Isotopic composition of strontium in the Valle de Tena (Spanish Central Pyrenees) fluorite deposits: relevance for the source of elements and genetic significance

SUBÍAS, I., MORITZ, Robert, FERNÁNDEZ-NIETO, C.

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Abstract The fluorite deposits of the Valle de Tena, Central Pyrenees, include stratabound (Portalet) and vein (Lanuza and Tebararray) deposits the formation of which are linked to a Namurian-Westfalian emersion episode and to post-Hercynian hydrothermal systems similar to those occurring elsewhere in Hercynian Europe. In this study, strontium isotopes were used to determine the source(s) of strontium, and by inference calcium, of the fluorite mineralizations, as well as the nature of the ore-forming fluids. Fluorite and calcite from each deposit have similar 87Sr/86Sr ratios (Portalet 0.7085–0.7108; Lanuza 0.7086–0.7104 and Tebararray 0.7086–0.7101). In all deposits, the Sr isotope composition of most of the Ca-minerals is more radiogenic than that of the host limestones. This indicates that the Ca-minerals contain a mixture of Sr derived locally from the host limestones and 87 Sr-enriched Sr leached from silicate minerals in the siliciclastic portion of the basement sequence and in granites from the study area. Volcanic rocks are ruled out as a significant Sr source for the fluorite deposits. The observed trend in 87Sr/86Sr versus 1/Sr support a fluid-rock interaction model which satisfactorily reproduces the marked 87Sr-enrichment in the fluorites and calcites from the deposits.

Introduction

The Valle de Tena, located in the northernmost part of the Huesca province, Spanish Central Pyrenees contains several subeconomic stratabound and vein-type fluorite mineralizations. Mining operations were established in the seventeenth century and operated until 1990. These deposits range in size from thin veins (Tebarray and Lanuza) worked by individuals to medium deposits such as that at Portalet. Production figures of 30 000 metric tons of fluorite can be estimated for the last 30 years.

The origin of such deposits have challenged some investigations and two divergent views exist on the questions of the period of mineralization, the mechanism of precipitation and the source of mineralizing components. Martin (1979) proposed a two-component mixing model between a hydrothermal F-bearing fluid coming from the volcanic rocks occurring in this area and a meteoric Si-bearing fluid. In his study, Martin hypothesized that stratabound fluorites at Portalet are Stephanian in age, whereas the fluorite vein at Lanuza (see Fig. 1), was formed by remobilization of the former during the Tertiary. In a recent paper, Subías and Fernández-Nieto (1995) explained the formation of the mentioned mineralizations as the result of two distinct hydrothermal systems linked to post-Hercynian tensional tectonics. One system was characterized by saline fluids which promoted vein deposits. These fluids share the typical characteristics of basement brines with sulphur derived from a mixture of regional igneous and sedimentary country rocks (Subías et al. in press). The second led to the formation of the stratabound fluorites by remobilization of the vein fluorites. The relatively cold and dilute fluids were connate waters, modified by some meteoric input and scavenged sulphur from the local country rocks (Subías et al. in press). In this contribution, Sr isotope geochemistry, partly in combination with previous geochemical data, supports our preliminary genetic model.

The scope of this study is twofold: first, to use strontium isotopes as tracers to constrain possible source rock reservoirs for various components of the mineralizations under study; and second, to integrate the strontium isotopic data with stable isotope, fluid inclusion and REE signatures in order to interpret them in terms of genetic implications. For this purpose, the Sr isotopes have been determined in fluorites and calcites from the mineralizations and in the different rock types of the area.
Roger 1977; Ríos et al. 1989). Alpine movements are responsible of Hercynian age are present in the investigated area (Muller and least, one extensional event and three di/C128erent compressive phases which W-Au skarn deposits are associated (Autran et al. 1980). Metamorphism aureole, consisting of hornfelses and marbles to (Bixel 1984). The intrusion of Panticosa granite produced a contact granite (Debon 1980) and andesites related to volcanic episodes thermal overprint during burial cannot be ruled out. Host limestones of the mineralizations under study underwent consider, on the basis on a combined mineralogical, textural, and gest, on the basis on a combined mineralogical, textural, and geochemical study, that the Devonian and Lower Carboniferous host limestones of the mineralizations under study underwent diagenetic alteration caused by surficial water with intermediate compositions between meteoric and sea waters, although a minor thermal overprint during burial cannot be ruled out. Igneous rocks in the area comprise the 290 Ma old Panticosa granite (Debon 1980) and andesites related to volcanic episodes that occurred during the opening of the Stephano-Permain basins (Bixel 1984). The intrusion of Panticosa granite produced a contact metamorphism aureole, consisting of hornfelses and marbles to which W-Au skarn deposits are associated (Autran et al. 1980). The structural pattern of the study area is a result of polyphase tectonics developed during the Hercynian and Alpine orogenies. At least, one extensional event and three different compressive phases of Hercynian age are present in the investigated area (Muller and Roger 1977; Rios et al. 1989). Alpine movements are responsible for the uplift and thrusting of the Hercynian basement over the Upper Cretaceous marine limestones during the Tertiary. Moreover, a number of Alpine faults striking N-S can be distinguished. However, the Variscan structures have been relatively unaffected between the Alpine faults.

**Geological setting**

The Valle de Tena fluorite ore deposits are situated within the western end of the Gavarnie nappe, an alpine structural unit located along the central portion of the Pyrenean Axial Zone. A geological sketch map of the Valle de Tena area is presented in Fig. 1. Sedimentary rocks consist of Silurian to Permian and Cretaceous carbonate and detrital rocks. Subias et al. (in press) suggest, based on a combined mineralogical, textual, and geochemical study, that the Devonian and Lower Carboniferous host limestones of the mineralizations under study underwent diagenetic alteration caused by surficial water with intermediate compositions between meteoric and sea waters, although a minor thermal overprint during burial cannot be ruled out. Igneous rocks in the area comprise the 290 Ma old Panticosa granite (Debon 1980) and andesites related to volcanic episodes that occurred during the opening of the Stephano-Permian basins (Bixel 1984). The intrusion of Panticosa granite produced a contact metamorphism aureole, consisting of hornfelses and marbles to which W-Au skarn deposits are associated (Autran et al. 1980). The structural pattern of the study area is a result of polyphase tectonics developed during the Hercynian and Alpine orogenies. At least, one extensional event and three different compressive phases of Hercynian age are present in the investigated area (Muller and Roger 1977; Rios et al. 1989). Alpine movements are responsible for the uplift and thrusting of the Hercynian basement over the Upper Cretaceous marine limestones during the Tertiary. Moreover, a number of Alpine faults striking N-S can be distinguished. However, the Variscan structures have been relatively unaffected between the Alpine faults.

**Fluorite deposit-types**

Based on geological arguments, stratabound and vein-type fluorite deposits can be distinguished in the Valle de Tena which show distinct mineralogical and geochemical features. Three different mines have been investigated in this study: the Portalet, Lanuza and Tebarray deposits (Figs. 1 and 2).

The mineralizations at the Portalet mines are stratabound to a siliceous horizon inserted between Tournasian-Namurian carbonates and Westfalian classic series. The mineralization consists of a siliceous horizon or “crust” that mantles a paleorelief developed over the aforementioned carbonates during emersion episodes related to Namurian extensional tectonics (Bichot 1986). This “crust” is distinguished by breccias with clasts of dominantly autochthonous carbonates and a matrix of sandy material composed of quartz, fluorite, and clay minerals. These detrital sediments are typically arranged as laminites which exhibit graded, and locally crossbedded or slumped structures. The peculiarity of this mineralized horizon is its almost complete silicification with a dominant fluorite presence as a result of “crustal” replacement process. The dominant ore fabrics of the silicified horizon are breccia, cockade and zebra ores. The main mineralogical constituents are white, coarse-grained quartz and fluorite accompanied by abundant calcite which postdates the former minerals as well as rare pyrite, sphalerite, galena and siderite. However, the most striking feature is the presence of a Li-bearing chlorite: donbassite (González López et al, 1993).

In short, our geological investigations suggest that although the Portalet fluorite deposits are, in part, syngenetic to crust formation, the dominant ore fabrics represent crystallization under diagenetic conditions. The vein-type deposits are located in the surroundings of the Panticosa granite and are hosted by Devonian limestones (Figs. 1 and 2). They consist of the Tebarray and Lanuza deposits. The Tebarray occurrences are located along vertical faults dominantly developed in Upper Devonian marbles. The veins range from a few centimetres to a metre in width and they are rarely continuous for more than 20 m without offset. Two phases of ore deposition have been distinguished. The first one, situated close to the vein margins, is made up of dark-sphalerite, galena, pyrite and chalcopyrite, whereas the second phase, occupying the main part of the vein, consists of light-sphalerite, silver-rich galena, tetrabehydrox, green fluorite and paragenetically later white fluorite. Both petrographic and geochemical studies indicate that the second phase sphalerite and galena resulted from the remobilization of the first stage phases (Subías et al. 1997), and that white fluorites can be considered as a remobilization product of the green ones (Subías and Fernández-Nieto 1995).

The fluorite mine at Lanuza occurs in a steeply dipping E-W trending 200 m long, 0.2 to 1.3 m wide and 60 m deep vein, hosted by Lower Devonian limestones. It is characterized by a simple mineralogy consisting of white-yellowish microcrystalline fluorite with disseminated chalcopyrite, pyrite, and quartz. Irregular and thin selvages made up of calcite and rare dolomite are cut and partially replaced by fluorite. Fluid inclusion studies and REE systematics (Subías and Fernández-Nieto 1995) confirm that fluorite formation in the study area took place during two different stages of fluid circulation. Vein deposits which exhibit elevated LREE contents were precipitated from deep seated saline waters (basement brines), whereas stratabound fluorites marked by low LREE/HREE ratios can be interpreted as a product of remobilization of the former ones by low-saline convective formation waters. A stable isotopic study (Subías et al. 2003) indicates that connate waters modified by some meteoric input, with sulphur derived from biogenic sulphides, were responsible for the stratabound deposits, whereas marine water with sulphur derived from a mixture of regional igneous and sedimentary rocks, account for the formation of the veins.

The exact timing of the mineralizations under study is still a matter of debate. However, some geological evidence allows us to bracket the age of the possible fluorite formation: (1) although syngenetic stratabound mineralizations can be ascribed to the Namurian-Westfalian, most of the Portalet stratabound fluorites are diagenetic and consequently, they could be younger; (2) veins crosscut and/or partially replace Permian diabase dykes (Debon 1975); (3) both stratabound and veins suffered post-ore deformations of Alpine age; and (4) fluids involved in fluorite deposition are similar to those characterizing post-Hercynian hydrothermal activity elsewhere in Europe (Boni et al. 1992; Lüders et al. 1993).
This information allows us to conclude that the studied fluorite mineralizations, with the exception of the syngenetic Portalet mineralization, may have been formed during the tensional movements related to the early Alpine rifting that affected wide areas of Southern Europe (Boni et al. 1992, and references therein). A more precise time reconstruction could be achieved by considering other Hercynian areas of Europe where geochronologic constraints are more precise. In fact, radiometric data (Galindo et al. 1994) and indirect dating (Canals and Cardellach 1993) in some Spanish post-Hercynian F-Ba deposits indicate an age-span between 225 and 145 Ma (Middle Triassic-Late Jurassic). Therefore, we used the extreme age noted already for calculations made in this study.

**Analytical methods**

Samples selected to encompass all varieties of mineralization were checked for purity by binocular examination and X-ray diffractometric analyses. Quantitative analyses of rubidium and strontium in these samples were obtained by X-ray fluorescence at ActLabs (Canada). Control measurements of the Sr concentrations of calcites were carried out by isotopic dilution.

For the strontium isotope determinations, dissolution and leaching of about 100 mg of calcite and fluorite, respectively, was achieved by 1N and hot (100 °C) 6N HCl treatment, respectively. In the case of calcite, a 86Sr spike was added to the acid prior to leaching for isotope dilution. Sr was separated from the solutions using ion exchange columns. Isotopic ratios were measured on a 7 collector Finnigan MAT 262 thermal ionization mass spectrometer.
at the University of Geneva. The reproducibility of duplicate samples was always better than 0.00005 (2σ). Measured blanks for the procedure are negligible giving the uncertainties significantly lower than reproducibility. The average value for the NBS 987 standard was 0.710242 ± 0.000005 (2σ). In addition, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of four fluorite samples were determined at the University of Saskatchewan (Canada) employing the following routine: 10 mg of fluorites were spiked with $^{84}\text{Sr}$ and $^{87}\text{Rb}$ and then digested with HF + HClO$_4$. After separation of Sr by chromatographic columns, isotopic determinations were performed on a Finnigan MAT 261 mass spectrometer using five collectors. Data corrected for blank contribution are reported to 0.00004 (2σ).

**Results**

**Sr source rock reservoirs**

Based on geological and geochronological results, possible source rocks of the Sr in the mineralization under study must be older than 225 Ma. The likely rock reservoirs are: the host limestones of the mineralization, the underlying clastic rocks and the late Hercynian igneous rocks, including granites and andesites.

Innocent et al. (1994) and McCaig et al. (1995) have characterized the range of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of andesites and clastic rocks, 0.7058 to 0.7075 and 0.7115 to 0.7471, respectively (Table 1). In this work, we have additionally determined the Sr-isotopic signatures of the host carbonates and the granites.

Our analyses of Devonian and Lower Carboniferous limestones that host the vein and stratabound deposits, respectively, range from 0.7084 and 0.7090 (Table 1). They are enriched in $^{87}\text{Sr}$ compared to those corresponding of Devonian and Carboniferous seawater reported by Burke et al. (1982) and Veizer (1992). This is the result of their post-depositional diagenetic alteration by fluids of meteoric parentage, as proposed by Subías et al. (in press).

Determination of the Sr-isotopic geochemistry of the Panticosa granite reflects the fact that its present-day $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.7151 to 0.7270 (Table 1) are within the range of other batholiths from the Central and Eastern Pyrenees where present-day $^{87}\text{Sr}/^{86}\text{Sr}$ ratios range from 0.7092 to 0.7792 (Vitrac-Michard et al. 1975; Michard-Vitrac and Allègre 1980; Ben Othman et al. 1984; McCaig et al. 1995).

**Valle de Tena fluorites**

The results of 33 Sr isotope analyses, together with Sr and Rb contents, of selected fluorite and calcite samples from the Valle de Tena mineralizations are given in Table 2. Considering Sr concentrations between 37 and 3788 ppm and Rb concentrations below the detection limit, no corrections of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are required for the decay of $^{87}\text{Rb}$ to $^{87}\text{Sr}$, and consequently, the isotopic ratios determined can be assumed as the isotopic ratio of the mineralizing fluids.

### Stratabound deposit

Sixteen analyses were performed on the full range of the different Portalet ore fabric types (breccias, zebra, nodules, and veins; Subías 1993). As can be seen in Table 2, the Sr-isotopic ratios of fluorite at Portalet range from 0.70848 to 0.71083. Note that $^{87}\text{Sr}/^{86}\text{Sr}$ values of fluorite nodules coincide with those of the host limestones. Breccia and vein fluorites have higher $^{87}\text{Sr}/^{86}\text{Sr}$ compositions. Calcite samples are in the range of the later fluorites. Therefore, most of the strontium isotope ratios for the Portalet Ca-minerals exceeds the range of values of the host limestones (0.7085 to 0.7090; Table 1 and Fig. 3). It is worth noting that there is a small but significant shift in the isotopic composition of fluid: vein fluorites and calcites that postdate the rest of fluorite fabrics are more radiogenic. The Sr content of the fluorites ranges from 54 to 134 ppm (Table 2) and shows no correlation with ore fabrics. The Sr abundances of calcite range from 671 to 3788 ppm (Table 2).

<table>
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<th>Table 1 $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of potential sources of Sr</th>
<th>Present-day $^{87}\text{Sr}/^{86}\text{Sr}$</th>
<th>Present-day $^{87}\text{Rb}/^{86}\text{Sr}$</th>
<th>$^{87}\text{Sr}/^{86}\text{Sr}$ at 225 Ma</th>
<th>$^{87}\text{Sr}/^{86}\text{Sr}$ at 145 Ma</th>
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Vein deposits

Seventeen samples of fluorite and calcite from the Tebarray and Lanuza mineralizations were analyzed for their Sr isotopic compositions (Table 2). Their $^{87}\text{Sr}/^{86}\text{Sr}$ ratios vary from 0.7086 to 0.7104 similar to that of the stratabound fluorites and calcites from Portalet. At the Tebarray veins, green fluorites which predate white fluorites, exhibit slightly more radiogenic Sr isotopic values (0.70974 to 0.71010) than those of the white fluorites (0.70911 to 0.7992). The Sr contents (79 to 482 ppm) of the Tebarray veins lie in a narrower range than those of the other fluorite deposits of the Valle de Tena. Sr abundances of the green fluorites are lower than those of the white ones.

The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of fluorite samples from the Lanuza mine, fluorite vein give a range between 0.70858 and 0.71036, and two calcite samples yield $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.70948 and 0.70970 (Table 2). In the fluorite dataset, two groups showing slightly different $^{87}\text{Sr}/^{86}\text{Sr}$ ratios can be recognized. Those samples collected from the vein centre (VC in Table 2) are more radiogenic than those from the vein margin (VM in Table 2). In addition, two samples (VM-1 and VM-2) yield Sr isotopic compositions that are similar to the Devonian host limestone range (0.7084 to 0.7089; Table 1). In short, the less radiogenic samples are located at the margin of the vein, while the more radiogenic ones are from the centre of the vein. This evolutionary trend is opposite to that of the Tebarray veins. Sr values for Lanuza fluorites range from 37 to 57 ppm, and for calcites from 824 to 1232 ppm.

### Discussion

The $^{87}\text{Sr}$-enrichment of the investigated Ca-minerals relative to host limestones (Fig. 3) suggests that part of the strontium in the mineralizing fluids was derived from a Rb-rich source. From inspection of Fig. 3, we recognize that the fluorite and calcite data fall in between a source with a seawater isotopic signature and several sources enriched in $^{87}\text{Sr}$.

The first reservoir marked by a seawater isotopic signature is consistent with derivation of Sr from the host Devonian and Lower Carboniferous carbonates at the time of fluorite emplacement. Regarding those reservoirs enriched in $^{87}\text{Sr}$ (Table 1), it is not possible to define a unique source for radiogenic strontium since detrital and igneous silicate minerals with high Rb/Sr ratios are potential sources of $^{87}\text{Sr}$. There are unfortu-
In short, the main sources for $^{87}$Sr-enriched Sr are plutonics and detrital lithologies, and vein fluorites in the case of Portalet fluorites, although Sr isotopes do not allow us to discriminate which is the more important supplier of radiogenic Sr. This is in concordance with both REE (Subias and Fernández-Nieto 1995) and stable isotope geochemistry (Subias et al. 1997).

The covariation of $^{87}$Sr/$^{86}$Sr with strontium content (1/Sr) are shown in Fig. 4 for the three mineralized areas. They can be explained by a mixing model involving the aforementioned reservoirs. Although two types of mixing may be distinguished: fluid mixing and fluid-rock interaction, microthermometric studies by Subias and Fernández-Nieto (1995) do not support fluid mixing. Alternatively, fluid/rock interaction could be responsible for the observed $^{87}$Sr/$^{86}$Sr ratios. Indeed, indications are strong that the Sr isotopic composition of the mineralizing fluids changed because of the influx of isotopically different strontium at the site of mineralizations. In the Portalet and Lanuza deposits the evolution trend toward higher $^{87}$Sr/$^{86}$Sr ratios suggests that the isotopic composition of Sr in mineralizing fluids was buffered at the beginning of mineral deposition by the host rocks and gradually became more radiogenic as the fluid/rock ratio became larger. On the contrary, the Tebarray veins show an isotopic evolution of the strontium to less radiogenic compositions with the paragenetic sequence. The clue to this behaviour lies in the fact that white fluorite is a remobilization product of the green fluorites and partially replaces the host limestones marked by lower $^{87}$Sr/$^{86}$Sr ratios.

For the Portalet and Lanuza deposits (Fig. 4a, c) we have to consider in modelling the mixing process: (1) a Sr-rich source with relatively low $^{87}$Sr/$^{86}$Sr ratios with a Devonian to Carboniferous seawater signature and similar to those of the immediate host rocks (Table 1) and (2) a Sr-poor source enriched in $^{87}$Sr with variable Sr concentrations. By contrast, Fig. 4b (Tebarray deposit) indicates a simple binary mixing process involving (a) a Sr-rich source with relatively low $^{87}$Sr/$^{86}$Sr ratios, similar to those of the immediate host rocks (Table 1) and (b) a Sr-poor source enriched in $^{87}$Sr.

The $^{87}$Sr-bearing source with variable Sr concentrations in the case of the Portalet and Lanuza deposits can be interpreted in different ways:

1. In the case of a single fluid involved in the fluorite precipitation, steeply dipping faults as conceivable fluid channels, favoured the migration of the solution deriving their components from a mixture, in different proportions, of regional igneous rocks and sedimentary country rocks. In the case of the Portalet deposit, vein fluorites are an additional source, as pointed out previously. Moreover, and in the case of stratabound fluorites at Portalet, the similarity in $^{87}$Sr/$^{86}$Sr between these fluorites and calcites and those from vein-type deposits support the idea that the latter could partially derive their strontium by remobilization of the vein fluorites and calcites, as...
previously suggested by Subías and Fernández-Nieto (1995) on the basis on REE systematics. Finally, it must be noted that kinetic effects such as crystal growth rate, possibly induced by changes in temperature during precipitation, could also affect the partitioning of Sr between fluorite and the $^{87}$Sr-bearing hydrothermal fluid.

2. We can also have the case of variable mixing between two fluids at depth; before the mixed fluid precipitates the fluorite at a later stage. In such a scenario, variable mixing rates between the fluids with different Sr concentrations and probably different $^{87}$Sr/$^{86}$Sr ratios produce a unique fluid which then interacts with the host limestone producing the fan-shaped dispersion of the data in the $^{87}$Sr/$^{86}$Sr versus 1/Sr diagram.

3. A combination of process (1) and (2) is also possible. Regarding the Tebarray deposit, the data probably shows that the precipitating fluid was more constant in its Sr content and isotopic composition during the time of fluorite formation. It is interesting to note that Tebarray mineralization, with the simpler data array on Fig. 4, is the deposit which is the closest to the Panticosa granite. By contrast Portalet and Lanuza deposits are more remote from such a granite. This may suggest that in the case of Tebarray deposit, the radiogenic ore-forming fluid is dominated by leaching of Sr from one major source, possibly the Panticosa granite, whereas in the case of the Portalet and Lanuza deposits, the larger dispersion of the data reflects a more complicated system involving the processes under points (1) to (3) previously described.

Genetic implications

Between the end of the Hercynian orogeny and the beginning of the Alpine cycle, the Valle de Tena was the site of several hydrothermal phases similar to those occurring in other areas of Western and Central Europe. These resulted in a range of distinct mineralizations in skarns (not studied here), veins and paleokarst. On the basis of the integration of previously published geological and geochemical data with constraints concerning metal sources based on Sr isotopes, it is possible to distinguish two distinct mineralizing systems.

A regional-scale model of brine migration is required to explain the elevated $^{87}$Sr/$^{86}$Sr ratios of the fluorites and calcites at the Lanuza and Tebarray veins. These veins which occur along subvertical faults most likely represent channelways to move mineralizing solutions expelled from sedimentary basins (basinal brines) to the site of ore deposition. Such a scenario implies that the most likely sources of $^{87}$Sr-enriched Sr are the clastic rocks and the Panticosa granite which is in line with the REE signature of the fluorites and calcites (Subías and Fernández-Nieto 1995). The vein deposits of the Valle de Tena are very similar in geologic setting, mineralogy and geochemical trends to those of other fluorite and base metals veins located in the Central Pyrenees (Castroviejo and Moreno 1983; Milliton 1987; Fanlo 1994). These mineral occurrences are typically associated with Late Palaeozoic steeply dipping faults along which metal-bearing brines were expelled from the Hercynian basement during Early Alpine times (Johnson et al. 1993; Fanlo et al. in press).
The model that best explains diagenetic stratabound mineralizations in the Portalet is gravity-driven fluid flow (Garven and Freeze 1984 a, b). Indeed, the formation of horst and graben structures during Early Alpine extensional tectonics favoured meteoric water, input in the uplifted blocks, with subsequent migration through the deeper parts of the basins, thereby acquiring heat and dissolved components. In this case, in the Panticosa granite, the clastic sequences and vein deposits are likely sources of the radiogenic strontium. This model also explains diagenetic changes recorded in the host limestones (Subias et al. in press). In such a context, it is reasonable to suggest that the mineralizing fluids used the paleorelief as a zone of weakness and channelway to transport fluorine and deposit the fluorite, thus remobilizing the pre-existing fluorite vein mineralization.

Moreover, the strontium isotope composition of the fluorites and the calcites indicates that the ore solutions, locally derived strontium from the host limestone. Fluid-rock interaction could be a plausible depositional mechanism for fluorite, as deduced from previous geochemical studies Subias and Fernández-Nieto (1995). This is one of the most important mechanisms of fluorite deposition proposed by Holland and Malinin (1979).

Conclusions

The Sr isotopic data summarized here provide strong support for the source of mineralizing components in the ore solutions. The Sr isotope compositions and the strontium content of fluorites and calcites indicate that the ore solutions, locally derived strontium from the host carbonate. Although a rigorous assessment of the strontium source is not possible, calculations show that the Panticosa granite and the clastic Paleozoic and Triassic sequences are a likely source of radiogenic strontium. This model also explains diagenetic changes recorded in the host limestones. In addition, the case of the Portalet stratabound deposits it is plausible to accept the idea that Sr-enriched Sr was partially derived from the remobilization of the previously formed vein fluorites. Finally, volcanic rocks had too low a Sr/Sr ratio and negligible volumetric significance to be considered as a major Sr source for the investigated mineralizations.

The regional marked Sr-enriched supports a genetic model based on fluid-rock interaction processes with fluids that have reacted with detrital and granitic lithologies, and with previously formed fluorite veins in the case of the Portalet mineralization. In that way, these interacting fluids have a range of compositions representing mixtures of the proposed sources of Sr-enriched Sr. These fluids also leached strontium from local limestone host rocks.

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