PS Subsurface Characterization of the Depositional System for the Paleocene Raton Formation, New Mexico and Colorado, USA*

J. R. Pisel[1] and T. Wawrzyniec[1]

Search and Discovery Article #50639 (2012)**
Posted July 3, 2012

*Adapted from poster presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012

[1]Western State College of Colorado, Gunnison, CO (jessepisel@gmail.com)

Abstract

The Raton Formation lies within the Raton Basin, which spans the Colorado-New Mexico border within the foreland of the Sangre De Cristo Range. The formation consists of sandstone, shale, coal, and conglomerates that were deposited within a closed intermountain basin and is now an important target for coal bed methane within the region. Foreland subsidence in the Raton Basin accommodates the deposition of four key formations; the Cretaceous Trinidad Sandstone, the Upper Cretaceous Vermejo Formation; the Paleocene Raton and Poison Canyon Formations. The Raton Formation is notable for the discovery by C. Pillmore who found that the formation contains the global K-T boundary iridium layer. The development of coal bed methane within the Raton Formation has provided a great deal of new subsurface data, which is the basis of this research. The goal is complete high-resolution correlations between available data to evaluate the influence of orogenic uplift to the west on sedimentation patterns as well as the extent and importance of a regional unconformity that persists within the western part of the basin. To the east, the section is conformable, which could be interpreted as a shifting and east directed broadening of the Raton Basin as a function of the growing orogenic wedge to the west. Alternatively, uplift of the western margin of the basin may have been driven by eastward migration of the deformation front. In the case of the latter one would expect to see evidence of sedimentary bypass and erosion that varies at a local scale. For the former, the western basin may have been abandoned entirely over regional scales producing a uniform progression of depositional facies. To evaluate these models we are conducting a high-resolution correlation study of electrofacies throughout the available data. The results of which can identify key stratigraphic events to test these models. A primary issue concerning the data is that many of the sand bodies within the system are arkosic and have a strong gamma response similar to shale. This will require that we consider a range of petrophysical characteristics to accurately differentiate sand from shale.

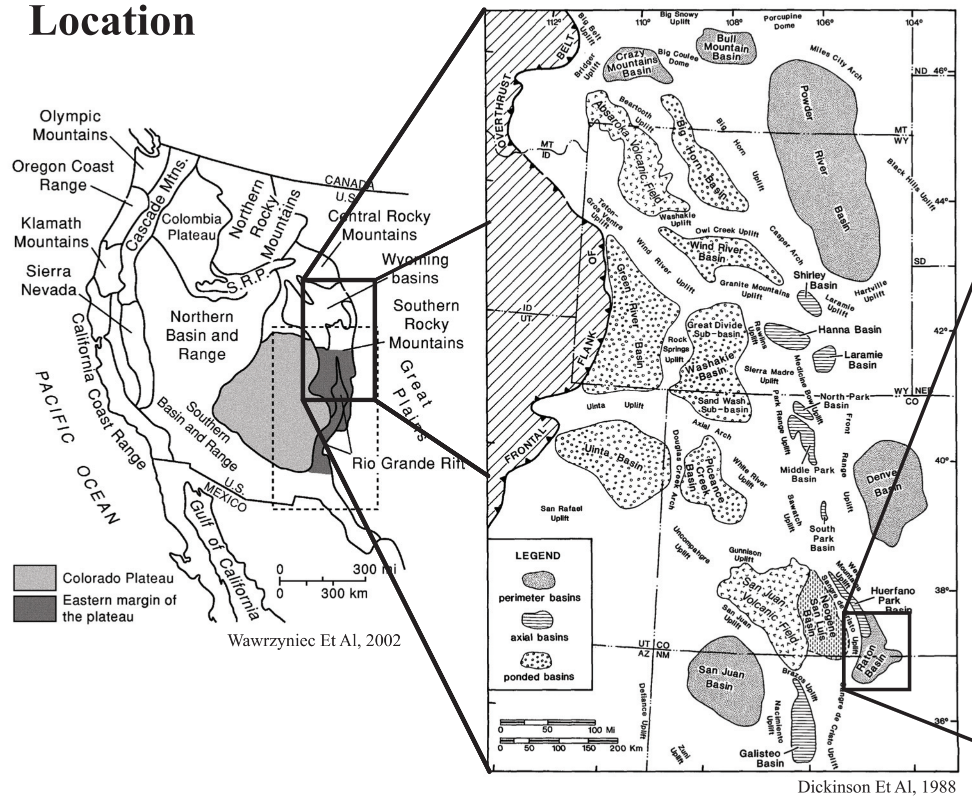
Subsurface Characterization of the Depositional System for the Paleocene Raton Formation, New Mexico and Colorado, USA

Pisel, J.R.[1] jesse.pisel@western.edu, Wawrzyniec, T[1]
[1]Department of Natural and Environmental Sciences, Western State College of Colorado, Gunnison, Colorado

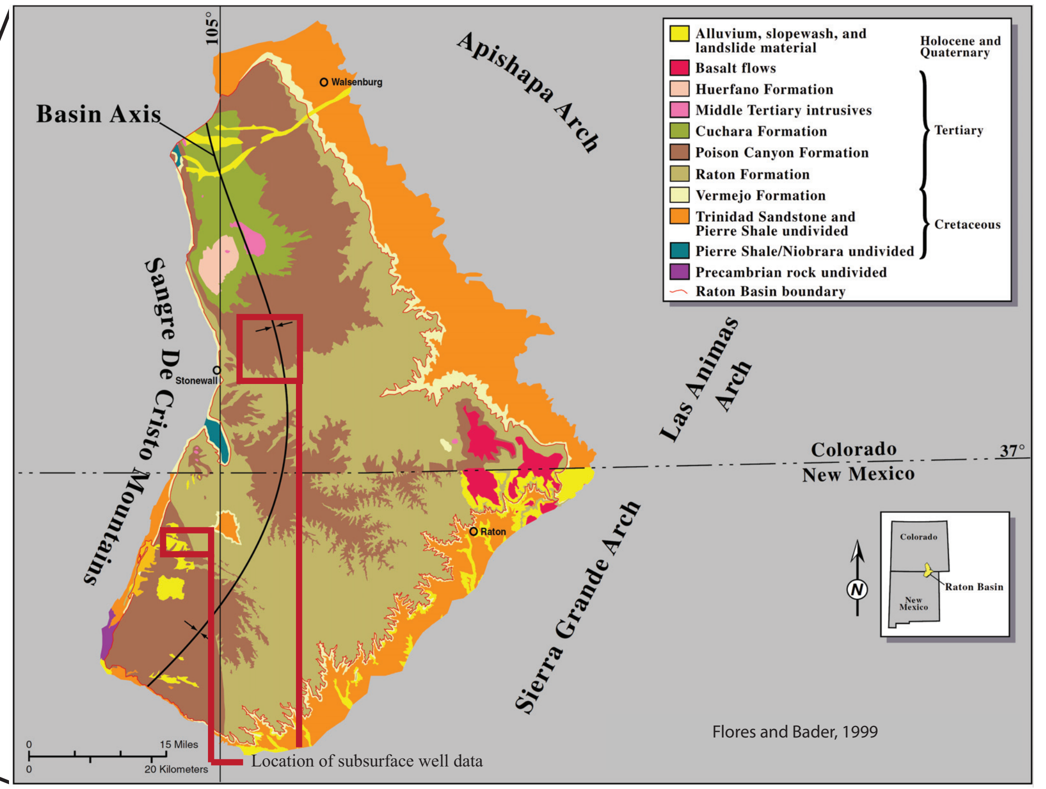
Abstract

The Raton Formation lies within the Raton Basin, which spans the Colorado-New Mexico border within the foreland of the Sangre De Cristo Range. The formation consists of sandstone, shale, coal, and conglomerates that were deposited within a closed intermountain basin and is now an important target for coal bed methane within the region. Foreland subsidence in the Raton Basin accommodates the deposition of four key formations; the Cretaceous Trinidad Sandstone, the Upper Cretaceous Vermejo Formation; the Paleocene Raton and Poison Canyon Formations. The Raton Formation is notable for the discovery by C. Pillmore who found that the formation contains the global K-T boundary iridium layer. The development of coal bed methane within the Raton Formation has provided a great deal of new subsurface petrophysical data, which is the basis of this research. The goal is complete high-resolution correlations between available data to evaluate the extent and importance of a regional unconformity that persists within the western part of the basin. To the east, the section is conformable, which could be interpreted as a shifting and east directed broadening of the Raton Basin as a function of the growing orogenic wedge to the west. Alternatively, uplift of the western margin of the basin may have been driven by eastward migration of the deformation front. In the case of the latter one would expect to see evidence of sedimentary bypass and erosion that varies at a local scale. For the former, the western basin may have been abandoned entirely over regional scales producing a more uniform progression of depositional facies. To evaluate these models we are conducting a high-resolution correlation study of electrofacies throughout the available data. The results of which can identify key stratigraphic events to test these models. A key issue concerning the data is that many of the sand bodies within the system are arkosic and have a strong gamma response similar to shale. This will require that we consider a range of petrophysical characteristics to accurately differentiate sand from shale.

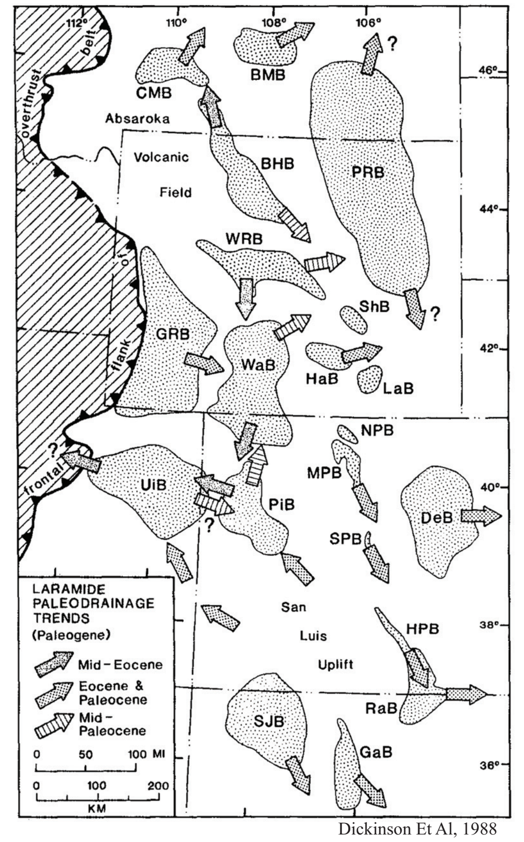
Location



Wawrzyniec Et Al, 2002
Dickinson Et Al, 1988



Flores and Bader, 1999



Dickinson Et Al, 1988

Introduction

Geologic Setting

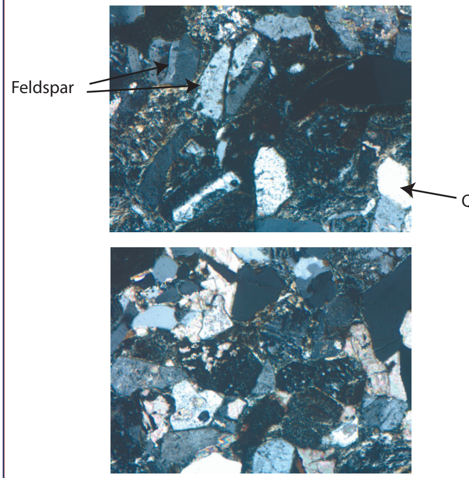
-The Raton Basin is a Laramide related perimeter basin with exclusively fluvial systems draining to the east
-The Raton Formation represents the onset of uplift of the Sangre De Cristo Range to the west
- Four major zones are found in the Raton Formation
  - The basal Raton conglomerate consists dominantly of pebbles and cobbles of quartzite, chert and gneiss
  - The lower coal zone consists of interbedded coal, mudstone, siltstone, and sandstone
    -The lower coal zone also contains the K-T boundary
  - The barren zone is dominated by sandstone, mudstone, and siltstone
  - The upper coal zone consists of coal, mudstone, siltstone, and sandstone
- In the western margin of the basin, the Poison Canyon Formation intertongues with and conformably overlies the Raton Formation
- The Poison Canyon Formation and Raton Formation contain arkose complicating the well log interpretation as potassium feldspar has a similar gamma response to shale.
- Coal bed methane is an important energy resource found in both the Vermejo and Raton Formations and has provided a wealth of subsurface data.
- Thicker coal seams are primary targets in the production of coal bed methane so channel clusters and sand fairways represent a decreased reservoir footage.

Stratigraphic Column

AGE		FORMATION NAME	GENERAL DESCRIPTION	LITHOLOGY	APPROX. THICKNESS IN FEET
TERTIARY	PALEOCENE	POISON CANYON FORMATION	SANDSTONE–Coarse to conglomeratic beds 13–50 feet thick. Interbeds of soft, yellow-weathering clayey sandstone. Thickens to the west at expense of underlying Raton Formation		500+
TERTIARY / MESOZOIC	PALEOCENE / UPPER CRETACEOUS	RATON FORMATION	Formation intertongues with Poison Canyon Formation to the west UPPER COAL ZONE–Very fine grained sandstone, siltstone, and mudstone with carbonaceous shale and thick coal beds BARREN SERIES–Mostly very fine to fine grained sandstone with minor mudstone, siltstone, with carbonaceous shale and thin coal beds LOWER COAL ZONE–Same as upper coal zone; coal beds mostly thin and discontinuous. Conglomeratic sandstone at base; locally absent		0?–2,100 ← K/T Boundary
MESOZOIC	UPPER CRETACEOUS	VERMEJO FORMATION	SANDSTONE–Fine to medium grained with mudstone, carbonaceous shale, and extensive, thick coal beds. Local sills		0–380
MESOZOIC	UPPER CRETACEOUS	TRINIDAD SANDSTONE	SANDSTONE--Fine to medium grained; contains casts of *Ophiomorpha*		0–300
MESOZOIC	UPPER CRETACEOUS	PIERRE SHALE	SHALE--Silty in upper 300 ft. Grades up to fine grained sandstone. Contains limestone concretions		1800-1900

Flores and Bader, 1999

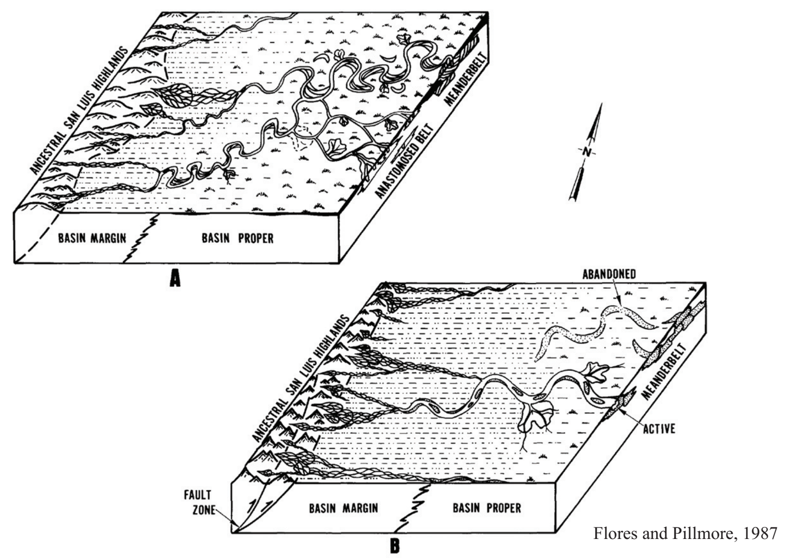
Microphotographs



-Microphotographs showing the large amounts of potassium feldspar in sands of the Raton Formation

Depositional Environment

- Surface outcrops indicate eastward flowing fluvial systems
- Subsequent uplift of the western margin of the basin or increase in sediment supply are possible causes for fluctuation between meandering and braided systems
- Swamps were most likely formed in the basin proper where lack of gradient and low sediment supply allowed accumulation of standing water.



Flores and Pillmore, 1987

Methods

Log Data

-Well logs for 142 wells were imported into Geoplus Petra as Log ASCII Standard 2.0 files with geographic locations, elevation above sea level to Kelly Bushing, total depths, and the Trinidad Sandstone and Vermejo Formation tops picked for each well.
- All logs were normalized by creation of histograms using Geoplus Petra and means and standard deviations were calculated for each well over the Raton and Vermejo Formation intervals checking for tool errors.

Gamma-Ray Curve

- The gamma ray index was calculated with:

$$I_{GR} = \frac{GR_{Log} - GR_{\min}}{GR_{\max} - GR_{\min}}$$

Where:
I_{GR} = gamma ray index;
GR_{log} = gamma ray reading of formation;
GR_{min} = minimum gamma ray; and
GR_{max} = maximum gamma ray (shale).

- The gamma ray curve was then centered in Track 1 with a linear scale from 0 to 200 API.

Resistivity Curve

- The induction medium log resistivity was centered in Track 1 with a linear scale from 0 to 275 ohm-m.
- Areas in which the gamma ray curve crossed over to the left of the induction medium log were shaded in yellow.
- This crossover shading represents sand bodies that do not have an arkosic gamma response
- The induction medium log resistivity was then converted to conductivity using:

$$C = \frac{1000}{R}$$

Where:
C = conductivity in millimho/m; and
R = resistivity in ohm-m.

- Conductivity curve was then plotted centered in Track 3 on a linear scale from 90 to -0.4 mmho/m.
- The spherically focused log was also plotted centered in Track 3 on a linear scale from 0 to 800 ohm-m.
- Areas in which the conductivity curve crossed over to the left of the spherically focused log were shaded in red.
- These red shaded areas identify zones of higher porosity in the well log.

Bulk Density Curve

- The bulk density curve was plotted in Track 4 from 3 to 0 gm/cc to allow coal bed identification.
-Areas where the bulk density was less than 2.0 gm/cc were shaded black to identify coal.

Neutron Porosity Curve

- The neutron porosity curve was plotted in Track 2 on a logarithmic scale from -0.2 to 0.5 V/V.
- This allowed identification of areas of high porosity in wells with neutron porosity data.

Zone Data

Vermejo Formation

- The top of the Vermejo Formation was picked using a large coal bed overlain by a thick high porosity sequence of sand and shale with little coal.

Basal Conglomerate

-The top of the basal conglomerate of the Raton Formation was picked at the top of a fining upwards sequence of a large sand unit less than 100 feet thick.

Coals 1 and 2

-Coal 1 was picked on the top of a laterally extensive 5 foot thick coal bed found throughout all wells in both study areas.
-Coal 2 was picked on the top of a much thicker succession of identical coal beds found in the study areas.
- The laterally extensive coals provided a time surface to correlate throughout all wells
- Compensational channel stacking between coal units was identified in several wells allowing depositional predictions to areas of increased coal thickness as well as increased sand thickness.

Sand and Coal Footages
-Gross coal was calculated with the bulk density log where the bulk density cut off of less than 2.0 g/cc identified a coal bed.
- Gross non-arkose sand was calculated for all zones in the Raton Formation with a gamma ray cutoff maxium of 90 API.
- Gross sand was calculated for all zones using a conductivity cutoff minimum of 40 mmho/m.
- Gross arkose was calculated with:

$$G_{Arkose} = G_{Sand} - G_{Non-arkose}$$

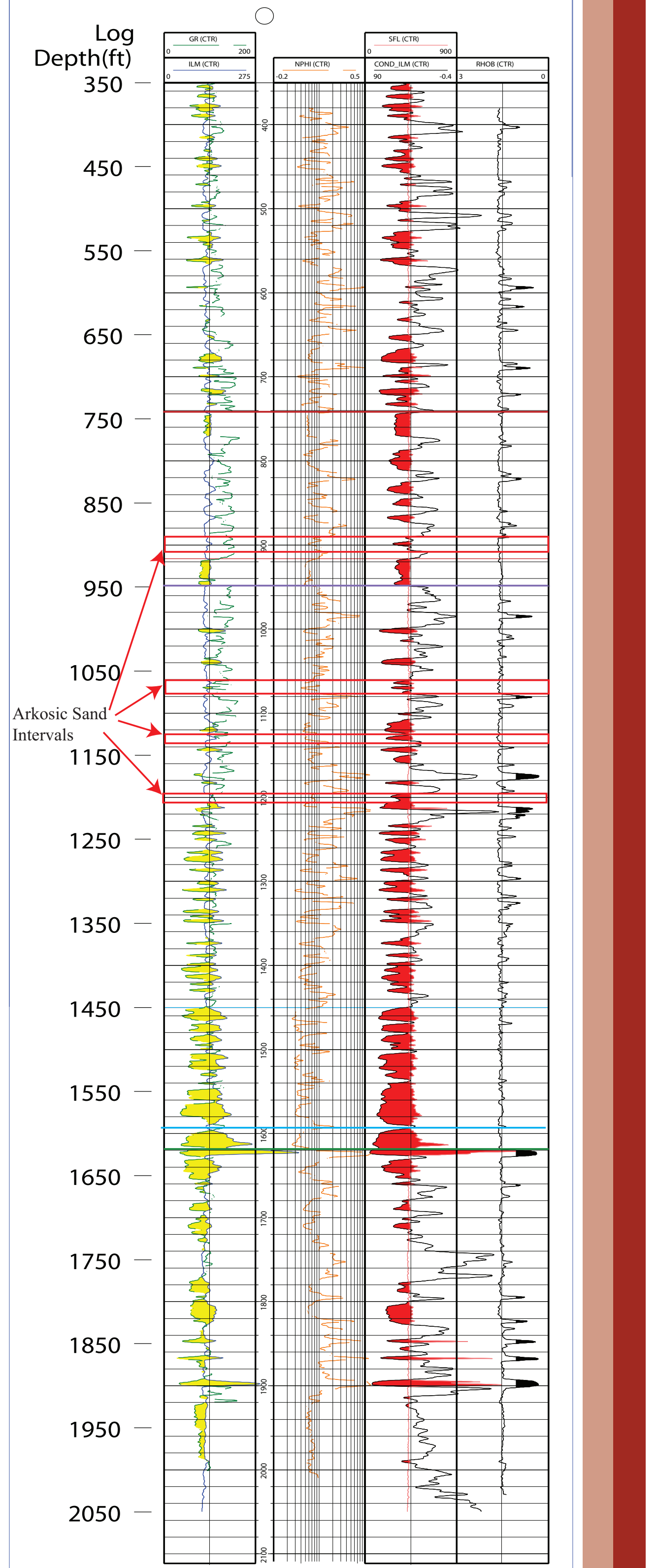
where:
G_{Arkose} = gross arkose sand footage;
G_{Sand} = gross sand footage; and
$G_{non\text{-}arkose}$ = gross non-arkose sand footage

Formation and Zone Tops

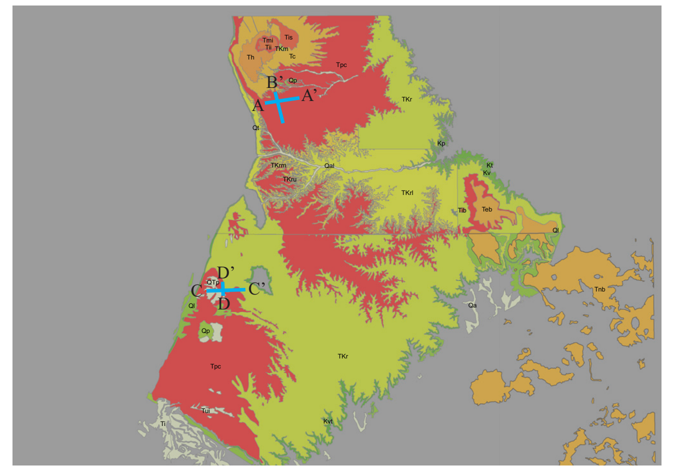
Top of Barren Zone
Top of Lower Coal Zone
Top of Basal Conglomerate
Top of Vermejo Formation

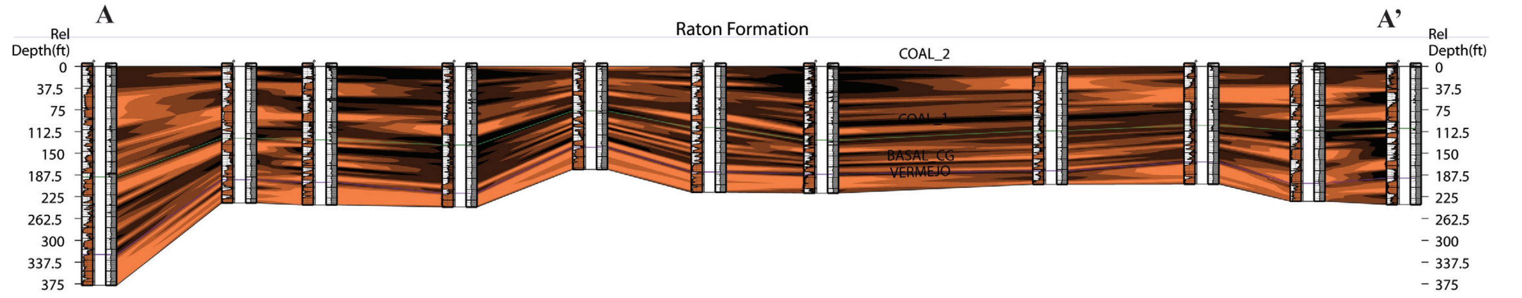
LOG CURVES

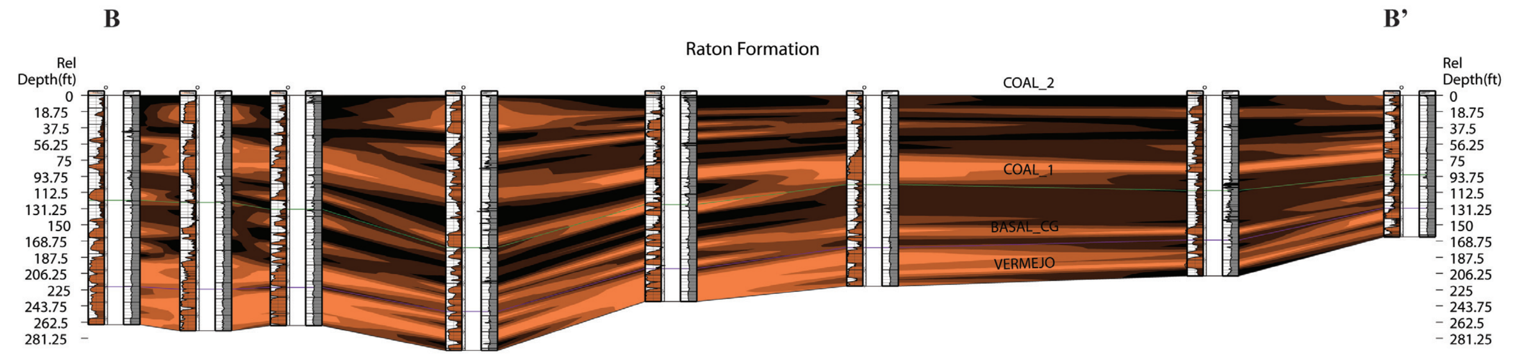
Min	Max	Curve
0	275	ILM (ohm-m)
-0.4	90	COND_ILM (mmho/m)
0	900	SFL (ohm-m)
3	0	RHOB (gm/cc) CUTOFF = 2.00
0	200	GR (GAPI)
-0.2	0.5	NPHI (V/V)

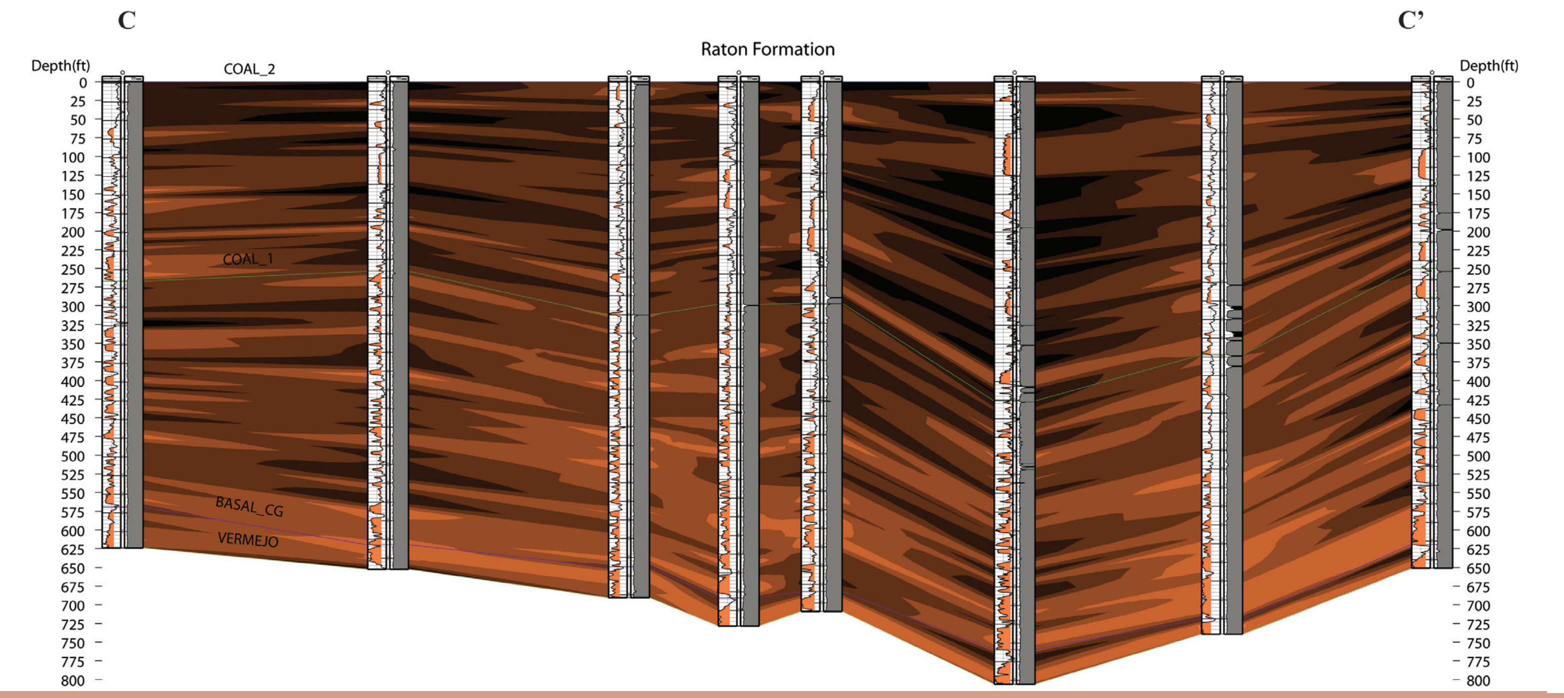


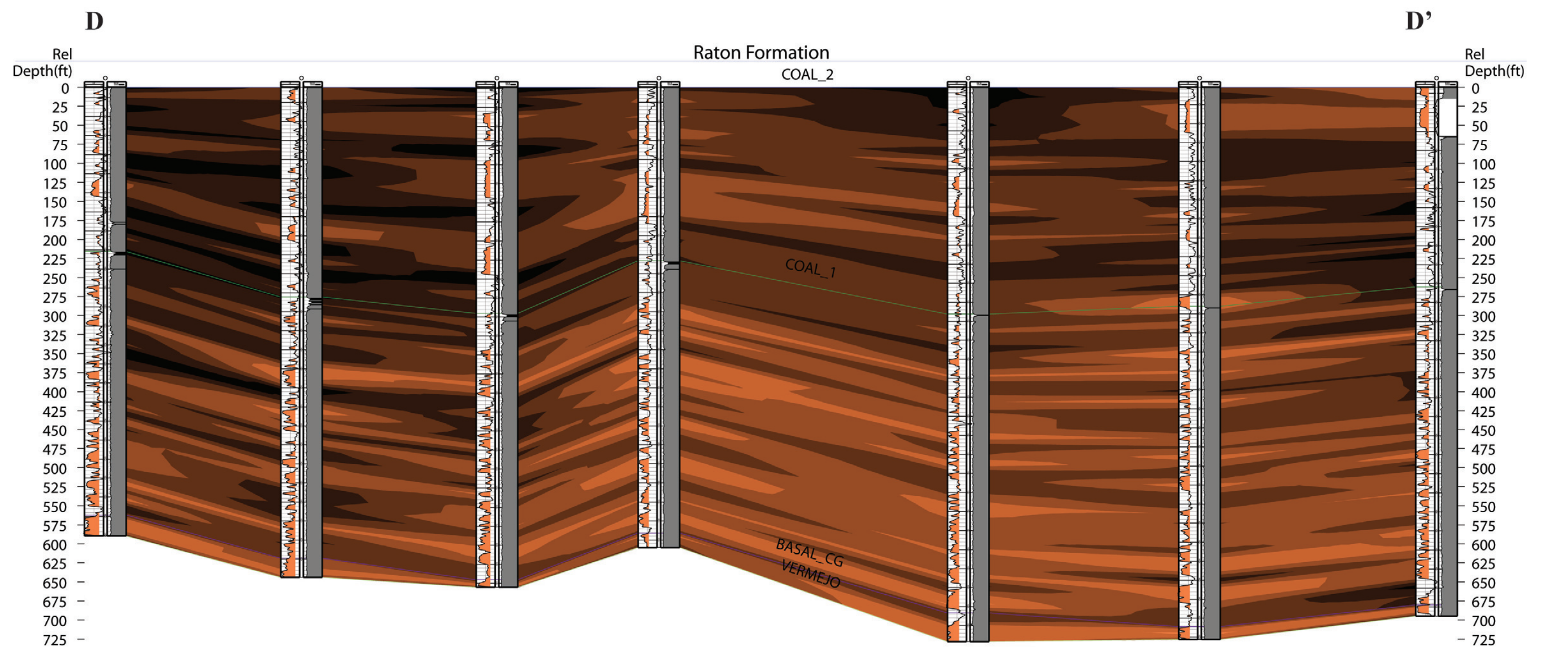
Cross Sections





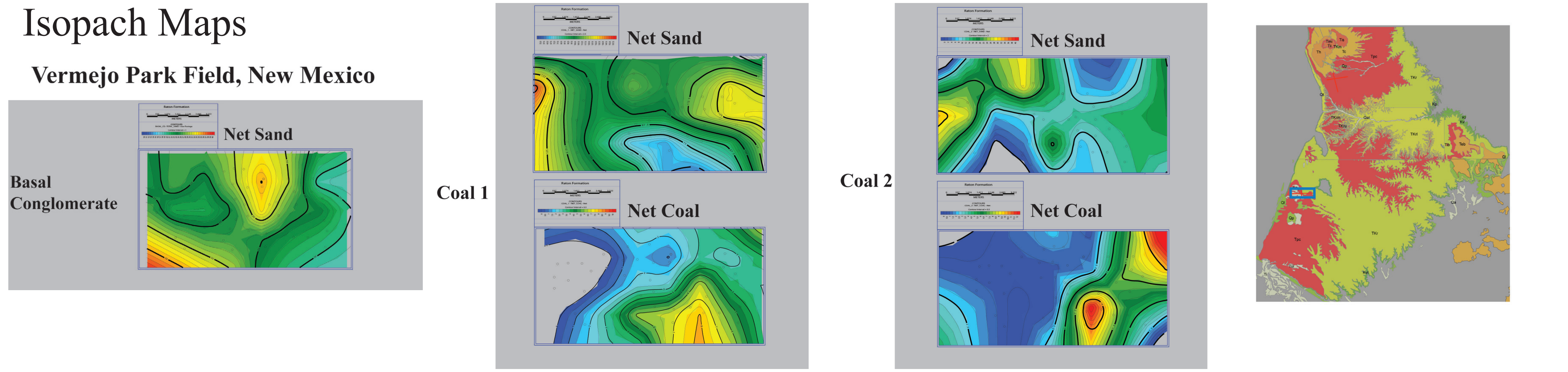




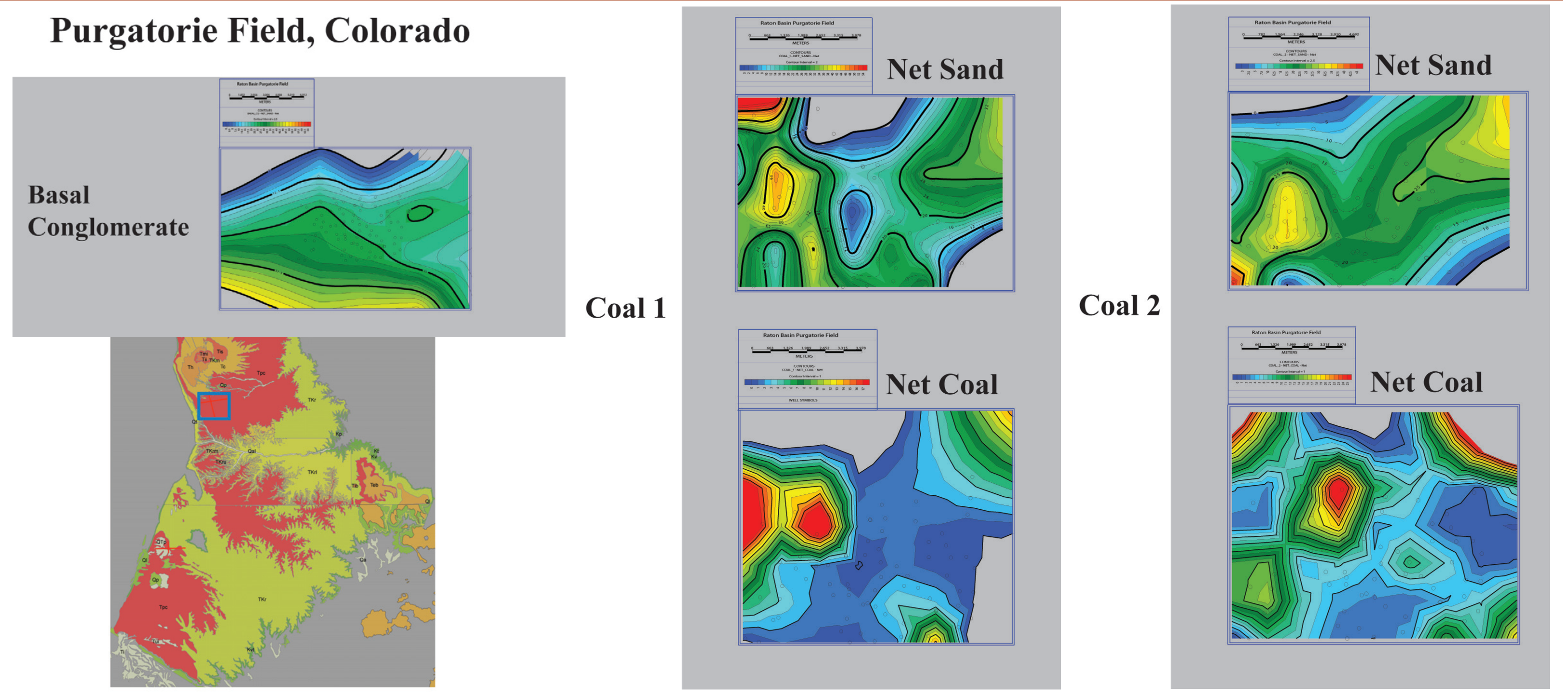


Isopach Maps

Vermejo Park Field, New Mexico

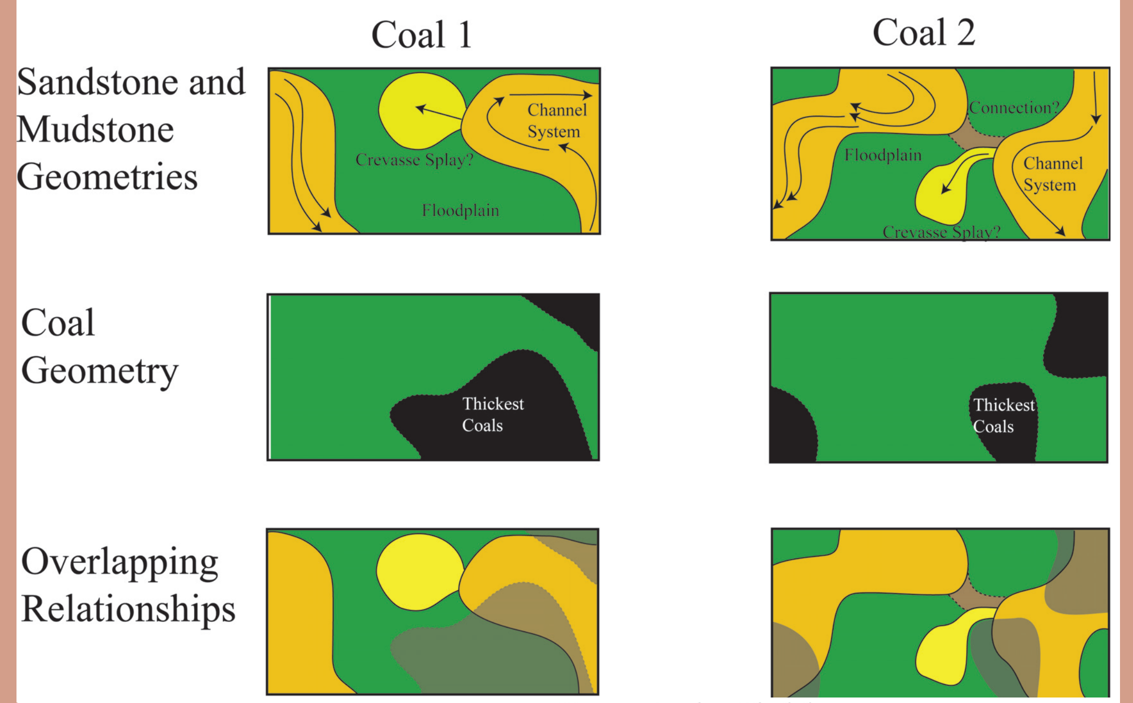


Purgatorie Field, Colorado

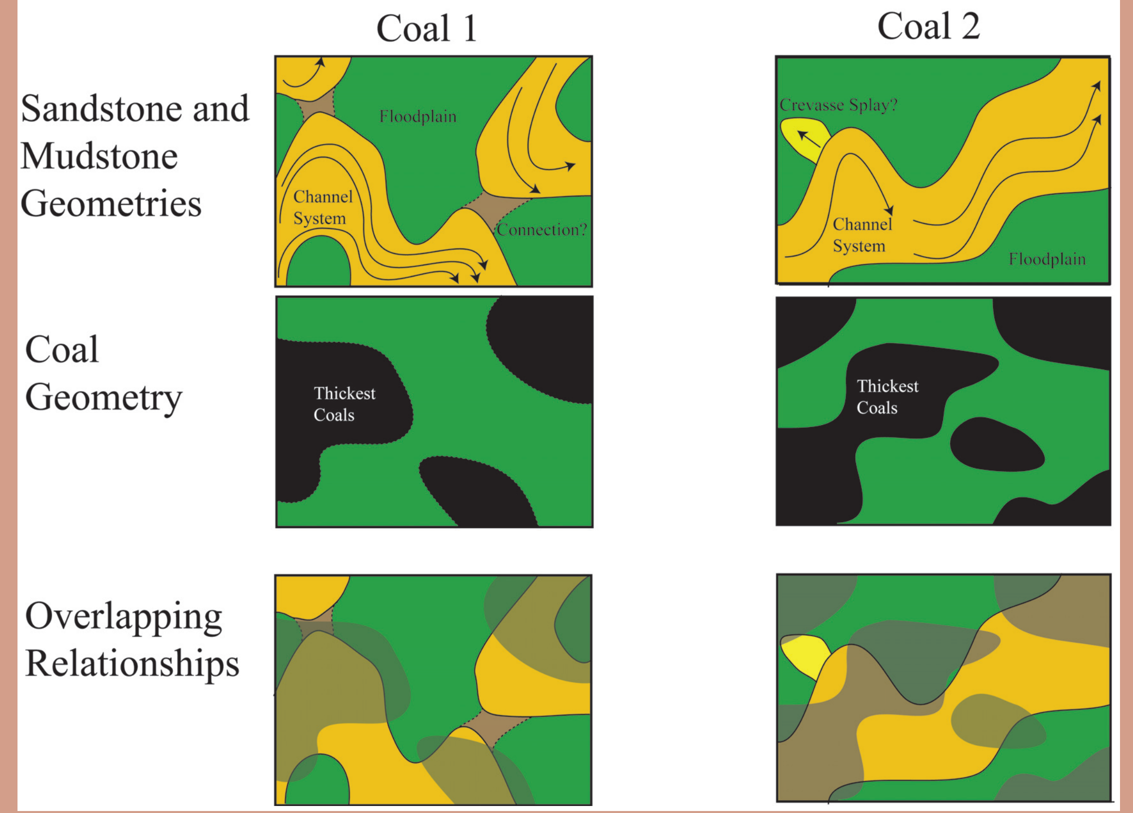


Results

Vermejo Park Field

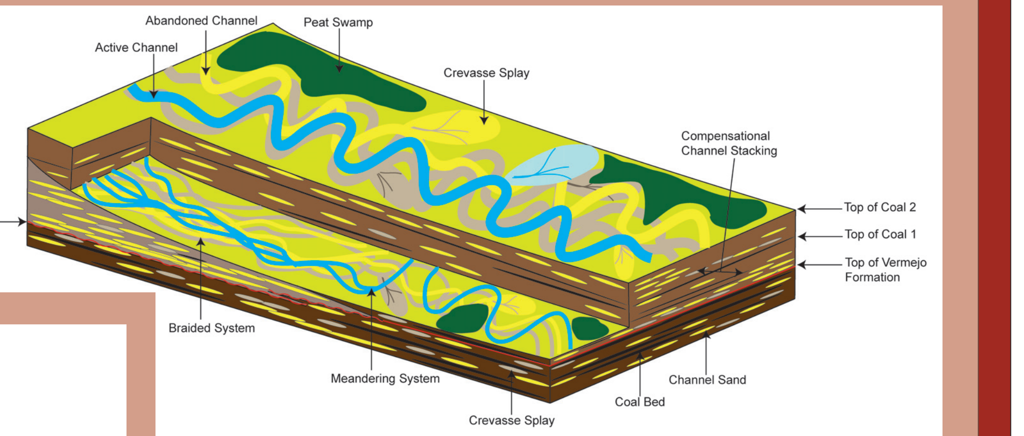


Purgatorie Field



Depositional Environment

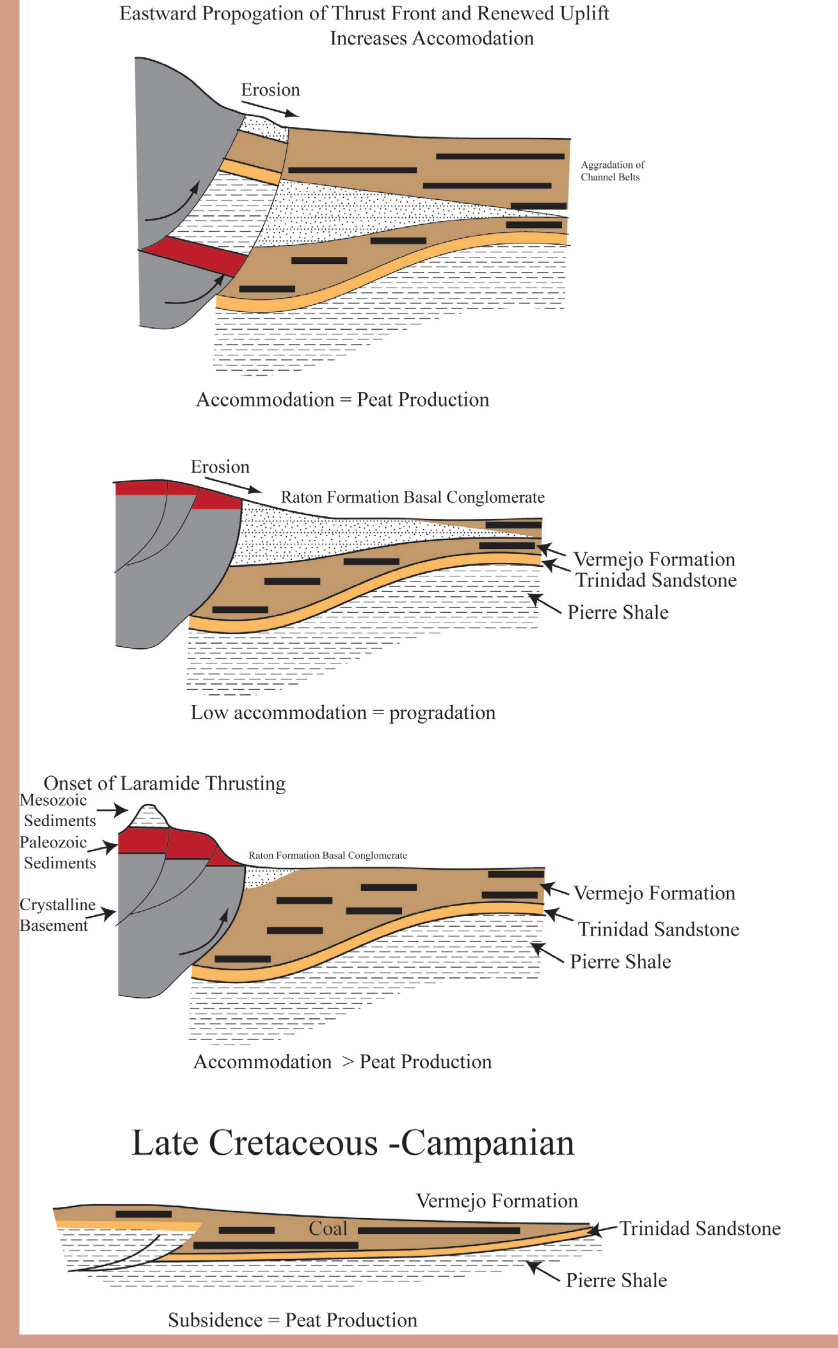
- Although the coal is laterally extensive in the study areas, coal is thickest in areas that were previously occupied by channel systems indicating an oxbow shape geometry for the thicker coal seams.
- The incised valleys and braided geometry of the basal conglomerate indicate uplift of the western margin of the basin providing a bypass surface.



- The Vermejo Formation was deposited in an environment where peat production was equal to the accommodation rate.
- During deposition of the basal conglomerate of the Raton Formation flexural loading of the crust by the Sangre de Cristo uplift to the west prduced accommodation that was greater than peat production creating a coal free zone.
- Progradation of the basal conglomerate out into the basin was then facilitated by a drop in accommodation.
- As the thrust front migrated eastward into the basin the accommodation was again equal to the rate of peat production resulting in the preservation of coal beds.
- In the Vermejo Park field this time was dominated by high avulsion frequency and low coal preservation, whereas the Purgatorie field was a low avulsion frequency dominated system and produced more thin coal beds.

Tectonic Model

Cretaceous Paleocene Boundary



Implications

- Well placement to maximize intersection of net pay intervals can be optimized based on oxbow geometry of thickest coals.
- Wells can be strategically placed based on target interval. Vermejo Formation target wells can be more widely spaced than Raton Formation target wells based on lateral extent and vertical thickness of Vermejo coals versus Raton coals.

Acknowledgements

- Western State College of Colorado Moncrief Petroleum Geology Fund provided funding for travel costs.
- IHS provided the GeoPlus Petra software used in this research, and El Paso Corporation provided the Vermejo Park dataset and thin sections.
- JRP would like to thank his undergraduate advisors Tim Wawrzyniec, Rob Fillmore and Jim Coogan.

References

Asquith, G.B., Krygowski D., 2004, Basic Well Log Analysis, 2nd edition: American Association of Petroleum Geologists Methods in Exploration Series 16, 244 p.

Bohacs, K., and Sueter, J., 1997, Sequence Stratigraphic Distribution of Coaly Rocks: Fundamental Controls and Paralic Examples: AAPG Bulletin, v. 81, no. 10, p. 1612-1639.

Dickinson, W. R., Klute, M.A., Hayes, M.J., Janecke, S.U., Lundin, E.R., McKittrick, M.A., and Olivares, M.D., 1988, Paleogeographic and paleotectonic setting of Laramide sedimentary basins of the central Rocky Mountain region: Geological Society of America Bulletin, v. 100, p. 1023-1039.

Flores, R.M., and Bader, L.R., 1999, A Summary of Tertiary coal resources of the Raton Basin, Colorado and New Mexico, United States Geological Survey Professional Paper 1625-A, 35 p.

Flores, R.M., and Pillmore, C.L., 1987, Tectonic control on alluvial paleoarchitecture of the Cretaceous and Tertiary Raton Basin, Colorado and New Mexico, in Ethridge, F.G., Flores, R.M., and Harvey, M.D., editors, Recent developments in Fluvial Sedimentology: Society of Economic Paleontologists and Mineralogists, Special Publication 39, p. 311-320.

Hofmann, M.H., Wroblewski, A., and Boyd, R., 2011, Mechanisms Controlling the Clustering of Fluvial Channels and the Compensational Stacking of Cluster Belts: Journal of Sedimentary Research, v. 81, p. 670-685.

IHS Inc., 2011, Geoplus Petra (Version 3.4.1) [Computer Software], Tulsa, OK: IHS Inc. Retrieved February 28, 2011, Available from http://www.ihs.com/products/oil-gas-information/analysis-software/petra.aspx

Jerrett, R.M., Davies, R.C., Hodgson, D.M., Flint, S.S., Chiverrell, R.C., 2011, The significance of hiatal surfaces in coal seams; Journal of the Geological Society, London, v. 168, p. 629-632.

Lee, W.T., 1917, Geology of the Raton Mesa and other regions in Colorado and New Mexico, in Lee, W.T. and Knowlton, F.H. editors, Geology and Paleontology of Raton Mesa and other regions in Colorado and New Mexico: United States Geological Survey Professional Paper 101, 450 p.

Pillmore, C.L., 1976, Commercial coal beds of the Raton coal field, Colfax County, New Mexico, in Ewing, R.C., and Kues, B.S., editors, Guidebook of Vermejo Park, northeastern New Mexico: New Mexico Geological Society, 27th Field Conference, 1976, p. 227-247.

Pillmore, C.L., and Flores, R.M., 1984, Field guide and discussions of coal deposits, depositional environments, and the Cretaceous-Tertiary boundary, southern Raton Basin, in Lintz, J., Jr., editor, Western Geological Excursions: Geological Society of America, Annual Meeting Guidebook, v. 3, p. 1-51.

Pillmore, C.L., and Flores, R.M., 1987, Stratigraphy and depositional environments of the Cretaceous-Tertiary boundary clay and associated rocks, Raton Basin, New Mexico and Colorado, in Fassett, J.E., and Rigby, J.K., Jr., editors, The Cretaceous-Tertiary Boundary in the San Juan and Raton Basins: New Mexico and Colorado: Geological Society of America, Special Paper 209, p. 111-130.

Posamentier, H.W., and Allen, G.P., 1993, Siliciclastic sequence stratigraphic patterns in foreland ramp-type basins: Geology, v. 21, p. 455-458.

Schumm, S.A., and Khan, H.R., 1972, Experimental Study of Channel Patterns: Geological Society of America Bulletin, v. 83, p. 1755-1770.