C-ISOTOPE STRATIGRAPHY OF SOME EDIACARAN-CAMBRIAN CARBONATE SUCESSIONS IN NW GONDWANA

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ABSTRACT

The C-isotope chemostratigraphic pathways displayed by exquisitely well-preserved marble successions from the Cajamarca-Valdivia (C-V) and Chicamocha (CH) Terranes, Central and Eastern Colombia respectively, suggest a late Ediacaran- early Cambrian deposition of their sedimentary pelagic protoliths. While marbles from the C-V Terrane (*i.e.* the C-V Metasediments and the Aleluya Complex) display C-isotope chemostratigraphic pathways that are indistinguishable from those displayed by late Ediacaran (~560 - ~545 ma) limestone successions worldwide, marbles from the CH Terrane (*i.e* Silgara Fm.) display C-isotope chemostratigraphic pathways that suggest a deposition spanning from the late Ediacaran to the early Cambrian. The C-isotope chemostratigraphic pathways displayed by the studied marble succession provide trustworthy information for 1) correlating the C-V Metasediments with the Aleluya Complex and the Silgara Formation and 2) inferring the occurrence of pelagic Ediacaran-Cambrian sedimentation along a marine realm located in NW Gondwana.

GEOLOGIC SETTING AND AGE

The three lithostratigraphic units in which this investigation was focused (*i.e.* The Cajamarca-Valdivia metasediments, the Aleluya Complex and the Silgara Formation) crop-out along three very distinctive (?) tectonostratigraphic entities, the Cajamarca-Valdivia Terrane, the Ibague Block and the Chicamocha Terrane (Fig. 1; for a provocative summary on the tectonostratigraphic division of NW Gondwana refer to Cediel et al., 2003)

The Cajamarca-Valdivia metasediments crop out along the eastern and western flank of the Central Cordillera of Colombia (CCC) and constitute the main stratigraphic unit of the Cajamarca-Valdivia Terrane (Fig. 1., Cediel et al., 2003). While the metasedimentary successions cropping out along the western flank of the CCC are characterized by intercalations of metapelites, marbles and abundant metamafic rocks, the metasedimentary successions cropping out along its eastern flank consist of intercalations of thick quartzites, amphibolite-facies marbles and graphite-bearing schists.

differences in metamorphic grade between this measedimentary successions and other well dated On spite of the noticeable lithoestratigraphic differences displayed by the C-V Metasediments along these two geographically distant areas, both successions have been considered as correlative based on its relationship with other lithostratigraphic units (Restrepo-Pace 1995). Although an Ordovician age have been proposed for the deposition of their sedimentary protoliths, based mainly on the occurrence of Devonian-Carboniferous orthogneisses, Triassic S-type granitoids and Cretaceous calc-alkaline granitoids intruding the metasedimentary succession (Cediel et al., 2003), not absolute ages have been jet obtained to support such depositional ages. In fact, based on the available geologic data, the depositional age of the sedimentary protoliths of the C-V metasediments can be placed some time between the early Neoproterozoic and the middle Paleozoic, as suggested by the possible early Neoproterozoic (?) age of the C-V Terrane basement; this age is suggested by the ~0.98 Ga U-Pb SHRIMP age obtained from inherited zircons in a Triassic granitoid (*i.e.* Amagá Pluton, Vinasco et al., 2003) that intrudes the metasedimentary succession, the Devonian orthogeneisses intruding the metasedimentary succession (Restrepo-Pace, 1992) and the strong folding and shearing that have affected the C-V metasediments at least since the middle Paleozoic (Cediel et al., 2003),

The Aleluya Complex, on the other hand, is a metasedimentary succession consisting of intercalations of marbles, quartzites and metarenites. This metasedimentary sucessions crops out along the eastern flank of the CCC along the Ibague Block (*sensus* Cediel et al., 2003, Fig.1) and is in faulted contact with the Jurassic Saldana Formation. The A;e;uya Complex is also intruded by the Jurassic Ibague batolith, which generated cornubian-piroxene facies of metamorphism (Velandia et al., 2001). The metasedimentary succession was also affected by regional metamorphism and metamorphosed to green-schist facies. Unfortunately no geochronologic data has been thus far published to constrain the age of such regional metamorphism, as have not been so geochronologic or biostratigraphic data supporting the depositional age of their sedimentary protoliths. However, despite the lack of geologic data a late Proterozoic age has been proposed based on metasedimentary successions cropping out along the study area (Velandia et al., 2001).

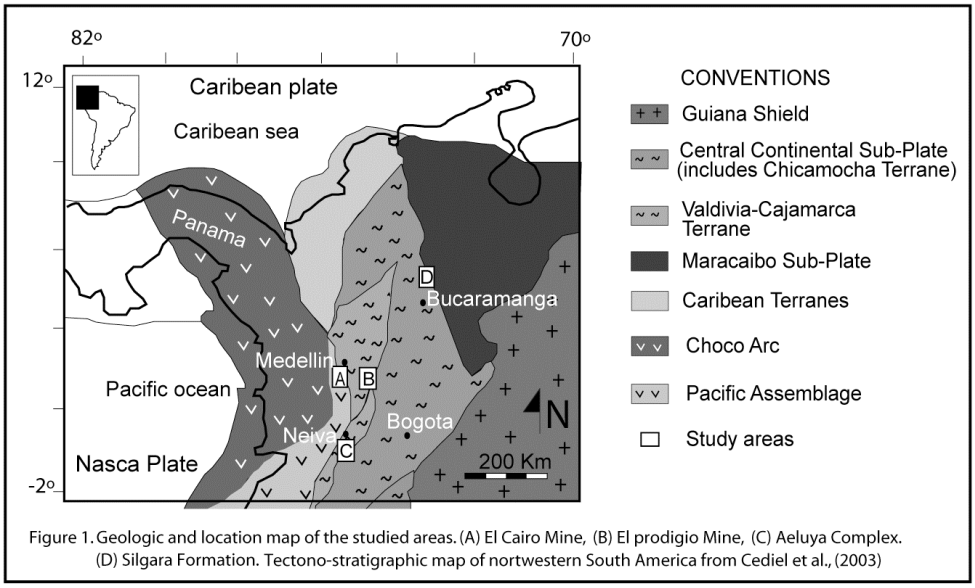

Figure 1. Geologic and location map of the studied areas. (A) El Cairo Mine, (B) El prodigio Mine, (C) Aeluya Complex. (D) Silgara Formation. Tectono-stratigraphic map of nortwestern South America from Cediel et al., (2003)

The Silgara Formation, on the other hand, is one of the extensively occurring high-grade metasedimentary successions overlaying Grenvillian-age massifs in northwestern Gondwana. It overlies metamorphic rocks from the Santander Massif (Fig. 1) and mainly consists of metapelites intercalated with scarce marbles and minor metamafic rocks of unknown age. The marble successions have been affected at least by three distinctive deformational events. The metasedimentary succession was metamorphosed to upper epidote-amphibolite to lower upper-amphibolite facies and is injected by Ordovician age orthogneisses. It is unconformably overlain by extensive non-metamorphosed Devonian siliciclastic successions, which in turn overlay both the Grenvillian age metamorphic basement (Bucaramanga Gneiss) and the Ordovician orthogneisses intruding the Silgara Formation. The depositional age of the Silgara Formation is poorly constrained. In a simplistic scenario the lower limit for deposition of its sedimentary protoliths has been considered as post-dating the terminal Mesoproterozoic-Early Neoproterozoic high-grade metamorphic event affecting northwestern Gondwana. This age is proposed based mainly on its discordant stratigraphic relationship with the Bucaramanga Gneiss. The upper limit for sedimentation of the sedimentary protoliths is considered as predating the injection of a 477± 16 Ma (U-Pb/conventional zircon) syn-tectonic orthogneiss (Restrepo-Pace, 1995), the deformation stiles of which is similar to that displayed by the Silgara metasediments.

ANALITICAL TECHNIQUES AND METHODS

One hundred forty six core marble samples from the C-V metasediments, 90 outcrop marble samples from the Silgara formation and 10 outcrop marble samples from the Aleluya Complex were analyzed for their C- and O-isotope compositions. About 25 mg of micro-drilled carbonate samples were initially reacted with 100% orthophosforic acid for 24 hours to produce gaseous CO_2 samples. Ultra-clean CO_2 samples were then extracted by using a high-vacuum extraction line and cryogenic cleaning, following the method proposed by Craig (1957), and finally analyzed for C- and O- isotopes in a double-inlet gas source, triple-collector mass spectrometer (Sira II), at the Stable Isotope Laboratory (LABISE), Department of Geology, Federal University of Pernambuco. The isotopic composition of the analyzed samples were contrasted against the in-house standard Borborema Skarn Calcite (BSC), which calibrated against the NBS-18, NBS-19 and NBS-20 standards, shows an isotopic composition of $\delta^{18}O$ = -1.28 ± 0.04‰ $_{PDB}$ and $\delta^{13}C$ = -8.58 ± 0.02‰ $_{PDB}$. The isotope data are reported in the international delta per-mil notation (δ ‰$_{PDB}$). The external reproducibility of the analisises is better than 0.01‰.

C-ISOTOPE STRATIGRAPHY

Marbles from the El Cairo Mine, C-V Metasediments, display $\delta^{13}C$ values between -1.91‰ and 3.16‰. The lowermost part of succession display $\delta^{13}C$ values that fluctuate between 0.9 and 1.95‰ (Fig. 2), and are interrupted upward section by a single negative excursion to $\delta^{13}C$ values near -0.72 ‰. Such negative excursion is subsequently interrupted by a new positive shift to $\delta^{13}C$ values between 1.6 and 3.16‰, which then shift back to $\delta^{13}C$ values near -1.91‰. The uppermost part of the marble succession displays $\delta^{13}C$ values between 0.1 and 2.0 ‰.

Marbles from the El Prodigio Mine, display $\delta^{13}C$ values between -3. and 4. ‰. The base of the marble succession displays a C-isotope plateau, with $\delta^{13}C$ values between 2.9 and 3.8 ‰, which fluctuates upward in the stratigraphic section between 2.5‰ and 4.0‰. Such positive C-isotope plateau is interrupted upward in the stratigraphic section by a sharp and pronounced decrease to $\delta^{13}C$ values around -3.‰, which in turn are subsequently interrupted by an increase to $\delta^{13}C$ values near 3.7 ‰$_B$ along the middle part of the stratigraphic succession (Fig.2). The marble succession terminates with $\delta^{13}C$ values averaging 3.6 ‰, which locally fluctuate between 3 and 3.7‰,.

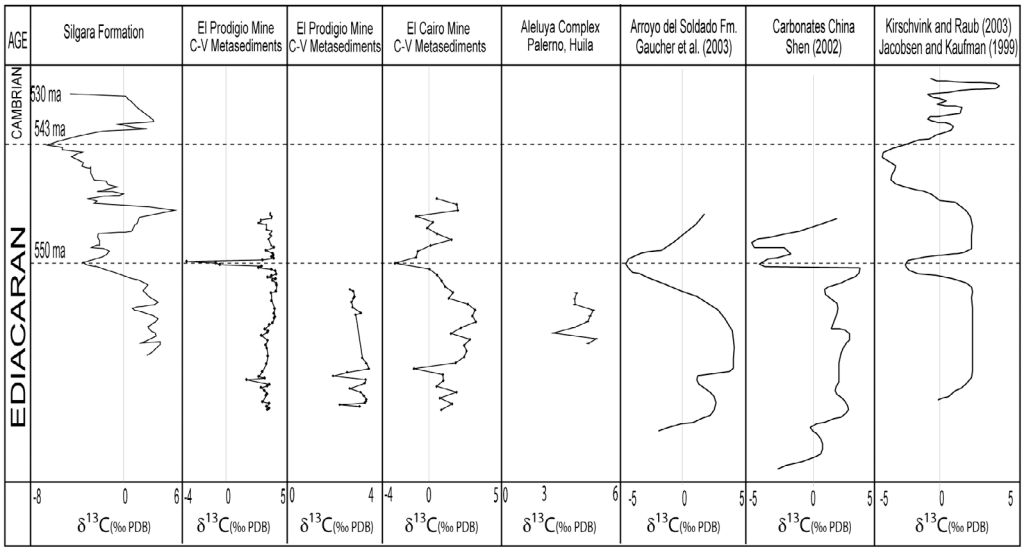

Figure 2. C-isotope stratigraphy of the studied marble sucessions. Included also are the C-isotope stratigraphy of geochronologically and biostratigraphically well-dated carbonate sucessions world-wide and the C-isotope stratigraphy of other Ediacaran-Cambrian marble sucessions from central and eastern Colombia.

Marbles from the Aleluya Complex (samples labeled as Neiva in Table 1, courtesy of Dr. Fabio Cediel, GEOTEC) display, on the other hand, $\delta^{13}C$ values between 3.4 and 5.12 ‰ (Fig.2). While marbles from the base of the succession display $\delta^{13}C$ values between 3.44 and 5.12‰, marbles from its upper-most part display almost invariant $\delta^{13}C$ values, between 4.4 and 4.5 ‰, which conform a C-isotope plateau.

Finally, Marbles from the lowermost part of the Silgara Formation also display an isotope plateau with $\delta^{13}C$ values averaging +3.0‰. These values locally fluctuate between +1.5‰ and ~+2.5‰ (Fig. 2) and are interrupted by a negative excursion to $\delta^{13}C$ values near -3.7‰. As in the Cajamarca-Valdivia metasediments, these values shift back up-section towards $\delta^{13}C$ values as high as +4.6‰. A second negative excursion to $\delta^{13}C$ values ~ -7‰ interrupts once again these positive values. The succession terminates with marbles displaying $\delta^{13}C$ values between ~ +1.0 and ~ +2.6‰, which finally fall towards $\delta^{13}C$ values near -5.0‰ (Fig. 2).

DISCUSSION AND CONCLUSIONS

The C-isotope chemostratigraphic pathways displayed by the analyzed marbles successions are undistinguishable from those displayed by terminal Proterozoic limestone successions worldwide (Fig. 2). The similar C-isotope chemostratigraphic pathways displayed by the marble successions from the El Prodigio and El Cairo mines constitute, for the first time, trustworthy evidences suggesting that the extensively occurring Pre-Devonian metasedimentary successions cropping out along the eastern and western flanks of the Central Cordillera of Colombia are correlative. Although an offset of near 1‰ in $\delta^{13}C$ values is observed between the two analyzed marble successions, we interpret such an offset as a being the result of changes in the C-isotope composition with water depth during carbopnate deposition. This way the marble successions from the El Cairo Mine, which seem to have been deposited in deeper waters than those from El Prodigio Mine, precipitated from more ^{12}C rich ocean waters. On the other hand, the similar C-isotope chemostratigraphic pathways displayed by marble successions from the C-V metasediments and by marbles from the Aleluya Complex also suggest a coeval depositional age for these two successions. Such coeval depositional age for the sedimentary protoliths of these marble successions suggest either that the Aleluya Complex, which crops out along the Ibague Block, is likely a disrupted fraction of the C-V Metasediments or that it was deposited along the Ibague Block, the latter already constituting the limit of the C-V and CH by the late Ediacaran. Finally, the similar C-isotope chemostratigraphic displayed by marbles from the C-V Metasediments and Silgara Formation suggest, for the first time, that 1) The C-V and CH tectonostratgraphic units have sheared similar geologic evolution at least since the late Ediacaran and 2) that an extensive pelagic sedimentation took place along a terminal Proterozoic (Ediacaran) – Cambrian continental margin installed along the northwestern most part of Gondwana. Such pelagic sedimentation may have occurred as a consequence of the opening of a northern realm of the Iapetus Ocean as suggested by the presence of similar late Ediacaran marble successions in Argentina (Sierra de Pie de PaloSial et al., 2001), which have been considered as deposited during the opening of such ocean (Cawood, 2005; Fig.3).

References

Cawood, P., 2005, Terra Australis Orogen: Rodinia breakup and development of the Pacific and Iapetus margins of Gondwana during the Neoproterozoic and Paleozoic. Earth Science Reviews, v. 69, p. 249-279

Cediel, F., Shaw, R., and Caceres, C., 2003, Tectonic assembly of the northern Andean Block, *in* Bartolini, C., Buffler, R., and Blickwede, J., eds., The circum-gulf of Mexico and Caribbean: Hydrocarbon habitats, basin formation and plate tectonics. AAPG Memoir 79, p. 815-848.

Craig H., 1957, Isotope standard for carbon and oxygen and correction factors for mass spectrometry analysis of carbon dioxide. Geochimica et Cosmochimica Acta, v. 12, p. 133-149.

Gaucher, C., Boggiani, P., Sprechmann, P., Sial, A.N., Fairchild, T. 2003. Integrated correlation of the Vendian to Cambrian Arroyo del Soldado and Corumbá Groups (Uruguay and Brazil): palaeogeographic, palaeoclimatic and palaeobiologic implications. Prec. Res. 120: 241-278.

Jacobsen, S., and Kaufman, A., 1999, The Sr-, C- and O-isotopic evolution of the Neoproterozoic seawater. Chemical Geology, v. 161, p. 37-57.

Restrepo-Pace, P., 1992, Petrotectonic characterization of the Central Andean Terrane, Colombia. Journal of South American Earth Sciences, v. 5, p. 97-116.

Restrepo-Pace, P., 1995, Late Precambrian to early Mesozoic tectonic evolution of Colombian Andes, based on new geochronological, geochemical and isotopic data. Doctoral Thesis, Department of Geosciences, University of Arizona. 195p.

Shen, Y. 2002. C-isotope variations and paleoceanographic changes during the late Neoproterozoic on the Yangtze Platform, China. Prec. Res. 113:121-133

Sial., A.N., Ferreira, V., Tosselli, F., Aceñolaza, F., Pimentel, M., Parada, M., and Alonso, R., 2001, C- and Sr- isotope evolution of carbonate sequences in NW Argentina: Implications for the probable Precambrian-Cambrian Transition. Carbonates and Evaporites, v. 16, p. 141-152.

Velandia, F., Nunes, A., Martines, G., 2001. Mapa Geologico del Departamento del Huila. Memoria explicativa. 153p.

Vinasco, C., Cordani, U., Gonzalez, H., Vasconcelos, P., and Liu, D., 2003, Tectono magmatic evolution of the northern part of the Central Cordillera of Colombia using Ar-Ar and U-Pb SHRIMP methodologies. IX Congreso Colombiano de Geologia. Abstracts, p. 57-58.

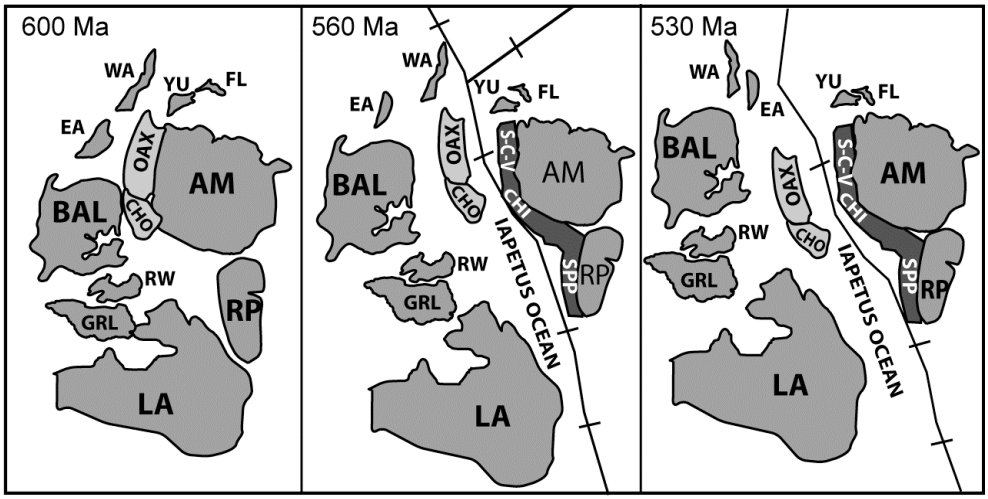

Figure 3. Terminal Proterozoic- Early Cambrian Paleogeographic evolution of NW Gondwana from a global perspective (modified after Cawood, 2005). Note the location of different Ediacaran Cambrian sedimentary successions deposited after the opening of the Iapetus Ocean in western Gondwana: (S-C-V) Silgara Formation and Cajamarca-Valdivia metasediments, (CHI) Chiguinda Formation, (SPP) Sierra de Pie de Palo. Amazon Craton (AM), Oaxaca (OAX), Chortis (CHO), Rio de la Plata (RP), Yucatan (YU), Florida (FL), Western Avalon (WA), Eastern Avalon (EA), Baltica (BAL), Laurentia (LA), Greenland (GRL), Rockwall (RW).

RESUMEN

Variaciónes de la composición isotópica de C (quimioestratigrafía de isótopos de C) de secuencias de mármoles bien preservadas y que afloran a lo largo de los terrenos tectonostratigraáficos Cajamarca-Valdivia (C-V) y Chicamocha (CH), parte central y occidental de Colombia, sugieren una edad de sedimentación para sus protolitos pelágicos entre el Ediacarano tardío y el Cambrico temprano. Mientras los mármoles del C-V (i.e. metasedimentos de Cajamarca-Valdivia y el Complejo Aleluya) muestran tendencias quimioestratigráficas ($\delta\ ^{13}C$ entre -3.58 y +5.2 $‰_{PDB}$) idénticas a aquellas encontradas en secuencias de carbonatos sedimentarios del Ediacarano tardío (~560 - ~545 ma), los marmoles del CH (i.e Fm. Silgara) muestran variaciones quimioestratigráficas ($\delta\ ^{13}C$ entre -7 y +4.6 $‰_{PDB}$) que sugieren una depositación extendiéndose desde el Ediacarano tardío hasta el Cambrico temprano. Las variaciones quimioestratigráficas mostradas por estas secuencias de marmoles proveen fuertes evidencias para 1) correlacionar los metasedimentos de Cajamarca-Valdivia con los metasedimentos del Complejo Aleluya, y 2) inferir la ocurrencia de una sedimentación pelagica a lo largo de un estrecho marino localizado al NW de Gondwana durante el Ediacarano tardío-Cambrico temprano.