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North Africa – Mediterranean Present-day Stress Field Transition: Implications for Fractured Reservoir Production

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Analysis of borehole breakouts in hydrocarbon exploration and development wells has been successfully applied to the interpretation of present-day stress field orientation in many parts of Africa and Arabia. This approach has been most successful when integrated with the results of field studies of late Quaternary outcrops and inversion of teleseismic earthquakes. Outcrop studies have included kinematic analysis of small-scale faults and interpretation of volcanic structures (vent alignments, caldera shapes). All these results generally apply to the upper 5 km or less of the Earth's crust.

Previous studies have shown that over large areas of Central Africa, the least horizontal stress, $\mathbf{S_{hmin}}$, is aligned north-south. This has been attributed to the far-field effects of ridge-push in the Atlantic and Indian Ocean basins. Earthquakes indicate that the stress regime is predominantly that of strike-slip faulting. Along the African Red Sea–Gulf of Suez margin, $\mathbf{S_{hmin}}$ remains north-south or NNE-SSW, but the stress regime shows larger components of normal faulting. In southern Arabia and the Arabian Gulf, $\mathbf{S_{hmin}}$ switches to approximately ESE-WNW as a consequence of convergence at the Zagros–Bitliss thrust zone. The nature and location of the change from the Red Sea to the Arabian stress fields is presently not known. Limited studies of earthquake mechanisms in West-Central Africa have suggested that $\mathbf{S_{hmin}}$ is north-south, but this has not been confirmed by borehole breakout or other data.

The present-day stress field of the Mediterranean region is, in detail, extremely complicated, but earthquake and geologic studies show clearly the effects of convergence at the Cyprian-Hellenic-Sicilian arc-trench system. $\mathbf{S_{hmin}}$ at and south of the arcs is generally east-west, but in detail rotates slightly according to the geometry of the individual arcs and thrust fronts. The stress regime is predominantly thrust and mixed thrust–strike-slip faulting. The western Mediterranean is dominated by the effects of the Azores–Gibraltar–northern Algerian strike-slip boundary, although earthquakes again show mixed thrust and strike-slip solutions. $\mathbf{S_{hmin}}$ is generally east-west to NE-SW.

Fundamental geodynamic questions for North Africa therefore include: 1) where does the Central African stress field (north-south $\mathbf{S_{hmin}}$, mixed strike-slip and normal fault stress regime) meet the Southern Mediterranean stress field (east-west $\mathbf{S_{hmin}}$, mixed strike-slip and thrust fault stress regime)?; and 2) how does this change in stress fields occur (gradually? at distinct structural boundaries?).

This paper presents the analysis of borehole geometry data from wells in Egypt, Libya, Tunisia and Algeria that address these questions. The total data base for this project included over 5000 wells; however, only several hundred had suitable 4-arm caliper measurements taken during their logging. Of these, about one hundred recorded fair to high-quality borehole breakouts. A few wells had multiple measurements over the same intervals, allowing an analysis of breakout development through time. Quaternary volcanic structures were also analyzed in Libya, and small-scale faulting (Quaternary to Recent) was examined in Egypt. Published interpretations of earthquakes were utilized wherever possible.

All of onshore Egypt and Libya was found to lie within the Central African stress field domain. Localized anomalies exist, but these are confined to individual wells or very small areas (perhaps localized fault blocks or wells drilled adjacent to old, large-scale faults). Tunisia, however, straddles the two stress regimes, with $\mathbf{S_{hmin}}$ oriented east-west in the north and north-south in the south. The boundary is located in the Pelagian Basin–Gulf of Gabes, and is not sharp. Within the boundary zone, wells show a mix of the two stress regimes, alternating vertically through the well bore. Preliminary interpretation does not show any consistent relationship between stratigraphy and stress regime; i.e., levels experiencing a given stress regime cannot be correlated between wells. In central Algeria, most wells examined show east-west $\mathbf{S_{hmin}}$ (Southern Mediterranean stress field), but the data base was not extensive and this area requires much further study.

These results have interesting implications for designing and completing horizontal wells in fractured reservoirs of North Africa. In particular, acquisition of appropriate data (borehole geometries, induced hydrofractures) would be strongly recommended prior to choosing an optimum well trajectory within the Central African–Southern Mediterranean stress regime boundary zone, which should extend into Algeria and the offshore of Libya. The data must relate to the specific reservoir zone of interest; generalizing the stress field vertically and laterally in this region would be incorrect. The Tunisian wells also raise interesting questions about the generation of fracture systems in such settings, and may help explain the long enigmatic origin of apparently coeval, orthogonal joint systems.