

# **Correlating Porosity with Acoustic Impedance in Sandstone Gas Reservoirs: Examples from the Atokan Sandstones of the Arkoma Basin, Southeastern Oklahoma\***

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## **Abstract**

It has been suggested by several researchers that seismic impedance values determined from the 3D seismic inversion data can be used to locate the zones of low and high porosities in sandstone reservoirs. We have applied this concept to three well known sandstone gas reservoirs in the Arkoma foreland basin, located in southeast Oklahoma. The reservoirs are the lower Atokan Spiro; and middle Atokan Brazil and Red Oak sandstones. We used 3D seismic acoustic inversion volume calibrated to well control to map porosity changes in these three gas reservoirs. Every well with a sonic log within the survey area has been analyzed to understand velocity changes in these reservoirs along strike and dip of the main direction of thrusting. Structural control plays a major role in the productivity of these sandstone reservoirs. Therefore, we also determined the structural control on the porosity of these reservoirs by constructing several balanced structural cross-sections in the area of seismic inversion data because understanding the structure over an area is just as important as identifying changes in rock properties.

Our interpretation of the seismic inversion data suggest that the areas of tighter anticlinal folds in our cross-sections correlate reasonably well with the lower acoustic impedance values due to fracture porosity in the Spiro Sandstone. In areas where the Spiro experienced facies changes, the acoustic impedance value is also a good predictor of porosity. Therefore, acoustic impedance shows a reliable correlation with higher porosities as seen in areas of lower acoustic impedance in the Spiro reservoirs. However, we have not found a very reliable correlation between the porosity and acoustic impedance in the Brazil and Red Oak sandstones. We suggest that this is due to the variable shale content together with the tuning thickness of intervals. The two sandstone units contain thick shale sections because of the nature of their depositional environment. Therefore, seismic inversion data seem not to be a reliable predictor of porosity where thick shale sections are present. When we isolate the homogeneous sandstone parts of the two units, however, there is a linear correlation between the acoustic impedance and porosity. We suggest that determining the linear relationship between the acoustic impedance and porosity may be used only in relatively thick sandstone reservoirs.

## References Cited

- Arbenz, J. K., 2008, Structural framework of the Ouachita Mountain, in Suneson, N. H., ed., Stratigraphic and structural evolution of the Ouachita Mountains and Arkoma Basin, south-eastern Oklahoma and west-central Arkansas: applications to petroleum exploration: 2004 field symposium. The Arbenz-Misch/Oles volume: Oklahoma Geological Survey Circular 112A, p. 1-40.
- Calderon, J.E. and J. Castagna, 2007, Porosity and lithologic estimation using rock physics and multi-attribute transforms in Balcon Field, Colombia: *Leading Edge*, v. 26/2, p. 142-150.
- Cemen, I., A. Sagnak, and S. Akthar, 2001a, Geometry of the triangle zone and duplex structure in the Wilburton gas field area of the Arkoma Basin, southeastern Oklahoma, *in* K.S. Johnson, ed., Pennsylvanian and Permian geology and petroleum in the southern Midcontinent, 1998 symposium: Oklahoma Geological Survey Circular, Report #104, p. 87-98.
- Çemen, I., J. Evans, and A. Sagnak, 2001b, Eastern continuation of the Wilburton triangle zone in the Red Oak gas-field area, frontal Ouachitas-Arkoma basin transition zone, southeastern Oklahoma, in Johnson, K.S.; and Merriam, D.F. (eds), Petroleum systems of sedimentary basins in the southern Midcontinent, 2000 symposium: Oklahoma Geological Survey Circular 106, p. 81-95.
- Houseknecht, D.W., J.K. Zaengle, D.J. Steyaerk, A.P. Matteo, Jr., and M.A. Kuhn, 1983, Facies and depositional environments of the Desmoinesian Hartshorne Sandstone, Arkoma Basin, *in* D.W. Houseknecht, ed., Tectonic-sedimentary evolution of the Arkoma Basin and guidebook to deltaic facies, Hartshorne Sandstone: SEPM, v. 1, p. 53-82.
- Pedersen-Tatalovic, R., A. Uldall, N. Lange-Jacobsen, T. Mejer-Hansen, and K. Mosegaard, 2008, Event-based low-frequency impedance modeling using well logs and seismic attributes: *Leading Edge*, v. 27/5, p. 592-603.
- Sahai, S., and I. Çemen, 2008, Enhanced structural interpretation in the Arkoma Basin with seismic attributes, in N.H. Suneson, and I. Çemen, eds., Stratigraphic and Structural Evolution of the Ouachita Mountains and Arkoma Basin, southeastern Oklahoma and west-central Arkansas: Applications to petroleum exploration, 2004 field symposium, technical papers: Oklahoma Geological Survey Circular 112B, p. 25-30.
- Sutherland, P.K., 1988, Late Mississippian and Pennsylvanian depositional history in the Arkoma Basin area, Oklahoma and Arkansas: GSA Bulletin, v. 100/11, p. 1787-1802.

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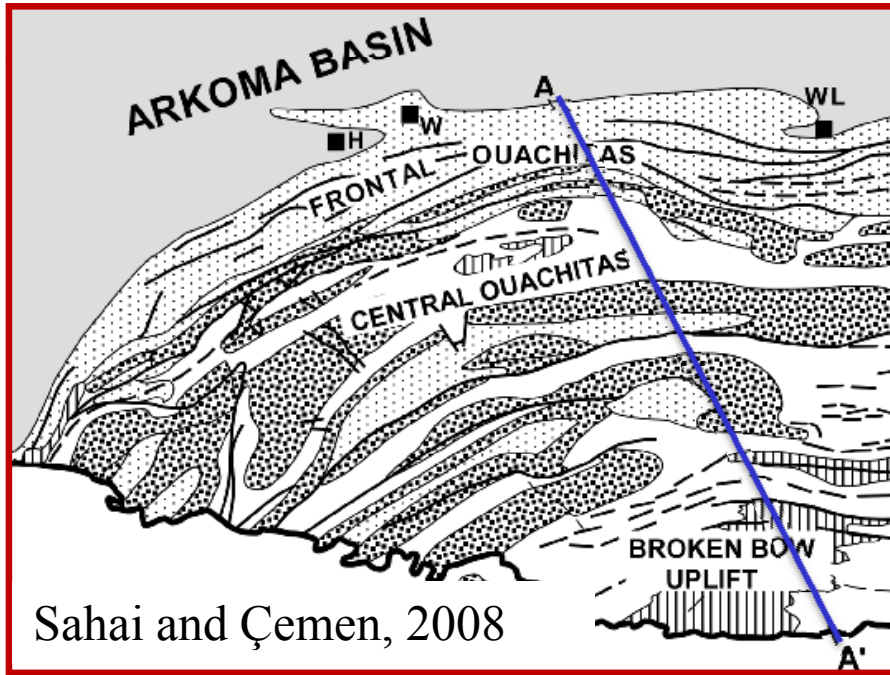


The Arkoma basin is a foreland basin of the Ouachita fold and thrust belt formed during the Pennsylvanian Ouachita Orogeny.



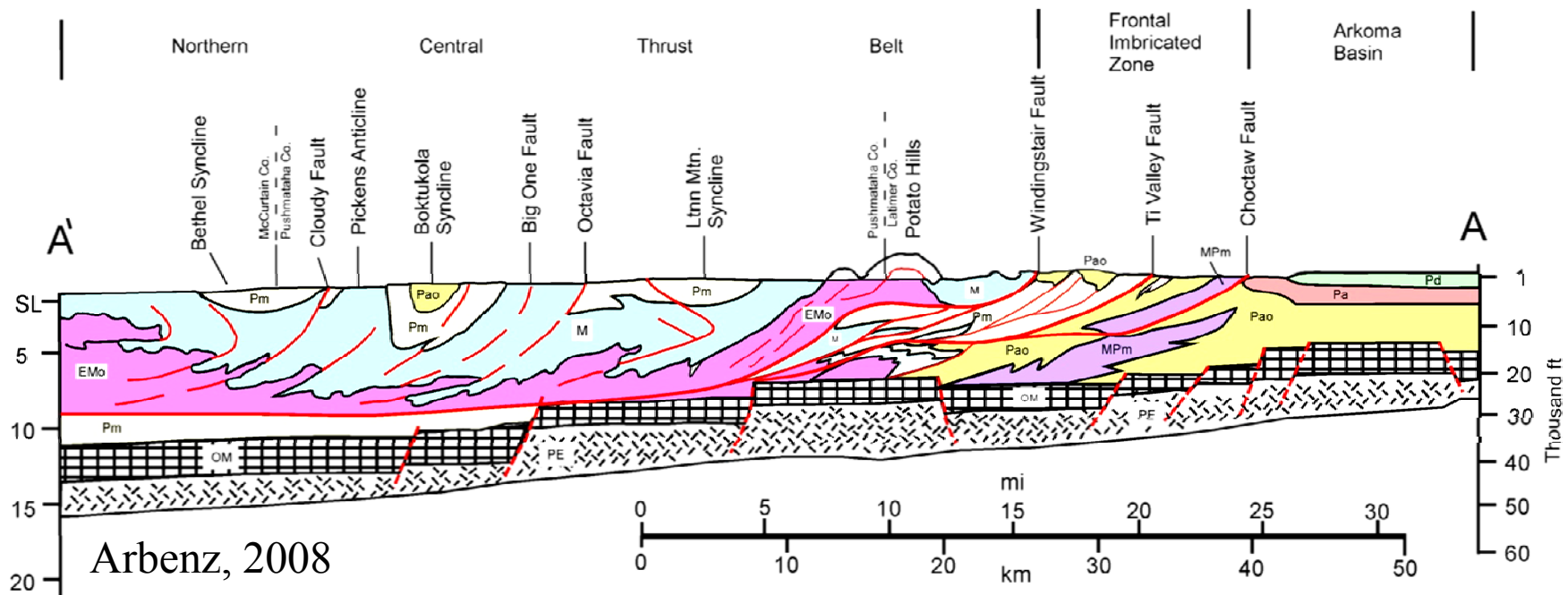
**The Arkoma Basin** contains **4.26 trillion cubic feet** undiscovered natural gas, mostly in the Atokan Sandstones. The basin produces gas mostly from the Atokan reservoirs, such as the lower Atokan Spiro, Panola, Brazil and middle Atokan Red Oak sandstones.

# Geologic overview

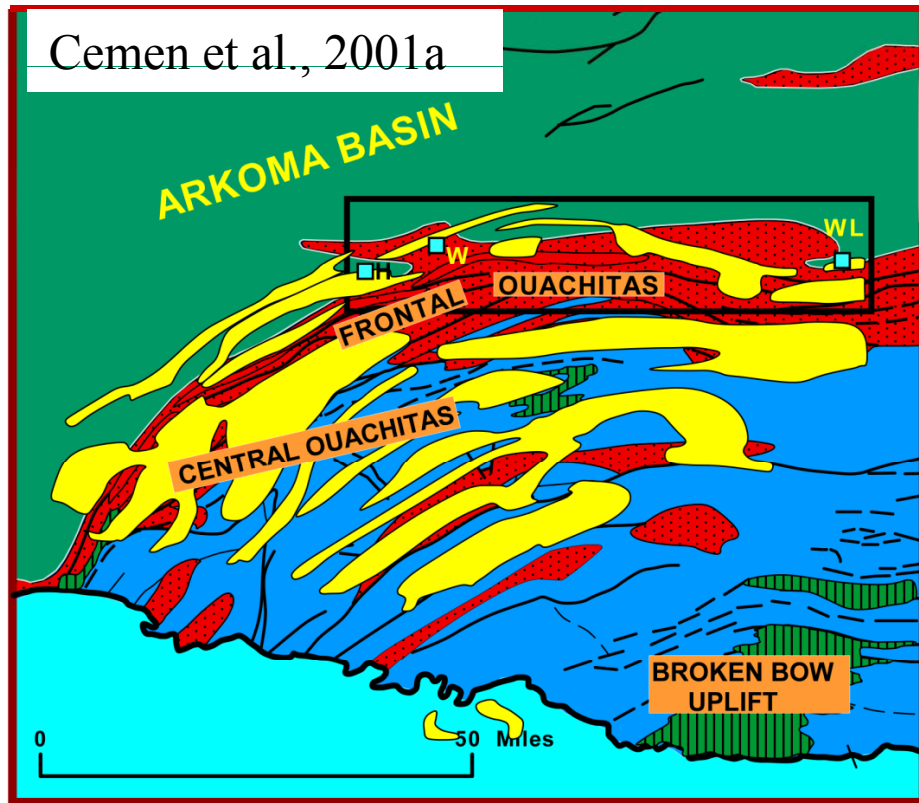


The Arkoma Basin is one of the best foreland basins in the world to study how strain partitions from highly deformed fold-thrust belt to mildly deformed foreland basins because:

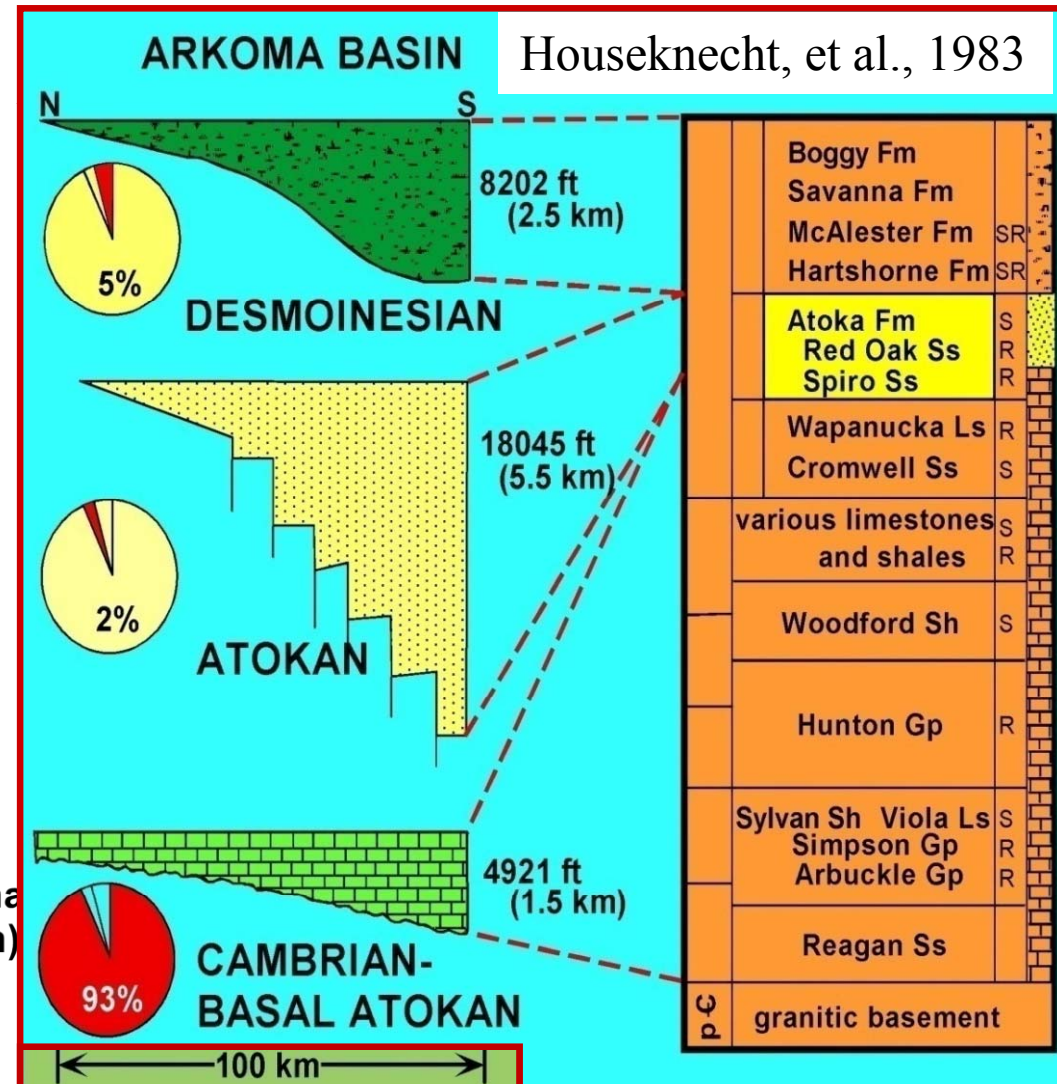
- High subsidence and sedimentation rates during thrusting in late Mississippian and Pennsylvanian;
- Thrusting has not been effected by later events such as extension and/or strike-slip faulting



# Generalized Stratigraphy of the Ouachitas and Arkoma Basin



- Desmoinesian ( Harshorne, McAlester, Savanna & Boggy Fm of Krebs Group of Arkoma basin)
- Atokan (Spiro / Wapanucka; and Atoka Fm of Frontal Ouachita and Arkoma basin)
- Morrowan ( Jackfork Group and Johns Valley Fms of Ouachita facies)
- Middle - Late Mississippian (Stanley Group of Ouachita facie)
- Early & Middle Paleozoic ( Cambrian - Early Mississippian)

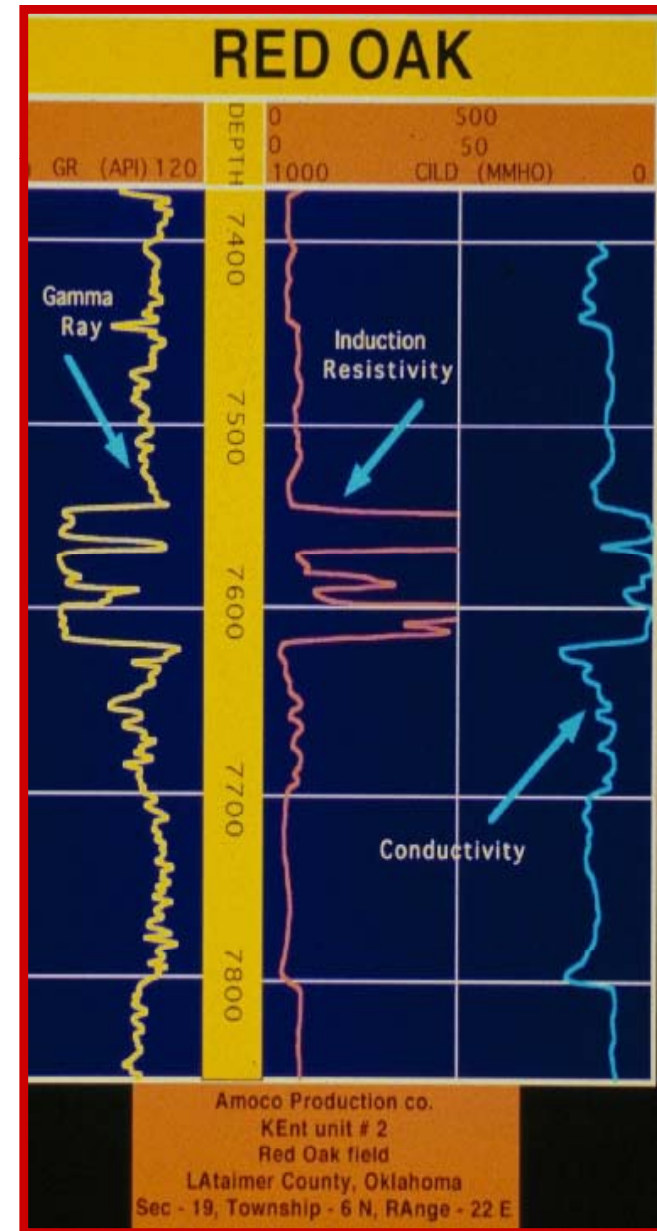
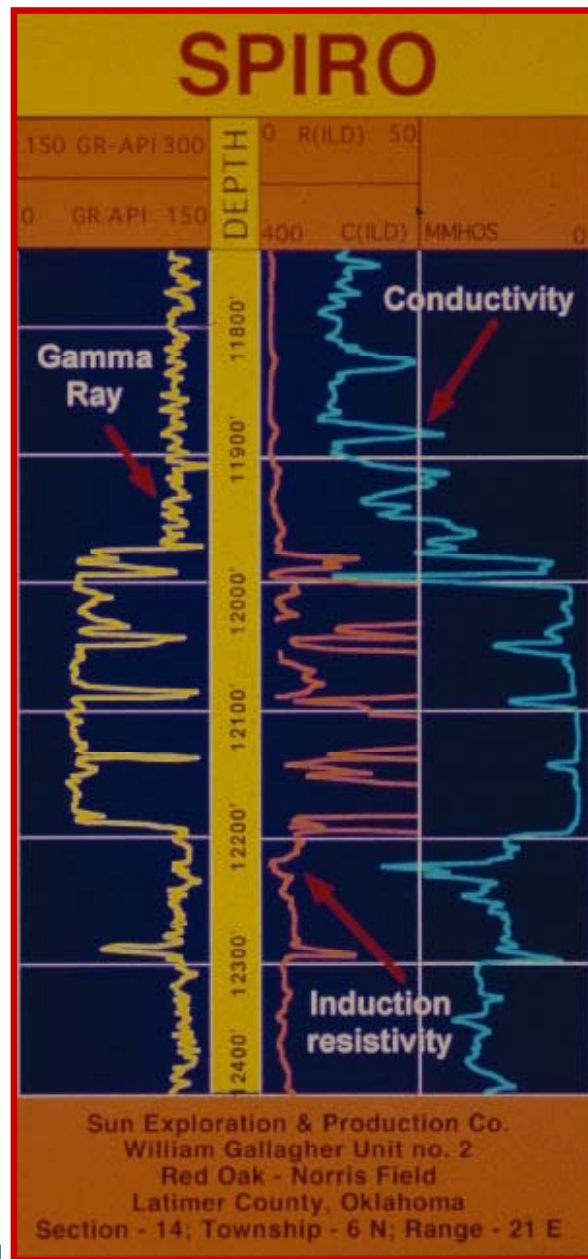


The Atoka Formation contains mostly deep marine shale deposits but also includes some sandstone units. The Spiro Sandstone forms the base of the Atokan Formation and is an important reservoir sand.

PENNSYLVANIAN				
MORROWAN	ATOKAN	DESMOINESIAN		KEOTA SANDSTONE TAMAHA SANDSTONE CAMERON SANDSTONE BOOCH SANDSTONE
				HARTSHORNE SANDSTONE
	ATOKA FORMATION	UPPER	WEBBERS FALLS SANDSTONE GILCREASE SANDSTONE FANSHAW SANDSTONE	
		MIDDLE	RED OAK SANDSTONE PANOLA SANDSTONE DIAMOND SANDSTONE BRAZIL SANDSTONE CECIL SANDSTONE SHAY SANDSTONE	
		LOWER	SPIRO SANDSTONE FOSTER SANDSTONE	
	WAPANUCKA LIMESTONE			
	UNION VALLEY LIMESTONE			
	CROMWELL LIMESTONE			
	SPRINGER SHALE			

Detailed stratigraphy the Pennsylvanian system of units within the Arkoma Basin (modified from Sutherland, 1988).

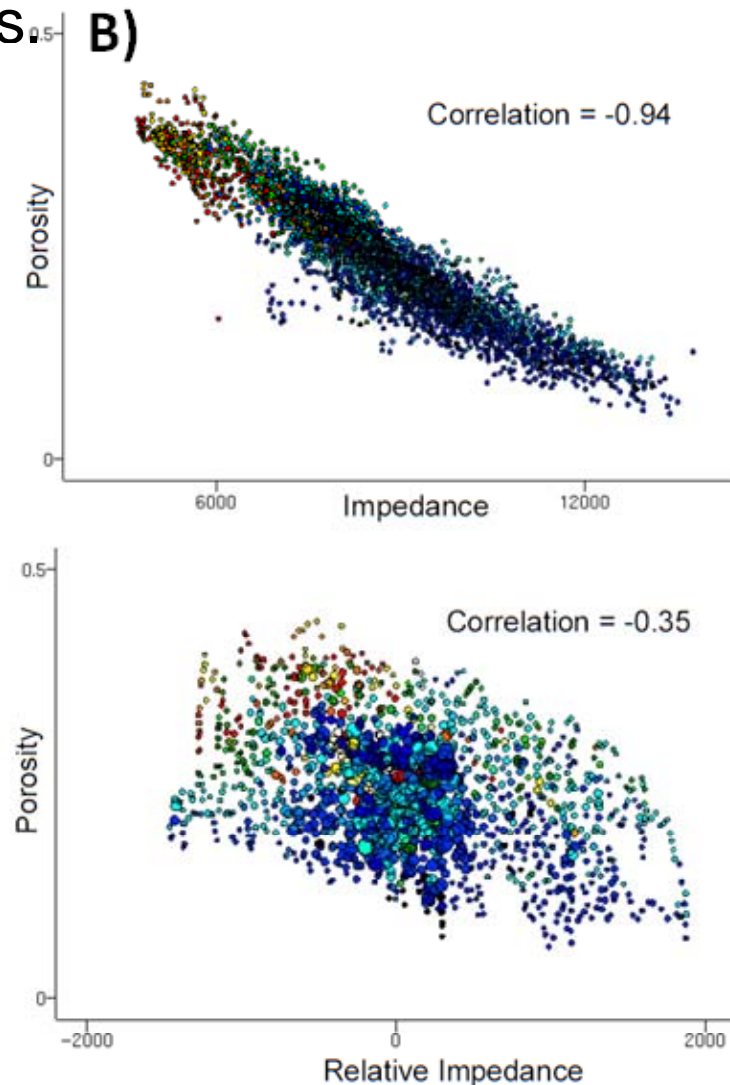
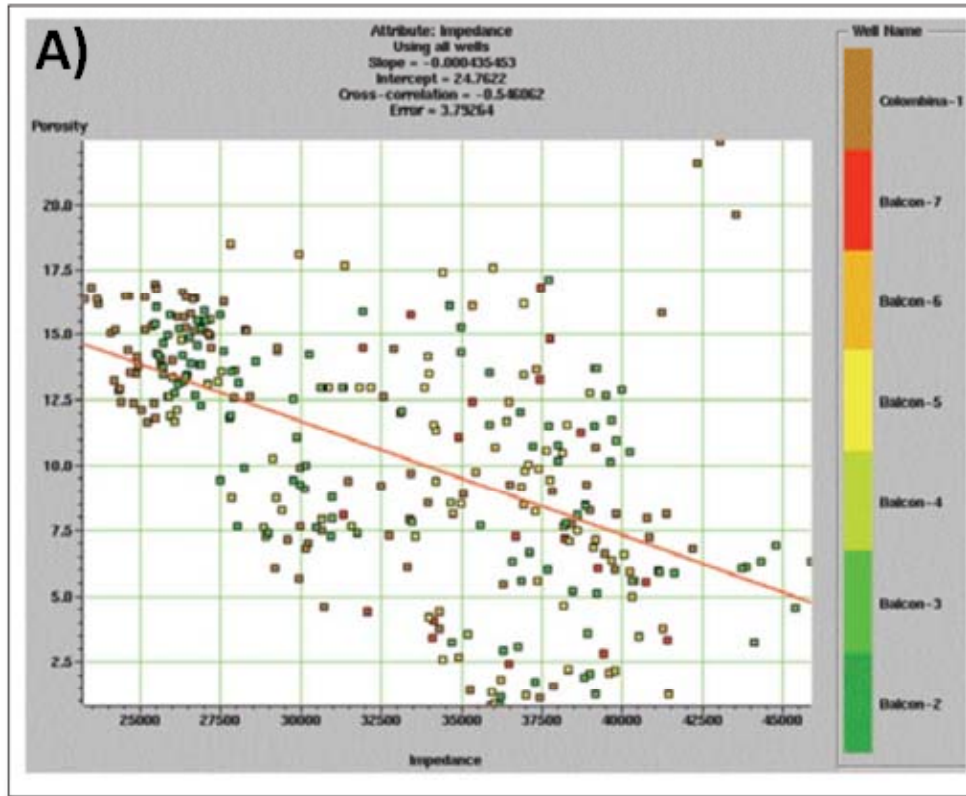
SYSTEM/SERIES		ATOKA FORMATION	
PENNSYLVANIAN	ATOKAN	UPPER	M
			L
			K
			J
			I
		MIDDLE	Fanshawe
			Red Oak
			Panola
			Brazil
			Cecil
			Shay
		LOWER	C
			B
			A
			<b>Spiro</b>



Major Pennsylvanian sandstones of the Atoka Formation (Cemen et al., 2001a)

Log Signatures of the Spiro and Red Oak sandstones, two major gas reservoirs in the Wilburton, and Hartshorne gas fields

**Seismic Inversion:** Seismic impedance values are shown to correlate with porosities in sandstone reservoirs.



A) Cross-plot of porosity versus acoustic impedance with the color scale corresponding to different wells for Cretaceous sandstones in Magdalena Valley, Columbia (Calderon and Castagna, 2007).

B) Examples from the Danish North Sea (Pedersen-Tatalovic et al., 2008). Lower acoustic impedance values correlate with higher porosity values.

- In recent years, we applied this concept to three well known sandstone gas reservoirs in the Arkoma basin.
- The reservoirs are the lower Atokan Spiro and middle Atokan Brazil and Red Oak sandstones.
- Every well with a sonic log within the survey area has been analyzed to understand velocity changes.

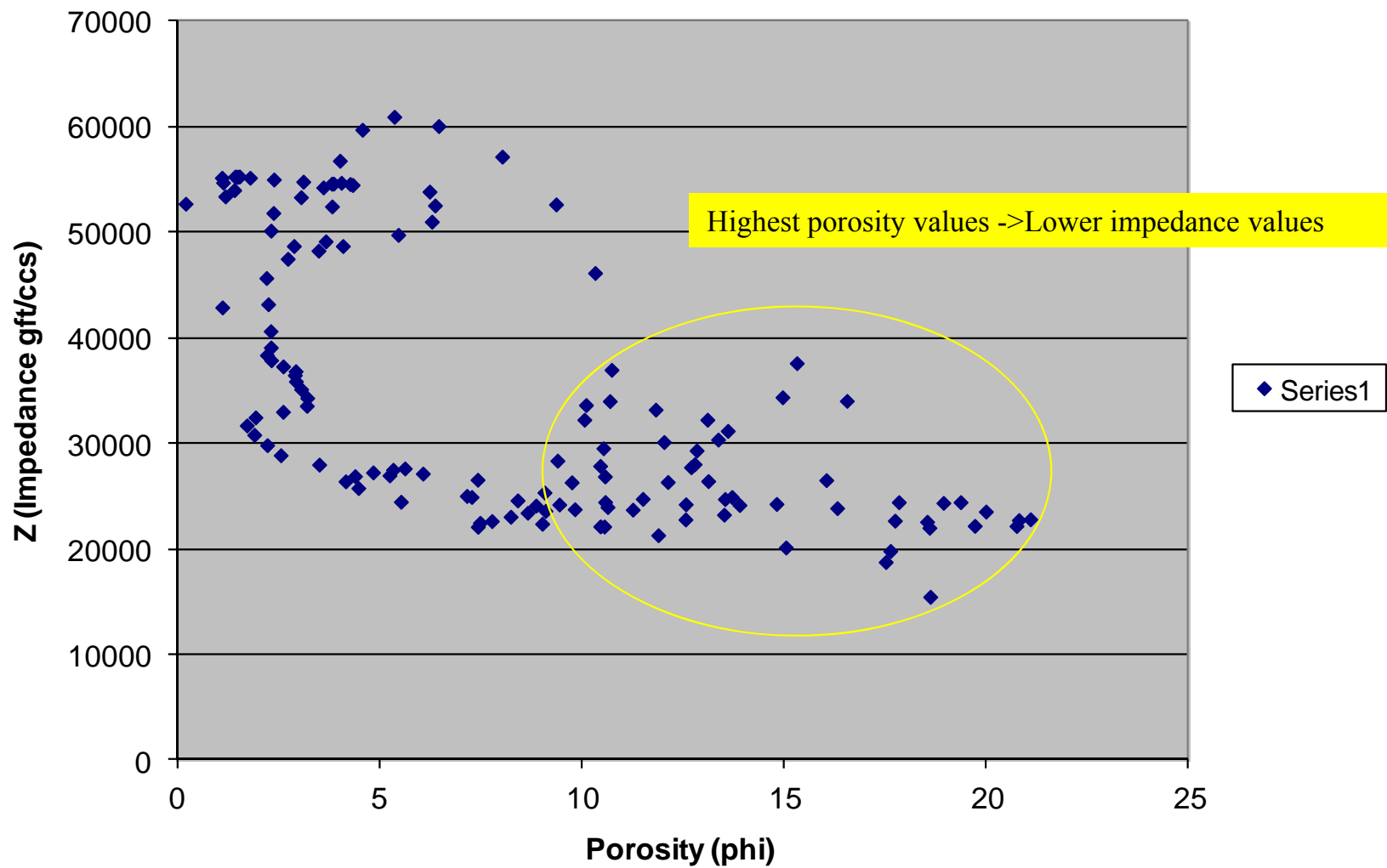
# Seismic Inversion

- Full stack inversion was done by Odegaard America Inc.

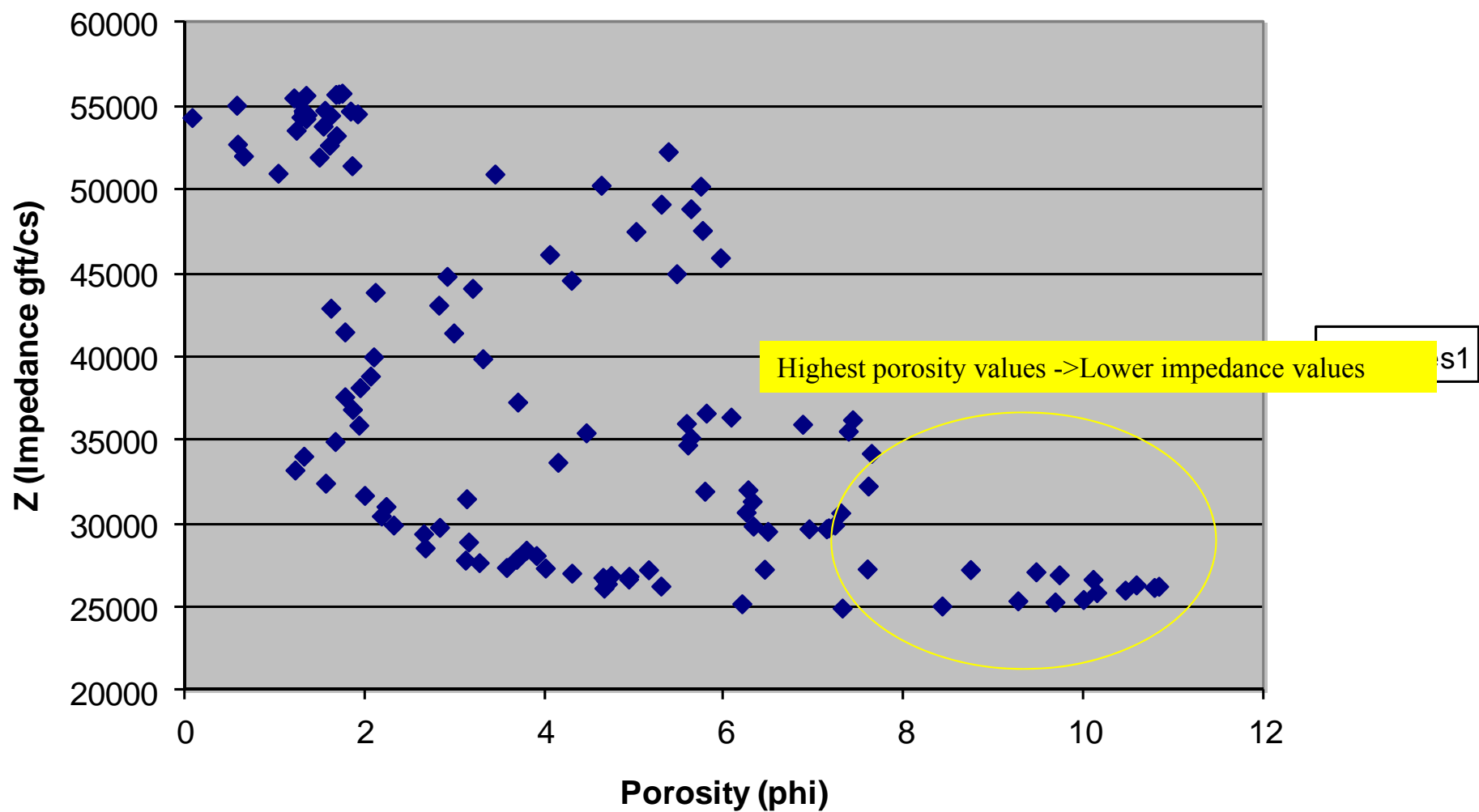
## Workflow

- Data QC- Seismic, wells and horizons
- Log calibration
- Wavelet estimation
- Low Frequency model
- Inversion
- 3 wells were used
- Inversion performed using a constant phase wavelet.

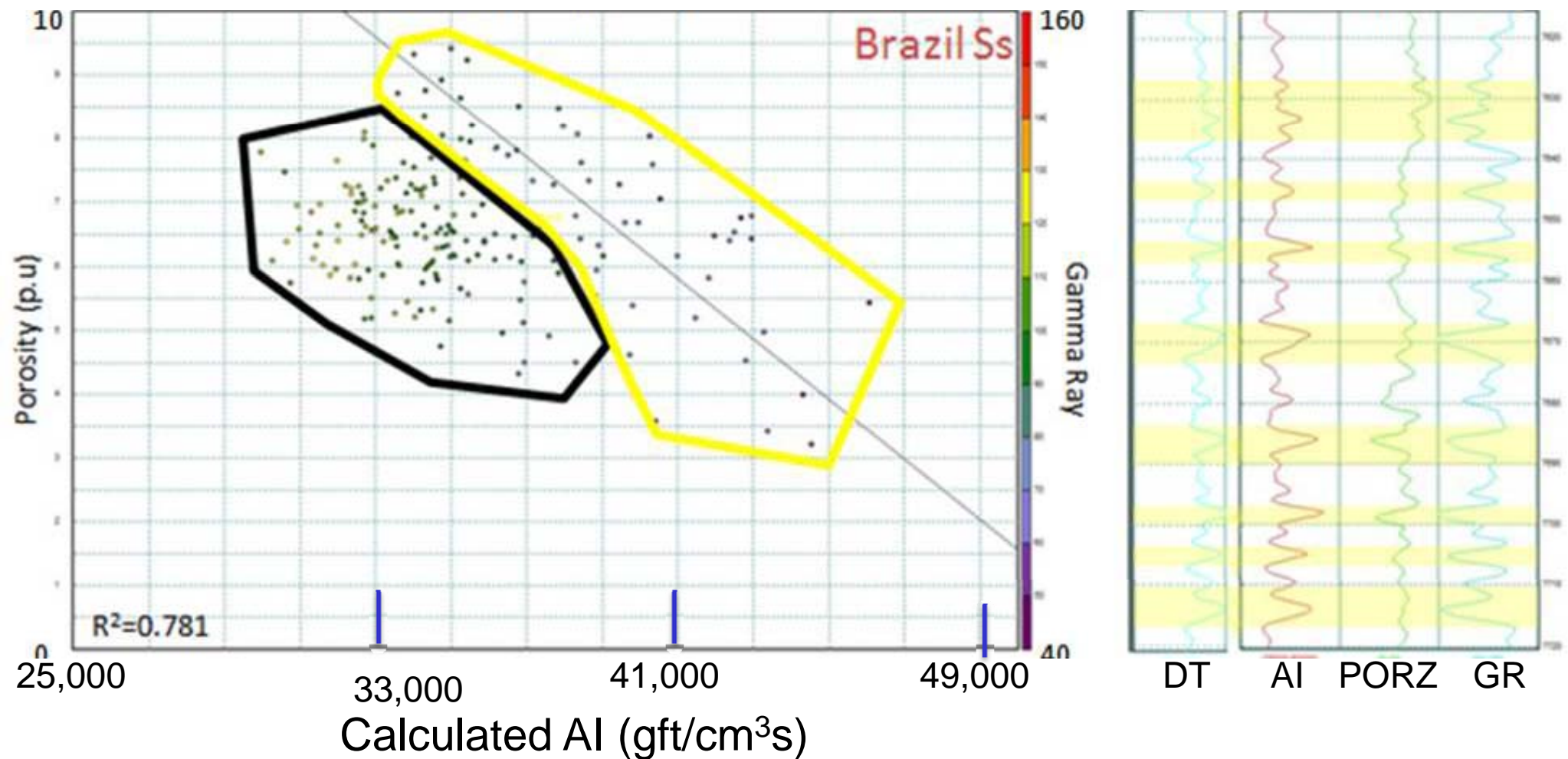
10577-10646 depth interval (69ft thick) structurally higher Spiro



11584-11646 (62 ft thick) Structurally lower Spiro

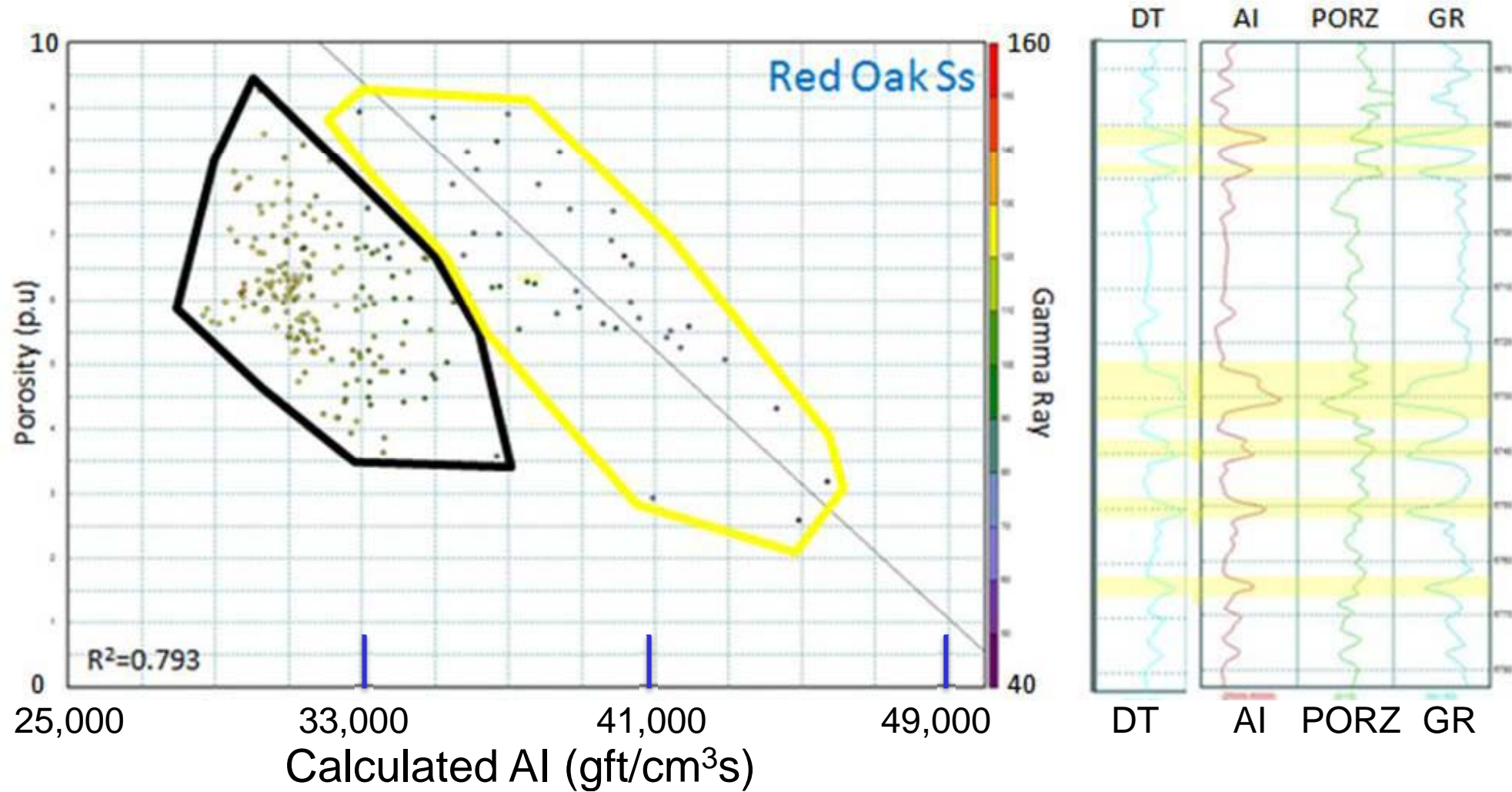


# Porosity vs Seismic Impedance: Brazil Sandstone



Cross-plots of porosity versus acoustic impedance for sandy (yellow polygon) and shaly (black polygon) portions of the Brazil Sandstone. Sand portions are marked with yellow on the logs. Points in yellow polygon are the sandy portions of the interval and points in black polygon are the shaly portions of the interval. DT=Sonic; AI=Acoustic Impedance PORZ=Porosity GR=Gamma Ray

# Porosity vs Seismic Impedance: Red Oak Sandstone



Cross-plots of porosity versus acoustic impedance for sandy (Yellow polygon) and shaly (Black polygon) portions of the Red Oak Sandstone. Sand portions are marked with yellow on the logs. Points in yellow polygon are the sandy portions of the interval and points in black polygon are the shaly portions of the interval. DT=Sonic; AI=Acoustic Impedance PORZ=Porosity GR=Gamma Ray

## **CONCLUSIONS**

- There is a relatively good correlation between the seismic impedance and porosity where reservoir is an homogenous, thick sandstone (at least 100 feet) like the Spiro Sandstone.
- A linear correlation between calculated acoustic impedance and porosity in the sandstone portions of the Red Oak and Brazil rock units also exists. Higher porosities in these two sandstone reservoirs are correlated with areas of lower acoustic impedance within the sandstone portions of the units.
- However, interbedded shale units within the Brazil and Red Oak reservoirs appear to inhibit a reliable correlation between the seismic acoustic impedance and porosity.