

AGE OF THE JURUÁ OROGENY – BRAZIL AND PERU

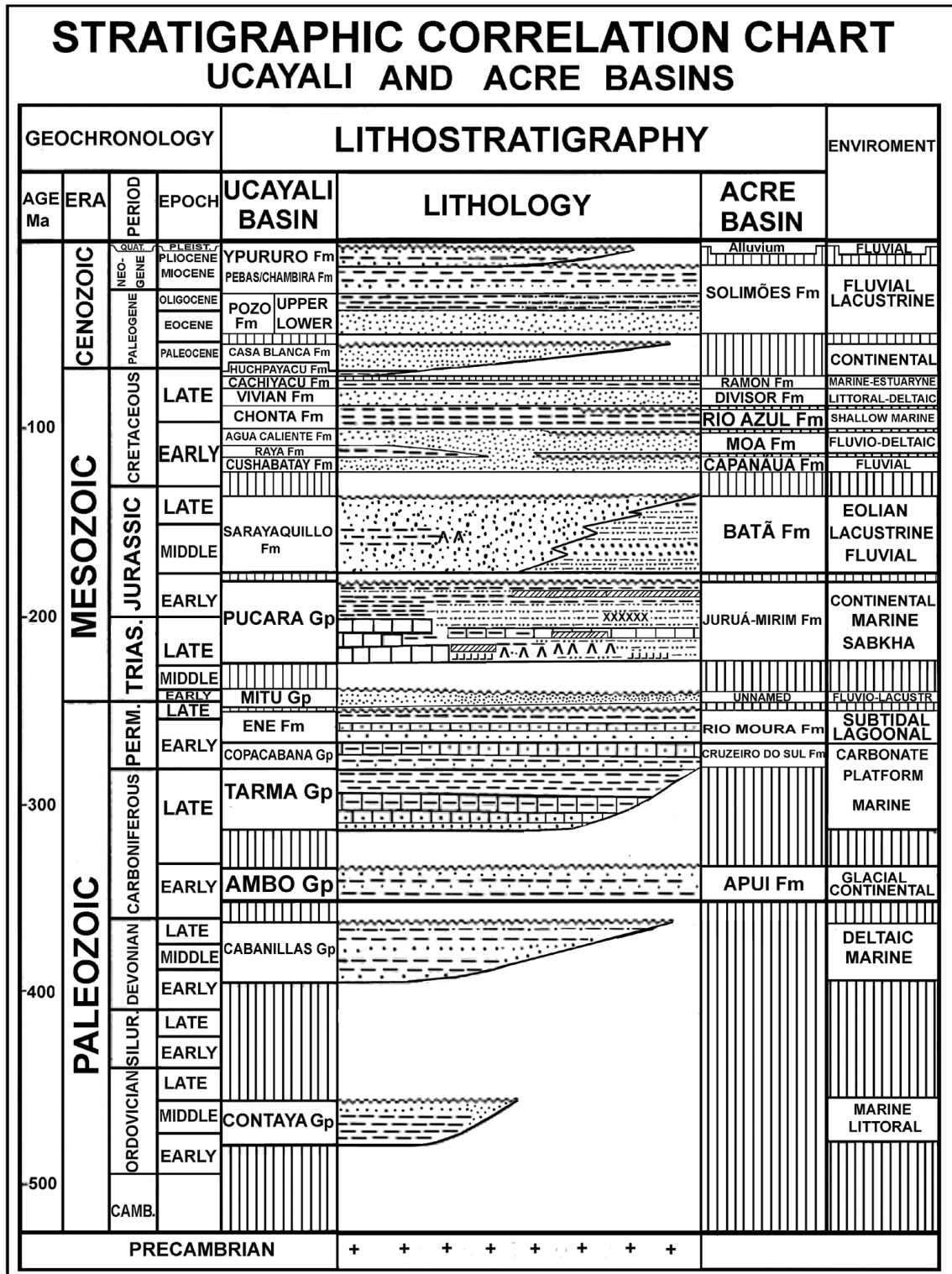
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ABSTRACT - Reflection seismic data from Petrobras sources show a wide belt of ENE-trending deformation developed in the Solimões and Acre sedimentary basins of Brazil, in the Juruá River. The 1400 km long ENE-oriented belt in Brazil is interpreted as right-slip displacement along a transpressive shear zone. The effects of the Juruá Orogeny, also called Solimões Megashear, increase from Solimões towards Acre, Peruvian and Ecuadorian Subandean basins. Structural inversion, block uplift, and an *en echelon* arrangement of asymmetrical folds are attributed to shearing along this large tectonic zone in the Juruá River. The severe Juruá diastrophism is of Late Jurassic age in the Juruá area, probably coincident with the separation between Laurasia and Gondwana continents and initial opening of Central Atlantic Ocean. In Peru and neighboring countries, the same Late Jurassic Juruá Orogeny is also present. It occurs as widespread regional uplifts, structural inversions and asymmetrical folds beneath a pronounced regional parallel or angular unconformity of Early Cretaceous age, marking a first-order sequence boundary above the Upper Jurassic Sarayaquillo and equivalent formations. The depositional hiatus at the end of the Jurassic Period is attributed to reorganization of stress fields that resulted in basin inversion and widespread peneplanation. The Cretaceous and Cenozoic beds, deposited above this regional parallel to angular unconformity, were not affected by this tectonism. There is an apparent disagreement about the age of this Juruá orogenic event in Brazil and Peru. Whereas Caputo (1985, 1991) proposed a Late Jurassic age for this belt of deformation in the ENE-trending Solimões-Acre basin tract, Barros and Carneiro (1991) used the same name, derived from the Juruá River area deformation, for a latest Permian-Triassic orogeny in Peru. In other words, geological and geophysical evidence show that there are two orogenic events, the first of latest Permian-Triassic age, the second of Late Jurassic age, both of which have been referred to the 'Juruá orogeny'. This age miscorrelation between the Brazilian Juruá Orogeny and Peruvian Juruá Orogeny should be corrected. The aim of this paper is to unify the age of the Juruá orogeny that affected central western Brazil and Subandean basins.

INTRODUCTION – The Solimões Basin, about 440,000 km² in area, is separated from the Marañon and Acre basins on its western margin by the Envira Arch and in the east from the Amazon Basin by the Purus Arch (fig. 2). The basin is bounded on the north by the Precambrian Guiana Shield and on the south by the Precambrian Brazilian Shield. The intrabasinal Carauari high separates the basin into a western Jandiutuba sub-basin and an eastern Juruá sub-basin (fig. 2). The Acre Basin, about 40,000 km² in area, is a small sedimentary basin located at the border between Brazil and Peru. It is separated from the Ucayali Basin on the western side by the Andean high-angle, basement-involved Divisor reverse fault, and from the Solimões Basin on the eastern side by the Late Jurassic Envira Arch of deformed Precambrian basement rocks (fig. 2). An E-trending Paraguá Arch, caused by the Juruá tectonism, divides the Acre Basin into the Jaquirana Trough in the north and the Central Trough in the South. Acre, Solimões, Madre de Dios, Ucayali, Marañon and other sub-Andean basins originally formed a single major basin that was later subdivided during various tectonic events. Previous studies of this structural framework and tectonism were carried out in Brazil by Sztamari (1983), Caputo (1985, 1991), Porsche (1985), Arana *et al.* (1990), Oliveira (1994), Oliveira & Zalán (1997), and Zalán (2004). Barros & Carneiro (1991) and Zelasco (2010) and many other investigators addressed specific Peruvian basins.

STRATIGRAPHY - The Acre sedimentary basin contains a Phanerozoic stratigraphic section up to 6.000 m thick, very similar to that of the Ucayali and Marañon basins (figure 1), but less complete. In the Acre Basin Ordovician to Devonian formations are unknown because oil and gas exploration drilling has not penetrated the deepest depocenters, but seismic data indicate their presence. The oldest section observed in outcrops and wells, the Apuí Formation (conglomerates, sandstones, thin shales and diamictites), correlates with the Mississippian Ambo Group of Peru and Bolivia. Above, the Lower Permian Cruzeiro do Sul Formation comprises the same lithologies (limestones, shales and fossils) as the upper part of the Copacabana Group of Peru and Bolivia. The next section is the Rio Moura Formation, composed of brown sandstone and sandy siltstone, gray shale, and thin limestone beds of Late Permian age. It correlates with the Ene Formation. Above is present an unnamed sandstone section. The succeeding Juruá Mirim Formation is a red bed succession: evaporites with siltstone interbeds, and red siltstone with sandstone interbeds. This upper red siltstone unit is now designated the Batã

Formation. In the Juruá Mirim Formation there are two extrusive events which are not far apart in time. One of them is as old as 177 ± 8 Ma (Cunha, 2007), although another analysis on the same rock, made by the Centro de Pesquisas Geocronológicas (USP - University of São Paulo), furnished K/Ar ages of 229 ± 7.9 and $221.8 \pm$ Ma (Triassic). There is also an intrusive event in this unit as old as 194 ± 12 Ma (Cunha, 2007), dated by K/Ar methodology. The deposition of this formation started with halites and anhydrites as old as Late Triassic and siltstone interbeds. The overlying unconformable Batã Formation is possibly as old as Middle to Late Jurassic. The Juruá Mirim Formation correlates with part of the Pucará Formation, and the Batã Formation with the Middle to Upper Jurassic Sarayaquillo Formation.



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The next section comprises clastics of the Capanáua, Moa, Rio Azul, Divisor and Ramon formations as old as Aptian to Maastrichtian. Peruvian Cretaceous Cushabatay, Agua Caliente, Chonta Vivian,

Cachiyacu and Huchpayacu formations correlate with the Brazilian Cretaceous formations (fig. 1). It appears that many Cretaceous formations have disconformable contacts in Brazil. The Cenozoic section consists of the Solimões Formation, composed by red and gray beds (Eocene?-Miocene). The Cenozoic of the Ucayali basin consists of the Casa Blanca, Pozo, Pebas and Ypururo formations. The stratigraphy of the Solimões Basin is similar to that of the Acre Basin, except for the absence of the Triassic-Jurassic sedimentary section. In the Solimões Basin lava flows are absent, but diabase dikes and sills as old as Late Triassic (204 Ma) occur.

BASIN TECTONICS - In western South America, Latest Jurassic to earliest Cretaceous times are characterized by strong tectonism and a change in the oceanic plate convergence orientation, from nearly southwards to nearly northeastwards, expressed in a magmatic arc and tectonic deformation (Jaillard *et al.*, 2000). This major plate kinematics reorganization correlates with geodynamic events in the southeastern Pacific and the Tethys Ocean (Jaillard *et al.*, 2000). This event, associated with strikeslip displacement in West-Central Brazil, also correlates with the accretion of a continental microplate to the Ecuadorian margin (Caputo, 1991). The Peruvian Oriente, Acre and Solimões basins were uplifted during the Late Jurassic, and at the end of this event they were subjected to extensive peneplanation before subsidence and deposition of Early Cretaceous strata (fig. 3), as observed in seismic lines and wells (Caputo, 1985, 1991; Oliveira, 1994; Oliveira & Zalán, 1997; Zalán, 2004). The Late Jurassic age of the Juruá Orogeny, observed in the Juruá River locality, is supported by the age of magmatic rocks, sedimentary petrography, seismic surveys and structural interpretation.

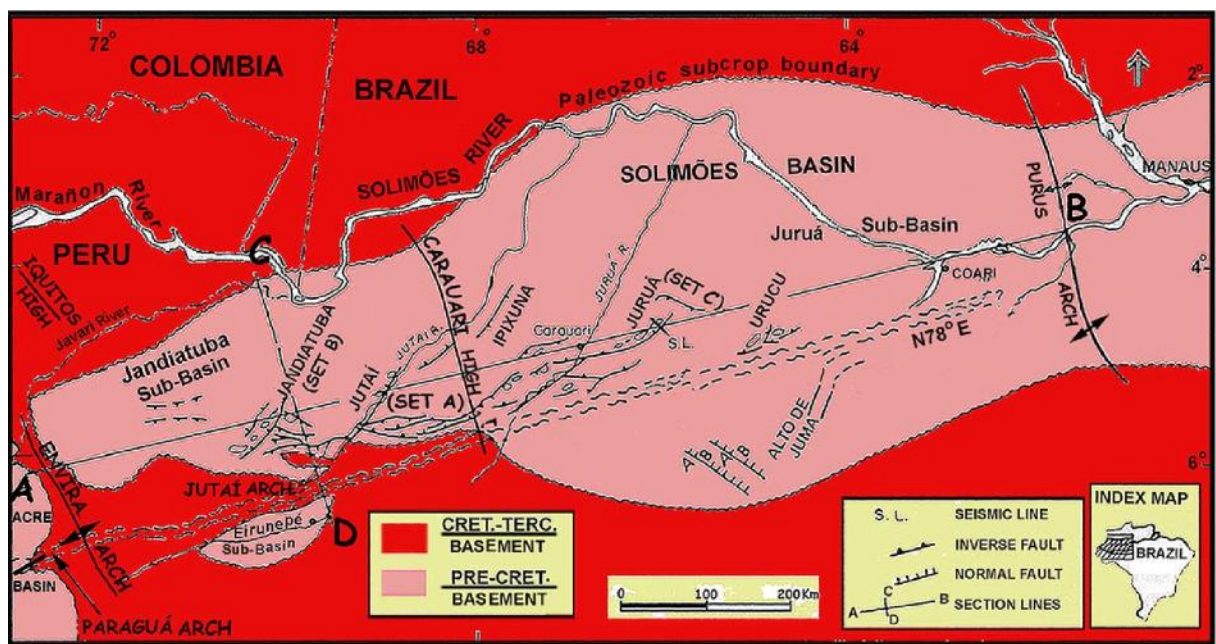


Figure 2. Location map of Solimões and Acre basins with main structural features.

MAGMATISM. In the past, the diabase intrusions in the Solimões Basin were considered as old as 150, 180 and 210 Ma based on the K/Ar method, but Ar/Ar dating provided an age around 200 Ma, suggesting a very short igneous event (Mizusaki *et al.*, 1992). There is a major worldwide change in stress fields and intense magmatism, marked by a first-order sequence boundary at the Triassic-Jurassic boundary (Anthony Tankard, written information - 2012). Juruá reverse faults cut these basic igneous rocks in Acre and Solimões basins, as well as middle to upper Jurassic beds in Acre Basin, so this tectonism should be younger than the Middle to Late Jurassic time and older than the Early Cretaceous time.

SEDIMENTARY PETROGRAPHY. According to Elias *et al.* (2007), based on authigenic illite K-Ar ages, two stages of illite authigenesis are observed in Carboniferous oil and gas reservoirs in the Solimões Basin. The first is related to the voluminous Late Triassic basic magmatism (204 Ma), and the second to Juruá tectonic strong stresses (about 150 Ma).

SEISMIC SURVEYS. Seismic lines in the Acre Basin (source Petrobras) show the Triassic-Jurassic

sequence well deformed and separated from less-deformed Early Cretaceous strata by an angular or parallel unconformity. The Juruá tectonism affected Middle to Late Jurassic strata, indicating a Late Jurassic age. The geological sketch of the seismic line 31 -RL- 183 (fig. 2; from Zalán, 2004) shows tectonic deformation of Middle to Upper Jurassic beds, produced by the Juruá Orogeny before Early Cretaceous sedimentation. Zelasco (2010) presents an instructive seismic section in which the Contaya Arch in Peru was uplifted after the Jurassic Pucará Formation deposition and before accumulation of Early Cretaceous beds. Also present in Zelasco's section is a Triassic unconformity, possibly related to breakup of Pangea and opening of the North Atlantic Ocean. In the Ene Basin, the base-Cretaceous unconformity overlies stratigraphic units of different ages, from Devonian to Late Jurassic (Pluspetrol), indicating that the same Late Jurassic tectonism affected the basin.

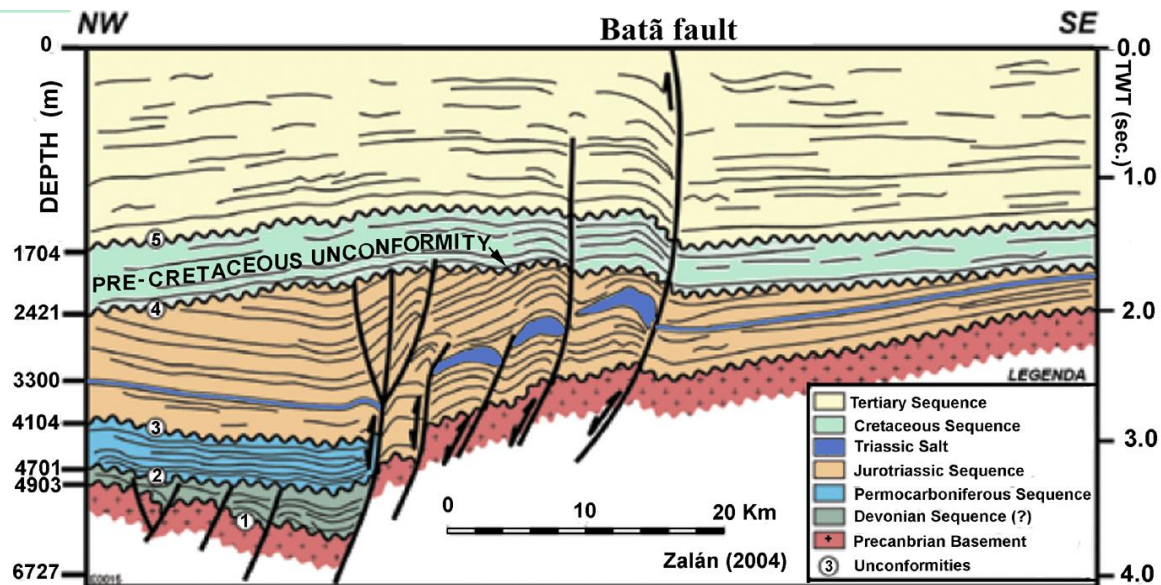


Figure 3 — Sketch of the seismic section 31-RL-183, in double time (vertical scale at right), from the Acre Basin. The vertical depth scale on the left is approximate, non-linear (it is dependent on the intervalar velocities of the sedimentary sequences) and is valid only for the northwest extremity of the line. Unconformities: (1) top of the crystalline basement, (2) Eo-Hercinian phase of the Hercinian Orogeny in South America (after Dalmayrac *et al.*, 1980, in Oliveira *et al.*, 1995), (3) neo-Hercinian phase of the Hercinian Orogeny in South America (after Dalmayrac *et al.*, 1980, in Oliveira *et al.*, 1995), (4) post Juruá Orogeny unconformity, (5) top of the Cretaceous. The harmonic folding of the unconformities (4) and (5) together with the cretaceous and tertiary strata, as well as the reactivation of the Batã Fault to the surface, reflect compressional tectonics related to the Quechua Phase of the Andean Orogeny (Miocene/Pliocene). Zalán (2004).

Flattening on the base-Cretaceous unconformity in Huallaga Basin seismic lines (PARSEP, 2001-figs. 5, 9 and 23) shows the tectonic tilting and deformation of the Sarayaquillo Formation below the Early Cretaceous parallel to angular unconformity. This Sarayaquillo deformation was caused by the same Juruá Orogeny. In a cross-section through the Shira Mountain (Perúpetro sources) large-scale deformation of pre-Cretaceous formations is observed and attributed here to the Juruá Orogeny (Perúpetro, 2009). In the Oriente Basin (Ecuador) there is very strong deformation of the Late Jurassic Chapiza Formation (Baby, 2012), as observed in seismic lines. In Peru, this pre-Cretaceous Orogeny is referred to as the Nevadan Orogeny, after the Sierra Nevada and Klamath mountains of Western North America, but it is better to use a South American local name for the Late Jurassic Juruá orogeny with its unique characteristics and large extent in West-Central South America.

CONCLUSIONS. A strong Late Jurassic diastrophism is responsible for the structural deformation observed in Solimões, Acre and Subandean basins of West-Central South America. The Triassic age proposed by Barros and Carneiro (1991) for this orogeny is not appropriate. These authors were referring to a Triassic orogeny in Peru that is older and does not correlate with the Late Jurassic Juruá orogeny type area of Brazil, as observed in the Juruá River area and Subandean basins.

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