Influence of Regional Tectonics on Trap Integrity in Zagros Foothills and Foreland, Kurdistan and SE Turkey

Richard R. Jones*, Jonathan J. Long, David M. Oxlade, Susie E. Daniels, Max W. Wilkinson, Sébastien Gilment

* richard@geospatial-research.co.uk

Summary

Arabia-Eurasia collision was caused by non-orthogonal transpressional closure of Tethys. Deformation partitioned into a broad belt of folds and thrusts, a large, seismically active, orogen-parallel right-lateral strike-slip fault (the Main Recent Fault), and an array of NNW-SSE right-lateral strike-slip and oblique-slip faults, recognised from new field data in SE Turkey and NE Iraq (Kurdistan). These faults are difficult to recognise and quantify in outcrop and in seismic data. However, they are generally long-lived, can segment large anticlines, and can have a highly detrimental effect on trap integrity.

Main objectives	Show important implications of previously unrecognised strike-slip faults in northern Zagros
New aspects	Extensive new field data, new regional model, new consideration of implications for trap integrity

Introduction

The Zagros mountain belt and Mesopotamian foreland remain as one of the World's most prolific regions for hydrocarbon exploration and production. Accumulation of several kilometres of stacked carbonate reservoirs, source rocks, and shale/evaporite seals occurred on the Arabian plate margin through Palaeozoic and Mesozoic times (Sharland et al. 2001, 2004; Aqrawi et al. 2010). Tethyan closure and the resultant Arabia-Eurasia collision in Cenozoic times (Allen & Armstrong, 2008) led to the formation of large anticlinal traps, accompanied by pervasive fracturing of carbonate reservoirs.

Relative plate motion during Zagros collision was oblique to the Tethyan plate margin, as are present-day geodetic measurements of relative plate motions recorded using regional networks of fixed GPS stations (e.g. McClusky et al. 2000, 2003; Homke et al. 2009). The geometry and kinematics of regional tectonic elements in the Zagros (Fig. 1) is typical of transpression zones (Harland 1971; Jones et al. 2004, 2005), and the recognition of the Zagros as an oblique collision zone, rather than a classic fold and thrust belt, has important implications for exploration across the region.

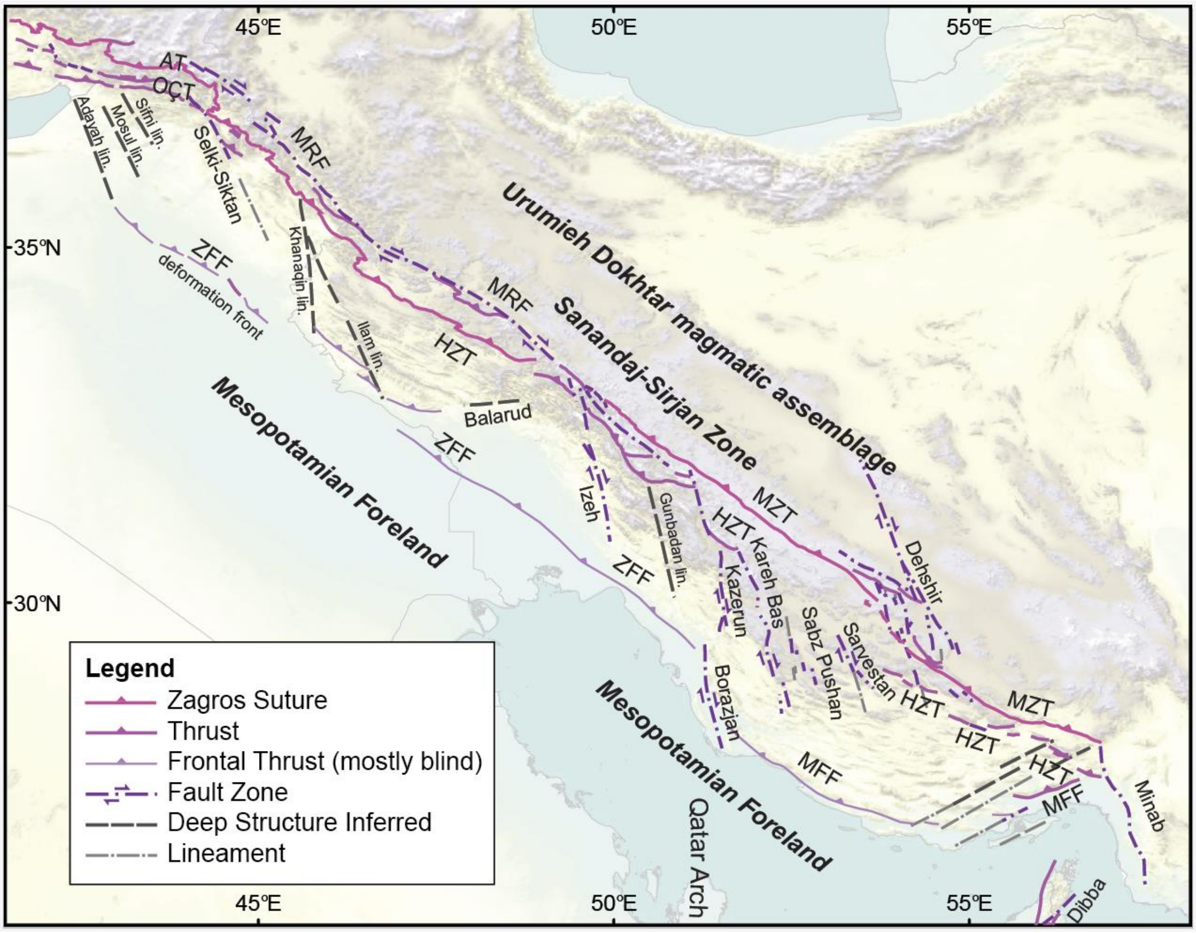

***Figure 1** Overview map showing the main regional tectonic elements of the Zagros. AT = Alandaș Thrust; HZT = High Zagros Thrust; MFF = Main Frontal Fault; MRF = Main Recent Fault; MZT = Main Zagros Thrust; OÇT = Ora-Çukurca & Ortabag-Çiğli Thrusts; ZFF = Zagros Frontal Fault; lin. = lineament. Coordinate system: WGS84. Background topographic data: ESRI, USGS, & NOAA.*

Methodolgy & Datasets

Primary new data for this study are derived from several hundred days of fieldwork in SE Turkey and NE Iraq carried out since 2009. Data gathered during this work include structural mapping, geological observations, samples for petrographic and biostratigraphic analyses, measurements of bedding orientation, and 35,000 georeferenced field photos. Structural interpretation was supplemented by analysis of additional third-party data:

- Multi-spectral satellite data and digital elevation data with a variety of spatial resolutions;
- Geology maps published by national geological surveys in Turkey, Iraq and Iran;
- Published seismological data (https://www.globalcmt.org/; https://earthquake.usgs.gov/);
- Topographic datasets including and topographic maps.
- Published geology maps, cross-sections, outcrop descriptions, biostratigraphic age determinations, sub-surface data etc. in scientific journals, books, theses, and company websites;
- Unpublished geology maps, proprietary maps, biostratigraphic age determinations, and other geological and geophysical data;

New outputs derived from interpretation of the above data include region-wide geological maps, ca. 8,000 km of balanced structural cross-sections, a series of proprietary reports, and a new transpressional model for the northern Zagros, presented here.

Transpression and Strain Partitioning applied to the Northern Zagros

The geometry and kinematics of the main tectonic elements of the Zagros (Fig. 1) are characteristic of transpression involving regional shortening plus right-lateral strike-slip. Transpressional deformation typically partitions into separate large-scale deformational domains (Figure 2). In the Zagros, shortening (i.e. the "compression" component of the transpression) is accommodated in a broad zone of folds and thrusts that collectively comprise the foreland, foothills, folded belts and the High Zagros. The strike-slip (the "transcurrent" component) is partitioned onto a number of narrower fault zones. A large proportion of strike-slip is accommodated by the seismically active, orogen-parallel right-lateral Main Recent Fault (Talebian & Jackson 2002). Further strike-slip is also accommodated on an array of NNW-SSE faults that cut across the fold belt. In Iran, this array includes the right-lateral Sarvestan, Sabz Pushan, Kareh Bas, Kazerun, Borazjan, Izeh, and Khanaqin faults (Baker et al. 1993; Berberian 1995; Blanc et al. 2003; Authemayou et al. 2009; Tavani et al. 2018). In the folded zone of the northern Zagros our mapping has revealed a comparable array of previously undocumented NNW/SSE faults and lineaments that we infer to extend into the foreland (see Fig. 1 west of Khanaqin)

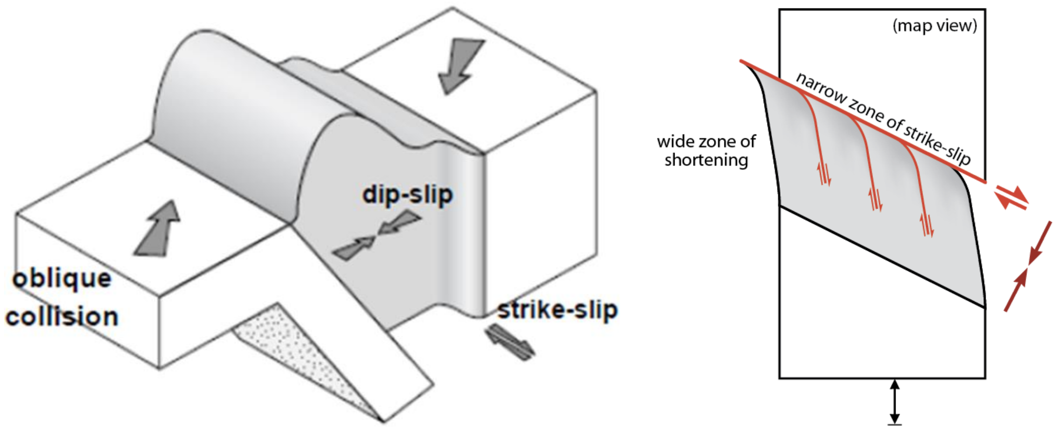

Figure 2 *Left: Schematic depiction of strain partitioning of transpressional deformation into a broad zone of shortening (characterised by folds and thrusts) and a narrower, orogen-parallel zone of strike-slip (Jones & Tanner 1995; Jones et al. 2005). Right: strike-slip deformation is accommodated on a NW-SE orogen-parallel fault and an array of NNW-SSE synthetic (right-lateral) faults.*

The structural history of these faults and their interaction with adjacent domains that are accommodating shortening is complex. This is illustrated by seismicity across the region that records a wide variety (spatially and temporally) of right-lateral strike slip, oblique-slip and thrust displacements (Fig. 3).

Implications for Exploration

The array of NNW-SSE strike-slip faults are enigmatic and challenging to characterise; they are likely to be poorly imaged in seismic data, are usually difficult to identify in surface outcrops, and their appearance in satellite imagery is often ambiguous. Importantly, there is often little demonstrable strike-slip offset in younger stratigraphy seen in surface outcrops. Where identified, they typically coincide with an alignment of small-scale faults, sudden dip-changes in bedding, co-aligned ends of anticlines (i.e. the plunging noses of periclines), and coincidence of other poorly defined linear features. Despite their typically benign appearance in the geology seen at surface, these faults are of major significance in the sub-surface, and can have a profound impact on the size and structural integrity of anticlinal traps across the region. This is particularly important in the foothills and foreland where the lower topographic relief and lack of older stratigraphy exposed at surface makes it even more challenging to recognise their existence.

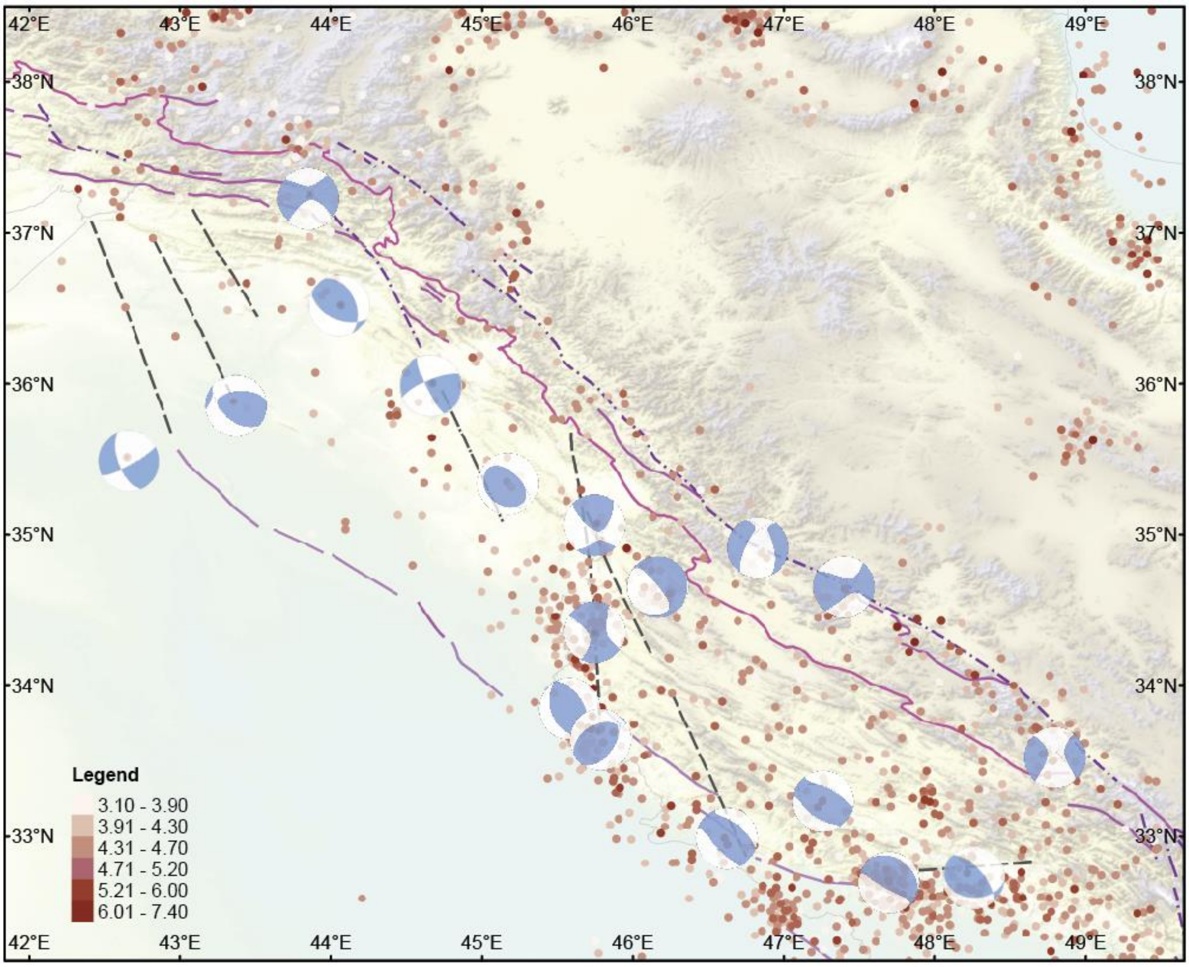

Figure 3 *Recent seismicity in NE Iraq and the Lurestan region of Iran. Focal mechanisms and moment tensor interpretations of larger earthquakes suggest a wide variety of thrust, strike-slip, and oblique-slip displacements. Coordinate system: WGS84. Seismicity data: https://www.globalcmt.org and https://earthquake.usgs.gov. Background topographic data: ESRI, USGS, & NOAA.*

References

Allen, M., Jackson, J., Walker, R. 2004. Late Cenozoic reorganization of the Arabia-Eurasia collision and the comparison of short-term and long-term deformation rates. Tectonics, 23, TC2008.

Allen, M.B., Armstrong, H.A. 2008. Arabia–Eurasia collision and the forcing of mid-Cenozoic global cooling. Palaeogeography, Palaeoclimatology, Palaeoecology 265, 52-58.

Aqrawi, A.A.M., Goff, J.C., Horbury, A.D., Sadooni, F.N. 2010. The Petroleum Geology of Iraq. 424pp.

Authemayou, C., Chardon, D., Bellier, O., Malekzadeh, Z., Shabanian, E., Abbassi, M.R. 2006. Late Cenozoic partitioning of oblique plate convergence in the Zagros fold-and-thrust belt (Iran), Tectonics, 25, TC3002, doi:10.1029/2005TC001860.

Authemayou, C., Bellier, O., Chardon, D., Benedetti, L., Malekzade, Z., Claude, C., Angeletti, B., Shabanian, E., Abbassi, M.R. 2009. Quaternary slip-rates of the Kazerun and the Main Recent Faults: active strike-slip partitioning in the Zagros fold-and-thrust belt, Geophys. J. Int., 178, 524–540.

Baker, C., Jackson, J. & Priestley, K. 1993. Earthquakes on the Kazerun Line in the Zagros Mountains of Iran: strike-slip faulting within a fold-and-thrust belt. Geophysical Journal International, 115, 41–61.

Berberian, M. 1995. Master "blind" thrust faults hidden under the Zagros folds: active basement tectonics and surface morphotectonics. Tectonophysics 241, 193-224.

Blanc, E. J.-P., M. B. Allen, S. Inger, and H. Hassani (2003), Structural styles in the Zagros Simple Folded Zone, Iran, J. Geol. Soc. London, 160, 401 – 412.

Harland, W.B., 1971. Tectonic transpression in Caledonian Spitzbergen. Geological Magazine 108, 27-42.

Homke et al. 2009. Late Cretaceous–Paleocene formation of the proto–Zagros foreland basin, Lurestan Province, SW Iran Geological Society of America Bulletin, 121, 963-978.

Jones, R.R., Tanner, P.W.G., 1995. Strain partitioning in transpression zones. Journal of Structural Geology 17, 793–802.

Jones, R.R., Holdsworth, R.E., Clegg, P., McCaffrey, K.J.W., Tavarnelli, E., 2004. Inclined transpression. Journal of Structural Geology 26, 1531-1548.

Jones, R.R, Holdsworth, R.E, McCaffrey, K.J.W, Clegg, P., Tavarnelli, E. 2005. Scale dependence, strain compatibility and heterogeneity of three-dimensional deformation during mountain building: a discussion. Journal of Structural Geology 27, 1190-1204.

McClusky, S., et al. (2000), Global Positioning System constraints on plate kinematics and dynamics in the eastern Mediterranean and Caucasus, J. Geophys. Res., 105, 5695 – 5719.

McClusky, S., R. Reilinger, S. Mahmoud, D. Ben Sari, and A. Tealeb (2003), GPS constraints on Africa (Nubia) and Arabia plate motions, Geophys. J. Int., 155, 126 – 138.

Sharland, P.R., Archer, R., Casey, D.M., Davies, R.B., Hall, S.H., Heward, A.P., Horbury, A.D., Simmons, M.D. 2001. Arabian Plate Sequence Stratigraphy. GeoArabia Special Publication 2, Gulf PetroLink, Bahrain, pp.371.

Sharland, P.R., Casey, D.M., Davies, R.B., Simmons, M.D., Sutcliffe, O.E. 2004. Arabian Plate Sequence Stratigraphy. GeoArabia, 9, 199-214.

Talebian, M., and J. A. Jackson (2002), Offset on the Main Recent Fault of NW Iran and implications for the late Cenozoic tectonics of the Arabia-Eurasia collision zone, Geophys. J. Int., 150, 422 – 439.

Tavani, S., Parente, M., Puzone, F., Corradetti, A., Gharabeigli, G., Valinejad, M., Morsalnejad, D., Mazzoli, S. [2018] The seismogenic fault system of the 2017 Mw 7.3 Iran-Iraq earthquake: Constraints from surface and subsurface data, cross-section balancing, and restoration. Solid Earth, 9, 821–831, 2018.