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A Fractured Gas Reservoir in a Composite Foreland Basin, Sichuan Province, China

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The northwestern Sichuan basin hosts significant gas resources in the Upper Triassic Xujiahe ('Xu') formation. Initial exploration had focused on a simple structural closure model that yielded many gas leads but failed to adequately define the entrapment. Understanding the tectonic history and modelling fractures are requirements for the optimal placement of exploration and delineation wells.

The Sichuan basin has a protracted, two-stage tectono-sedimentary history: early marine, extensional, and later terrestrial, compressive. It originated on the Neoproterozoic western passive margin of the South China block, which collided with both the North China block and Tibet during the Upper Triassic Indosinian orogeny, resulting in the closure of the Paleotethys. Until the India–Eurasia collision during the Eocene Himalayan orogeny, Tibet's eastern flank was extruding episodically along the Longmenshan (Dragon's gate mountains). The weight of the basinward, SE-propagating nappes led to flexural foredeep development and their erosional debris constitutes its flysch infill.

The northeasterly-trending Longmenshan had been considered a conventional fold-thrust belt. However, its small width (20-50 km) and minor crustal shortening can hardly explain its large vertical uplift at the margin of the earth's highest relief. The uplift mechanism is therefore considered by some to be inflation by the ductile lower crust ('channel flow'). Draping of southern China around the Indian indenter may have caused rotation of the Sichuan basin. The *in-situ* stress field is E–W and the current deformation of the Longmenshan is accommodated by dextral transpression.

The Zitong area in the Longmenshan foreland hosts the Upper Triassic clastic, fluvial-alluvial Xujiahe formation at depth, which constitutes both source and overpressured, tight reservoir for natural gas. Matrix permeability is very low. Large, very gentle, slightly asymmetrical anticlines are believed to act as structural traps and, more importantly, as loci of high fracture densities as well as of individual, large fractures. The anticlines closer to the Longmenshan trend parallel to its front whereas the more distal ones trend approximately orthogonal to it. There are no clear overprinting relationships, but sediment onlaps reveal their quasi-simultaneous initiation in the Upper Triassic. This folding also affects the Cretaceous surface

rocks (and Triassic ones elsewhere) indicating a prolonged history. Most folds are dismembered along reverse faults which root in a Mid-Triassic detachment that extends at least into the basin centre.

Understanding the structural configuration and fracture systems is vital for drilling successful commercial gas wells. Vertical wells drilled in the past confirmed the presence of thick gas columns in various Triassic and Jurassic formations. Analysis of the results revealed the importance of the fractures for commercial production and the need of unconventional thinking to solve the problem of low permeability. Vertical wells do not intercept the steep natural fractures that are the primary conduits of commercial gas flow, at high angles. Delineating the timing and orientations of these fracture sets will result in better placement of directional wells in the northwestern Sichuan basin.