Trenton and Black River Carbonates in the Union Furnace Area of Blair and Huntingdon Counties, Pennsylvania

A Field Trip Guidebook for the Eastern Section AAPG Annual Meeting, September 10, 2003 and the PAPG Spring Field Trip, May 26, 2004

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Ordovician Carbonates in Central Pennsylvania

Introduction

Carbonate rocks of the Upper Ordovician Trenton and Black River Formations are the targets of active petroleum exploration in western and north central Pennsylvania (Figure 6), as well as the rest of the Appalachian basin. The potential reservoir targets are fractured dolostone or limestone traps in narrow grabens that are related to basement structures (Avary, 2002). Although this is a seismic play searching for structural traps, the sedimentary geology of the Trenton and Black River Formations is also critical to exploration efforts. The distribution of porous and permeable carbonate facies undoubtedly influenced the subsurface fairways traveled by dolomitizing fluids; in many instances these fluids initially entered the Trenton and Black River rocks along vertical fractures related to faulting, but then spread out laterally through permeable grainstones (Colquhoun and Trevail, 2000). In these cases understanding the sedimentary history of the carbonates means understanding their reservoir storage capacity. The spatial distribution of reservoir seals, reservoir compartmentalization, and diagenetically controlled pore geometry are partially or wholly sedimentological features. The Trenton/Black River play is basin wide in scope, and accurate stratigraphic correlations and analyses are necessary for rigorous petroleum exploration and development (Figure 7). Sequence stratigraphic analysis promises to provide such correlations and analyses (Cornell and others, 2001), but robust facies analyses must first be available before high-resolution surface and subsurface sequence stratigraphy can be accomplished (see Pope and Read, 1997). Finally, the sedimentary geology of the Trenton and Black River Formations has a direct bearing on understanding the petroleum source rocks of this play, as well as the migration and accumulation of oil and gas in these rocks (Ryder and others, 1998; Obermajer and others, 1999).

The primary purpose of this field trip is to acquaint geologists with the complex diversity of carbonate depositional facies that characterize the Trenton and Black River Formations in Pennsylvania. In addition to all of the reasons listed above, such an acquaintance can facilitate core and cutting sample interpretations in subsurface work. These rocks also have been the target of petroleum exploration here in the Valley and Ridge province. We will comment on the hydrocarbon potential of these rocks in the deep plateau and Ridge and Valley here in central Pennsylvania. We also wish to share with you the exciting economic geology of these rocks in this region, and hope you find the other uses people put these carbonates to as interesting as we do. Finally, as a side benefit to our excursion here today, we will casually examine some of the most spectacular karst features found in Pennsylvania, and learn a little bit of history concerning some remarkable underground explorations literally happening beneath our feet.

Setting

During Ordovician time, Pennsylvania comprised a tiny portion of the Laurentian craton, lying about 25° south of the equator (Figure 8). From Late Precambrian through Middle Ordovician time, this region was part of an eastward-thickening, miogeoclinal basin that accommodated mostly carbonate platform sediments (Thompson, 1999). These carbonate rocks constitute part of the " Great American Bank" (Ginsburg, 1982) that extended more than 3,000 km (1,864 mi) along nearly the entire length of what was the southern seaboard of the Laurentian continental mass (Figure 3). The platform prograded eastward through Cambrian and Early Ordovician time, and its eastern terminus seaward was at a continental slope beyond which lay deep ocean basin sediments. Beginning in the Middle Ordovician, the craton margin was uplifted during the Taconic orogeny (Faill, 1999). The platform was progressively submerged. The Appalachian basin changed from a miogeoclinal carbonate platform to an exogeosynclinal foreland molasses basin (Thompson, 1999). This basin received large amounts of terrigenous sediment from eastern highlands, which were deposited in the foreland basin as the Taconian clastic wedge.

The distribution of landmasses and oceans suggested for the late Middle and early Late Ordovician (Figure 9) should have affected global seasonal weather patterns essentially the same as we experience today (Wilde, 1991), but with the northern and southern hemispheres reversed. Summer months feature low pressure air masses developing over large landmasses, resulting in the flow of large amounts of moist air (monsoons). Because landmasses were essentially restricted to the southern hemisphere at this time (Figures 8 and 9), monsoons would have occurred only in that hemisphere. Anti-trade monsoonal winds generated along the coast of Gondwana drove warmer water northward between Siberia and Kazakhstan, countering the flow of cooler water from northern midlatitude high pressure systems. Because Pennsylvania lay on the southwest-facing coast of Laurentia around 25^{o} south latitude, the dominant winds would have been trades similar to Recent trade winds, with some variation due to continental configurations. Warm maritime air from the Iapetan embayment between Laurentia and Siberia (Figure 9) would have provided abundant rainfall from the equator to about 35^{o} or 40^{o} south latitude.

The Ordovician stratigraphic record in Pennsylvania reflects the control of tectonics and paleogeography on sedimentation (Figure 10). Lower and Middle Ordovician rocks tell the tale of prolonged passive margin carbonate accumulation in semi-arid conditions. Upper Ordovician clastics reveal a history of basin filling by marine and terrestrial clastics on a continental margin subjected to moist air traveling westward in lower latitude. In between are the Upper Ordovician Trenton and Black River Formations, and their equivalents, which were deposited during the transition from passive margin carbonates deposited on the Great American Bank to foreland deposition of the Taconian clastic wedge, subjected to transitional climates. These carbonate rocks developed on a northeast-trending ramp that lay northwest of the Taconic foreland basin (Read, 1980). The Trenton and Black River Groups of central Pennsylvania reflect the transition from carbonate shelf to ramp in response to flexure and increasing down warping due to the growing Taconic orogeny to the southeast. Subjacent Cambrian carbonates, the Lower to Middle Ordovician Beekmantown Group, and the Middle Ordovician Loysburg Formation were deposited on a rimmed carbonate shelf, with restricted circulation and wave action, on which vast peritidal and shallow water carbonate facies flourished (Goldhammer and others, 1987; Faill, 1999). With the reversal of plate motion that stopped the spreading of Iapetus, compressional down warping of the Laurentian continental margin occurred as the Taconic thrust belt approached from the east. Subsidence rates increased markedly beginning 460 ma, and marked the termination of the "Great American Carbonate Bank" (Goldhammer and others, 1987) (Figure 11). This stratigraphic sequence reveals the passive margin history of the eastern part of the Laurentian craton from Early Cambrian to Middle Ordovician time, and the shift to down warping that led to terminal drowning of the platform during Late Ordovician time.

Stratigraphic Nomenclature

Stratigraphic nomenclature for the Middle and Upper Ordovician rocks of central Pennsylvania is somewhat controversial. The stratigraphic column shown in Figure 10 represents that of the

Stratigraphic Correlation Chart of Pennsylvania (Berg and others, 1983), with some modification from Faill and others (1989). These authors replaced the name Nealmont Formation (Figure 7) with the name Rodman Formation (Figure 10). The Rodman is the upper member of the Nealmont Formation in previous schemes (see Rones, 1969 and Berg and others, 1983). Sudden, intricate facies changes, variations in stratigraphic thickness, and poor exposures make lithostratigraphic correlations outside of their type areas difficult. Leslie and Bergstrom (1997) showed that biostratigraphic studies based on graptolites and conodonts, and the use of K-bentonite beds and sequence boundaries as stratigraphic markers helps to lessen the confusion, but serious correlation problems within the Middle and Upper Ordovician Series still exist.

The Hatter, Snyder, and Linden Hall Formations of central Pennsylvania are equivalent to the Black River Formation of western Pennsylvania (Figure 7). Likewise, the Nealmont, Salona, and Coburn Formations in the outcrop are equivalent to the Trenton Formation of western Pennsylvania (Figure 7). Some workers have included the Hatter, Snyder, and Linden Hall Formations of central Pennsylvania in the Black River Group, and the Nealmont, Salona, and Coburn Formations in the Trenton Group (Cullen-Lollis and Huff, 1986; Leslie and Bergstrom, 1997). We use these group names in this guidebook.

K-Bentonites

Kolata and others (1996) identified and described 29 K-bentonites from the Mohawkian rocks of central Pennsylvania. Nineteen K-bentonites are recognized and designated at the Union Furnace outcrop along PA 453. We have identified another possible K-bentonite near the top of the Hatter Formation. Cullen-Lollis (1986) and Berkheiser and Cullen-Lollis (1986) discussed the K-bentonite occurrences here at the Union Furnace exposure. Six of the K-bentonites in the Salona Formation have unique chemical signatures, and are particularly useful for regional correlations (Kolata and others, 1996). Two of these, the Deicke (Figure 12) and Millbrig K-bentonites, have been especially useful in calibrating sequence stratigraphic correlations (Holland and Patzkowsky, 1996; Pope and Read, 1997).

There are several useful criteria for identifying the K-bentonites in the field (Kolata and others, 1996). The K-bentonites have a soapy, waxy texture when wet. They are light to dark gray, buff, orange, or tan in outcrop exposures. The variability is due to composition, variable oxidation due to ground water activity, and weathering. They appear greenish gray to bluish gray to white in cores. The K-bentonites may contain euhedral to anhedral flakes of biotite and relict glass shards. They also might contain euhedral crystals of zircon, feldspar, and apatite. The bentonites appear like fine-grained clay bands that might extrude under compactional loading by the carbonate rocks, but they weather and recess with exposure time. Chert bands in the limestones often underlie thicker bentonites. Many bentonite layers are overgrown with trees and shrubs due to the moist, nutrient-rich clay. The bentonite beds are stratigraphically persistent.

Geochemical fingerprinting of these bentonites involves discriminant function analysis of 26 variables (elements) and four groups (beds) (see Kolata and others, 1996). The chemistry of the bentonite discerns a volcanic ash origin from a calc-alkaline destructive plate margin volcanic setting.

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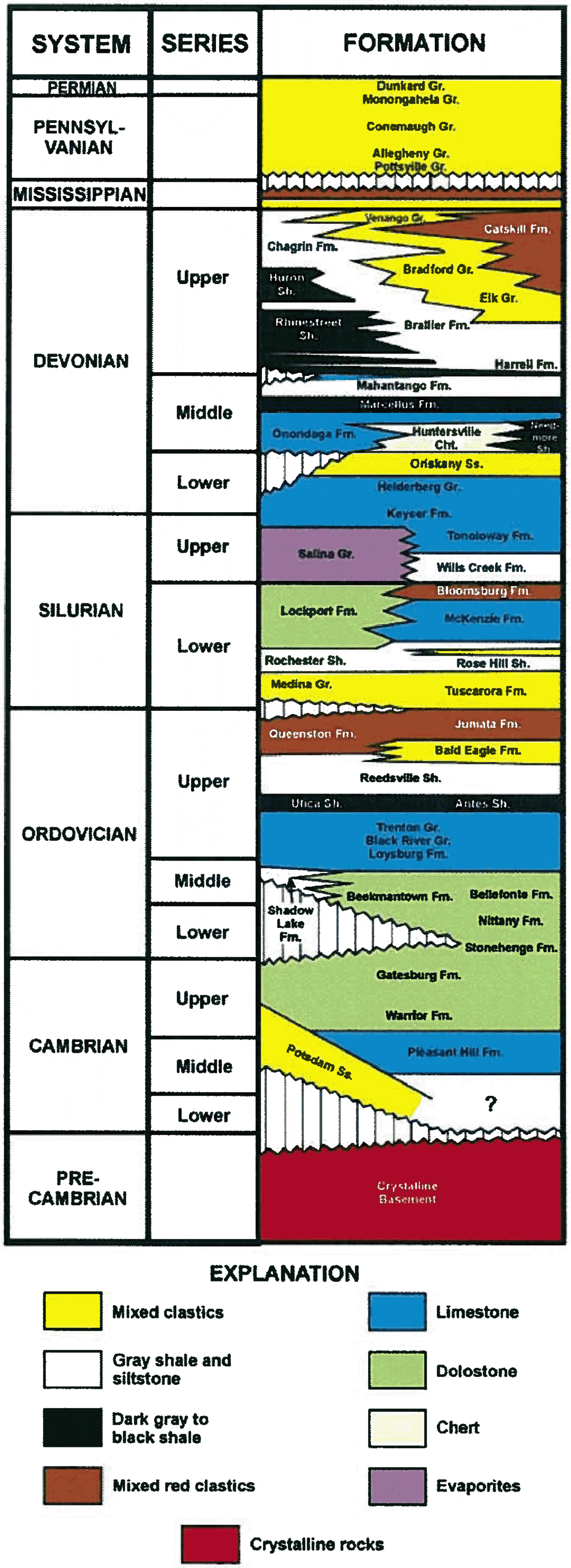


Figure 3. Generalized stratigraphic column representing the rocks exposed in the vicinity of the field trip route.

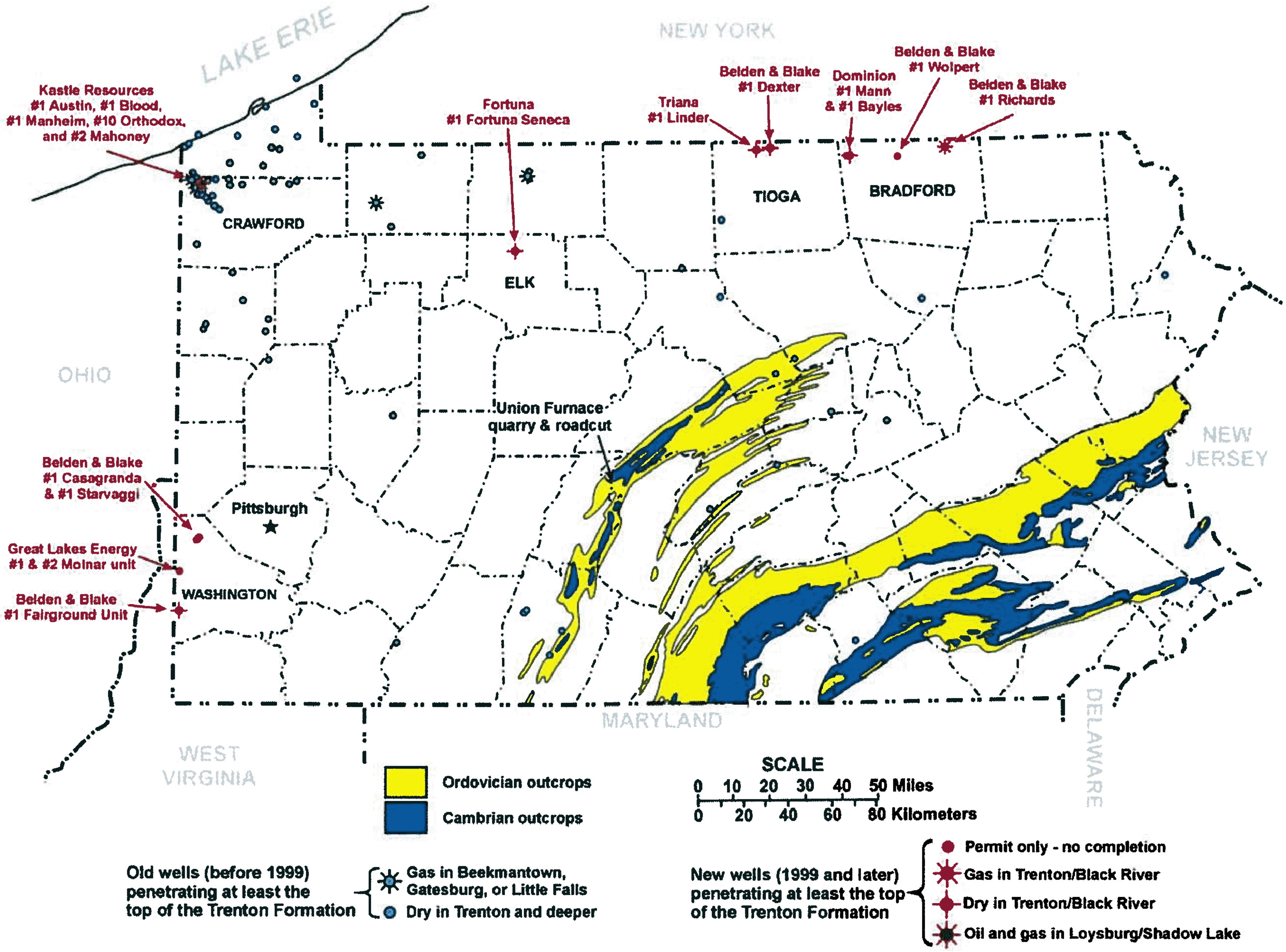


Figure 6. Location of Cambrian and Ordovician outcrops, wells that penetrate the top of the Trenton Group, and new permits for testing Trenton/Black River play in Pennsylvania. The location of the Union Furnace area is indicated.

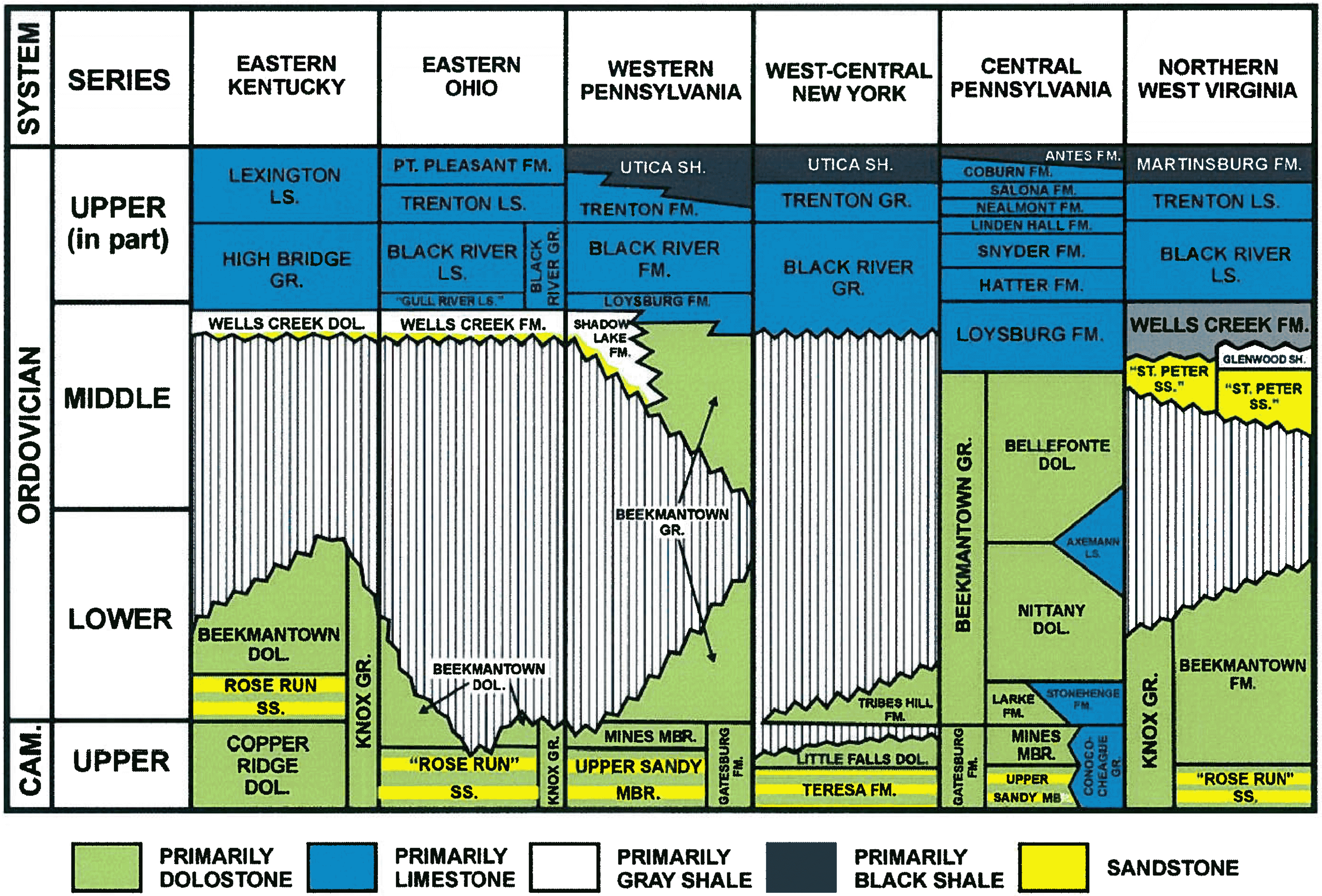


Figure 7. Regional lithostratigraphic correlation diagram for uppermost Cambrian and Ordovician rocks in the central Appalachian basin. We will examine the Coburn through Loysburg Formations of central Pennsylvania on this field trip.

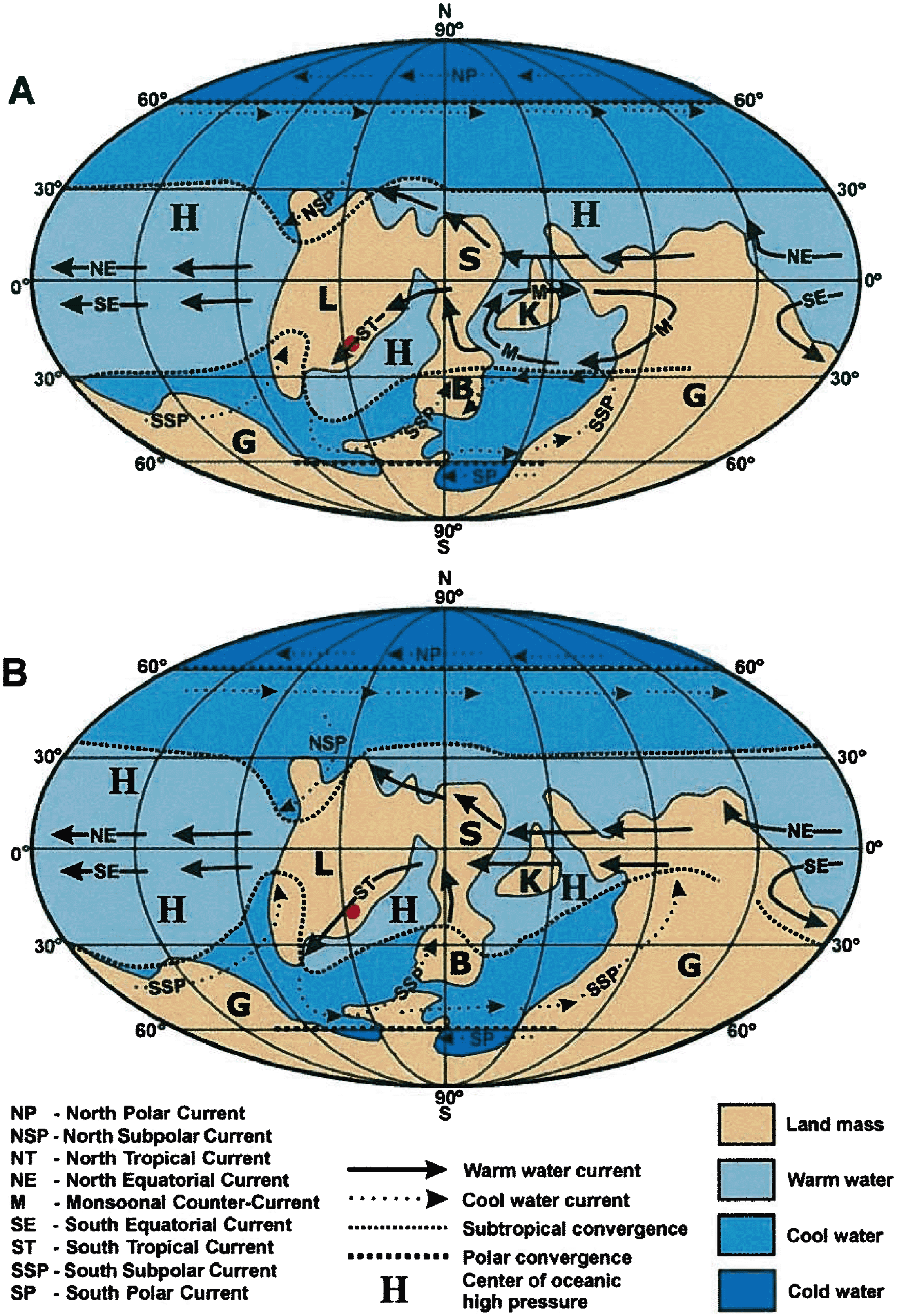
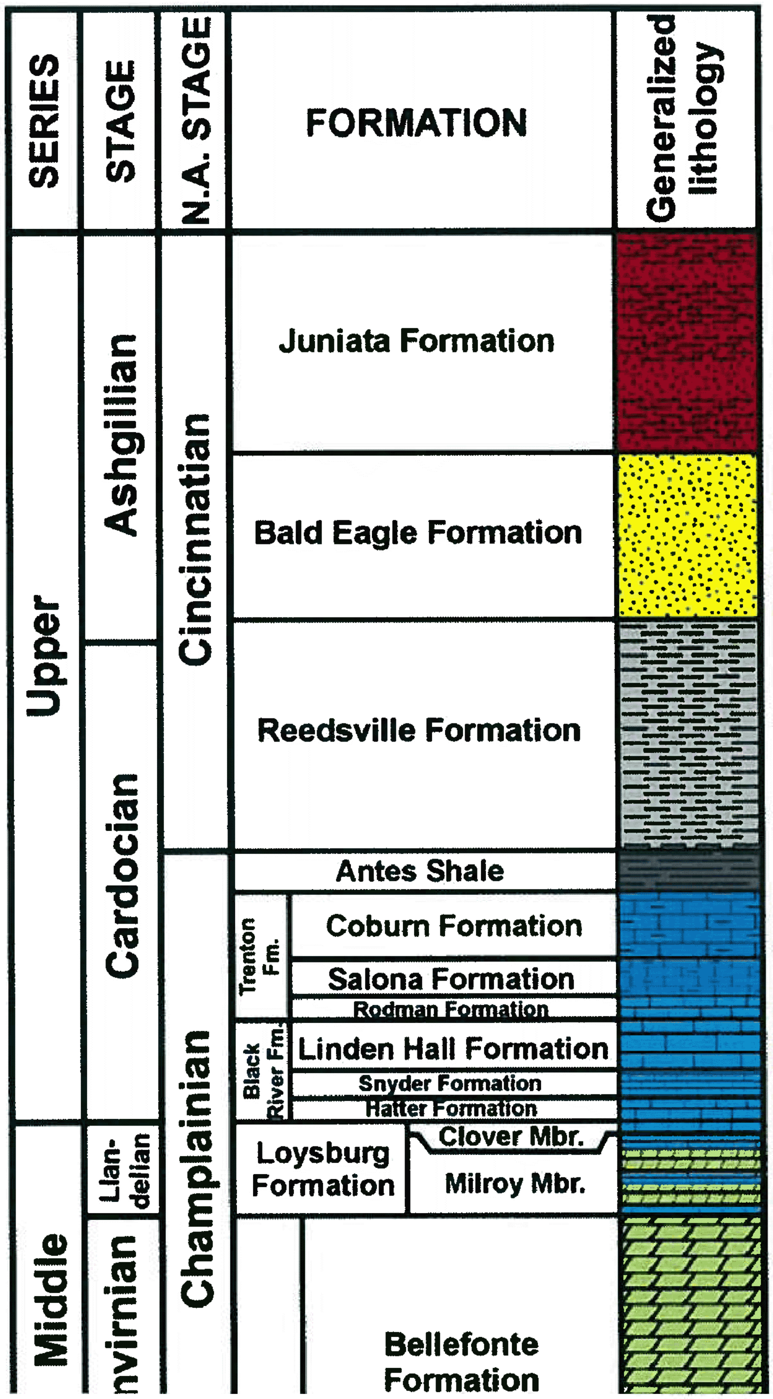


Figure 9. Paleoceanography of Earth during the Late Ordovician (modified from Wilde, 1991). A – Southern hemisphere summer and northern hemisphere winter. B – Southern hemisphere winter and northern hemisphere summer. Continents and seas are the same as those in Figure L-3. The red dot is the approximate location of the Union Furnace area. B – Balto-Scandinavia. G – Gondwana. K – Kazakhstan. L – Laurentia. S – Siberia.


SERIES
STAGE
N.A. STAGE
FORMATION
Generalized lithology
Upper
Middle
Ashgillian
Cardocian
Llan-delian
nvirnian
Cincinnatian
Champlainian
Juniata Formation
Bald Eagle Formation
Reedsville Formation
Antes Shale
Trenton Fm.
Coburn Formation
Salona Formation
Rodman Formation
Black River Fm.
Linden Hall Formation
Snyder Formation
Hatter Formation
Loysburg Formation
Clover Mbr.
Milroy Mbr.
Bellefonte Formation

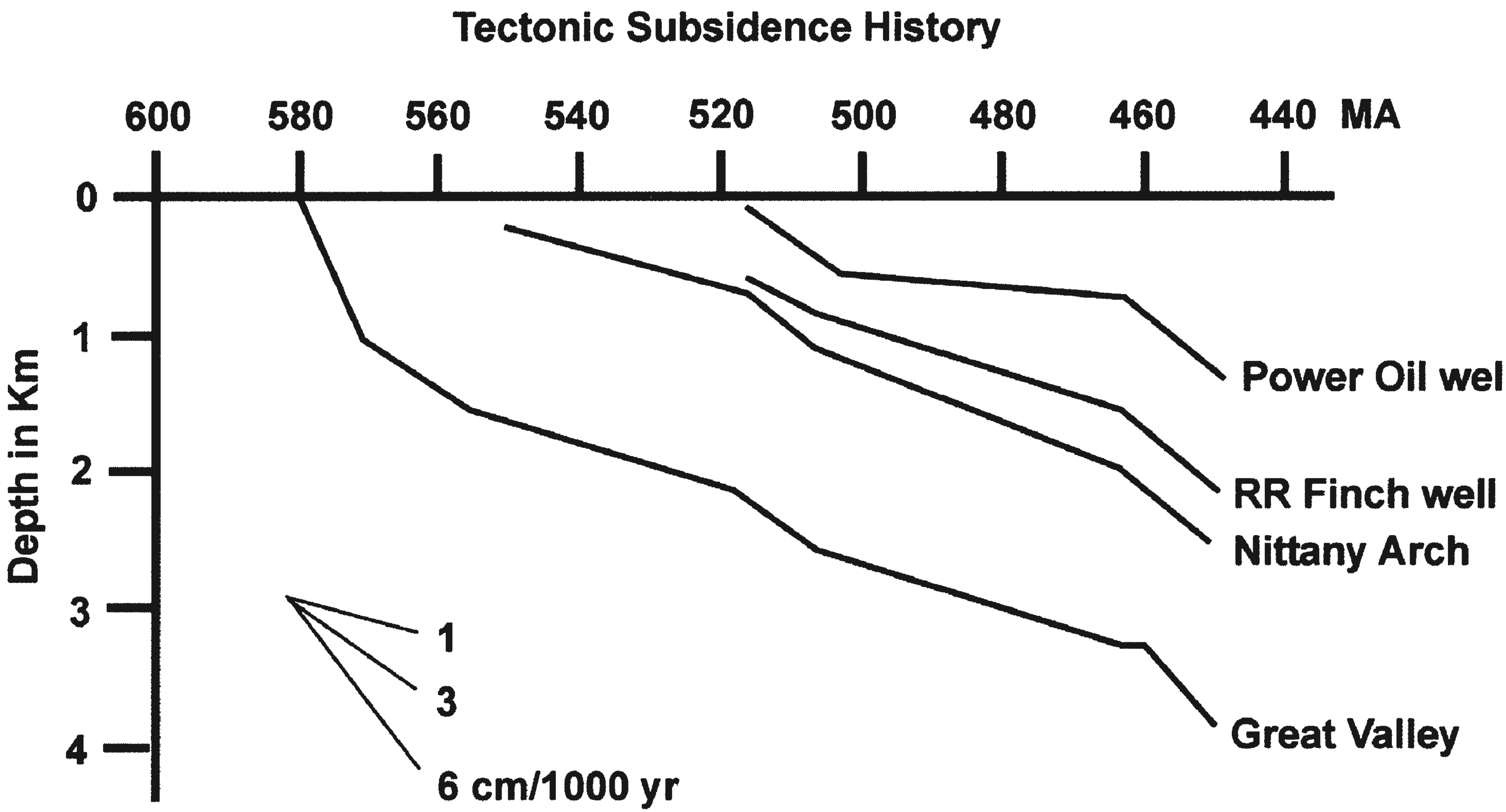


Figure 11. Ancient Appalachian tectonic subsidence history (modified from Goldhammer and others, 1987). Note the abrupt change in slope of the curves at approximately 460 ma. This time was the start of Black River sedimentation, and it marks the development of the carbonate ramp in response to the Taconic orogeny.

Figure 12. Photograph of the Deicke K-bentonite at the exposure along Pennsylvania Route 456 near Union Furnace, Pennsylvania.