



GEOCHRONOLOGY OF PROTEROZOIC BASEMENT INLIERS FROM THE COLOMBIAN ANDES: TECTONIC HISTORY OF REMMANTS FROM A FRAGMENTED GRENVILLE BELT

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INTRODUCTION

Global orogenic events on the 1,2-0,98 Ga age interval (the Grenville orogenic cycle) have been attributed to successive continental collisions leading to the agglutination of the Rodinia Supercontinent (Hoffmann, 1991). Within the eastern Colombian Andes a few tectonic inliers of high grade metamorphic rocks are described, whose broad metamorphic and geochronological constrains have been shown to record a Grenvillian history. (Kroonenberg, 1982, Restrepo-Pace et al., 1997, Ordoñez 2001). However, the details of the tectono-metamorphic episodes are not clear, and the regional correlations with broader tectonic provinces are still poorly constrained.

The Colombian Andes are formed by three main mountain ranges that crosscut the country in a NE-SW direction. Geologically they are formed by several tectono-stratigraphic terranes (Fig. 1). The westernmost of these is a composite oceanic-derived terrane whose Meso-Cenozoic accretionary history has been fundamental for the understanding of the Andean orogeny. The eastern Andean domain is formed by at least three terranes (Tahamí, Chibcha and Andaquí), that include several tectonic inliers of Precambrian age. (see Toussaint, 1993, for review).

The basement of the easternmost continental terranes (Andaqui and Chibcha), is Proterozoic, however they show significant differences in their Paleozoic evolution. Whereas undeformed Cambro-Ordovician rocks cover the Andaqui terrane, the Chibcha terrane is characterized by a strong Early Paleozoic tectono-magmatic episode and by an extensive Late Paleozoic cover sequence (Toussaint, 1993). Their common Meso-Cenozoic tectonic evolution includes the installation of a Jurassic continental arc and associated basins, followed by an extensive Cretaceous transgression, and tectonic inversion in the Cenozoic, producing the high mountains.

New integrated geochronological data (U/Pb SHRIMP zircon and Sm-Nd garnet-whole rock analyses) were obtained on key samples from the Santa Marta, Guajira, Santander and Garzón massif (Fig 1). The U-Pb analyses were made either at ANU or at the Chinese Academy of Geological Sciences, and the methodological details can be found in Williams (1998). The Sm-Nd analyses were made at the USP, according with the methods described by Sato et al.(1995).

These results, combined with the previously available data, allowed to confirm the regional correlations already attempted, as well as to track a more dynamic tectonic evolution of the studied rocks, providing means to understand their crustal evolution.. The chapter that follows will report a short description of the geological setting of each geologic unit, followed by the presentation of the geochronological data acquired in this work.

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GARZON COMPLEX

The Garzon Complex (Figure 1) in southeastern Colombia is by far the more extensive and continuous exposure of the Proterozoic crust within the northern Andes. Kroonenberg (1982) and Ingeominas and Geoestudios (2001) considered a three-fold subdivision for the complex:

- (1) – Guapoton-Moncagua Gneisses, consisting of hornblende-biotite augen orthogneisses;
- (2) – Vergel Granulites, comprising quartz-feldspathic gneisses, charnockite to enderbite garnet granulites, with subordinate intercalated mafic, ultramafic and calc-silicate rocks;
- (3) - Las Margaritas Gneiss, a unit of predominantly meta-sedimentary character, made up by banded biotite-garnet-sillimanite gneiss and related rocks, injected by granitic leucosomes formed by partial fusion.

A geothermobarometric study on rocks of the Las Margaritas Gneiss indicated a near-isothermal decompression (ITD) path, with pressures between 8-4 Kb and temperatures between 800°-630°C. In contrast, the Vergel Granulites showed a counter-clockwise path along 6-7,0 Kb and 700°-733°C (Jimenez, 2003). Petrological evidence suggest prograde metamorphic conditions at about the amphibolite-granulite facies transition, with associated partial fusion related to biotite breakdown (Jimenez, 2003).

The previously available geochronological data from the Garzon Complex include a U-Pb zircon age of 1088 ± 6 Ma on the Guapoton-Mancagua Gneiss. In addition, there were some Rb-Sr whole-rock ages indicating a regional event around 1180 Ma, and several K-Ar ages between 975-915 Ma (Priem et al., 1989; Restrepo-Pace et al., 1997, and references therein)

New U-Pb SHRIMP ages for the Garzón Complex are reported in figures 2A, B and C. Figure 2A brings the data obtained on a sample of the Guapoton-Mancagua orthogneiss. In this rock, the zircons are elongated prisms, weakly rounded. CL images show core-border patterns, the latter clearly related to a metamorphic origin. The 12 analyses can be grouped in two main age populations: an older one with a $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1127 ± 35 Ma (MSWD= 0.14) defined by cores, and a younger one of 1000 ± 25 Ma (MSWD= 0,76) on the metamorphic overgrowths. The older age is considered as crystallization of the granitic protolith, and the younger one corresponds to the high-grade metamorphic event responsible for the fabric of the rock. Protolith age overlaps within error with the conventional U/Pb ages of 1098 ± 9 Ma presented by Restrepo-Pace et al. (1997).

Figure 2B brings the U-Pb SHRIMP results obtained from a sample of leucosome from a migmatite of the Las Margaritas Gneiss. The zircons are prismatic, with well developed faces, and all of them are nearly concordant, with a $^{207}\text{Pb}/^{206}\text{Pb}$ age of $1015 \pm 7,8$ Ma (MSWD=0,76). This age is interpreted as the crystallization of the leucosome, formed by partial fusion in a magmatic event associated with regional decompression and exhumation.

Figure 2C brings the U-Pb SHRIMP results on zircons from an enderbite belonging to the Vergel Granulites. Two main zircon populations were identified, one with strongly rounded crystals, and a second with elongated prisms. The zircons have high U contents, and metamict zones are common. Most apparent ages are discordant, and the points follow different trends of Pb loss. Two of the analyses suggest the presence of >1300 Ma compounds. A few of the prismatic zircons roughly define an upper intercept around 1100 Ma, whereas three rounded zircons seem to indicate a different intercept close to 1000 Ma. Although these data cannot be considered definitive, it is possible to interpret them in terms of a protolith formed at about 1100 Ma, by crustal derivation, and a metamorphic age around 1000 Ma.

A few Sm-Nd whole rock–garnet two point isochrones were obtained by Jimenez (2003) on rocks from the Garzón Complex. Two high-grade gneisses from the Las Margaritas Gneiss yielded 1034 ± 6 Ma and 990 ± 8 Ma, representing cooling below 600 °C, after the main metamorphism. A charnockite and a garnet gneiss of the Vergel Granulites presented ages of 935 ± 5 Ma and 925 ± 7 Ma, also corresponding to cooling ages below 600 °C. Such apparent ages confirm a different thermal evolution between the metamorphic units of the Garzón Complex. A Rb-Sr whole rock isochron of 959 ± 28 Ma was also obtained by Jimenez (2003), on a rock of the Vergel Granulites. The apparent ages around 1100 Ma of the rocks of the Garzón Complex are contemporaneous with the igneous activity recorded in the Guapoton-Mancagua Gneiss, and are coherent with the interpretation of these units being related within the same orogenic belt (Kroonenberg, 1982).

DIBUYA GNEISS

In the Sierra Nevada de Santa Marta, northern Colombia (Figure 1) a series of high-grade rocks occur, including banded felsic and intermediate gneisses, pelitic paragneisses, hornblende-pyroxene gneisses, and calc-silicate rocks, closely related to anorthositic stocks and dikes (Tschanz et al., 1974). This unit has been considered as derived from a volcano-sedimentary sequence. The Dibuya Gneiss is part of the northeastern exposure of this unit (MacDonald and Hurley, 1969), and corresponds to a centimetric to decimetric banded sequence of amphibolite and quartz-feldspathic rocks with associated migmatitic bands. Amphibole-plagioclase thermobarometry on amphibolites indicates metamorphic conditions between 6.0-7,6 Kb and 760-810° C, within the amphibolite-granulite facies transition (Cardona, 2003).

Previous geochronological data from the Dibuya Gneiss and other Santa Marta proterozoic rocks have shown metamorphic cooling ages around 970 Ma (Sm-Nd whole rock-garnet isochron, and Ar-Ar mineral ages), as well as complex U-Pb zircon ages between 1000-1500 Ma. (Tschanz et al., 1974, Restrepo-Pace et al., 1997, Ordoñez, 2001). Rb-Sr whole rock data yielded apparent ages around 1300-1400 Ma (MacDonald and Hurley, 1969).

A biotite gneiss was analyzed by the U-Pb SHRIMP method, on zircon crystals that are elongated, with rounded edges. They are frequently fragmented, and many exhibit metamict zones. The ages are distributed between 1400 Ma and 980 Ma (Figure 2D), with some of the analyses showing Pb loss. Five concordant zircons with a remarkably narrow Th/U ratio, around 0.3, yielded a strongly coherent $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1374 ± 13 Ma (MSDW= 0,51). Two other nearly concordant zircons present a $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1145 ± 14 Ma, and two more concordant grains presents $^{207}\text{Pb}/^{206}\text{U}$ ages of 1071 ± 15 Ma and 991 ± 12 Ma. The discordant zircons are the ones with more intense metamictization and Pb loss.

The ca. 1370 Ma. age can be attributed to the magmatic crystallization of the zircons within a magmatic protolith, and the zircon ages of 1145 ± 14 Ma are probably geologically meaningful since they are confirmed by the Rb-Sr isotopic systematics on the same samples (Cardona, 2003), and can be related to a strong metamorphic event. The 991 ± 12 Ma age can be related to a younger metamorphic event that must have been of high-grade, considering the thermobarometric evidence given above.

BUCARAMANGA GNEISS

The Bucaramanga Gneiss is regionally affected by the Paleozoic tectono-magmatic episodes that characterized the Chibcha Terrane (Figure 1). Lithologically it corresponds to a metamorphic sequence of andalusite, sillimanite, cordierite and garnet paragneisses, with intercalated amphibolites, marbles and calc-silicatic rocks. Mineral parageneses suggest metamorphic conditions within the low pressure type amphibolite facies (Ward et al., 1973), and preliminary plagioclase-hornblende thermobarometry on amphibolites indicate pressures between 4-6 Kb and temperatures of 600° - 800° C (Cardona, 2003).

Previous geochronological data are scanty. A K-Ar age on biotite indicated a cooling age of about 920 Ma (Ward et al., 1973), however Ar-Ar analyses on different minerals have shown a more complex thermal evolution, pointing to a strong Early Jurassic resetting episode related to the Mesozoic Andean tectono-magmatic activity (Restrepo-Pace et al., 1997, Cardona, 2003).

Figure 2E brings the analytical points of sixteen U-Pb SHRIMP analyses carried out on zircon crystals from a biotite gneiss. The zircons are prismatic, with rounded edges. Several points are concordant, and are distributed along the concordia between 1550 Ma and 900 Ma. Three grains exhibited ages older than 1430 Ma. Other grains scattered close to concordia between 1200 Ma and 900 Ma, and may indicate metamorphic resetting and/or mixed domains picked up during the spot analysis. Three of these zircons can be grouped at a $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1057 ± 28 Ma (MSDW=0,61) whereas an isolated but strongly concordant zircon yielded an age of 1112 ± 24 Ma. The younger group presented a $^{207}\text{Pb}/^{206}\text{Pb}$ age of 864 ± 66 Ma (MSDW=0,26), that is considered as related to a late metamorphic or hydrothermal episode.

JOJONCITO GNEISS

The Jojoncito Gneiss (Alvarez, 1967) represents the northernmost exposure of proterozoic rocks in South America. It is a fine to medium grained quartz-feldspatic rock comprised within the Pre-Mesozoic basement of the Guajira Peninsula in the Caribbean region of Colombia. Stratigraphic relations are predominantly tectonic, however gradational contacts with meta-sedimentary rocks

were observed. Previous geochronological datings include a Pb- α age of 1250 Ma (Banks, 1975). Moreover, gneissic boulders from a Cenozoic conglomerate on Bonaire, whose previous tectonic position can be related to the Guajira Peninsula presented U/Pb zircon ages of about 1160 Ma age (Priem et al., 1986).

The zircon crystals of the Jojoncito Gneiss show a variable external morphology, from prismatic to ovoid, with dimensions between 50 and 150 μm . Their internal structure on CL images is characterized by very clear core-border patterns. Most cores show oscillatory zoning typical of magmatic zircons, while borders are usually diffuse and homogenous, typical of metamorphic overgrowth. Such typologies indicate metamorphic conditions of high-grade amphibolite-granulite rocks (Vabrá et al., 1999).

Figure 2F brings the U-Pb SHRIMP results obtained in the zircon crystals of the Jojoncito Gneiss. The analytical point of cores with oscillatory zones are mainly concordant, and spread along the concordia with $^{207}\text{Pb}/^{206}\text{Pb}$ ages between 1200 and 1550 Ma. Three main groupings with similar ages and Th/U ratios can be suggested, with apparent ages of 1529 ± 43 Ma (MSDW= 0,05), 1342 ± 25 Ma and 1236 ± 16 Ma. The overgrowth domains present U concentrations typical of metamorphic zircon within high amphibolite to granulite facies (Vabrá et al., 1999). Six of them define a $^{207}\text{Pb}/^{206}\text{Pb}$ age of 916 ± 19 Ma (MSDW= 0,48), and two others yielded individual ages of ca. 1165 Ma.

The results indicate a complex geological history for the Jojoncito Gneiss. The different apparent ages are interpreted as related to a sedimentary protolith with Mesoproterozoic magmatic sources, while two superimposed metamorphic events occurred at 1165 Ma and 916 Ma. Time of deposition of the sedimentary protolith is bracketed by the oldest metamorphism at 1140 Ma and the youngest detrital zircon at 1260 Ma.

Nd ISOTOPIC CONSTRAINTS

Sixteen samples from all the studied Proterozoic inliers were considered for whole-rock Nd isotopic analyses, and the results are plotted in Figure 3. All Sm-Nd T_{DM} model ages are between 1,4-1,9 Ga and the Nd isotopic evolution lines exhibit strong similarities.

Negative to weakly positive ϵ_{Nd} values at 1140-1200 Ma, as well as the Sm-Nd model age pattern, indicate a mixture between Mesoproterozoic juvenile material and older crustal components for the protoliths of the high-grade metamorphic rocks. The pre-metamorphic zircon populations confirmed the importance of crustal reworking processes, and therefore the existence of an ancient continental basement of possible Paleoproterozoic age.

These Nd isotopic constraints are similar with data already reported for the same units, and other Proterozoic exposures from Colombia (Restrepo-Pace et al., 1997, Ordoñez, 2001). Therefore, an isotopic coherence is indicated for the basement domains of the Tahamí, Chibcha and Andaquí terranes, that may have been exposed to a common crustal evolution.

TECTONIC EVOLUTION

Their high-grade metamorphic character and the apparent synchronism of their metamorphic evolution, suggest that all studied Colombian proterozoic domains can be regionally correlated.

Due to the more extensive available data from the Garzon Complex, a reasonable interpretation of its tectonic evolution can be attempted. A magmatic arc can be envisaged at about 1130 Ma, established over an older continental margin. A first metamorphic event took place between 1100 and 1040 Ma, followed by a younger one at about 990 Ma. The latter was possibly due to a continental collision that produced large overthrusts and possibly a duplication of the crust, inducing the observed anticlockwise path for the metamorphism in the Vergel Granulites (Jimenez, 2003).

Within the northern units (Bucaramanga, Dibuya, and Jojoncito Gneisses) the tectonic environment may have been a continental rift over a previous continental mass (Cardona, 2003), with a maximum sedimentation age between 1200-1300 Ma. The metamorphic evolution includes a first event between 1140-1190 Ma, and a clearly defined later high-grade event with an age corresponding to the continental collision described for the Garzón Massif.

The presence of a possible active magmatic arc around 1130 Ma in the Garzon Complex, possibly synchronous with the first metamorphic episode in the other tectonic domains, suggests that a Cordilleran type tectonic setting was in existence at that time. Moreover, the younger events at about 950-1000 Ma can be associated to a strong collisional episode involving the entire region. The orogenic activity may have ceased between 950-920 Ma as suggested by several Ar-Ar cooling ages on minerals from rocks of the Garzon Complex and the Dibuya Gneiss (Cardona, 2003, Jimenez, 2003).

Regarding provenance, the older U/Pb zircon apparent ages from the Colombian Proterozoic rocks, roughly between 1300 and 1600 Ma, can be traced to sources that can be easily found within the Amazonian Craton (Tassinari et al., 2000). Arc magmatism at 1140 Ma within the Garzon Complex also compares well with the evolution of the Sunsas belt, at the SW corner of the Amazonian Craton. In addition, the Nd systematics shown by the Colombian domains (figure 3) also compares well with the SW part of the Amazonian Craton (Cordani et al., 2000; Tassinari et al., 2000). Moreover, the available Pb isotopic data from some Colombian rocks can also be related to the SW Amazon Craton (Tosdal and Bettencourt, 1994 and Ruiz et al., 1999).

Looking for large scale correlations, the proterozoic rocks south of the Ouachita suture in Mexico have been correlated with the Andean inliers by Ortega-Gutierrez et al. (1995). The tectonic history there includes an older crust with 1400-1500 Ma, an arc-rift tectonic environment between 1280-1110 Ma, a poorly constrained tectono-metamorphic event at 1100 Ma, and a granulite facies metamorphism between 990-974 Ma (Keppie et al., 2001, Solari et al., 2003 and reference therein). Moreover, within the South-Central Andes of South America a series of high-grade metamorphic rocks occurs, forming the basement of the Arequipa-Antofalla terrane in Southern Peru, Northern Chile and Bolivia. This domain yielded metamorphic ages between 1.20-0.98 Ga (Tosdal, 1996).

Orogenic events at the 1.2-1.0 Ga time interval have been related to the continental collisional processes that eventually produced the Rodinia Supercontinent (Hoffman, 1991). The Grenville Province of Laurentia is the more representative orogenic belt of this age. It is characterized by high-grade metamorphism and three successive tectonometamorphic events (Rivers, 1997): the older at about 1190-1140 Ma (Elzevirian pulse), the intermediate and more widespread at 1080-

1020 Ma (Ottawan) and the younger at 1000-980 Ma (Rigolet). The Elzevirian episode has been related to back arc closure and arc accretion, and the younger episodes have been related to continental collision (Rivers, 1997, Wasteneys et al., 1999). The age and metamorphic character found in the Colombian proterozoic rocks, as well as in their correlative terranes in Mexico and the Central Andes, show striking similarities with the Grenville belt. The common tectonic evolution of all these continental masses strongly suggest that they are fragments of the once coherent high-grade collisional belt that participated of the agglutination of Rodinia.

When the tectonic inliers from Colombia are merged with the correlatable Mexican and Central Andean domains, as well as with Laurentia, to form an extensive Grenville belt, as envisaged firstly by Hoffman (1991), a huge Meso-Neoproterozoic continental mass must be considered for the global paleogeographic reconstructions. When Laurentia separated from Gondwana forming the Iapetus Ocean at about 580 Ma (Cawood et al., 2001), it is apparent that many fragments were left behind not far from the western margin of Gondwana. Some of them, and specifically the Colombian terranes with basement inliers dealt with in this article, were later re-distributed and accreted to South America as allochthonous terranes, during Paleozoic orogenic pulses, in the process of agglutination of Pangea.

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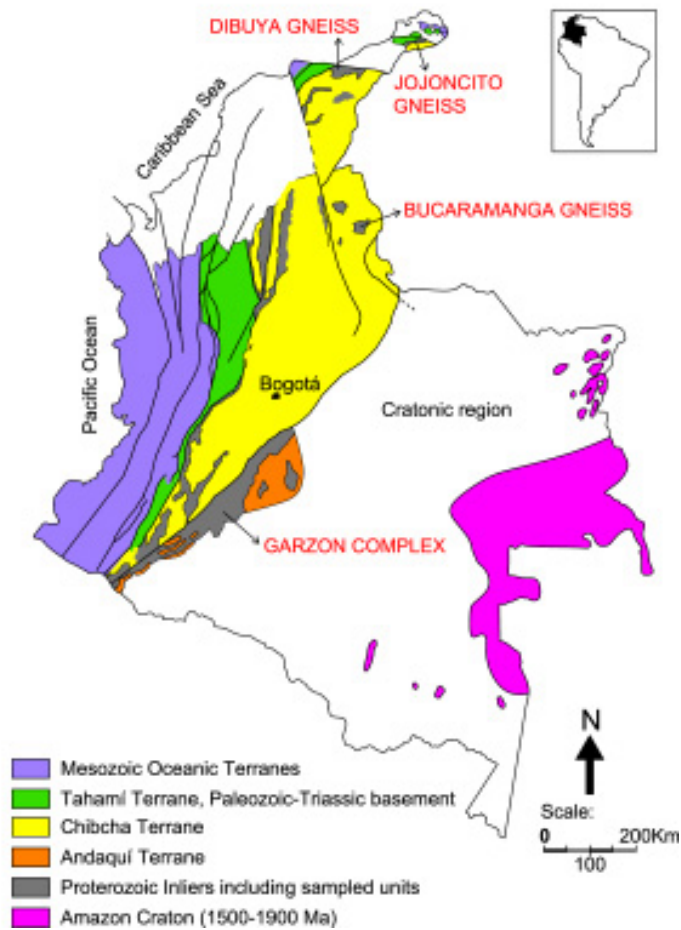


Figure 1. Terrane map from the Colombian Andes, regional faults (thick black lines) are included but not named, sampled units are shown, white areas are flat lands cover by Cenozoic sediments (Adapted from Toussaint, 1993)

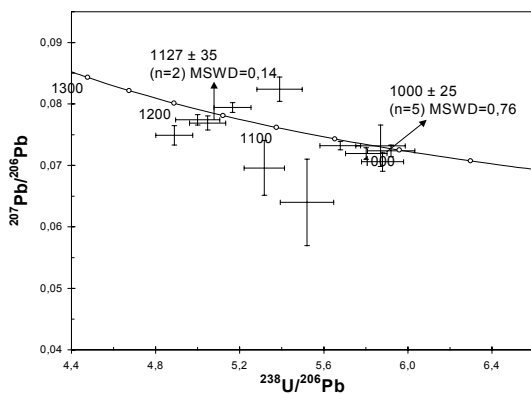


Figure 2A, zircon U/Pb results from hornblende-biotite gneiss, Guapotón-Mancagua Gneiss.

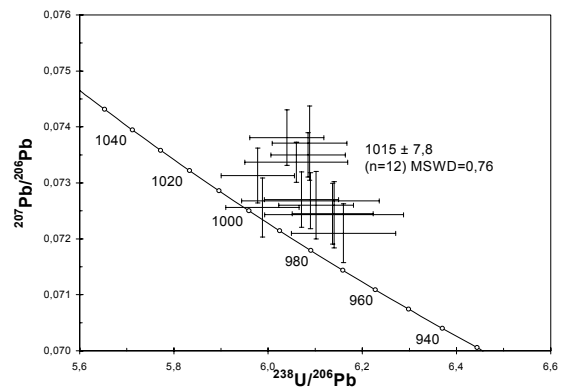


Figure 2B, zircon U/Pb results from an injected leucosome, Las Margaritas Gneiss.

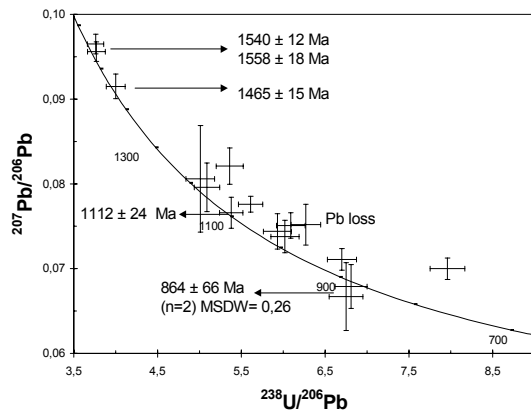


Figure 2C, zircon U/Pb results from an enderbite, El Vergel Granulites.

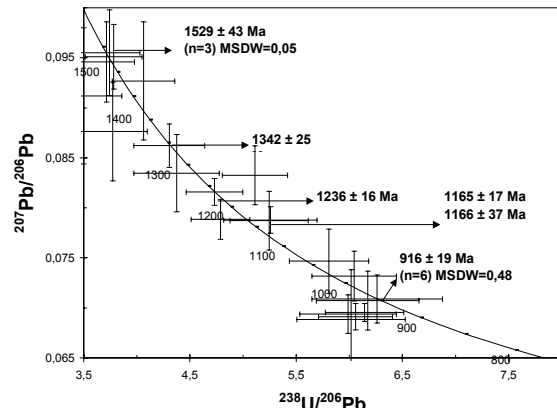


Figure 2D, zircon U/Pb results from a biotite gneiss, Dibuya Gneiss.

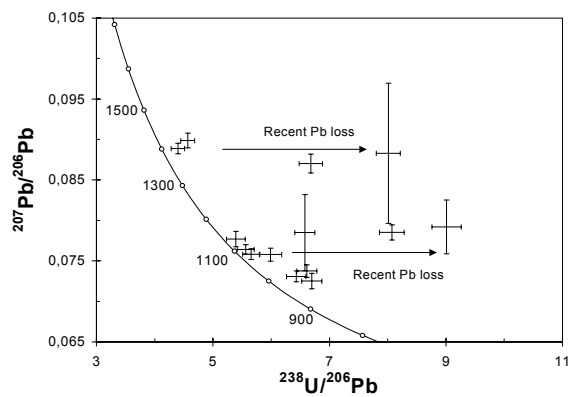


Figure 2E, zircon U/Pb results from sample a biotite-gneiss, Bucaramanga Gneiss.

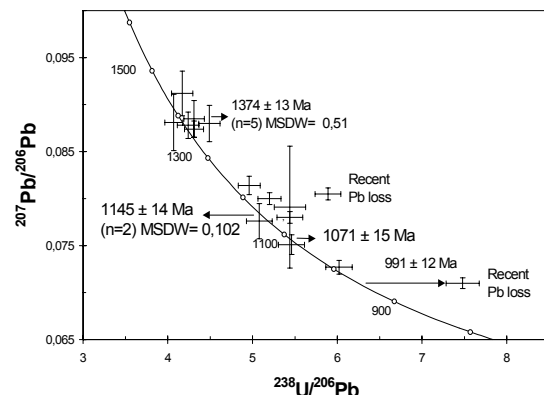


Figure 2F, zircon U/Pb results from a sample of the Jojoncito Gneiss.

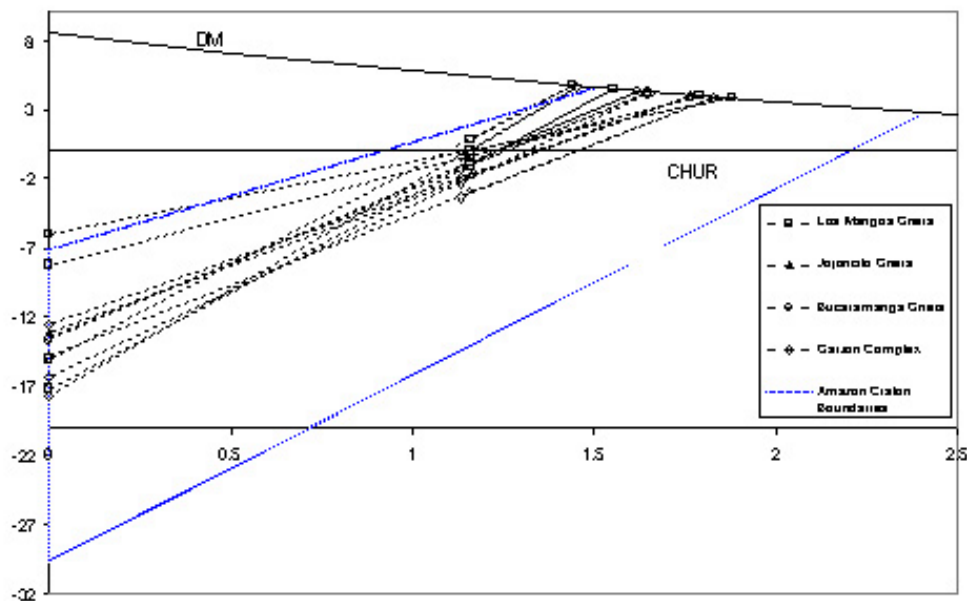


Fig. 3. Nd isotopic evolution of samples from the Colombian basement inliers. The envelope of Nd evolution of the Amazonian Craton is also included.