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Basin deconstruction–construction: Seeking thermal–tectonic consistency through the integration of geochemical thermal indicators and seismic fault mechanical stratigraphy – Example from Faras Field, North Western Desert, Egypt

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ABSTRACT

To construct a model of a sedimentary basin's thermal tectonic history is first to deconstruct it: taking apart its geological elements, searching for its initial conditions, and then to reassemble the elements in the temporal order that the basin is assumed to have evolved. Two inherent difficulties implicit to the analysis are that most organic thermal indicators are cumulative, irreversible and a function of both temperature and time and the non-uniqueness of crustal strain histories which complicates tectonic interpretations. If the initial conditions (e.g. starting maturity of the reactants and initial crustal temperature) can be specified and the boundary conditions incrementally designated from changes in the lithospheric heat engine owing to stratigraphic structural constraints, then the number of pathways for the temporal evolution of a basin is greatly reduced. For this investigation, model input uncertainties are reduced through seeking a solution that iteratively integrates the geologically constrained tectonic subsidence, geochemically constrained thermal indicators, and geophysically constrained fault mechanical stratigraphy.

The Faras oilfield in the Abu Gharadig Basin, North Western Desert, Egypt, provides an investigative example of such a basin's deconstructive procedure. Multiple episodes of crustal extension and shortening are apparent in the tectonic subsidence analyses which are constrained from the fault mechanical stratigraphy interpreted from reflection seismic profiles. The model was iterated with different thermal boundary conditions until outputs best fit the geochemical observations. In so doing, the thermal iterations demonstrate that general relationship that basin heat flow increases decrease vertical model maturity gradients, increases in surface temperatures shift vertical maturity gradients linearly to higher values, increases in sediment conductivities lower vertical maturities with depth, and the addition of "ghost" layers (those layers removed) prior to the erosional event increase maturities beneath, and conversely. These integrated constraints upon the basin evolution model indicate that the principal source rocks, Khatatba and the lowest part of the Alam El Bueib formations, entered the oil window at approximately 95 Ma and the gas window at approximately 25 Ma. The upper part of the Alam El Bueib Formation is within the oil window at the present day.

Establishing initial and boundary value conditions for a basin's thermal evolution when geovalidated by the integration of seismic fault mechanical stratigraphy, tectonic subsidence analysis, and organic geochemical maturity indicators provides a powerful tool for optimizing petroleum exploration in both mature and frontier basins.

1. Introduction: problem definition

To construct the evolution of a basin is to deconstruct a basin's history by taking apart the information recorded within its

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preserved sedimentary record (its episodes of sedimentary fill, burial, uplift, erosion, hiatus, faulting, heating and cooling, fluid flow, and organic and inorganic diagenesis), searching for its initial conditions, and then putting the pieces back together as a theoretical model for validation. Though overly simplified, Fig. 1 schematically illustrates the procedure that must be undertaken in order to develop a basin model. The basin must first be disassembled ("back stripped"), piece by piece, initial conditions specified, and then reassembled ("forward loaded") under the appropriate evolving thermal conditions so that the end product matches the present day geology, geochemistry, and geophysics. The final assembly of Layers L_D (for deposition) and Layers L_E (for erosion) for testing the model may be written symbolically as:

$$\sum_{i=1}^{n}\sum_{t=1}^{t} L_D - \sum_{i=1}^{n}\sum_{t=1}^{t} L_E \quad (1)$$

where i represents layer number and t represents time of the event.

The geovalidation of the basin's theoretical construction must be within the limits of precision of the observed borehole stratigraphy, of the thermal indicators specified geochemically, and of the required tectonics verified by the seismic reflection records. If the model lies within the boundaries, it is assumed to be a valid approximation to reality; if outside the boundaries, based upon the observations the model is invalid.

Such a procedure in theory is straight forward. But in practice, there is a dilemma in determining a basin's path history from its present conditions. That is, a basin's tectonic thermal and strain product has non-unique pathway possibilities which are analogous to the multiple possibilities of reconstructing a stress history from the strain history (Means, 1976). That is, if the tectonic record is overprinted and complex, and as the major information for constraining a basin's thermal history is the use of irreversible geochemical maturity products which are both a function of time and temperature (Pigott, 1985), there can exist equivocal pathways for a basin's organic maturation. The problem is exacerbated by the sparseness of data which accompanies petroleum exploration and the need for precise thermal control for the assessment of a basin's evolving hydrocarbon potential. Taken together, the challenge of effectively determining a basin's evolution for petroleum exploration can appear daunting.

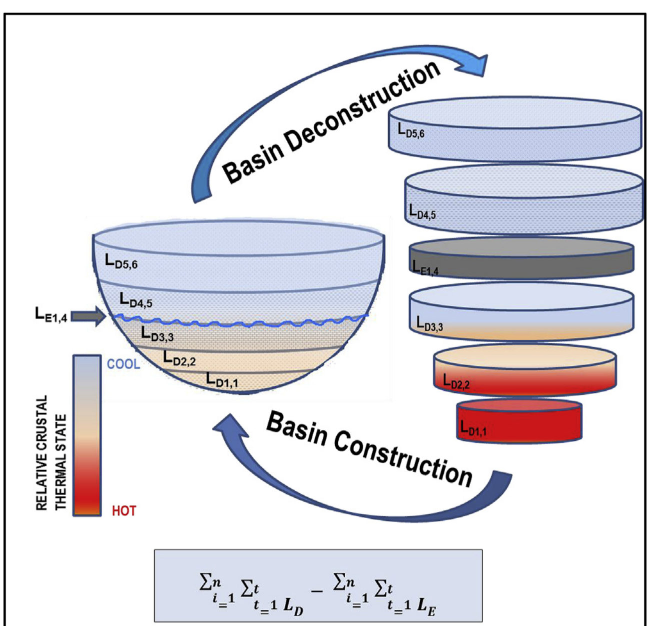

Fig. 1. Schematic diagram indicating basin deconstruction and construction for a theoretical basin with five discrete layers of deposition (L_D) and one layer which was eroded (L_E). The first subscript number represents the number of the layer and the second number represents the time.

Fortunately, there is a way out of the dilemma. If one can specify the initial conditions (e.g. starting maturity of the reactants and initial crustal temperature) and incrementally specify the boundary conditions from changes in the lithospheric heat engine from stratigraphic structural constraints, then the number of pathways for the temporal evolution of a basin is greatly reduced. To demonstrate such a basin modeling procedure, this paper will examine borehole and 2D reflection seismic data from the recently developed Faras field of the North Western Desert, Egypt.

In the last three decades, basin modeling theory and practice have become an essential tool for the determination of the thermal-tectonic evolution of sedimentary basins and the associated predicted organic maturities in a variety of tectonic settings (e.g. reviews in the seminal volumes of Barker, 1996; and Allen and Allen, 2005; with specific examples of passive margin basins by Ru and Pigott, 1986; wrenched basins by Pigott and Sattayarak, 1993; and island arcs by Brandes et al., 2008 to name a few). While this particular investigation does indeed study yet another basin, for the Faras Field within the Abu Gharadig Basin, there is a different focus. The subsurface data presented in this study provide the basis for a test of a principal and implicit basin model premise: **that there exists a method that will find not just a general solution but a particular solution to the backward boundary value problem posed by the observed physical-chemical conditions of a contemporary sedimentary record.**

2. Basin deconstruction: methods and materials

2.1. Regional tectonic history

Basin disassembly commences with data extraction, regional and local, from the surface downward. In terms of the regional setting, Faras field is located within the Qattara Depression of the Abu Gharadig Basin, within the North Western Desert of Egypt (Fig. 2A). The field was discovered in October of 1995 with the Faras-1 well which lies at −80 MSL within the middle of the Qattara Depression (Fig. 2B). Oil and condensate are trapped in an up-thrown block bounded by a normal fault with 610 m of throw (Darahem and Nassar, 1998). The discovery of Faras field is significant as the Western Desert is a challenging area for hydrocarbon exploration. The difficulties arise in part to difficulties in seismic acquisition and to a larger part to its sub-basins being segmented and having complex thermal histories owing to the region's multi-phased tectonic history: a Paleozoic passive margin, Jurassic rift, early Cretaceous passive margin, and subsequent inversion during the Syrian Arc deformation. Consequently, to understand the variety of tectonic events which have shaped the sedimentary record of this part of Egypt, it is appropriate to briefly review the significant amount of research which has been undertaken in the region, both in terms of tectonics and with respect to concomitant effects upon the petroleum systems.

Following the initial oil discoveries in the Cretaceous and