

PS Analysis of Sequence Stratigraphic Models for the Jurassic Cretaceous Sedimentary Fill of the Intrashelf Basins of the Eastern Margin the Arabian Plate*

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Abstract

Two critical conceptual sequence stratigraphic models for exploration and production were analyzed with sedimentary computer simulations of the Jurassic and Cretaceous sedimentary fill of the Intrashelf Basins (ISB) of the Eastern margin the Arabian Plate. One tracked the Hanifa Basin fill from Jurassic argillaceous carbonates to evaporites to the Cretaceous carbonates and the other the Aptian/Albian fill of the Bab ISB during a glacially induced sea level low. The Hanifa ISB simulation demonstrated Lower to Middle Jurassic sediments onlapped the uplifted eastern plate margin of the UAE and Oman as carbonates prograded and filled westward. Uplift ended Middle Jurassic accumulation with subaerial and progressive erosion of the Tuwaiq and Dhurma Formations on the eastern plate margin. Margin collapse caused a drowning unconformity. Westward of the platform margin the intra-shelf basin a base-level fall accompanied Arab and Hith evaporites accumulation. In the Early Cretaceous, the platform extended to North Oman with deposition of argillaceous hemipelagic carbonates of the Habshan. The lack of evaporites supports a climatic change from the Jurassic arid climate to a Cretaceous humid one. The simulation of the Mid Cretaceous carbonates supports division into Early Aptian and Late Aptian carbonate platform second order supersequences that aggraded and prograded to fill the Bab ISB. An unconformity initiates the sequence with westward prograding lowstand clinoforms onlapping eastward onto the Lower to early Upper Aptian carbonate platform of the SW margin of the Bab ISB. The simulation captures an initial sharp sea-level drop of 35–40 m from the early Upper Aptian shelf break to the topset of the first lowstand clinoform, and the sea-level drop by another 10 m during the progradation of following eight clinoforms. Each progradational pulse of the clinoforms is modeled over 405 k.y. Simulation illustrates the initial sharp sea-level drop of some 40 m followed by continued slow sea-level fall producing lowstand clinoforms prograding towards the ISB. Sedpak, developed at the University of South Carolina assumes clastic transport based on slopes and carbonate production based on water depth. Output geometries display a sequence stratigraphic framework of erosional and depositional surfaces of the simulated section enabling the extension of interpretation of depositional setting and predictions of lithofacies geometries away from well data.

Simulation and analysis of sequence stratigraphic models for the Jurassic Cretaceous sedimentary fill of the Eastern margin of the Arabian Plate

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ABSTRACT

Critical conceptual sequence stratigraphic models for exploration and production can be analyzed with sedimentary computer simulations of sedimentary fill of the intrashelf basins of the Eastern margin of the Arabian Plate. Examples from the Jurassic and Cretaceous sedimentary fill of the Eastern margin were simulated:

- 1) Evolution of the Torqian fill of the Marrat Basin from Lower Jurassic evaporites through a prograding carbonate margin with basinal argillaceous carbonates capped by evaporites
- 2) Evolution of the Middle to Upper Jurassic fill of the Hanifa Basin from argillaceous carbonates to evaporites capped by Cretaceous carbonates, and;
- 3) Aptian/Albian fill of the Bab Basin during a glacially induced sea level low.

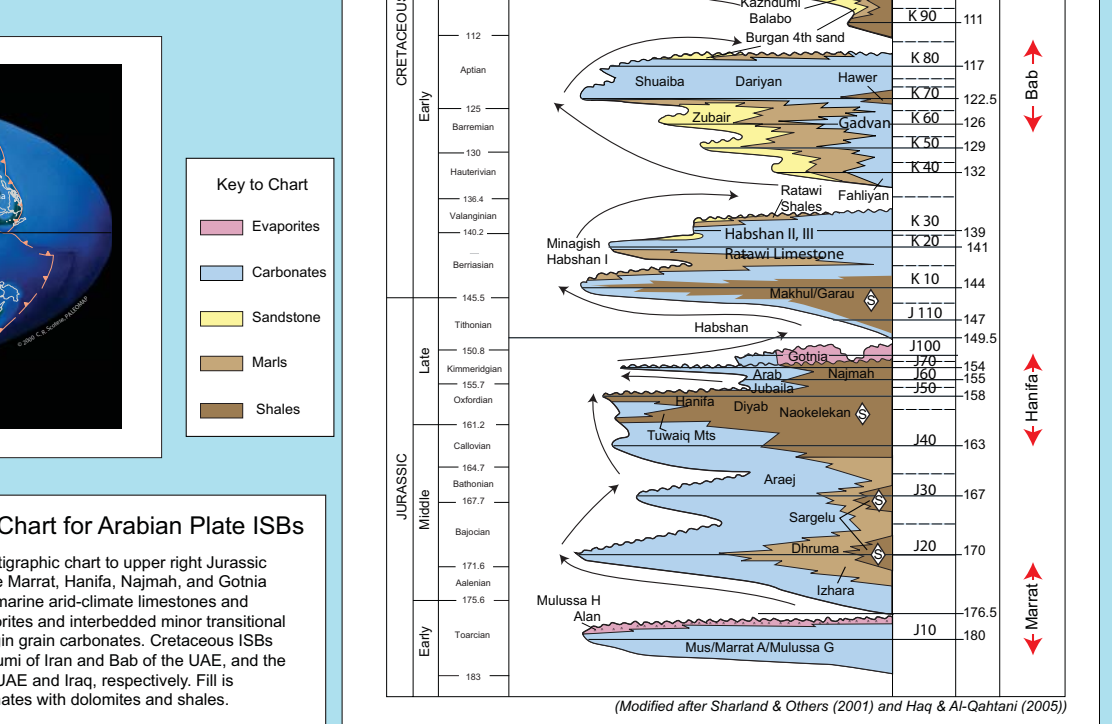
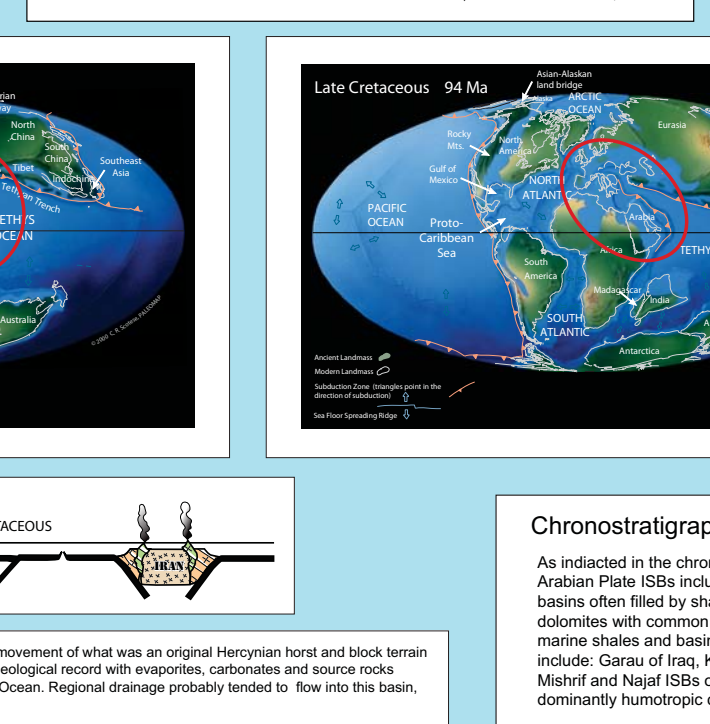
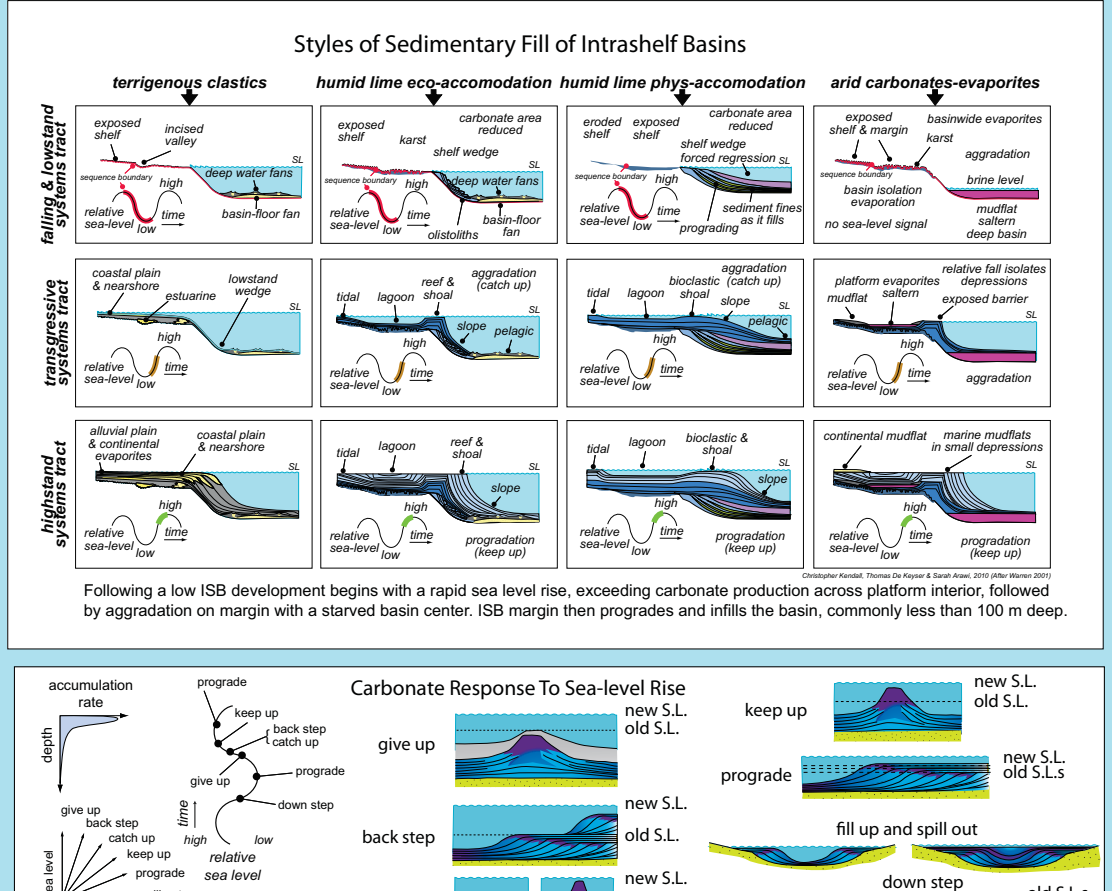
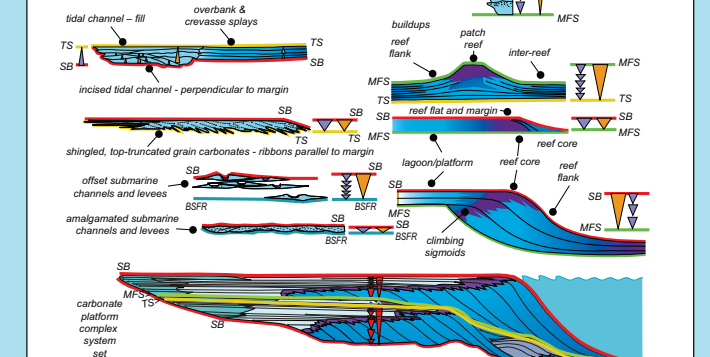
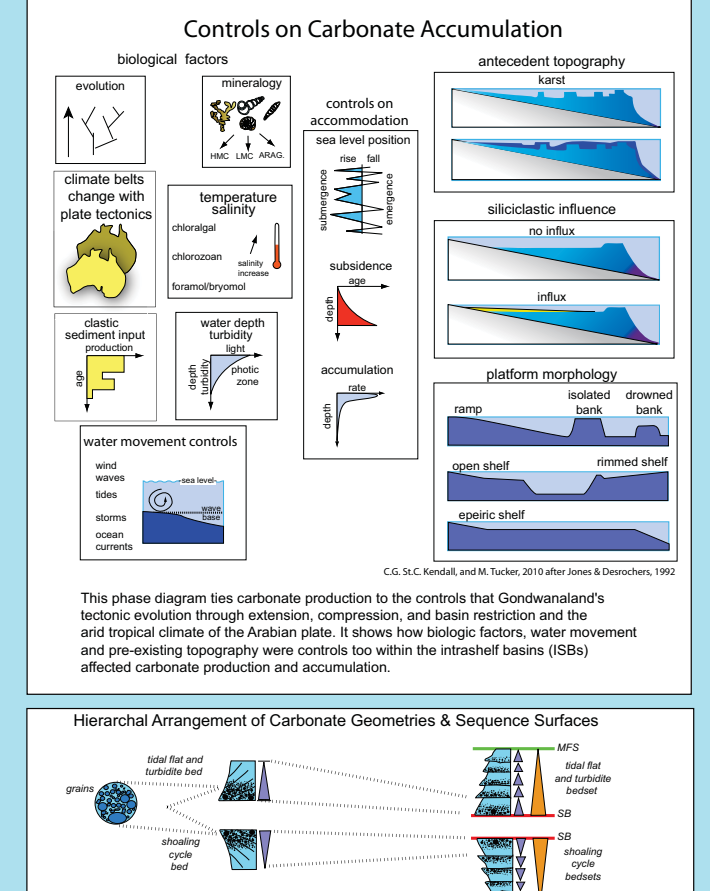
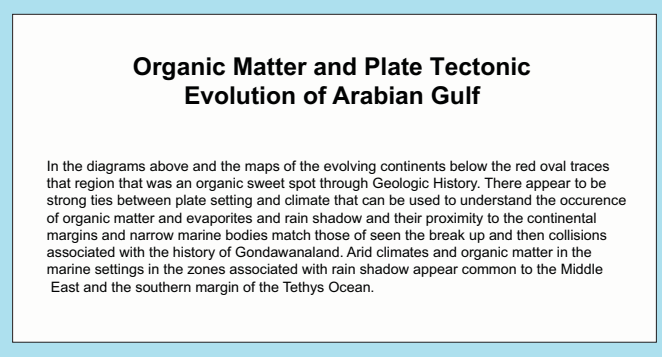
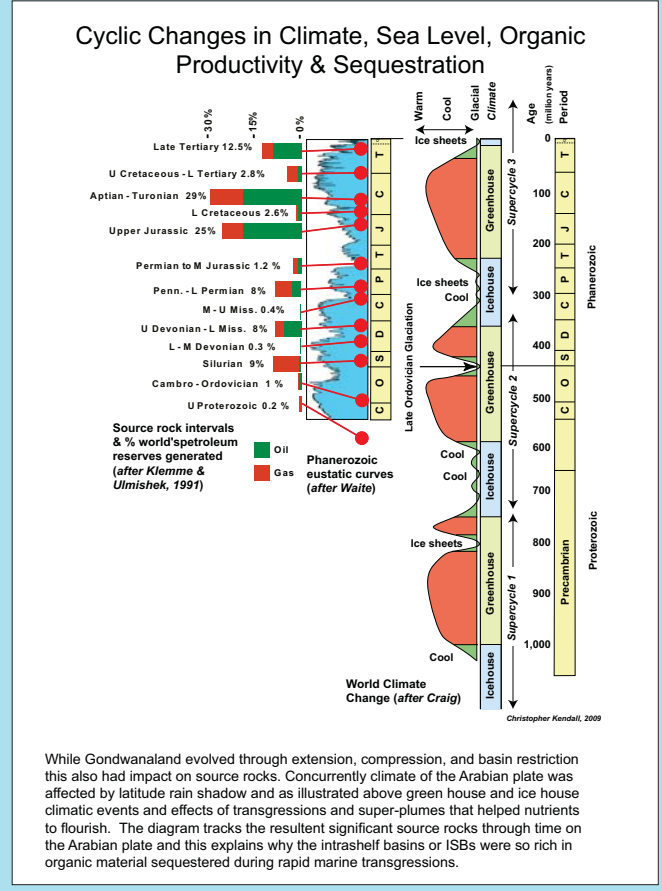
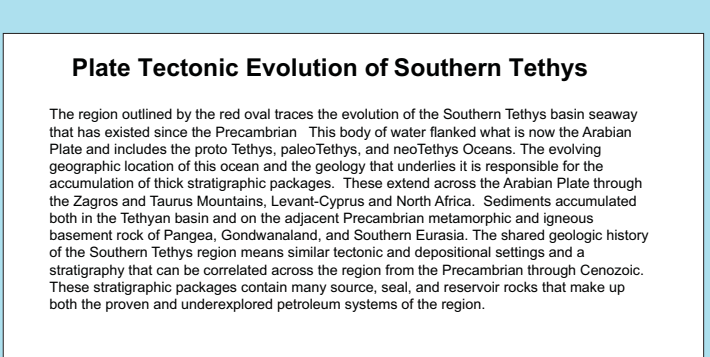
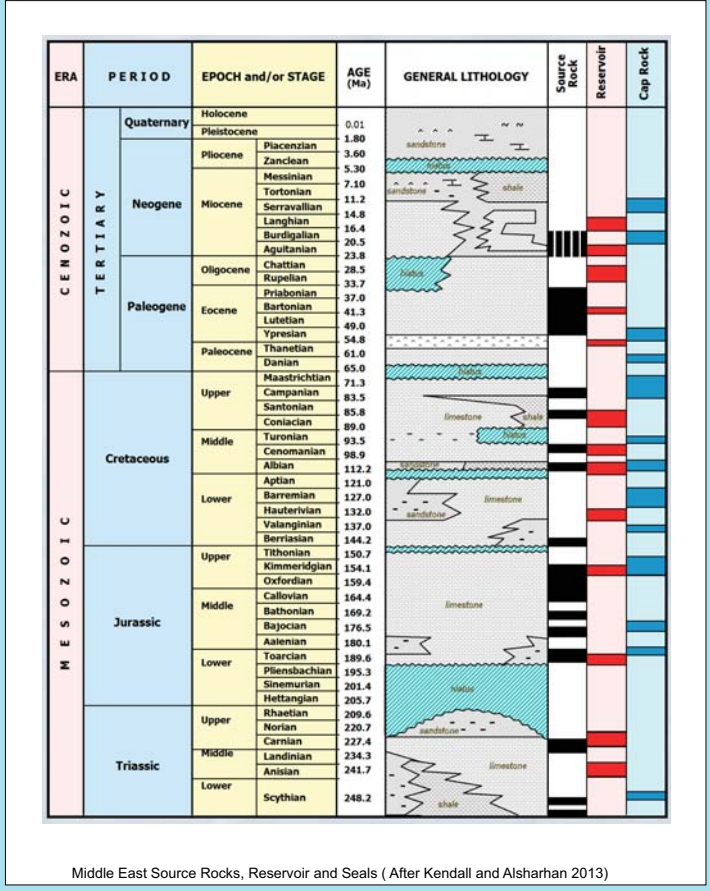
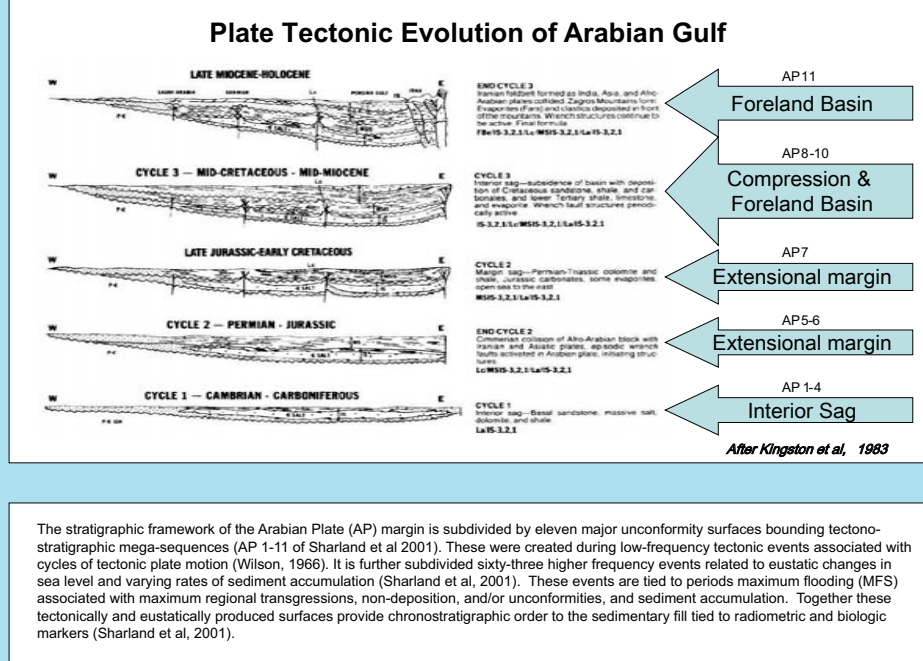
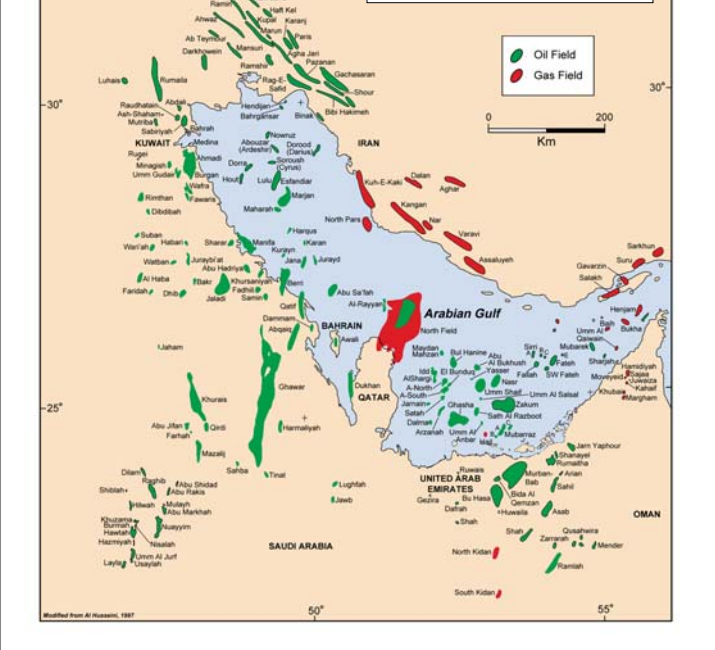
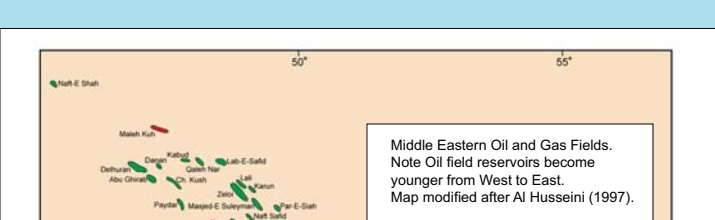
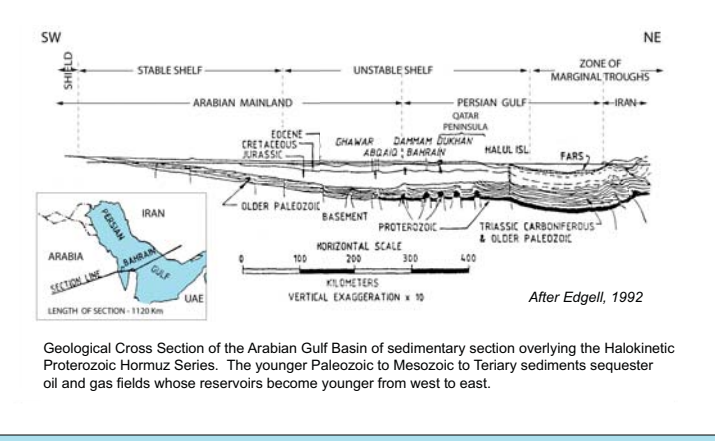
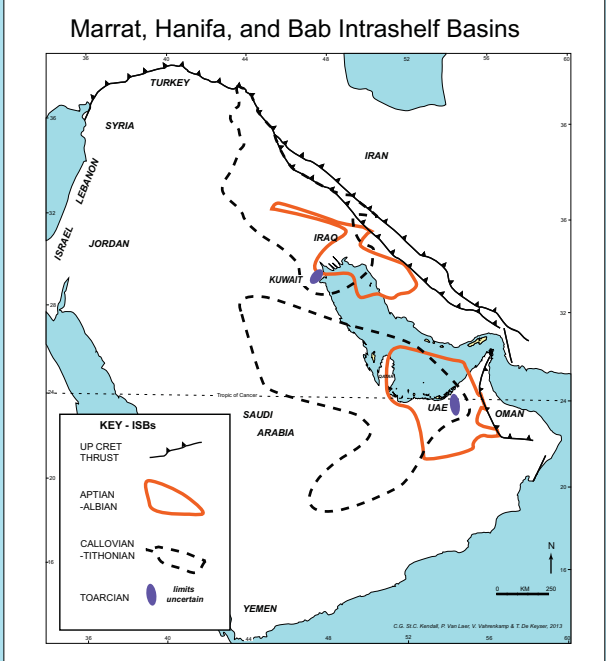
Results for the Marrat and Hanifa Basins simulations demonstrate the Lower to Middle Jurassic overlapping the uplifted Arabian plate margin in Kuwait, Saudi Arabia, the UAE and Oman as two phases of carbonate margin progradation and basinward infilling. The Middle Jurassic ended with uplift and subaerial exposure and progressive erosion of the Tuwaig and Dhurma Formations along the plate margin. The margin then collapsed with a drowning unconformity, away from the platform margin of the intra-shelf basin a base-level fall accompanied Arab and Hith evaporites accumulation.

In Early Cretaceous times the platform of the Arabian Shield extended to North Oman with deposition of argillaceous hemipelagic carbonates of the Habshan. The lack of evaporites supports a climatic change from the arid climate of the Jurassic to a humid climate of the Cretaceous.

The simulation of Mid Cretaceous carbonates supports their division into the second order supersequences of Early Aptian and Late Aptian carbonate platforms aggrading and prograding while filling the Bab intrashelf basin. An unconformity initiates the sequence with westward prograding lowstand clinoforms also overlapping onto the south-western margin of the Bab intrashelf basin and its Lower to early Upper Aptian carbonate platform. The simulation captures the initial sharp sea-level drop of 35-40 m from the early Upper Aptian shelf break to the topset of the first lowstand clinoform, and the sea-level drop by another 10 m during the progradation of following eight clinoforms. Each pulse of progradation of the clinoforms is modeled over 405 k.y. Cross-sections illustrate the initial sharp sea-level drop of some 40 m followed by continued slow sea-level fall producing lowstand clinoforms prograding towards the basin.

The Sedpak sedimentary simulation, developed at the University of South Carolina, recreated the sedimentary fill of the Marrat and Hanifa Basins, and the Bab Basin. It assumed carbonate production based on water depth and clastic transport based on slopes. Output geometries display a sequence stratigraphic framework of erosional and depositional surfaces of the simulated section enabling the extension of interpretation of depositional setting and predictions of lithofacies geometries away from well data. This aids prediction of facies likely to contain both hydrocarbon and water resources and their characteristic fabrics.

The advantage of these simulations is that it provides a template to the complexities of sediment stratigraphy, enabling identification, testing, and modeling of sedimentary systems and the sharing of data with others; enhancing the understanding of biostratigraphy and providing age constraints for stratal geometries and sequence stratigraphic interpretations. They reduce time for understanding interpretations of seismic and well data by identifying and constraining key factors that control sequence stratigraphic geometries and architectures, including rates of sedimentation, eustatic sea level, and tectonics.



Introduction to SEDPAK

The computer simulation sedimentary SEDPAK was developed at the University of South Carolina as a simulation tool that models the geometry of the generalized lithofacies of a basin, resulting from the interaction between the major geological processes including:

Eustatic Sea Level
Tectonic Movement
Sediment Accumulation

SEDPAK constructs empirical models of sedimentary geometry. These sedimentary geometries are created by the infilling of a two dimensional basin from both sides with a combination of in situ carbonate growth and clastic sediment in the 15 steps outlined to the right.

Intuitive model input parameters are based on physical processes, including clastic transport based on depositional distance, quantity and slopes and carbonate production based on water depth. Data entry is accomplished by using a graphical user interface. Values are entered for the initial basin configuration and, as a function of time, the following variables may be specified: local tectonic behavior, sea level behavior, amount and direction of clastic deposition, accumulation rates of carbonates both as a function of water depth and pelagic accumulation. The model traces the evolving geometries of clastic and carbonate sediments through time, responding to the depositional processes previously itemized. Sediment geometries are plotted as they are computed, so the results are viewed immediately. Based upon these observations, parameters can be changed interactively and the program rerun until the resultant geometries are satisfactory.

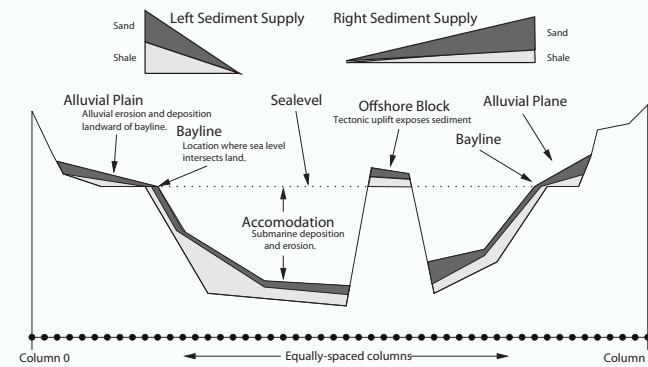
Rates of both carbonate and clastic sediment accumulation and transport distance down slope are modeled in two dimensional simulation space, and offer valuable insight into a more quantitative modeling approach. Further information on the fabrics of the deposits can be obtained by means of coupling computer models of sedimentary geometries with physically based submodels that describe the spatial and temporal evolution of relatively small portions of the entire system.

Output geometries display a sequence stratigraphic framework of erosional and depositional surfaces of the simulated section.

The origins of sediment geometries and facies are interpreted by comparison with observations of similar features in modern sedimentary systems and their processes and then the interpretations are tested with the SEDPAK simulation. The question is: do input parameters match those inferred from current field observations parameters set to create basic sequences stratigraphic systems tracts, including prograding low-stand and highstand systems tracts, and retrogradational transgressive systems tracts? The same applies to in-situ carbonate accumulation. Are the depth-production rates reasonable?

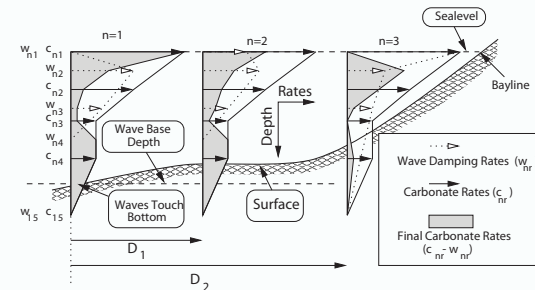
Computer modeling of sedimentary geometries that match interpreted sections is a repetitive exercise in parameter estimation, viewing of resulting geometries and adjusting of parameters to converge on a best match.

SEDPAK extends interpretation of depositional setting and predictions of lithofacies geometries away from the studied areas. It aids prediction of facies likely to contain both hydrocarbon and water resources and their characteristic fabrics.



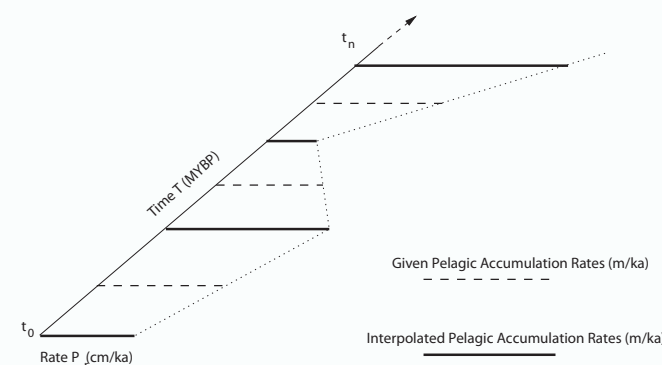
Basin Setting. The basin is divided into equally-spaced columns. After the bayline is located, alluvial sediment is eroded landward then submarine sediment is deposited or eroded. Offshore blocks created by sea level change or tectonic adjustments may be eroded to the initial basin surface.

STEPS 1 through 6



Winnowing of shale by waves. Waves touch bottom at left (n=1). The winnowing curves specify the percentage of shale to remove from the sediment column to the right of wave base.

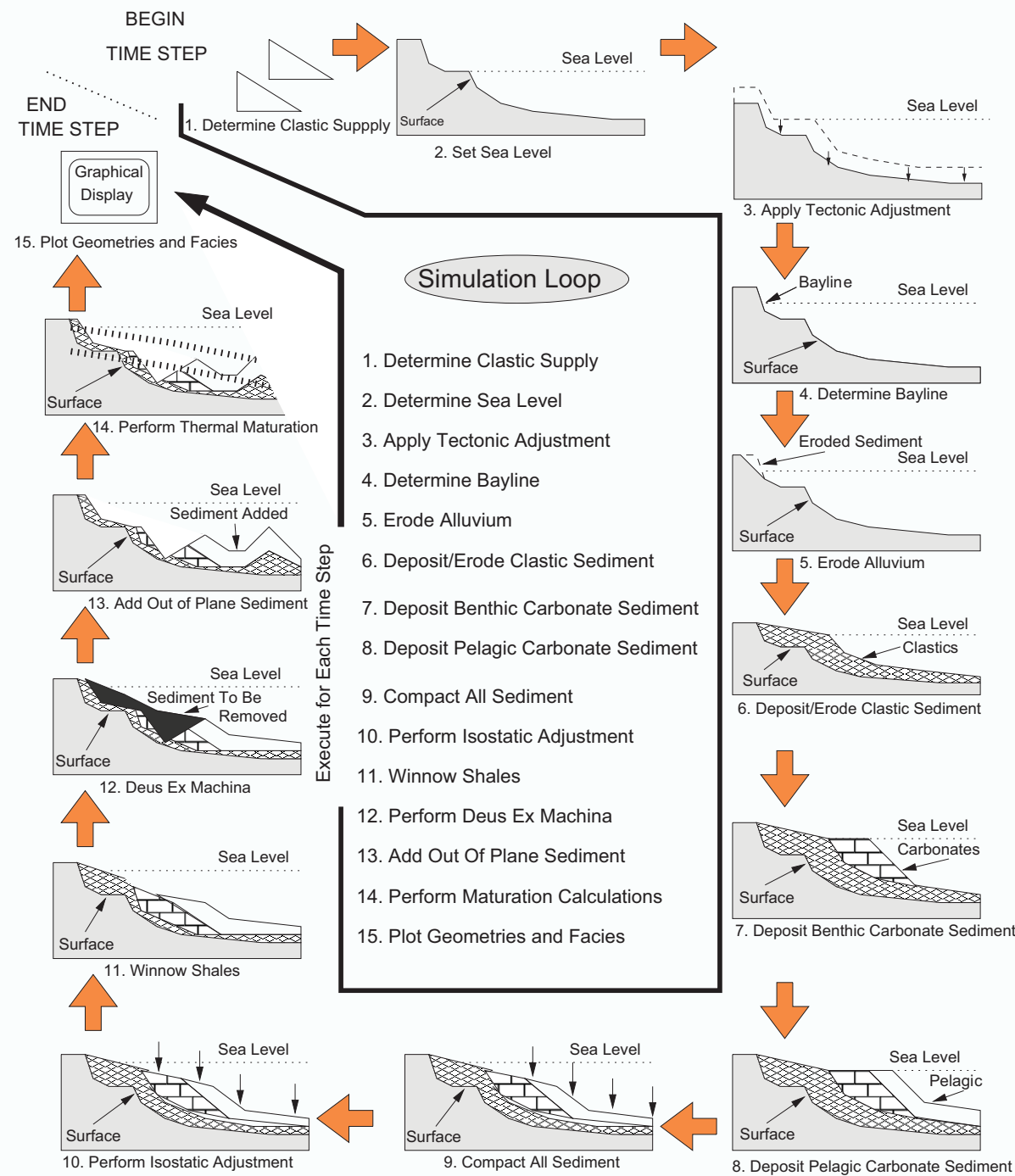
STEP 11



Pelagic deposition of Carbonates. Pelagic rates in meters/Ka can vary over time and are linearly interpolated between user defined rates at specific times.

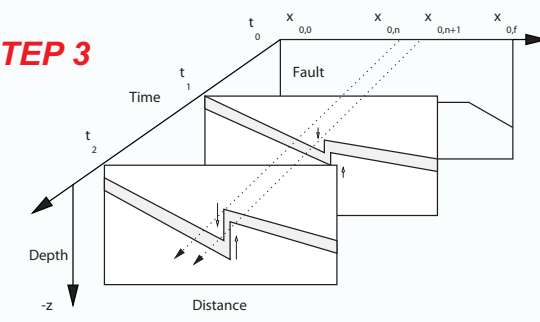
STEP 8

SEDPAK Time Step Operations



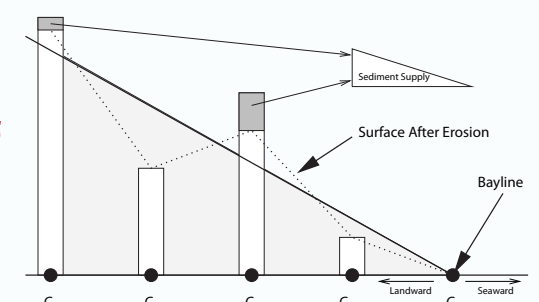
Within each time step, a fixed sequence of operations creates or modifies the sedimentary geometries. First, tectonic adjustments change the accommodation at points defined by the user across the basin. Next, the intersection of the sea level position with the basin surface defines a bayline location (Posamentier and Vail, 1988) marking the base of the alluvial plain. Sediment eroded landward from the bayline location is added to the sediment supply. Seaward of the bayline, sediment erodes or is deposited according to geometrical rules. After clastic deposition is completed, carbonates accumulate in-situ to form reefs. From the reef positions, excess carbonate is transported downslope as talus or turbidite, or backslope as lagoonal sediment. Next, a pelagic drape, specified as a rate, blankets the submarine setting. Sediment loading and compaction adjustments, followed by winnowing of shales, and out-of-plane erosion and deposition complete the operations for the time step. These operations are summarized by the 15 steps are represented above diagrammatically.

STEP 3



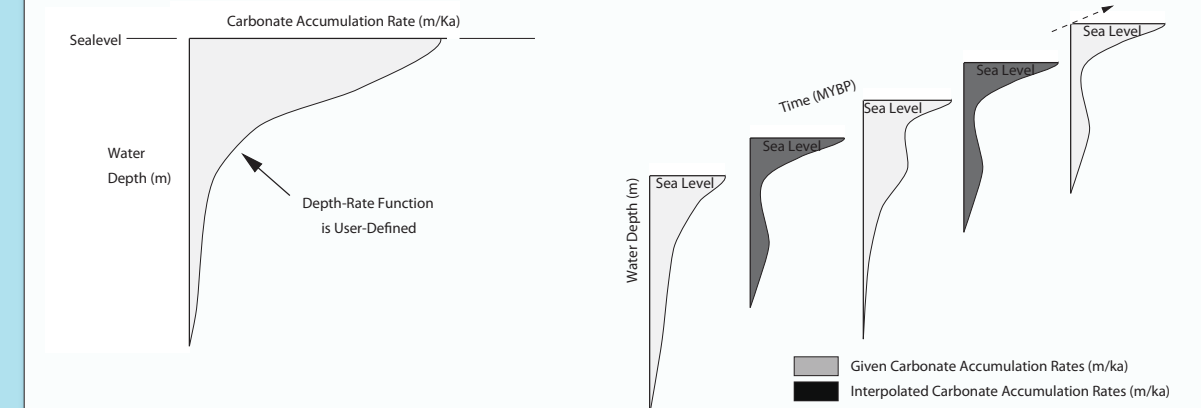
Vertical Fault Displacement. A vertical fault begins at time t . The vertical arrows show displacement occurring between two adjacent columns over time.

STEP 5



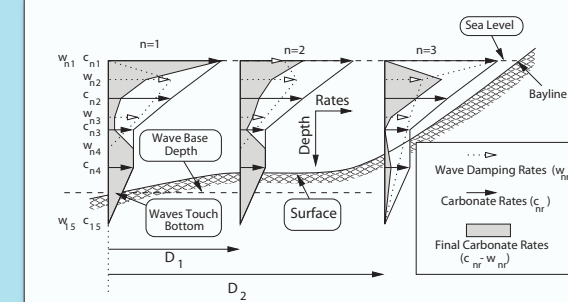
Schematic representation of Erosion. Sediment above the erosional line at columns Cn-2 and Cn-4 is removed. No sediment is eroded from Cn-1 or Cn-3. Eroded sediment is returned to the sediment supply for later deposition.

STEP 7



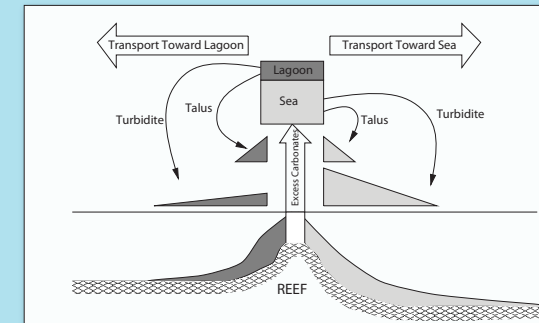
Varying Carbonate Rates. Rates are interpolated between depth-rate curves given at specified times in model parameters

STEP 7

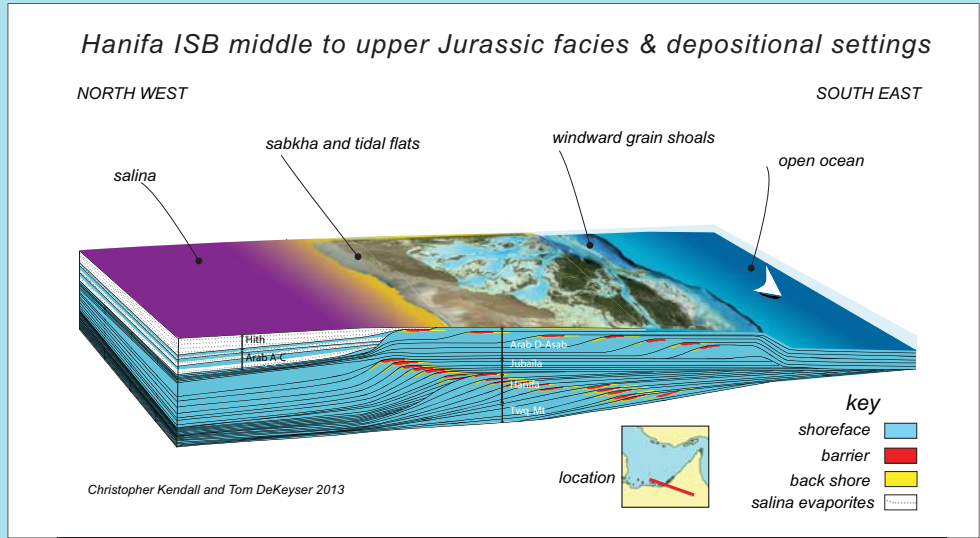
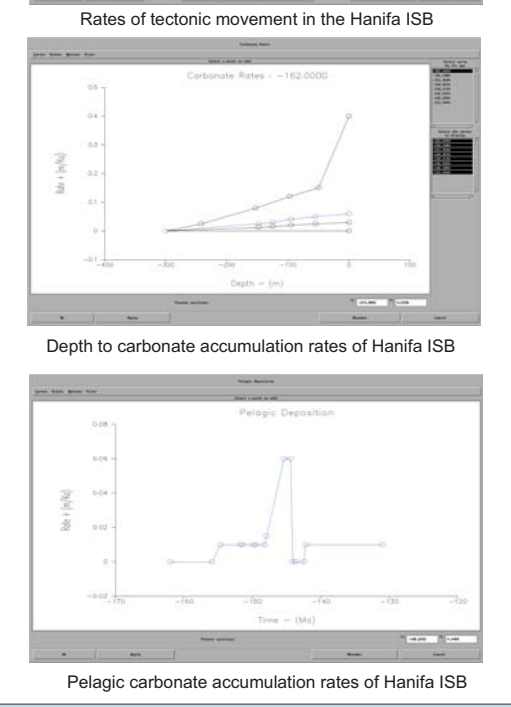
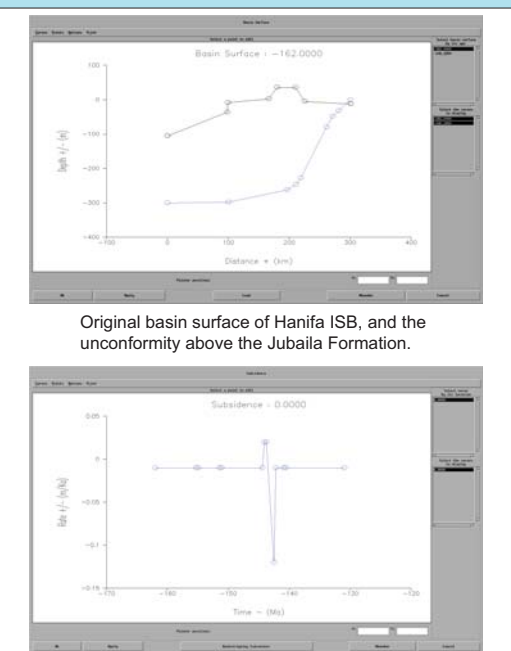
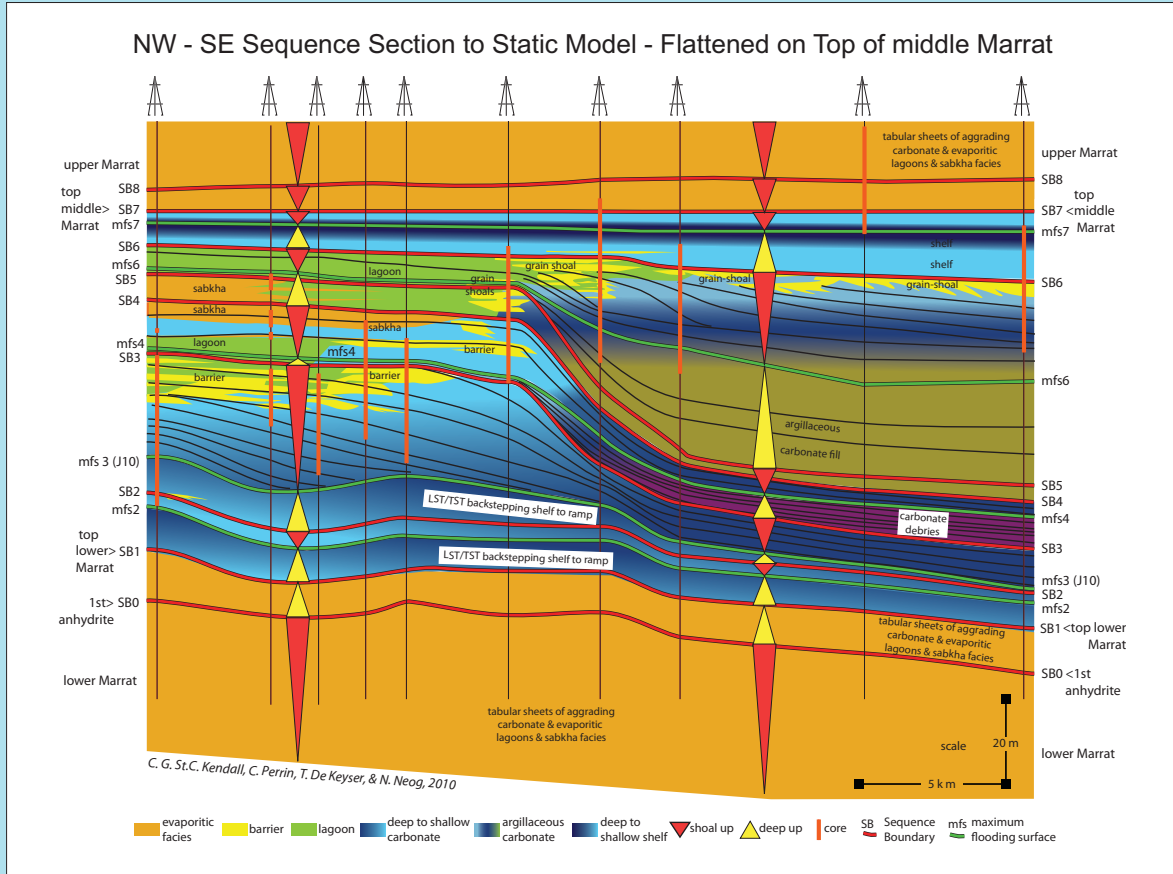
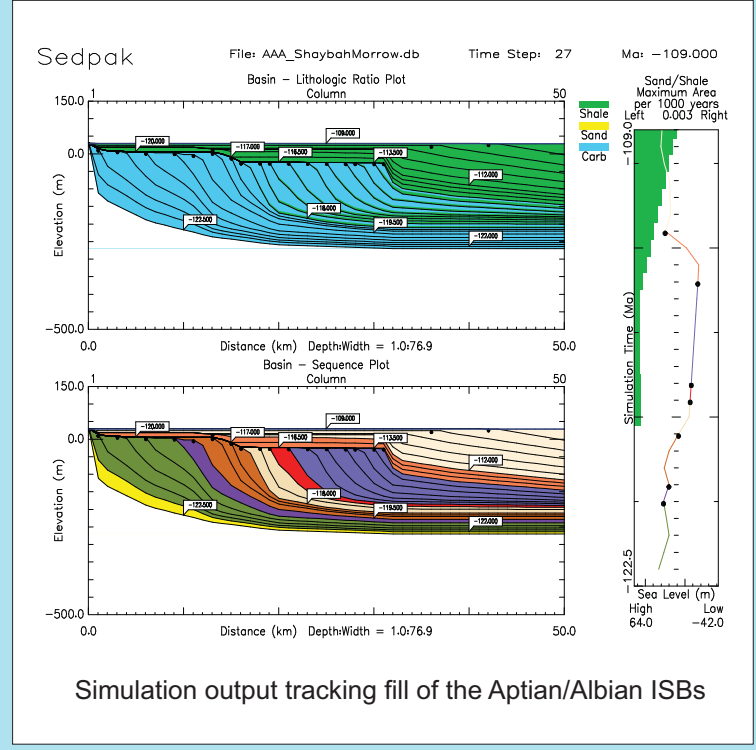
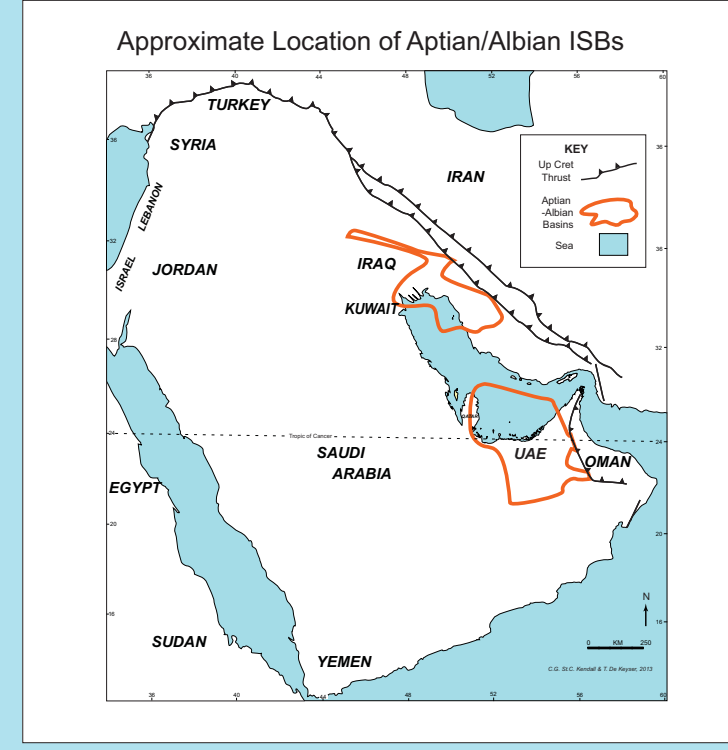
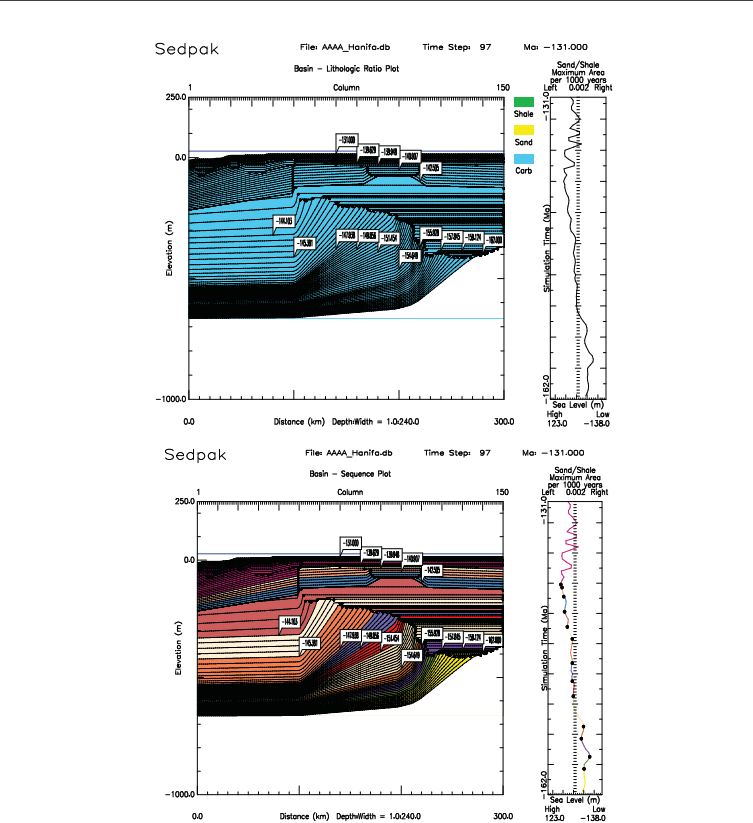
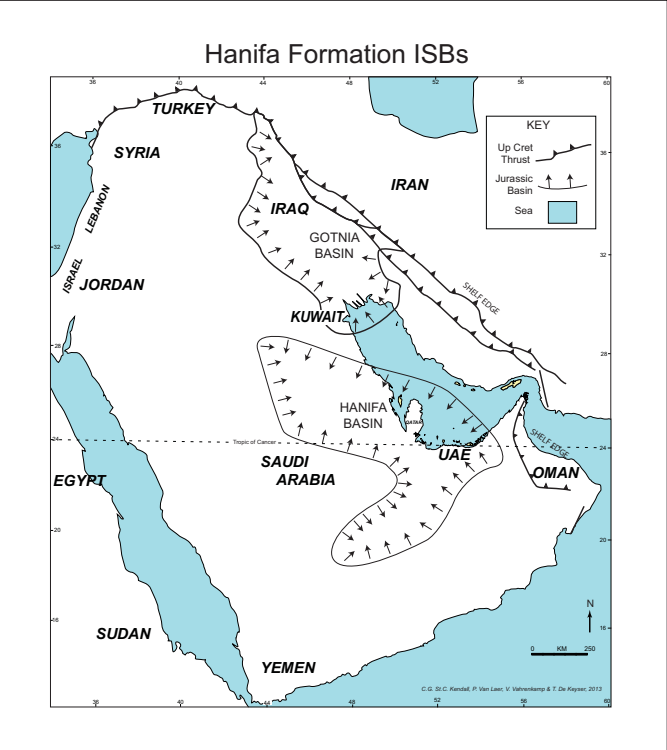
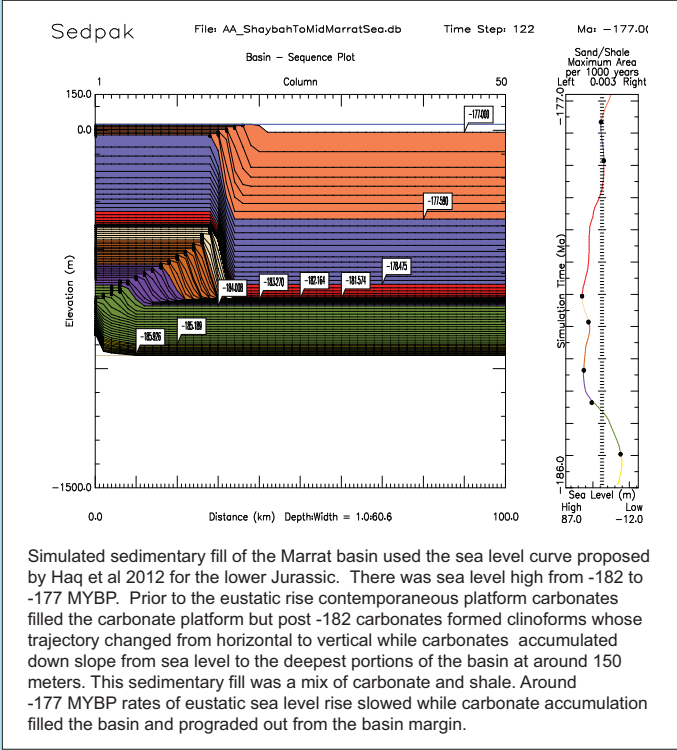
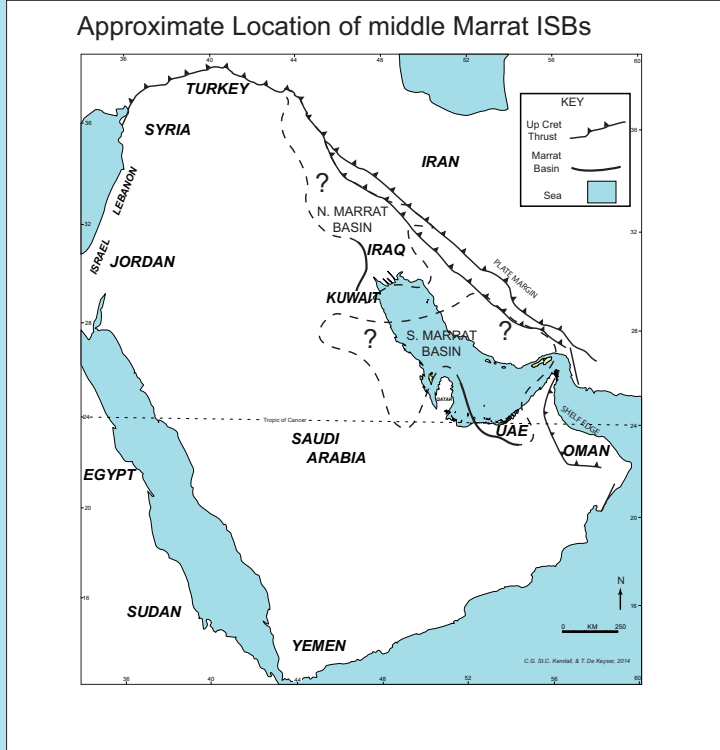


Wave damping of carbonate accumulation. From wave base in a landward direction to the right, wave damping rates (Wnr) are subtracted from the carbonate rates (Cnr) where n is the distance from wave base and r is the rate at that distance

STEP 7

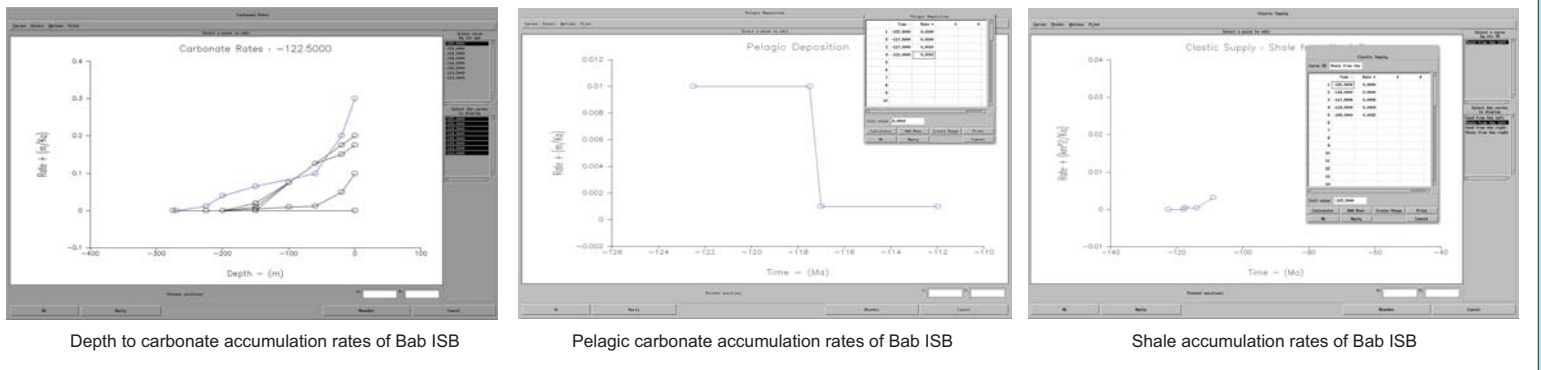
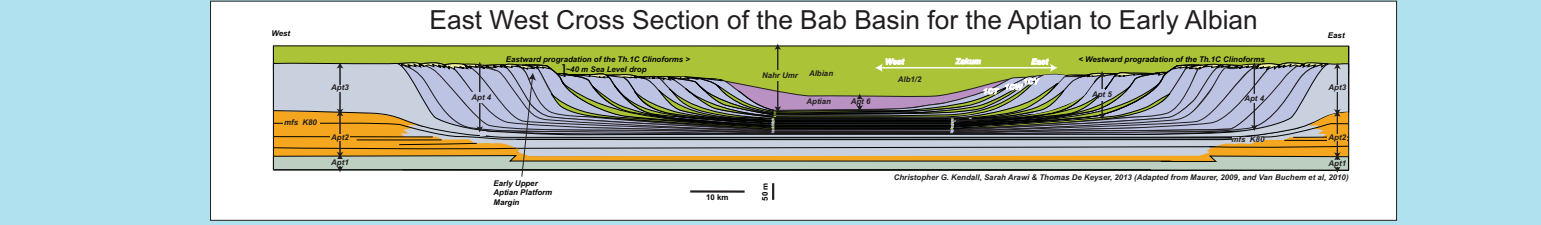
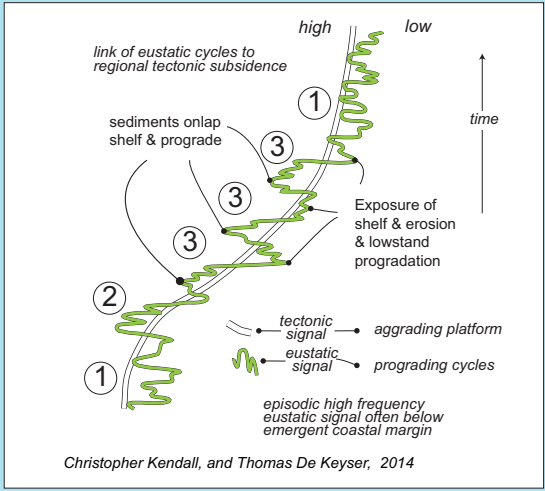


Excess carbonate production is bypassed in the lagoon and basin. A proportion of the excess is transported either into the lagoon or basin as a percentage. For each proportion, another percentage can be specified as talus or turbidites with specified distance of penetration.



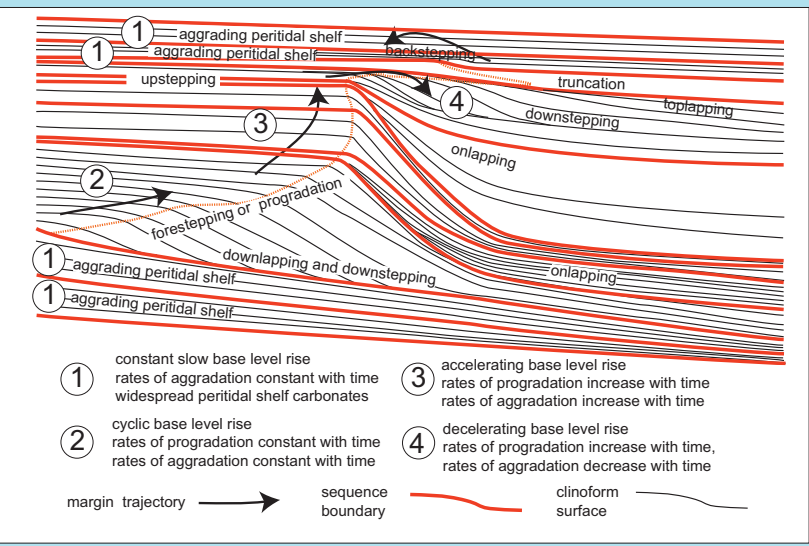
Major Conclusion

Simulations support mix of tectonic subsidence and eustasy as source of accommodation.



Simulation results of the fill of the Aptian/Albian ISBs

Simulated sedimentary fill of the Bab basin used the sea level curve proposed by Maurer et al 2012 for the Aptian Albian. These authors proposed a glacially induced sea level low from -117 to -113 MYBP. Prior to the eustatic fall contemporaneous rudist rich carbonates formed clinoforms that accumulated down slope from sea level to the deepest portions of the basin at around 200 meters. This sedimentary fill was close 100% carbonate but following the sea level low at -117 alternations of shale and carbonate filled the basin margin. Around -113 MYBP in the mid Albian eustatic sea level rose while carbonate accumulation fell and the Wasia calcareous shale filled and overlapped the basin margin.



Conclusions

The simulations suggest that the driving mechanisms behind accommodation, though model dependent, are the product of both a varying eustatic driver and an equally important varying tectonic driver. Both eustasy and tectonic subsidence appear to have moved in and out of phase with each other. In the simulation portions of the cyclic sedimentary section are produced when eustatic accommodation lies above the depositional surface, but when the rates of tectonic accommodation are slow, then eustatic sea level drops below the carbonate depositional surface and long periods of often unrecognized exposure ensue.

An argument against such a model might be the lack of diagenetic evidence of long exposure but one finds sections of sedimentary rock that from radiometric dating suggest long periods of time are involved in the creation of carbonate sections which show only evidence of short lived exposure. Our conclusion from running the simulations is that both eustatic and tectonic accommodation may be both rapid or may be slow.

Often the easy out, when looking at sedimentary sections, is to assume that the rate of tectonic movement was slow. However the simulations argue against this. Never the less it has to be accepted that this is an unprovable hypothesis, though from our point of view this is an elegant proposal even though conceptual models are the building blocks of the simulations.

