Prediction and Mapping of Deep-Water Slope Carbonate Reservoirs Using Seismic Data, Tengiz Field, Western Kazakhstan*

By

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Abstract

The supergiant Tengiz field of western Kazakhstan produces oil from an isolated carbonate platform (160 km^2) of Devonian and Carboniferous age. An initial broad Late Devonian platform exhibits accentuated vertical growth with punctuated backsteps during the Lower Carboniferous (Tournaisian and Visean). The uppermost Lower Carboniferous (Serpukhovian) is characterized by several kilometers of platform progradation, seaward of the Late Visean platform break. Late Visean and Serpukhovian boundstone dominates slope lithofacies.

In situ upper slope microbial boundstone and allocthonous lower slope boundstone debris form thick and areally extensive mappable reservoirs with distinctive seismic facies and production characteristics. Areas dominated by boundstone exhibit lower porosity (<4%) than time equivalent grainy carbonates on the platform (8-12%), but they may have much higher permeability and flow capacity due to extensive fractures and dissolution. The highest rate wells (10,000 to 30,000+ barrels/day) are located at the platform margin and within the slope.

Because platform and slope production characteristics differ significantly at Tengiz, criteria are developed to identify, map, and assess volume of slope boundstone. Criteria include: 1) positive structural relief above thick upper slope boundstone, 2) chaotic reflection character frequently with high-amplitude bursts within both *in situ* boundstone and boundstone debris intervals, 3) mosaic distribution of seismic amplitude, 4) isopach thicks associated with boundstone intervals, and 5) slump scars indicative of slope failure. Criteria described here could be applicable to other similar hydrocarbon-bearing isolated platforms (e.g., Korolev and Kashagan) that extend from onshore western Kazakhstan into the offshore North Caspian Sea.

Prediction and Mapping of Deep-Water Slope Carbonate Reservoirs Using Seismic Data - Tengiz Field, Kazakhstan

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Abstract

The supergiant Tengiz field of western Kazakhstan produces oil from an isolated carbonate platform (3.60 sq. km.) of Devonian and Carboniferous age. An initial broad Late Devonian platform exhibits accentuated vertical growth with punctuated backsteps during the Lower Carboniferous (Tournasian and Visean). The uppermost Lower Carboniferous (Serpukhovian) is characterized by several kilometers of platform progradation seaward of the late Visean platform break (East and Northeast side of the field). Late Visean and Serpukhovian boundstone dominates the slope lithofacies.

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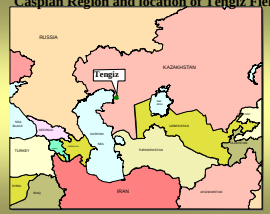
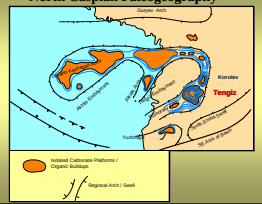
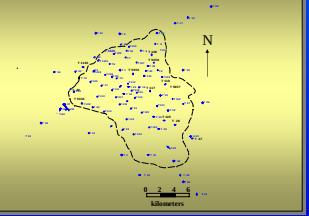
Caspian Region and location of Tengiz Field



North Caspian Paleogeography

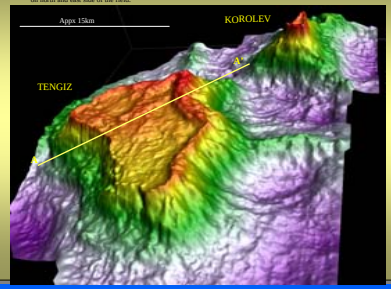


Tengiz Base Map Showing Well Locations



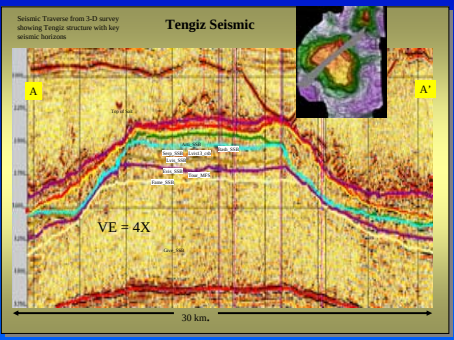
Tengiz and Korolev Structural Perspective

Structural Perspective at the top of the Bashkirian (top of reservoir interval). Key southwest to northeast seismic profile shows key structural features of the Tengiz platform and slope including prominent raised rim on north and east side of the field.

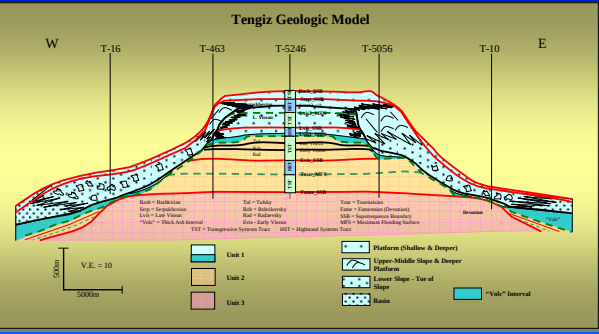


Tengiz Seismic

Seismic Traverse from 3-D survey showing Tengiz structure with key seismic horizons

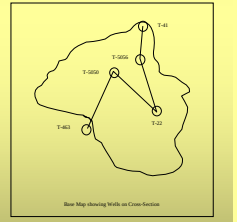


Tengiz Geologic Model

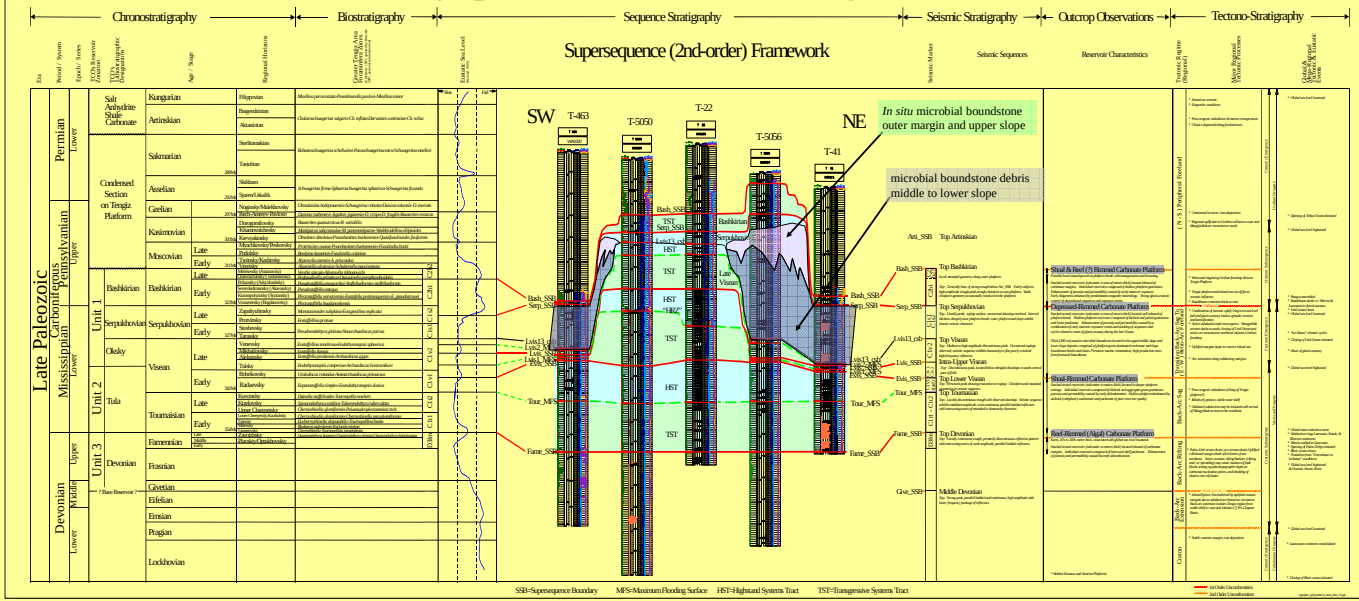


Data used for this study

- 1000 sq km 3-D seismic
  - post-stack time
  - pre-stack depth
- 4000 m core, 47 wells (~2500 m, 11 wells TCO)
- 3000 thin section descriptions
- 300 biostratigraphy pinning points



Stratigraphic Characteristics of Tengiz Field



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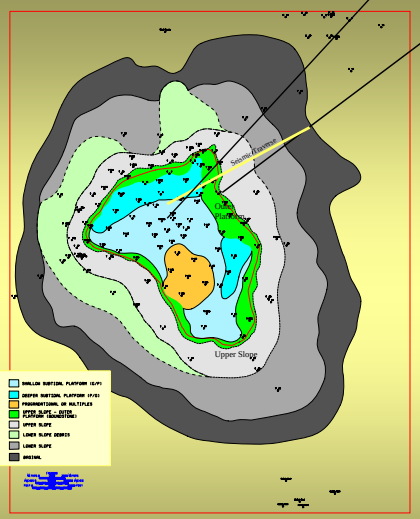
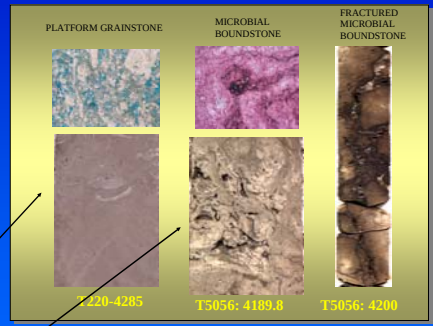
- To predict occurrence, distribution, and thickness of *In Situ* Boundstone and Boundstone Debris Facies
  - Develop seismic recognition criteria
  - Map top, base, and extent of boundstone dominated interval
  - Impact: develop best possible 3-D model w/ data-constrained geologic inputs to fluid flow simulation leading to defensible metrics of reserves and expected recovery

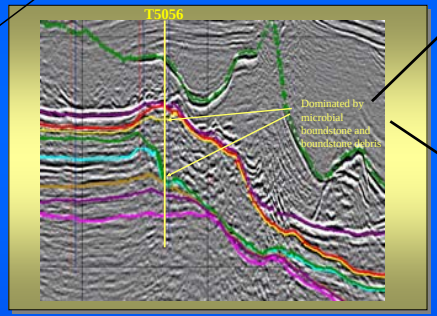
- Seismic challenges include sub-salt imaging and noise generated by shallow faulting and rafted anhydrite (within salt)

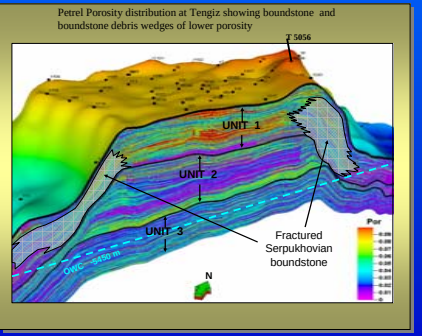
TENGIZ SERPUKHOVIAN ENVIRONMENTS OF DEPOSITION



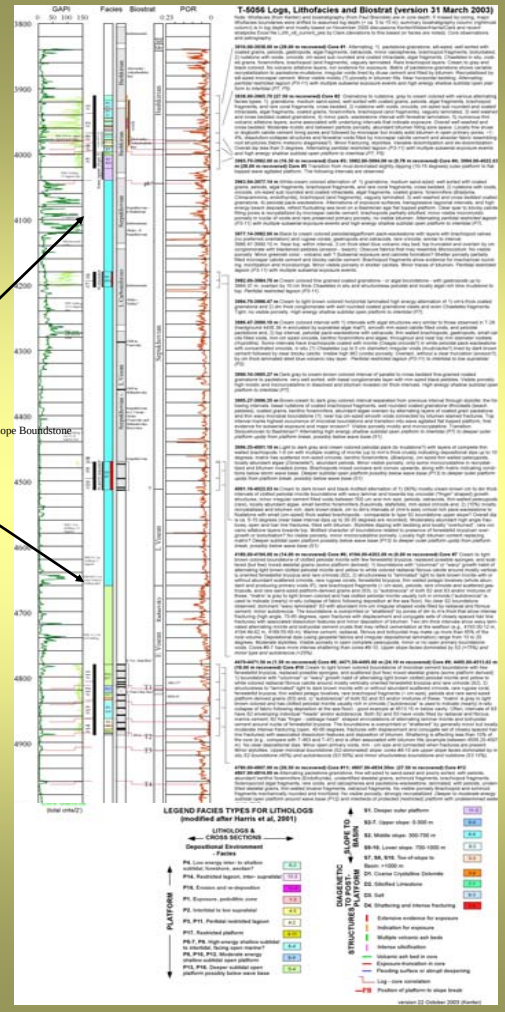
In Situ microbial boundstone is dominant in the platform margin (dark green) and upper slope (light gray). Boundstone debris accumulates in the lower slope and is particularly thick in the light green shaded area.



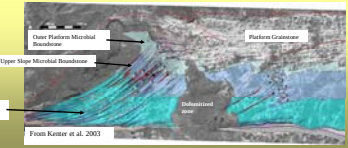




TENGIZ T-5056

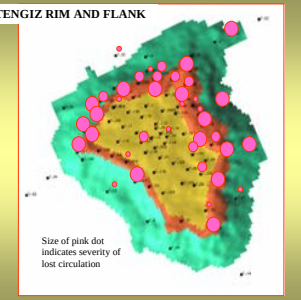


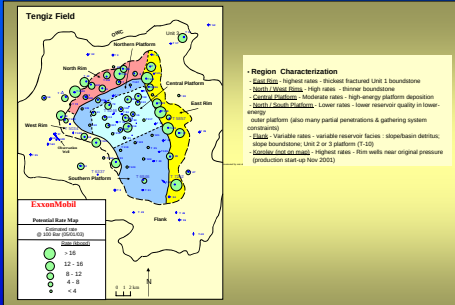
Analogous Outcrop from Carboniferous of Northern Spain



LOST CIRCULATION TENGIZ RIM AND FLANK

Wells drilled along the raised rim and further out on the flanks of the field have all encountered intervals dominated by microbial boundstone which is thought to have been deposited in an outer platform to upper slope environment. Wells frequently encounter zones of enhanced permeability within the microbial boundstone facies probably due to fracturing and dissolution. These zones frequently cause lost circulation.





In addition to experiencing lost circulation, wells drilled in this facies often have very high production rates

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Seismic Characteristics of Microbial Boundstone at Tengiz and Korolev

1) Occurrence of *in situ* boundstone is often coincident with the the raised structural rim such as on the east side of Tengiz and the south side of Korolev fields. This raised rim may be a result of differential compaction between the microbial boundstone facies and the adjacent platform grainstones.

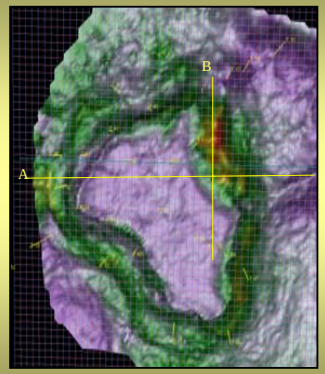
2) Seismic profiles display a chaotic to steeply dipping discontinuous progradational character within the boundstone interval. Discontinuous bursts of high amplitude frequently occur within these intervals and in some cases are indicate excess permeability due to solution enhanced fractures or karsted intervals.

3) In map view, seismic amplitude based attributes display a complex mosaic of higher seismic amplitude than observed on the platform.

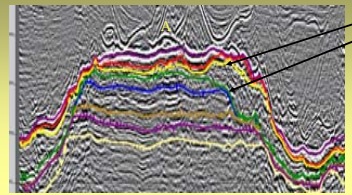
4 Isopachs of the Serpukhovian display abrupt thickening at the platfrom margins. At Tengiz, this thickening is asymmetrical with the thickest Serpukhovian near the platform edge on the east and north sides of the field. On the west side of the field the isopach thicks are located well down the flank.

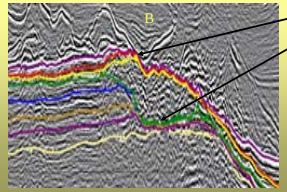
5) There are apparent slump scars and other evidence of down-slope instability within the Serpukhovian and overlying formations in the vicinity of the raised rim and platform margin area.

Top of Bashkirian Structure Perspective with Serpukhovian Isopach color drape. Greens through red indicate thick Serpukhovian dominated by boundstone and boundstone debris facies



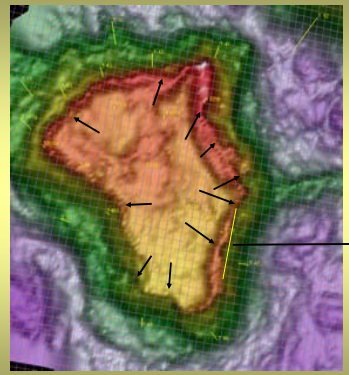
SEISMIC EXPRESSION OF BOUNDSTONE FACIES



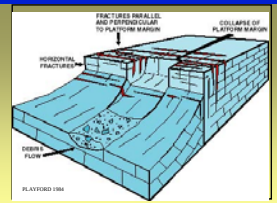


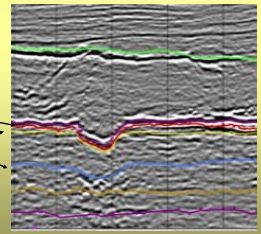
Typical Tengiz seismic profiles through areas of thick microbial boundstone facies (yellow to green interval on seismic line) showing discontinuous steeply dipping reflections on seismic profiles perpendicular to the platform boundary. Strike lines often display a chaotic reflection pattern with anomalous bursts of high amplitude. In the lower slope reflections become more parallel, higher amplitude, and continuous

EVIDENCE OF MARGIN FAILURE TENGIZ



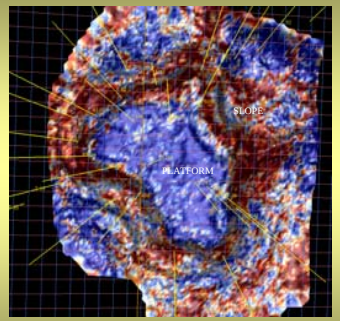
Top of Bashkirian Structure in perspective showing crescent shaped failure escarpments along the rim area at Tengiz. Morphology appears similar to carbonate margin failure described from Devonian Canning Basin Australia.





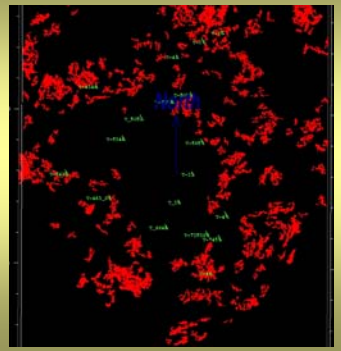
Strike profile from 3-D survey showing rim gravity failure

SEISMIC AMPLITUDE DISTRIBUTION SERPUKHOVIAN



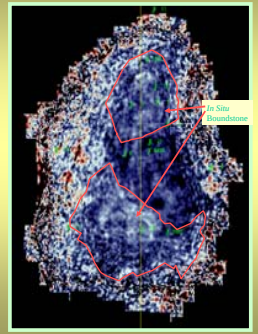
Average Peak amplitude of the Serpukhovian draped on top of structural perspective showing high amplitude mosaic appearance of the outer margin and slope facies compared to the platform

Voxel Geo-body display showing distribution of Tengiz high amplitude bursts on the rim and slope.



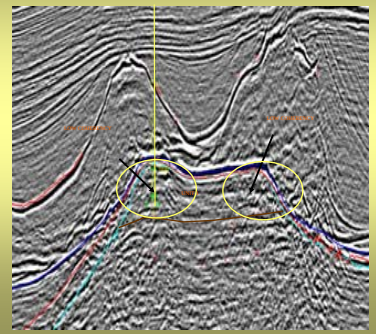
Korolev Displays Similar Seismic Characteristics to Tengiz

Amplitude attribute display showing high amplitudes as white and red (cloudy) area in map view a result of the bursts of amplitudes which are characteristic of boundstone seismic facies



A thick boundstone interval occuring at the Korolev raised rim has a chaotic seismic character.

Korolev 3882



Acknowledgements

This study was a team effort. We sincerely thank the ExxonMobil "Tengiz team" for their hard work and many discussions of all aspects of Tengiz geology. Tom Kane analyzed well production data. Ray Garber and Phil Bassant (ChevronTexaco) provided core descriptions, which were instrumental in our work. We warmly thank Jeroen Kenter (Vrije Universiteit, Amsterdam), Paul Brenckle (Consultant), Jeroen's knowledge of modern and ancient carbonate slope settings, and Paul Brenckle's biostratigraphic data were invaluable to our studies.

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