or Santa Rita, light stable isotope studies (SHEPPARD et al., 1971; SHEPPARD and TAYLOR, 1974) show that magmatic fluids can be contaminated by external waters heated in the vicinity of the intrusions, as early as the potassic alteration stage;

— at Echassières, FOUILLAC et al. (1987) observed a decrease of the $\delta^{18}O$ values of the Li-F granite minerals (quartz, micas, feldspars) which can be explained to result from an interaction between the Li-F-albite magma and an external (meteoric) fluid.

— in the Rössing alaskite (Namibia) uraninite crystallization is caused by the influx of reducing fluids into the magma from the metamorphic surroundings (CUNEY, 1980).

— in the porphyry case, interaction with external fluids usually becomes a predominant process as the temperature is lowered, for instance at the stage of «sericitic alteration». At this stage, aqueous Na-dominated fluids with less than 12% wt eq. NaCl circulate at temperatures of 400°C and less (ROEDDER, 1971; MOORE and NASH, 1974; CHIVAS and WILKINS, 1977; ETMINAN, 1978; EASTOE, 1978; RAMBOZ, 1979; DENIS et al., 1980; REYNOLDS and BEANE, 1985). These fluids are of meteoric origin, as indicated from stable isotope studies of the associated phengites (SHEPPARD et al., 1971) (Fig. 3);

— at Echassières, fluid inclusions also record a change in the nature and composition of circulating fluids in the 350°-420°C temperature range (AÏSSA et al., 1987; FOUILLAC et al., 1987).

b. *In many cases*, early magmatic fluids cannot be observed (for instance, because of subsequent overprinting by external fluids - RANKIN and ALDERTON, 1985), and the earliest fluids encountered within the granitic body and in its close vicinity are of external derivation. This is clearly demonstrated in granitic cupolas intruded into low-grade clastic sedimentary piles with black shales, such as those associated with many Sn-W deposits. Medium to high grade thermal metamorphism of such piles gives rise to fluids belonging to the C-O-H-N-(S) system (H_2O, CO_2, CH_4 N_2). These fluids result either from the degassing of organic matter, or from C-N loss from rock forming minerals (reaction with graphite, release of NH^{4+} from micas or feldspars, etc.), often under non equilibrium conditions (DUBESSY, 1985; DUBESSY and RAMBOZ, 1986; BASTOUL, 1983; BOUTALEB et al., 1986; WEISBROD, 1986). Such fluids are frequently observed in the granite or its surroundings, where they have been trapped as fluid inclusions at temperatures in the range 400°-600°C (RAMBOZ et al., 1985; WEISBROD, 1986).

At lower temperatures, however, the predominance of (nearly) purely aqueous solutions of low to moderate salinities (RANKIN and ALDERTON, 1985) and stable isotope data (TURPIN, 1984) give evidences for the influx of meteoric fluids. In some cases, the meteoric fluids are the only ones to be observed, as, for instance, in the Hercynian granites of the Southern Black Forest (SIMON and HOEFS, 1987) and in Cornwall (CHAROY, 1979; JACKSON et al., 1982).

3. Late fluid circulations

After cooling, granites may undergo again large fluid circulations, provided that there is a heat source able to drive a new convective system. There is a great variety of such situation: lamprophyric basic magmatism at 290 Ma in the 325 Ma leucogranites of Limousin (French Massif Central) (LEROY, 1978); alpine thrust piling onto the Hercynian Mont Blanc granite, in the Alps (POTY, 1969; POTY et al., 1974); radioactive decay in the granites themselves, periodically triggering rather low-temperature convective circulations in their vicinity (HHP granites, as for instance those of the Cornubian batholith, FEHN, 1985; DURRANCE, 1985). Fluid inclusions related to these late stages of circulation are often well represented, as is the case of the Cornubian batholith (CHAROY, 1979; RANKIN and ALDERTON, 1985, SHEPHERD et al., 1985).

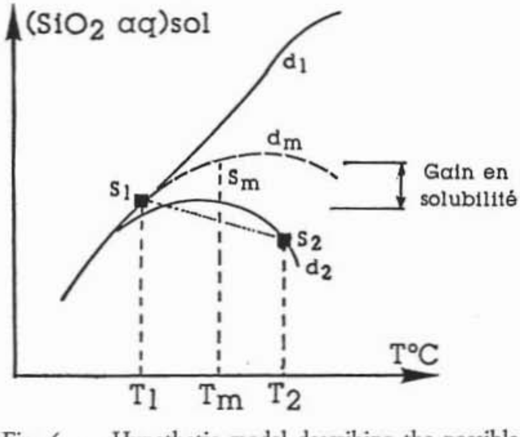

Fig. 6. — Hypothetic model describing the possible increase of the quartz solubility consecutive to the mixing of two aqueous solutions having the same composition but different densities (d1, d2) and temperatures (T1, T2). At the mixing temperature (Tm), the quartz solubility (Sm) at the mixing temperature for a fluid having an intermediate density (dm) is higher than the quartz solubility in the two initial fluids, thus yielding to the quartz dissolution.

Two contrasting situations in the Variscan belt granites are given as examples: 1) the quartz dissolution process («episyenitization») (LEROY, 1978; CATHELINEAU, 1986), at the end of hercynian times and 2) the «smectitization» process commonly observed in the Variscan belt during Jurassic and Cretaceous times (CATHELINEAU, 1982, 1987a):

— the process of hydrothermal dissolution of magmatic quartz and subsequent deposition of feldspars or phengites («episyenitization»), has been extensively studied because of the importance of «episyenites» as a trap for ore formation (CHEILLETZ and GIULIANI, 1982; see also the review in CATHELINEAU, 1986), and especially for U deposition (e.g. LEROY, 1978; 1984). Whatever the various occurrences, the fluids are aqueous solutions of low to moderate salinity circulating at temperatures in the range 250° - 350°C. In the Limousin occurrences, they were demonstrated to be of meteoric origin (TURPIN, 1984).

The origin of quartz undersaturated solutions able to circulate through quartz bearing rocks such as granites is an old and difficult problem to solve. As the fluid composition is rather trivial, explanations are usually sought in variations of external parameters, especially temperature (LEROY, 1978). However, it was recently realized that, in the episyenitic environment, coexisting fluid inclusions exhibit very distinct densities, but no changes in salinities and volatile contents, thus implying the turbulent mixing (DRUMMOND, 1981; ROEDDER, 1984) of two fluids of different temperatures and densities (a «vapor» and a «liquid») (CATHELINEAU, 1987a). As the quartz solubility is strongly dependent upon the solution density (LAUDISE and BALLMAN, 1961; WALTHER and HELGESON, 1977), it is conceivable that the mixing results in a density change which is in turn responsible for quartz undersaturation in some instances (CATHELINEAU, 1987a) (Fig. 6);

— «smectitization», the process of development of smectites at the expense of all the granite minerals (excepted quartz), results of quartz saturated solutions. Fluid inclusion studies show that they are aqueous and have relatively low salinities; circulation temperatures are typically in the range 100°-150°C. Chemical modelling of the process shows a cooling of the solutions (LEROY et al., 1985). It should be noticed here that kaolinite, which is currently observed in the vicinity of the smectite rich zones, cannot have been formed by the same fluids, and probably results from weathering.

Mineralogical and chemical consequences of fluid-rock interactions in granitic environment

Such long-duration multi-stage fluid circulations, as exemplified in the previous sections, cannot be without consequence on the final granite mineralogy and geochemistry. Indeed, the hydrothermal alterations developed in domains affected by strong fracturation are most spectacular, such as those observed in the pervasively microfractured porphyries. However, careful examination usually reveals a host of sealed microcracks (as fluid inclusions trails) even in apparently fresh granites (PECHER et al., 1985; LESPINASSE and PECHER, 1986). The question arises, whether or not the fluid circulations, thus evidenced, have produced significant mineralogical and/or geochemical changes.

As a first example, we will consider the episyenitic environment: in the southern part of the French Massif Central, episyenite pipes are developed both at the expense of the Margeride monzogranite, the age of which is 330 Ma (COUTURIÉ et al., 1979; RESPAUT, 1984), and of the peraluminous leucogranites, dated at 300 Ma (RESPAUT, 1984). In the St Chély-d'Apcher district, the Rb-Sr system of quartz depleted granites is completely rehomogenized, at around 280 Ma. The point is that the *apparently fresh rocks*, through a distance of 5 to 10 m from the episyenitization front, *display the same isotopic disturbance* (CAEN-VACHETTE, 1986, in CATHELINEAU, 1987a). Similarly, the U-Pb system is disturbed, due to the recrystallization processes affecting monazite, in the Pierre Plantées pipe as well as in its close vicinity (RESPAUT, 1984). As a consequence, slight changes in the REE pattern of the whole rocks are observed, due to slight LREE leaching during the monazite recrystallization (CATHELINEAU, 1987b).

Such disturbances are not uncommon. In the Bushveld granites of South Africa, WALRAVEN et al. (1985) describe small volumes in unmineralized granites in which the trace element and the Rb-Sr isotopic patterns are significantly disturbed at the sub-solidus stage and very similar to the patterns observed in the nearby specialized Sn-granites.

In such cases, the cryptic alteration processes are of limited extent, and develop only at the close vicinity of main fluid channels, along which there is sometimes, but not necessarily, apparent alteration. But granites are often highly faulted and/or microfracturated, ;and in such occurrences, one can wonder if the granitic bodies are not affected in their whole mass by the subsolidus processes. There are indeed some instances where transformations are obvious in the whole granitic body, such as the textural differences between the various plutons of the Cornubian batholith (RANKIN and ALDERTON, 1985). In particular, this is the case of most peraluminous «two-mica» granites, in which processes may well grow in importance, and CHAROY (1986) documents the subsolidus transformation of a former biotite granite into a two-mica one in the Carnmenellis massif.

New formed muscovites (phengites) are usually very low in titanium and very high in rubidium (LEROY and CATHELINEAU, 1982). In such cases, subsolidus transformations have the same kind of geochemical signature as the

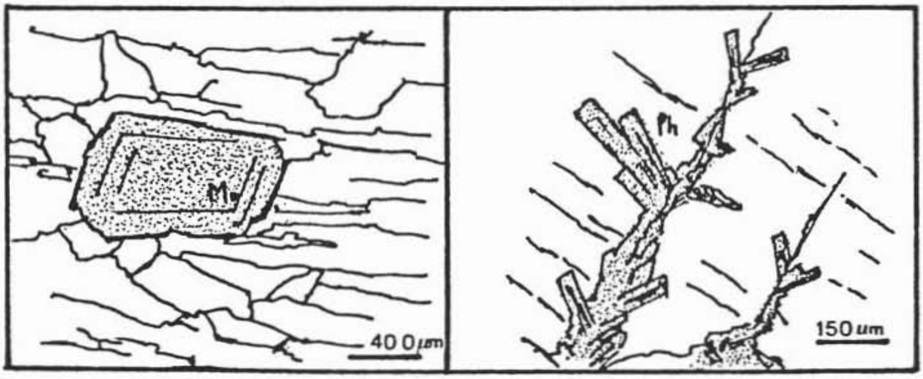

Fig. 7. — a) zoned muscovite crystals superimposed on the plastic foliation (Walmes granite, Morocco, BOUTALEB, 1988); b) phengite crystals within late microcracks affecting an orthoclase crystal (La Commanderie, South Armorican area, CATHELINEAU, 1982).

a significant part — if not all in some instances — of muscovite crystals developed under subsolidus conditions.

A good example is the Walmes two-mica granite stock in Central Morocco, the cupola of which is strongly flattened in the plastic stage, producing a spectacular flat foliation (DIOT et al., 1987). This granite has been known from long for its automorphic zoned muscovite crystals (TERMIER et al., 1950), which are classically thought to be of typical magmatic origin. But, as these crystals are clearly superimposed onto the plastic foliation (Fig. 8), they evidently formed at a subsolidus high temperature stage.

Muscovite developed in feldspar microcracks is frequent (Fig. 7). It often represents a weak greisenization process, according to the very classical «reaction»: feldspars + protons $(+K^{+}(*))$ = muscovite (phengite) + quartz + (K^{+}, Na^{+}, Ca^{2+})
(*: in the case of plagioclases only).

Biotite also may be replaced by muscovite (GARCIA and FONTEILLES, 1985). Both magmatic differentiation (CHAROY, 1984; 1986).

A peculiar case is realized in the Saint-Sylvestre peraluminous two-mica granite (French Central Massif). This granite is pierced by a few late small intrusions of Li-F-enriched peraluminous granites. Subsolidus transformations of the St Sylvestre granite, accompanied by a strong uranium enrichment, result from circulation of the magmatic fluids released from these Li-F-granites; this process is very significant for the genesis of uranium deposits in this district (FRIEDRICH et al., 1987).

It is then apparent that, throughout the hydrothermal history of a granitic body, hydrothermal processes can significantly contribute to the final geochemical features that are observed nowadays. In fact, this is not uncommon (for a more extended bibliography, see CATHELINEAU, 1987a). Therefore, careful petrologic examinations, including the rare heavy minerals, are a necessary prerequisite to the geochemical modeling of the magmatic processes.

Conclusions

Fluids now observed within the granitic bodies, either as fluid inclusions or structural $(OH)^-$ in hydrated minerals, are of many origins, and may have percolated into the granite at any time since its emplacement. Broadly speaking, one can identify: magmatic fluids, unmixed from the late-stage melt; early external (metamorphic) fluids, generated in the surrounding rocks by the very process of granite emplacement (heating); late external waters (of any origin, but mainly of meteoric derivation), circulating as a consequence of either the cooling of plutons or reheating by various mechanisms.

It is worth noticizing that external fluids can always be recognized. In a number of cases, they are the only ones available for analyses, possibly because the earliest fluids are overprinted. As a consequence, the magmatic mineralogical and/or geochemical features of the granites are often disturbed, in many cases locally and lightly, but in a very significant fashion in some instances; these changes concern mainly the trace element and isotope patterns.

Among the trace elements, the ore-forming ones are of special interest; in view of the importance of mineralogical and chemical (mass transfers) changes sometimes associated with the long duration fluid circulations in the granites, it appears that the orthomagmatic metallogenic models (Burnham and Ohmoto, 1980; Eugster, 1985) are probably too simple and cannot explain all the observed facts.

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