Sandstone at the base, this sequence is composed of three shale-limestone couplets, possible products of the complex interaction of sea level fluctuations and gentle tectonism along reactivated Precambrian structural elements. In ascending order, these couplets are the Wolsey Shale and Meagher Limestone, the Park Shale and Pilgrim Limestone, and the Dry Creek Shale and Sage Pebble members of the Snowy Range Formation.

In south-central Montana, the Park Shale is 50 m (165 ft) of green, micaceous shale with interbedded siltstone at the base and intercalated limestone at the top. However, in the northern Bridger Range, the lower 30 m (100 ft) is a prominent interval of interbedded arkosic sandstone and micaceous shale. Here, thin sandstone beds are characterized by sharp, commonly graded bases, weakly developed cross-stratification, load structures, and a distinctive suite of glauconite, quartz, orthoclase, and plagioclase grains. Quartzofeldspathic gneiss pebbles and biomicrite intraclast pebbles and cobbles occur in these beds, in striking contrast to the fine to medium sand that composes most of the sandstone beds of the interval. These arkosic sandstone beds are localized in the northern Bridger Range and are unknown in the southern Bridgers and in Cambrian outcrops of surrounding areas.

The occurrence of Park sandstone beds that contain orthoclase and plagioclase grains and pebbles of quartzofeldspathic gneiss requires (1) the presence of a localized island of Precambrian crystalline rock, an erosional remnant that must have risen at least 200 m (650 ft) above the surrounding Cambrian/Precambrian erosion surface and was exposed above the depositional interface through most of the Middle Cambrian, or (2) an island of Precambrian crystalline rock that was exposed by late Middle Cambrian reactivation of zones of Precambrian structural weakness. Probably the strongest argument favoring the second alternative is the paucity of conspicuous feldspar grains and gneiss clasts in the middle and upper Wolsey Shale and Meagher Limestone of the Bridger Range. This evidence, coupled with the abundance of these basement-generated grains in the basal part of the overlying Park Shale, strongly suggests that the arkosic interval of the Park is the product of weathering and erosion of a nearby island. This island was tectonically activated during the late Middle Cambrian and was available as a source of coarse clastic sediment principally during that time.

The location, size, and shape of this island are unknown: no abbreviated Cambrian section is known in the area, and the arkose beds show no strong paleocurrent or paleosource directions. However, because the arkose beds are restricted to the northern Bridger Range and because a relatively local source is required for this type of sediment, the sediment-producing island must be close by. The most spatially and lithologically feasible tectonic feature along which late Middle Cambrian movement might have produced an island or series of islands is the Willow Creek-Jefferson Canyon fault zone, along which significant movement occurred during deposition of the LaHood Formation (Precambrian Y); the fault zone structurally divides the northern and southern parts of the Bridger Range, and later Paleozoic movement has been documented along this zone.

GAUTIER, D. L., U.S. Geol. Survey, Denver, CO

Gas Reservoirs in Composite Shale-Sandstone Lithologies: A Rocky Mountain Energy Frontier

Thick sequences of marine rocks consisting of thin (1 to 5 cm) composite bedsets of sandstone and shale constitute a major part of the Cretaceous sedimentary prism that accumulated in the Western Interior. Today, these rocks include significant source beds and are locally important reservoirs for natural gas. Because of their large areal extent, immense volume, and ubiquitous gas content, sequences of composite sand-shale bedsets constitute an important potential resource of hydrocarbons throughout the Rocky Mountains region—an energy frontier.

The composite bedsets contain the reservoirs, source beds, and seals. The shale layers serve as both source beds and seals, and very thin (1 to few cm) wavy and lenticular beds of sandstone make up the reservoir rocks. Because these lithologies are associated generally with marine regressions, most of the constituent organic matter is terrigenous and the strata are gas-prone. The composition of the gas varies, depending on the degree of thermal maturity, from biogenic methane in Upper Cretaceous strata of the northern Great Plains of the United States and Canada, to supermature dry gas in the Mancos Shale in parts of the Piceance Creek basin in Colorado.

The reservoirs in these rocks do not require structural closure for gas entrapment, but successful commercial production generally requires fracture stimulation. In general, the reservoirs are characterized by high irreducible water saturation, high ratios of horizontal to vertical permeability, and sensitivity to water-based fluids. Field boundaries are determined by economic factors. The maximum depth of production is determined ultimately by reservoir porosity which, in turn, is the product of two distinct porosity loss trends. The shale component undergoes almost complete loss of effective porosity during early compaction, although products of organic matter transformations, shale dewatering, and clay diagenesis continue to be expelled into adjacent sandstone layers throughout most of the subsidence history of the basin. The porosity trend in the sandstone layers is controlled mainly by cementation by-products of shale diagenesis and by the original sand composition. The overall reservoir porosity reflects the ratio of sandstone to shale in the sequence and the extent of porosity loss in the sandstone layers. Generally, porosity loss increases with increasing depth and maturity and is irreversible and predictable.

Thus far, production from these rocks has been mainly a result of accidental discovery during exploration for more conventional reservoirs and subsequent field development. Successful exploitation of the enormous gas resources in these strata will require intentional exploration programs.

GAYNOR, GERARD C., Univ. Texas at Dallas, Richardson, TX, and DONALD J. P. SWIFT, ARCO Oil and Gas Co., Dallas TX

Shannon Sandstone, Powder River Basin: Hydrodynamic Control of Sand Body Geometry and Facies Sequences in Western Interior Cretaceous Seaway

The Campanian Shannon Sandstone Member of the Cody Shale forms the reservoir for several significant oil fields in the western Powder River basin of Wyoming. Linear Shannon sand bodies were deposited on the muddy shelf of the Cretaceous Interior Seaway up to 200 km (125 mi) east of the paleoshoreline. The sandstone bodies are asymmetric in transverse section: northeastern flanks are shorter and steeper than the gentle accretion surfaces on the southwest flanks. The long axes of these bodies are aligned northwest-southeast to north-northwest-south-southeast. Paleocurrent direction is generally southerly, hence the sandstone bodies are aligned at a small angle to the prevailing transport direction, as required by hydrodynamic theory.

Three major facies types are recognized in cores, in subsurface wireline logs, and in outcrop. In a typical coarsening-upward vertical sequence, a large-scale cross-bedded facies overlies a thin-bedded facies which in turn overlies a bioturbated facies. These facies are genetically related lateral equivalents.

The large-scale cross-bedded facies lies on the upcurrent flank and crest of the sandstone body, and grades down the down-current flank into a thin-bedded facies, which grades in turn into bioturbated facies. The cross-bedded facies is typified by current-rippled surfaces, and by trough to tabular cross-bed sets. The sandstone is glauconitic, very fine to medium-grained, and commonly contains sideritic and shale intraclasts. The thin-bedded facies consists of sand and shale in flaser-, wavy-, and lenticular-bedded associations which may exhibit significant burrowing. Thin-bedded sandstones are generally very fine to fine-grained with a significant silt and clay component. The bioturbated facies is a shaly fine sandstone to siltstone interpreted as a distal thin-bedded facies extensively reworked by burrowing.

The Shannon appears to have been deposited by intermittent storm flows in an outer shelf environment where the water was deep enough for sharp-crested rather than hummocky megaripples to develop. Numerical modeling of geostrophic circulation due to wind stress forcing of Campanian shelf waters demonstrates a good correlation between measured paleotransport indicators and model results. The time-averaged bottom circulation induced by a typical mid-latitude storm is southerly. However, a significant onshore or offshore component of bottom flow may be present due to interaction of storm setup and resultant geostrophic currents with a varying coastal and bathymetric configuration.

In this model, storm currents decelerating across the crests of subtle topographic highs on the shelf surface would deposit preferentially the coarser fraction of their transported load, so that the aggrading sea floor would become enriched in sand. When a portion of the Campanian shelf