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THE TRANSITION FROM DIAGENESIS TO LOW-GRADE METAMORPHISM IN THE ARGENTINE PRECORDILLERA: AN APPLICATION OF THE CONODONT COLOUR ALTERATION INDEX

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ABSTRACT. The colour alteration index of conodonts (CAI) is used to describe the temperature distribution in the Precordillera of western Argentina, especially in rocks, which are still in the field of diagenesis or were only subject to a very low-grade metamorphic overprint. A map of temperature domains shows a simple pattern of temperature decrease from W to as a consequence of a tectono-metamorphic event in the western Precordillera during the Silurian and Early Devonian.

INTRODUCTION

The Argentine Precordillera is an Andean orogene composed of a thick pile of Phanerozoic sediments. Non-metamorphic Lower Palaeozoic limestones and clastics in the eastern and central ranges have their equivalents in anchizonal and epizonal metaclastics to the west.

There, radiometric dating, microfabric studies and petrographic analyses allow detailed observations on metamorphic processes and the thermal history. In the non-metamorphic rocks spatial effects of this thermal alteration are difficult to detect.

In 1977, Epstein et al. provided a new tool for study of regional temperature distribution, especially at the transition from diagenesis to low-grade metamorphism: the colour alteration index (CAI) of conodonts. Several regional applications of this concept, among which are Epstein et al. (1977), Harris (1979), Bergström (1981), Aldridge (1984) and Raven & Pluijm (1986) have proven its usefulness in deciphering the thermal history of sedimentary basins.

In the present study, the determination of the CAI is applied to the Early Palaeozoic sediments of the Argentine Precordillera in order to show the effects of the "western tectonometamorphic event" in the central and eastern ranges.

GEOLOGICAL SETTING

The Precordillera of Western Argentina is a high-level thrust- and fold-belt, mainly composed of Palaeozoic rocks and a few sequences belonging to the Early Mesozoic and Tertiary. Main crustal shortening occurred during Andean deformation and is estimated in about 50% in a transect along the Rio San Juan (Gosen 1992). This last and main deformation was not accompanied by important thermal heating, because even in sediments as old as the Carboniferous there is no evidence, that they were heated beyond the boundary between diagenesis and the very low-grad stage of metamorphism. This is indicated by kaolinite and illite/smectite, which are present (Buggisch et al. in press; Krumm pers. comm.) throughout the Precordillera.

During the Lower Palaeozoic (Cambrian to Silurian), the sedimentary succession of the Precordillera shows two main sequences (fig.1): In the eastern and central Precordillera (Ortiz & Zambrano 1981, Baldis et al. 1982) carbonate platform deposits are widespread during Cambrian and Early Ordovician times. From the Middle Cambrian onward, a continental slope developed to the W of the platform, where a variety of siliciclastic ("Cambrian of San Isidro"; Los Sombreros Fm.) and carbonate sequences (Las Aguaditas Fm.) were deposited. During Ordovician and Silurian times the area remained a stable clastic shelf. Furtheron, this area will be referred to as the "eastern" Precordillera.

The western Precordillera (Baldis et al. 1982) is characterized by a thick pile of basin clastics with intercalations of rift-related basic volcanics (Kay et al. 1984) of Late Ordovician age. Sediments older than the Early Ordovician are not yet documented.

Carbonates are extremely scarce and restricted to few dolomites and marbles in the Bonilla Fm. and Don Polo Fm.

The sedimentary sequences of both areas show a marked difference in deformation and metamorphic grade. In the western area, anchizonal to epizonal conditions are indicated by the presence of slates and phyllites with at least one marked cleavage, quartz recrystallisation and illite crystallinity data (Buggisch et al. in press, Krumm pers. comm.). Deformation and metamorphism are thought to be of pre-Carboniferous age (e.g. Cucchi 1971; Varela 1973; Buggisch et al. in press). In contrast, the Lower Palaeozoic of the eastern ranges lacks evidence of metamorphism and intense deformation, although a cleavage locally may be observed.

The colour alteration index (CAI) of conodonts: Methods and material Conodonts are microfossils composed of carbonate apatite (francolite: Pietzner et al. 1968).

As demonstrated by Epstein et al. (1977), conodonts change their colours progressively from colourless transparent (CAI = 0) to black (CAI = 5) with increasing temperature.

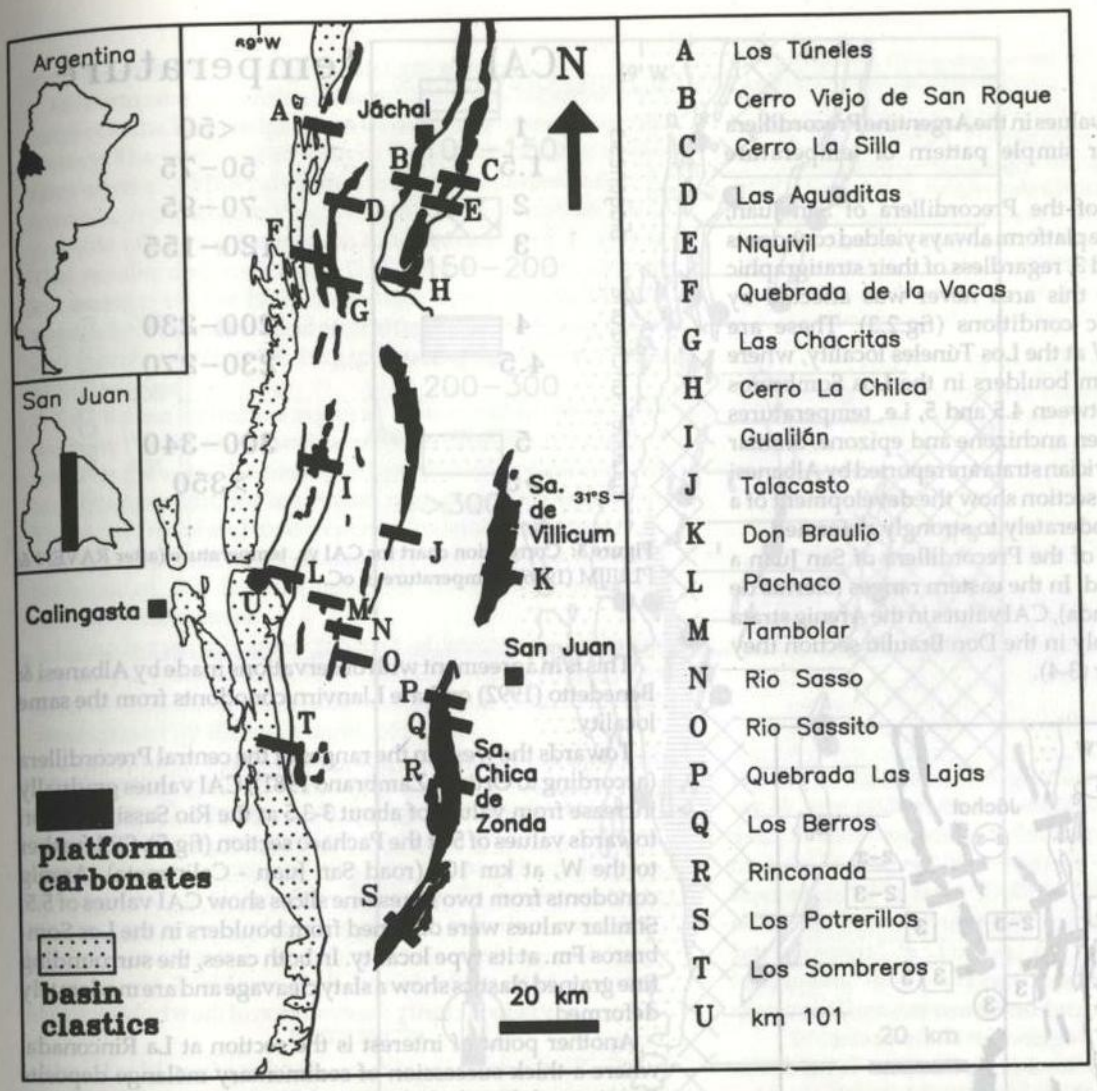

Figure 1: Distribution of Cambro-Ordovician sediments in the Argentine Precordillera and position of the sections.

Volatization of organic carbon at still higher temperatures leads to grey (CAI = 6) and finally to crystal clear colours (CAI = 8). Epstein et al. (1977) reported that the CAI also is time-dependant, i.e. the CAI should increase with increasing time that conodonts are exposed to peak temperature conditions. However, Price (1983, 1985) demonstrated that geologic time has no effect on maturation of organic material, even over geologically significant periods. Therefore, the CAI seems to reflect only peak metamorphic conditions.

The CAI was determined in comparison with the standard samples of HARRIS. In general, determination of the CAI was possible within a range of 0.5. From each locality (fig.2) several samples, each with a minimum of at least 10 individuals were counted. In some cases, phosphatic brachiopods were used complementarily. The correlation between CAI and corresponding metamorphic temperature (fig.3) is based on Epstein et al. (1977) and Raven & Pluijm (1986). In terms of metamorphic grade, CAI values between 1 and 3.5 indicate the field of diagenesis, 4 and 4.5 the anchizone, and values >5 epizonal (i.e. greenschist facies) conditions.

Conodonts with a CAI >5 normally show a beginning recrystallization which leads to granular surfaces. As demonstrated by Flajs (1980), the size of the individual apatite crystals can be used as a direct indicator of temperature conditions especially in the greenschist facies, but as samples of this metamorphic grade are not very abundant, this criterion was not applied to the study. Additionally, individuals with a CAI >5 are slightly deformed or cleaved.

The samples mainly were obtained from the Lower Ordovician San Juan Fm. but also from the Las Aguaditas Fm. (Llanvirn-Llandeilo), both predominantly sequences of carbonates.

Additionally, there are a few limestone samples of the Cambro-Ordovician boundary beds at the Cerro La Silla and the Los Túneles section (fig.1) and also from olistoliths at the type-section of the Los Sombreros Fm. (fig.1). Samples were dissolved in acetic acid for a maximum of three days in order to avoid etching of conodont surfaces and a leaching of the apatite, which may lead to an artificial alteration of the original colour.

RESULTS

Determinations of CAI values in the Argentine Precordillera seem to reflect a rather simple pattern of temperature distribution (fig.4).

In the northern part of the Precordillera of San Juan, limestones of the carbonate platform always yielded conodonts with a CAI between 2 and 3, regardless of their stratigraphic position, indicating that this area never was affected by anchizonal metamorphic conditions (fig.2,3). These are observed further to the W at the Los Túneles locality, where Cambrian conodonts from boulders in the Los Sombreros Fm. show CAI values between 4.5 and 5, i.e. temperatures near the transition between anchizone and epizone. Similar values from Middle Ordovician strata are reported by Albanesi et al. (1992). Rocks in this section show the development of a slaty cleavage and are moderately to strongly deformed.

In the central segment of the Precordillera of San Juan a similar pattern is observed. In the eastern ranges (Sierras de Villicum and Chica de Zonda), CAI values in the Arenig strata vary between 2 and 3. Only in the Don Braulio section they seem to be slightly higher (3-4).

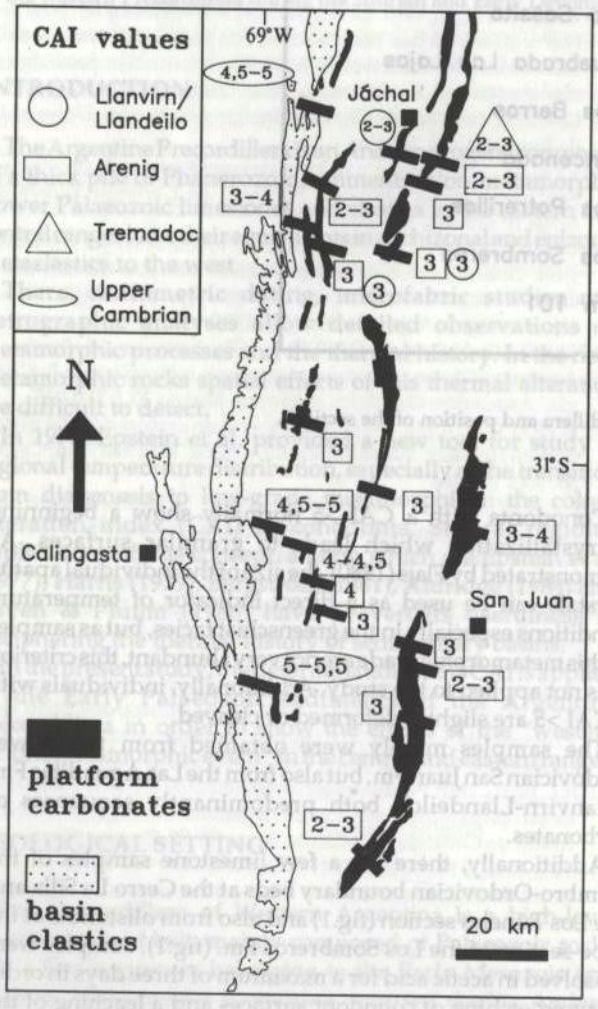

Figure 2: Distribution of CAI values in the Precordillera of San Juan. Sections as in fig.1.

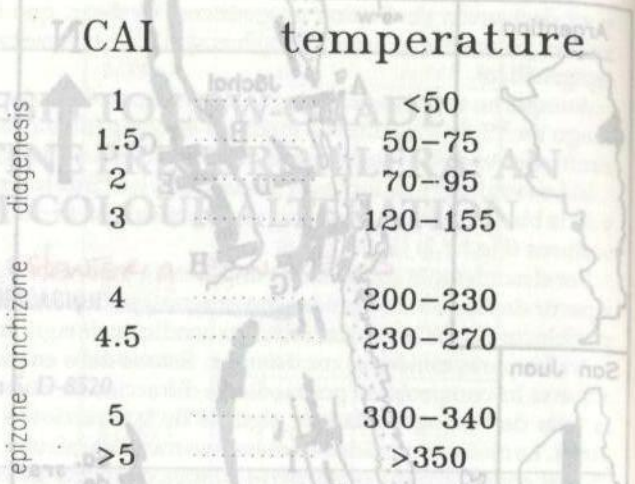

Figure 3: Correlation chart for CAI vs. temperature (after RAVEN & PLUIJM (1986). Temperature in oC.

This is in agreement with observations made by Albanesi & Benedetto (1992) on Late Llanvirn conodonts from the same locality.

Towards the west, in the ranges of the central Precordillera (according to Ortiz & Zambrano 1981), CAI values gradually increase from values of about 3-3.5 at the Rio Sassito section towards values of 5 at the Pachaco section (fig.5). Still further to the W, at km 101 (road San Juan - Calingasta), Arenig conodonts from two limestone slices show CAI values of 5.5. Similar values were obtained from boulders in the Los Sombreros Fm. at its type locality. In both cases, the surrounding fine grained clastics show a slaty cleavage and are moderately deformed.

Another point of interest is the section at La Rinconada, where a thick succession of sedimentary mélange deposits (continental slope facies) crop out. These sediments have long been attributed to as potential indicators of an inferred suture zone between the Precordillera terrane and the Sierras Pampeanas (Ramos et al. 1984; Dalla Salda et al. 1992a,b).

Recent studies on illite crystallinity (Buggisch et al. in press) indicate, that the sediments were exposed to metamorphic conditions at the boundary between the achizone and the epizone. This is contrasted by CAI values between 2 and 3, which plot in the field of diagenesis.

DISCUSSION

Comparing the northern section of the San Juan Precordillera with its central part, a comparable thermal evolution can be observed. There is a gradient from diagenetic conditions in the east towards anchizonal and finally epizonal overprint of the sediments to the west (fig.4).

At least in the Rio San Juan section, this is an almost linear function of CAI versus palinspastically corrected distance (fig.5) and seems to indicate the activity of a westerly heat source, which affected all areas of the Precordillera. However, we still do not know, whether the nearly linear increase from

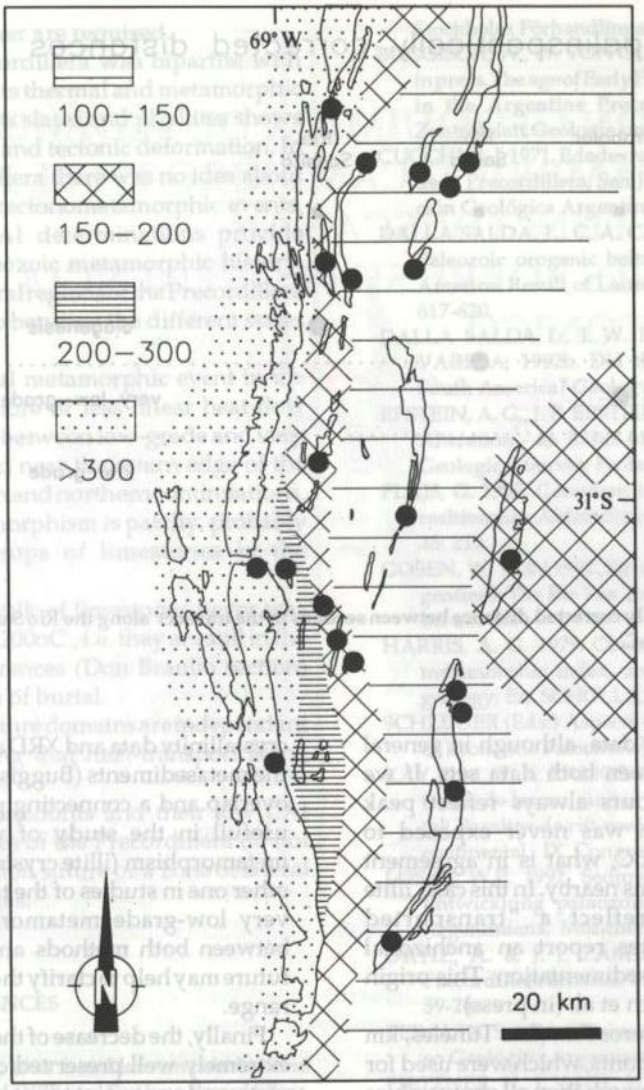

Figure 4: CAI-based temperature domains in the Precordillera of San Juan. Temperature estimates are based on EPSTEIN et al. (1977) & RAVEN & PLUIJM (1986). Black circles: Location of CAI-control.

the Rio Sassito section to the section at km 101 (road San Juan -Calingasta) further continues in a westerly direction (towards Calingasta).

In a southern transect between Uspallata and Mendoza, a similar pattern is observed, if microfabcrics and illite crystallinity data are considered: The Villavicencio Group near Mendoza shows lower metamorphism than the Early Palaeozoic near Uspallata (Buggisch et al. in press). Hence it may be concluded, that from the Rio Jáchal in the N to Mendoza in the S, a W-E directed metamorphic gradient developed during pre-Carboniferous times.

The effect of this (Silurian-earliest Devonian?) metamorphism was strongest in the west, gradually decreasing towards the east. The transition from low-grade metamorphism to very low-grade metamorphism is located near the eastern limit of the Sierra del Tontal and its southern and northern equivalents. There are no indications, that structurally important fault lines (e.g. falla del Tigre) had an influence on the thermal history of the mountain range. In addition, the boundaries of temperature domains do not follow any structural subdivision of the Precordillera (e.g. Ortiz & Zambrano 1981).

A problem are the relatively "high" CAI values (3-4) in the Don Braulio section (figs.2,3), which contrast to the lower values in the Sierra Chica de Zonda and in the sierras near Jáchal. One pecularity of the Don Braulio section is the existence of a thick pile of Siluro-Devonian(?) sedimentary mélange deposits (Mogotes Negros Fm.), with a thickness of about 4000m (Peralta 1990). Such a thickness of pre-deformational sediments cannot be observed in any other section. Given this thickness, an average thermal gradient of about 30-40o/km may account for the temperatures observed. Hence it seems reasonable to assume, that in the Sierra de Villicum burial might have caused the higher CAI values in comparison with other sections in the Sierra Chica de Zonda.

The section at La Rinconada shows a discrepancy between

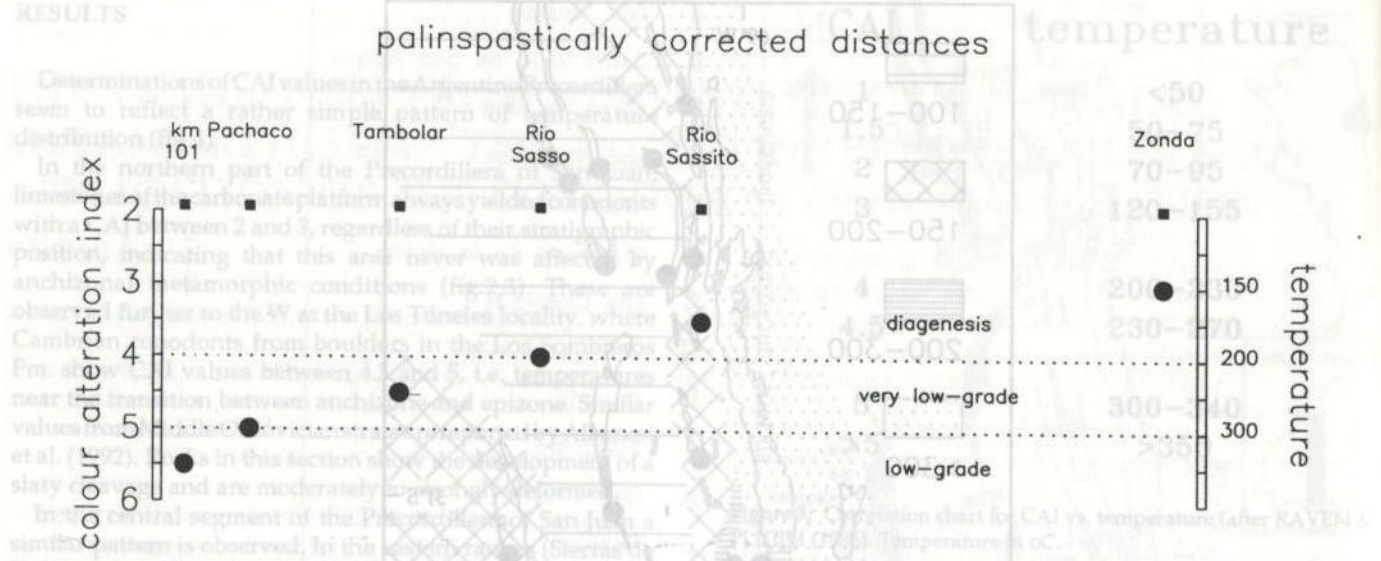

Figure 5: CAI values vs. palinspastically corrected distance between sections in the transect along the Rio San Juan. Palinspastic distances are taken from GOSEN (1992). Temperature in oC.

CAI values and illite crystallinity data, although in general there is a good correlation between both data sets. If we assume, that the conodont colours always reflect peak temperatures, then this section was never exposed to temperatures above approx. 150oC, what is in agreement with CAI values in the other sections nearby. In this case, illite crystallinity data seem to reflect a "transported metamorphism", i.e. clastic illites report an anchizonal overprint prior to erosion and resedimentation. This origin was already supposed by Buggisch et al. (in press).

Three sections of the Los Sombreros Fm. (Los Túneles, km 101, Los Sombreros) yielded conodonts, which were used for the determination of the CAI. Although they all show values between 4.5 and 5.5, there is a clear difference in preservation of the conodonts. In the two northern sections, conodonts were obtained from limestone beds intercalated into fine-grained metaclastics. As they are cleaved and fractured, they obviously suffered from the same deformational event as the surrounding host-rocks. In contrast, conodonts from the Los Sombreros section are very well preserved and do not show any sign of deformation. This is due to the fact, that they were obtained from allochthonous limestone boulders embedded in fine-grained siliciclastics. Shear-stress was catched by the softer matrix and as a result, the carbonate boulders were only exposed to thermal heating.

Another interesting point is the relation of slaty cleavage to CAI. Although it is locally present in the eastern Precordillera (e.g. in shales at La Rinconada), the regional occurrence of slaty cleavage coincides with a thermal heating to temperatures above ca. 250oC (CAI > 4.5). Similar results are reported by Epstein et al. (1977: Appalachians) and Raven & Pluijm (1986: Cantabrian Mountains, N-Spain). It may therefore be concluded, that a minimum temperature is required for the formation of this kind of cleavage.

Epizonal metamorphism west of Pachaco is indicated by CAI values of >5 (fig.4). This is in good agreement with illite crystallinity data and XRD analyses of mineral paragenesis in the metasediments (Buggisch et al. in press). There is thus an overlap and a connecting point between two methods, one usefull in the study of very low-grade and low-grade metamorphism (illite crystallinity) mainly in clastics and the other one in studies of the transition between diagenesis and very low-grade metamorphism in limestones. The link between both methods and their combined results in the future may help to clarify the evolution of the whole mountain range.

Finally, the decrease of thermal heating from W to E and the extremely well preserved conodonts in some of the eastern sections do not point to a strong collisional event between two terranes at the present-day eastern boundary of the Precordillera or a nearby terrane boundary (Ramos et al. 1984, 1986; Dalla Salda et al. 1992a,b) between the Precordillera and the Sierras Pampeanas. There also no indications of shearing in the samples as a possible result of lateral movements between both terranes (e.g. Baldis et al. 1989; Loske 1992). Both observations may indicate, that the zone of collision or lateral displacement, respectively, is restricted to a sharply bounded narrow belt between both blocks, today covered by Tertiary and Quaternary sediments of the Valle de Tulum and Valle de Bermejo (cf. Ortiz & Zambrano 1981).

CONCLUSIONS

In the Precordillera of Western Argentina, the study of the conodont CAI seems to be a helpfull tool in the determination of palaeo-temperature domains and, in consequence, of the regional distribution of diagenesis, very low-grade and low-grade metamorphism.

There is coincidence between the occurrence of slaty cleavage and CAI values >4.5, indicating that minimum temperatures

for the development of the former are required.

Hitherto, the Argentine Precordillera was bipartite with respect to the knowledge about its thermal and metamorphic history. The western part with its slates and phyllites shows clear signs of thermal alteration and tectonic deformation. In contrast, in the eastern Precordillera there was no idea about possible effects of the western tectonometamorphic events. The results obtained from CAI determinations provide information on the Early Palaeozoic metamorphic history, especially of the eastern and central regions of the Precordillera and therefore help to fill the gap between the different states of knowledge.

CAI values indicate a regional metamorphic event in the western Precordillera with a more or less linear heat-flow towards the east. The transition between low-grade and very low-grade conditions is situated near the estern edge of the Sierra del Tontal and its southern and northern continuations. The record of anchizonal metamorphism is patchy, probably because of the limited outcrops of limestones in the corresponding areas.

In the remaining areas, the bulk of limestones never was exposed to temperatures above 200oC., i.e. they are still in the field of diagenesis. Local differences (Don Braulio section) were caused by different depth of burial.

The boundaries of the temperature domains are independant of structural features, indicating that heat-transport along faults only played a minor role.

The good preservation of conodonts and their low CAI values in the easternmost ranges of the Precordillera do not indicate the existance of a collision suture or a zone of lateral displacement in their proximities.

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