Geologic Framework for the Tengiz and Korolev Fields, Kazakhstan – Carboniferous Isolated Carbonate Platforms*

By

Paul M. (Mitch) Harris1

Search and Discovery Article #20060 (2008)

Posted June 26, 2008

*Adapted from 2000-2001 AAPG International Distinguished Lecture

1Chevron Petroleum Technology Company, Houston, TX; currently ETC, Chevron, San Ramon, CA, USA. (MitchHarris@chevron.com)

Abstract

The supergiant Tengiz field exhibits depositional features typically observed in isolated carbonate platforms but rare for the Carboniferous: extensive inner and outer platform deposits, a raised rim feature, steep platform margins, and thick flank deposits. Many of the same platform and slope features observed in Tengiz are inferred from much less well data for Korolev.

Platform Growth and Stratigraphic Framework

The Tengiz and Korolev platforms formed during the Carboniferous on the Primorskian Arch, one of several structural highs in the southeast portion of the PriCaspian Basin in western Kazakhstan. The platform edges are abrupt, showing a relatively rapid change from the platform top (platform, shoal, or platform margin) to slope environment. Platform deposition includes cycles shoaling upward from open marine packstones to shoal grainstones. A reef (microbial boundstone with scattered megafossils) is localized to a very narrow belt along the platform margin. Boundstones give way downslope to breccias and finally argillaceous lime mudstone beds. A variety of open porosity types are present; karst zones are best developed in the rim, and fractures characterize both the rim and flanks.

A hierarchy of cycles, sequences, and composite sequences is developed by integrating core and well logs with newly acquired 3D seismic data. The stratigraphic framework, although not finalized, explains many aspects of the reservoir quality. The buildup (actual thickening) of the platforms was seemingly initiated in the Devonian and accentuated greatly during Visean time. The position of the platform margins is controlled, in part, by deep-seated faults. The areal extent of both platforms generally diminished during the Carboniferous as evidenced by backstepping of the younger margins.

Key Platform Well

Tengiz well T-220, because of the great amount of continuous core taken in the well, is invaluable from the perspective of understanding the nature of deposition, stratigraphy, diagenesis, reservoir quality, and log response for the interior portion of the platform.
The upper contact of the Bashkirian is significant as it represents the demise of the shallow water platform. Three sequences of similar grainstone-dominated deposits form a composite sequence that comprises most of the Bashkirian. Four sequences recognized within the Serpukhovian form another composite sequence. The boundary between the Bashkirian and Serpukhovian is significant as it represents a major change in the style of deposition on the top of the Tengiz platform and equates with a time gap. Serpukhovian facies reflect slightly deeper water and more skeletal-rich environments. Three composite sequences are tentatively identified within the Visean (Oksky) interval; each contains three sequences consisting of grainstone-packstone cycles that are similar to those of the Serpukhovian. A portion of one sequence recognized within the upper part of the Visean (Tula) contains packstone-grainstone cycles. The difference in the character of the cycles between the Visean (Oksky)-Serpukhovian and the Bashkirian reflects changes in the nature of sea-level variations that occurred between Early and Late Carboniferous.

Porosity loss in T-220, and other Tengiz platform wells, is by calcite cementation and minor compaction. The variety of open primary and secondary pore types is a principal reason for the permeability variation that is observed within the well. Core samples are dominantly limestone with local partial dolomitization and silicification associated with tuffs or subaerial exposure.

T-220 displays more-or-less constant 15% porosity with 1-10 md permeability, separated by thin tighter intervals at sequence and cycle boundaries. Where bitumen occurs, it displays an inverse correlation with porosity (that is, bitumen is more abundant in rocks with low porosity). Samples with bitumen occur in short intervals, almost always at sequence or cycle boundaries, with long intervals in between with zero bitumen. The downhole porosity logs show an excellent match to core porosities; gamma-ray response increases where tuffs and shales are present.

Key Flank Well

Tengiz well T-47 is a flank well located off the southeast edge of the platform; it is an important well from the perspective of understanding the nature of deposition, diagenesis, reservoir quality, and log response in the flanks of the platform.

The Bashkirian through Visean (Oksky) consists of two general rock types: (1) coarse-grained (rudstones and grainstones rich in boundstone intraclasts), and (2) finer-grained (grainstones, packstones, and wackestones). Both rock types represent debris that was shed down the slope from the platform margin. The Visean (Tula) is predominantly fine-grained slope packstones. The Devonian (Famennian) consists of shallow platform grainstones and packstones.

T-47 penetrated a generally limestone stratigraphy, with three important exceptions: (1) dolomite-rich intervals with 50% to 70% dolomite in the basal Serpukhovian, and lower Visean (Tula) through top Devonian; (2) a silica-rich interval in the Visean (Tula); and (3) a barite-rich interval with 0% to 26 wt.% (17 vol.%) barite near the top Devonian. Bitumen fills 10% to 15% of the potential porosity (defined as core measured porosity plus bitumen) in most samples.

The Bashkirian through Visean (Oksky) slope deposits have open porosity of three types: isolated vugs, pores between clasts, and microfractures. The Visean (Tula) packstones are varyingly silicified, and a few small, open vugs are the only visible porosity.
Wireline logs indicate a porosity distribution that is generally consistent with the limited core data. Small, isolated, bitumen-stained vugs, fenestral pores, and microfractures remain open in a few Devonian grainstone and packstone samples.

Wireline logs indicate a porosity distribution that is generally consistent with the limited core data. Porosity from 0% and 9% typifies the section above the Devonian; porosity generally <4% is representative for the Devonian. The Visean (Oksky) slope deposits appear on an FMI log as irregular layers dipping up to 30° that are rarely continuous across the image, and thin continuous layers gently dipping way from the platform characterize the Visean (Tula) slope deposits. Irregular continuous layers with dips <5° typify the Devonian platform deposits.

Acknowledgements

I am grateful to the following coworkers for their collaboration: Michael E. Clark, Tengizchevroil, Tengiz, Kazakhstan; Raymond A. Garber, Chevron Petroleum Technology Company, Houston, TX; and Jeff. L. Warner, LA Petrophysical, La Habra Heights, CA.
GEOLOGIC FRAMEWORK FOR TENGIZ AND KOROLEV FIELDS, KAZAKHSTAN

CARBONIFEROUS ISOLATED CARBONATE PLATFORMS

AAPG International Distinguished Lecture Tour

Paul M. (Mitch) Harris
Chevron Petroleum Technology Company
Houston, Texas U.S.A.
OUTLINE OF TALK

Geological Setting

Key Platform Well

Key Flank Well

Summary
TENGIACHEVROIL
JOINT VENTURE

LOCATION MAP

Tengiz Field

Kazakhstan

Caspian Sea

30 Mi

30 Km

JV BLOCK
4000 km²

Korolev Field

Atyrau

4000 km²
TIMING OF IMPORTANT EVENTS

SALT DEPOSITION

NON-DEPOSITION

drowning

unconformity

PLATFORM BUILD-UP

TIMING OF IMPORTANT EVENTS

- Kun
- Art
- Sac
- Ass
- Vir
- Mss
- Des
- Ato/Der
- Mor
- Chs
- Mer
- Osa
- Kin
- Fam
- Frs
- Giv
- Elf

Harrand et al.
<table>
<thead>
<tr>
<th>Ma (BASE)</th>
<th>HORIZONS</th>
<th>RUSSIAN STAGES</th>
<th>RUSSIAN SERIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>311.5 (top)-312.0 312.5</td>
<td>Asatausky (Asa) Tashastinsky (Tas)</td>
<td>LATE</td>
<td>BASHKIRIAN</td>
</tr>
<tr>
<td>312.8 313.2 313.6 314.0</td>
<td>Askynbashsky (Ask) Akavassky (Ak) Syuransky (Syu) Bogdanovsky (Bog)</td>
<td>EARLY</td>
<td>EARLY MIDDLE CARBONIFEROUS</td>
</tr>
<tr>
<td>316.75 319.5</td>
<td>Zapaltyubinsky (Zap) Protvinsky (Pr)</td>
<td>LATE</td>
<td>SERPUKHOVIAN</td>
</tr>
<tr>
<td>322.25 325.0</td>
<td>Steshevsky (St) Tarussky (Tar)</td>
<td>EARLY</td>
<td></td>
</tr>
<tr>
<td>328.5</td>
<td>Venevsky (Ven) Oksky Super-horiz.</td>
<td>LATE</td>
<td>VISEAN</td>
</tr>
<tr>
<td>330.5</td>
<td>Mikhailovsky (Mik)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>332.75</td>
<td>Aleksinsky (Al)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>335.0</td>
<td>Tulsky (Tul)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>341.5 343.0</td>
<td>Bobrikovsky (Bob) Radaevsky (Rad)</td>
<td>EARLY</td>
<td></td>
</tr>
<tr>
<td>345.5 348.0</td>
<td>Kosvinsky (Kos) Kizelovsky (Kiz)</td>
<td>LATE</td>
<td></td>
</tr>
<tr>
<td>349.5 351.0 352.5 354.0</td>
<td>Cherepetsky (Ch) Upinsky (Up) Malevsky (Mal) Gumerovsky (Gum)</td>
<td>EARLY</td>
<td>TOURNAISIAN</td>
</tr>
<tr>
<td>364.5 369.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FRASNIAN DEVO NI UNCONFORMITY</td>
</tr>
</tbody>
</table>

**PLATFORM EVOLUTION**

**FAMENNIAN**

**LATE DEVONIAN**

**UNCONFORMITY**

**DROWNING**
TENGIZ WELL LOCATIONS

Tengiz Reservoir
Top Bashkirian (m)

Kilometers

Platform
Flank
KOROLEV FIELD MAP
TENGIZ 3-D SEISMIC

FLANK

PLATFORM

BASHKIRIAN

EARLY VISEAN

DEVONIAN

FLANK
TENGIZ STRATIGRAPHIC MODEL

SW

T-483

T-220

BASHKIRIAN

SERPUKHOVIAN

LATE VISEAN

EARLY VISEAN

TOURNAISIAN

DEVONIAN

T-5050

RETROGRADING

AGGRADING

FILL-IN RELIEF

RELIEF ON SB

AGGRADING

AGGRADING

AGGRADING

AGGRADING

MAJOR SB

DROWNING

FLANK DEPOSITION

PROGRADING

BACKSTEP

T-5056

T-41

(~ 5X vertical exaggeration)
**TENGIZ GEOLOGIC MODEL**

August 2000 - Structural Datum

- **T/BASH**
  - Minor Flank
  - Generally Retrogradational

- **T/SERP**
  - Serp Dominates Flank
  - Aggrading Then Prograding Margin
  - Major Backstep

- **T/E. VISEAN**
  - Relief on Sequence Boundary
  - Aggrading Platform
  - Minor Margin/Slope

- **T/TOURN**
  - Famennian Platform Smaller
  - Platform Margin/Slope Possible

- **T/DEV**

- **~312 MA**
  - ~314 MA
  - ~337 MA
  - ~354 MA

Improved Reservoir Quality

TENGIZ GEOLOGIC MODELS

Improved Reservoir Quality

August 2000 - Structural Datum
**DEPOSITIONAL MODEL**

- **Highstand Facies**
  - Platform Margin (Reef and Grainstone)
  - Slope (Breccias)
  - Toe-of-Slope (Mud and Grainstone Debris)

- **Transgressive Facies**
  - Shoal (Grainstone)
  - Deposition on Slope

- **Lowstand Facies**
  - Karst
  - Minor Deposition on Slope

- **Platform**
  - Fully Developed Carbonate Platform Top, Margin and Flanks
  - Deep Platform

- **FLANK**
  - Shallow Platform (Cyclic Packstone and Grainstone with Crinoids, Algae and Locally Reefs)
  - Packstone with Crinoids, Brachiopods, and Locally Reef Mounds

- **Non-Deposition**
  - Subaerial Exposure
  - Calcrete
- GOOD INTERPARTICLE POROSITY IN PLATFORM
- PLATFORM CYCLES THIN, POTENTIALLY DISCONTINUOUS
- MINOR EQUANT CALCITE FILLING INTERPARTICLE POROSITY
- BEST POROSITY AND MATRIX PERMEABILITY IN PLATFORM FACIES
- BEST PERMEABILITY IN PLATFORM MARGIN AND SLOPE BOUNDSTONES - SURFACE - BURIAL KARST AND/OR TECTONIC FRACTURES
- BITUMEN FILLED POROSITY INCR. TOWARD PLATFORM MARGIN AND SLOPE
STRATIGRAPHY AND ROCK TYPE
PLATFORM CYCLE

Grainstone
15.8%
3.9 mD

Packstone
4.5%
0.06 mD
BASHKIRIAN CYCLE

TOP

SKELETAL - COATED GRAIN GRAINSTONE

4 MM ACROSS FIELD

BOTTOM
SERPUKHOVIAN CYCLE

SKELETAL GRAINSTONE AND PACKSTONE

4 MM ACROSS FIELD
UPPER VISEAN CYCLE

TOP

SKELETAL - PELOID GRAIN-PACKSTONE

4 MM ACROSS FIELD

BOTTOM
SUMMARY OF PLATFORM DIAGENESIS

EARLY DIAGENESIS

RIM AND SYNTAXIAL CEMENTS
MOLDIC POROSITY AND MICROPOROSITY
EQUANT CALCITE CEMENTS
KARST - VUGS, BRECCIA, AND MICROFRACTURES

BURIAL DIAGENESIS

MICROFRACTURES AND MICROSTYLOLITES
MICROVUGGY POROSITY AND MICROPOROSITY
CALCITE, DOLOMITE, SILICA, OR ANHYDRITE CEMENTS
BITUMEN EMPLACEMENT
AUTHIGENIC PYRITE
CROSS-CUTTING FRACTURES
COARSE CALCITE IN VUGS, VEINS, AND FRACTURES
### MOSCOVIAN (?) SEQUENCE
- Microporosity in grains and matrix, minor interparticle porosity, and an open microfracture.

### UPPER BASHKIRIAN SEQUENCE
- **B1** - Solution-enlarged interparticle and intraskeletal porosity, microfractures, microporosity in grains and between cement crystals.

### LOWER BASHKIRIAN COMPOSITE SEQUENCE
- **B2** - Solution-enhanced interparticle and intraskeletal porosity, moldic porosity, microporosity in grains, local microvuggy and microfracture porosity.
- **B3** - Cement-reduced interparticle, moldic, microfracture, and microvuggy porosity; microporosity in grains.
- **B4** - Solution-enlarged interparticle, intraskeletal, vuggy, moldic, and microfracture porosity; microporosity in grains.

### SERPUKHOVIAN COMPOSITE SEQUENCE
- **S1** - Solution-enhanced interparticle, microvuggy, moldic, and microporosity in grains.
- **S2** - Solution-enhanced interparticle, intraskeletal, moldic, microvuggy and microfracture porosity; microporosity in grains and matrix.
- **S3** - Interparticle, intraskeletal, moldic, microfracture, and microvuggy porosity; microporosity in grains and matrix.
- **S4** - Solution enhanced interparticle, intraskeletal, moldic microfracture, and microvuggy porosity; microporosity in matrix and grains.

### UPPER VISEAN (OKSKY) COMPOSITE SEQUENCE
- **VO1** - Locally solution-enhanced interparticle and intraskeletal porosity; moldic, microfracture, and microvuggy porosity. Microporosity in grains and matrix.
- **VO2** - Interparticle and intraskeletal porosity, locally solution enhanced; moldic and microvuggy porosity; microporosity in matrix and peloids.
- **VO3** - Interparticle, moldic, and intraskeletal porosity; microporosity in grains and matrix; microvuggy and microfracture porosity.

### MIDDLE VISEAN (OKSKY) COMPOSITE SEQUENCE
- **VO4** - Solution-enhanced interparticle, intraskeletal, microvuggy, and microfracture porosity; microporosity in grains.
- **VO5** - Solution-enhanced interparticle, intraskeletal, local microvuggy porosity; microporosity in grains and matrix.
- **VO6** - Interparticle, intraskeletal, and moldic porosity; microporosity in grains and matrix.

### LOWER VISEAN (OKSKY) COMPOSITE SEQUENCE
- **VO7** - Solution-enhanced interparticle to microvuggy porosity.
- **VO8** - Interparticle, intraskeletal, moldic and microfracture porosity; microporosity in grains.
- **VO9** - Intraskletal, moldic, and interparticle porosity.

### UPPER VISEAN (TULA) COMPOSITE SEQUENCE
- **VT1** – Intraskletal, moldic, and microfracture porosity; also microporosity in grains.
STRATIGRAPHY AND
RESERVOIR QUALITY
BITUMEN AND POROSITY

BITUMEN (vol. % of Rock) vs. Potential Porosity (% BV)

- 100% Filled
- 75% Filled
- 5% Filled

T-220 All Data
N = 1,420 Corrected Data

N = 1,420 Corrected Data
BASHKRIAN RESERVOIR QUALITY AND MINERALOGY
SERPUKHOVIAN RESERVOIR QUALITY AND MINERALOGY

[Graph showing various data points and mineral abundances]
UPPER VISEAN RESERVOIR QUALITY AND MINERALOGY
PLATFORM POROSITY DISTRIBUTION
PLATFORM POROSITY DISTRIBUTION

CYCLES

T905C

T220
WELL TIE TO 3D SEISMIC
DEPOSITIONAL MODEL

**Highstand Facies**
- Shoal (Grainstone)
- Platform Margin (Reef and Grainstone)

**Transgressive Facies**
- Slope (Breccias)
- Toe-of-Slope (Mud and Grainstone Debris)
- Deposition on Slope

**Lowstand Facies**
- Karst
- Minor Deposition on Slope

**Deep Platform**
- Deep Platform

**Shallow Platform**
- Shallow Platform (Cyclic Packstone and Grainstone with Crinoids, Algae and Locally Reefs)
- Fully Developed Carbonate Platform Top, Margin and Flanks

**Subaerial Exposure**
- Calcrete
- Non-Deposition
OUTCROP OF PLATFORM FLANK

ASTURIAS, SPAIN
FLANK FACIES DISTRIBUTION

BOUNDSTONE AND GRAINSTONE

DETRITAL BRECCIA
DEPOSITIONAL MODEL FOR SLOPE
STRATIGRAPHY AND ROCK TYPE

- All Tengiz-47
- Artinskian
- Bashkirian
- Serpukhovian
- Visean (Oksky)
- Visean (Tula)
- Devon. Shallow
- Devonian Deep
LOWERSLOPEGPACKSTONES

- SILICA REPLACEMENT
- FRACTURE
SLOPE RESERVOIR QUALITY

Porosity (%)

Permeability (md)

Fractured

Slope Reservoir Quality

- Bashkirian
- Serpukhovian
- Visean (Oksky)
- Visean (Tula)
BITUMEN AND POROSITY

Potential Porosity (%)

Bitumen (vol. %)

- All Tengiz-47
- Bashkirian

100% Filled
30% Filled
10% Filled
SLOPE
DIAGENESIS

BURIAL
(HYDROTHERMAL?)

DOLOMITE
SILICA
BARITE
URANIUM

Abundance (wt.%)
### VUGS IN FLANK WELLS

<table>
<thead>
<tr>
<th>IMAGE_STATIC.IMVI</th>
<th>DEPTH METRES</th>
<th>IMAGE_DYNAMIC.IMVI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4556</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4557</td>
<td></td>
</tr>
</tbody>
</table>

Large Vug
FRACTURES IN FLANK WELLS

Fractures
Fracture with whole mud invasion
SUMMARY POINTS

- Carboniferous Isolated Carbonate Platforms with Steep Flanks
- Platform Growth Viewed in Sequence Stratigraphic Context
- Reservoir Quality in Platform Controlled by Stratigraphy and Limited Diagenesis
- Reservoir in Flanks Related to Fracturing and Diagenesis