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SIGNIFICANCE OF AN EARLY CRETACEOUS Rb-Sr AGE IN THE PESCADERO PLUTON, SANTANDER MASSIF.

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ABSTRACT

A Rb-Sr whole rock-mineral age of 129±8 Ma was yielded by the Pescadero Pluton. Stratigraphic relationships preclude an early Cretaceous age for this pluton. The occurrence of fluorite, quartz and calcite veins and a pervasive alteration at a mineral scale suggest that the Pescadero pluton has been affected by hydrothermal activity.

The new age is interpreted as dating an early Cretaceous hydrothermal event recorded in the area. This event is not associated with the magmatic evolution of the pluton, but is temporarily related to the Santander Massif paleo-topographic high, which separated the Tablazo-Magdalena and the Cocuy sedimentary basins.

Key words: Rb-Sr Geochronology, Santander Massif, Pescadero Pluton, hydrothermal event.

SIGNIFICADO DE UNA EDAD Rb-Sr DEL CRETÁCICO TEMPRANO EN EL PLUTON DE PESCADERO, MACIZO DE SANTANDER

RESUMEN

Una edad Rb-Sr roca total-mineral de 129±8 Ma fue obtenida para el Plutón de Pescadero. Las relaciones estratigráficas descartan una edad Cretácica para el pluton. La ocurrencia de venas de fluorita, cuarzo y calcita y una alteración generalizada a escala mineral sugieren que el plutón de Pescadero ha sido afectado por actividad hidrotermal.

La nueva edad es interpretada como la edad de un evento hidrotermal del Cretácico temprano registrado en el área. Este evento no esta asociado con la actividad magmática del pluton, pero si relacionado temporalmente con la paleo-elevación del Macizo de Santander, la cual separaba las cuencas sedimentarias del Tabalazo-Magdalena y el Cocuy.

Palabras clave: Geocronología Rb-Sr, Macizo de Santander, Plutón de Pescadero, evento hidrotermal.

[1] C o r r e o

INTRODUCTION

The Santander Massif (FIGURE 1) is a morphological structure located in the northern part of the Eastern Cordillera. The massif is mostly composed of Precambrian to Paleozoic metamorphic rocks, and igneous rocks of Mesozoic and Tertiary ages. Sedimentary rocks are less abundant and are restricted to some tectonic blocks (Ward *et al.*, 1973).

Igneous rocks in the Santander Massif record three important magmatic events developed during 1) late Triassic-middle Jurassic, 2) early Cretaceous, and 3) late Cretaceous-early Tertiary. The late Triassic-middle Jurassic event is mainly of plutonic origin and is formed by stocks and plutons of dioritic and granitic composition (Goldsmith *et al.*, 1971; Ward *et al.*, 1973; Polania, 1980). These plutonic rocks were named the Santander Plutonic Group (SPG) by Ward *et al*. (1973). Early Cretaceous magmatic activity is represented in the massif by porphyry rhyolite dykes (Goldsmith *et al.*, 1971; Restrepo *et al*., 1984), and probably by microgabbro (diabase) dykes. These mafic intrusions appear to have similar origin to the mafic dykes intruding the Cretaceous sedimentary rocks of the Eastern Cordillera (Fabre and Delaloye, 1982; Marquinez and Moreno, 1993; Moreno and Concha, 1993; Vásquez *et al*., 2000; Moreno *et al*., 2001). The late Cretaceous-early Tertiary magmatism has been recognized in the California gold-mining district (Central part of the Santander Massif). This event is recorded by porphyry dacite and granodiorite intrusions (Nippon Mining Company, 1967; Polania, 1980; Mathur *et al.,* 2003).

The studied Pescadero pluton crops out in the southwestern part of the Santander Massif and belongs to the Santander Plutonic Group. A K-Ar biotite age of 193±6 Ma yielded by the Pescadero pluton is interpreted as the age of this pluton (Goldsmith *et al*., 1971).

This study reports new geologic and geochronological data (Rb-Sr) for the Pescadero pluton aiming to contribute to the understanding of the tectonothermal history of the Santander Massif.

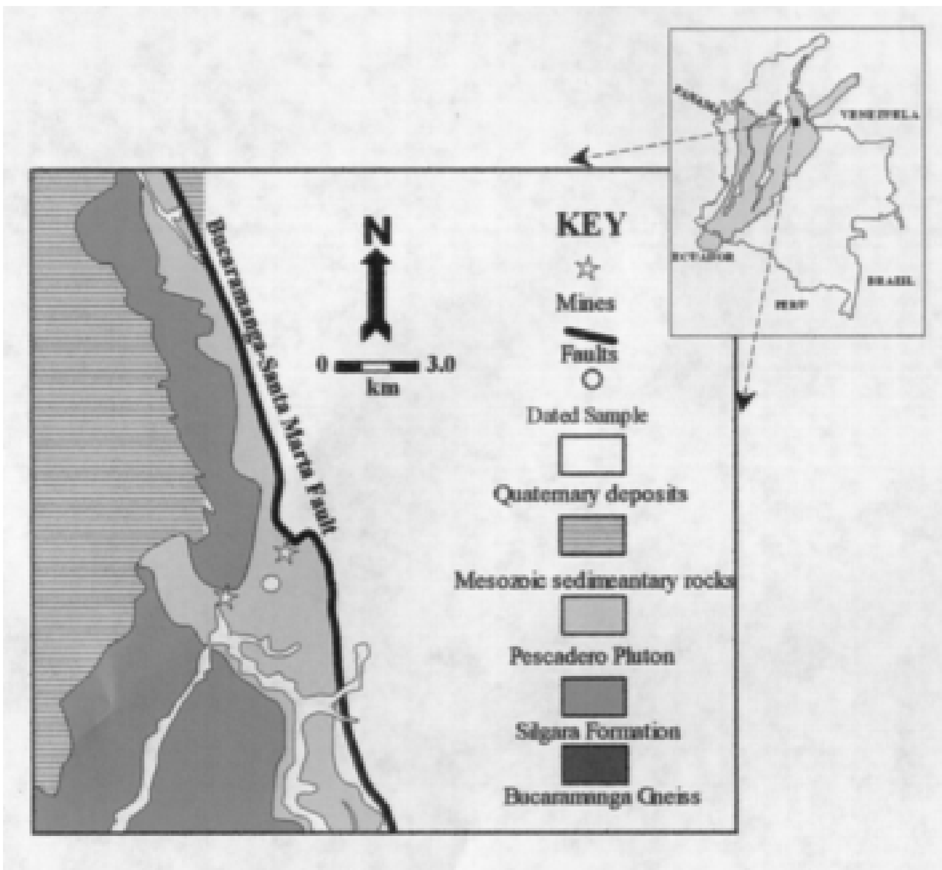

FIGURE 1. Geological map of the Pescadero pluton.

GENERAL GEOLOGY OF THE PLUTON

Macroscopic features

The Pescadero pluton (FIGURE 1) is *ca.* 21 km long, forming an irregular elongated body trending NNW. The eastern edge of the pluton is mainly a fault-bounded contact with the Precambrian Bucaramanga Gneiss, but further south it has an intrusive contact with this metamorphic unit. The Pluton has an intrusive contact with the lower Paleozoic Silgara Formation. The early Cretaceous Los Santos Formation unconformably overlay the Pescadero pluton. Alternatively, an unconformity between the upper Jurassic Giron Formation and the Pescadero pluton was found in this work (FIGURE 2).

The Pescadero pluton is a pink monzogranite with several textural variations. Fine grained monzogranites are found in the topographically uppermost parts of the pluton and along intrusive contacts. Monzogranite porphyry is the most exposed facies of the pluton. Coarse grained monzogranite crops out in the central parts of the pluton. Sample dated here (JP18) was collected from the coarse grained monzogranite, 3 km north of the Pescadero bridge along the Bucaramanga-Bogota road (FIGURE 1).

This igneous body shows evidence of fracturing (joints and veins) and hydrothermal alteration. At least two structural joint families are identified: a) highly penetrative joints trending N60W/75SW, with planes about 5-50 cm apart; and b) joints trending N40W/55NE, younger and with more spaced planes relative to the other joint family.

A series of highly penetrative fractures (foliations) is locally observed. These structures are trending about N10E/10-15SE. Field relationships suggest these structures are older than the joint families described above. Silicification and epidotization along these older structures have also been observed.

At outcrop scale hydrothermal activity is manifested by veining and alteration envelopes developed along individual veins or as isolated patches across the pluton. In the topographically uppermost part of the pluton, local shear zones host hydrothermal veins (FIGURE 3a) with quartz + muscovite ± hematite filling. Calcite, siderite and (±) hematite (specularite) fill joints forming veins up to 5 cm wide (FIGURE 3b) in the topographically lowermost parts of the pluton.

An epithermal lode fluorite deposit is formed in the marginal zone of the intrusive along the contact with Silgara Formation. Near the lodes, hydrothermal alteration is extreme with intermediate argillic alteration. Fluorite ± calcite also occur, filling dissolution cavities within the pluton.

The chronology of the hydrothermal events having affected the area is not established, however, Mantilla *et al.* (2001; 2004) interpreted a Cretaceous age for the Pescadero lode fluorite deposit.

Petrographic features

Mineral scale alteration is less evident but more pervasive. Although samples were collected where no alteration was observed at a hand sample scale, microscopic studies show that minerals are variably altered across the whole pluton. Sericitic alteration characterizes the Pescadero pluton.

Primary magmatic minerals are quartz (26-38%), K-feldspar (25-37%), plagioclase (26-40%), biotite (0-5%) and muscovite (0-4%). Common accessory minerals (0.7-1.4%) are magnetite, zircon, sphene, apatite and allanite. Calcite and quartz ± calcite ± epidote ± plagioclase ± chlorite microveins commonly occur.

Magmatic plagioclase is weakly to strongly altered to sericite (FIGURE 4a). Where alteration is extreme, plagioclase is replaced to coarse muscovite. Epidote locally occurs as an alteration product of plagioclase. K-feldspar exhibits weak kaolinitic alteration. Calcite usually replaces primary K-feldspar (FIGURE 4b) in the porphyritic facies of the Pescadero pluton. Biotite is generally altered to green chlorite (FIGURE 4c).

Secondary muscovite + chlorite (FIGURES 4d-e) and calcite + epidote + muscovite ± chlorite (FIGURE 4f) commonly replace the groundmass in the porphyritic facies of the pluton.

METHODS

Field work was done with the cooperation of the Investigation Group in Mineralogy, Petrology and Geochemistry “MINPETGEO” from the Geology

Department of the Universidad Industrial de Santander (UIS). Rb-Sr geochronology was carried out in the Geoscience Department of Shimane University (Japan).

Whole rock Rb and Sr content was measured on glass beads using a RIGAKU X-ray spectrometer (RIX-2000). Glass beads were made by mixing 1.8 g of sample with 3.6 g of flux consisting of lithium metaborate and lithium tetraborate. Standard samples JB-1a and JG-1a (Imai *et al.*, 1995) of the Geological Survey of Japan (GSJ) were analyzed.

Rb and Sr content of K-feldspar was determined by isotope dilution, mixing the mineral sample with $^{87}Rb/^{86}Sr$ mixed spike before decomposition. Whole rock and mineral samples of 100 mg were decomposed for $^{87}Sr/^{86}Sr$ isotope analyses. Whole rock and mineral isotopic ratios, and Rb, Sr concentrations in mineral were measured using a FINNIGAN MAT 262 thermal ionization mass spectrometer equipped with five collectors. $^{87}Sr/^{86}Sr$ ratios were normalized to $^{87}Sr/^{86}Sr$ = 0.1194. NBS987 Sr standard yielded values between 0.710221±09 and 0.710243±09. $^{87}Sr/^{86}Sr$ Measuring errors (2σ) are ±09%. Whole rock-mineral isochron age was calculated using the Isoplot/Ex software (Ludwing, 2001). Decay constant is $\lambda^{87}Rb = 1.42 \times 10^{-11}\ y^{-1}$ (Steiger and Jäger, 1977).

Rb-Sr GEOCHRONOLOGY

The least altered sample (JP18) was selected for whole rock-mineral Rb-Sr isotope analysis. This sample is a pink coarse grained biotite-bearing monzogranite and is locally cut by calcite microveins.

K-feldspar was separated by hand picking from a coarse grained monzogranite in the Pescadero pluton. This mineral was selected because its lowest alteration degree and highest Rb and $^{87}Sr/^{86}Sr$ isotope ratio relative to the whole rock, making isotope determination easy.

We report a whole rock-mineral isochron age of 129±8 Ma (FIGURE 5, TABLE 1). Considering the error, this age can be placed in early Cretaceous from Valanginian to Barremian, according to the Geologic time scale of the Geological Society of America (Palmer and Geissman, 1999). This age is younger than expected for the pluton according to field evidence and previous geochronological work carried out by Goldsmith *et al.* (1971). The significance of the new age reported here is addressed in the next sections.

The younger age suggests that the whole rock radiogenic ^{87}Sr was redistributed among the constituent minerals during an important thermal event, interpreted here, due to hydrothermal alteration. As consequence, the K-feldspar and the whole rock form an isochron whose slope records the time elapsed since the main episode of isotopic reequilibration (early Cretaceous). These reequilibration processes are common for igneous rocks and have been broadly documented (Faure, 1986; Dickin, 1995).

GEOLOGICAL IMPLICATIONS OF THE Rb-Sr AGE

Early Cretaceous Paleogeography

During the late Jurassic and the early Cretaceous the proto-Caribbean sea began to occupy the space among North and South America as result of rifting (Klitgorg and Schouten, 1986; Meschede and Frish, 1998). According to Ghosth *et al.* (1984), the alignment of the spreading axis in the proto-Caribbean ocean took place between 153 and 127 Ma for the Venezuela basin, and finished around 100 Ma.

In Colombia, regional sedimentary basins were formed during this time. They are represented by the Middle Magdalena Valley, the Eastern Cordillera, and the Llanos basins. Subsidence and basin formation began during the Triassic and spanned through Cretaceous with development of syn-rift megasequences related to the separation of the North and South America (Cooper *et al.*, 1995).

The sedimentary accumulation in the Eastern Cordillera was restricted to sites of the active basin subsidence which were generally located near the sites of maximum crustal stretching. The sites of maximum stretching are identified in Colombia by the presence of scattered microgabbro dykes. These gabbroic-rocks are restricted to the margins of major depocentres in both sides of the Eastern Cordillera and restricted to regions located north of Bogota and south of the Bucaramanga city (Fabre and Delaloye, 1982; Moreno and Concha, 1993).

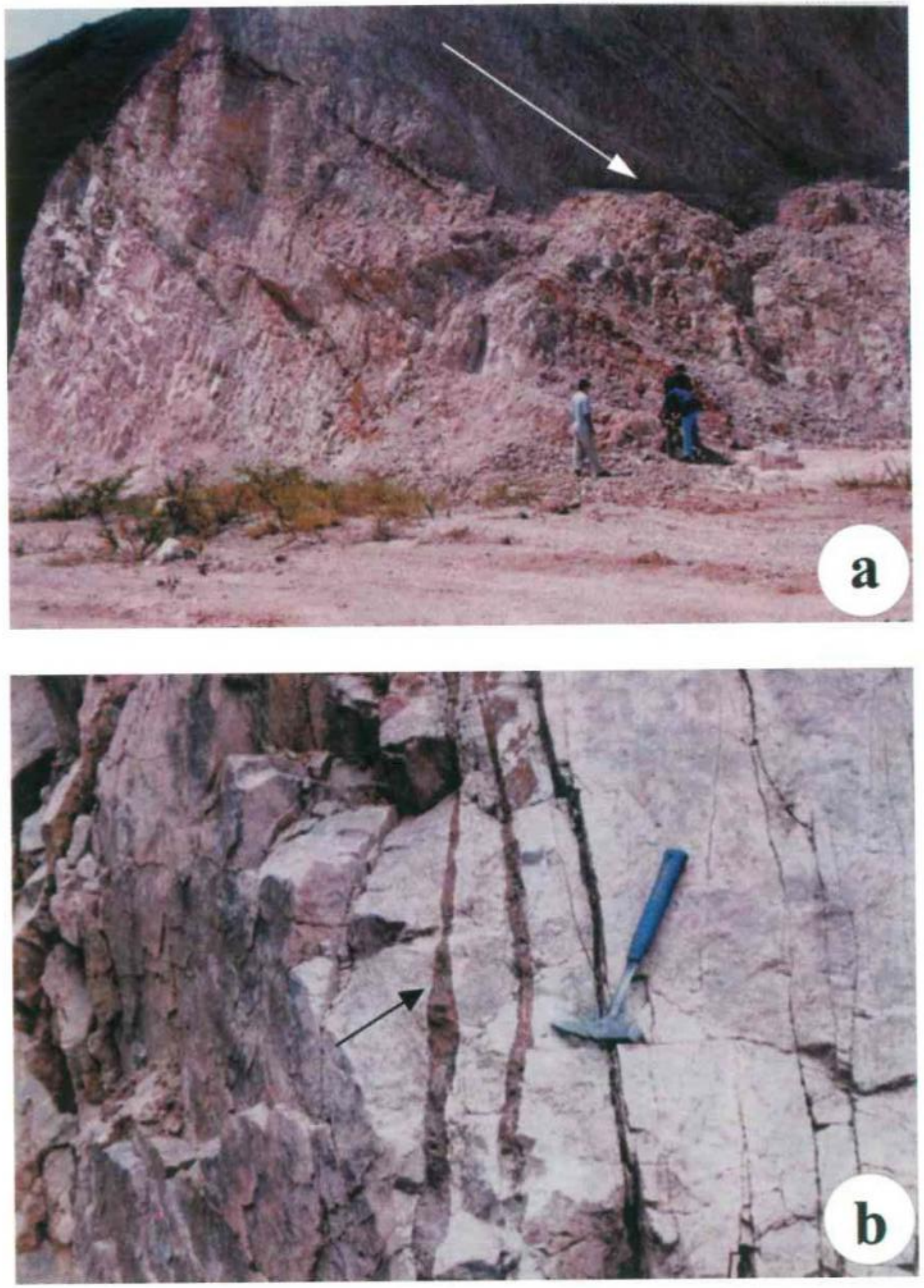

FIGURE 3. a) Shear zone hosting hydrothermal veins trending N30-35E/5NW (arrow). This outcrop is located in the Los Santos-Curos road. b) Calcite+siderite veins (arrow) and joints cutting the coarse grained lithologies of the Pescadero pluton along the Bucaramanga-Bogota road.

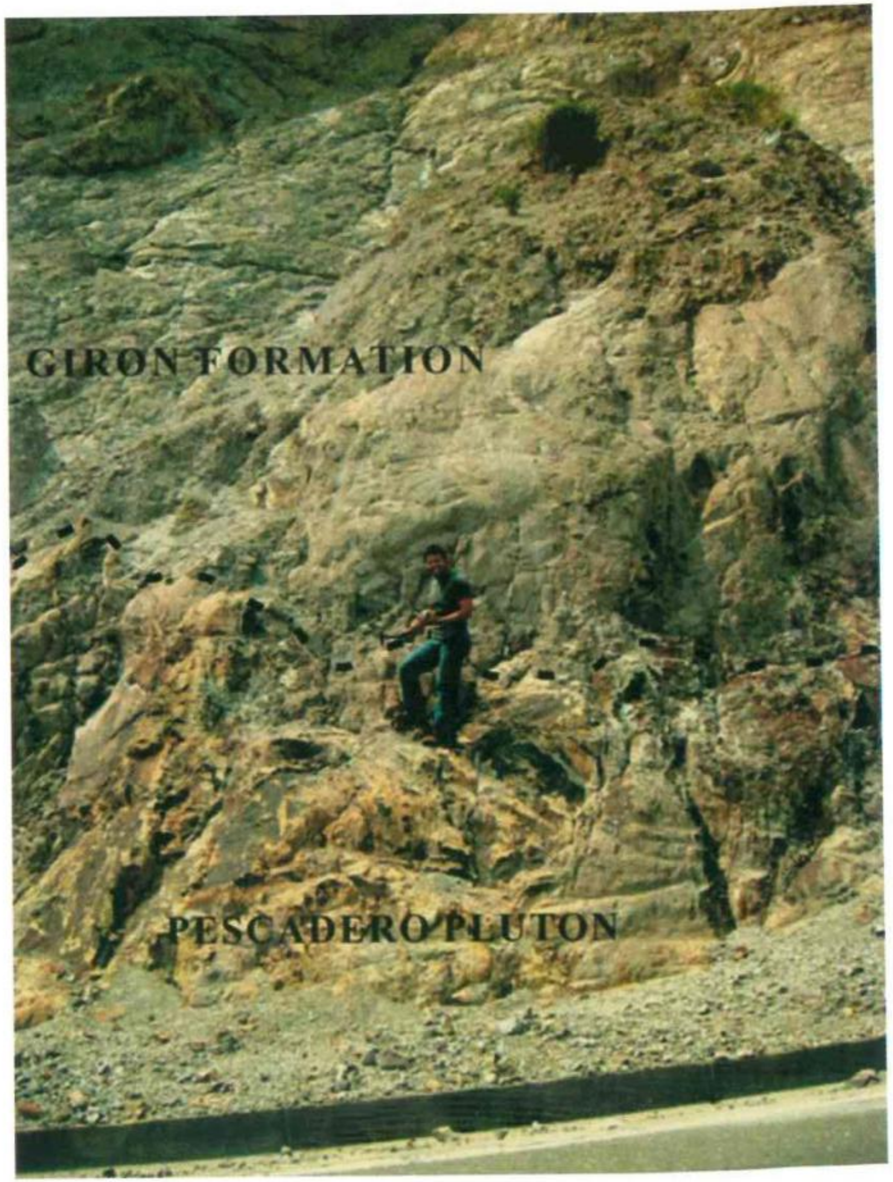

FIGURE 2. Unconformity between Giron Formation and Pescadero pluton (Los Santos-Piedecuesta road).

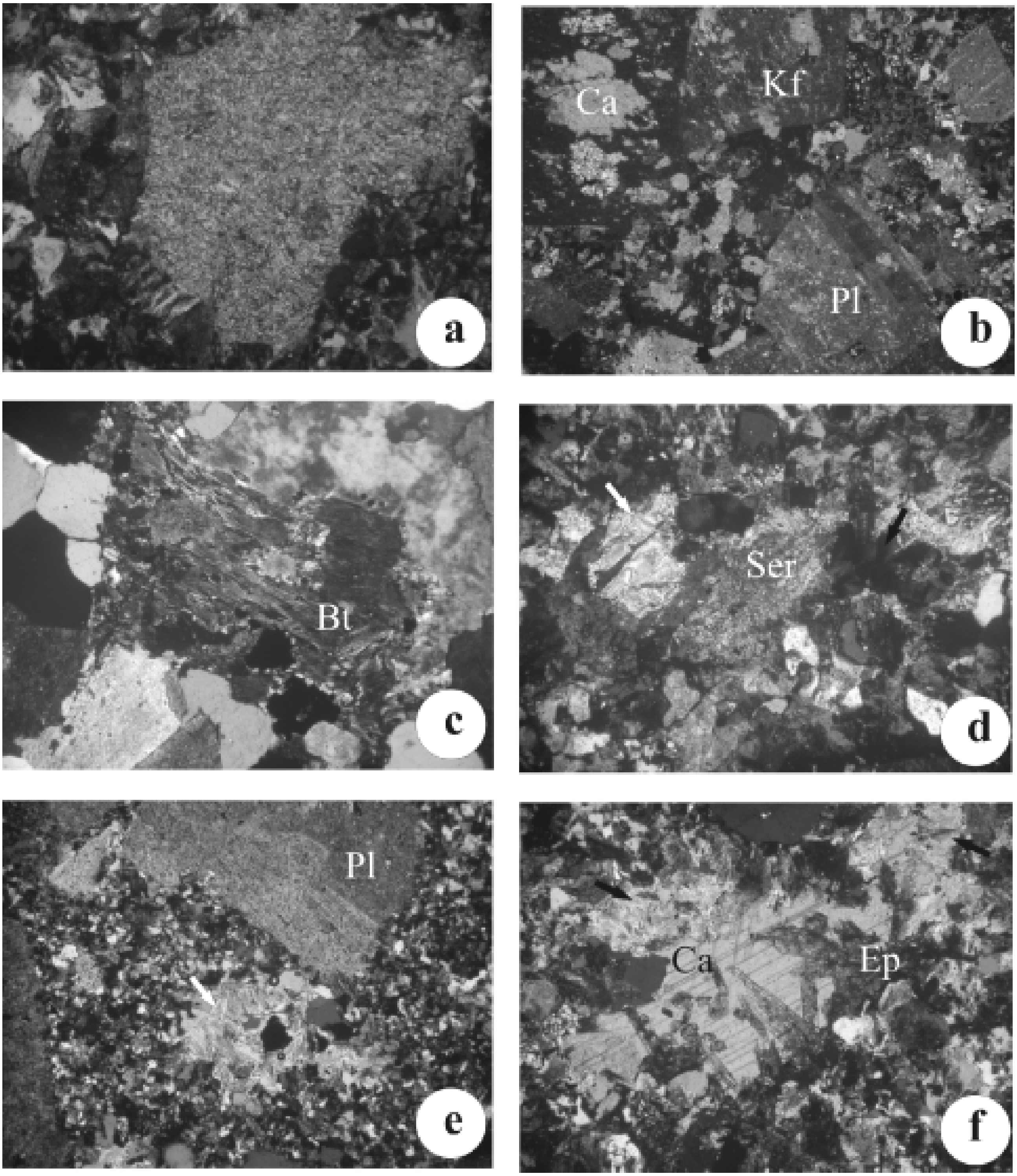

FIGURE 4. Alterations of the Pescadero pluton. Field of view in figures a) and d) is 1.45 mm, and 3.4 mm in the other figures. a) Strong sericitic alteration in plagioclase phenocryst. b) Patchy replacement of plagioclase (Pl) and K-feldspar (Kf) by calcite (Ca). c) Magmatic biotite (Bt) completely replaced by chlorite. d) Secondary muscovite (white arrow) and chlorite (black arrow) replacing the fine grained groundmass. Plagioclase is replaced by sericite (Ser). e) Secondary muscovite filling dissolution cavity (arrow). f) Calcite, epidote (Ep), Muscovite (arrows) replacing the fine grained groundmass.

TABLE 1. Rb-Sr isotopic data for whole-rock and K-feldspar in sample JP18.

	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Whole rock	152.46	247.96	1.780	0.714118 ± 09
K-Feldspar	326.15	229.75	4.111	0.718380 ± 09

An outstanding feature of the Cretaceous paleogeographic setting in the study area is the presence of a paleo-topographic high defined by the Santander Massif. This paleo-high acted as a barrier separating the Tablazo-Magdalena and Cocuy basins.

The Santander Massif paleo-high has economic significance due to the presence of evaporitic rocks surrounding the Santander Massif and evidence of paleo-hydrothermal events (fluorite veins?) possibly associated with its uplifting. The origin of this paleo-high as a mechanical response due to tensional stress (trending E-W) is improbable and contrasts with the crustal stretching and thermal subsidence occurring at that time. We believe that the paleo-high formation could be the result of thermal processes, which increased the crustal buoyancy and caused uplifting in this sector.

Early Cretaceous thermal events and uplifting are well documented north, in the Perija Range. Shagam *et al.* (1984) reported fission track zircon ages of 117±19 and 127±20 Ma for La Quinta Tuff, and 124±13 Ma for the Perija Gneiss. Those ages, similar to the age reported in this study, are interpreted as the age of subaerial volcanism (La Quinta Tuff) and the uplifting of the Perija Gneiss.

Local significance

Field relationships clearly show that the Pescadero pluton is unconformable with the early Cretaceous Los Santos Formation and the late Jurassic Giron Formation (Detailed descriptions of these stratigraphic units in Etayo and Laverde, 1985). Therefore, the Pescadero pluton is older than late Jurassic. Consequently, the 129±8 Ma age reported in this work is interpreted as a resetting age.

Calcite filled joints and shear zones hosting veins suggest that the Pescadero pluton has undergone extensive post-magmatic fracturing and hydrothermal activity. Secondary minerals such as sericite and chlorite, calcite-replaced K-feldspar and microveins suggest interaction with fluids. The above clearly postdate the pluton formation. In this context, we interpret the early Cretaceous age reported here as dating the hydrothermal event recorded in the Pescadero pluton.

Although lack of geochronological work on hydrothermal deposits in the area precludes direct correlation, other evidence supports our interpretations of an early Cretaceous hydrothermal event. Fluid inclusion studies (Mantilla *et al*. 2001; 2004) suggest that the fluorite lode deposit hosted in the marginal zones of the Pescadero pluton postdate the magmatic event (late Triassic-middle Jurassic). In addition, the occurrence of organic components in fluorite micro-cracks suggests the deposit predates the hydrocarbon generation (Tertiary). As a result, Mantilla *et al*. (2001) proposed a Cretaceous-early Tertiary age for the fluorite mineralization.

Rare Earth Elements (REE) studies in fluorite and altered host granite show a distinctive Ce and Eu negative anomaly (Mantilla *et al*. 2002). This was interpreted by those workers as inherited from sea water. Consequently, the fluorite deposit was formed during the Cretaceous marine transgression (Mantilla *et al*., 2004). Therefore, studies of fluorite deposits hosted in the marginal zones of the Pescadero pluton support an early Cretaceous hydrothermal event. Hence, the 129±8 Ma age could represent the age of the fluorite deposit.

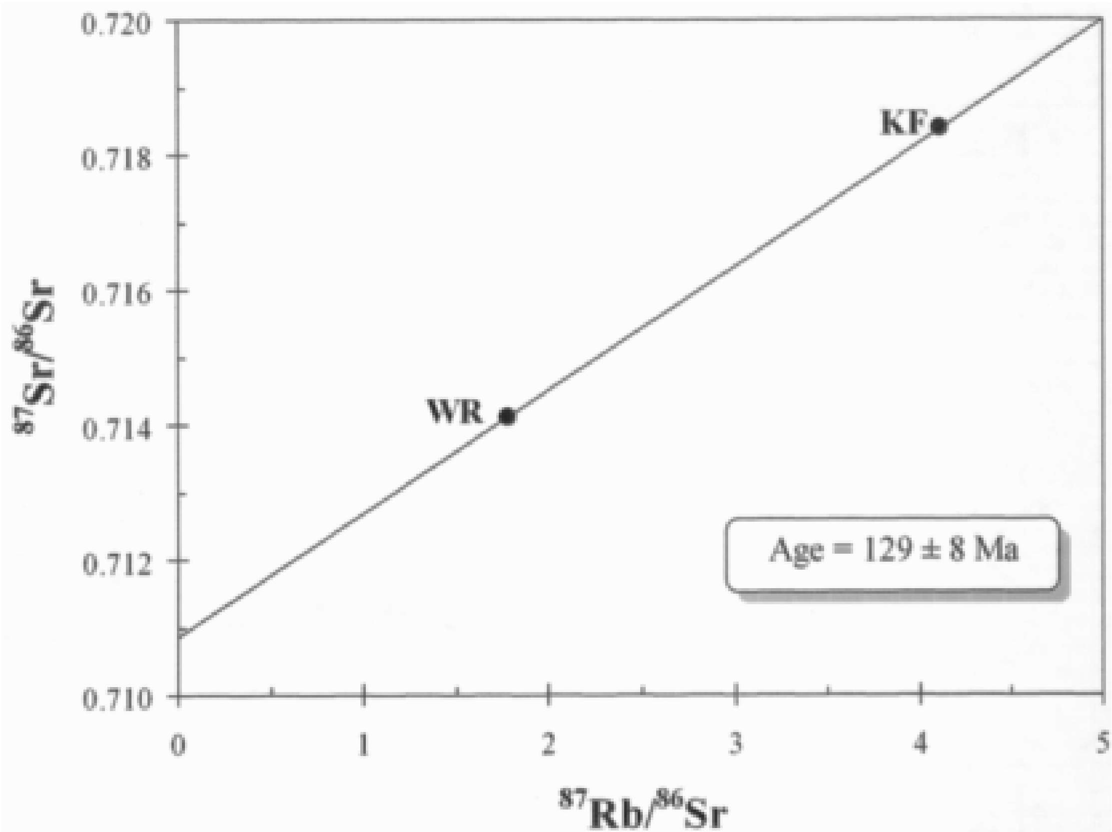

FIGURE 5. Rb-Sr whole-rock mineral isochron. WR = whole rock; KF = K-feldspar.

Descending marine waters could drive the fluid-rock interaction process that originated the fluorite veins. The heat source necessary for heating these waters could be temporarily related to the early Cretaceous magmatic event reported by Goldsmith *et al*. (1971) and Fabre (1983) and that caused the basic and felsic intrusions (bimodal magmatism?).

Regional significance

Goldsmith *et al*. (1971) reported two ages for the Corcova pluton: a muscovite K-Ar age of 199±7 Ma which they interpreted as the age of the pluton, and a conflicting biotite K-Ar age of 113±4 Ma which they interpreted as an unidentified thermal event. A rhyolite porphyry (*ca*. 160 km north from Pescadero pluton), considered to be Triassic-Jurassic, yielded a conflicting K-Ar sanidine age of 130±3 Ma. This age is similar to the age reported in this work.

The conflicting ages pointed out above and the age reported in this study cluster in the early Cretaceous. These ages are interpreted here as resetting due to thermal overprinting. Therefore, we consider that the hydrothermal event recorded in the Pescadero pluton is not local but a regional event developed throughout the Santander Massif.

Alternatively, Sillitoe *et al.* (1982) defined a middle Jurassic-early Cretaceous porphyry copper belt extending along the Eastern Cordillera. The resetting ages discussed here could reflect the late stage of this regional hydrothermal event recorded throughout the Cordillera.

Paleotectonic considerations

Cretaceous in eastern Colombia is characterized by extensional tectonics (Fabre, 1983) as a consequence of continental rifting. Crustal extension and coeval subsidence allowed marine transgressions and sedimentation of Cretaceous sequences, which are also present in the Santander Massif. Crustal thinning and normal faulting favored the emplacement of mafic and felsic dykes (Goldsmith *et al.,* 1971; Fabre y Delayole, 1982; Fabre, 1983; Moreno y Concha 1993) which are common in the Santander Massif.

This context favors the model mentioned above, in which sea water circulating through faults and fractures was heated by high geothermal gradient due to crustal thinning. In addition, the geothermal gradient was locally enhanced by the emplacement of mafic and felsic dykes. This model would explain the fluorite deposit (in terms of heat source) in the study area and the regional character of the early Cretaceous hydrothermal event suggested by the resetting ages discussed in this study.

CONCLUSIONS

The Rb-Sr whole rock-mineral isochron age of 129±8 Ma obtained in this work is interpreted as a resetting age dating in an early Cretaceous hydrothermal event overprinted in the Pescadero pluton. This event is not related to the magmatic evolution of the pluton. Similar resetting ages in the Santander Massif allow interpreting this event as regional.

The uplifting (thermal uplifting?) of the Santander Massif paleo-topographic high probably took place as a consequence of the bimodal magmatism (felsic and mafic) and its associated hydrothermal processes of the early Cretaceous age, contrasting with the widespread subsidence that was taking place at that moment and with mafic dykes in the more subsidence places. Apparently these differences are largely responsible for this opposite crustal behavior in the early Cretaceous, but in both cases the tectonic features are typical of the stage B in the Wilson cycle, as it is described and compiled in several internet sites (e.g: http://csmres.jmu.edu/geollab/Fichter/Wilson/Wilson.htm).

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