2010

Morpho tectonic units of the Zagros Orogenic Belt, NE Iraq: a modern analogue for subduction accretion processes

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Publication Details

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Abstract
The Zagros Mountain Belt extends over more than 1800 km through Iraq and southern Iran in front of the Zagros Mountain chain. It forms the boundary between the Iranian Plateau and the Mesopotamian and Gulf basins (Fig. 1). It can be subdivided geomorphologically into: the High Zagros Belt and the Zagros Simply Folded Belt separated by the High Zagros Fault (Berberian and King, 1981; Falcon, 1974; Stockline, 1968). From a tectonic point of view, however, five zones along the length of the Zagros Orogenic Belt can be distinguished (e.g. Stocklin, 1974, 1986; Falcon, 1974; Sten, 1985; Berberian, 1995): the Zagros Imbricate Zone, the Simply Folded Zone, the Zagros Foredeep, the Mesopotamian Foreland Basin and the Arabian foreland. However, the most common subdivision of the Zagros Orogenic Belt is the five structural zones parallel to NW-SE trend through the belt; from the NE to the SW they are: the Urumieh-Dokhtar Magmatic Arc, the Sanandaj-Sirjan Metamorphic Zone, the High Zagros Zone (Imbricate or Crush zone), the Zagros Simply Folded Belt and the Mesopotamian Foreland Basin (Fig. 2). The High Zagros Zone is referred to by Jassim et al. (2006) as the Penjween-Walash Sub-zone. Towards the SW the Main Zagros Thrust separates the Sanandaj-Sirjan and Imbricate Zones (Berberian, 1995; Agard et al., 2005) and constitutes the suture between Arabian and Iranian plates. The Imbricate Zone represents the innermost part of the Arabian deformed margin, featuring radiolarian chert-bearing accretionary terrane and the Upper and Lower Allochthonous Thrust Sheets over the NE Arabian margin. The aim of this paper is to describe the characteristic morphological features of the Penjween-Walash Subzone and to discuss the tectonic implications of this subzone.

Keywords
Tectonic, Zagros, Iraq, ophiolite, subduction, collisional tectonics, GeoQuest

Disciplines
Medicine and Health Sciences | Social and Behavioral Sciences

Publication Details

This conference paper is available at Research Online: http://ro.uow.edu.au/smhpapers/2046
Morpho-tectonic units of the Zagros Orogenic Belt, NE Iraq: a modern analogue for subduction accretion processes

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Keywords: Tectonic, Zagros, Iraq, ophiolite, subduction, collisional tectonics

Introduction

The Zagros Mountain Belt extends over more than 1800 km through Iraq and southern Iran in front of the Zagros Mountain chain. It forms the boundary between the Iranian Plateau and the Mesopotamian and Gulf basins (Fig. 1). It can be subdivided geomorphologically into: the High Zagros Belt and the Zagros Simply Folded Belt separated by the High Zagros Fault (Berberian and King, 1981; Falcon, 1974; Stockline, 1968). From a tectonic point of view, however, five zones along the length of the Zagros Orogenic Belt can be distinguished (e.g. Stocklin, 1974, 1986; Falcon, 1974; Sten, 1985; Berberian, 1995): the Zagros Imbricate Zone, the Simply Folded Zone, the Zagros Foredeep, the Mesopotamian Foreland Basin and the Arabian foreland. However, the most common subdivision of the Zagros Orogenic Belt is the five structural zones parallel to NW-SE trend through the belt; from the NE to the SW they are: the Urumieh-Dokhtar Magmatic Arc, the Sanandaj-Sirjan Metamorphic Zone, the High Zagros Zone (Imbricate or Crush zone), the Zagros Simply Folded Belt and the Mesopotamian Foreland Basin (Fig. 2). The High Zagros Zone is referred to by Jassim et al. (2006) as the Penjween–Walash Sub-zone. Towards the SW the Main Zagros Thrust separates the Sanandaj-Sirjan and Imbricate Zones (Berberian, 1995; Agard et al., 2005) and constitutes the suture between Arabian and Iranian plates. The Imbricate Zone represents the innermost part of the Arabian deformed margin, featuring radiolarian chert-bearing accretionary terrane and the Upper and Lower Allochthonous Thrust Sheets over the NE Arabian margin.

The aim of this paper is to describe the characteristic morphological features of the Penjween–Walash Sub-zone and to discuss the tectonic implications of this subzone.

Geological setting

The Penjween–Walash Sub-zone is apart of the Iraqi Zagros Suture Zone (IZSZ), the “Main Zagros Thrust”, and is located in northern and northeastern Iraq (Fig. 3). This sub-zone is characterized by two allochthonous thrust sheets (Aswad, 1999; Aziz, 2008): the Upper and Lower Allochthonous thrust sheets. In the studied area, the Lower Allochthonous thrust sheet is composed of the Walash volcano-sedimentary rocks intertwined with Naopurdan sedimentary group forming the Walash-Naopurdan nappe (Fig. 3). The Upper Allochthonous thrust sheet encompasses mainly ophiolitic massifs of Alban – Cenomanian (97-105 Ma) and Gemo-Qandil sequence (Aswad and Elaise, 1988). The Mawat ophiolite massif, for example, has almost all the characteristic members of an ophiolite suite with highly sheared basal serpentinites juxtaposed onto the lower allochthonous thrust sheet (Figs. 4, 5, 6, and 7).
Fig. 1 The Zagros Orogenic Belt (after Agard, 2005).

Fig. 2 Main tectonic units of Iraq and contiguous territories.

Fig. 3 Simplified geological map of Iraqi Zagros Suture Zone. Note that the Lower Allochthon comprises the Walash volcano-sedimentary rocks intertwined with the Naopurdan sedimentary group forming the Walash – Naopurdan nappe.
The Walash group of Walash–Naopurdan nappe comprises, from the base, the following subgroups (see Jassim and Goff, 2006): Basal Red Beds, Lower Volcanics consisting of mafic, less common felsic, lavas and frequently pillow lavas laterally adjacent to the sedimentary sequence (i.e. volcano-flysch unit), Middle Red Beds (±limestones), Upper Volcanics and finally the Upper Red Beds. The latter consisting of red mudstone and conglomerate near the base and brownish red siltstone and greywacke higher up (Fig. 8).

**Tectonic implications**

The Late Cretaceous was characterised by an accretionary complex terrane (the Qulqula radiolarite and serpentinite-matrix mélange) that adhered to the Arabian continental margin (i.e. the Albian–Cenomanian autochthonous platform carbonates at Balambo) developing a foreland assemblage on its inboard side (Aziz, 2008). Thus the Arabian Platform phase was terminated and Mesopotamian Foreland Basin phase was established. The configuration of sedimentary facies in the Late Cretaceous–Paleogene foreland basin was probably triggered by plate convergence, which was incipient in the early Campanian (first episode) and continued through Paleogene time (second episode). During this period the volcano-flysch Walash deposits and the Naopurdan Nummulite carbonate deposits were still accumulating on the remaining oceanic lithosphere (Aswad, 1999) farther to the northeast and were, in part, coeval with molasse sedimentation in the foreland basin farther to the southwest of the accretionary complex terrane (Qulqula rise). The Upper Allochthonous Thrust Sheet, however, was juxtaposed onto the Lower Allochthonous Thrust Sheet in the late Paleogene. The $^{40}$Ar–$^{39}$Ar geochronological data suggest that the middle Paleogene magmatic history of an early phase of the Walash Upper Volcanics (i.e. andesitic volcanism) occurred around 43.1 ± 0.3 Ma and a subsequent extensional-arc phase of magmatism took place between 40.1 ± 0.3 and 32.3 ± 0.4 Ma (Al-Saman and Aswad, personal communication, 2010).

Recent microfacies and age determinations of the sedimentary units in the Upper Volcanics suggest a deepening-upward depositional environment. The deepening-upward was largely manifest through continued convergence of the arc during Lutetian age (42.5–48 Ma; Al-Bana and Al-Mutawali, 2008).

In view of that both Qulqula Radiolarite and serpentinite-matrix mélange form a Late Mesozoic accretionary complex terrane related to the eastward intra-oceanic subduction of the Neotethys. Based on the accretionary prism formation model (Fig. 9), it may be suggested that the arc-volcanicity of Walash was synchronous to early molasse sedimentation in the proto-foreland basin.

**Fig. 4** Geological map of the Mawat-Chowarta area modified from (Al-Mehaidi, 1974).
The timing controversy of the collision

The timing of the collision is poorly constrained, and estimates range from Late Cretaceous to late Miocene. By progressively removing the Miocene supra-tectonic events (i.e. folding, gravity sliding and wrench displacement), the distally separated Mawat and Penjwin nappes might jointly represent a postulated slab of ancient allochthonous oceanic lithosphere (Aswad, 1999). The obliquity of convergent motion between Arabian and Urasian was finally evolved into strike-slip motion along the collision boundary. Therefore, the Mawat and Penjwin nappes are potentially useful markers for measuring offset on the Main Recent Fault, which is ~40 km. The dextral strike-slip offset, which is obtained from other geomorphological features, is ~50 km on the Main Recent Fault (Talebian and Jackson, 2002). Nonetheless, the preserved offsets in the geology of the studied area are not grossly in conflict with the proposed offsets of ~50 km. This offset, which can be achieved in 5 ± 2 Ma at present rates, implies a reorganization of deformation in the collision zone at that time, after the initial collision at ~12 Ma. The new geochronological evidence from the Walash Upper Volcanics stated above may specify that a further investigation dealing with Walash volcanics is more appealing as an explanation for the Arabia–Eurasia collisions.
Continental undertow versus slab pull driving mechanism: Baghdad and Basra tracks

Based on Torsvik et al. (2008), Alvarez (2010) calculated the tracks of the Iraqi Zagros foreland sites (Baghdad, Basra) by rotating the SAFR (southern Africa) relative to EUR (Eurasia), then Arabia relative to SAFR. He concluded that the Arabia–Eurasia convergence (Basra track) was not halted or slowed by collision. Convergence velocities have been calculated along portions of the tracks where the down-going continent is approaching the collisional suture on a roughly linear track oriented approximately perpendicular to the Zagros suture between 80 Ma and 0 Ma (Fig. 10).

The evidence stated above contradicts the slab-pull driving mechanism of plate tectonics. The debate over the stated driving mechanism has continued since the early 1970s, with increasing sophistication but still no general solution. There has long been a preference for top-down, density-driven slab-pull as the dominant driver of plate tectonics. Sometimes this is simply stated as a fact, applicable to plate tectonics in general: For example, “Subduction provides the main driving force for the motion of tectonic plates at the Earth’s surface through slab-pull and sinking-induced flow in the surrounding mantle” (Billen and Andrews, 2007). However, although slab-pull is an attractive driving mechanism for the motion of subducting oceanic plates, it is less appealing as an explanation for the protracted Arabia–Eurasia continent–continent collision (e.g. convergence velocity was not halted or slowed by collision). This seems to require a different mechanism. The protracted continental collisions are better explained by horizontal traction of the mantle on the base of deep continental roots, dragging the continents together along a Tethyan axis of mantle convergence. The “continental undertow hypothesis” thus might resolve the collision anomaly (i.e. non-stopped convergence) in plate tectonics.

Fig. 9 A postulated model for the formation of an accretionary prism by the process of offscraping of sediments and emplacement of serpentinite mélange, (Aswad et al, in press).
Fig. 10 Tracks for Baghdad and Basra during Arabia–Eurasia convergence (from Alvarez, 2010).

References


