# LATE TRIASSIC-EARLIEST JURASSIC GEOMAGNETIC POLARITY REFERENCE SEQUENCE FROM CYCLIC CONTINENTAL SEDIMENTS OF THE NEWARK RIFT BASIN (EASTERN NORTH AMERICA)

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## Introduction

The global nature of geomagnetic polarity reversals has made magnetostratigraphy an essential tool for precise correlation between widely distributed sections of rocks of different lithological and biotic facies. The best documented history of geomagnetic polarity reversals is for the Jurassic to Recent and is based on the analysis of numerous marine magnetic anomaly profiles from the global ocean [e.g., Cande and Kent, 1992; Gradstein et al., 1994]. The relative spacing of polarity intervals established from the anomaly patterns is calibrated in time by correlation to magnetostratigraphic sections with biostratigraphy, radiometric dates, and cyclostratigraphy. Because of the absence of seafloor and hence marine magnetic anomalies, a precise geomagnetic polarity reference scale for pre-Jurassic time has been more difficult to develop. There has already been significant progress made for the Late Triassic by assembling relatively condensed or discontinuous marine [e.g., Gallet et al., 1992; 1993] and continental [e.g., Molina-Garza et al., 1991] sedimentary sections, but thick, continuous magnetostratigraphic sections with good chronostratigraphic control are needed to construct a high resolution reference scale.

A very thick sequence of lacustrine and fluvial sediments is represented in the Newark Basin, one of the largest of a chain of Mesozoic rift basins that developed along the margin of eastern North America in the early stages of formation of the Atlantic Ocean (Fig. 1a). Deposition in the basin is now known to span much of the Late Triassic to earliest Jurassic [Cornet and Olsen, 1985] and was punctuated only by a brief igneous intrusive and extrusive episode just after the Triassic/Jurassic boundary [Olsen and Sues, 1986; Fowell et al., 1994] and dated at 201-202 Ma [Sutter, 1988; Dunning and Hodych, 1990]. The lacustrine sediments that constitute much of the Newark Basin section record climatically induced lake level variations reflecting Milankovitch orbital forcing [Van Houten, 1964; Olsen, 1986]. These climatic cycles constitute a basis for detailed lithostratigraphic correlation as well as chronological scaling.

The Newark Basin sedimentary section has revealed the presence of numerous polarity reversals [McIntosh et al., 1985; Witte et al., 1991] and thus provides an opportunity to obtain a cyclostratigraphically scaled, high-resolution timescale of Late Triassic and earliest Jurassic geomagnetic polarity reversals. Outcrop exposure is, however, typically poor and discontinuous due to the low relief and urbanized setting of the basin. This difficulty was addressed by the U.S. National Science Foundation-sponsored Newark Basin Coring Project (NBCP) which resulted in the recovery of a virtually complete stratigraphic section through the thick continental rift basin sequence of central New Jersey. The lithostratigraphy and cyclostratigraphy of the

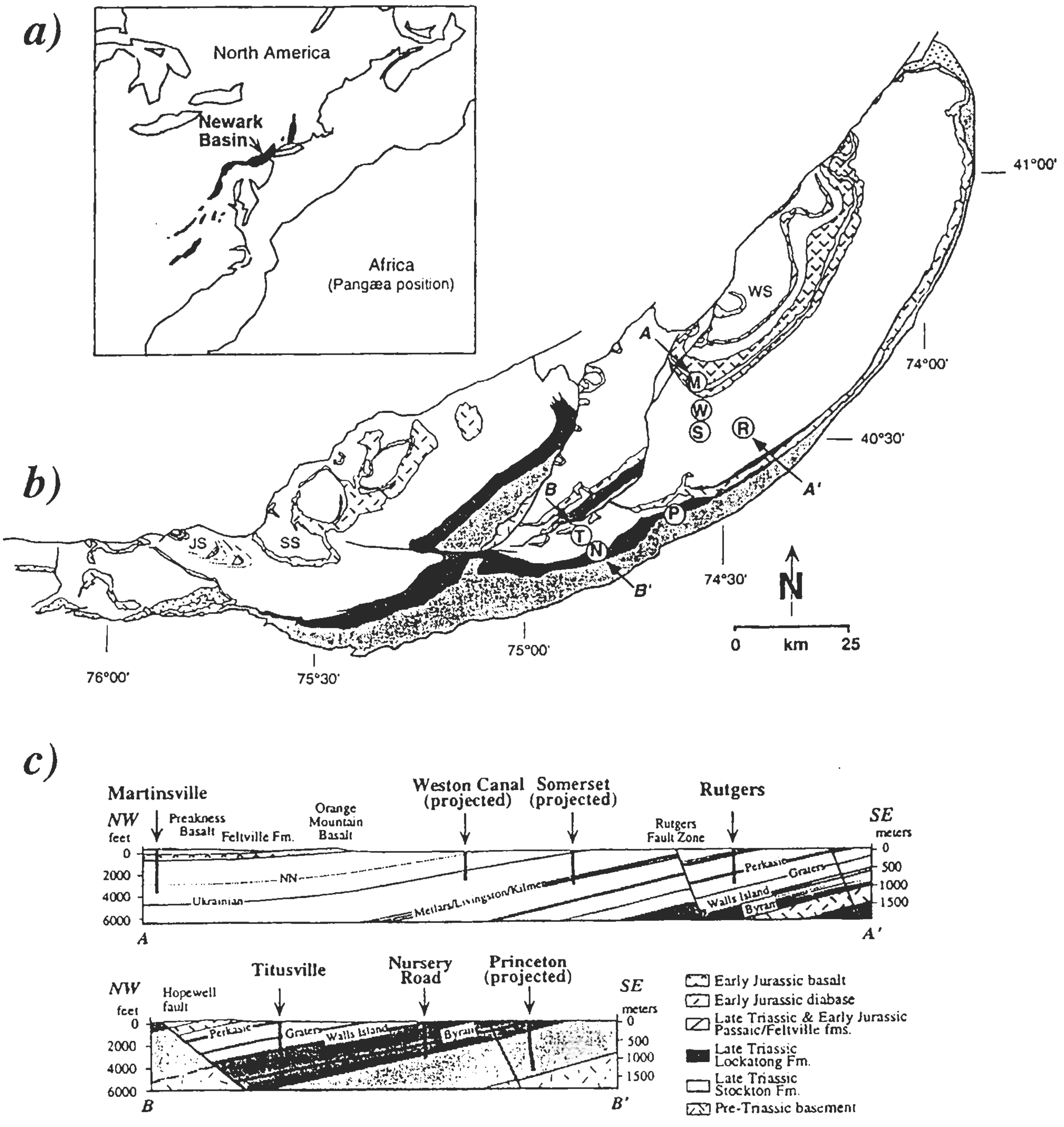
NBCP cores are described by Olsen et al. [1995] and Olsen and Kent [1995]. The magnetostratigraphy of the NBCP cores is reported in Kent et al. [1995] and summarized here.

## Geological Setting

A complete stratigraphic section was obtained by drilling in the rift basin sequence of the eastern and southeastern parts of central New Jersey (Figure 1b). The section was assembled from an array of seven relatively shallow (~800 to 1200 m) continuously cored drill holes. The drill holes intersected overlapping stratigraphic intervals along two transects (Figure 1c) to avoid drilling through the Palisade sill, a thick igneous intrusive unit. The regional 5° to 15° northwest formation dip made the offset drilling strategy possible. A total of 6770 m of 6.3-cm-diameter core was drilled at the seven coring sites, including about 25% redundancy between the stratigraphically overlapping drill cores. Core recovery overall was virtually complete (better than 99% of the cored intervals). Supporting information was obtained from a full suite of slimhole geophysical logs [Goldberg et al., 1994].

Cornet [1977, 1993] and Cornet and Olsen [1985] recognized four pollen and spore zones in the Newark Basin section (Figure 2). These provide the best presently available ties to standard geologic ages, and the age assignments are generally supported by vertebrate assemblages from the Newark Supergroup [e.g., Huber et al., 1993]. The Stockton and Lockatong Formations are of Carnian age, although there are hardly any age diagnostic fossils in the lower and middle Stockton Formation. Assemblages belonging to the New Oxford-Lockatong palynofloral zone of late Carnian age occur in the upper Stockton Formation, the Lockatong Formation, and up to member C (called member B by Cornet [1977]) in the lowermost Passaic Formation. The Carnian/Norian boundary should lie between member C and the Graters Member in the lower Passaic Formation where the lowest assemblage of the Lower Passaic-Heidlersburg palynofloral zone of Norian age occurs. The Lower Passaic-Heidlersburg palynofloral zone extends to member FF and is succeeded in the lower Cedar Hill Member by the Upper Balls Bluff-Upper Passaic palynofloral zone (renamed from Manassas-Upper Passaic by Litwin et al. [1991]). This palynofloral change may approximate the level of the Norian/Rhaetian boundary, although criteria for recognition of the "Rhaetian" are very uncertain [e.g., Tozer, 1993]. The Triassic/Jurassic boundary is placed within the Exeter Member in the uppermost Passaic Formation, 20 m below the contact with the Jacksonwald Basalt that is correlative to the Orange Mountain Basalt, based on the well-defined transition from the Upper Balls Bluff-Upper Passaic palynofloral zone to the Corollina meyeriana palynofloral zone [Fowell and Olsen, 1993; Fowell et al., 1994]. A spike in the spore/pollen ratio is found to be coincident with a regional extinction of more than half of the palynoflora at the Triassic/Jurassic boundary which is also closely associated with terrestrial vertebrate extinctions [Olsen et al., 1990; Silvestri and Szajna, 1993]. An assemblage of the Corollina meyeriana palynofloral zone can be found just below the Boonton fish bed of the Boonton Formation [Olsen, 1980], suggesting that the overlying igneous extrusive sequence and interbedded sediments are all within the Hettangian (earliest Jurassic).

*Figure 1. (a) Location of the Newark Basin among other early Mesozoic rift basins (dark shading) in eastern North America which is shown in a predrift (Pangea) continental configuration with respect to Africa. (b) Geological sketch map of the Newark Basin with the location of Newark Basin Coring Project drill sites indicated by the circled first letter of the site name. Other localities are WS, Watchung syncline; SS, Sassamansville syncline; JS, Jacksonwald syncline. (c) Cross sections showing positions of NBCP drill sites projected onto A-A′ and B-B′ of Figure 1b.*


a)
North America
Newark Basin
Africa
(Pangæa position)
b)
WS
A
M
W
S
R
A'
40°30'
41°00'
74°00'
B
T
N
P
B'
74°30'
JS
SS
76°00'
75°30'
75°00'
N
0 km 25
c)
Martinsville
Weston Canal (projected)
Somerset (projected)
Rutgers
NW
feet
Preakness Basalt
Feltville Fm.
Orange Mountain Basalt
Rutgers Fault Zone
SE
meters
0
2000
4000
6000
NN
Ukrainian
Metlars/Livingston/Kilmer
Perkasie
Graters
Walls Island
Byram
0
500
1000
1500
A
A'
Titusville
Nursery Road
Princeton (projected)
NW
feet
Hopewell fault
SE
meters
0
2000
4000
6000
Perkasie
Graters
Walls Island
Byram
0
500
1000
1500
B
B'
Early Jurassic basalt
Early Jurassic diabase
Late Triassic & Early Jurassic Passaic/Feltville fms.
Late Triassic Lockatong Fm.
Late Triassic Stockton Fm.
Pre-Triassic basement

The sedimentary facies of the lacustrine Lockatong, Passaic and Feltville Formations have several orders of cyclic variation that are interpreted to represent climatically-induced changes in lake level reflecting Milankovitch orbital forcing [Van Houten, 1964; Olsen, 1986; Olsen and Kent, 1995]. The fundamental sedimentary variation is referred to as the Van Houten cycle, which is recognized on a stratigraphic scale of 3 to 6 m in the NBCP cores. The expression of Van Houten cycles in terms of development of lamination and drab to black colors is modified by three orders of modulating cycles termed the short, intermediate or McLaughlin, and long cycles; the sedimentary expression of the long modulating cycles is the weakest, and that of the McLaughlin cycles is the strongest. Indeed, the McLaughlin cycles are effectively mappable lithostratigraphic units and provide the basis for subdivision of the Lockatong and Passaic Formations into 53 members for precise correlation within the basin [Olsen et al., 1995]. Sedimentary facies and depositional environments represented by Newark sedimentary rocks are described by Smoot [1991].

## Magnetostratigraphy

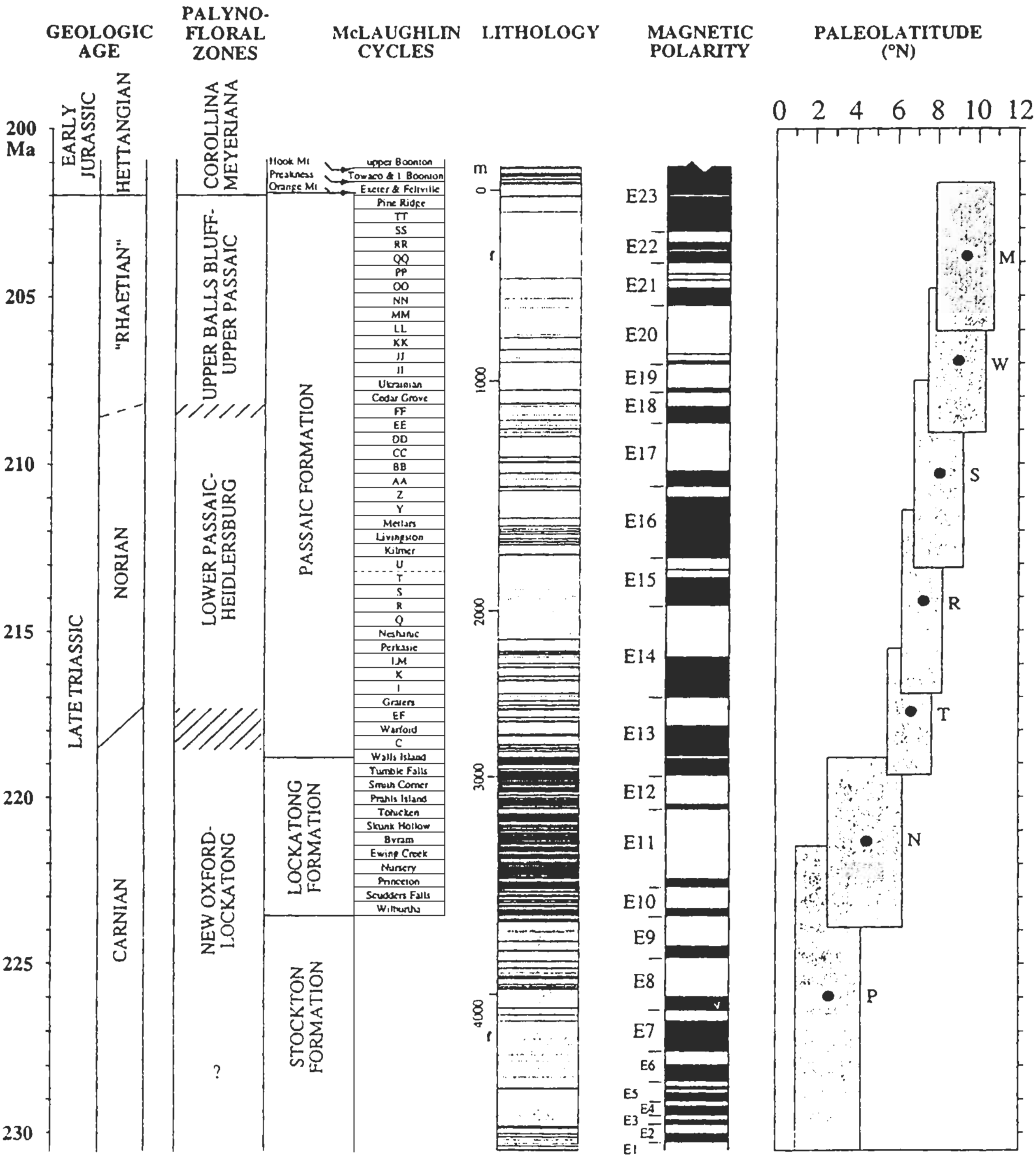
Paleomagnetic sampling was done at a nominal 3 m interval, about the Van Houten cycle frequency. Each of the ~2400 samples was subjected to progressive thermal demagnetization in a minimum of 9 steps for separation of secondary and characteristic components of magnetization. The secondary components were used to orient the samples in azimuth; the characteristic magnetizations delineate a record of normal and reversed polarity magnetozones. Rock magnetic studies show that the magnetic carriers of the characteristic magnetizations are hematite in the red sediments and magnetite in the gray shales; a ferromagnetic sulphide is present in some of the more reduced black shales where no characteristic magnetization could be resolved.

For identification of the magnetozones, we assign integers (in ascending numerical order from the base of the recovered section) to successive pairs of predominantly normal and predominantly reversed polarity intervals. Each ordinal number is prefixed by the acronym for the source of the magnetostratigraphy (Newark Supergroup of the Newark Basin, but using "E" rather than "N" which can be confused with the conventional designation for normal polarity), and has a suffix for the dominant polarity (n is normal polarity, r is reversed) of each constituent magnetozone. Polarity intervals that occur within a magnetozone of higher rank can be labeled in a parallel manner, appended after a decimal point to the higher-order magnetozone designation and given a suffix indicating dominant polarity. The basic scheme is thus similar to that used for the Late Cretaceous and Cenozoic geomagnetic polarity sequence based on marine magnetic anomalies [Cande and Kent, 1992], except that the numbering sequence in the present system always proceeds from older to younger which is more convenient for stratigraphic description.

We designate the incomplete reversed polarity interval at the bottom of the recovered section as magnetozone E1r, and define succeeding polarity magnetozone couplets (e.g., E2 = E2n and

*Figure 2. Newark Basin composite section transformed into a chronostratigraphy, using an age of 202 Ma for the Triassic/Jurassic boundary and assuming that the lithologic members (McLaughlin cycles) each represent 413 kyr and that the Stockton Formation has a sedimentation rate of 140 m/m.y. Palynofloral zonation is from* Cornet *[1977, 1993] and* Cornet and Olsen *[1985]. Mean paleolatitudes (solid circles) and associated 95% confidence intervals (width of shaded boxes) are based on the mean characteristic magnetizations for the NBCP drill cores whose stratigraphic intervals are indicated by the heights of the shaded boxes.*

# NEWARK BASIN SECTION



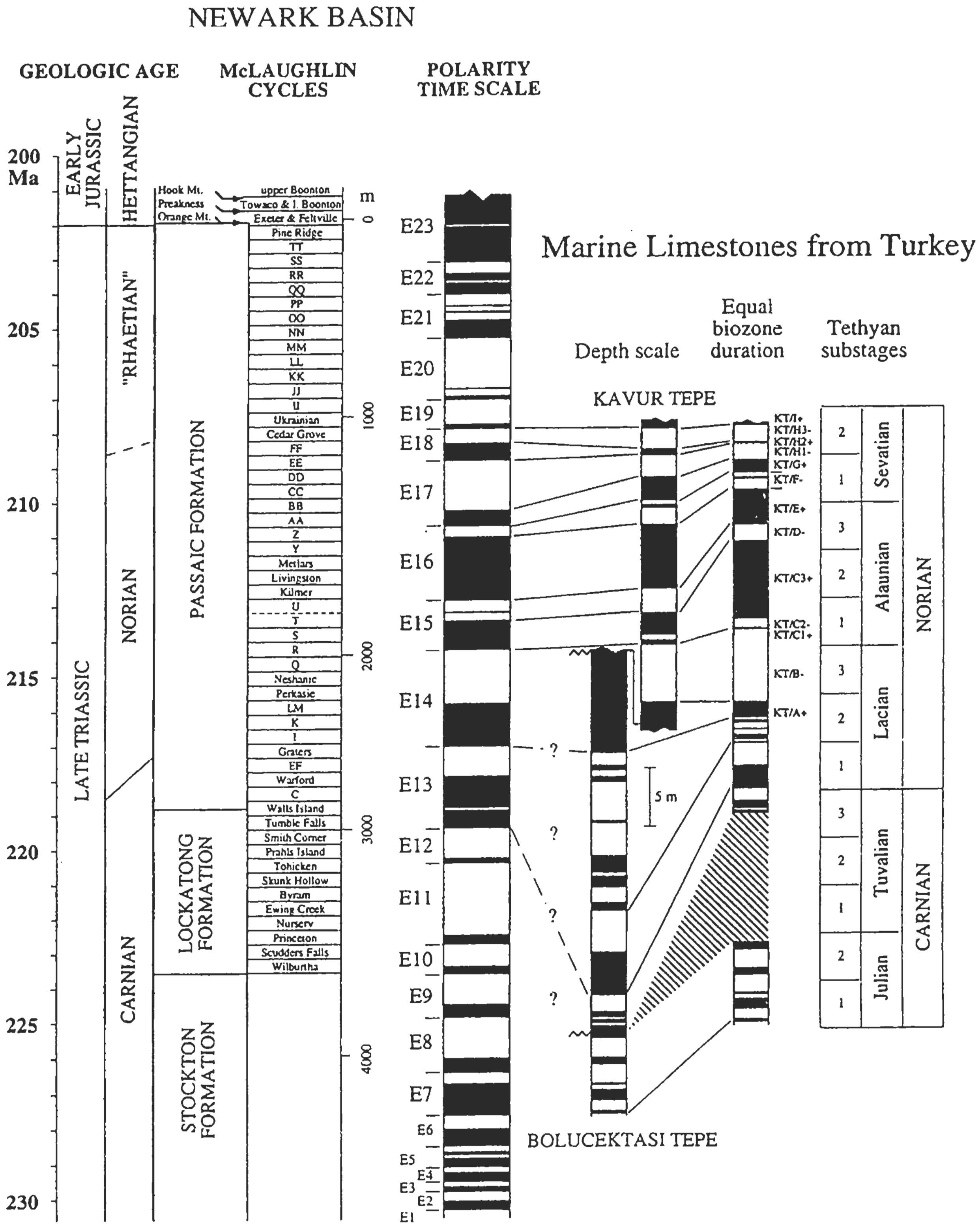
E2r, E3 = E3n and E3r, etc.) from the base of the overlying normal polarity interval (Fig. 2). To balance the stratigraphic thickness of first rank magnetozones over the entire section and to avoid having short polarity intervals at their boundaries, several short polarity intervals were assigned to a lower rank (e.g., submagnetozones E13n.1n, E13n.1r, and E13n.2n in magnetozone E13n). Although the ranking of magnetozones is inevitably arbitrary, the hierarchical scheme should nevertheless be useful for description at different levels of resolution and to accommodate refinements.

The magnetozones and lithostratigraphic members in the lacustrine facies are in excellent mutual agreement in all six between-site comparisons, supporting their interpretation as isochronous levels for correlation. The between-site correlations allow the assembly of a lithostratigraphic and magnetostratigraphic composite section for the Newark Basin from the seven NBCP core holes. The cored stratigraphic section has a composite thickness of 4660 m (normalized to the Rutgers drill core) and a total of 59 polarity intervals (magnetozones E1r to E23n). The uppermost normal polarity interval (magnetozone E23n.2n) in the NBCP cores evidently extends through the overlying Preakness Basalt, Towaco Formation, Hook Mountain Basalt, and at least the lower part of the Boonton Formation on the basis of previous studies of samples from outcrop and Army Corps of Engineers drill cores [McIntosh et al., 1985; Witte and Kent, 1990]. Even though the top is not defined, magnetozone E23n.2n at about 750 m (including the lavas) is already the thickest magnetozone in the Newark sequence. The remaining 58 polarity intervals have an average stratigraphic thickness (scaled to the Rutgers drill core) of about 70 m, ranging from about 4 m (e.g., magnetozone E23n.1r) to over 300 m (e.g., magnetozone E11r).

## Geomagnetic polarity timescale

To convert the Newark Basin magnetostratigraphic sequence into a geomagnetic polarity timescale, an age model is developed on the basis of biostratigraphy, radiometric dates, and cycle stratigraphy. The Triassic/Jurassic boundary is constrained by palynology to lie within the Exeter Member, correlated to be about 20 m below the contact with the Orange Mountain Basalt in the NBCP section [Olsen et al., 1990; Fowell and Olsen, 1993; Fowell et al., 1994; Olsen et al., 1995]. There is no physical evidence of an unconformity associated with the Triassic/Jurassic boundary interval. Concordant radiometric dates of 202 ± 1 Ma [$^{40}$Ar/$^{39}$Ar date on biotite; Sutter, 1988] and 201 ± 1 Ma [U-Pb dates from zircon and baddeleyite; Dunning and Hodych, 1990] were obtained from the Palisade sill which is linked physically and geochemically to the basaltic lavas (most likely the Preakness Basalt) of the Newark igneous extrusive zone [Ratcliffe, 1988]. On the basis of cyclostratigraphy of the sediments of Jurassic age that are interbedded with the lavas, the entire Newark extrusive zone is believed to represent a relatively short (~1 m.y.) igneous and depositional episode [Fedosh and Smoot, 1988; Olsen and Fedosh,

*Figure 3. Magnetostratigraphies from marine limestone sections from Turkey (BolŸ cektasi Tepe [*Gallet et al., *1992] and Kavur Tepe [*Gallet et al., *1993]) with possible correlations to the Newark geomagnetic polarity timescale. Subdivisions of the Norian and Carnian are plotted on a linear timescale with arbitrary scale assuming equal duration of the Tethyan (sub)substages; magnetostratigraphies of the limestone sections are shown in terms of measured thickness (see scale) and as transformed in a composite to an equal biozone duration timescale on the basis of conodont biostratigraphy [*Gallet et al., *1992, 1993]. The upper third of the BolŸ cektasi Tepe section, which includes an approximately 25-m-thick normal polarity interval which was correlated to the KT/C3+ magnetozone in Kavur Tepe [*Gallet et al., *1993], has been omitted for clarity.*


NEWARK BASIN
GEOLOGIC AGE
McLAUGHLIN CYCLES
POLARITY TIME SCALE
200 Ma
205
210
215
220
225
230
EARLY JURASSIC
HETTANGIAN
"RHAETIAN"
NORIAN
CARNIAN
LATE TRIASSIC
PASSAIC FORMATION
LOCKATONG FORMATION
STOCKTON FORMATION
Hook Mt.
Preakness
Orange Mt.
upper Boonton
Towaco & l. Boonton
Exeter & Feltville
Pine Ridge
TT
SS
RR
QQ
PP
OO
NN
MM
LL
KK
JJ
II
Ukrainian
Cedar Grove
FF
EE
DD
CC
BB
AA
Z
Y
Metlars
Livingston
Kilmer
U
T
S
R
Q
Neshanic
Perkasie
LM
K
I
Graters
EF
Warford
C
Walls Island
Tumble Falls
Smith Corner
Prahls Island
Tohicken
Skunk Hollow
Byram
Ewing Creek
Nursery
Princeton
Scudders Falls
Wilburtha
m
0
1000
2000
3000
4000
E23
E22
E21
E20
E19
E18
E17
E16
E15
E14
E13
E12
E11
E10
E9
E8
E7
E6
E5
E4
E3
E2
E1
Marine Limestones from Turkey
Depth scale
Equal biozone duration
Tethyan substages
KAVUR TEPE
KT/I+
KT/H3-
KT/H2+
KT/H1-
KT/G+
KT/F-
KT/E+
KT/D-
KT/C3+
KT/C2-
KT/C1+
KT/B-
KT/A+
?
?
?
?
5 m
BOLUCEKTASI TEPE
2
1
3
2
1
3
2
1
3
2
1
2
1
Sevatian
Alaunian
Lacian
Tuvalian
Julian
NORIAN
CARNIAN

1988]. This suggests that the radiometric dates can be used to provide an estimate of ~202 Ma for the palynological Triassic/Jurassic boundary as recorded in the uppermost Passaic Formation. U-Pb zircon dates of 202±1 Ma from the North Mountain Basalt [Hodych and Dunning, 1992], which lies a few meters above the palynological Triassic/Jurassic boundary in the Fundy basin, Nova Scotia [Fowell and Olsen, 1993], support the close synchroneity of igneous activity in the Newark rift basins and a Triassic/Jurassic boundary age of ~202 Ma.

Although age estimates for the Triassic/Jurassic boundary vary widely among published geologic timescales and criteria for recognition of the Norian/"Rhaetian" boundary are very uncertain [e.g., Van Veen, 1995], most timescales give consistent estimates of around 15-17 m.y. for the duration between the Carnian/Norian and Triassic/Jurassic boundaries (e.g., 220.7 Ma to 205.7 Ma [Gradstein et al., 1994]). There are 38 to 40 lithologic members or McLaughlin cycles in this 15-m.y. interval (using the most recent timescale of Gradstein et al. [1994]) of the Passaic Formation. The resulting average duration of about 400 kyr for the McLaughlin cycles is close to a main Milankovitch periodicity of climate change, calculated as 413 kyr from celestial mechanical terms of the cycle of eccentricity of Earth's orbit [Berger et al., 1992]. The same periodicity is found in spectral analyses of the full, broadband Newark climatic record [Olsen, 1986; Olsen and Kent, 1995].

Assuming that the McLaughlin cycles represent the 413-kyr celestial mechanical cycle, the Lockatong Formation with 11 to 12 members spans about 4.75 m.y. and the Passaic Formation with 41 to 42 members spans about 17 m.y. The long term sedimentation rate in the lacustrine Lockatong and Passaic Formations averages about 160 m/m.y.; the magnetostratigraphic sampling interval of ~3 m corresponds to a nominal temporal resolution of 15 to 20 kyr, approximately at the level of the Van Houten cycles. Cycles have not been identified in the Stockton Formation, and with the absence of biostratigraphic control the timescale in this fluvial facies is poorly constrained. If the sedimentation rate in the Stockton Formation was similar to that of the lower Lockatong Formation in the Princeton drill core, the cored interval of the Stockton Formation might span about 6.8 m.y. Allowing approximately 1 m.y. for the igneous extrusive zone, the entire Newark section may thus represent nearly 30 m.y. of the Late Triassic and earliest Jurassic.

The sequence of Newark magnetozones was transformed into a geomagnetic polarity timescale using the chronological control outlined above (Figure 2). Polarity reversal ages in the Lockatong and Passaic Formations were interpolated from the position of magnetozone boundaries within the members (McLaughlin cycles) which were each assumed to be 413 kyr in duration. In the Stockton Formation, where McLaughlin cycles are not apparent, polarity reversal ages were estimated assuming a constant sedimentation rate of 140 m/m.y. Average geomagnetic reversal frequency for the entire section is about 2/m.y., or an average polarity interval duration of approximately 500 kyr. For the better chronicled post-Stockton Formation sequence, average polarity interval duration is 560 kyr and reversal frequency is about 1.8/m.y. Polarity intervals range from a number as short as 0.03 m.y. (magnetosubchrons E15r.1n and E22n.1r) to a few as long as about 2 m.y. (magnetochrons E11r and E16n), with an overall resemblance to an exponential distribution of polarity lengths. There is no significant polarity bias, with 46% (54%) of the total section duration represented by normal (reversed) polarity.

In addition to a detailed polarity sequence, paleomagnetic data from the NBCP drill cores provide improved constraints on paleogeography. The paleopoles from the NBCP drill cores generally agree well with other North American reference poles and show a systematic age progression. An important element of this apparent polar wander can be portrayed as the change of the locality's paleolatitude with time, a representation that is not strongly dependent on uncertainties in azimuthal core orientation or any local vertical-axis rotations. Over the ~30 m.y. interval of the Late Triassic-earliest Jurassic represented by the Newark Basin section, eastern North America evidently drifted northward by about 7° (Figure 2). The NBCP drill cores suggest a shift in paleolatitude from about 2.5° to 6.5° north over the Carnian (Princeton to Nursery to Titusville) and from about 6.5° to 9.5° north over the ensuing Norian-"Rhaetian" and earliest Jurassic (Titusville to Martinsville). A tropical setting for the Newark Basin and an overall slow rate of northward motion over the Late Triassic and earliest Jurassic are robust interpretations of the data that are also relevant to Pangea paleogeography.

## Conclusions

We suggest that the magnetic polarity sequence from the NBCP drill cores constitutes a reference section for a Late Triassic-earliest Jurassic geomagnetic polarity timescale. The inferred ages of the palynologically defined stage boundaries are generally a few million years younger but within the quoted uncertainties of age estimates in the most recent Mesozoic timescale of Gradstein et al. [1994]. A possible correlation with magnetic polarity sequences derived from Carnian and Norian "Hallstatt" marine limestones in southwestern Turkey [Gallet et al., 1992, 1993] is shown in Figure 3. While the correlation should be regarded as tentative and needs to be tested, we believe that the available results provide motivation and opportunity to develop an integrated (marine and nonmarine), global timescale for the Late Triassic comparable in detail to that developed for the later Mesozoic and Cenozoic.

## References

BERGER, A., LOUTRE, M.F. and LASKAR, J., 1992. Stability of the astronomical frequencies over the Earth's history for paleoclimate studies. Science, 255: 560-566.

CANDE, S.C. and KENT, D.V., 1992. A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. J. Geophys. Res., 97: 13,917-13,951.

CORNET, B., 1977. The palynostratigraphy and age of the Newark Supergroup, Ph.D. thesis, 504 pp., Pa. State Univ., University Park.

CORNET, B., 1993. Applications and limitations of palynology in age, climatic, and paleoenvironmental analyses of Triassic sequences in North America. N. M. Mus. Nat. Hist. Sci. Bull., 3: 75-93.

CORNET, B. and OLSEN, P.E., 1985. A summary of the biostratigraphy of the Newark Supergroup of eastern North America with comments on Early Mesozoic provinciality, paper presented at III Congresso Latinoamericano de Paleontologia, Mexico, Simposio Sobre Floras del Triasico Tardio, su Fitogeografia y Paleoecologia, Memoria, pp. 67-81, Instituto de Geologia, Universidad Nacional Autonoma de Mexico, Mexico City.

DUNNING, G.R. and HODYCH, J.P., 1990. U/Pb zircon and baddeleyite ages for the Palisades and Gettysburg sills of the northeastern United States: Implications for the age of the Triassic/Jurassic boundary. Geology, 18: 795-798.

FEDOSH, M.S. and SMOOT, J.P., 1988. A cored stratigraphic section through the northern Newark Basin, New Jersey. U.S. Geol. Surv. Bull., 1776: 19-24.

FOWELL, S.J. and OLSEN, P.E., 1993. Time calibration of Triassic/Jurassic microfloral turnover, eastern North America. Tectonophysics, 222: 361-369.

FOWELL, S.J., CORNET, B. and OLSEN, P.E., 1994. Geologically rapid Late Triassic extinctions: Palynological evidence from the Newark Supergroup. Spec. Pap. Geol. Soc. Am., 288: 197-206.

GALLET, Y., BESSE, J., KRYSTYN, L., MARCOUX, J. and THEVENIAUT, H., 1992. Magnetostratigraphy of the Late Triassic Bolucektasi Tepe section (southwestern Turkey): Implications for changes in magnetic reversal frequency. Phys. Earth Planet. Inter., 73: 85-108.

GALLET, Y., BESSE, J., KRYSTYN, L., THEVENIAUT, H. and MARCOUX, J., 1993. Magnetostratigraphy of the Kavur Tepe section (southwestern Turkey): A magnetic polarity time scale for the Norian. Earth Planet. Sci. Lett., 117: 443-456.

GOLDBERG, D., REYNOLDS, D., WILLIAMS, C., WITTE, W.K., OLSEN, P.E. and KENT, D.V., 1994. Well logging results from the Newark Basin Coring Project (NBCP). Scientific Drilling, 4: 267-279.

GRADSTEIN, F.M., AGTERBERG, F.P., OGG, J.G., HARDENBOL, J., VAN VEEN, P., THIERRYM, J. and HUANG, Z., 1994. A Mesozoic Time Scale. J. Geophys. Res., 99: 24,051-24,074.

HODYCH, J.P. and DUNNING, G.R., 1992. Did the Manicouagan impact trigger end-of-Triassic mass extinction? Geology, 20: 51-54.

HUBER, P., LUCAS, S.G. and HUNT, A.P., 1993. Vertebrate biochronology of the Newark Supergroup Triassic, eastern North America. N.M. Mus. Nat. Hist. Sci. Bull., 3: 179-186.

KENT, D.V., OLSEN, P.E. and WITTE, W.K., 1995. Late Triassic-earliest Jurassic geomagnetic polarity sequence and paleolatitudes from drill cores in the Newark rift basin, eastern North America: J. Geophys. Res., 100: 14,965-14,998.

LITWIN, R.J., TRAVERSE, A. and ASH, S.R., 1991. Preliminary palynological zonation of the Chinle Formation, southwestern U.S.A., and its correlation to the Newark Supergroup (eastern U.S.A.). Rev. Palaeobot. Palynology, 68: 269-287.

MCINTOSH, W.C., HARGRAVES, R.B. and WEST, C.L., 1985. Paleomagnetism and oxide mineralogy of upper Triassic to lower Jurassic red beds and basalts in the Newark Basin. Geol. Soc. Am. Bull., 96: 463-480.

MOLINA-GARZA, R.S., GEISSMAN, J.W., VAN DER VOO, R., LUCAS, S.G. and HAYDEN, S.N., 1991. Paleomagnetism of the Moenkopi and Chinle Formations in central New Mexico: Implications for the North American apparent polar wander path and Triassic magnetostratigraphy: J. Geophys. Res., 96: 14,239-14,161.

OLSEN, P.E., 1980. The latest Triassic and Early Jurassic formations of the Newark Basin (Eastern North America, Newark Supergroup): Stratigraphy, structure, and correlation. N. J. Acad. Sci. Bull., 25: 25-51.

OLSEN, P.E., 1986. A 40-million-year lake record of early Mesozoic orbital climatic forcing. Science, 234: 842-848.

OLSEN, P.E. and FEDOSH, M.S., 1988. Duration of the early Mesozoic igneous episode in eastern North America determined by use of Milankovitch-type lake cycles. Geol. Soc. America, Abstr. Programs, 20: 59.

OLSEN, P.E. and KENT, D.V., 1995. Milankovitch climate forcing in the tropics of Pangea during the Late Triassic. Paleogeogr. Paleoclimatol. Paleoecol., in press.

OLSEN, P.E., and SUES, H.-D., 1986. Correlation of continental Late Triassic and Early Jurassic sediments, and patterns of the Triassic-Jurassic tetrapod transition, *in* Padian, K. (ed.): The Beginning of the Age of Dinosaurs: Faunal Change Across the Triassic Jurassic Boundary (p. 321-351), Cambridge Univ. Press, NY.

OLSEN, P.E., FOWELL, S.J. and CORNET, B., 1990. The Triassic/Jurassic boundary in continental rocks of eastern North America: A progress report. Spec. Pap. 247, Geol. Soc. Am., 585-593.

OLSEN, P.E., KENT, D.V., CORNET, B., WITTE, W.K. and SCHLISCHE, R.W., 1995. High resolution stratigraphy of the more than 5000 m Newark rift basin section (early Mesozoic, eastern North America). Geol. Soc. Am. Bull., in press.

RATCLIFFE, N.M., 1988. Reinterpretation of the relationship of the western extension of the Palisades sill to the lava flows at Ladentown, New York, based on new core data. U.S. Geol. Surv. Bull., 1776: 113-135.

SILVESTRI, S.M. and SZAJNA, M.J., 1993. Biostratigraphy of vertebrate footprints in the Late Triassic section of the Newark Basin, Pennsylvania: Reassessment of stratigraphic ranges. N.M. Mus. Nat. Hist. Sci. Bull., 3: 439-445.

SMOOT, J.P., 1991. Sedimentary facies and depositional environments of early Mesozoic Newark Supergroup basins, eastern North America. Paleogeogr. Paleoclimatol. Paleoecol., 84: 369-423.

SUTTER, J.F., 1988. Innovative approaches to the dating of igneous events in the early Mesozoic basins of the eastern United States. U.S. Geol. Surv. Bull., 1776: 194-200.

TOZER, E.T., 1993. Triassic chronostratigraphic divisions considered again. Albertiana, 11: 32-37.

VAN HOUTEN, F.B., 1964. Cyclic lacustrine sedimentation, Upper Triassic Lockatong Formation, central New Jersey and adjacent Pennsylvania. Kans. Geol. Surv. Bull., 169: 497-531.

VAN VEEN, P.M., 1995. Time calibration of Triassic/Jurassic microfloral turnover, eastern North America - Comment. Tectonophysics, 245: 91-95.

WITTE, W.K. and KENT, D.V., 1990. The paleomagnetism of red beds and basalts of the Hettangian extrusive zone, Newark Basin, New Jersey. J. Geophys. Res., 95: 17,533-17,545.

WITTE, W.K., KENT, D. V. and OLSEN, P.E., 1991. Magnetostratigraphy and paleomagnetic poles from Late Triassic-earliest Jurassic strata of the Newark Basin. Geol. Soc. Am. Bull., 103: 1648-1662.