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Foraminiferal biostratigraphy of the pennsylvanian cerro prieto formation, amotape mountains, NW Peru: Correlation with the Central Andean basin

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ABSTRACT

Carboniferous-Permian successions in the Amotape Mountains (NW Peru) are poorly dated due to the predominant siliciclastic intervals and the scarcity of fossils. The biostratigraphy of the formations is thus poorly constrained and, in general, limited to major systems or subsystems. The Cerro Prieto Formation was assigned to the Pennsylvanian or middle Pennsylvanian, but at the Caseta de la Antena section, the lower half of the formation contains carbonate horizons where diverse foraminiferal assemblages are recorded. Foraminifers allow to assign the base of the formation to the basal Bashkirian Stage, Morrowan Substage or *Globivalvulina-Millerella* Zone. This biostratigraphy can be extrapolated to the base of the Tarma Formation in central and south Peru, where this part of the latter formation remains undated. The upper limestone levels at Caseta de la Antena are assigned to the late Bashkirian, Atokan Substage or *Eoschubertella-Pseudostaffella* Zone. The upper half of the Cerro Prieto Formation, only composed of siliciclastics, might correspond to the uppermost late Bashkirian/lowermost Moscovian, or the mid-upper Atokan, due to fusulinids recorded at the top of the Tarma Formation. Foraminiferal assemblages are rather similar to those recorded from the lower part of the Copacabana Formation in Bolivia, although some differences occur, and apparently rather different from those in south Peru, a fact which suggests a slight biogeographic differentiation between the Amotape Mountains and the Central Andean Belt possibly related to its distinct geological setting.

1. Introduction

Exposures of Upper Paleozoic rocks are located in the Amotape Mountains, in northwest Peru (Fig. 1), included within the Amotape-Tahuin Range, in the Huancabamba Andes. The succession in this region is rather different and separated from the main Paleozoic outcrops of the rest of the country, which are grouped into the Central Andean Basin. The stratigraphy of the region was described by Martínez (1970), who defined four formations for the Late Paleozoic sedimentary Amotape Group: Cerro Negro (Devonian), Chaleco de Paño (Mississippian), Cerro Prieto (Pennsylvanian) and Palaus (Permian) formations. Carboniferous biostratigraphy of Peru was mostly based on brachiopods, bivalves and plants, as well as rare goniatites and foraminifers (e.g., Rocha-Campos, 1985). This study is focused on the Cerro Prieto Formation (Fig. 1), composed of shales and siltstones with rare limestones and conglomerates in the lower part of the unit (Palacios, 1994).

The Cerro Prieto Formation has been correlated with the Tarma Formation (previously considered as a group) in central and south Peru (e.g., Dunbar and Newell, 1946; Rocha-Campos, 1985; Palacios, 1994) (Fig. 2). The biostratigraphy of the Tarma Formation in the Andean Belt is mostly based on the record of *Fusulinella peruana* Meyer (1914), attributed by Dunbar and Newell (1946) to the Moscovian/Desmoinesian, later reinterpreted as Atokan by Newell et al. (1953). This Atokan age, is the biostratigraphic age assumed for the Tarma Formation in more recent studies (Megard et al., 1996). It must be highlighted that, as Newell et al. (1953) clarified, this fusulinid was recorded from the top of the formation.

Direct biostratigraphic evidences in the Cerro Prieto Formation, as mentioned above, are scarce and of low precision. The occurrence of the goniatites *Paralegoceras peruvianum* Berry (1928) was interpreted as "Atokan or slightly older age" by Newell et al. (1953). Crinoids recorded in the middle part of the formation suggest a "middle Pennsylvanian age" (Girón et al., 2014). Brachiopods and bivalves described in the region suggest a "Pennsylvanian age" (Newell et al., 1953; Palacios,

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1994; Neves et al., 2014). On the other hand, Sánchez et al. (2006) proposed a Viséan age on the basis of palynomorphs for their Unit II, which was interpreted as possible equivalent to the Cerro Prieto Formation. However, owing the age of the rocks, it most probably corresponds to the underlying Chaleco de Paño Formation.

The aims for this study are the analysis of the foraminifers yielded in limestones in the lower half of the Cerro Prieto Formation, in order to determine precisely its biostratigraphy and correlation with other coeval units in the Central Andes. In addition, its possible palaeogeographic relationships are analysed to discuss its likely origin as a para-autochthonous terrane (Bellido et al., 2009). Foraminifers were studied at the "Caseta de la Antena" section, 500 m east of the Antenna's House and 2 km south of "Cerro del Muerto" (Fig. 1; geographic coordinates at the base 4°39′48.5″S/81°03′39.9″W).

2. Stratigraphical and sedimentological context

Newell et al. (1953) estimated the Cerro Prieto Formation to be 1300 m thick at the type section in Palaus Hill (19 km north of the studied section), as selected by Martínez (1970), whereas this latter author estimated c. 1600 m maximum thickness. However, its thickness has been reduced considerably, down to 160 m (Girón et al., 2014) or 250 m (García et al., 2014, 2015) at Quebrada Pazul (17 km north of the studied section).

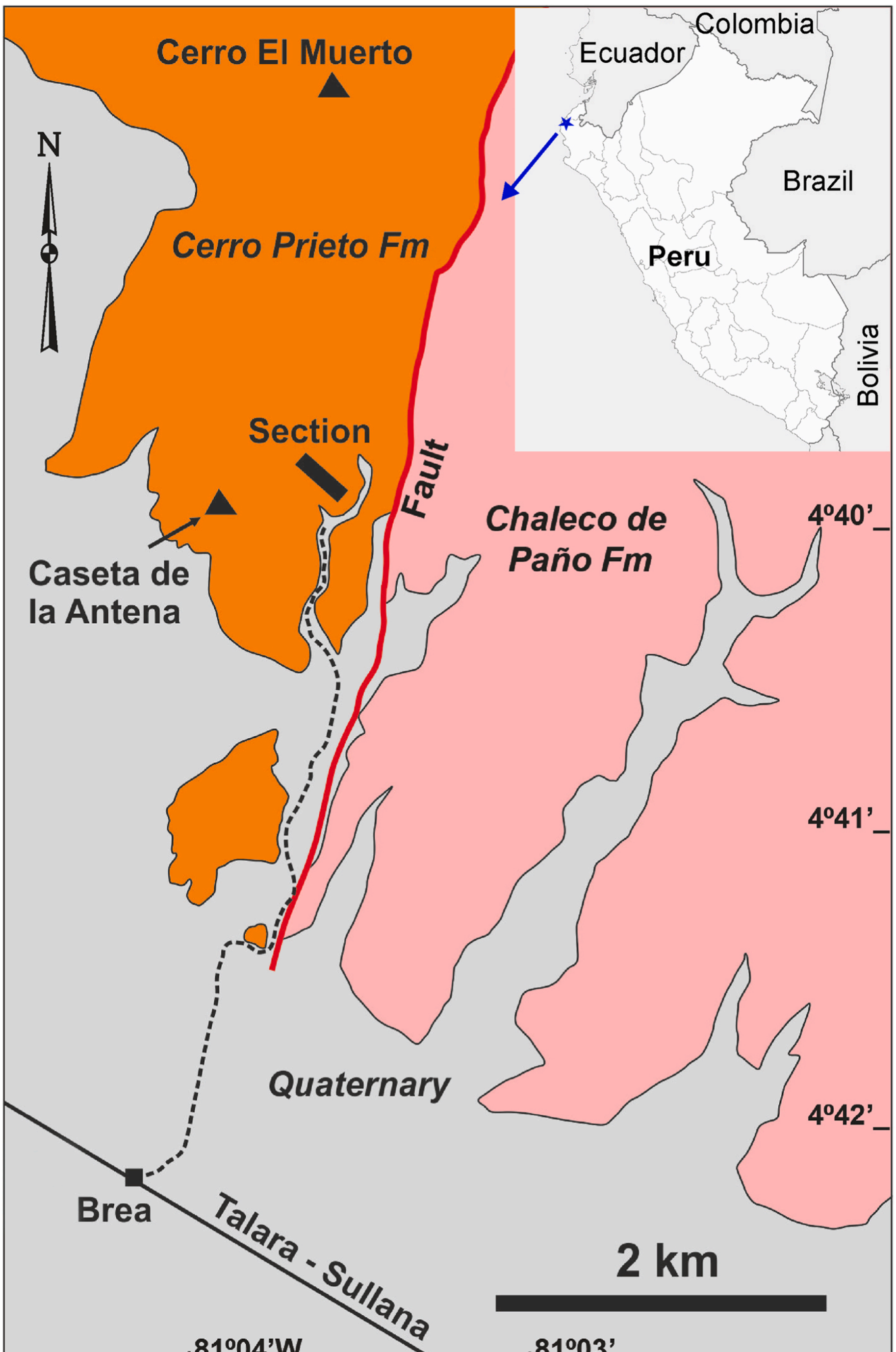

Fig. 1. Geological map and location of the Caseta de la Antena section in the north of Peru (encased box).

The formation at Quebrada Pazul is much thinner (only 250 m thick), and contains common limestones, calcareous sandstones and conglomerates in the lower 50 m of the succession (García et al., 2014, 2015). Common regressive sequences also occur, and environments change from talus to shallow platform. The carbonate deposits were recognized in the talus facies.

At the Caseta de la Antena section, there is a notable presence of limestone beds in the lower 110 m, and rare sandstones, whereas the upper part is mostly composed of shales, with very sparse thin sandstone beds (Fig. 3). Compared to other sections, it is noteworthy for the abundance of limestones (mostly coarse-grained encrinites), the poverty in sandstones, and the absence of typical coarsening-upward sequences. Slumped beds are recognized in the lower part, and compared to Quebrada Pazul, they seem to be emplaced in the talus. There are numerous faults and folds in the region, and it cannot be discarded that there is a thicker succession composed of shales, although it could not be proved biostratigraphically.

3. Geological setting

The Huancabamba Andes are located across southern Ecuador and northern Peru, being considered as the connection between the Central and Northern Andes. Pre-Mesozoic rocks outcrop mostly in the Amotape-Tahuin Range, Paita and Illescas massifs. The Amotape-Tahuin Range contains Precambrian–Early Paleozoic series, usually overlain unconformably by Devonian to Permian rocks, which evolved from marine to continental environments (Palacios, 1994). In the Mesozoic coastal rocks, a post-Permian to pre-Albian hiatus was recognized (Mourier et al., 1988).

Two volcanic arcs trended NNE were interpreted for the Huancabamba Andes during the Mesozoic, of which one arc that developed during the Jurassic, separated the Olmos Massif (inland) from the Amotape-Tahuin Range (Mourier et al., 1988). Palaeomagnetic data on the pre-Mesozoic massifs suggest a clockwise rotation (≈25°) and a northward transport (≈17° in latitude) of the Amotape-Tahuin Range with respect to South America, with the region being considered as a terrane accreted to the Gondwana margin during the early Cretaceous (Mourier et al., 1988).

The study of granitoids in the Amotape-Tahuin Range allowed Bellido et al. (2008, 2009) to propose the evolution of the region in four phases: (i) a cortical thickening during the Devonian-Carboniferous; (ii) a thinner crust and rifting during the Permian and Triassic, which implied the separation of the Amotape-Tahuin Range from the Gondwana margin; (iii) followed by a northern displacement parallel to the continental margin during the Jurassic; and (iv), a final phase of accretion and deformation of the Amotape-Tahuin Range and also of other terranes located further to the north. Thus, for those authors, the Amotape-Tahuin Range was interpreted as a para-autochthonous terrane. The model implies the filling of the basin in a continental-margin forearc setting. This model contrasts with that proposed by Jaillard et al. (2000), where the region developed under a back-arc setting.

4. Foraminiferal assemblages

Foraminifers are commonly found within coarse-grained crinoidal

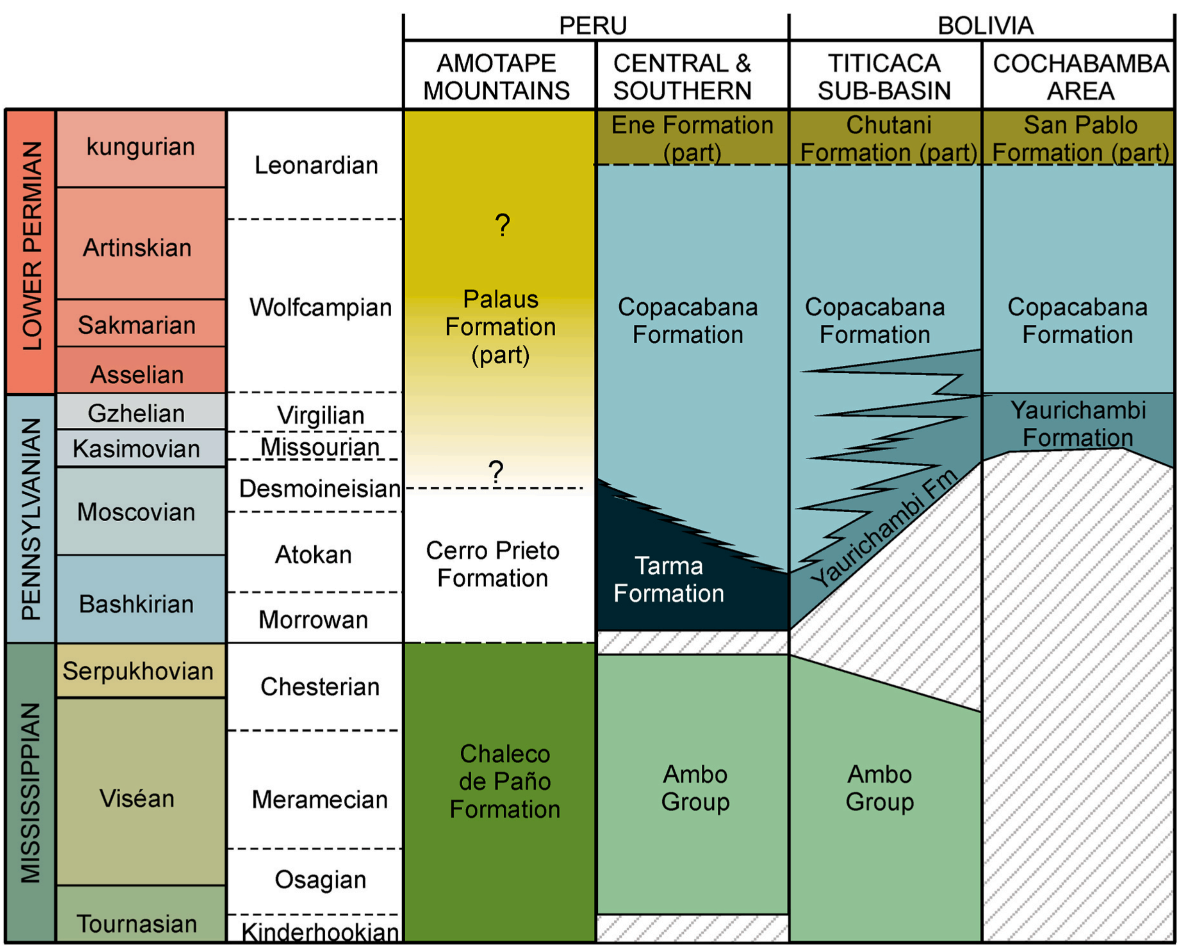

Fig. 2. Carboniferous-Early Permian lithostratigraphic correlation of selected regions in Peru and Bolivia. Data from Bolivia and southern & central Peru are modified from Grader et al. (2008).

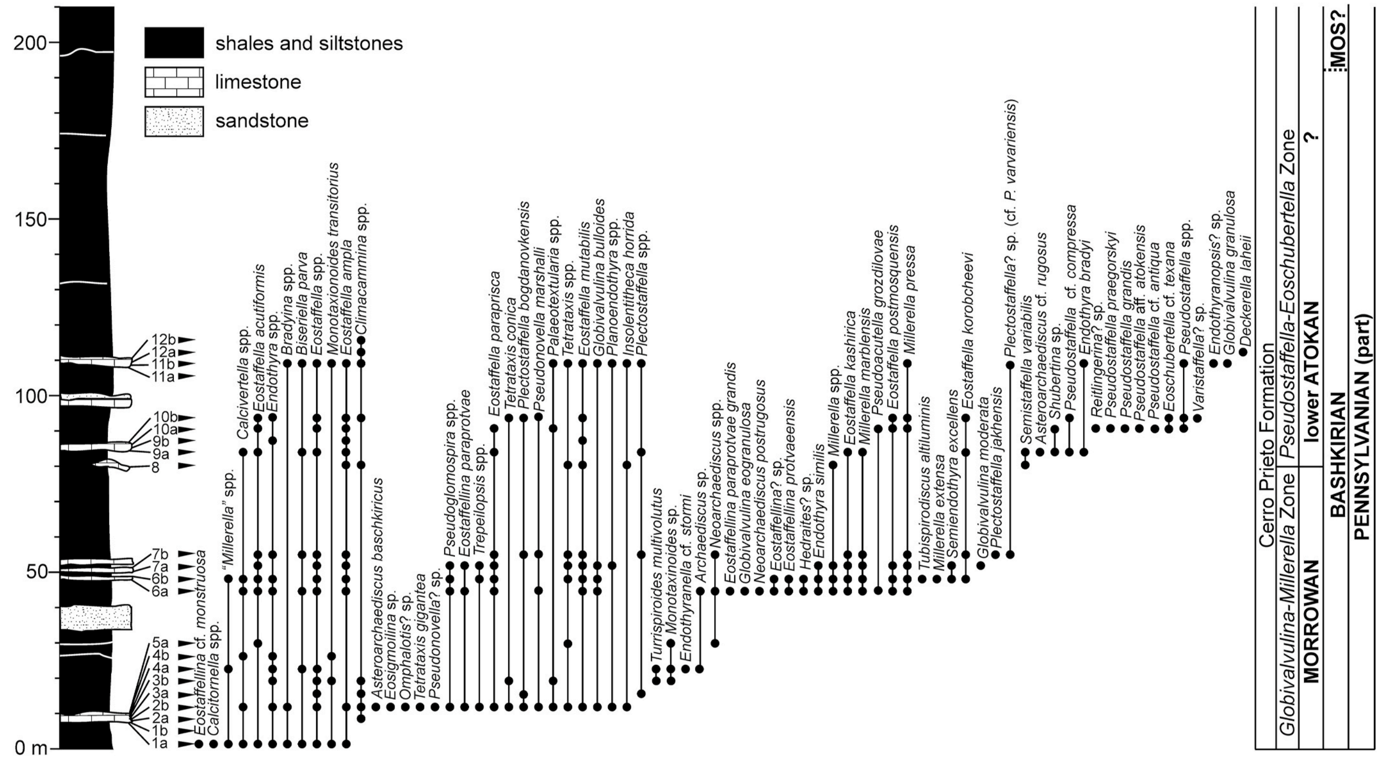

Fig. 3. Foraminiferal distribution in the Caseta de la Antena section of the Cerro Prieto Formation. Mos = Moscovian.

facies, and thus, assemblages are considered transported and fragmented. The suprageneric classifications published by Vachard et al. (2010), Vachard (2016) and Vachard and Le Coze (in press) are followed herein.

Representative of the class Miliolata (e.g., calcivertellids; Fig. 4.1–4.3) are rather scarce, and although they mostly occur in the lower part of the section (below sample 8; Fig. 3), its distribution does not seem biostratigraphically significant. It is noteworthy for the absence of the genus *Hemigordius*, which in North America has been proposed as the only distinct element to subdivide the Morrowan Substage (Groves, 1984).

The class Fusulinata shows representatives of the subclasses Afusulinana and Fusulinana. The Asufulinana are mostly composed of *Archaediscus* (Fig. 4.6), *Asteroarchaediscus* (Fig. 4.5), *Eosigmoilina* (Fig. 4.4), *Tubispirodiscus* (Fig. 4.7) and *Neoarchaediscus*, included in the superfamily Archaediscoidea; as well as *Monotaxinoides* (Fig. 4.8–4.9) and *Turrispiroides* (Fig. 4.10) of the superfamily Lasiodiscoidea. The Archaediscoidea are rather sparse, whereas *Monotaxinoides* is relatively common in the lower part of the section (below bed 5; Fig. 3), although usually, the specimens are silicified (Fig. 4.8). On the other hand, *Insolentitheca* is the only genus representative of the superfamily Caligelloidea (Fig. 4.13).

The Fusulinana are more widely represented by the orders Endothyrida and Fusulinida. Within the former order, specimens of *Endothyra*, *Tetrataxis* and *Climacammina* (Fig. 4.16) are common (Fig. 3), as well as *Globivalvulina* and *Biseriella* species (Fig. 4.18–4.22). Other genera are rare, such as *Bradyina* (Fig. 4.15), *Planoendothyra* (Fig. 4.11), *Semiendothyra*, *Endothyranella* (Fig. 4.12), *Deckerella* (Fig. 4.17) and *Palaeotextularia*, and the poor orientation of the species, usually, prevent their identification at species level. It is noteworthy for the occurrence of questionable specimens attributed to *Omphalotis*? sp. and *Endothyranopsis*? sp. (Fig. 4.14). Both genera usually become extinct below the mid-Carboniferous boundary, although rare exceptions have been published (e.g., Mamet and Isaacson, 1997; Cózar et al., 2014, 2018).

Fusulinida are mostly represented by genera of the superfamily Ozawainelloidea, which are the dominant forms in the foraminiferal assemblages from sample 6a upwards (Fig. 3), mostly of the genus *Eostaffella* (Fig. 5.1–5.8). The genus *Plectostaffella* (Fig. 5.14–5.16) is sparsely distributed, whereas *Millerella* (Fig. 5.19–5.21) occurs in sample 6a, and its ancestral forms '*Millerella*' (i.e. *Zellerinella* auct.; Fig. 5.17–5.18) occurs from older levels (Fig. 3), but rarely. A questionable specimen assigned to *Varistaffella* (Fig. 5.22) is recorded from the upper part of the limestones (Fig. 3), interpreted to be a derived genus from evolved *Plectostaffella* (Kulagina and Sinitsyna, 2003). On the other hand, representatives of the genus *Eostaffellina* (Fig. 5.9–5.13) only occur in the lower part of the section (below sample 7b; Fig. 3). *Pseudonovella* (Fig. 5.23) and *Pseudoacutella* (Fig. 5.24) are rare, but are distributed through the section.

The superfamily Fusulinoidea is represented by the genera *Semistaffella* (Fig. 6.1–6.2) (considered by many authors as a subgenus of *Pseudostaffella,* as originally defined by Reitlinger, 1961) and *Pseudostaffella* which are recorded from samples 8 (a slumped horizon) and 9a, and common in sample 10b (Fig. 3). Specimens of *Pseudostaffella* are poorly oriented and fragmented, and in sample 10b the genus seems to be rather diversified and five species might be present (Fig. 6.3–6.5, 6.10–6.11).

The superfamily Schubertelloidea occurs with rare specimens of the ancestral forms *Eoschubertella* and *Schubertina* (Fig. 6.6–6.9) in the upper limestones (Fig. 2).

The superfamily Staffelloidea is only represented by a questionable specimen of *Reitlingerina* (Fig. 6.12).

5. Biostratigraphy

Most species in the lower part of the section (samples 1 to 5) are typically recorded from the upper Chesterian, although most of them also extend into the Morrowan. However, nearly from the base of the section (at sample 2b), *Plectostaffella bogdanovkensis* Reitlinger (1980), *Pseudonovella marshalli* Vachard et al. (2013) and *Globivalvulina bulloides* (Brady, 1876) are recorded. It is noteworthy that *Globivalvulina* in the Panthalassa Ocean is restricted to the Pennsylvanian and Permian (e.g.,

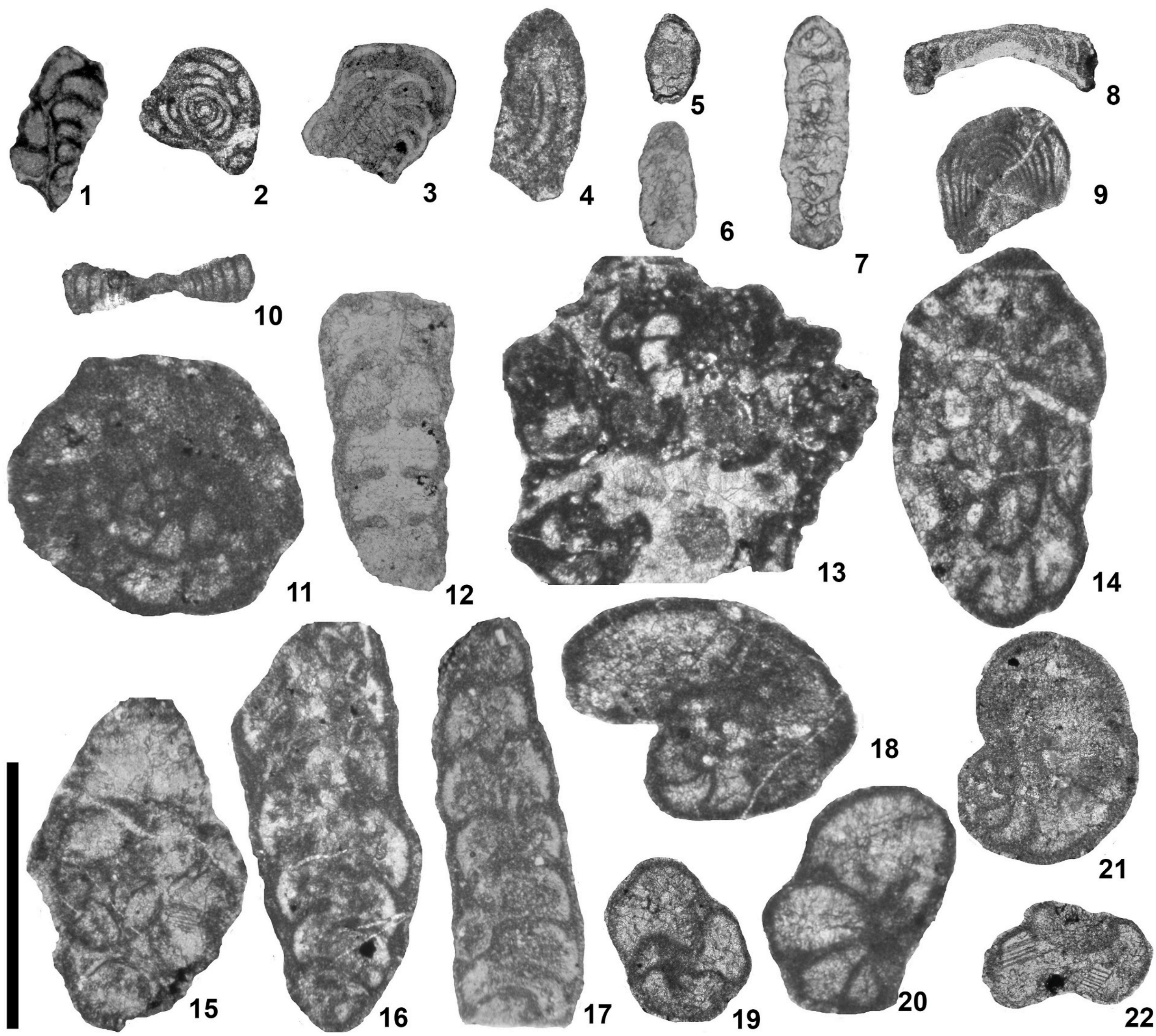

Fig. 4. Selected Archaediscoida, Lasiodiscoida, Caligelloidea, Endothyroidea Bradyinoidea, Palaeotextularioidea and Globivalvulinoidea. Scale bar = 500 μm, except for Figs. 13–17 = 1 mm. **1** *Trepeilopsis* sp. (=*Volvotextularia* auct.), transverse section, sample 7a. **2** *Calcivertella* sp., transverse section, sample 6a. **3** *Hedraites*? sp., transverse section, sample 6b. **4** *Eosigmoilina* sp., oblique sagittal section, sample 2b. **5** *Asteroarchaediscus* cf. *rugosus* Rauser-Chernousova (1948b), juvenile axial section, sample 9a. **6** *Archaediscus* sp. (with marked final whorls at *angulatus* stage), axial section, sample 4a. **7** *Tubispirodiscus altiluminis* (Brenckle, 1973), axial section, sample 6b. **8–9** *Monotaxinoides transitorius* Brazhnikova and Yartseva (1956), near-axial sections, samples 3b and 11b. **10** *Turrispiroides multivolutus* (Reitlinger, 1949), sagittal section, sample 1a. **11** *Planoendothyra aljutovica* (Reitlinger, 1950), near-equatorial section, sample 2b. **12** *Endothyranella* cf. *stormi* (Cushman and Waters, 1928), oblique section of the uncoiled part of the test, sample 4a. **13** *Insolentitheca horrida* (Brazhnikova in Brazhnikova et al., 1967), transverse section, sample 2b. **14** Indet Endothyridae, near-equatorial section, (cf. *Endothyranopsis*? sp. or *Semiendothyra*? sp.), sample 11b. **15** *Bradyina* cf. *cribrostomata* Rauser-Chernousova and Reitlinger in Rauser-Chernousova and Fursenko, 1937), oblique section, sample 2b. 16 *Climacammina* sp., transverse section, sample 12a. **17** *Deckerella laheei* Cushman and Waters (1928), transverse section, sample 12a. **18** *Globivalvulina granulosa* Reitlinger (1950), near-sagittal section, sample 11b. **19** *Globivalvulina moderata* Reitlinger (1949), tangential-axial section, sample 7a. **20–21** *Globivalvulina bulloides* (Brady, 1876), near-sagittal sections, sample 2b. **22** *Biseriella parva* (Chernysheva, 1948), tangential-axial section, s sample 4a.

Brenckle et al., 1997, 2019; Pinard and Mamet, 1998). The genus in the Western Paleotethys first occurs from the latest Serpukhovian (e.g., Reitlinger et al., 1996; Cózar and Somerville, 2012), and the genus occurs a few metres below the Serpukhovian-Bashkirian boundary in the Arctic Realm, in the Franklin Corridor in Alaska (Harris et al., 1997; Baesemann et al., 1998). The occurrence of *Plectostaffella bogdanovkensis* is also rarely documented from the latest Serpukhovian (Reitlinger et al., 1996), but its stratigraphic range is usually restricted to the Pennsylvanian (e.g., Kulagina and Sinitsyna, 2003). On the other hand, *Pseudonovella* was described by Vachard et al. (2013) from the late Bashkirian and questionably from the Morrowan of Idaho (in Groves, 1984).

These three taxa allow us to assign the lower levels of the section to the early Bashkirian or Morrowan, which, correspond to the *Millerella* Zone in the classical American biozonation (Thompson, 1945). The absence of typical *Millerella* specimens from the base of the zone is not unusual (e.g., Brenckle et al., 1997, 2019; Groves, 1983, 1984), a fact which led Brenckle et al. (2019) to rename the interval as the *Globivalvulina-Millerella* Zone (Fig. 3).

Eosigmoilina is usually restricted to the upper Chesterian or late Serpukhovian in Panthalassa (Lane and Brenckle, 2005), but in the Mid-Carboniferous GSSP at Arrow Canyon, the genus is recorded just above the boundary (Brenckle et al., 2019). This occurrence suggests that the base of the Cerro Prieto Formation coincides or nearly coincides with the base of the Baskhirian or base of the Morrowan Substage.

Other markers of the zone are recorded slightly higher up in the section, from samples 6 and 7, where *Millerella marblensis* Thompson (1942), *Millerella extensa* Marshall (1969) and *Millerella pressa*

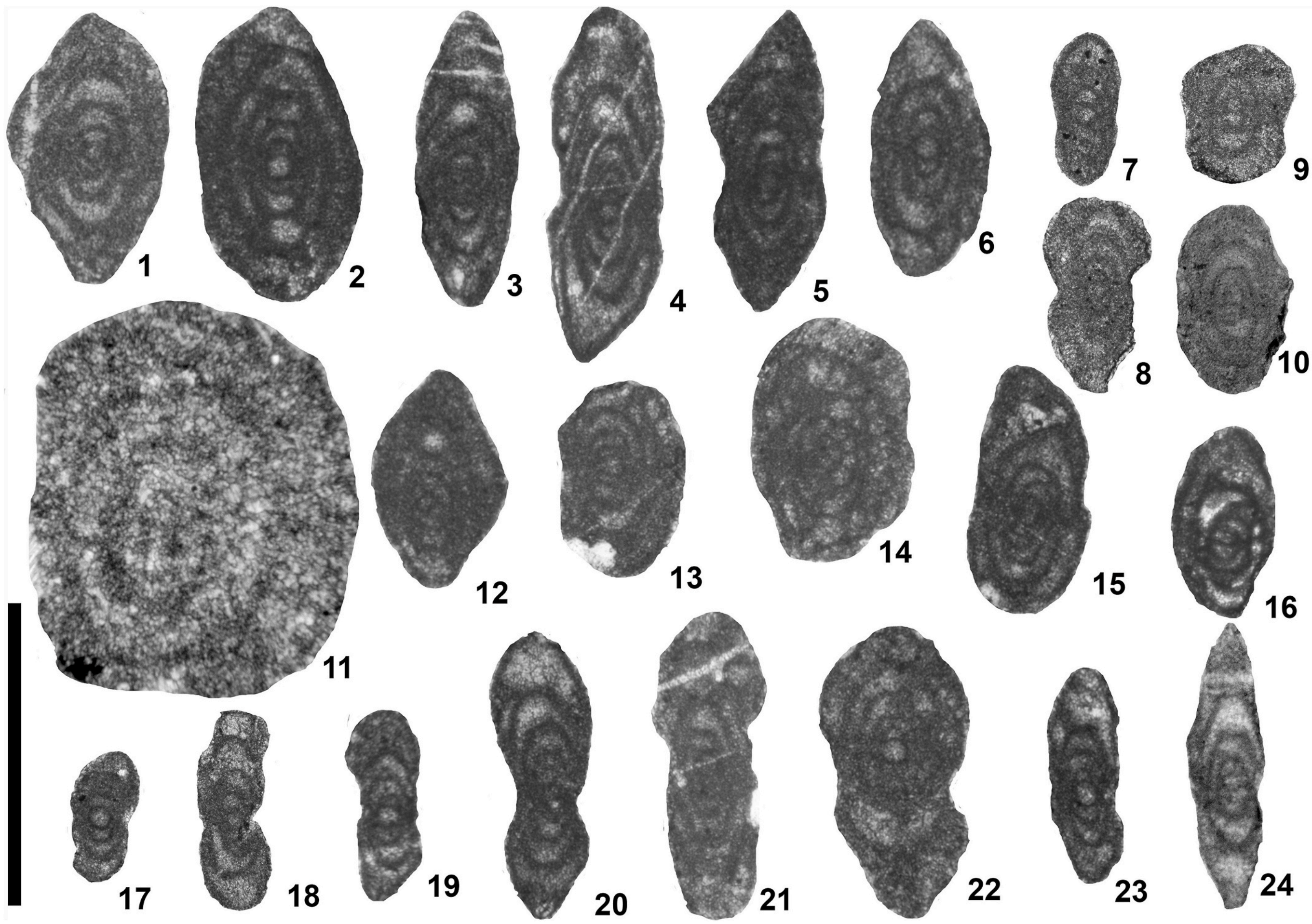

Fig. 5. Selected Ozawainelloidea. Scale bar = 500 μm. **1** *Eostaffella ampla* (Thompson, 1944), axial section, sample 6a. **2** *Eostaffella kashirica* Rauser-Chernousova in Rauser-Chernousova et al. (1951), axial section, sample 6a. **3** *Eostaffella mutabilis* (Rauser-Chernousova in Rauser-Chernousova et al., 1951), near-axial section, sample 6b. **4** *Eostaffella* aff. *mutabilis* (Rauser-Chernousova in Rauser-Chernousova et al., 1951), axial section, sample 11b. **5** *Eostaffella korobcheevi* Rauser-Chernousova in Rauser-Chernousova et al. (1951), axial section, samples 7b. **6** *Eostaffella acutiformis* Kireeva in Rauser-Chernousova et al. (1951), near-axial section, samples 6a. **7** *Eostaffella paraprisca* Durkina (1959), axial section, sample 2b. **8** *Eostaffella postmosquensis* Kireeva in Rauser-Chernousova et al. (1951), axial section, samples 6b. **9** *Eostaffellina protvae* (Rauser-Chernousova, 1948a), axial section, sample 6b. **10** *Eostaffellina paraprotvae* (Rauser-Chernousova, 1948a), near-axial section, sample 6b. **11** *Eostaffellina* cf. *monstruosa* (Reitlinger in Reitlinger and Melnikova, 1977), tangential section, sample 1a. **12** *Eostaffellina*? sp., near-axial section, samples 6a. **13** *Eostaffellina paraprotvae grandis* Manukalova-Grebenyuk et al., (1969), oblique section, sample 6a. **14** *Plectostaffella bogdanovkensis* Reitlinger (1980), oblique section, samples 3a and 7a. **15** *Plectostaffella*? sp. (cf. *P. varvariensis* (Brazhnikova and Potievskaya, 1948)), near-axial section, samples 7b. **16** *Plectostaffella jakhensis* (Reitlinger, 1971), near-axial section, sample 7b. **17** "*Millerella*" *tortula* Zeller (1953), axial section, sample 6b. **18** "*Millerella*" *designata* Zeller (1953), axial section, sample 6b. **19** *Millerella extensa* Marshall (1969), axial section, sample 6b. **20** *Millerella pressa* Thompson (1944), near-axial section, sample 10b. **21** *Millerella marblensis* Thompson (1942), near-axial section, sample 7b. **22** *Varistaffella*? sp., axial section, sample 10b. **23** *Pseudonovella marshalli* Vachard et al. (2013), near-axial section, sample 6a. **24** *Pseudoacutella grozdilovae* (Maslo and Vachard, 1997), near-axial section, sample 7b.

Thompson (1944) are first recorded.

The base of the Atokan is defined at sample 8, where the more evolved fusulinids first occur, such as *Semistaffella*, *Eoschubertella*, *Pseudostaffella* and *Varistaffella*. It is highlighted by the first occurrence of *Deckerella laheei* Cushman and Waters (1928), considered also as a marker for the Zone 21 (Atokan) of Pinard and Mamet (1998). These species and genera are recorded in the Paleotethys from intermediate positions within the early Bashkirian (e.g., Groves et al., 1999), although in the American Realm, they represent the lower subdivision of the Atokan (Groves, 1986).

Nevertheless, the upper 100 m of the section contain exclusively shales and siltstones, that could not be dated, and therefore, its upper stratigraphic range is unknown, and it could range up to the Moscovian (see Discussion Section).

6. Discussion

The three subdivisions of the Atokan are marked by the first occurrence of *Eoschubertella-Pseudostaffella*, *Profusulinella*, and finally *Fusulinella* (Wilde, 1990), of which, only the first two taxa are recorded in the Cerro Prieto Formation.

The *Fusulinella* Zone is correlated with the basal Moscovian, whereas the *Profusulinella* Zone is usually considered as the uppermost Bashkirian. The precise correlation of the base of the Atokan (*Eoschubertella-Pseudostaffella* Zone) with the international stages is still controversial, and some possibilities have been proposed (see details in Groves et al., 1999). Currently, the base of the Atokan is used as nearly coincident with the base of the late Bashkirian (e.g., Davydov et al., 2012; Aretz et al., 2020; Lucas, 2021; Lucas et al., 2022).

The Tarma Formation of the Central Andean basin is usually correlated with the Cerro Prieto Formation (e.g., Newell et al., 1953). The recognition of a precise age for the lower levels of the Cerro Prieto

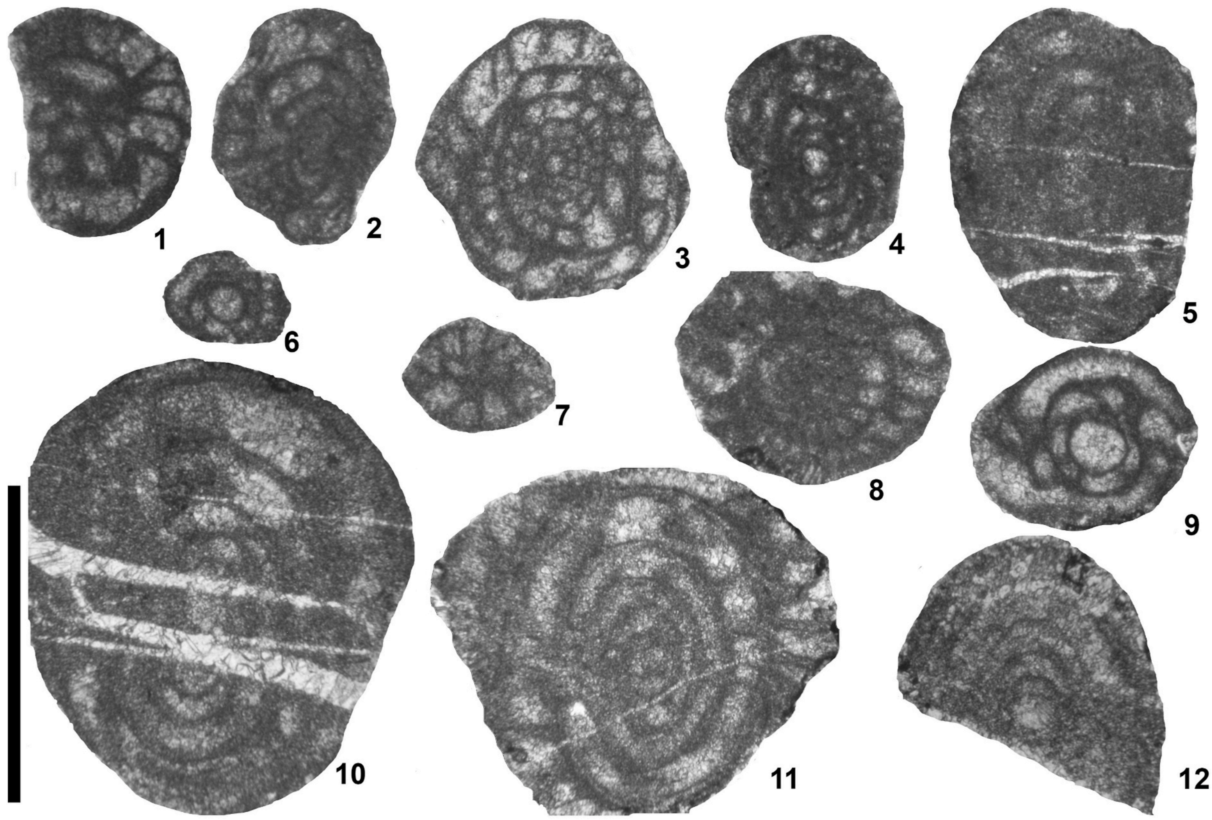

Fig. 6. Selected Staffelloidea, Schubertelloidea, and Fusulinoidea. Scale bar = 500 μm. **1–2** *Semistaffella variabilis* (Reitlinger, 1961), oblique sections, samples 8 and 9a. **3** *Pseudostaffella* cf. *antiqua* (Dutkevich, 1934), near-equatorial section, sample 10a. **4** *Pseudostaffella* cf. *compressa* (Rauser-Chernousova, 1938), oblique section, sample 9a. **5** *Pseudostaffella* aff. *atokensis* (Thompson, 1935), oblique section, sample 10a. **6–7** *Schubertina* sp., oblique sections, samples 9a and 10a. **8–9** *Eoschubertella* cf. *texana* Thompson (1947), oblique sections, samples 10a and 10b. **10** *Pseudostaffella praegorskyi* Rauser-Chernousova (1949), near-axial section, sample 10a. **11** *Pseudostaffella grandis* Schlykova in Grozdilova and Lebedeva (1950), near-axial section, sample 10a. **12** *Reitlingerina*? sp., axial section, sample 10a.

Formation allows us to propose a Morrowan Substage or early Bashkirian for the base of the Tarma Formation (Fig. 2). Conversely, the occurrence of *Fusulinella* in the upper beds of the Tarma Formation suggests that the upper part of the Cerro Prieto Formation, composed exclusively of shales and siltstones, might represent the *Profusulinella* and *Fusulinella* zones, and thus, reaching the basal levels of the Moscovian at its top (Fig. 3). Thus, the Permian age attributed to the Palaus Formation by its higher stratigraphic position has been never proved (Fig. 2), and it could be only late Pennsylvanian, or late Pennsylvanian-Permian, assuming a continuous succession, as described by Palacios (1994).

In the Central Andean basin of Bolivia, Grader et al. (2003, 2008) demonstrated that the Copacabana Formation is early Bashkirian at its base, interfingered with the predominantly siliciclastic Yaurichambi Formation (Fig. 2). In particular, the lower levels of the Copacabana Formation were assigned to the *Millerella* Zone (Mamet, 1996; Mamet and Isaacson, 1997). The former authors interpreted a similar lateral facies change for central and south Peru, with the Copacabana Formation interfingered with the Tarma Formation (considered as a formation), and the Tarma Formation extending through the Pennsylvanian, and the Copacabana Formation extended from the Bashkirian to the Early Permian. Certainly, this biostratigraphy has never been proved in Peru, and the younger contrasted age for the Tarma Formation is lower Moscovian.

As it is assumed for the Cerro Prieto Formation in the Amotape Mountains, the younger age is possibly the same as for the Tarma Formation. Above the Cerro Prieto Formation, the overlying Palaus Formation was interpreted to be Early Permian in age based on its stratigraphic position (Palacios, 1994), but the fauna is poorly preserved and it was never dated. Some authors, such as Rocha-Campos (1985), interpreted an unconformity between the Cerro Prieto and Palaus formations, which could justify a Permian age for the Palaus Formation. However, Palacios (1994), regarded it as a continuous succession, and thus, the Palaus Formation should be considered as late Pennsylvanian, whereas its attribution to the Early Permian is uncertain.

Foraminiferal assemblages described by Mamet and Isaacson (1997) from the base of the Copacabana Formation in Bolivia are, overall, rather similar to those recorded from the Cerro Prieto Formation. However, several marked differences are observed.

- Palaeotextulariidae and Lasiodiscidae are scarce in Bolivia, and relatively common in the Amotape Mountains, including some genera lacking in Bolivia.
- *Bradyina* is recorded in Bolivia in younger levels.
- *Plectostaffella* and *Semistaffella* are not recorded in Bolivia.
- Primitive '*Millerella*' are common in Bolivia, and rather scarce in Peru.
- *Hemigordius* and *Seminovella* have not been recorded in the Amotape Mountains.

Despite some similarities, the similarity indices are very low (Jaccard index for the genera = 0.46; Simpson index = 0.75).

On the other hand, Wood et al. (2002) studied the Copacabana Formation in south Peru, recording poorer assemblages for the lower interval of the formation, attributed by those authors to the "Morrowan-Atokan". The entire assemblage recorded from four sections only contain 17 genera, which seem sparsely distributed. Only the Río Urabamba section seems to have some similarity with the Cerro Prieto Formation, with common *Eostaffella*, *Millerella*, *Globivalvulina* and *Biseriella*, but it contains also *Hemigordius*. The same interval in other sections, in addition, contain *Syzrania* (considered by those authors as the oldest record of the genus; usually Desmoinesian or younger) and *Eoschubertella* (Atokan), and thus, the Morrowan part can be considered as poorly characterized, and with few similarities with the data from Amotape Mountains. Similarity indices with the Amotape Mountains is also very low (Jaccard index = 0.27; Simpson index = 0.67).

These differences might be primarily attributed to the poor preservation and/or scarce foraminiferal assemblages, or alternatively, they might be the result (at least in part) of a slight biogeographic differentiation: the para-autochthonous terrane origin of the Amotape Mountains late Paleozoic basin (Bellido et al., 2009) implies an original continental-margin forearc setting, as opposed to the continental interior backarc transtensional setting of the main Central Andean Peru-Bolivia basin (Jaillard et al., 2000). It needs to be highlighted though that even between south Peru and Bolivia, the foraminiferal assemblages show low similarities (Jaccard index = 0.35; Simpson index = 0.67), which assuming that they belong to the same Copacabana Formation in nearby parts of the same basin, suggest that the main problem might be the poor preservation stage or low sampling effort in those basins. This would imply that foraminiferal assemblages are still rather incomplete, and further investigation should be done to understand the palaeobiogeographic relationship of the basins. If the second hypothesis is correct, a forearc setting instead of a backarc setting, the low similarity indices might justify those differences in term of palaeobiogeography, but as a secondary result, that the above assumed correlations between formations of different basins and countries should be revised carefully. The assumed biostratigraphy for the tops and bases of some formations (taking into account their comparable stratigraphic positions, and the absence of reliable biostratigraphy data) are questionable and need further sampling work to determine biostratigraphically the precise base and top of each formation in each region (Fig. 2).

7. Conclusions

Diverse foraminiferal assemblages from the lower half of the Cerro Prieto Formation in the Amotape Mountains in the northwest of Peru contain a similar fauna to that described for the southern part of the basin in Bolivia. These foraminifers can be used for biostratigraphy using the biozonation from Panthalassa (American Realm), and allow us to distinguish the Morrowan and lower subdivision of the Atokan substages. These substages are identified by means of the *Globivalvulina-Millerella* Zone and the *Eoschubertella-Pseudostaffella* Zone defined by American authors in the USA.

Compared with the international stages, the succession contains most of the Bashkirian Stage, and assuming stratigraphical correlations with Central Andean basins in central and south Peru, and its lateral equivalent formation (Tarma Fm), the complete stratigraphic range for the Cerro Prieto Formation might be Bashkirian up to the lower levels of the Moscovian. This stratigraphic range reduces significantly the previously assumed 'Pennsylvanian' age, originally attributed to the Cerro Prieto Formation, and suggests that the overlying Palaus Formation is in part Pennsylvanian, and not exclusively Permian.

Although, overall, assemblages are similar to those recorded in Bolivia and south Peru's Copacabana Formation, nevertheless, significant diversity and abundance differences seem to confirm that the Amotape Mountains, apart from a limited database, can be interpreted as a slightly different palaeobiogeographic setting, which could be justified if they were located in a continental-margin forearc setting, as opposed to the continental interior backarc transtensional setting of the main Central Andean Peru-Bolivia basin. However, the nascent knowledge on the biostratigraphy of those basins in South America does not permit considering the foraminiferal data (as well as those from other fossil groups) as sufficiently reliable enough as to allow precise tectonic and palaeogeographic models to be proposed for the region.

CRediT authorship contribution statement

Pedro Cózar: Writing – original draft, Methodology, Investigation, Conceptualization. **Enrique Díaz-Martínez:** Writing – original draft, Investigation, Funding acquisition. **Víctor Carlotto:** Writing – review & editing, Resources, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data used are presented in the figures. Thin-sections are housed in the Palaeontological collection of the Universidad Complutense de Madrid (Spain).

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References

Aretz, M., Herbig, H.G., Wang, X.D., 2020. The carboniferous period. In: Gradstein, F.M., Ogg, J.G., Schmitz, M.D., Ogg, G.M. (Eds.), Geologic Time Scale 2020, vol. 2, pp. 811–874.

Baesemann, J.F., Brenckle, P.L., Gruzlovic, P.D., 1998. Composite standard correlation of the mississippian-pennsylvanian (carboniferous) lisburne group from prudhoe bay to the eastern arctic national wildlife refuge, Alaska. In: Clough, J.G., Larson, F. (Eds.), Short Notes on Alaska Geology 1997, vol. 118. Alaska Department of Natural Resources, Divison of Geological and Geophysical Surveys, Professional Report, pp. 23–36.

Bellido, F., Jaimes, F., Carlotto, V., Díaz Martínez, E., 2008. Los granitoides peralumínicos triásicos de los Cerros de Amotape y del Macizo de Illescas (Noroeste de Perú): Implicaciones para la evolución geodinámica del Terreno Amotape. XIV Congreso Peruano de Geología y XIII Congreso Latinoamericano de Geología, Lima, Perú, CD-ROM, G-07 6.

Bellido, F., Valverde, P., Jaymes, F., Carlotto, V., Díaz-Martínez, E., 2009. Datación y caracterización geoquímica de los granitoides peralumínicos de los Cerros de Amotape y de los macizos de Illescas y Paita (noroeste del Perú). Bol. Soc. Geol. Peru 103, 197–213.

Berry, E.W., 1928. An ammonoid from the Carboniferous of Peru. American Journal of Sciences 15, 151–153.

Brady, H.B., 1876. A monograph of Carboniferous and Permian foraminifera (the genus Fusulina excepted). Palaeontographical Society of London 30, 1–166.

Brazhnikova, N.E., Potievskaya, P.D., 1948. Results of the foraminiferal study of materials from wells of the western outskirts of Donbass. Collection of works about paleontology and stratigraphy 1, 76–101 (in Russian).

Brazhnikova, N., Yartseva, M.V., 1956. On the question of the evolution of the genus *Monotaxis*. Voprosy Mikropaleontologii 1, 62–68 (in Russian).

Brazhnikova, N.E., Vakarchuk, G.I., Vdovenko, M.V., Vinnichenko, L.V., Karpova, M.A., Kolomiets, YaI., Potievskaya, P.D., Rostovtseva, L.F., Shevchenko, G.D., 1967. Microfaunal marker horizons from the carboniferous and permian deposits of the dniepr-donets depression. Akademiya Nauk Ukrainskoi SSR, Instituta Geologicheskikh Nauk, Trudy, Izdatelstvo. Naukova Dumka, Kiev, p. 224 (in Russian).

Brenckle, P.L., 1973. Smaller mississippian and lower pennsylvanian calcareous foraminifers from Nevada. Cushman Found. Foraminifer. Res. Spec. Publ. 11, 1–82.

Brenckle, P.L., Baesemann, J.F., Lane, H.R., West, R.R., Webster, G.D., Langenheim, R.L., Brand, U., Richards, B.C., 1997. Arrow Canyon, the mid-Carboniferous boundary stratotype. In: Brenckle, P.L., Page, W.R. (Eds.), Paleoforams'97 Guidebook: Post-Conference Field Trip to the Arrow Canyon Range, Southern Nevada, USA, vol. 36. Cushman Foundation for Foraminiferal Research, Special Publication, pp. 13–32.

Brenckle, P.L., Manger, W.L., Titus, A.L., Nemyrovska, T.I., 2019. Late Serpukhovian foraminifers near the Mississippian-Pennsylvanian boundary at south syncline ridge, southern Nevada, USA: implications for correlation. J. Foraminifer. Res. 49, 229–240.

Chernysheva, N.E., 1948. Some new species of foraminifera from the Visean stage of the Makarovo region (South Ural). Akademya Nauk SSSR Trudy Instituta Geologicheskikh Nauk, 62, geologicheskaya seriya 19, 246–250.
Cózar, P., Somerville, I.D., 2012. Mississippian Biseriamminaceae and their evolutionary development. J. Foraminifer. Res. 42, 216–233.
Cózar, P., Medina-Varea, P., Somerville, I.D., Vachard, D., Rodriguez, S., Said, I., 2014. Foraminifers and conodonts from the late Viséan to early Bashkirian succession in the Saharan Tindouf Basin (southern Morocco): biostratigraphic refinements and implications for correlations in the western Palaeotethys. Geol. J. 49, 271–302.
Cózar, P., Somerville, I.D., Blanco-Ferrera, S., Sanz-López, J., 2018. Palaeobiogeographic context in the development of shallow-water late Visean-early Bashkirian benthic foraminifers and calcareous algae in the Cantabrian Mountains (Spain). Palaeogeogr. Palaeoclimatol. Palaeoecol. 511, 620–638.
Cushman, J.A., Waters, J.A., 1928. Some foraminifera from the pennsylvanian and permian of Texas. Contributions from the Cushman Laboratory for Foraminiferal Research 4, 31–55.
Davydov, V.I., Korn, D., Schmitz, M.D., Gradstein, F.M., Hammer, O., 2012. Chapter 23-the carboniferous period. In: Gradstein, F.M., Ogg, J.G., Schmitz, M.D., Ogg, G.M. (Eds.), The Geologic Time Scale 2012. Elsevier, Amsterdam, pp. 603–651.
Dunbar, C.O., Newell, N.D., 1946. Marine early permian of the central Andes and its fusuline faunas. American Journal of Sciences 244, 377–402.
Durkina, A.V., 1959. Foraminifera of the lower carboniferous deposits of the timan-pechora province. Tr. Vsesoyuznogo Neft. Nauchno-Issledovatel'skogo Geol. Inst. 136, 132–389 (in Russian).
Dutkevich, G.A., 1934. Stratigraphy of the middle carboniferous in the urals. Trudy Vsesoyuznogo Neftyanogo Nauchno-issledovatel'skogo Geologo-razvedochnogo Instituta (VNIGRI) serija A 55, 3–41 (in Russian).
García, B., Girón, I., Oviedo, M., Astete, I., Cedano, D., 2014. Análisis sedimentológico del Pensilvaniano en las montañas de Amotapes-Talara, nuevas evidencias de formas arrecifales. Resumen extendido, XVII Congreso Peruano de Geología. Sociedad Geológica del Perú – SGP, Lima 4. https://hdl.handle.net/20.500.12544/2341.
García, B., Girón, I., Oviedo, M., Astete, I., Cedano, D., 2015. Análisis sedimentológico del Pensilvaniano en las montañas de Amotapes-Talara. Bol. Soc. Geol. Peru 110, 24–27.
Girón, I., García, B., Oviedo, M., Astete, I., 2014. Placas columnares de crinoideos del Carbonífero (Pensilvaniano) en la Formación Cerro Prieto. Resumen extendido, XVII Congreso Peruano de Geología. Sociedad Geológica del Perú – SGP, Lima 4. https://hdl.handle.net/20.500.12544/2731.
Grader, G.W., Isaacson, P.E., Arispe, O., Pope, M., Mamet, B., Davydov, V., Díaz-Martínez, E., 2003. Back-arc carbonate-siliciclastic sequences of the pennsylvanian and permian Copacabana Formation, titicaca group, Bolivia. Rev. Tec. Yacimientos Pet. Fisc. Boliv. 21, 207–228.
Grader, G.W., Isaacson, P.E., Díaz-Martínez, E., Pope, M.C., 2008. Pennsylvanian and Permian sequences in Bolivia: direct response to Gondwana glaciation. In: Fielding, C.R., Frank, T.D., Isbell, J.L. (Eds.), Resolving the Late Paleozoic Ice Age in Time and Space, vol. 441. Geological Society of America Special Paper, pp. 143–159.
Groves, J.R., 1983. Calcareous foraminifers and algae from the type Morrowan (Lower Pennsylvanian) region of northeastern Oklahoma and northwestern Arkansas. Okla. Geol. Surv. Bull. 133, 1–39.
Groves, J.R., 1984. Foraminifers and biostratigraphy of the arco hills, bluebird mountain, and lower snaky Canyon formations (Mid-Carboniferous) of east-central Idaho. J. Foraminifer. Res. 14, 282–302.
Groves, J.R., 1986. Foraminiferal characterization of the morrowan-atokan (lower middle pennsylvanian) boundary. Geological Society of America Bullletin 97, 346–353.
Groves, J.R., Nemyrovska, T.I., Alekseev, A.S., 1999. Correlation of the type bashkirian stage (middle carboniferous, south urals) with the morrowan and atokan series of the midcontinental and western United States. J. Paleontol. 73, 529–539.
Grozdilova, L.P., Lebedeva, N.S., 1950. Some species of *staffella* of middle carboniferous deposits of the western slope of the urals. Trudy Vsesoyuznogo Neftyanogo Nauchno-issledovatel'skogo Geologo-razvedochnogo Instituta. (VNIGRI) novya seriya 50, 5–45 (in Russian).
Harris, A.G., Brenckle, P.L., Baesemann, J.F., Krumhardt, A.P., Gruzlovic, P.D., 1997. Comparison of conodont and calcareous microfossil biostratigraphy and lithostratigraphy of the lisburne group (carboniferous), sadlerochit Mountains, northeast brooks range, Alaska. In: Dumoulin, J.A., Gray, J.E. (Eds.), Geologic Studies in Alaska by the U.S. Geological Survey, 1995. U.S. Geological Survey Professional Paper 1574, pp. 195–219.
Jaillard, E., Hérail, G., Monfret, T., Díaz-Martínez, E., Baby, P., Lavenu, A., Dumont, J.F., 2000. Tectonic evolution of the Andes of Ecuador, Peru, Bolivia and northernmost Chile. In: Cordani, U.G., Milani, E.J., Thomaz Filho, A., Campos, D.A. (Eds.), Tectonic Evolution of South America, pp. 481–559. Rio de Janeiro.
Kulagina, E.I., Sinitsyna, Z.A., 2003. Evolution of the pseudostaffellidae in the bashkirian stage (middle carboniferous). Riv. Ital. Paleontol. Stratigr. 109, 213–224.
Lane, H.R., Brenckle, P.L., 2005. Type Mississippian subdivisions and biostratigraphic succession. Guidebook Series Illinois State Geological Survey, Report 34, 76–98.
Lucas, S.G., 2021. Rethinking the Carboniferous chronostratigraphic scale. Newslett. Stratigr. 54, 257–274.
Lucas, S.G., Schneider, J.W., Nikolaeva, S., Wang, X., 2022. The Carboniferous chronostratigraphic scale: history, status and prospectus. In: Lucas, S.G., Schneider, J.W., Wang, X., Nikolaeva, S. (Eds.), The Carboniferous Timescale, vol. 512. Geological Society, London, Special Publications, pp. 19–48.
Mamet, B.L., 1996. Late Paleozoic small foraminifers (endothyrids) from South America (Ecuador and Bolivia). Can. J. Earth Sci. 33, 452–459.
Mamet, B.L., Isaacson, P.E., 1997. Bashkirian (early Pennsylvanian) small foraminifers from Bolivia. In: Podemski, M., Dybova-Jachowicz, S., Jaworowski, K., Jureczka, J., Wagner, R. (Eds.), CLVII Proceeding of the XIII International Congress on the Carboniferous and Permian, Part 1. Prace Panstwowego Instytutu Geologicznego, Krakow, pp. 319–328.
Manukalova-Grebenyuk, M.F., Ilina, M.T., Serezhnikova, T.D., 1969. Atlas of foraminifers from the middle carboniferous of the dniepr-donetz basin. Ministerstvo Geolologii USSR, Ukrainskii Nauchno-Issledovatelskii Geologorazvedochnyi Institut (UkrNIGRI) 20, 1–287. Trudy.
Marshall, F.C., 1969. Lower and middle pennsylvanian fusulinids from the bird spring formation near mountain springs pass, clark county, Nevada. Geol. Stud. 16, 97–154.
Martínez, M., 1970. Geología del basamento paleozoico en las Montañas de Amotape y posible origen del petróleo en rocas paleozoicas del Noroeste del Perú. Primer Congreso Latinoamericano de Geología 2, 105–138. Sociedad Geológica del Perú – SGP, Publicación Especial, Lima.
Maslo, A., Vachard, D., 1997. Inventaire critique des eostaffellinae (foraminifères) du carbonifère. Rev. Micropaleontol. 40, 39–69.
Megard, F., Caldas, J., Paredes, J., de la Cruz, N., 1996. Geología de los cuadrángulos de Tarma, la Oroya y Yauyos. Boletín del INGEMMET. Serie A: Carta Geológica Nacional 69, 1–279.
Meyer, H.L.F., 1914. Carbonfaunen aus Bolivia und Perú. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band 37, 590–652.
Mourier, T., Laj, C., Mégard, F., Roperch, P., Mitouard, P., Farfán-Medrano, A., 1988. An accreted continental terrane in northwest Peru. Earth Planet Sci. Lett. 88, 182–192.
Neves, J.P., Anelli, L.E., Pagani, M.A., Simões, M.G., 2014. Late Palaeozoic South American pectinids revised: biostratigraphical and palaeogeographical implications. Alcheringa 38, 281–295.
Newell, N.D., Chronic, J., Roberts, T., 1953. Upper paleozoic of Peru. Geological Society of America Memoirs 58, 1–276.
Palacios, O., 1994. Geología de los cuadrángulos de Paita, Piura, Talara, Sullana, Lobitos, Quebrada Seca, Zorritos, Tumbes, Zarumilla. Boletín del INGEMMET. Serie A: Carta Geológica Nacional 54, 1–190.
Pinard, S., Mamet, B.L., 1998. Taxonomie de petits foraminifère du Carbonifère supérieur-Permien inférieur du bassin de Sverdrup, Arctique canadien. Palaeontogr. Can. 15, 1–225.
Rauser-Chernousova, D.M., 1938. The upper paleozoic foraminifera of samara bend and the trans-volga region. Proceedings of the Geological Institute of the USSR Academy of Sciences (Leningrad) 7, 69–168 (in Russian).
Rauser-Chernousova, D.M., 1948a. Some new species of foraminifera of the Early Carboniferous deposits of the Moscow basin). Akademiya Nauk SSSR, Trudy Instituta Geologicheskikh Nauk, 62, geologicheskaya seriya 19, 227–238 (in Russian).
Rauser-Chernousova, D.M., 1948b. Contributions to the foraminiferal fauna of the Carboniferous deposits of central Kazakhstan. Akademiya Nauk SSSR, Trudy Instituta Geologicheskikh Nauk, 66, geologicheskaya seriya 21, 1–28 (in Russian).
Rauser-Chernousova, D.M., 1949. On the ontogeny of some Palaeozoic foraminifera. Trudy Paleontologischeskogo Instituta, Akademiya Nauk SSSR, Moskva 20, 339–353 (in Russian).
Rauser-Chernousova, D.M., Fursenko, A.V., 1937. Determination of foraminifera in the oil bearing regions of the USSR, pt.1. Leningrad-Moscow, ONTI p. 315 (in Russian).
Rauser-Chernousova, D.M., Gryzlova, N.D., Kireeva, G.D., Leontovich, G.E., Safonova, T. P., Chernova, E.I., 1951. Middle Carboniferous Fusulinids of the Russian Platform and Neighboring Regions. Akademiya Nauk SSSR, Moscow, p. 380 (in Russian).
Reitlinger, E.A., 1949. Smaller foraminifera of the lower middle carboniferous of the central urals and kama river basin. Akademiya Nauk SSSR, Izvestia, geologicheskaya seriya 6, 149–164 (in Russian).
Reitlinger, E.A., 1950. Foraminifera of the Middle Carboniferous deposits of the central part of the Russian Platform (exclusive of family Fusulinidae). Akademiya Nauk SSSR., Trudy Instituta Geologicheskikh Nauk 126 (geologichevskaya seriya 47), 1–128 (in Russian).
Reitlinger, E.A., 1961. Stratigraphy of middle carboniferous deposits of the krasnaya polyanya No. 1 well in middle zavolzh'. In: Semikhatova, S.V. (Ed.), Carboniferous Deposits of the Central and Eastern Part of the Russian Platform, Akademiya Nauk SSSR, Geologicheskiy Lnstitut, vol. 5. Regional'naya Stratigrafiya SSSR, pp. 218–260 (in Russian).
Reitlinger, E.A., 1971. Some problems of systematics in the light of evolutionary stage of Upper Paleozoic foraminifers. Voprosy Mikropaleontologii 14, 3–16 (in Russian).
Reitlinger, E.A., 1980. On the problem of the boundary between the Bogdanovsky and Krasnopolyansky horizons (foraminifers of the Homoceras Zone). Voprosy Mikropaleontologii 23, 23–38 (in Russian).
Reitlinger, E.A., Melnikova, A.S., 1977. On characteristics of Fusulinidea of the Serpukhovian time. Voprosy Mikropaleontologii 20, 68–80 (in Russian).
Reitlinger, E.A., Vdovenko, M.V., Gubareva, V.S., Shcherbakov, O.A., 1996. European part of the USSR: lower carboniferous. The former USSR. In: Wagner, R.H., Winkler Prins, C.F., Granados, L.F. (Eds.), The Carboniferous of the World III, the Former USSR, Mongolia, Middle Eastern Platform, Afghanistan and Iran. Instituto Geológico y Minero de España/Nationaal Natuurhistorisch Museum, Madrid, pp. 23–54. IUGS Publication No. 33.
Rocha-Campos, A.C., 1985. North andean area. In: Wagner, R.H., Winkler Prins, C.F., Granados, L.F. (Eds.), The Carboniferous Of the World II, Australia, Indian Subcontinent, South Africa, South America & North Africa. IUGS Publication No. 20. Instituto Geológico y Minero de España, Madrid, pp. 180–188.
Sánchez, J., Carlotto, V., Díaz-Martínez, E., Chacaltana, C., 2006. Estratigrafía y sedimentología del Paleozoico Superior de la Quebrada Gramadal, Cerros de Amotape. Norte de Perú. Resumen extendido, XIII Congreso Peruano de Geología 570–573. Lima. Sociedad Geológica del Perú – SGP, Publicación Especial. https://hdl.handle.net/20.500.12544/3891.
Thompson, M.L., 1935. The fusulinid genus *staffella* in America. Journal of Palaeontology 9, 111–120.

Thompson, M.L., 1942. New genera of Pennsylvanian fusulinids. American Journal of Sciences, 5th series 240, 409–431.
Thompson, M.L., 1944. Pennsylvanian Morrowan rocks and fusulinids of Kansas. Bulletin of the Geological Survey of Kansas 52, 409–431.
Thompson, M.L., 1945. Pennsylvanian rocks and fusulinids of east Utah and northwest Colorado correlated with Kansas section. State Geological Survey of Kansas Bulletin 60, 17–84.
Thompson, M.L., 1947. Stratigraphy and fusulinids of pre-desmoinesian pennsylvanian rocks, llano uplift, Texas. J. Paleontol. 21, 147–164.
Vachard, D., 2016. Macroevolution and biostratigraphy of paleozoic foraminifer. In: Montenari, M. (Ed.), Stratigraphy & Timescales. Elsevier, Amsterdam, pp. 257–323.
Vachard, D., Le Coze, F., in press Paleozoic Foraminifera: current state of the classification and perspectives. Acta Paleontologica Romaniae. .
Vachard, D., Pille, L., Gaillot, J., 2010. Palaeozoic Foraminifera: systematics, palaeoecology and responses to the global changes. Rev. Micropaleontol. 53, 209–254.
Vachard, D., Krainer, K., Lucas, S.G., 2013. Pennsylvanian (late carboniferous) calcareous microfossils from cedro peak (New Mexico, USA). Part 2: smaller foraminifers and fusulinids. Ann. Paleontol. 99, 1–42.
Wilde, G.L., 1990. Practical fusulinid zonation: the species concept; with Permian basin emphasis. West Texas Geological Society 29, 5–34.
Wood, G.D., Groves, J.R., Wahlman, G.P., Brenckle, P.L., Alemán, A.M., 2002. The paleoeographic and biostratigraphic significance of Fusulinacean and smaller foraminifers, and palynomorphs from the Copacabana Formation (Pennsylvanian-Permian), Madre de Díos Basin, Peru. In: Hills, L.v., Henderson, C.M., Bamber, E.W. (Eds.), Carboniferous and Permian of the World, vol. 19. Canadian Society of Petroleum Geologists, Memoir, pp. 630–664.
Zeller, D.E.N., 1953. Endothyroid foraminifera and ancestral fusulinids from the type chesteran (upper mississippian). J. Paleontol. 27, 183–199.