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Devonian Gas Shales and Related Tight Reservoir Rocks of Appalachian Basin

Devonian gas shales, a sequence of brown to black, low-permeability laminated rocks that contain 2 to 16% by volume of organic matter, underlie more than 170,000 mi^2 (440,000 km^2) of the Appalachian basin, mainly under the Appalachian plateaus. Their volume exceeds 12,600 mi^3 (52,500 km^3), and they contain more than 3.3 trillion tons of gas-producing organic matter. Their permeability ranges from 0.1 to 10 microdarcys and their porosity from 1 to 4%. Although their total gas production has been only about 3 tcf during the past 160 yr (since 1821), mainly from the Big Sandy area of eastern Kentucky, their gas-in-place resource has been estimated in the range from 200 to 1,860 tcf. Shale gas is of low thermal maturity near the western outcrops, whereas dry gas deep in the basin to the east is of high thermal maturity. Because most of the shale-generated gas has been adsorbed by the organic components in the rock, gas shales must be broken by an extensive natural fracture system before they will yield gas in commercially exploitable volume. In the western part of the basin, gas shales are both source and reservoir for gas. To the east, dark gas shales interfinger with an eastward thickening sequence of low-permeability siltstone and sandstone turbidites. Where fractured, these more brittle beds are also reservoirs for gas migrating from adjacent gas shales. Successful exploitation of shale gas requires careful evaluation of geologic and engineering factors.

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Regional Source Rock Mapping Using Source Potential Rating Index

A method has been developed to combine sediment thickness, organic carbon content, and thermal maturity data from potential source rock units into a single mappable parameter which can be used to indicate areas of potential hydrocarbon generation. This is accomplished by taking the product of the average percent organic carbon and the effective source rock thickness of a formation to give a richness factor. The richness factor is then multiplied by maturity scaling factors to give source potential ratings for oil and/or gas generation. The rating values can be combined with kerogen-type data, if available, to refine these assessments of generating potential. The resulting ratings provide semiquantitative measures by which the source potential of a single formation can be compared within an area or the source potential of 2 or more formations can be compared in the same basin or different basins. By using burial history curves and thermal maturity modeling, the rating index can also be used to estimate source potential through geologic time.

Source potential rating index maps in conjunction with structural analysis of a basin can help the explorer explain the occurrence of already discovered hydrocarbon accumulations and point toward new areas for exploration. Examples are given of applications of rating index mapping to exploration problems in the Williston and Illinois basins.

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Thrust Faults that Violate Classic Thrust Belt Rules: Marathon Basin, Texas

One generally accepted rule of thrust belt geometry is that folding does not occur before thrust faulting; thrust faults do not cut across folds in cross-section view. Original mapping in the Marathon basin documents that the Hell's Half Acre thrust sheet was emplaced after an episode of large-scale folding.

The Hell's Half Acre thrust fault is a shallow, low-angle fault which separates the northeasterly trending, broad (4-km or 2.5-mi wavelength), open folds on the north from the imbricately thrust faulted and overturned, tightly folded (1-km or 0.6-mi wavelength) Paleozoic rocks of the thrust sheet. The thrust fault trends east and truncates the structures on the north. Within the thrust sheet, folds plunge into and are truncated by thrust faults. The Tesnus Formation (Mississippian) is the principal formation of the sheet, but large blocks of younger Dimple Limestone (Morrowan) and Haymond Formation (Atokan) are lodged within fault planes bounded by Tesnus, thereby documenting folding before thrust faulting.

This nonclassic geometry is due to lithology. Classic thrust belt style was developed for a miogeoclinal sequence. The Ouachita stratigraphy is a eugeoclinal sequence composed of lower and middle Paleozoic, thin limestones and cherts with numerous shale interbeds and an upper Paleozoic flysch sequence with a low sand/shale ratio and numerous thick shale horizons. The many thick, incompetent horizons allowed the thrust fault to cut across preexisting structures.

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Expected Paleozoic Stratigraphy Beneath Western Part of Metamorphic Overthrust in Southern Appalachians

A stratigraphic cross section from Roanoke, Virginia, to Alabama shows the formations and facies of the easternmost Valley and Ridge outcrops. This cross section, coupled with 3-dimensional insights on facies changes, siliciclastic sources, and regional unconformity patterns, delimits stratigraphic expectations directly beneath the metamorphic overthrust of the Blue Ridge–Great Smoky–Piedmont terrain as far east as the Brevard zone. These strata are in the Saltville structural block south of central Tennessee and in the Pulaski block to the north.

The stratigraphic column in the block directly beneath the metamorphic overthrust is up to 5,100 m (17,000 ft) thick and contains Upper Precambrian (Chilhowee Group) to middle Mississippian beds. The Chilhowee in the block beneath the metamorphic overthrust is probably less shaly and thinner than equivalent Chilhowee exposed along the leading edge of the metamorphic overthrust block. The Shady Formation becomes less dolomitic eastward, passing into dark, shaly limestone east of the carbonate bank edge. Rome-Conasauga siliciclastics change to carbonates eastward and northeastward. The Knox Group changes to limestone beneath the overthrust, and the post-Sauk unconformity probably disappears. Middle Ordovician siliciclastics coarsen eastward toward the Blount delta. The Wallbridge discontinuity expands eastward, so that Silurian and Lower Devonian strata probably do not occur beneath the metamorphic overthrust. The pre-Upper Devonian unconformity truncates more section eastward, so that Chattanooga Shale locally rests on Middle Ordovician Bays Formation in southeastern Tennessee. In Tennessee, Georgia, and possibly North Carolina, Mississippian strata include sandstone, dark shale, limestone, and bedded chert passing beneath the Great Smoky–Cartersville fault.

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Jurassic-Cretaceous Nonmarine Foreland Basin Sedimentation in Western United States

Synorogenic foreland basin deposition during deformation in the Wyoming Overthrust belt occurred along the active western margin, along the axis of the subsiding trough, and along the eastern cratonic margin. Debris derived from rising thrusts comprise a nonmarine sequence which is underlain and overlain by preorogenic and synorogenic marine formations. In northwestern Wyoming, basal shallow marine units include, in ascending order, the Twin Creek, Preuss, and Stump formations, which pass eastward into the generally coeval Sundance Formation of central Wyoming. Synorogenic nonmarine units of the Gannett Group in northwestern Wyoming pass cratonward into the generally coeval Morrison and Cloverly Formations. Synorogenic marine units consist of basal transgressive clastics overlain by black marine shales. These comprise the marginal marine "Rusty Beds" overlain by the Thermopolis Shale. These grade westward into the lower part of the Wayan group which overlies the Gannett.

Whereas exposures in the Overthrust belt proper have produced extensive documentation of sedimentation patterns along the active basin margin, excellent exposures along the Gros Ventre River in Teton County, Wyoming, allow examination of nonmarine depositional systems across the basin axis during initial subsidence. The preorogenic Stump formation consists of fine-grained glauconitic sandstone and limestone with abundant tabular and trough cross bedding. Flow directions are strikingly bimodal, recording deposition in low-relief coastal settings. Overlying nonmarine units are lithologically intermediate between typical Gannett Group lithologies which occur to the west and typical Morrison-Cloverly lithologies which occur to the east. These consist predominantly of numerous fining-upward sandstone channels isolated in variegated siltstone and mudstone. These were deposited in low-gradient meandering fluvial channel and related flood-plain settings, respectively. The Draney Limestone in the upper part of Gannett Group extends eastward across this area into the top of the "Lilac Beds" of the Cloverly Formation, demonstrating synchroniety of deposition across the foreland basin. Nonmarine units are overlain by rippled, crossbedded, and burrowed transgressive nearshore sands of the "Rusty Beds," which are in turn overlain by the normal marine dark shales of the Thermopolis Formation.

Paleoflow directions in nonmarine axial foreland basin units are predominantly to the north, ranging from northwest to northeast. As such, these fine-grained meanderbelt facies demonstrate that while synorogenic rivers of the tectonically active basin margin carried sediment of the Gannett Group eastward toward the basin axis, rates of axial basin subsidence exceeded rates of fluvial input, even during the earliest stages of deformation. Synorogenic rivers, bounded on the west by the rising orogen and the east by the stable craton were constrained to flow northward, parallel to the belt of orogenic deformation. As such, major fluvial systems of the Western Interior were analogous to those of other foreland basin settings such as the Paleozoic Michigan River system which paralleled and flowed to the west of the rising Appalachians, and the east-flowing Quaternary Indogangetic system south of and parallel with the rising Himalayas.

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Evidence for Post-Cementation Migration of High-Temperature, High-Pressure Fluids—Siluro-Devonian Helderberg Group, Central Appalachians

Fluid inclusion data and fracture-filling cements in carbonate and siliciclastic rocks of the Siluro-Devonian Helderberg Group, central Appalachians, indicate post-cementation, late Paleozoic migration of high-pressure, high-temperature fluids.

Void-filling quartz and calcite cements contain secondary, 2-phase fluid inclusions that give freezing temperatures of -20 to -25° C (-4 to -13°F) (salinity > 22 wt.% NaCl). Homogenization temperatures are 200 to 300 + °C (392 to 572°F) (temperatures calibrated and pressure corrected) and greatly exceed maximum paleotemperatures (120 to 160°C; 248 to 320°F) given by conodont color-alteration index values or calculated from known sedimentary overburden. High homogenization temperatures suggest rapid movement of metamorphic fluids so that ambient burial temperature was not raised for long enough periods of time to affect conodont CAI values. These fluids probably came from Blue Ridge–Piedmont thrust sheets that were undergoing metamorphism during late Paleozoic deformation. These fluids migrated more than 75 km (47 mi) during thrusting.

Well-cemented sandstone and limestone have multiple crosscutting trains of secondary hydrocarbon inclusions. Some trains crosscut cement-filled fractures. Hydrocarbons also occur as thin films along cement crystal boundaries and as secondary inclusions trapped along calcite deformation twins. These inclusions indicate geopressured fluids moved along intercrystalline boundaries and along deformation twin planes in calcite under deep burial conditions either during or after deformation.

Rare fractures contain transported skeletal grains, "exotic" clasts, recemented clasts of fracture-filling cement, and mud. Cement clasts contain included mud and skeletal grains, and indicate several episodes of particle transport, cementation, and refracturing prior to final fracture filling. Primary(?) 2-phase fluid inclusions in vein-filling calcite give homogenization temperatures of 120 to 150°C (248 to 302°F). Coarse-grained "clastic" fracture fills indicate migration of rapidly moving fluids capable of transporting clasts through fracture conduits under deep burial conditions.

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Paradox of Great Thicknesses of Carbonate Turbidites—Some Synergistic Observations from French Western Pyrenees and Upper West Florida Continental Slope

By the end of the Turonian, a westward-trending flysch trough was well established in what is now the western French Pyrenees. Over the next 22 m.y., to the end of the Maestrichtian, up to 5 km (16,000 ft) of carbonate flysch were deposited, uninterrupted by major silicoclastic sedimentation. Individual carbonate turbidites vary from a few centimeters to occasional massive deposits tens of meters thick. One carbonate megaturbidite can be traced 90 km (56 mi) and is still 10 m (33 ft) thick at its most distal exposure. Carbonate constituents lack shallow water indicators, suggesting that deposition and mass movement initiation occurred on continental slopes. Carbonate sediments were fed into the trough from both north and south.

Are there modern carbonate depositional environments we can turn to that will help us understand how such great thicknesses of carbonate flysch can build up without major clastic input? We believe that the west Florida upper continental slope is one such environment. It is part of a system which has been a carbonate depocenter since Jurassic time. A lime mud slope facies has accumulated at the rate of about 30 cm/1,000 years (12 in./1,000 years) for the last 25,000 years. At that rate (and allowing for a 50% reduction due to compaction) about 3.3 km (11,000 ft) of carbonate could accumulate in 22 m.y. A large variety of structures show that mass movement is continually displacing sediment downslope. If a second carbonate margin were close, accumulation of 5 km (16,000 ft) of carbonate flysch in 22 m.y. in a subsiding trough need not be extraordinary, even in an orogenically quiescent system.

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Shallow Structure and Carbonate Sedimentation of West Florida Upper Continental Slope

An extensive mini-sparker (3.5 kHz) and piston-coring survey of the continental slope above the West Florida Escarpment has revealed a Pleistocene sequence up to 160-msec (2-way travel time) thick overlying a second strong reflector of either Pliocene or Miocene age. South of 27°20′N, the contact between the two is clearly erosional and includes a band of karst features. The Pleistocene drape thins to a minimum, in some places exposing the second layer, at about 525 m (1,725 ft) water depth, and then thickens dramatically downslope. We attribute this thinning to the north-south-flowing Loop Current blocking deposition and scouring the bottom. Present depth of the erosional surface suggests as much as 400 m (1,300 ft) of subsidence after its formation.

Two parallel reefs mark the upper slope from its southern limit to 26°40′N. Sediments on the upper slope are a foraminifera-coccolith ooze, the compositional equivalent of a chalk deposit. Radiocarbon dating indicates that ooze below the erosional minimum accumulated at more than 60 cm/1,000 years (24 in./1,000 years) for at least the last 25,000 years, a surprisingly high rate. High sedimentation rates are also reflected in a wide variety of mass-wasting features from creep to massive slides to gravity-induced folds tens of kilometers long.

Fan deposits have formed at the foot of the continental slope off the southwestern corner of the west Florida margin. Orientation of sand-wave fields on the outermost shelf suggests that offbank transport combined with high slope sedimentation rates and subsequent mass wasting have provided material for these deposits.

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Basement Faults and Cover Tectonics in Southernmost Appalachians

Stratigraphic and seismic data indicate that basement faults occur beneath the Appalachian foreland fold and thrust belt in Alabama. Some of the high-relief basement faults control the locations of thrust-related