Integrated Tectonic and Petrophysical Investigation of the Williston Basin Sediments in and around the Weyburn CO_2 Sequestration Reservoir

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Introduction

As a part of Phase I of the International Weyburn CO_2 Sequestration Project, regional seismic investigations have been conducted around a 100 km radius of the reservoir in Southern Saskatchewan. The objective is to answer the following question: Do the tectonic, petrophysical and rheological properties of the sedimentary fill guarantee the permanent storage (~10000 years) of CO_2 in the region?

Regional Setting and Tectonics

To achieve this goal, 2000 km of industry-donated seismic reflection data and over 1000 boreholes and related wireline information, as well as a 15 km^2 3D seismic coverage of the reservoir were analyzed (Fig. 1a and 1b)

Eleven seismically recognizable geologic (structural) horizons were mapped from top of the Cretaceous to the basement unconformity. These are: 2nd White Specs, Lower Colorado, Manville, Upper Watrous, Lower Watrous top, Lower Watrous bottom /top of Midale/, Bakken, Prairie Evaporite, Winnipegosis, Winnipeg, Deadwood and Precambrian.

An integrated analysis of these structural horizons over 100 seismic sections was used to map the regional structural setting of the sedimentary fill and the top of the Precambrian (Fig. 2). By establishing a correlation between the basement structures and the disturbances in the sedimentary column, the influences of deep epirogenic movements on the development of the investigated part of the basin has been determined.

To date, the integration of seismic and borehole data has led to a better delineation of a number of prominent regional geologic structures (e.g. Roncott Anticlinorium, Missouri Coteau, Elbow-Hummingbird Monoclinal Flexure, Brockton-Froid-Fromberg Fault zone and the Nesson Arch. Furthermore this effort also yielded enhanced images of previously known and some newly identified ring-faults.

The resolution of the ages of the epirogenic movements in the region, which generated the mappable structures, is an important issue. A number of faults and their temporal extent were recognized on the seismic sections. All the faults recognized to date and the time period through which they were active will be illustrated.

Moreover, within an area designated as a ‘Risk Assessment area’ in the immediate vicinity of the reservoir, two previously unknown fault zones were identified on the 3D seismic data set (Fig. 3).

In the investigated area no large scale regional tectonic elements intersect the Weyburn field. There are, however, recognizable structural disturbances present; their properties and historical influences on the reservoir and its vicinity are under investigation.

Petrophysics

Further analyses were done to set up a 3 dimensional volumetric model for the Lower Watrous reservoir seal including the seismic inversion of the long regional section (Fig. 4). The Lower Watrous is a complex 40 m thick siltstone-sandstone sequence interbedded with nodular anhydrite and anhydritic claystones. Porosity and shale content mappings of this critical unit above the reservoir were carried out on a combined borehole/wireline and seismic datasets. The different 3D stochastic geostatistical models, which can be set up for the Lower Watrous, are also included in the study (Fig.5).

Conclusion

Although many small scale structural disturbances (i.e. fault with small offsets/local flexures) have been identified above the reservoir in the Weyburn field, it is presently not possible to know with certainty, if these faults extend through the regional seal, act as a potential migration path way for CO_2.

The knowledge of the geometry (derived from integrated analysis of the seismic and the borehole data) and the physical/geochemical properties of the rock volume (derived from the well logs and core data) will be required to resolve the above stated uncertainties.

Comment: Some other details of the investigation will be presented at the poster session.

Acknowledgements

This research is conducted through the generous support of the following sponsors:

Industry: BP (British Petroleum), ChevronTexaco, Dakota Gasification Co., Engineering Advancement Assoc. Of Japan, EnCana Corporation, Nexen Inc., SaskPower, Total, TransAlta Utilities. Government: Alberta Energy Research Institute, European Community, Natural Resources Canada, Petroleum Technology Research Centre, Saskatchewan Industry and, Resources, US Department of Energy We thank Schlumberger-GeoQuest-Petrel, Hampson-Russell Software Services Ltd., and the Landmark Graphics Corp. for maintaining a multifaceted system in our laboratory.

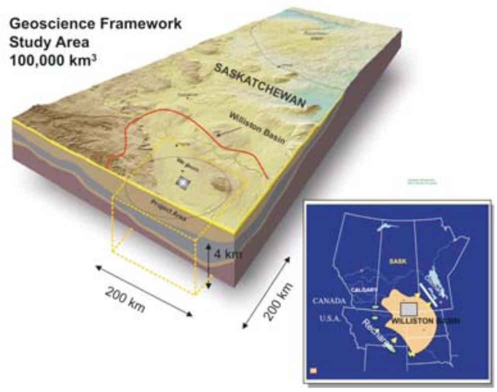

Figure 1a. Regional extension of the investigated area (with 100 km radius circle around the Weyburn Field.

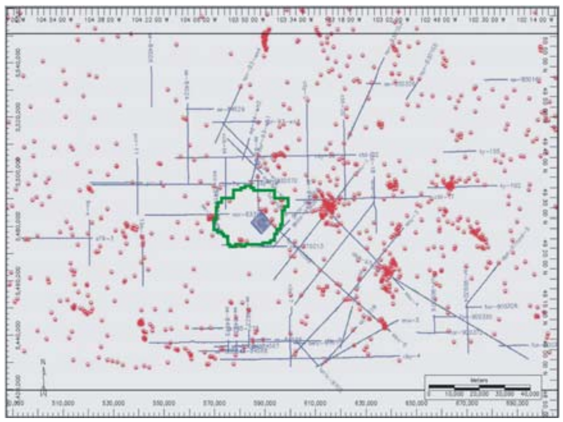

Figure 1b. Basemap with wells (red circles), seismic sections (blue lines) and the outline of the Weyburn field (green polygon).

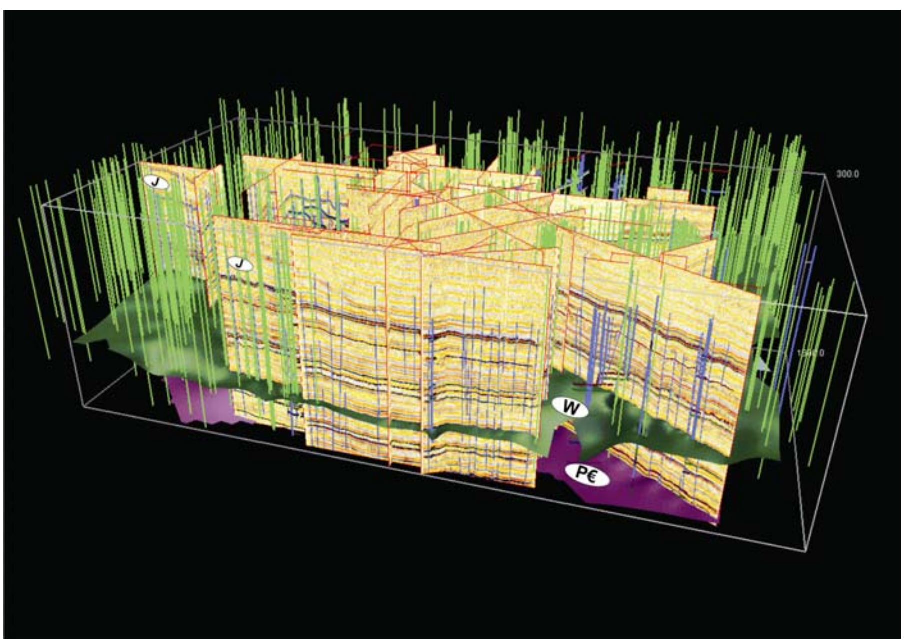

Figure 2. 3D network presentation of all seismic sections (subhorizontal lines indicate the reflective horizons) and the 1000 boreholes (green lines). Blue lines identify the recognized faults. "P€" illustrates a segment of the new Precambrian unconformity. Similarly "W" is the structural map of the Winnipegosis horizon. J = Judith River clinoforms.

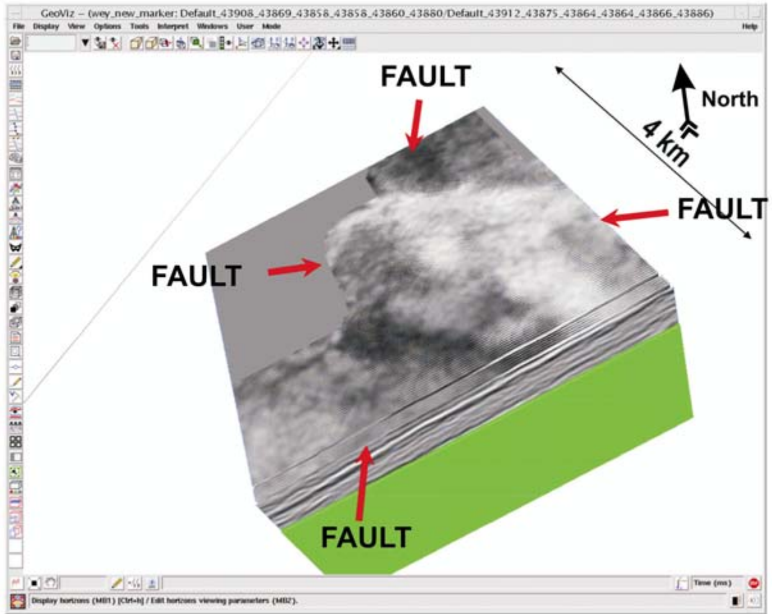

Figure 3. 3D seismic volume within the Weyburn field. The CDP distance is 25 meters in both (X-Y) directions. The "Variance Cube" algorithm was applied to the dataset which is a special statistic based algorithm to enhance the fault pattern recognition. The cube was horizontally sliced at the level of the Prairie Evaporite. Two main previously unknown faults directions are discovered and fully visible. These two directions coincide with the regional trends and at the same time with the measured fracture directions on the core samples in the Weyburn field.

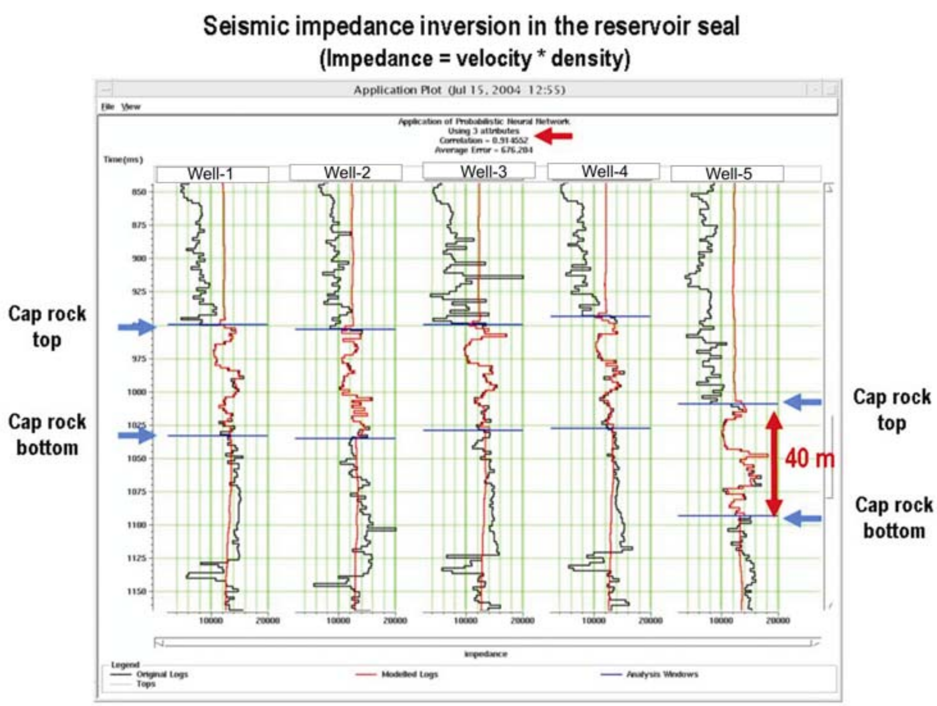

Figure 4. The basis of the joint (well log/seismic) porosity estimation lies in the seismic impedance inversion of the reservoir seal. The original logs derived from the acoustic velocity and density are in black. The red curves show the impedance values obtained from the seismic data; the procedure was limited to the caprock only. The correlation between the impedances derived from the well-logs and the seismic data was enhanced from about 60% to 91 % using the neural network algorithm. It is important to note that a resolution of about 2,5 m has been achieved (in the 40 meter thick zone the distance between two kinks of the curves is 2,5 m).

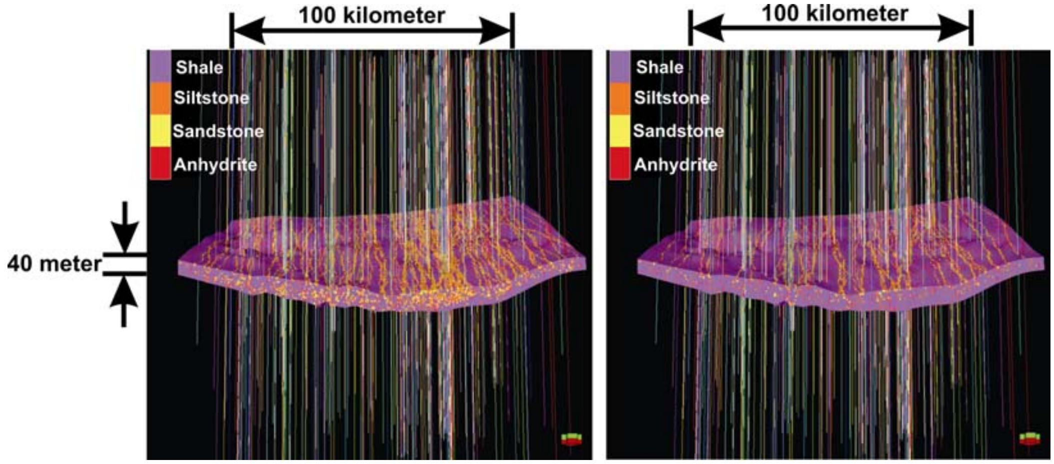

Figure 5. a and b. Extending the well-log analyses (based mainly on acoustic, density and gamma-ray logs) to 350 appropriate boreholes (vertical lines) different stochastic geostatistical model can be set up for the Lower Watrous.The method is based on Clayton V. Deutsch's procedure in geostatistical reservoir modeling. As an example, Figure 5.a and b show the subdivisions of this unit when the a priori assumptions are 20% or 5% of the sandstone units are fluvial/shallow marine channels or levees (view from south). Such models can be further enhanced by more detailed knowledge about the direction of the sedimentation based on core data and by incorporating the results of the impedance inversion (Figure 4.) along the long seismic lines as linear trends.

References

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