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A greenhouse interval between icehouse times: Climate change, long-distance plant dispersal, and plate motion in the Mississippian (late Visean–earliest Serpukhovian) of Gondwana

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ABSTRACT

The late Paleozoic ice age (LPIA) is the closest example that can be compared with current climate conditions. Near the beginning of the LPIA fossil plants of Mississippian (late Visean to earliest Serpukhovian) age indicate a widespread frost-free climate in a wide belt on Gondwana indicating an interval of greenhouse conditions between the earlier Visean and later Serpukhovian icehouse times. This warm-temperate floral belt has been named the Paraca floral belt after the locality on the Peruvian coast where it was first recognized. The origin of this particular zono-biome was due to the interplay of (1) climate oscillations, (2) several kinds of long-distance plant dispersal within, between or through zono-biomes, and (3) plate motion. The Carboniferous age strata on the Paracas Peninsula in Peru serve as an example for an analysis of these large scale patterns through the analysis of local geology, paleobotany, and paleoecology. The processes observed during this time interval can serve as a model for long-distance plant dispersal at other times.

Contents

1. Introduction

The late Paleozoic ice age (LPIA) extended over approximately 100 Ma from late Devonian through mid Permian times and consists of icehouse and greenhouse climate intervals where each icehouse interval had a duration of one to ten million years (Montañez et al., 2007; Fielding et al., 2008). In turn, each icehouse interval experienced much shorter Milankovitch scale glacial–interglacial oscillations (Heckel et al., 2007; Heckel, 2008; Birgenheier et al., 2009). At the same time plates were moving and the most significant motion was a clockwise rotation of Gondwana that moved western Gondwana away from the South-polar regions and eastern Gondwana towards it (Pfefferkorn, 1997; Iannuzzi and Rösler, 2000; Iannuzzi and Pfefferkorn, 2002). In addition, changes in elevation of mountains, cold coastal upwelling, and locally increased precipitation played a role in modifying the degree of ice cover locally and over time (Isbell et al., 2012). We are addressing here the interplay of continental motion

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with worldwide temperature fluctuations and long-distance plant dispersal that is also known as "plant migration." Plant fossils are excellent climate proxies both through their autoecology as expressed in morphology and anatomy and their paleobiogeographic distribution. We are reviewing here the late Visean to earliest Serpukhovian Paraca Floral Belt as the expression of a relatively short greenhouse interval that occurs between the earlier Visean and the later Serpukhovian–Pennsylvanian icehouse intervals. This greenhouse time is best expressed at the type locality at Paracas, Peru. With this review we offer a synthesis of the current state of knowledge about geology, paleobotany, paleoclimatology and their Gondwana wide correlation and significance. In addition, six patterns of long distance plant dispersal (LDPD) were found that contributed to the formation of the warm-temperate Paraca zono-biome. These patterns of LDPD are important phenomena that can help in the understanding of modern biogeographic patterns (Lieberman, 2004; Nathan, 2006; Parenti and Ebach, 2009, p.103–113; Lomolino et al., 2010).

The Carboniferous of Paracas by itself is a small occurrence, but it has played a major role in Carboniferous paleobotany and over the decades has attracted scientists from Peru and many other countries, who have studied, either the site itself or material originating from the site. Plant fossils from Paracas are present in natural history collections in Peru itself and in many leading museums of the world. In addition the locality is in a nature preserve and park area that is easily accessible and has numerous visitors each year.

The Carboniferous beds of Paracas occur about 250 km south of Lima on the Pacific Coast (Fig. 1-A). The specific site is situated on the Paracas Peninsula (Fig. 1-B) south of Pisco in the province of Ica. The Carboniferous is bounded by normal faults and is overlain by Tertiary sediments (Fig. 1-C).

After the discovery of the Carboniferous rocks at Paracas (Fuchs, 1900) geologists and paleobotanists reported on the plant fossils found at Paracas mostly collected by others, during relatively short visits (Berry, 1922a,b; Seward, 1922; Gothan, 1928; Steinmann, 1929; Read, 1938; Jongmans, 1954; Doubinger and Alvarez-Ramis, 1980).

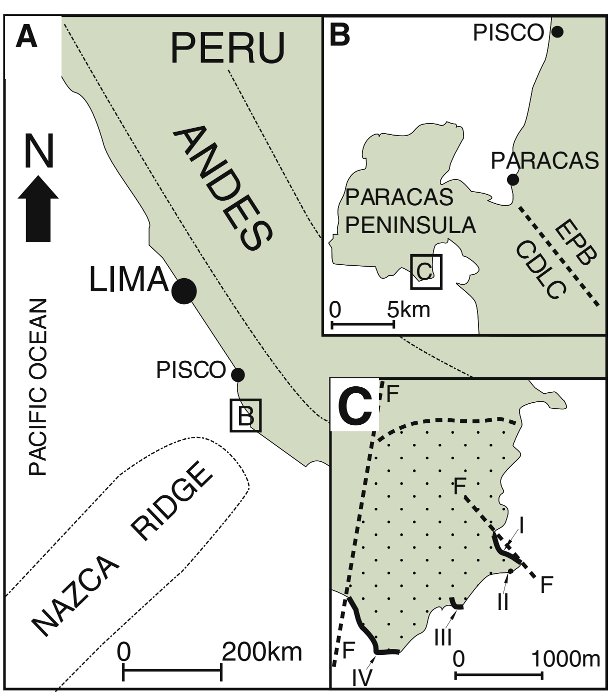

Fig. 1. Location of the Paracas Carboniferous. A — Position of Paracas area on the southern coast of Peru where the Nazca Ridge is being subducted. B — Paracas Peninsula showing the approximate boundary between the Cordillera de la Costa (CDLC) and the East Pisco Basin (EPB). C — Southeastern corner of Paracas Peninsula. Part underlain by Carboniferous stippled. Faults (F) shown by dashed lines. Location of exposures of Carboniferous beds marked by Roman numerals. I = La Mina section.

When one of the authors (V.A.) discovered excellently preserved material and suggested cooperative research to the other author (H.W.P.) a team of Peruvian, South and North American scientists and their students restudied the locality and collected fresh material. Based on this flora Alleman and Pfefferkorn (1988) recognized the Paraca warm temperate floral belt distinguished from the Amerosinian (Euramerican) realm to the north and the Gondwanan realm to the south. Iannuzzi and Pfefferkorn (2002) reinterpreted this belt and recognized its Mississippian age (late Visean to earliest Serpukhovian) on the basis of similarity to other Southern Hemisphere Mississippian floras. Alleman and Pfefferkorn (1991) and Alleman et al. (1995) presented paleoecological studies, Pfefferkorn (1995b, 1997) discussed the paleoclimatological significance, and Erwin et al. (1994) and Iannuzzi et al. (1998, 1999) described lycopsids and pteridosperms.

The La Mina section on the Paracas Peninsula is rich in plant fossils that occur as fragments in the float that comes down the slope and lies on the footpath winding along the cliff. This material is weathered even though this might not be obvious at first inspection. Fine features, as for instance ligules in lycopsids, are not preserved. Even within this material there are different degrees of weathering and one can see anything from nearly fresh material on the wave cut platform to highly weathered material higher up the slope, where fossils become ultimately unrecognizable as is the case on the desert floor. In addition there are differences in the grain sizes of the rocks in which the plant fossils are preserved, which ranges from fine-grained shales to medium-grained sandstones. It is obvious from the photographs in publications by earlier paleobotanists and from our inspection of specimens in various collections (Bonn, Heerlen, London, Washington, DC) that the majority of the specimens were collected from float.

While plant fossils are plentiful, most are preserved only as fragments. This fragmentation is in most cases primary, in other words it happened as part of taphonomic processes before the plant fragment was entombed in the sediment. Thus, one has to collect for significant amounts of time before specimens are brought together that show enough features and are well enough preserved to advance paleobotanical knowledge and allow a description of variability and the reconstruction of whole plants and paleoecological associations.

2. Geology of the Paracas Carboniferous

2.1. Geologic setting

The Carboniferous of the Paracas Peninsula occurs only in a small area (Fig. 1-C) and in four sites they form sea-cliffs that have developed along fault-lines. Due to the constant active erosion by the ocean fresh material is available in these cliffs that are labeled I through IV on the map (Fig. 1-C). However, only sections I and II are safely accessible. Section IV experiences constant rock falls and is therefore unsafe, even though it is accessible. Section I, called the La Mina Section, has also the advantage that the beds are dipping at a low angle and one can therefore walk the entire section with fresh material at sea-level (Figs. 2 and 3). The sections are safely accessible only during low tides and become inaccessible during the days of new moon and sometimes also during full moon.

The Paracas Peninsula is geologically part of the Cordillera da Costa that exists in this part of the Peruvian coast, because the fore-arc is lifted where the Nazca Ridge is being subducted (Fig. 1-A). The Cordillera da Costa and the area of the Paracas Peninsula are formed by tectonic horst and graben structures that are a few kilometers wide and largely, but not exclusively, arranged parallel to the trench. These horst and graben structures shape the larger part of the topography that is then modified by blowout basins and coastal erosion and deposition. Mississippian age rocks occur only in one small tectonic horst while the adjacent tectonic horsts consist under the Tertiary cover of either metamorphic rocks of Precambrian age or Jurassic–Cretaceous volcanics.