northeastern part of the state (Williston basin). The ratio of sodium plus potassium plus chloride to dissolved-solids concentration is greatest in northeastern Montana where the Madison contains salt beds, and decreases toward recharge areas. The ratio of sulfate to total anions is greatest in north-central and southeastern Montana where anhydrite probably is the source of the sulfate. The ratio is smallest in northeastern and northwestern Montana; however, the concentration of sulfate, in milligrams per liter, can be greater in northeastern Montana than in other areas because of the greater concentration of all dissolved solids.

FISCHER, HOWARD J., Univ. North Dakota, Grand Forks, ND
Depositional Framework for Lower Member of Metalline Formation (Cambrian), Northeastern Washington.

The Metalline Formation is a Cambrian unit that crops out in Stevens and Pend Oreille Counties, northeastern Washington. The 985 to 1,250-m (3,200 to 4,100-ft) thick formation has been divided into lower, middle, and upper members, although structural complications and numerous covered intervals have made measurement of complete stratigraphic sections impossible. Based mainly on triboite studies, early workers assigned a Middle Cambrian age to the 120 to 290-m (390 to 950-ft) thick lower member. The present study divides the lower member into the following five lithofacies: (1) gray mudstone, (2) ooid-arenite, (3) gray packstone-wackestone, (4) black packstone-wackestone, and (5) black mudstone facies.

The gray mudstone facies grades upward from underlying fine-grained siliciclastics, and it is composed of bioturbated lime mudstones with a small admixture of thin-shelled trilobite fragments, chitinophosphatic arthropods, and disarticulated echniomerids. The ooid-arenite facies occurs as pods within the gray mudstone facies, and it is composed of spherical quartz grains and ooids developed around quartz cores in a neomorphic spar matrix. The facies is extremely well-sorted. The gray packstone-wackestone facies is composed of ooid-oncoid packstones, with ooids and oncoids the secondary components. Fossil allochems include robust triboite fragments, echinoderm plates, and rare (7) Epiphyton algae. The black packstone-wackestone facies contains the same components as underlying rocks but is characterized by an increase in carbonaceous material and pyrite causing the black color. Fossils are less robust than in the underlying facies. The black mudstone facies is characterized by bioturbated lime mudstones with rare fossil fragments. The top of the member is marked by a red-stained, well-cemented zone below a disconformable contact with the middle member.

The lower member of the Metalline Formation represents the first carbonates deposited on a ramp-type shelf margin during a major Middle Cambrian transgression. The observed lithologies suggest deposition under conditions of changing water depth, agitation, and oxygenation in the shallow subtidal zone. The mudstones and wackestones in all facies were deposited under low-energy conditions. Shallowing allowed increased agitation, and oxygenation suitable for the local development of ooids and oncoids. Periodic storms produced high-energy packstone deposits composed of concentrations of the components found in the typically low-energy subtidal zone. Along with the transgression of marine environments, oxygen-starved waters migrated shoreward from an offshore, lower shelf basin. This transgression of the pycnocline caused dysaerobic and anaerobic conditions in shallow subtidal waters of the upper shelf. Aerobic and dysaerobic conditions produced gray rocks, and anaerobic conditions produced black rocks rich in organic material. Biofaches were also affected by the low oxygen levels. Thin-shelled and chitinophosphatic forms dominated the epifauna when dysaerobic conditions occurred. With decreasing oxygen content, the epifauna was progressively excluded from the shallow subtidal zone. The result of maximum anoxia was the cessation of carbonate sedimentation and the formation of a submarine hardground at the end of "lower Metalline deposition."

FRENCH, DON E., Milestone Petroleum Inc., Billings, MT
Origins of Oil in Railroad Valley, Nye County, Nevada.

Trap Spring field was discovered in 1976, becoming the second commercial oil field in Nevada. The first, Eagle Springs, was discovered in 1955 and is about 6 mi east of Trap Spring. Currant, a third, noncommercial, one-well field, was found in 1978 and is about 7 mi north of Eagle Springs. Trap Spring field is productive from Oligocene welded ash-tuff flows, and Currant produced from the Eocene Sheep Pass Formation. Production at Eagle Springs is from both of these units plus some production from the Elly Limestone (Pennsylvanian). Possible sources of oil for these fields are beds within the nonmarine Sheep Pass Formation and the marine black shales of the Chainman Formation (Mississippian). Prior to discovery of Currant field, the origin of the Eagle Springs and Trap Spring oils was problematical, and a wide range of source rock and post-generation alteration possibilities were considered. The n-C15+ chromatograph of the Currant oil shows unusually high peaks of pristane and phytane and a slight even-carbon preference in the n-C15 to n-C25 range. These factors are indicative of a recently generated oil from a source rock in a carbonate-evaporative sequence. The geochemical data and geologic conditions support the hypothesis that the oil produced at the Currant well was generated in the Sheep Pass Formation. The n-C15+ distribution of Trap Spring oils differs significantly from that of the Currant oil and is more typical of oil generated in source rock deposited in a marine environment. The most likely source of this oil is the Chainman Formation. The origin of the oil from Eagle Springs remains unclear as it has chemical affinities to both Trap Spring and Currant oils. It is possible that the Eagle Springs oil is a mixture of oil generated in the Sheep Pass Formation and Chainman Shale.

FRENCH, DON E., Milestone Petroleum Inc., Billings, MT
Different rock units in Nevada. The first, Eagle Springs, was discovered in 1976, becoming the second commercial oil field in Nevada. The third, Currant, was discovered in 1955 and is about 6 mi east of Trap Spring. Trap Spring field is productive from Oligocene welded ash-tuff flows, and Currant produced from the Eocene Sheep Pass Formation. Production at Eagle Springs is from both of these units plus some production from the Elly Limestone (Pennsylvanian). Possible sources of oil for these fields are beds within the nonmarine Sheep Pass Formation and the marine black shales of the Chainman Formation (Mississippian). Prior to discovery of Currant field, the origin of the Eagle Springs and Trap Spring oils was problematical, and a wide range of source rock and post-generation alteration possibilities were considered. The n-C15+ chromatograph of the Currant oil shows unusually high peaks of pristane and phytane and a slight even-carbon preference in the n-C15 to n-C25 range. These factors are indicative of a recently generated oil from a source rock in a carbonate-evaporative sequence. The geochemical data and geologic conditions support the hypothesis that the oil produced at the Currant well was generated in the Sheep Pass Formation. The n-C15+ distribution of Trap Spring oils differs significantly from that of the Currant oil and is more typical of oil generated in source rock deposited in a marine environment. The most likely source of this oil is the Chainman Formation. The origin of the oil from Eagle Springs remains unclear as it has chemical affinities to both Trap Spring and Currant oils. It is possible that the Eagle Springs oil is a mixture of oil generated in the Sheep Pass Formation and Chainman Shale.

FRENCH, DON E., Milestone Petroleum Inc., Billings, MT
Different rock units in Nevada. The first, Eagle Springs, was discovered in 1976, becoming the second commercial oil field in Nevada. The third, Currant, was discovered in 1955 and is about 6 mi east of Trap Spring. Trap Spring field is productive from Oligocene welded ash-tuff flows, and Currant produced from the Eocene Sheep Pass Formation. Production at Eagle Springs is from both of these units plus some production from the Elly Limestone (Pennsylvanian). Possible sources of oil for these fields are beds within the nonmarine Sheep Pass Formation and the marine black shales of the Chainman Formation (Mississippian). Prior to discovery of Currant field, the origin of the Eagle Springs and Trap Spring oils was problematical, and a wide range of source rock and post-generation alteration possibilities were considered. The n-C15+ chromatograph of the Currant oil shows unusually high peaks of pristane and phytane and a slight even-carbon preference in the n-C15 to n-C25 range. These factors are indicative of a recently generated oil from a source rock in a carbonate-evaporative sequence. The geochemical data and geologic conditions support the hypothesis that the oil produced at the Currant well was generated in the Sheep Pass Formation. The n-C15+ distribution of Trap Spring oils differs significantly from that of the Currant oil and is more typical of oil generated in source rock deposited in a marine environment. The most likely source of this oil is the Chainman Formation. The origin of the oil from Eagle Springs remains unclear as it has chemical affinities to both Trap Spring and Currant oils. It is possible that the Eagle Springs oil is a mixture of oil generated in the Sheep Pass Formation and Chainman Shale.
Sandstone at the base, this sequence is composed of three shale-limestone couplets, possible products of the complex interaction of sea level fluctua-
tions and climate. 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, micaeous shale with interbedded siltstone at the base and intercalated 
toggle interval at the top. However, in the northern Bridger Range, the lower 30 m (100 ft) is a prominent interval of interbedded arkosic sandstone and 
micaeous 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 
intralastic 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 Cam-
brian 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 low-relief island of Precambrian crystalline rock, and a dis-
sional remnant that must have risen at least 200 m (650 ft) above the sur-
crounding Cambrian/Precambrian erosion surface and was exposed 
above the depositional interface through most of the Middle Cambrian, 
cr an island of Precambrian crystalline rock that was exposed by late 
Mid 
care of Cambrian recycling of zones of Precambrian structural weak-
ness. 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 elastic sediment 
principally during that time. The location, size, and shape of this island are unknown: no abbrevi-
ated 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 low 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 separately divides the northern and southern parts of the 
Bridger Range, and later Paleozoic movement has been documented 
along this zone.


Gas reservoirs in composite Shale-Sandstone Lithologies: A Rocky 
Mountain Energy Frontier

Thick sequences of marine rocks consisting of thin (1 to 5 cm) composi-
tive bedsets of sandstone and shale constitute a major part of the Creta-
cenoic sedimentary prism that accumulated in the Western Interior. Today, 
these rocks include significant source beds and are locally important res-

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, low 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 the 
two distinct porosity loss trends. The shale component undergoes 
amost complete loss of effective porosity during early compaction, 
which products of organic matter transformation, shale dewetting, 
and clay diagene 

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 Creta-
cenoic 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 m)
east of the paleoshoreline. The sandstone bodies are asymmetric in transverse 
section: northeastern flanks are shorter and steeper than the gentle acce-

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. These facies are genetically related lateral 
equivalents. The thin-bedded facies consists of sand and shale in flaser-, wavy-, and 
pebbly bedded associations which may exhibit significant burrowing. 
Thin-bedded sandstones are generally very fine to fine-grained with a sig-
ificant silt and clay component. The bioturbated facies is a shaly fine 
sandstone to siltsiltstone interpreted as a distal thin-bedded facies exten-

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 induced by wind stress forcing of Cam-
panian shelf waters demonstrates a good correlation between measured 
early, late, and augmented models. 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 
local during the storm setup and resultant geostrophic cur-
rents with a varying coastal and halyometric 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 accumulating sea floor 
would become enriched in sand. When a portion of the Campanian shelf