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Carbonate fracture stratigraphy: An integrated outcrop and 2D discrete element modelling study

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Constraining fracture stratigraphy is important as natural fractures control primary fluid flow in low matrix permeability naturally fractured carbonate hydrocarbon reservoirs. Away from the influence of folds and faults, stratigraphic controls are known to be the major control on fracture networks. The fracture stratigraphy of carbonate nodular-chert rhythmite successions are investigated using a Discrete Element Modelling (DEM) technique and validated against observations from outcrops. Comparisons are made to the naturally fractured carbonates of the Eocene Thebes Formation exposed in the west central Sinai of Egypt, which form reservoir rocks in the nearby East Ras Budran Field. DEM allows mechanical stratigraphy to be defined as the starting conditions from which forward numerical modelling can generate fracture stratigraphy. DEM can incorporate both stratigraphic and lateral heterogeneity, and enable mechanical and fracture stratigraphy to be characterised separately. Stratally bound stratified chert nodules below bedding surfaces generate closely spaced lateral heterogeneity in physical properties at stratigraphic mechanical interfaces. This generates extra complexity in natural fracture networks in addition to that caused by bed thickness and lithological physical properties. A series of representative geologically appropriate synthetic mechanical stratigraphic models were tested. Fracture networks generated in 15 DEM experiments designed to isolate and constrain the effects of nodular chert rhythmites on carbonate fracture stratigraphy are presented. The discrete element media used to model the elastic strengths of rocks contain 72,866 individual elements. Mechanical stratigraphies and the fracture networks generated are placed in a sequence stratigraphic framework. Nodular chert rhythmite successions are shown to be a distinct type of naturally fractured carbonate reservoir. Qualitative stratigraphic rules for predicting the distribution, lengths, spacing, tortuosity, apertures and quantitative fracture indices (P21, P22 and fractal dimension) of natural fractures in the subsurface are generated from DEM fracture networks. The results of this study have widespread significance for characterising naturally fractured carbonate nodular-chert rhythmite reservoirs.