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Structural analysis of the Itapucumí Group in the Vallemí region, northern Paraguay: Evidence of a new Brasiliano/Pan-African mobile belt

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A B S T R A C T

The Neoproterozoic (Ediacaran) Itapucumí Group in northern Paraguay is composed of carbonate and siliciclastic rocks, including ooid grainstones, marls, shales and sandstones, containing Cloudina fossils in the eastern region. It is almost undeformed over the Rio Apa Cratonic Block but shows a strong deformational pattern at its western edge. A detailed structural analysis of the Itapucumí Group was conducted in the Vallemí Mine, along with a regional survey in other outcrops downstream in the Paraguay River and in the San Alfredo, Cerro Paiva and Sgt. Lopez regions. In the main Vallemí quarry, the structural style is characterized by an axial-plane slaty cleavage in open to isoclinal folds, sometimes overturned, associated with N–S trending thrust faults and shear zones of E-vergence and with a low-grade chlorite zone metamorphism. The structural data presented here are compatible with the hypothesis of a newly recognized mobile belt on the western side of the Rio Apa Cratonic Block, with opposite vergence to that of the Paraguay Mobile Belt in Brazil. Both belts are related to the Late Brasiliano/Pan-African tectonic cycle with a Lower Cambrian deformation and metamorphism age. The deformation could be due to the late collision of the Amazonian Craton with the remainder of Western Gondwana or to the western active plate boundary related to the Pampean Belt. The structural and lithologic differences between the western Itapucumí Group in the Vallemí and Paraguay River region and the eastern region, near San Alfredo and Cerro Paiva, suggest that this group could be divided into two lithostratigraphic units, but more stratigraphic and geochronological analyses are required to confirm this possibility.

R E S U M O

O Grupo Itapucumí é constituído por rochas carbonáticas e siliciclásticas, caracterizadas pela presença de *grainstones* com oóides, margas, folhelhos e arenitos de idade neoproterozóica (ediacarana), devido à ocorrência do fóssil Cloudina na sua porção leste. Apresenta-se quase indeformado quando recobre o bloco cratônico do Rio Apa, porém mostra um intenso padrão deformacional na sua porção ocidental. Análise estrutural detalhada foi realizada na mina Vallemí, norte do Paraguai, bem como reconhecimento de outros afloramentos ao longo do rio Paraguai e na região entre San Alfredo, Cerro Paiva e Sargento Lopez. Na mina principal em Vallemí, o estilo estrutural caracteriza-se pelo desenvolvimento de clivagem ardosiana plano-axial de direção aproximada N–S em dobras abertas a isoclinais, por vezes com flanco inverso e associadas a empurrões com vergência para E com desenvolvimento de metamorfismo de baixo grau, na zona da clorita. Os dados estruturais levantados reforçam a hipótese da existência de uma nova faixa móvel na margem oeste do Bloco Rio Apa, com vergência oposta à da Faixa Paraguai Meridional, relacionada ao final do evento Brasiliano/Pan-Africano, com deformação e metamorfismo no Cambriano Inferior. A deformação pode ser atribuída à colisão tardia entre o craton Amazônico e o restante do Gondwana Ocidental, ou à borda de placa ativa associada à Faixa Pampeana. As diferenças estruturais e em parte litológicas, entre as exposições da parte ocidental do Grupo Itapucumí, na região de Vallemí, das

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da parte oriental, nos arredores de San Alfredo e Cerro Paiva, conduzem à possibilidade do Grupo Itapucumí vir a ser dividido no futuro em duas unidades estratigráficas distintas, o que requer estudos estratigráficos e geocronológicos mais pormenorizados para uma conclusão definitiva.

R E S U M E N

Un análisis estructural detallado fue realizado en la Mina Vallemí en el norte de Paraguay. Afloran allí litotipos del Grupo Itapucumí, de edad neoproterozoica, constituído por calcarenitas oolíticas, margas, lutitas y areniscas. En la mina principal, la sucesión presenta deformación relativamente intensa, con desarrollo de clivaje de plano axial y rumbo N–S. Se observan pliegues abiertos a isoclinales, a veces con flanco invertido y asociados a cabalgamientos con vergencia al NE y E. Se registra asimismo metamorfismo de grado bajo (zona de clorita). Los datos estructurales refuerzan la hipótesis de una nueva faja móvil en el margen oeste del Bloque Río Apa, con vergencia opuesta a la del Cinturón Paraguay meridional, este último relacionado al evento Brasiliano/Pan-Africano. Las diferencias estructurales y en parte litológicas entre las exposiciones de la parte occidental del Grupo Vallemí y las de la parte oriental, en los alrededores de Colonia San Alfredo, sugieren la posibilidad de que el Grupo Itapucumí pueda ser subdividido en dos unidades litoestratigráficas distintas. Para llegar a una conclusión definitiva son necesarios estudios estratigráficos y geocronológicos más pormenorizados.

1. Introduction

The geology of northern Paraguay is dominated by extensive Phanerozoic sedimentary covers, including the Cenozoic Chaco Basin and the Paleozoic Paraná Basin. The southern portion of the Rio Apa Cratonic Block outcrops between these sedimentary covers in continuity with the exposures in the state of Mato Grosso do Sul, Brazil. The eastern side of the Rio Apa Block is flanked by the Paraguay Fold Belt and its correlated cratonic covers, represented by the Corumbá and Cuiabá groups, while its southern region is covered by the Itapucumí Group.

The Late Neoproterozoic to Cambrian tectonic evolution of this region is related to the amalgamation of Western Gondwana and its proto-Pacific margin. The main cratonic blocks involved are the Amazonian, Rio Apa, São Francisco-Congo, Paranapanema (or Paraná), Rio de La Plata, Pampia and Arequipa-Antofalla (Fig. 1). Recent review articles about this sector of Gondwana were published by Rapela et al. (1998), Kröner and Cordani (2003), Rapela et al. (2007), Ramos and Coira (2008), Cordani et al. (2009) and Cordani (2009).

The Paraguay Fold Belt (Almeida, 1968; Alvarenga et al., 2000), sometimes referred to as the Paraguay–Araguaia Belt or the Paraguay-Pampean Belt, is a curved belt around the Amazonian and Rio Apa cratonic blocks. It has undeformed or slightly deformed sedimentary covers over the cratons, passing to a marginal fold-and-thrust belt with tectonic vergence towards the cratonic areas, and it is characterized by low-grade metamorphism (Fig. 1). The

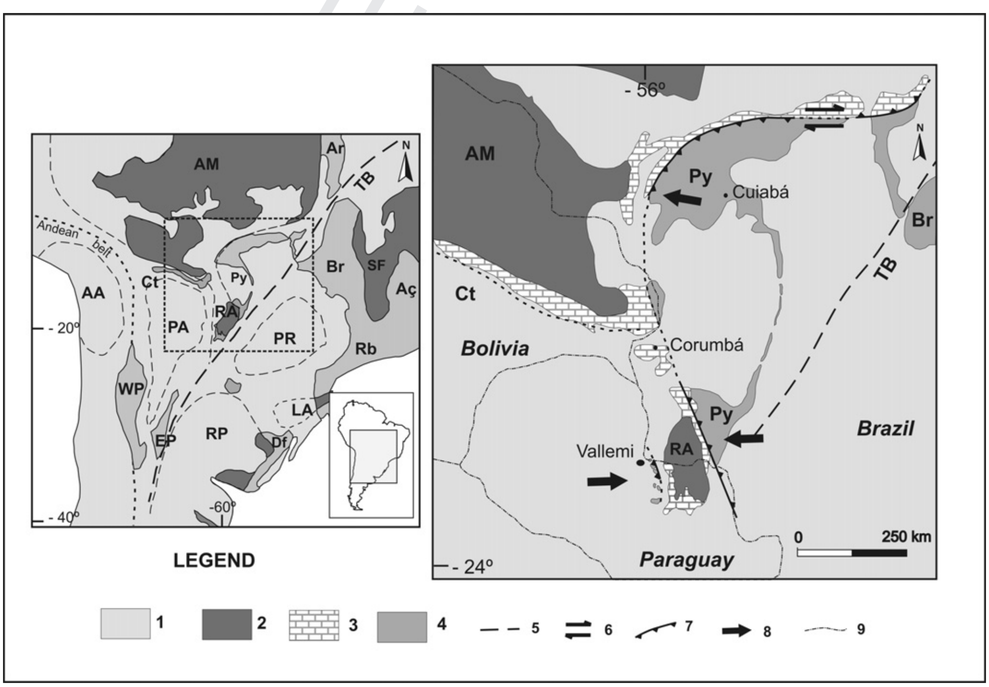

Fig. 1. Geotectonic context of the study area. (1) Phanerozoic covers; (2) cratons and cratonic blocks: AM – Amazonian, AA – Arequipa/Antofalla, LA – Luís Alves, RP – Rio de La Plata, PA – Pampia, PR – Paraná, RA – Rio Apa, SF – São Francisco; (3) Neoproterozoic cratonic covers; (4) Neoproterozoic fold belts: Rb – Ribeira, Ct – Chiquitos-Tucavaca; Aç – Araçuaí; Br – Brasília, Df – Dom Feliciano, Py – Paraguay, Ar – Araguaia, WP – Western Pampean; EP – Eastern Pampean; (5) Transbrasiliano lineament; (6) strike-slip fault; (7) reverse fault; (8) tectonic vergence; (9) international borders (modified from Alvarenga and Trompette, 1993; Kröner and Cordani, 2003; Rapela et al., 2007; Ramos and Coira, 2008; Cordani, 2009; Ramos et al., in press).

Chiquitos-Tucavaca Belt in Bolivia (Litherland et al., 1986) forms a branch at an angle to the northern and southern Paraguay belts, separating the Amazonian Craton from the southern Rio Apa, Pampia, and Arequipa-Antofalla blocks. Jones (1985) interpreted the combined system of the northern Paraguay, Chiquitos-Tucavaca and southern Paraguay belts as a triple (RRR) plate junction.

The eastern side of the Paraguay Belt in Brazil is covered by the Paleozoic Paraná sedimentary basin, making it difficult to establish its relationship to the Paranapanema Block and the Brasília Belt. Some authors have suggested that the Transbrasiliano Lineament separates the large Amazonian Craton, the Rio Apa Block and the Paraguay and Araguaia Belts from the Paranapanema and Rio de La Plata Cratons and the Brasilia Belt (Ramos and Coira, 2008; Cordani, 2009).

The western and southwestern sides of the Rio Apa Block in northern Paraguay are poorly understood due to widespread Cenozoic sedimentary covers and difficult accessibility. The Paleoproterozoic and Mesoproterozoic gneissic-granitic basement (Rio Apa Complex, São Luís Group, and San Ramón Suite) is exposed mainly northeast of the San Alfredo region (Araújo et al., 1982; Cordani et al., 2005).

In northern Paraguay, terrigenous and carbonate metasedimentary successions were identified as the Itapucumí Group (Fig. 2), representing a Precambrian cratonic cover over the

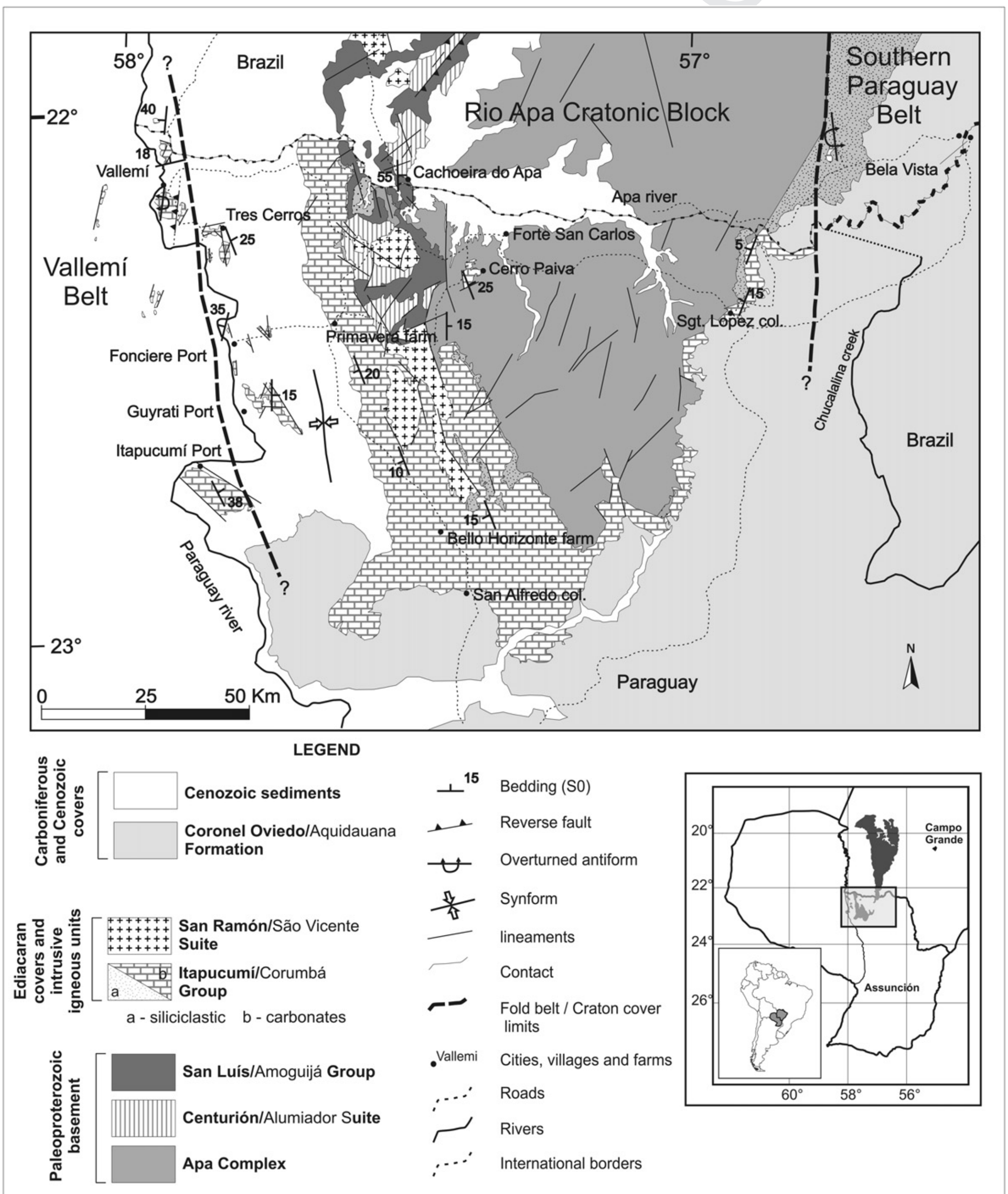

Fig. 2. Location and geologic map of the study area (based on Schobbenhaus et al., 1981; Araújo et al., 1982; Clerici, 1986; Wiens, 1986; DSGMP, 1993; Lacerda Filho et al., 2004).

southern portion of the Rio Apa Cratonic Block. The Itapucumí Group has been bio- and chrono-correlated with the Ediacaran Tamengo Formation (Corumbá Group, Almeida, 1965) of the Paraguay Belt in Brazil based on the discovery of a *Cloudina* fossil in the San Alfredo region (Boggiani and Gaucher, 2004).

In preliminary studies of the Vallemí region of northern Paraguay, Boggiani (1998) identified systems of overturned folds-and-thrust faults with east vergences, contrary to those identified in the Paraguay Belt.

The analysis of this region suggests that there are two distinct lithostratigraphic and structural domains for the Precambrian carbonates that outcrop in central-northern Paraguay, which are usually attributed to the Itapucumí Group. The first domain is located in the Vallemí region and the surrounding hills along the Paraguay River in the southwestern edge of the Rio Apa Cratonic Block. It is composed of siliciclastic rocks (red sandstones, siltstones, and claystones) with intercalations of basic rocks in the basal portion, overlaid by carbonate rocks (ooid grainstones) and marls that have been partially affected by low-grade metamorphism (chlorite zone) and intense deformation. The second domain is an extensive horizontal or sub-horizontal sedimentary cover over the southern portion of the Rio Apa Cratonic Block (San Alfredo – Cerro Paiva region) with shallow water sedimentary facies (breccias, thrombolites, stromatolites, grainstones with tidal bundle laminations, and ooid grainstone layers with cross-stratification, Fig. 6). To date, the *Cloudina* has been found only in this second domain.

The work presented here is the result of a structural characterization carried out at the Vallemí Mine (Industria Nacional de Cemento – INC, Paraguay) and the neighboring Tres Cerros area, as well as a reconnaissance along the Paraguay River in the San Alfredo, Cerro Paiva and Sargento José E. López regions. Recent advances in the exploitation of the Vallemí Mine have allowed a better understanding of the deformation pattern of these rocks.

In this article, we analyze the hypothesis that the Itapucumí Group at the southwest edge of the Rio Apa Cratonic Block (Vallemí and other exposures along the Paraguay River) represents the outcropping vestiges of a fold-and-thrust belt with a vergence opposite to that of the Southern Paraguay Belt. We also address the idea that these belts form a system of belts with centripetal vergences directed towards the Rio Apa Cratonic Block. Detailed geological and structural data are presented and compared to the regional geologic knowledge currently available.

2. The Itapucumí group

The units currently known as the Itapucumí Group in Paraguay were preliminarily described in regional geological reconnaissance studies (DuGraty, 1865; Boettner, 1947) and were named the "Itapucumi Series" by Harrington (1950), who thought that they were possibly of Ordovician age. Eckel (1959) described the succession as being about 300–400 m thick, composed of light to dark gray carbonates (locally oolitic) in erosive contact over the basement and culminating at the top with marls and pelitic rocks. The lithologic similarity of the Itapucumí Series to successions described in Brazil allowed Putzer (1962) to suggest a Cambrian or Precambrian age and a correlation with the Tamengo Formation of the Corumbá Group.

Wiens (1986) carried out the first detailed stratigraphic study of the Itapucumí Series, in which he reclassified the unit as a group. It was proposed that this group be divided into two distinct formations: the predominantly terrigenous *Vallemí* at the bottom and the carbonatic *Camba Jhopo* at the top (Fig. 3).

According to Boggiani (1998), the Vallemí quarry section is a succession with siliciclastic rocks (arkoses) at the bottom and

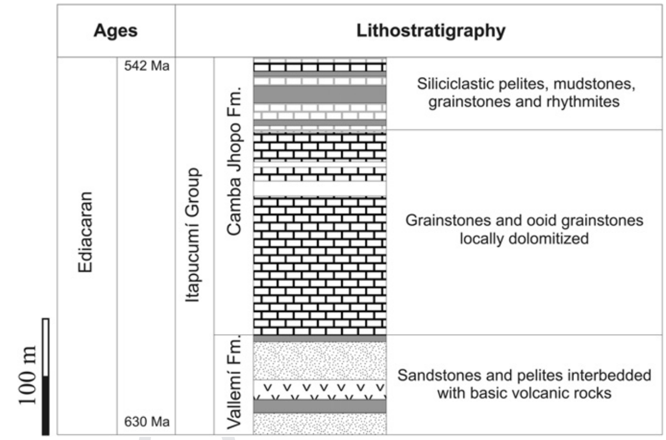

Fig. 3. Stratigraphic column of the Itapucumí Group.

calcareous rocks intercalated with marly rhythmites at the top. The calcareous rocks, predominantly ooid grainstones, were formed in oolitic sandbanks and barrier islands that had undergone post-depositional dolomitization under evaporitic conditions.

Isotopic data for the Itapucumí Group are not conclusive. Kawashita (1996), Oliveira (2004), and Cordani et al. (2005) analyzed $^{87}Sr/^{86}Sr$ isotopes in carbonates from the Vallemí Mine and compared them with the Proterozoic seawater variation curve (Gorokov et al., 1995). The results suggested a sedimentation age of about 560 Ma (Ediacaran). An Rb/Sr isochron obtained from calcareous samples of the Vallemí Mine (Oliveira, 2004) yielded an age of 517 ± 24 Ma, which was interpreted as an isotopic homogenization event and attributed by the author to diagenesis.

3. Local geology

The current study was carried out in the westernmost Itapucumí Group outcrops of the Vallemí region. The primary study site was the INC Mine, but additional work took place in small calcareous rock quarries in the neighboring Tres Cerros region and in outcrops following the Paraguay River southwards (Fig. 2).

The Itapucumí Group comprises the lower Vallemí Formation and uppermost Camba Jhopo Formation (Wiens, 1986; Fig. 3).

The lower Vallemí Formation comprises meter-scale layers of massive and cross-stratified arkoses as well as a decameter-scale body of basic rock, possibly effusive, overlain by intercalations of fine-grained massive red sandstones and pelites.

The basal unit is overlaid by the Camba Jhopo Formation, possibly through an unconformity. The upper unit begins with a 130-m-thick succession of massive to stratified ooilitic calcareous rocks, sometimes with trough and low-angle cross-stratifications. At the top, the unit changes to a 90-m-thick succession comprised of marly rhythmite intercalations with terrigenous pelites, dark mudstones and meter- to decameter-scale layers of massive, partially dolomitized calcareous rock (Fig. 3).

3.1. Structures

The rocks in the main exploitation area of the Vallemí Mine are affected by a relatively intense deformation pattern, marked by the development of axial-plane slaty cleavage and open to isoclinal folds. Some of these folds are overturned and are associated with thrust faults (Fig. 4).

The foliation that developed under metamorphic conditions is characterized as a fine slaty cleavage in the pelitic layers (S_1; Fig. 5A,

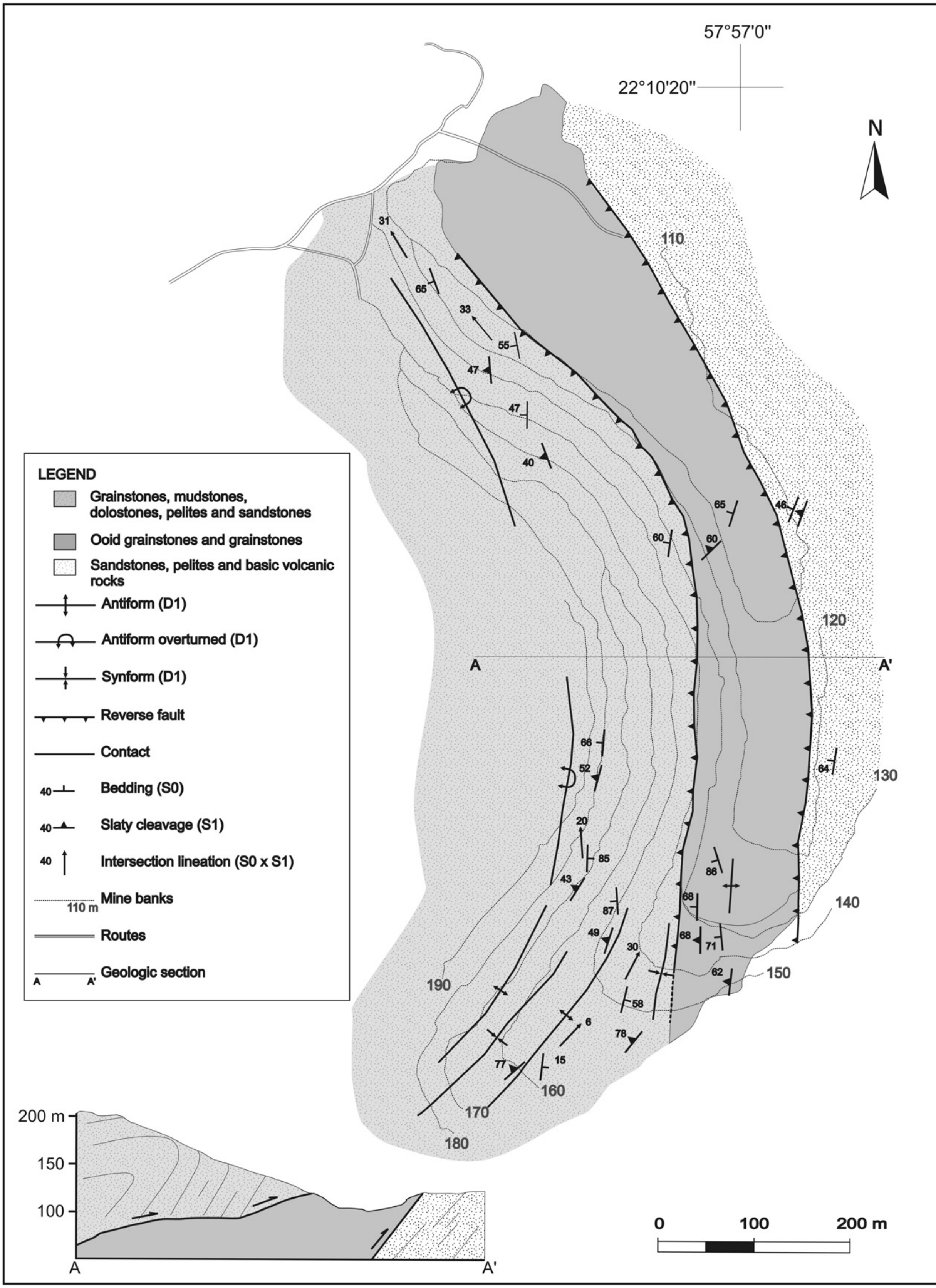

Fig. 4. Structural-geologic map and cross-section of Vallemí Mine.

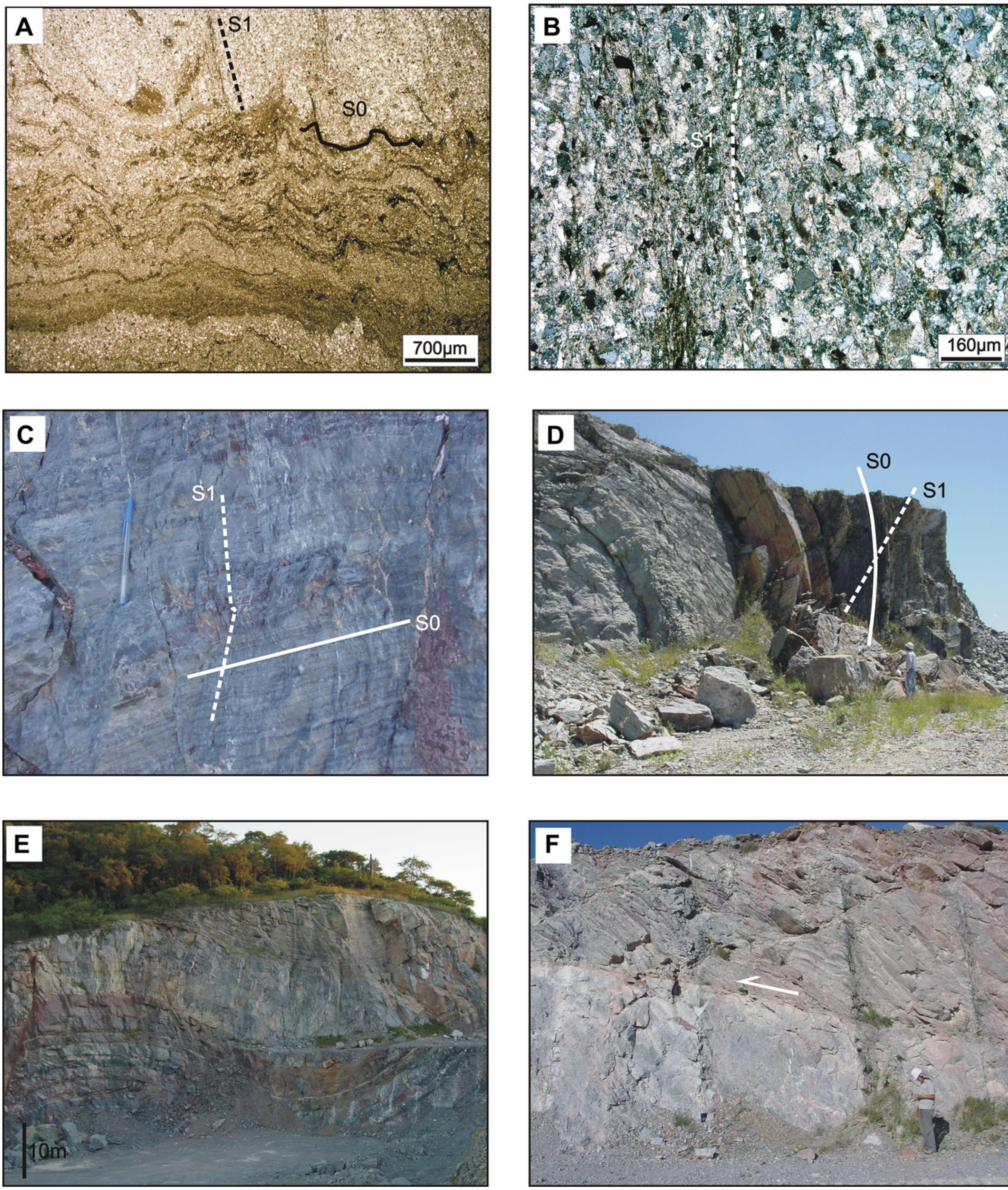

Fig. 5. Structural features of the Camba Jhopo Formation in the Vallemí Mine: (A) photomicrograph showing microfolded sedimentary bedding with axial-plane slaty cleavage (plane parallel light); (B) photomicrograph showing clastic sedimentary texture cut by slaty cleavage (crossed polarized light); (C) impure carbonate levels (marls) with well-developed rhythmic bedding and perpendicular slaty cleavage; (D) inverted limb of fold with upright sedimentary stratification and tectonic cleavage with lower dip angle; (E) southern portion of the Vallemí Mine with decameter-scale open folds affecting alternating layers of marly rhythmites and grainstones; (F) ductile-brittle shear zone of low angle (thrust fault) with pelitic marly rhythmites in the hanging wall and grainstones in the footwall; (G) detail of previous photo showing S/C structures indicating transport towards ESE; (H) conjugate kink bands indicating horizontal maximum compression (σ_1) WNW-ESE; (I) strike-slip fault in the southern portion of the Vallemí Mine, with the slip direction indicated by the attitude of the observed slickenside striae (350/10); (J) detail of the previous photo showing cataclastic breccia associated with the fault plane.

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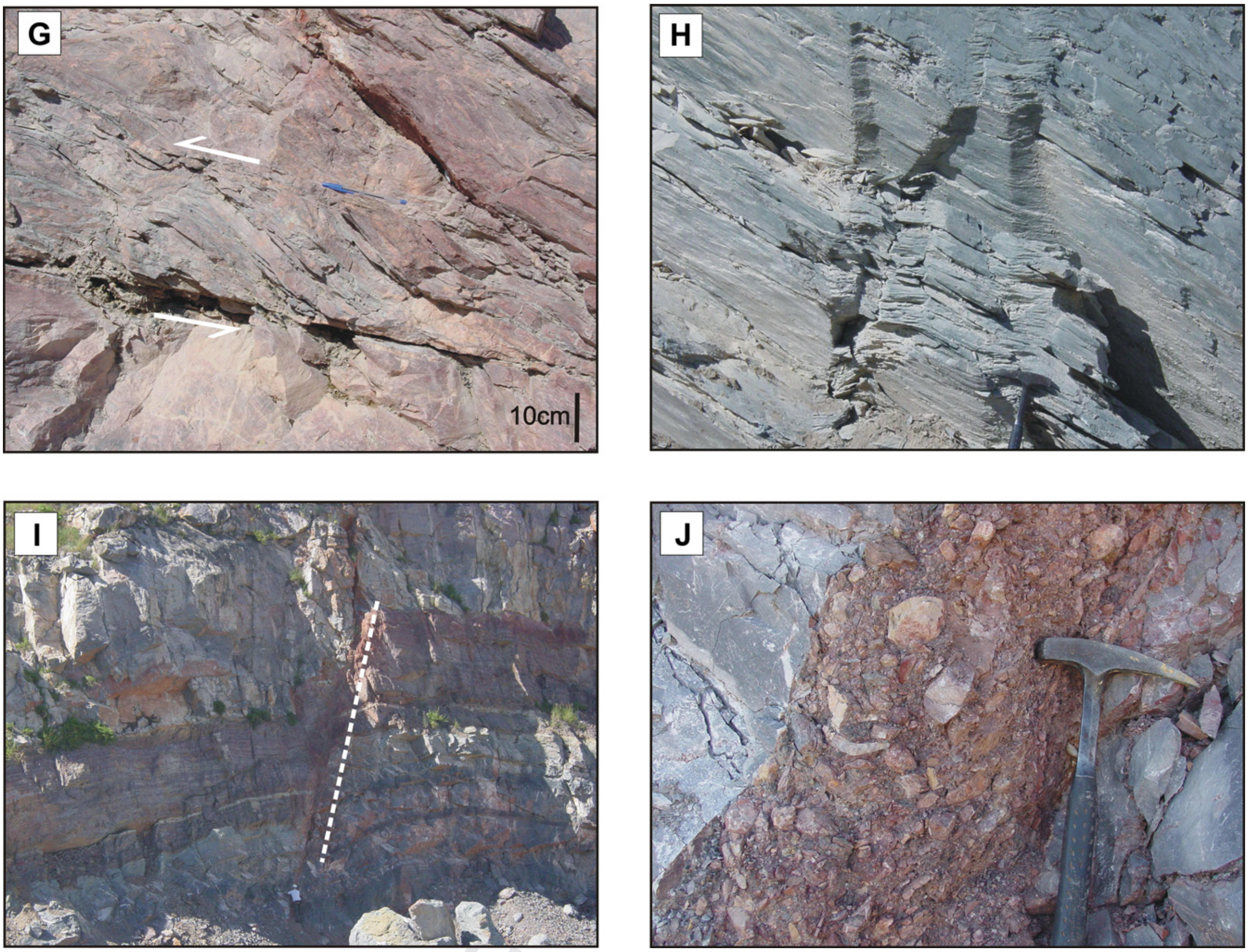

Fig. 5. (*continued*).

B, C and D) formed by the orientation of very fine sericite-chlorite grains. This mineral association and the absence of other metamorphic minerals (e.g., biotite) characterize a low metamorphic grade (greenschist facies, chlorite zone). This slaty cleavage has an average dip of 56° at an azimuth of 290° (Fig. 7B) and frequently cuts the sedimentary stratification (S_0) at an angle.

The sedimentary stratification (S_0) is more prominent in the impure carbonates, where it is marked by alternating layers with variable siliciclastic and carbonate contents (Fig. 5A). The bedding poles fit to a girdle in the stereonet, indicating a mean fold axis plunging 14° at an azimuth of 358° (Fig. 7A). The S_1 cleavage is in the axial-plane position. The intersection of lineations between S_0 and S_1 confirms this pattern, with an average plunge of 28° at an azimuth of 352° (Fig. 7C).

The northwest and central-eastern portions of the mine expose tight overturned folds with an axial plane that dips to the west (Fig. 5D). Most of this area is located within an inverted fold limb on top of sub-horizontal basal thrust faults.

In the southern portion of the mine, the fold pattern changes to a succession of more open antiforms and synforms (Fig. 5E). The fold axis and axial-plane foliation gradually pass from N–S in the northern portion of the mine to NNE in the southern portion (Fig. 4), which could be explained by a second-generation fold with an approximately E–W trending axial plane and an NW plunging axis, as suggested by the dispersion of S_1 poles and L_1 lineations (Fig. 7B and C). However, there is no additional evidence supporting this interpretation, e.g., axial-plane cleavages with E–W strike.

The thrust faults (Fig. 5F and G) have sub-horizontal undulating planes, which in certain locations make the faults appear extensional, but the continuity of the faults is evident in several places. The ductile-brittle character of these thrusts and the associated S/C structures are consistent with the low metamorphic grade (greenschist facies, chlorite zone) observed in the pelitic rocks. They display attitude (Fig. 7D and E) and kinematic indicators compatible with a sub-horizontal WNW-ESE maximum compressive stress (σ_1) orientation. They further display a transport direction towards ESE compatible with the observed eastward vergences of the D_1 folds and S_1 foliation. The presence of sub-horizontal tension gashes and kink bands with approximately N–S upright axial planes (Fig. 5H) corroborates this interpretation of a sub-horizontal WNW-ESE σ_1 orientation. Brittle normal and transcurrent faults (Fig. 5I and J) cut these structures, but without more precise stratigraphic or chronological data, it is difficult to precisely determine the age of these younger brittle deformation events.

This structural pattern contrasts with that found in other nearby areas. In Tres Cerros and some outcrops along the Paraguay River, such as the Fonciere and Guyrati Ports, the bedding is tilted with dips ranging from horizontal to almost 35° (Fig. 6F) but without apparent evidence of metamorphism or tectonic cleavage development.

However, at the Itapucumí Port located downstream of the Paraguay River, the westernmost quarries show a deformation pattern similar to that found in the Vallemí area. In particular, the deformation includes open to tight asymmetrical folds with upright

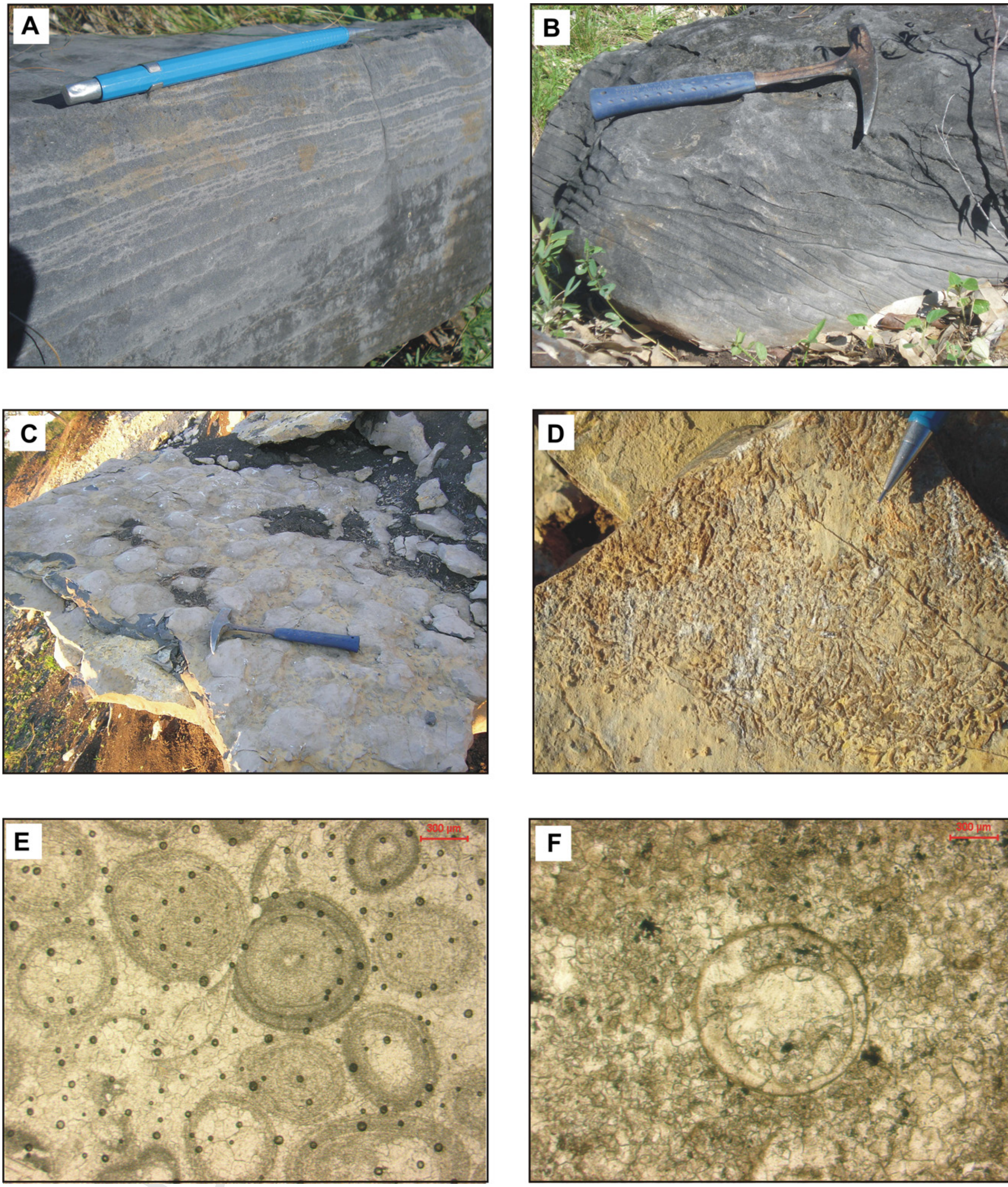

Fig. 6. Field and petrographic features of the undeformed Itapucumí Group domain in the southern Rio Apa Cratonic Block (San Alfredo and Sgt. Lopez colonies, Cerro Paiva, Bello Horizonte and Primavera Farms): (A) laminated microbialitic facies composed of laterally continuous and disrupted laminae, occasionally with curls and desiccation cracks; (B) fine-grained grainstone with trough cross-stratification; (C) thrombolitic domes; *Cloudina* occurs in the troughs; (D) lenticular concentration of Cloudina shells; (E) photomicrograph of ooid grainstone (small dark circles are bubbles in the mounting medium); and (F) transverse section typical of *Cloudina* shells (note the excentric emplacement of the inner shell).

short limbs, slaty cleavage in the pelitic rocks and en-echelon carbonate-filled tension gashes. It is thus possible that the limit between the western deformed domain and the eastern undeformed domain is nearly N–S where it passes the Vallemí and ItapucumíPorts (Fig. 2).

Outcrops west of the Paraguay River are rare and very difficult to reach, thus impeding a full understanding of the development of deformation in the western area.

On the southeast side of the Rio Apa Cratonic Block, the limit with the Paraguay Belt (the limit between the eastern deformed

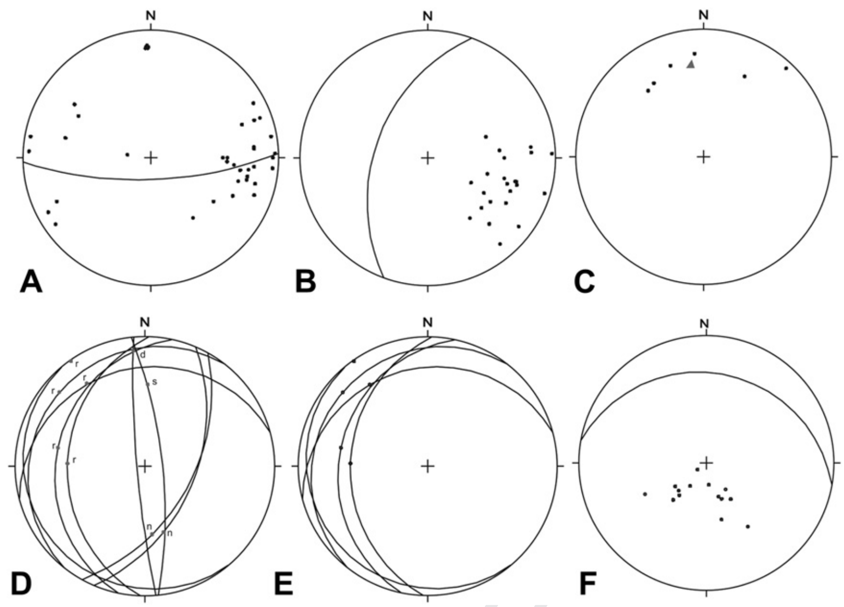

Fig. 7. Stereonets of structural data (Schmidt–Lambert diagram, lower hemisphere), Vallemí Mine: (A) poles of sedimentary stratification (S_0) with the best-fit girdle and pi axis indicated; (B) poles of slaty cleavage (S_1) with average pole and plane indicated; (C) intersection lineations between bedding and slaty cleavage (L_1) with average attitude indicated; (D) measured faults with slickensides represented as great circles and striae represented as points with the following kinematic indications: r: reverse, n: normal, d: dextral, s: sinistral; (E) the reverse faults only; (F) poles of sedimentary stratification in the Tres Cerros region with the average plane indicated.

and western undeformed domains) is roughly located between Sargento José E. López (Paraguay) and Bela Vista (Brazil).

On the south-central portion of the Rio Apa Cratonic Block near San Alfredo, Cerro Paiva, Primavera Farm and the Apa River, the Itapucumí Group (in some places the carbonatic Camba Jhopo Formation) rests unconformably on the basement (Fig. 6), with sub-horizontal to low-dipping bedding (up to 15°).

4. Discussion

The attitudes of fold axes, slaty cleavage (S_1), and axial planes in the Vallemí Mine are similar to those observed in the southern Paraguay Belt (e.g., in the Serra da Bodoquena on the Brazilian side). The most conspicuous difference is the structural vergence shown by the dip of the axial-plane cleavage, the fold asymmetry, and the kinematic indicators that indicate a westward vergence in the Paraguay Belt and an eastward vergence in Vallemí.

The Vallemí region and the southern Paraguay Belt are separated by the Rio Apa Cratonic Block (Figs. 1 and 2), which is overlain in its southern part by sedimentary carbonates of the undeformed domain of the Itapucumí Group. These rocks have been correlated with the Ediacaran Corumbá Group in the southern Paraguay Belt in Brazil based on the occurrence of *Cloudina* fossils in both regions (Boggiani and Gaucher, 2004).

Cloudina is an important index fossil associated with the Precambrian-Cambrian limit. In Oman (Ara Group, Huqf Supergroup), *Cloudina* occurs beneath an ash bed, with a U–Pb zircon concordia age of 542.0 ± 0.3 Ma (Amthor et al., 2003). Similar ages have been obtained for *Cloudina*-bearing carbonates in Namibia (Grotzinger et al., 1995). Fike et al. (2006) consider the first appearance of *Cloudina* to have occurred about 548 Ma. Thus, 542 to 548 Ma can be considered as the age range for this fossil. In Brazil, an average SHRIMP age of 543 ± 3 Ma for zircon in volcanic ash in the Tamengo Formation near Corumbá (Boggiani et al., 2005; Babinski et al., 2008) is consistent with the 542 to 548 Ma range suggested by Fike et al. (2006).

Reliable radiometric ages from Vallemí are still precarious but are also suggestive of an Ediacaran age.

Isotopic analyses of the carbonate rocks from the Vallemí Mine (Kawashita, 1996; Cordani et al., 2005) yielded an average $^{87}Sr/^{86}Sr$ value of about 0.7085, which is compatible with the end of the global increase in these values in marine water that occurred in the Ediacaran age (see Halverson et al., 2007). However, the low-grade metamorphism in Vallemí rocks could have affected this result.

The only direct radiometric age available from the Vallemi Mine was a Rb/Sr isocron age obtained by Oliveira (2004) of 517 ± 24 Ma, which was interpreted as the age of an isotopic homogenization event during diagenesis. However, it is also possible to attribute this age to the deformation and metamorphism that these rocks have undergone. If this were the case, the deformation and metamorphism of the Vallemí area would be synchronous with those of the southern Paraguay Belt, with a lower Cambrian age.

Thus, the available age information favors the hypothesis that the Itapucumí carbonate sequences in Vallemí (deformed rocks), San Alfredo (cratonic cover) and the Tamengo Formation in Brazil are chrono-correlated, with the lithologic differences arising as the result of distinct sedimentary settings.

In this context, the existence of a newly recognized Brasiliano mobile belt in the Vallemí region is a reasonable hypothesis. This belt would be parallel and symmetric to the southern Paraguay Belt, both showing centripetal vergence towards the Rio Apa Block.

Much discussion has focused on whether the Rio Apa Block is linked to the Amazonian Craton (e.g., Ruiz et al., 2005). If a new fold belt did exist in the Vallemi region, the Rio Apa Block would represent either a relatively small cratonic fragment in the context of the Western Gondwana orogeny or a narrow promontory of the southern portion of the Amazonian Craton, flanked by two mobile belts (Fig. 1).

The Ediacaran sedimentation age and the Lower Cambrian deformation age of this region are markedly younger than the orogenic ages from the eastern Brasília and Ribeira Belts, with the main peak having an age of about 630 Ma (Trompette et al., 1998;

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Brito Neves et al., 1999; Alkmim et al., 2001; Valeriano et al., 2004, 2008). It has been suggested that the Paraguay–Araguaia basin was related to the Brasiliano Orogenic Chain of the Brasilia and Ribeira Belts as a foreland basin (Trompette, 1994; Trompette et al., 1998). Another interpretation postulates that the sedimentation of the Paraguay Belt units evolved from a rift to a passive margin (Boggiani, 1998; Gaucher et al., 2003). In this model, an ocean should have existed to the east, but evidence of this ocean would be buried under the Paraná sedimentary basin. However, Woldemichael (2003) suggested the presence of a collision margin between the Rio Apa and Paranapanema Cratons based on magnetothelluric and gravimetric data.

Paleomagnetic data (Trindade et al., 2003; Tohver et al., 2006; Cordani et al., 2009) suggest that the Amazonian Craton was not linked to Western Gondwana before Early Cambrian times. In this scenario, the collision between the Amazonian and the remainder of Western Gondwana (e.g., the São Francisco, Congo and Paranapanema Cratons) would be responsible for the Paraguay–Araguaia orogeny in the Lower Cambrian. Campanha and Brito Neves (2004) proposed that a WNW-ESE to NW-SE general compression was responsible for the final amalgamation of Western Gondwana during its late stages of convergence.

On the other hand, the sedimentation and deformation ages of the Vallemí region and the Paraguay Belt are similar to the ages of the Pampean (Puncoviscan) Belt in Argentina. This belt is also characterized by Ediacaran sedimentation followed by late Neoproterozoic to Cambrian deformation, magmatism, and metamorphism, with Ordovician and Devonian post-orogenic magmatism (Rapela et al., 2007; Ramos and Coira, 2008; Siegesmund et al., 2009). A western and an eastern branches of the Pampean Belt are recognized, limiting the Pampia Cratonic Block (Fig. 1). The eastern Pampean Belt is a magmatic arc developed over the western border of the Rio de La Plata Craton (Rapela et al., 2007; Ramos and Coira, 2008; Cordani, 2009; Ramos et al., in press). Thus, E–W compression in the Vallemí region could be related to a western active plate boundary. The deformation of the Vallemí Belt could be the distant expression of the Pampean orogeny and represent the closure of the westernmost Gondwana boundary, including the Pampia, Rio Apa, Rio de La Plata and Paranapanema Cratonic Blocks.

5. Conclusions

New structural data from the Itapucumí Group in northern Paraguay strengthen the hypothesis of a new Brasiliano/Pan-African mobile belt on the western margin of the Rio Apa Cratonic Block, with a vergence opposite to that of the southern Paraguay Belt. The confirmation of this idea would have implications for the regional tectonic framework of the region. In particular, the Rio Apa Block would consist of a smaller cratonic fragment surrounded by the southern Paraguay Belt to the east and by the newly proposed mobile belt to the west.

The deformation and metamorphism of the Vallemí area would be synchronous with those of the southern Paraguay Belt and the Pampean Belt, suggesting a lower Cambrian age. The deformation could then be attributed either to the late collision of the Amazonian Craton with the remainder of Western Gondwana or to the western active plate boundary related to the Pampean Belt.

Lithological and structural differences observed between the western (Vallemí) and eastern (San Alfredo) exposures of the Itapucumí Group suggest the division of the Itapucumí Group in Paraguay into two distinct stratigraphic units. Support for this hypothesis requires more detailed stratigraphic and geochronological studies.

Uncited reference

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