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Review Article

The formation of Pangea

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ABSTRACT

The making of Pangea is the result of large-scale amalgamation of continents and micro-continents, which started at the end of the Neoproterozoic with the formation of Gondwana. As pieces were added to Gondwana on its South-American, Antarctica and Australia side, ribbon-like micro-continents were detached from its African and South-Chinese side: Cadomia in the late Neoproterozoic, Avalonia and Hunia in the Ordovician, Galatia in the Devonian and Cimmeria in the Permian. Cadomia was re-accreted to Gondwana, but the other ribbon-continents were accreted to Baltica, North-China, Laurussia or Laurasia. Finding the origin of these numerous terranes is a major geological challenge. Recently, a global plate tectonic model was developed together with a large geological/geodynamic database, at the Lausanne University, covering the last 600 Ma of the Earth's history. Special attention was given to the placing of Gondwana derived terranes in their original position, using all possible constraints. We propose here a solution for the Variscan terranes, another paper deals with the Altaids. The Galatian super-terrane was detached from Gondwana in the Devonian, during the opening of Paleotethys, and was quickly separated into four sub-terranes that started to by-pass each other. The leading terranes collided at the end of the Devonian with the Hanseatic terrane detached from Laurussia. In the Carboniferous, Gondwana started to impinge onto the amalgamated terranes, creating the Variscan chain and the Pangean super-continent. East of Spain Paleotethys remained opened until the Triassic, subducting northward under Laurasia. Roll-back of the Paleotethyan slab triggered the collapse of most of the European Variscan orogen, which was replaced by series of Permian rifts, some of them becoming oceanized back-arc basins during the Triassic. Major force changes at the Pangean plate limits at the end of the Triassic provoked its break-up, through the opening of the proto-Caribbean, central-Atlantic, Alpine-Tethys oceanic seaways.

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1. Introduction

Pangea reached its final shape at the end of the Triassic, following a long history of terranes and continent accretion. The timing of these collisions is usually quite well known from sedimentary and metamorphic records, what is less clear is the kinematics of the terranes involved in these collisions.

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In a new model developed at UNIL these last 10 years, a database including a wide range of constraints was used to produce a global plate tectonic model starting at 600 Ma (Hochard, 2008). More than one thousand "geodynamic units" (GDU) were defined based on their present day geological history, and then assembled as building stones to form terranes, according to geodynamic scenario in space and time (Fig. 1 and Table 1 as an example). Using the synthetic isochrones methodology (Stampfli and Borel, 2002), plates were reconstructed by adding/removing material, along plate limits. Plate velocities are major constraints in the kinematics of the involved terranes and continents and were closely monitored.

This was an iterative process where geological data were always put forwards, but at a certain stage the model is also becoming a predictive tool, enabling to make choices according to plate tectonic principles (Wilhem, 2010). Having a global model in hand, it is also possible to derive the main forces acting at the plate boundaries (Vérard et al., 2012a), and this can be challenged through the analysis of geological data.

The full global model is reached around 520 Ma, enabling the exact measure of oceanic versus continental areas from that time onward, as well as the ratio of old versus new oceanic crust (Hochard et al., in prep.). The long-term eustatic variations curve derived from a 3D version of the model is very similar to the generally accepted long-term curve from the literature (Vérard et al., in prep.). Our curve largely depends on the many plate tectonics options that were discussed and chosen for these 600 Ma years of Earth's history.

Large portions of the model have already been published (e.g. Bagheri and Stampfli, 2008; Bandini et al., 2011; Bonev and Stampfli, 2011; Chablais et al., 2011; Ferrari et al., 2008; Meinhold et al., 2010; Moix et al., 2008; Stampfli and Hochard, 2009; Vérard et al., 2012b; Wilhem et al., 2012). Regarding the Variscan cycle, several papers have been published (e.g. Stampfli et al., 2011; von Raumer and Stampfli, 2008; von Raumer et al., 2009) mainly centred on the place of the Alpine basements in the Variscan orogen, and we intend here to enlarge this discussion to present a new overview of the plate tectonics mainly for the Paleozoic times of the Variscan-Tethyan area.

Two recent meetings were devoted to the Variscan cycle, one in Madrid in 2011 (Gutiérrez-Marco et al., 2011), and one in Sassari in 2012 (Géologie de la France, 2012), in which many new data were presented, and we want to show here how they can be integrated in our model and where are the remaining challenges.

2. Origin of Gondwana

The history of amalgamation of Gondwana has been heavily treated in the literature, and is still a matter of strong debate. The model presented herein is therefore tentative and not definitive, and we provide the reader with a large number of key references.

The present model for the amalgamation of Gondwana strongly relies on the linkage in space and time of many ophiolitic sutures (Fig. 2). Many sutures (in blue in Fig. 2) have collision ages older than our first reconstruction at 600 Ma, and crustal fragments, therefore, are already shown amalgamated. Such sutures include those in the Nubian area (ca. 710–750 Ma in the Onib-Sol Hamed zone; Meert, 2003), and all along the western side of the east Pan-African orogeny (from ca. 680 Ma in the Nabitah zone to 650 Ma in the Urd Al Amar zone and 630–650 Ma in its southern continuation along the Tanzania craton; ages after Meert, 2003 and references therein). Sutures in South America (Paraguai and Araguaia, ca. 635 after Rodrigues et al., 2010), in western Africa (Mauritanides-Bassarides and Rockelides with a collision age ranging between 650 and 600 Ma; e.g. DeAraújo et al., 2010; Lytwyn et al., 2006; Paixão et al., 2008; Rodrigues et al., 2010), and in central Africa (Yaoundé and Central Africa with unclear ages; DeAraújo et al., 2010; Dos Santos

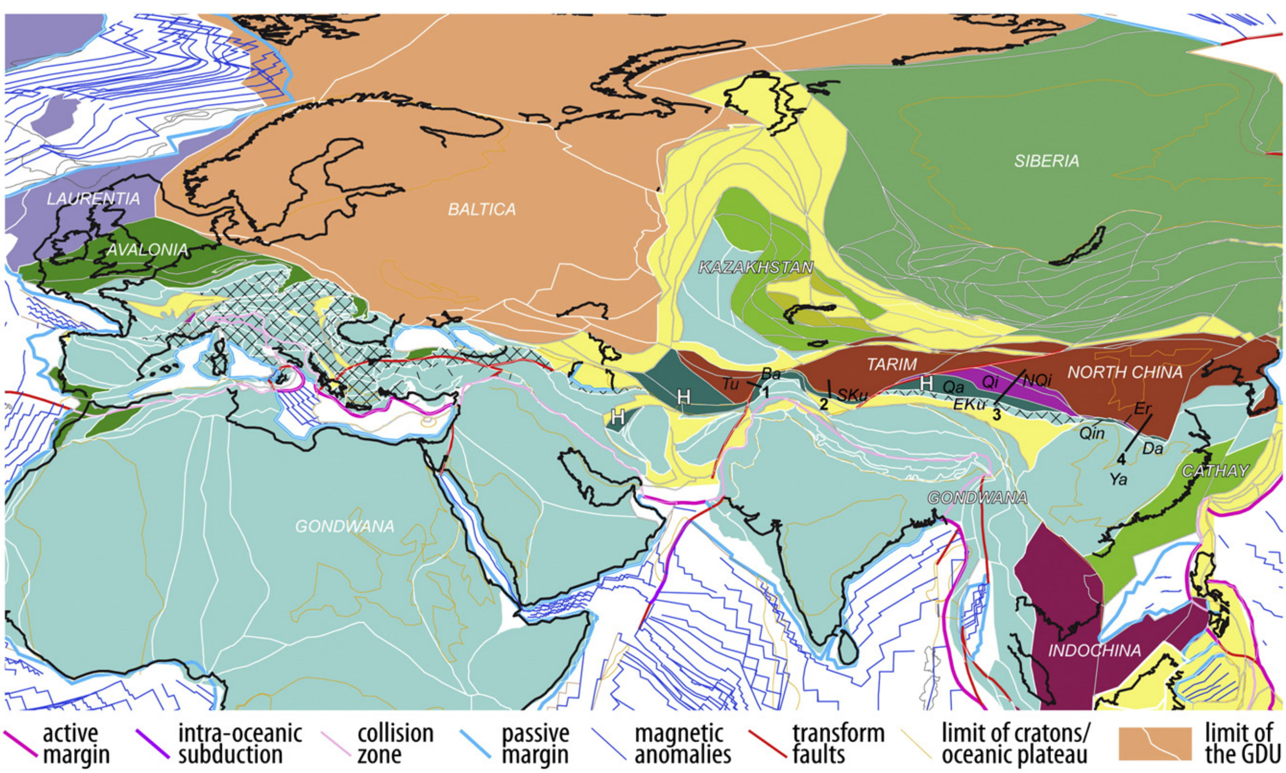

Fig. 1. Present-day map showing GDUs and terranes as defined on the reconstruction of Fig. 4. Transects presented in Table 1: Turan-Pamir (1); Western Kunlun (2); Qilian-Qaidam (3); Qinling-Yangtze (4); GDUs mentioned in Table 1: Tu, Turan; Ba, Badakshan; SKu, South Kunlun; NQi, North Qilian; Qi, Qilian; Qa, Qaidam; EKu, East Kunlun; Er, Erlangping; Qin, Qinling; Da, Dabie and Ya, Yangtze. Light yellow: post-460 Ma formation; dark green, Hunia (H); light blue: Gondwana, its blocks are found also in the Kazakhstan terranes: the criss-cross pattern corresponds to the Intra-Alpine terrane of Fig. 6. This figure is in part derivative from the Neftex Geodynamic Earth Model. © Neftex Petroleum Consultants Ltd. 2011.