Geophysical Research Abstracts
Vol. 13, EGU2011-7996, 2011
EGU General Assembly 2011

Fracture patterns and generations in the simply folded part of the Zagros fold-and-thrust belt, Northern Iraq

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Numerous studies of fracture patterns in the Iranian part of the Zagros Mountains emphasize the importance of this information for understanding the tectonic evolution, for characterizing orientations, densities and morphology of anisotropies in fractured reservoirs which can be crucial for hydrocarbon productivity. The studies of the fracture patterns generally compare regional trends of fractures to local scale orientations within fold structures.
This field based work extends these previous studies and focuses on the fracture systems developed in the lesser investigated parts of the Zagros Simply Folded Belt northeast of the city of Erbil in Northern Iraq. The geological structures are dominated by open, partly box-shaped NW-SE trending folds with amplitudes of less than 2.5 km and wavelengths of 5-10km. Major thrusts or imbricates do not occur in the frontal parts of the fold belt. Balanced cross-sections show an overall shortening of about 10-15%, depending on the interpretation of the shape of the synclines, covered by Neogene sediments. The exposed stratigraphy consists mainly of Jurassic to Paleogene limestones, dolomites and sandstones, which are more competent units compared to the interlayering incompetent claystones, marls and anhydrites. The thickness of the competent units controls the wavelength by buckling while the incompetent layers adjust space problems in the hinge areas.
Pre-folding fracture sets are fractures having their origin before folding in either a similar or a different stress field to the later folding event. These early fractures are commonly reactivated (reopened, sheared) or passively tilted during folding. Fractures caused by local stresses related to accommodation of strain within folded strata are frequently related to bending stresses at fold hinges and bedding-parallel slip in the fold limbs.
Four different fault and fracture generations have been identified in the studied part of the Simply Folded Belt. (1) The earliest is a penetrative conjugate shear fracture set developed in an N to NNE and ENE-E trending direction. The angle between these shear fractures show a strong dependency on the lithology and is best developed in the limestones and dolomites (e.g. Eocene Pilaspi Formation., Upper Cretaceous Shiranish Formation) and sandstones of the Tanjero Formation, but is also developed in less competent lithologies like in shales, marls or claystones (e.g. Paleocene Kolosh Formation). Since these conjugate fracture sets are rotated in the flanks of the anticlines and - after un-folding of the bedding planes - their bisector is parallel to the shortening direction of folding, their formation is considered to be pre- or early folding. (2) Another distinct fracture set includes extensional mode I fractures, oriented normal to the sedimentary bedding and striking NW-SE parallel to the major trend of the fold axis. These fractures, which mainly developed in competent formations, result from decreased spacing in the hinges of the folds and are therefore associated with the folding event. (3) Joints, which cross-cut all other fracture sets and trend perpendicular to the fold axes are probably reactivation structures of Late Precambrian extension faults in the basement and have formed in a late folding stage. (4) Fractures, which have a roughly NW to N trending orientation are commonly reactivated as dextral strike-slip faults probably reflecting the dextral shear of the Zagros fold-belt under N-S compression induced by the northward movement of the Arabian plate relative to the Eurasian Plate.
Comparing the inferred palaeostrain directions with kinematics of recent GPS measurements, we conclude that the N-S compression and the partitioning into NW-SE trending folds and NW to N trending strike-slip faults likely remained unchanged throughout the Neogene tectonic history of the Zagros Simply Folded Belt in Iraq.