Cellular Model Construction

Basic Workflow

1. Build structural model (s)
2. Determine layering (169 total)
3. Block lithofacies to wells
4. Model lithofacies (SIS)
5. Block porosity to wells
6. Model porosity (SGS)
7. Calculate permeability and Sw with transforms
8. Calculate OGIP

Model Dimensions:

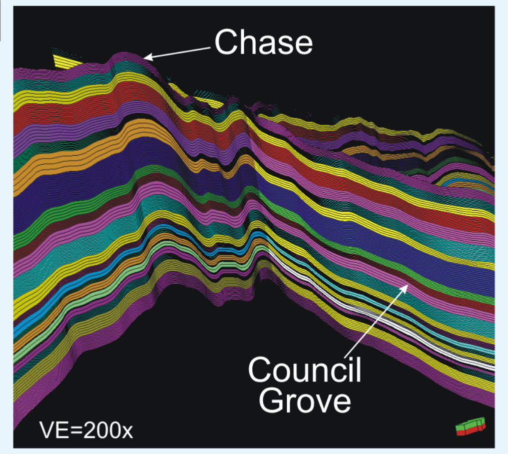
XY = 660'
Z = 2-5' mean (variable)
77x130 miles
10,100 sq mi
169 layers
X = 618 rows
Y = 1040 columns
108 million cells

Build Structural Model

Model split stratigraphically

The extremely large area (10,042 sq mi), small XY cells (660 x 660 ft) and relatively thin layers (169 layers, 3.3 ft-thick average) resulted in a 108 million-cell model that required subdividing the model into parts due to computational limitations.

- Six models in single project (three in Chase, three in Council Grove) bounded by seven "framework" horizons
- Built with the same starting architecture and layering
- Models capable of being viewed simultaneously (hardware limited)



Model Architecture

Intersecting cross-sections illustrate 169 conformable layers in 24 zones from six 3D grids combined. Marine zones are more finely layered than continental intervals.

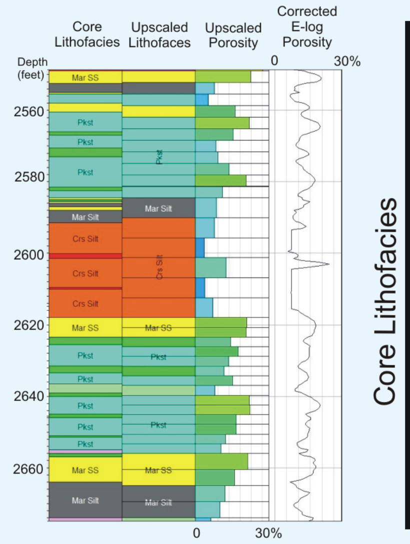
Layering determined by node well statistics

ZONE	zero h count	Mean h	Layer h	#layers	Avg h	
HRNGTN		25.6	3	9	2.8	
KRIDER		34.7	3	12	2.9	
ODELL		16.4	4	4	4.1	
WINF		34.1	3	11	3.1	
GAGE		25.8	4	6	4.3	
TWND		40.9	3	14	2.9	maximum
B/TWND		15.6	4	4	3.9	
FTRLY		70.8	3	14	5.1	
MATFIELD		19.7	4	5	3.9	
WREFORD		22.9	3	8	2.9	
A1_SH		17.5	4	4	4.4	
A1_LM		43.0	3	14	3.1	
B1_SH		15.1	4	4	3.8	
B1_LM	3	15.1	2	8	1.9	
B2_SH		9.2	4	2	4.6	
B2_LM	13	11.1	2	6	1.8	
B3_SH		11.9	4	3	4.0	
B3_LM	39	6.4	2	3	2.1	
B4_SH		9.5	4	2	4.7	
B4_LM		8.5	2	4	2.1	
B5_SH		5.6	4	2	2.8	minimum
B5_LM		20.8	2	10	2.1	
C_SH		23.6	4	6	3.9	
C_LM		56.2	3	14	4.0	maximum
		560		169		

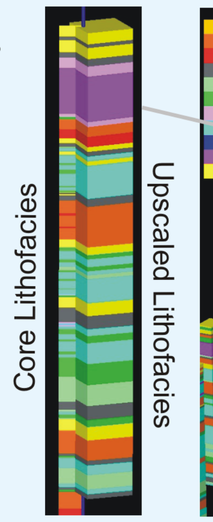
24 zones covering 13 cycles. Two ½-cycles combined with adjacent ½-cycle in Herington and Matfield.

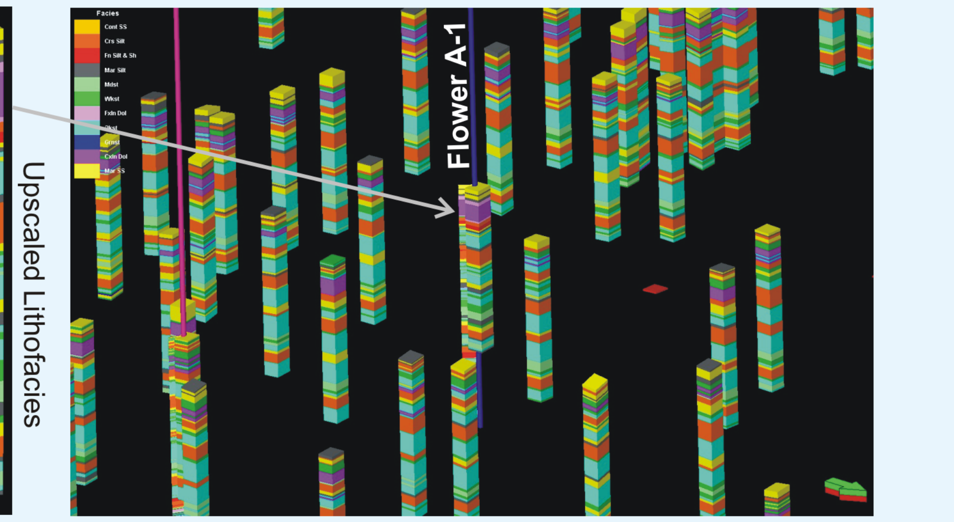
Populate Cells with Properties

"Block" lithofacies and porosity to node wells (upscale)



Flower A-1; Winfield, Gage, Towanda, Holmesville





Chase group, Flower A-1 core lithofacies, otherwise upscaled predicted lithofacies in node wells

Porosity and lithofacies are upscaled at the wells from 0.5 feet to an average 3.3 (0.15 m to 1 m) according to the layers. Lithofacies were assigned by "most" criteria and porosity is arithmetically averaged.

Populate Model with Lithofacies and Porosity: Voxel-based methods were chosen over object-based methods for facies due to relatively dense well control and geometry of lithofacies bodies being modeled (thin and laterally extensive). We used a limited number of variograms and broad ranges,sequential indicator simulation for lithofacies and sequential gausian simulation for porosity. Due to the well density the modeling was nearly deterministic.

Lithofacies proportions

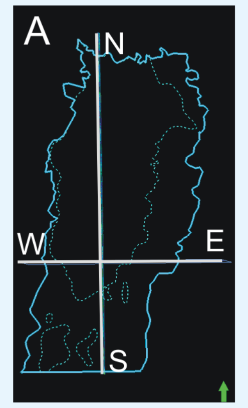
Lith. Code	Thickness: 0.5 feet; Source: Actual (Training)	0.5 feet, NNet Predicted (Node Wells)	Variable*, Upscaled (Node Wells)	Variable*, Modeled (SIS) (All cells)
0	5.6%	2.2%	1.0%	1.1%
1	23.3%	19.7%	17.0%	16.7%
2	12.9%	9.6%	7.1%	6.7%
3	7.5%	9.6%	9.0%	9.1%
4	5.4%	4.3%	3.6%	3.9%
5	14.5%	20.1%	22.2%	22.5%
6	2.8%	4.9%	3.9%	3.6%
7	14.7%	24.7%	25.9%	25.2%
8	2.7%	0.2%	0.2%	0.2%
9	5.6%	1.4%	3.8%	3.8%
10	5.4%	3.4%	6.3%	7.1%
Count (N)	8,540	993,146	183,949	107,765,147

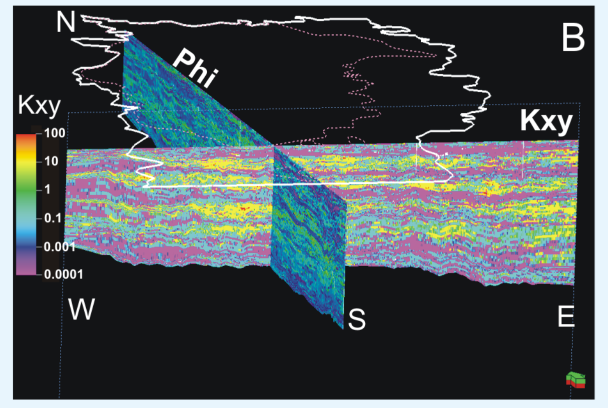
*Average mean layer h = 3.3 feet.
Range of mean h = 1.9 - 5.2

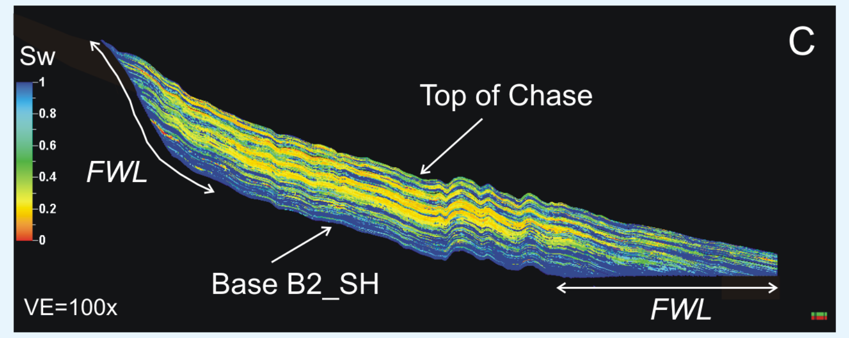
Properties and their Distribution

Once the model is populated with lithofacies and porosity, and the height above the FWL is established by cell, other critical properties may be calculated on a cellular basis using empirical relationships established in the core petrophysics portion of the study:

- Permeability (Kxy, Kz) based on porosity and lithofacies
- Water saturation based on porosity, lithofacies and height above FWL
- Knowing Sw, OGIP for BHP = 450 psi (3.1 MPa) and compressibility index (Z) = 0.92







Property distribution for Hugoton model in cross-section

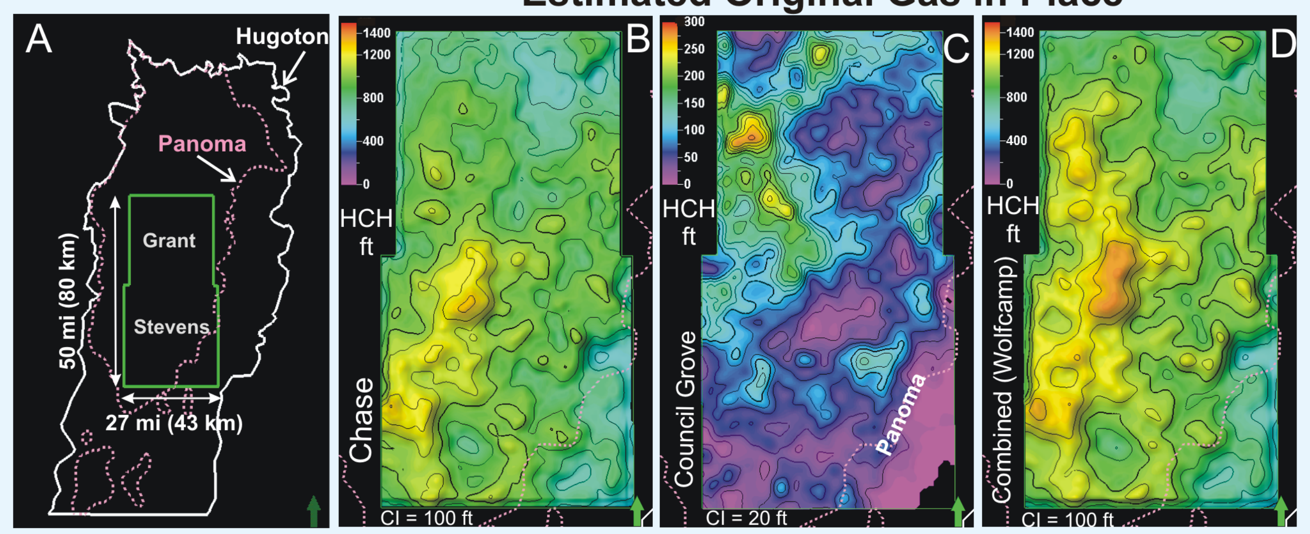
(A) Location of cross-sections.

(B) Chase group stratigraphic cross-section (datum is top of Chase). Horizontal permeability is shown in west-east section and porosity (0-30%, yellow is 22%) is in the north-south section.

(C) Chase Group through Easly Creek shale (B2_SH, Council Grove) water saturation. Free water level is the base of the cross-section on the west and east side and the base of the Easly Creek (B2_SH) in the middle where the FWL is lower in the stratigraphic column (not able to display all models simultaneously). FWL crosses stratigraphic boundaries in both updip and downdip positions.

Highest permeability (Kxy) and porosity (Phi), and lowest water saturation (Sw) is found in marine carbonates and sandstones. Continental siltstones separating the marine carbonates are the intervals with low Kxy and Phi, and higher Sw.

Estimated Original Gas in Place



Grant and Stevens counties Kansas, are the two most prolific gas producing counties in the study area. Map views to the right are model estimates for volumetric original gas in place (OGIP) in hydrocarbon height (HCH) at surface conditions

Chase Group OGIP Areas with highest productivity (yellow) coincides with excellent storage and flow conditions associated with the Krider dolomitized grainstone shoal illustrated in map view below.

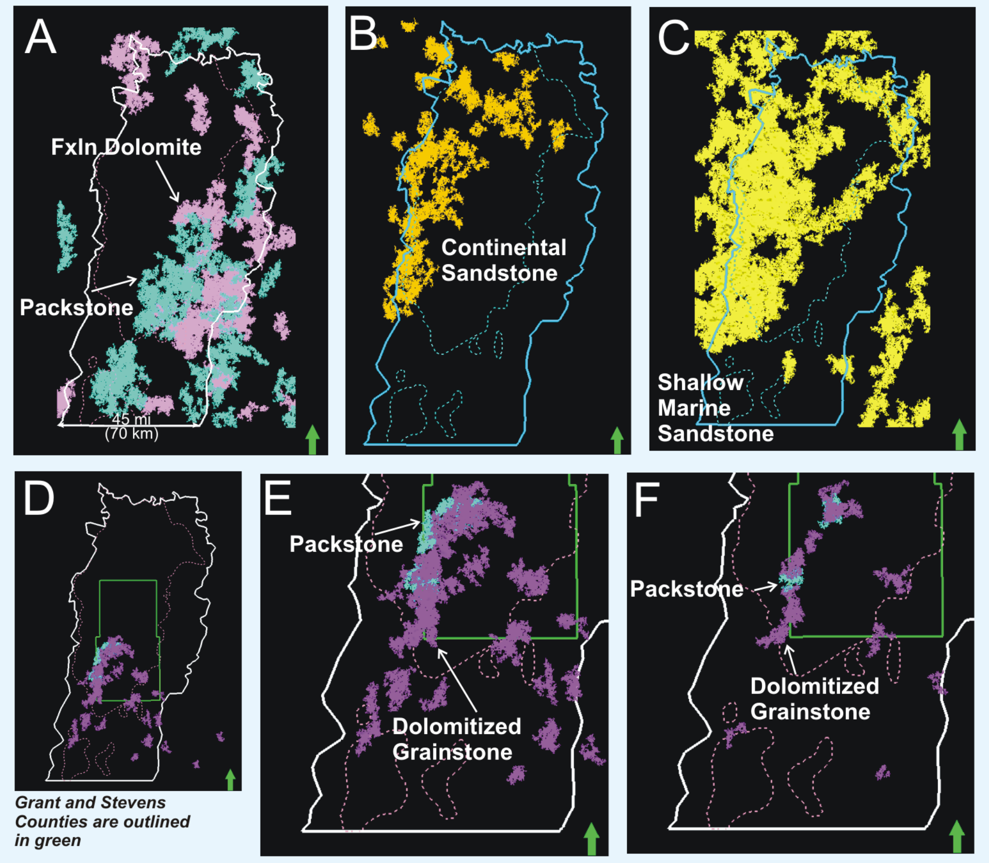
Council Grove Group OGIP *(note scale change)* Distinctive rectilinear pattern may be related to basement fractures and faults that do not extend through the Permian but may have influenced lithofacies distribution. Edge of "Panoma" parallels zero GIP edge.

Wolfcamp OGIP (Combined Chase and Council Grove). Pattern for the Wolfcamp is primarily a function of the Chase gas distribution. Only 11% of Wolfcamp gas is attributed to Council Grove wells in Kansas.

Distribution of Lithofacies in Hugoton Model

Lithofacies and property distribution in the 3D Hugoton cellular geomodel presented here on a larger scale and with finer resolution, are consistent with earlier work on the Hugoton (Garlough and Taylor, 1941; Hubbert, 1953; Pippin, 1970; Parham and Campbell, 1993; Fetkovitch, et al., 1994; Oberst et al., 1994, Seimers and Ahr, 1990; Olson et al., 1997; Heyer; 1999; Sorenson, 2005).

- Full-field geomodel reveals facies and property patterns not easily viewed at smaller scales.
- Continental rocks are thickest and marine carbonate intervals thin or pinch out at Hugoton's western updip margin and the relationship is nearly reciprocal basinward.
- Important reservoir lithofacies (grain supported carbonate, dolomite, marine and continental sandstone) are laterally extensive and the marine carbonates, the primary pay zones, are separated by laterally continuous continental siltstone with poor vertical transmissibility.



Grant and Stevens Counties are outlined in green

One of the more striking aspects of the model from a reservoir perspective is the demonstration of lateral continuity in the lithofacies illustrated county-scale "connected volumes" of the more significant reservoir lithofacies that are sub-parallel to depositional strike and the field margin.

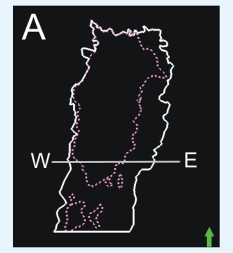
(A) Thirty largest connected volumes in Crouse limestone (B1_LM) packstone, packstone-grainstone (L7, blue) and fine-crystalline dolomite (L6, pink) having porosity > 8%.

(B) Fifteen largest connected volumes in the Speiser shale (A1_SH) continental sandstone (L0) with porosity > 12%.

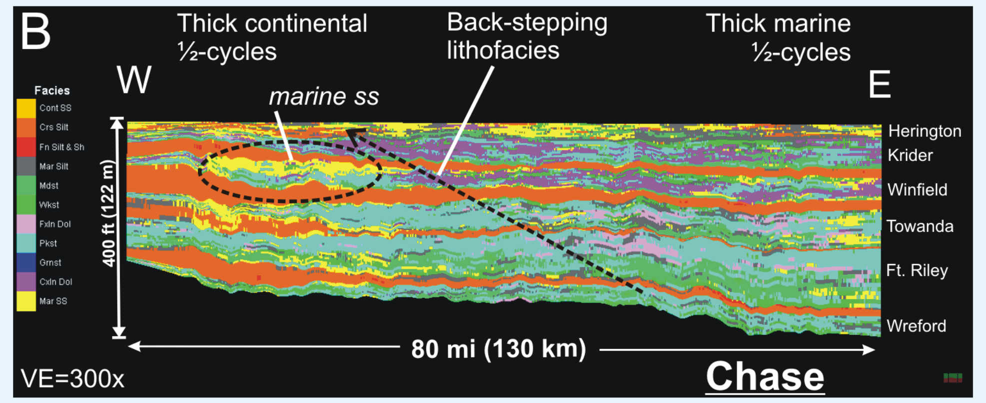
(C) Twenty largest connected volumes of marine sandstone (L10) having porosity > 15% in the Upper Chase.

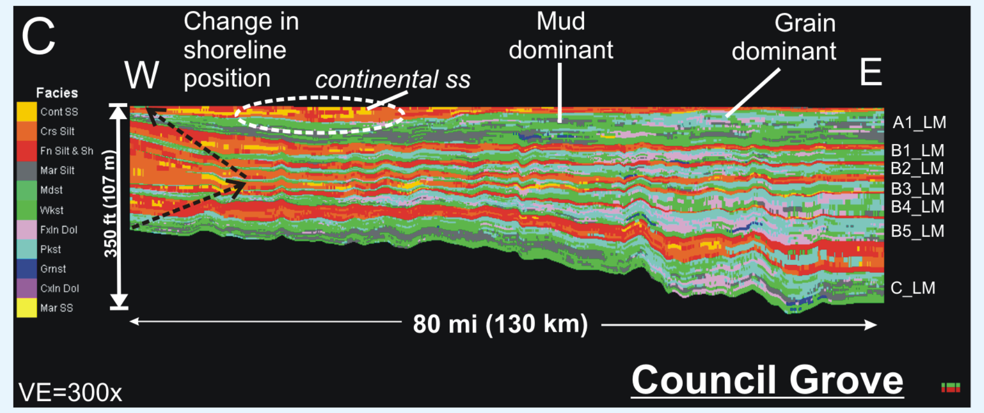
(D) Top 20 connected volumes for Krider packstone, packstone-grainstone (L7, blue) and coarse-crystalline dolomite (L9, purple) having porosity > 16%. **(E)** Enlarged area of D. Packstone actually underlies the dolomitized grainstone in a stacked shoal system.

(F) Same as E except for porosity > 18%.



Stratigraghic Cross Sections of Chase and Council Grove

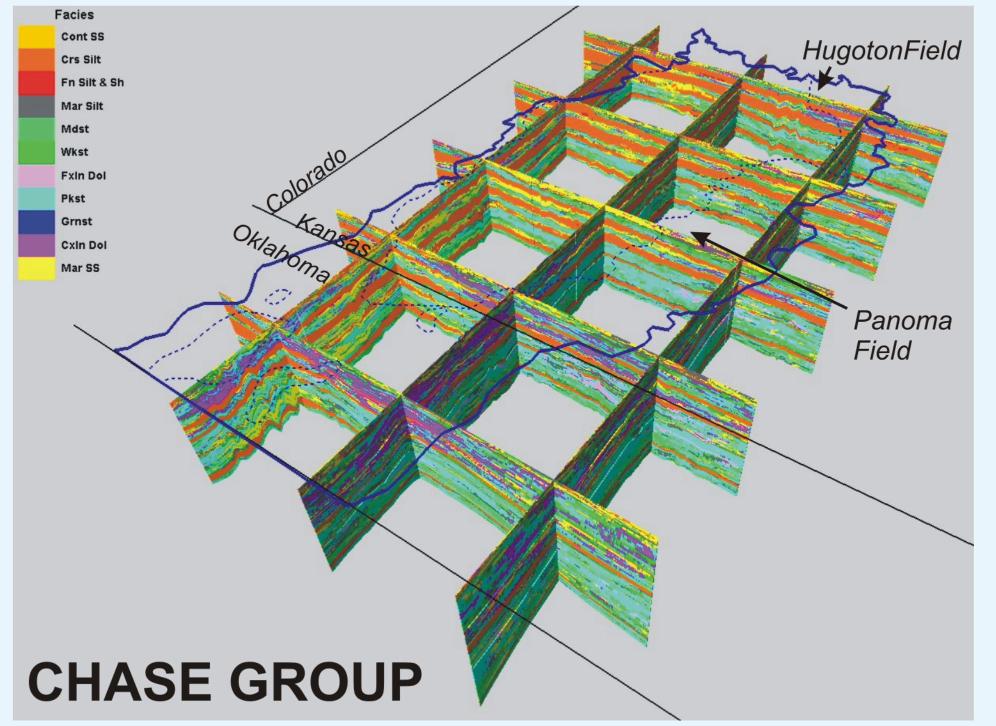




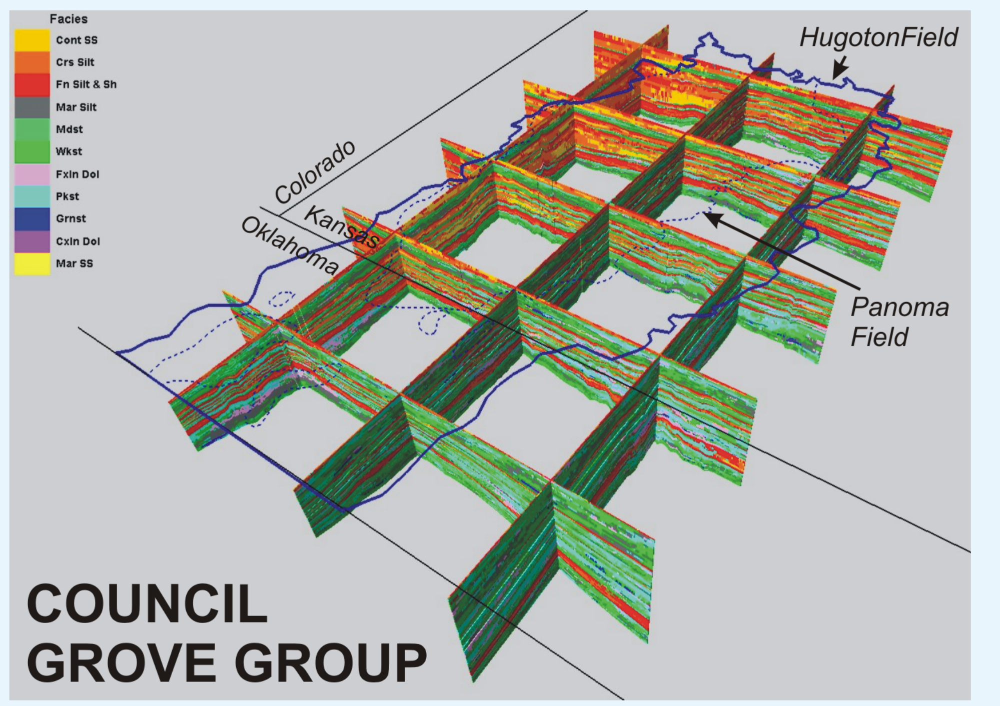
Lithofacies in stratigraphic cross-sections across the Hugoton shelf (A). Cross-sections are 10-15 degrees from being dip sections and are hung on the top of the Chase **(B)** and the Council Grove **(C)**. Some key observations can be made:

1) In both the Chase and Council Grove, continental half-cycles (yellow-orange to red lithofacies) are thickest at the west field margin and thin basinward (southeasterly). The pattern for the marine half-cycles is the opposite and somewhat reciprocal relationship with the continental half-cycles.
2) Back-stepping pattern in lithofacies distribution from one marine cycle to the next in the Chase.
3) Three Council Grove marine half-cycles "pinch out" near the west field margin, marking a paleo-shoreline that appears to then move northwesterly (landward) up section.
4) Trend in carbonate rock texture from mud dominated (landward) to grain dominated (basinward), especially in the Council Grove.

Large-scale sedimentation patterns and distribution of resultant lithofacies (at the cycle scale) is largely a function of the position on the shelf and reflect the interaction of shelf geometry, sea level, and possibly, the proximity to siliciclastic sources. Lithofacies distribution and cycle stacking patterns at larger scales may be a function of higher order cyclicity and a shift from icehouse to green house conditions (upward) during the Lower Permian



Full-field scale 3D model provides unprecedented views of sedimentation patterns through time on the stable Hugoton shelf (or gently dipping ramp) during the shift from icehouse to green house conditions (upward) in the Lower Permian



Gas in Place, Differential Depletion, and Remaning Gas

Estimation of OGIP using the matrix capillary pressure method employed in this study is sensitive to the position of the FWL. We have focused on the central portion of the field, Grant and Stevens Counties, where there is greatest confidence in the FWL. This is also the most productive area in the study. The model OGIP for the two counties is 21.8 tcf (0.62 trillion m^3), mostly in the Chase (see table). Cumulative gas production is 14.1 tcf (0.4 trillion m^3) or 65% of calculated OGIP, slightly low compared to earlier work by others. For the Chase in Kansas, Oberst et al. (1994) estimated OGIP volumetrically at 31.1 tcf (0.88 trillion m^3), whereas Olson et al. (1997) placed it at 34.5-37.8 tcf (0.98-1.1 trillion m^3). Since their estimates were for different reservoir volumes (Chase in Kansas versus Chase and Council Grove in two counties) we cannot compare directly, but assuming similar reservoir performance we can compare the estimates on the basis of production efficiency. The ratio of Chase cumulative production to date (24.8 tcf, 0.7 trillion m^3) to OGIP is 79.7% by Oberst et al. (1994) and 65.6-71.9% by Olson et al. (1997). We estimate higher OGIP than either.

ORIGINAL (volumetric) / REMAINING

Group	Zone	OGIP (BCF)	OGIP (10^9 m^3)	HCPV (BCF)	HCPV (10^9 m^3)	*WHSIP (psig)	Percent Depleted	GIP (BCF)
CHASE	Herington	1,210	34.3	37.5	1.06	40	91%	114
	Krider	2,755	78.0	85.5	2.42	20	95%	130
	Odell	285	8.1	8.9	0.25	40	91%	27
	Winfield	3,171	89.8	98.4	2.79	40	81%	597
	Gage	784	22.2	24.3	0.69	30	81%	148
	Towanda	4,575	129.6	142.0	4.02	150	65%	1,615
	Holmesville	647	18.3	20.1	0.57	200	53%	305
	Ft. Riley	4,906	138.9	152.3	4.31	200	53%	2,309
	Matfield	120	3.4	3.7	0.11	280	34%	79
	Wreford	923	26.1	28.7	0.81	240	44%	521
COUNCIL GROVE	A1_SH	314	8.9	9.7	0.28	300	29%	221
	A1_LM	498	14.1	15.5	0.44	300	29%	352
	B1_SH	75	2.1	2.3	0.07	300	29%	53
	B1_LM	101	2.8	3.1	0.09	300	29%	71
	B2_SH	8	0.2	0.3	0.01	300	29%	6
	B2_LM	143	4.1	4.4	0.13	50	88%	17
	B3_SH	56	1.6	1.7	0.05	300	29%	40
	B3_LM	32	0.9	1.0	0.03	350	18%	26
	B4_SH	65	1.8	2.0	0.06	300	29%	46
	B4_LM	21	0.6	0.7	0.02	100	76%	5
	B5_SH	7	0.2	0.2	0.01	250	41%	4
	B5_LM	109	3.1	3.4	0.10	100	76%	26
	C_SH	4	0.1	0.1	0.00	300	29%	3
	C_LM	19	0.5	0.6	0.02	350	18%	16
	TOTAL	20,825	589.7	646.4	18.3		68%	6,725

Current Zone Pressure: LOW / MID / HIGH

Target

*Preliminary estimate based on limited pressure data

Pressure by Zone

Group	Zone	1994 Science Well DST-SIP psi (kPa)	Composite psi (kPa)	2005 Replacement Well XPT-SIP* psi (kPa)
CHASE GROUP	Herington	120 (830)	104 (720)	19 (130)
	Krider	88 (610)		21 (145)
				30 (210)
	Winfield SS	105 (720)		141 (970)
	Winfield LS	121 (830)		217 (1500)
	Towanda	230 (1590)		165 (1140)
	U. Ft. Riley	>400 (2750)		192 (1320)
	Florence	398 (2740)		265 (1830)
	Wreford	372 (2570)		219 (1510)
COUNCIL GROVE GROUP	A1_LM	400 (2760)	156 (1080)	nt
	B1_LM	350 (2410)		nt
	B2_LM	131 (900)		nt
	B3_LM	368 (2540)		386 (2660)
	B4_LM	215 (1480)		nt
	B5_LM	160 (1100)		348 (2400)

Zone Pressure: LOW / MID / HIGH

Pressures by zone for two relatively closely spaced wells. Well drilled in 1994 was done so with foam. Pressures are 24-hr shut-in pressures from drill stem tests. Well drilled in 2005 is located 6 mi (10 km) north of the earlier well and pressures were recorded in an open hole by a repeat formation tester. Differential zonal depletion is readily apparent in both wells, a phenomena recognized by earlier workers (Ryan et al, 1994; Oberst et al, 1994; Fetkovich et al, 1994). Project partners have made a concerted effort to acquire zone pressure data, previously available in a limited number of wells. Using these data, we can make very preliminary estimates of remaining GIP by zone. Assuming the OGIP is correct, 70% of remaining gas is contained by four zones in the middle of the Wolfcamp, zones with relatively low permeabilty that are not being efficiently produced.

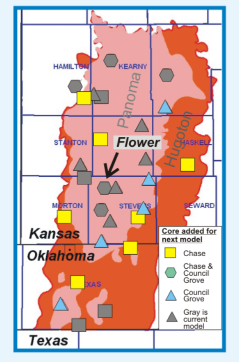
Conclusions:

The 100+ million cell, 3D geologic and petrophysical property geomodel of the Hugoton demonstrates application of a detailed reservoir characterization and modeling workflow for a giant field.

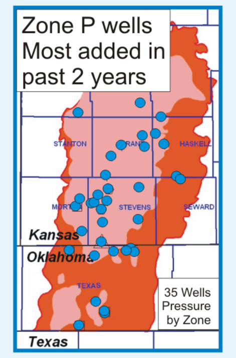
- Core-based calibration of neural net prediction of lithofacies using wireline log signatures, coupled with geologic-constraining variables, facilitates construction of accurate lithofacies models at well- to field-scales.
- Differences in petrophysical properties exists among lithofacies and illustrate the importance of integrated lithologic-petrophysical modeling.
- The model provides a tool to predict lithofacies and petrophysical properties distribution, water saturations, and OGIP; a quantitative basis for evaluating remaining GIP, particularly in low-permeability intervals; and helps direct field management and production practices that will potentially enhance ultimate recovery.
- The reservoir characterization and modeling from pore to field scales provides a comprehensive lithologic and petrophysical view of a mature giant Permian gas system.

Both the knowledge gained and the techniques and workflow employed have implications for understanding and modeling similar reservoir systems

Cores added to data set



Zone P wells Most added in past 2 years



Additional Work:

The work presented is part of an ongoing study that includes another iteration of the Hugoton Geomodel.

- Core data from an additional 13 wells provides a larger training set for facies estimation.
- More rigorous variogram analysis is being undertaken.
- Free water level estimates will be refined in certain areas.
- The relationship of zone pressures to stratigraphy, lithofacies, and rock properties may aid in estimating remaining gas by zone, field-wide.
- Additional simulation studies.

Future?

Modify wellbore and hydraulic fracture configuration to provide better access to remaining reserves that might not be produced with current configurations.

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OXY USA, Inc.
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