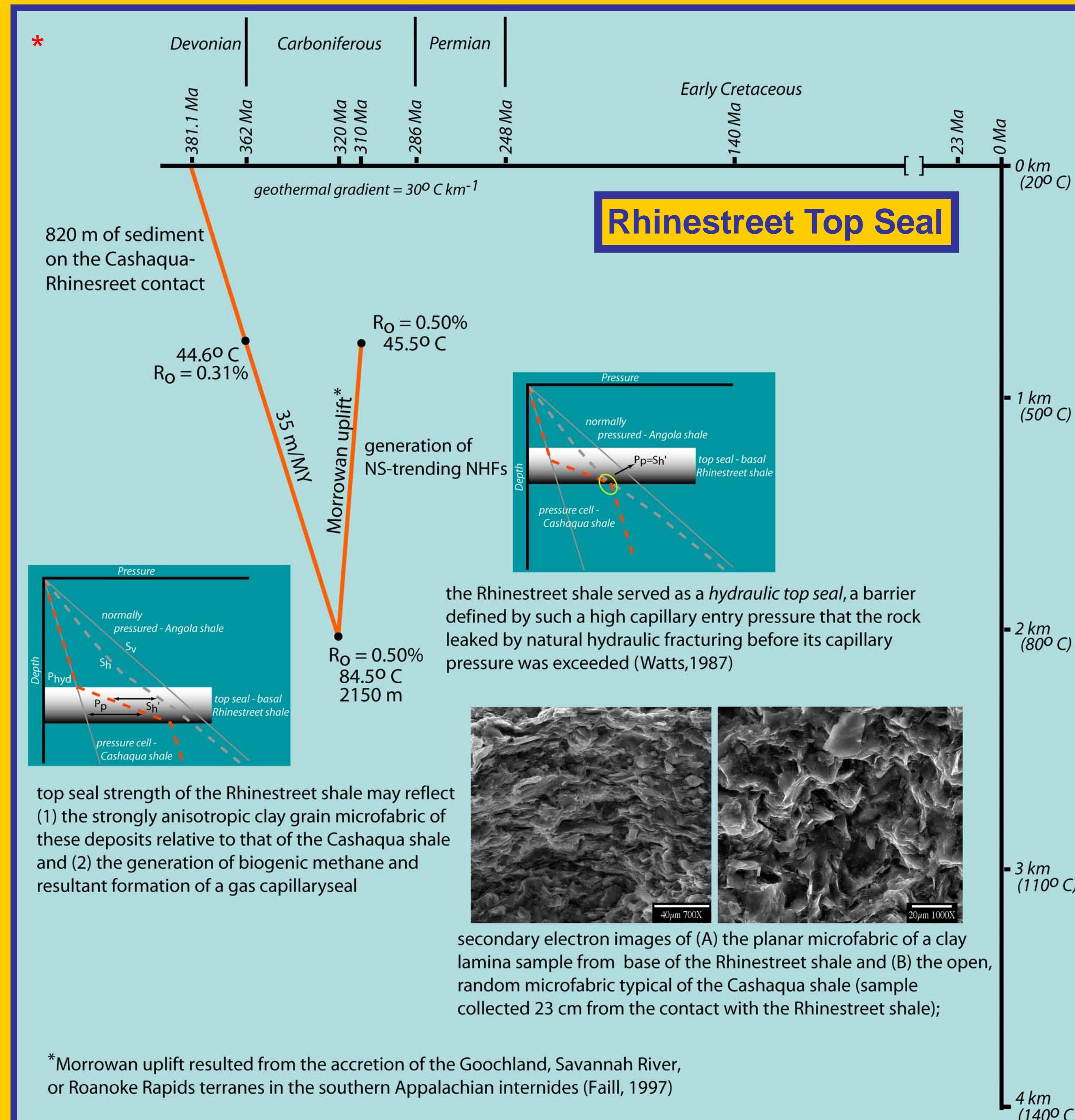
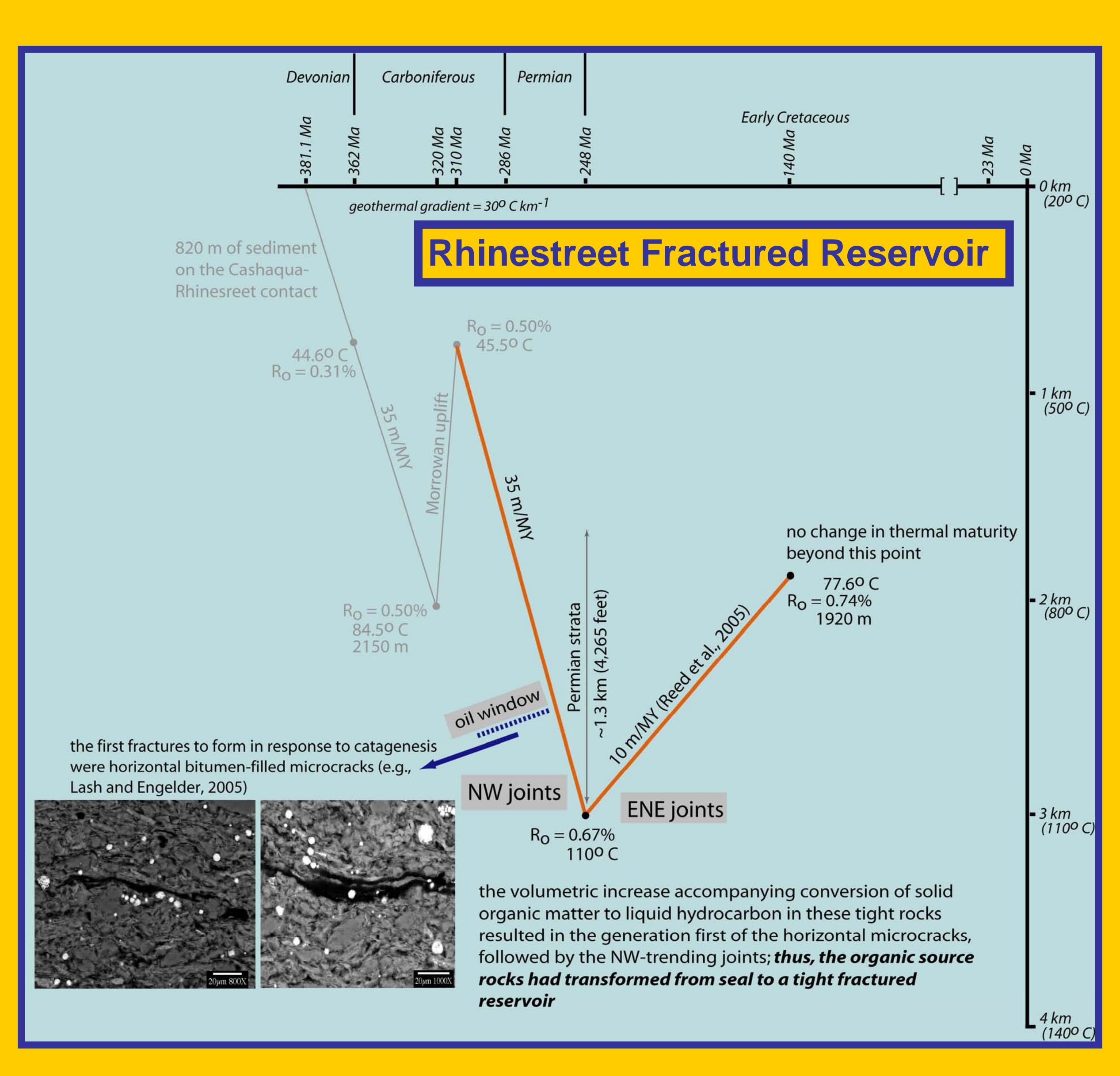


## JOINTING AND THERMAL (BURIAL) HISTORY: FROM SEAL TO FRACTURED RESERVOIR

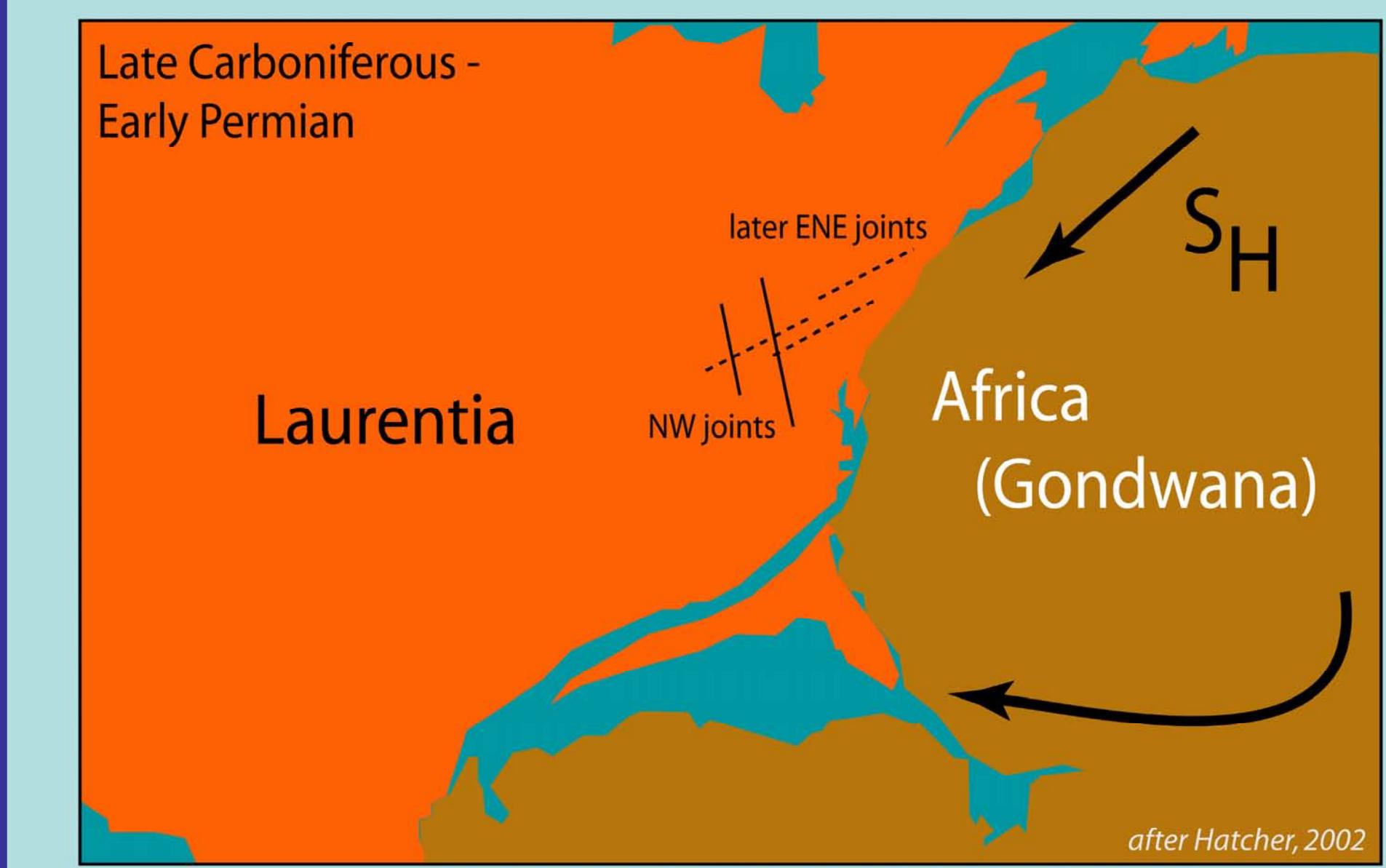
The concentration of NS-trending joints in the upper part of the Casahaqua gray shale and at the base of the Rhinestreet shale, as well as the upper contacts of gray shale intervals within the Rhinestreet shale, suggests that natural hydraulic fracturing was not linked to the thermal generation of hydrocarbons in the Rhinestreet shale. Indeed, the NS joints likely formed before the Rhinestreet was buried deep enough to produce thermally generated hydrocarbons. However, disequilibrium compaction, common to deeper shales within regressive deltaic sequences (e.g., Burrus et al., 1993), alone appears insufficient to generate fluid pressures capable of driving NHFs (Hart et al., 1995; Kooi, 1998). Propagation of the NS-joints prior to the entry of the Rhinestreet shale into the oil window may reflect Morrowan uplift of the basin related to accretion of the Goochland, Savannah River or Roanoke River terranes in the Southern Appalachian internides (Faill, 1997).



\*The EASY%Ro kinetic model of vitrinite reflectance (Sweeney and Burnham, 1990), used to model the burial/thermal history of the Rhinestreet black shale, requires knowledge of (1) the age(s) of the unit(s) of interest (the base of the Rhinestreet shale), (2) at least a partial thickness of the local stratigraphic sequence, and (3) the measured vitrinite reflectance of the unit(s) of interest (average vitrinite reflectance of the base of the Rhinestreet shale = 0.74%). We estimate that the Casahaqua shale exposed along Lake Erie was overlain by as much as 850 m of Devonian strata and that the age of the base of the Rhinestreet shale can be dated by the Belpre ash bed at ~ 381 Ma (Tucker et al., 1998). Finally, our model assumes a geothermal gradient of  $30^{\circ} \text{C km}^{-1}$  and a 20°C seabed temperature (e.g., Gerlach and Cercone, 1993).



The remote stress field appears to have undergone a major change in orientation by the time the ENE joints formed. The strongly oriented character of ENE joints may reflect the Early Cretaceous change in the remote stress system from one dominated by rift-related dynamics to one of compression caused by sea floor spreading of the North Atlantic Ocean (Miller and Duddy, 1989). Alternatively, the ENE joints formed in response to Alleghanian dextral plate dynamics, as shown in the figure below.



## CONCLUSIONS

The Rhinestreet shale, like other Upper Devonian organic-rich shale units of western New York State, served as a top seal early (pre-catagenesis) in its burial history;

Compromise of the top seal by a combination of natural hydraulic fracturing elastic contraction prior to entering the oil window may have resulted from widespread uplift and consequent reduction of confining pressure ( $Sh$ ) of the basin during Morrowan time;

Passage of the Rhinestreet shale into the oil window is first recorded by formation of horizontal bitumen-filled microcracks, followed by NW-trending joints that record the Late Carboniferous-Early Permian collision of Africa and Laurentia related to the clockwise rotation of Gondwana;

ENE-trending joints propagated soon after the NW joints probably as a consequence of further oblique convergence of Gondwana and Laurentia;

Those features of the Rhinestreet shale that made it such a strong seal prior to entry into the oil window, the strongly oriented clay grain microfabric and flattened ductile organic particles, resulted in pressurization of these rocks during catagenesis and consequent propagation of natural hydraulic fractures (NW- and ENE-trending joints).

## REFERENCES

- Burrus, J., Osadetz, K., Gaulier, J.M., Brosse, E., Doligez, B., Choppin de Janvy, G., Barlier, J., and Visser, K., 1993. Source rock permeability and petroleum expulsion efficiency: modelling examples from the Mahakam delta, the Williston Basin and the Paris Basin, in , Parker, J.R., editor, *Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference*: The Geological Society, London, p. 1317-1332.
- Engelder, T., and Fischer, M.P., 1996. Loading configurations and driving mechanisms for joints based on the Griffith energy-balance concept: *Tectonophysics*, v. 256, p. 253-271.
- Engelder, T., and Geiser, P.A., 1980. On the use of regional joint sets as trajectories of paleostress fields during the development of the Appalachian Plateau, New York: *Journal of Geophysical Research*, v. 94, p. 6319-6341.
- Engelder, T., and Oertel, G., 1985. The correlation between undercompaction and tectonic jointing within the Devonian Catskill Delta: *Geology*, v. 13, p. 863-866.
- Engelder, T., Haith, B.F., and Younes, A., 2001. Horizontal slip along Alleghanian joints of the Appalachian plateau: evidence showing that mild penetrative strain does little to change the pristine appearance of early joints: *Tectonophysics*, v. 336, p. 31-41.
- Faill, J.B., 1997. Former Carboniferous overburden in the northern Appalachian Basin: a reconstruction based on vitrinite reflectance: *Organic Geochemistry*, v. 20, p. 223-232.
- Hart, B.S., Flemings, P.B., and Deshpande, A., 1995. Porosity and pressure: Role of compaction disequilibrium in the development of geopresures in a Gulf Coast Pleistocene basin: *Geology*, v. 23, p. 45-48.
- Hatcher, R.D., Jr., 2002. Alleghanian (Appalachian) Orogeny, a product of zipper tectonics: rotational transpressive continent-continent collision and closing of ancient oceans along irregular margins: *Geological Society of America Special Paper* 364, p. 199-208.
- Kooi, H., 1997. Insufficiency of compaction disequilibrium as the sole cause of high pore fluid pressures in pre-Cenozoic sediments: *Basin Research*, v. 9, p. 227-241.
- Lacazette, A., and Engelder, T., 1992. Fluid-driven cyclic propagation of a joint in the Ithaca siltstone, Appalachian Basin, in Evans, B., Wong, T.-F., editors, *Fault Mechanics and Transport Properties of Rocks*: Academic Press, London, p. 297-324.
- Ladeira, F.L., and Price, N.J., 1981. Relationship between fracture spacing and bed thickness: *Journal of Structural Geology*, v. 3, p. 179-183.
- Lash, G.G., and Loewy, T., 2004. Preferential jointing of Upper Devonian black shale, Appalachian Plateau, USA: evidence supporting hydrocarbon generation as a joint-driving mechanism, in J. Cosgrove and T. Engelder, eds., *The initiation, propagation, and arrest of joints and other fractures*: Geological Society, London, Special Publications, 231, p. 129-151.
- Luther, D.D., 1993. Stratigraphy of the Portage Formation between the Genesee Valley and Lake Erie: New York State Museum Bulletin 69, p. 1000-1029.
- McConaughay, D.T., and Engelder, T., 1999. Joint interaction with embedded concretions: joint loading configurations inferred from propagation paths: *Journal of Structural Geology*, v. 21, p. 1637-1652.
- Miller, D.S., and Duddy, I.R., 1989. Early Cretaceous uplift and erosion of the northern Appalachian Basin, New York, based on apatite track analysis: *Earth and Planetary Science Letters*, v. 93, p. 35-49.
- Reed et al., 2005.
- Sweeney, J., and Burnham, A.K., 1990. Evaluation of a simple model of vitrinite reflectance based on chemical kinetics: *American Association of Petroleum Geologists Bulletin*, v. 74, p. 159-1570.
- Tucker, R.D., Bradley, C.R., Ver Steeren, C.A., Harris, A.G., Ebert, J.R., and McCutcheon, S.R., 1998. New U-Pb zircon ages and the duration and division of Devonian time: *Earth and Planetary Science Letters*, v. 158, p. 175-186.
- Watts, N.L., 1987. Theoretical aspects of cap-rock and fault seals for single- and two-phase columns: *Marine and Petroleum Geology*, v. 4, p. 274-307.