Olsen, 1986, Reprinted from Lamont Newsletter 13, p. 6-7.

Milankovich Cycles in Early Mesozoic Rift Basins of Eastern North America Provide Physical Stratigraphy and Time Scale for Understanding Basin Evolution

Nonmarine sedimentary basins are important elements in many tectonic regimes, but understanding their history is usually hampered by a lack of a reliable biostratigraphic or radiometric time scale. The early Mesozoic rift basins of the North American Atlantic passive margin (Fig. 1) share this problem. Hidden in the thick (3–10 km) fluvial and lacustrine sequences (the Newark Supergroup) which fill these basins is the chronology of the rifting history of the Atlantic Ocean. Recent analysis by Paul Olsen of the ubiquitous transgressive-regressive cycles (Fig. 2) which typify the lacustrine intervals of the Newark greatly clarify the details of the rifting history recorded in these basins. These cycles provide a basin-wide physical stratigraphic base and a time scale, potentially accurate to less than 10,000 years for these basins.

Most Newark lacustrine deposits consist of transgressive-regressive cycles which fall into a single general type of sequence, named a Van Houten Cycle, after Franklyn Van Houten of Princeton who first recognized and described them in the 1960's. The total range of thickness of these cycles over the whole of the Newark Supergroup is between 1.5 m and 70 m, but the amount of variability is small within a single formation or a basin. Van Houten ascribed the origin of the cycles to climate changes controlled by the precession of the equinoxes, an interpretation strongly supported and expanded on by Olsen's work.

Olsen's field studies have shown that individual Van Houten Cycles can be traced throughout individual basins, showing that the cycles represent basin-wide changes in lake level and hence provide a fine-scale physical stratigraphy. His preliminary stratigraphic studies of the Newark, Gettysburg and Culpeper basins suggest that the same Van Houten Cycles are traceable through these three basins and that during high lake level the largest of these lakes would have been at least as great in area as the present Lake Tanganyika of East Africa or Baikal of Siberia, both of which are also rift valley lakes. On the assumption that the finely laminated deep water sediments could not have been deposited above wave base, the largest lakes would have been more than 100 m deep.

However, Olsen concludes that even the deepest lakes dried out during the deposition of a single cycle, as shown by the abundant desiccation cracks in the regressive and low-stand facies of almost all cycles. These very large changes in the depths of lakes are most easily explained by changes in precipitation and cloud cover governing lake level within a deep and closed drainage basin.

The longest completely unbroken sequence of Van Houten Cycles consists of the Lockatong (1100 m) and overlying Passaic (3300 m) formations of the Newark Basin of early Late Triassic to earliest Jurassic age (Fig. 2). Olsen's Fourier analysis of long sections of these formations (Fig. 3) shows thickness periodicities of 5.9, 10.5, 25.2, 32.0, and 96.0 m thick corresponding to periodicities in time of roughly 25, 44, 100, 133, and 400 Kyrs, based upon biostratigraphically correlated radiometric time scales and varve calibrated sedimentation rates (Fig. 4, Table 1).

These periods are very similar to the present orbital cycles of precession of the equinoxes (21 Kyrs), obliquity of the Earth's axis (41 Kyrs), and eccentricity of the Earth's orbit (98, 125, 400, and 1600-2000 Kyrs). They also correspond to the Milankovich-type orbitally induced climate cycles documented in Neogene marine deposits by other Lamont researchers. Similar long sequences of Van Houten Cycles have been identified by Olsen through both the Middle Triassic and Early Jurassic sequences of other parts of the Newark Supergroup spanning a total more than 40 my. According to Olsen, this is strong evidence of orbital forcing of climate in the ice-free Early Mesozoic and indicates that the main periods of the orbital cycles were not very different 200 million years ago from today.

Van Houten Cycles and the other more complex Milankovich-type cycles they make up thus provide a time scale for the Newark far finer than available through any other means.

An example of the use of these cycles is the estimation of the duration of the igneous episode of the Newark rifting history. Thoeliitic dikes, plutons, and flows, chemically similar to mid-ocean-ridge basalts, are present in various Newark basins and in the basement rocks in Eastern North America. All Newark extrusive units lie in one pollen and spore biostratigraphic zone of the Early Jurassic and most if not all of the intrusive units seem to be directly related to the flows, but the duration of the biostratigraphic zone is uncertain, perhaps spanning 5 to 10 MY. K-Ar and $^{40}Ar/^{39}Ar$ dates from these thoeliites range from about 150 MA to 250 MA with a strong mode at about 200 MA. The large age range must be due to incomplete closure of the K-Ar system and therefore radiometric methods are of little help in constraining the true duration of the igneous interval.

Olsen has been able to use the hierachy of Van Houten and higher order Milankovich-type cycles present above and below the extrusive units to arrive at a much more precise estimate. The number of 21-Kyr cycles in the sediments interbedded between the basalt flow formations and the phase relationship of the 100- and 400-Kyr cycles indicate a duration of roughly 640 Kyrs for the entire extrusive episode in the Newark Basin. This estimate is consistent with the basalt fractionation models of Anthony Philpotts and Ingrid Reichenbach of the University of Connecticut. Similarly, the 100 Kyr and 400 Kyr cycles in the Newark and Hartford basins (Fig. 1) are exactly in phase, showing that the basalt eruptions in these two isolated basins were almost perfectly contemporaneous. Neither of these two conclusions could be derived from traditional dating techniques.

Another example, in very preliminary stage of analysis, is the use of Van Houten Cycles to examine the variability of sedimentation rates through rift basin history. In the case of the Newark Basin, average sedimentation rates in the depocenter begin at greater than 0.24 mm/yr for the first 5 MY of deposition, level out at 0.24 mm/yr for the next 6 MY and then slowly drop to 0.19 mm/yr over the next 9 MY towards the Triassic-Jurassic boundary. Average sedimentation rates jump up to 1.9 mm/yr during the igneous episode, but then drop into the overlying sediments to around 0.2 mm/yr towards the close of basin subsidence 10 to 15 MY into the Jurassic.

Presumably, the dramatic increase in the sedimentation rate during the igneous episode reflects some interaction of an increase in extension rate and loading from intrusions and extrusions within the basins. However, within each of these intervals there are apparently no large jumps in rates and on the whole, sedimentation rates are surprisingly even over very long periods of time. This is something we might not expect in rift basins and something which must be taken into account by attempts at modeling the history of these basins.

Transgressive-regressive lacustrine cycles occur in many other nonmarine basins. Examples from non-rift settings include the Eocene Green River Basin of Wyoming (foreland basin), the Pliocene Ridge Basin of California (strike slip basin), the Devonian Orcadian Basin of Scotland (?strike slip basin), and Jurassic and Cretaceous Chinese Style Basins of Asia. In all of these basins, deciphering the history of sedimenation is hampered by a lack of stratigraphic and temporal control which can be supplied by the type of analysis of lacustrine cycles Olsen has outlined for the Newark Supergroup. In addition to the elucidation of basin evolution patterns never before observable, the use of these Milankovitch cycles opens the possibility of comparing the predictions of models of basin development with actual basin records at an unprecedentedly fine level. □

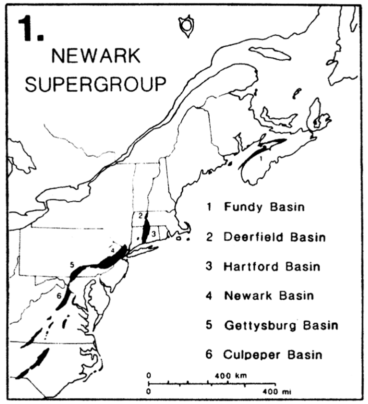

Fig. 1: **The Early Mesozoic Newark Supergroup** *comprises the exposed remnants of rift basins formed on the thinned crust between the separating North American and African continental plates. These Triassic and Jurassic basins formed along reactivated Paleozoic thrust faults and filled with thousands of meters of continental sediments and minor igneous rocks. Most Newark Supergroup sections are dominated by lacustrine cycles produced by the periodic rise and fall of large lakes, themselves controlled by Milankovich-type climate changes.*

Table I. **Comparison of the main orbital periods** *with the main periods derived from the Lockatong and Passaic formations of the Newark basin, with sedimentation rates derived from varve thickness measurements and various radiometric scales.*

Abbreviations as follows: P, precession of the equinoxes; O, cycle of the obliquity of the Earth's axis; E1, E2, and E3, first, second, and third terms of eccentricity of the Earth's orbit.

	P	O	E1	E2	E3	SED.RATE
ORBITAL PERIODS	21K	41K	95K	123K	413K	
AVERAGE CYCLES (m)	5.9	10.5	25.2	32.0	96.0	
VARVE SEDIMENTATION	25K	44K	100K	125K	400K	0.24mm/yr
RADIOMETRIC SCALES (various authors)						
18 MY (200-218MA)	25K	44K	100K	125K	400K	0.24mm/yr
19 MY (208-227MA) (204-223MA)	26K	46K	109K	139K	417K	0.23mm/yr
20 MY (208-228MA)	27K	48K	115K	145K	436K	0.22mm/yr
14 MY (213-227MA)	19K	34K	81K	103K	309K	0.31mm/yr

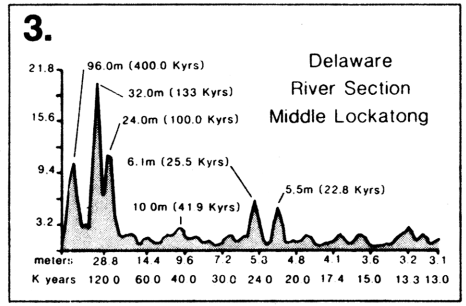

Fig. 3: **Long measured section of the middle Lockatong Formation** *(Late Triassic) of the Newark Basin exposed along the Delaware River, south of Frenchtown, N. J. showing the larger-scale cyclical and periodic changes in relative lake level. The three major types of cycles visible at this outcrop are shown along with their interpreted durations. The individual Van Houten Cycle indicated is shown in detail in Fig. 2. The lithological symbols used in this figure and the explanation of relative lake level are also given in Fig. 2.*

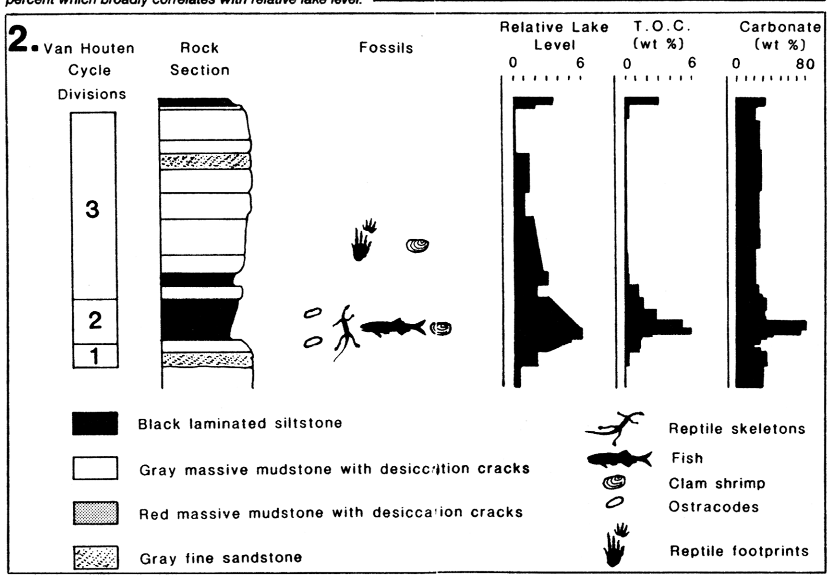

Fig. 2: **A representative Van Houten Cycle** *caused by the trangression (division 1), high stand (division 2) and regression (division 3) of a large Late Triassic Lake. Cyclical and periodic changes in precipitation, governed by the precession of the equinoxes, controlled lake depth in a single Van Houten cycle of approximately 21 Kyrs duration. Quantification of "Relative Lake Level" is based on a classification of sediment fabrics which vary according to relative lake depth. At 0, the lake was more often dry than filled and at 6, the lake was probably over 100 m deep. T.O.C. refers to total organic carbon content in weight percent which broadly correlates with relative lake level.*

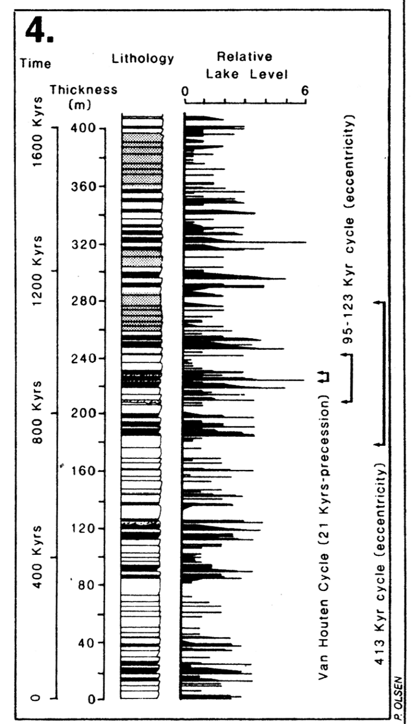

Fig. 4: **Power spectrum based on Fourier analysis** *of cyclic lacustrine section shown in Fig. 3. x-axis is thickness of cycles in meters and duration of cycle based on sedimentation rate derived from lacustrine varve counts (2.4 mm/yr). y-axis indicates spectral density, which is a measure of the relative contribution of a cycle of a given period to the total variance of the original relative lake level curve (Fig. 3). The 6.1-m and 5.5-m cycles correspond to Van Houten Cycles thought to be controlled by the precession of the equinoxes which has a present average period of 21 Kyrs (19 and 23 Kyrs). The 10.0-m cycle is less significant than the others, but probably corresponds to the cycle of the obliquity of the Earth's axis with a present period of 41 Kyrs. The 24-m and 32-m cycle represent the first two terms of the cycle of the eccentricity of the Earth's orbit with present periods of 95 Kyrs and 123 Kyrs, and the 96-m cycle corresponds to the 413 Kyr third term of the eccentricity cycle.*