

## VERIFICATION THAT GREEN RIVER VARVES ARE ANNUAL LAYERS

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Regarding the laminations ("varves") in Green River oil shale representing annual events:  
From John R. Dyni, Geologist, USGS

The laminations displayed by the Green River oil shale have long been thought to represent annual cycles of sedimentation, although, in fact, it hasn't yet been positively demonstrated that these units are indeed annual events. For proof of annual cycles, it would require radiometrically dating two volcanic tuffs that separate a sequence of oil shale several hundred feet thick in which the laminations are counted. Dividing the difference between the dates of the two tuffs (assuming good precision and accuracy) by the number of laminations, one could better determine whether the laminae are indeed annual events.

The laminations in Green River oil shale consist of pairs of laminae, one being richer in organic matter than the other. Similar laminations are also found in marlstone and finegrained sandstone in addition to those in oil shale. These paired laminations vary considerably in thickness depending upon the type of sediment and the amount of organic matter in the rock. The richest grades of oil shale are characterized by the thinnest laminae because the organic matter compresses more than the mineral fraction of the rock during burial. Conversely, the poorer grades of oil shale, and the marlstone and sandstone, display thicker laminae. Using this idea, W.H. Bradley (1930) counted laminae of different grades of oil shale, as well as those in marlstone and sandstone, and found them to range from about 0.014 to nearly 10 mm in thickness. On this basis, Bradley estimated that the duration of Green River sedimentation was 5 to 8 million years. This is a several million years lower than current estimates, but still a good guess.

Bradley also notes that larger-scale variations displayed by these laminated rocks suggest correlations with astronomical cycles including the 11-year sunspot cycle and the 21 thousand-year eccentric orbital cycle of the earth which lends further evidence that the paired laminae are indeed varves, or annual units of sedimentation. Units of laminated oil shale are laterally very persistent. Individual laminae within certain units of oil shale have been correlated in drill cores over distances of 100 kilometers.

It is of interest to note that evaporites deposited within the Green River Formation in the deeper parts of several basins in Utah, Colorado, and Wyoming also exhibit rhythmic sedimentation suggestive of yearly events. In the Piceance Creek Basin in northwestern Colorado, thick units of nahcolite and halite are found in the oil-shale-bearing Parachute Creek Member of the Green River Formation. Some units are composed of alternating layers of nahcolite and halite ranging from a less than a thickness. Such units can be correlated between core holes over distances of several kilometers.

Some references that address the laminated rocks of the Green River Formation follow: Bradley, W.H., 1930, The varves and climate of the Green River Epoch: U.S. Geological Survey Professional Paper 158, p. 87-110.

Fischer, A.G., and Roberts, L.T., 1991, Cyclicity in the Green River Formation lacustrine (Eocene) of Wyoming: *Jour. Sedimentary Petrology*, v. 61, p. 1146-1154.

Trudell, L. G., Beard, T. N., and Smith, J. W., 1970, Green River Formation lithology and oil-shale correlations in the Piceance Creek basin, Colorado: U.S. Bureau of Mines Report of Investigations 7357, 226 p.

### **Additional note from Jere Lipps, Professor & Curator, UCMP, Berkeley, CA**

The Green River Formation laminae are considered varves, although not formed under glacial conditions. They consist of a thin, dark winter layer and a thicker lighter summer layer. These formed by seasonal events - increased spring and summer productivity of algae, and accumulation of finer material in the winter. Some geologists have had a few other ideas about the Green River Fm, but the seasonal changes accounting for the laminations seems secure. Thus, they are annual varves.