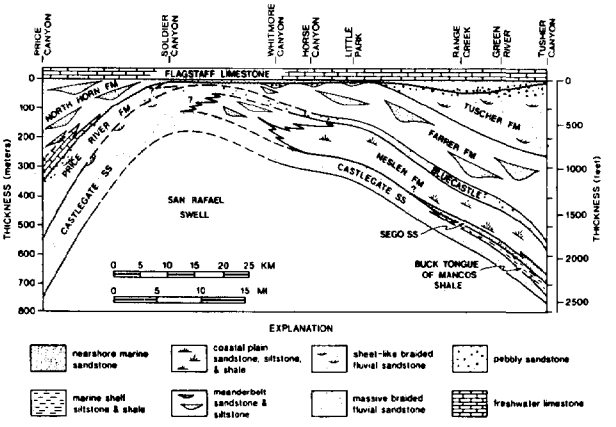
transition from thin-skinned deformation in the thrust belt to basement-cored uplift in the foreland region. Thick sections of the Mesaverde Group in the Wasatch Plateau on the west and the Book Cliffs on the east are separated by the San Rafael swell, a basement uplift across which the group is erosionally thinned. Strata in the west (Castlegate Sandstone and Price River Formation) were deposited by east to northeast-flowing braided rivers. Time-equivalent eastern sections comprise a lower sequence of mixed braided fluvial deposits (Castlegate Sandstone and Bluecastle Tongue of Castlegate), coastal swamp and meander-belt deposits (Neslen Formation), and nearshore marine deposits (Buck Tongue of Mancos Shale and Sego Sandstone), and an upper sequence that coarsens upward from meander-belt deposits (Farrer Formation) into pebbly braided river deposits (Tuscher Formation). Paleocurrent data indicate that rivers of the lower sequence flowed east, while those of the upper sequence flowed northeast.



Sandstones within the section consist of two distinct compositional suites, a lower quartzose petrofacies and an upper lithic petrofacies. The compositional boundary occurs at the top of the Bluecastle Tongue and can be correlated across the San Rafael swell. The quartzose suite contains mostly compositional quartzarenites and sublitharenites; the lithic suite is composed of litharenites and feldspathic litharenites. Lithic grain populations of the upper petrofacies are dominated by sedimentary fragments in sections of the Wasatch Plateau and volcanic fragments in sections near the Green River. The sedimentary lithic grains were transported generally eastward from miogeoclinal strata uplifted within the thrust belt. The volcanic lithic grains of the Farrer and Tuscher Formations were derived from more distal arc sources to the southwest, and transported through the thrust belt somewhere west of the Kaiparowits region, where time-equivalent sedimentary rocks are also rich in volcanic lithic fragments. Disappearance of volcanic lithics and appearance of pebbles at the top of the Tuscher Formation is interpreted to reflect a latest Campanian reorganization of drainage patterns that marked initial growth of the San Rafael swell and similar basement uplifts to the south of the swell. Contemporaneous fluvial systems that deposited the uppermost part of the Price River Formation in the Wasatch Plateau were apparently unaffected by the uplift and continued to flow northeast. Depositional patterns thus indicate that initial growth of the San Rafael swell was probably concurrent with late deformation in the thrust belt. Depositional onlap across the Mesaverde Group by a largely post-tectonic assemblage of fluvial and lacustrine strata (North Horn Formation) indicates a minimum late Paleocene age for growth of the San Rafael swell and deformation within the thrust belt.

LEFEVER, JULIE A., and SIDNEY B. ANDERSON, North Dakota Geol. Survey, Grand Forks, ND, and RICHARD D. LEFEVER, Univ. North Dakota, Grand Forks, ND

"Spearfish Water Sand": An Overlooked Play?

The Waskada-Pierson plays in the Amaranth Formation in southern Manitoba have prompted a study of similar units in Bottineau County, north-central North Dakota. The pay zone in the Waskada field is a sequence of sandstones and siltstones trapping oil which has migrated from the underlying Mississippian strata. The Triassic Spearfish Formation of North Dakota, correlative with the Amaranth Formation of Manitoba, consists of a similar sequence of interbedded sandstones and siltstones which unconformably overlie carbonate and anhydrite rocks of the Madison Group. Log characteristics show the sandstones and siltstones of this sequence to be laterally continuous over the study area.

Except for one well, production in the Bottineau area of North Dakota has been confined to either a portion of the Madison Group or a basal Spearfish sand. This basal sand is overlain by a 20 to 25-ft (6 to 7-m) thick impermeable siltstone which acts as a vertical seal for the Newburg/South Westhope pay. Above this siltstone is a unit locally known as the Spearfish "water sand," a water-bearing sandstone in the Newburg/South Westhope fields.

The one exception to basal Spearfish production is located in Sec. 6, T163N, R78W, where the Cardinal Petroleum 1 Oscar Aftem well has been producing from the Spearfish water sand since December 1961, indicating that the water sand may have potential for more production in the area.

LINDHOLM, ROSANNE, Univ. North Dakota, Grand Forks, ND

Bivalve Associations of Cannonball Formation (Paleocene, Danian) of North Dakota

The Paleocene Cannonball Formation, cropping out primarily in southwest-central North Dakota, is a marine deposit with variable lithologic characteristics ranging from medium to dark-gray-weathering mudstone to fine-grained, well-sorted, brownish-yellow-weathering sandstone. Also, two distinct tongues of the formation, exposed in southwestern North Dakota, are comprised of organic-rich siltstones and claystones.

There are 30 known species of bivalves in the Cannonball. Because bivalves are abundant and well known, and because their morphology and life habits are highly reflective of environmental demands, they are used to more accurately define depositional environments of the Cannonball sea. Based on Q-mode and R-mode cluster analysis, five bivalve associations are defined: *Ostrea-Corbicula, Crassostrea-Corbula, Isognomon, Crassatella-Nucula,* and *Glycymeris-Arctica* associations.

The *Ostrea-Corbicula* association, in the lower Cannonball tongue, and the *Crassostrea-Corbula* association, in the upper tongue, suggest that the Cannonball sediments in southwestern North Dakota were deposited in lagoonal or estuarine environments.

Where present, *Isognomon* occurs in abundance. However, it is found at only a few known localities in southwest-central North Dakota, and it has not been found in association with any other macrofossils. *Isognomon*, found in organic-rich sands, appears to have lived attached to vegetation in shallow-water environments.

The *Crassatella-Nucula* and *Glycymeris-Arctica* associations, common throughout southwest-central North Dakota, are most characteristic of the Cannonball. The *Crassatella-Nucula* association occurs in silty, clayey sand with moderately high organic content. It is dominated by both deposit and suspension-feeding bivalves, and has a high species diversity. It appears to have been deposited in a low energy environment with moderately high turbidity. In contrast, the *Glycymeris-Arctica* association is found in fine-grained, well-sorted sandstone with low organic content. It is dominated by infaunal suspension-feeding bivalves that indicate both a higher energy environment and low turbidity. Crabs and *Ophiomorpha* commonly occur stratigraphically above this association. These two associations most likely represent foreshore, shoreface, and/or shelflike environments.

The distribution of these bivalve associations, along with lithologic characteristics, suggest that the Cannonball Formation was primarily deposited in a barrier island complex and included lagoonal, beach, and offshore environments.

LINDQUIST, PAUL E., and PATRICIA I. HAGAR, ARCO Exploration Co., Denver, CO

Exploration Significance of a Possible Subsurface Meteorite Impact Feature in Garfield County, Montana