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A Jurassic Time Scale[1]

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Abstract Application of geologic ages expressed in numeric time (millions of years) is a recent but rapidly expanding factor in petroleum exploration (rates of tectonic movements; basin models; geohistory analysis; prediction of reservoir quality, source potential, and HC maturation; correlation of geophysics with geologic events, etc.). This paper proposes an emendation of published versions of the Jurassic time scale. The standard geochronologic subdivision is combined with a linear-numeric scale, with a biostratigraphic scheme (ammonites, calcareous nannofossils), and with the geomagnetic-reversal time scale. To this purpose, basement ages at some Deep Sea Drilling Project sites are evaluated and related to the geomagnetic-reversal scale. The numeric scale certainly cannot be regarded as precisely and firmly determined throughout the Jurassic, but it seems adequate as a broad framework.

INTRODUCTION

A rather reliable and detailed numeric time scale has become available for the Tertiary (e.g., Berggren, 1972). This scale is based on many radiometric age determinations which tie key units of the biostratigraphic scheme to a linear time scale. Until recently, constructing such a continuous linear scale was difficult because many biohorizons ("biostratigraphic datums") could not be related closely to a radiometrically dated level. The breakthrough came with recognition of a continuous record of geomagnetic reversals recorded in a linear magnetic-anomaly pattern in oceanic sea floors and subsequent paleontologic dating by deep-sea drilling of oceanic basement at key anomalies. The assumption of constancy of sea-floor-spreading rate between the dated anomalies then allowed for a linear age interpretation of the pattern between these points and, with additional extrapolation beyond the calibration points, yielded a linear geomagnetic-reversal time scale for the entire Tertiary. Because geomagnetic reversals also can be recognized in sediments, the reversal time scale now makes possible the assignment of numeric ages to biohorizons, which are not radiometrically dated, by interrelating the magnetostratigraphy and biostratigraphy of sedimentary sections. As a result, it has become possible to place a linear time scale beside the biostratigraphic zonal scheme. The addition of new and better data to this feedback system continues to improve it. Increased reliability and resolution are being obtained now, for example, by studies on both biostratigraphy and magnetostratigraphy of deep-sea cores (e.g., Theyer and Hammond, 1974) and by intercalating an increasing number of radiometric dates for which the biostratigraphic position is known.

This intricate approach using a paleomagnetic time scale for linear extrapolation between paleontologically correlated, radiometrically dated calibration points only with uncertainty can begin to be applied to construct a Jurassic numeric time scale. Only very few useful Jurassic radiometric dates are available, and the biostratigraphic position of most of these is vague. Also, oceanic sea floor of that age with a well-defined magnetic-anomaly pattern is uncommon, and calibration points provided by deep-sea drilling are uncommon and of rather uncertain numeric age. Consequently, the Jurassic magnetic-reversal time scale is not well established. Availability of the reliable Tertiary time scale, however, led to development of stratigraphic techniques that also can be applied for older parts of the geologic column,

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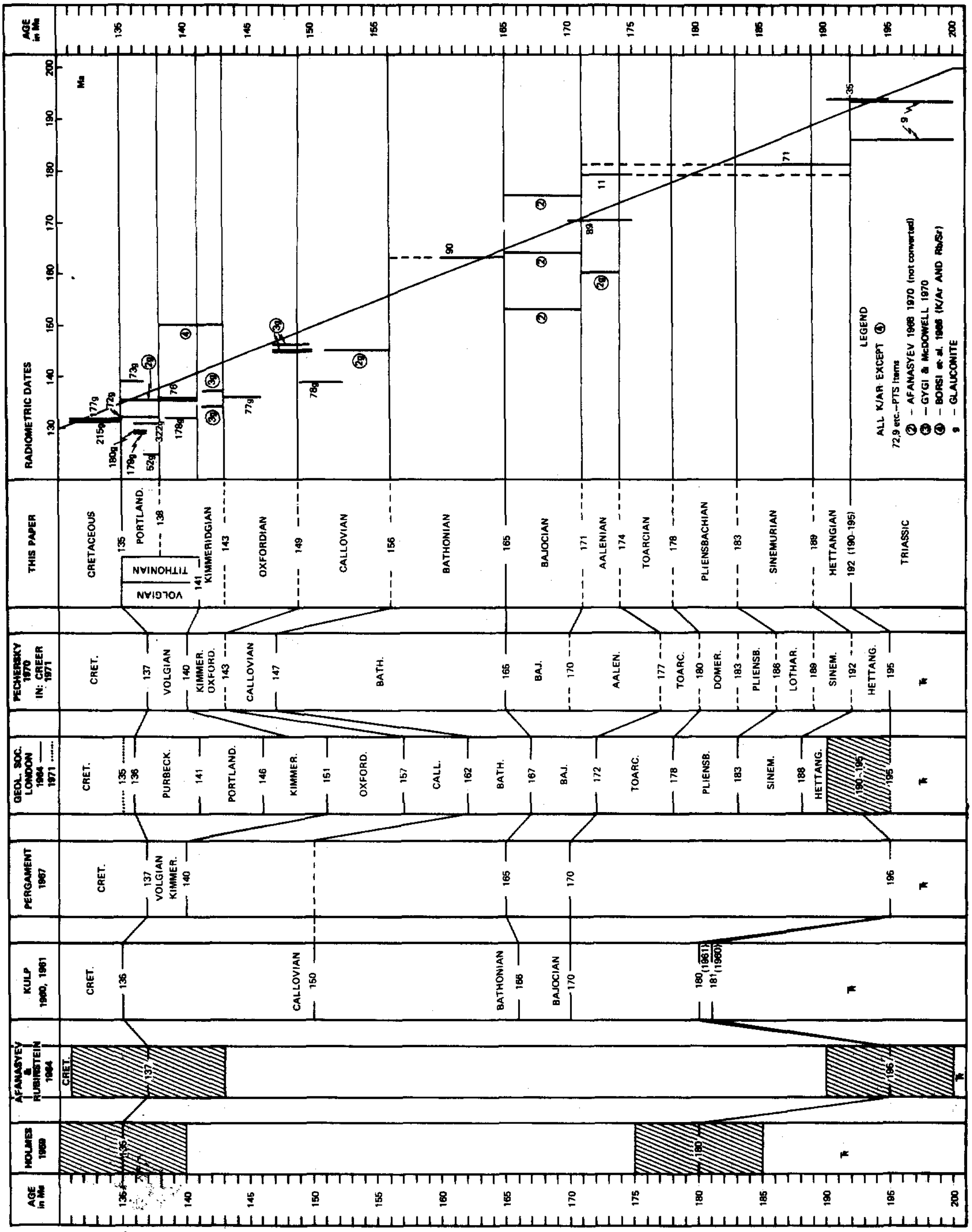


FIG. 1—History of Jurassic numeric time scale and comparison of radiometric dates with proposed scale. Russian dates have not been converted to accord with PTS constants.

be it with a wider margin of error. Thus, the present article provides a framework that serves the current needs and constitutes a basis for incorporation of additional information which will add needed precision for future requirements.

Our geochronologic terminology follows the recommendations of the International Geological Congress (1964), which discourage general usage of the term Purbeckian and support the use of the Aalenian as a stage covering the lower three ammonite zones of the Bajocian of others. Placement of the boundaries between Early, Middle, and Late Jurassic and between Lias, Dogger, and Malm also follows the IGC recommendations.

Calcareous nannofossil zonal boundaries are drawn in accordance with the definitions by Barnard and Hay (1974) following the species ranges given in their Figure 2 (which is not always the same as the boundaries in the third column of that figure). An exception had to be made for the *Stephanolithion speciosum* s.s. zone because the two lowest occurrences defining the zonal interval coincide on the range chart; for its top we used the lowest occurrence of *Diadozygus asymmetricus* instead of *Diazomatolithus lehmanni,* the lowest occurrence of *D. asymmetricus* also defining the base of the *D. lehmanni* zone.

Proposed Jurassic Time Scale

During the past few years, the writer and associates successfully have used a Jurassic time scale that is an emended version of the scale proposed by the Geological Society of London, 1964 (the Phanerozoic time scale, in the following referred to as PTS). The PTS was "set up purely as a basis for discussion in the absence of a more positive scale of calibration" (Casey, 1964, p. 199) and is "no more than a simple working hypothesis" (Internat. Union Geol. Sci., 1967, p. 378). Incentive for emendation came when application of the PTS to exploration problems led locally to geologic inconsistencies and improbabilities. Some changes are based on new information, but others are pragmatic and intuitive; by necessity, the emended scale is no less a simple working model than the PTS. Nevertheless, it seems opportune to make the scale more widely available for practical use and for discussion that may test and improve it. This model has proved useful in oceanic studies (Berggren et al, 1975), has brought more "natural" proportions to the eustatic-cycle chart of Vail et al (1974), and, most significant, has yielded rates of sediment accumulation that compare well with those of reliably dated facies equivalents in the Tertiary.

The PTS proposed that the Jurassic covers the time-span −135 to −(190-195) Ma (megayears before present, one megayear = 1 million years), with −165 Ma as its Bathonian approximate midpoint. Eleven Jurassic ages were recognized, and a linear scale was derived by (1) using the just-cited dates as calibration points and (2) assuming that the ages were of equal duration (5 Ma). Three exceptions to this assumption were includ-

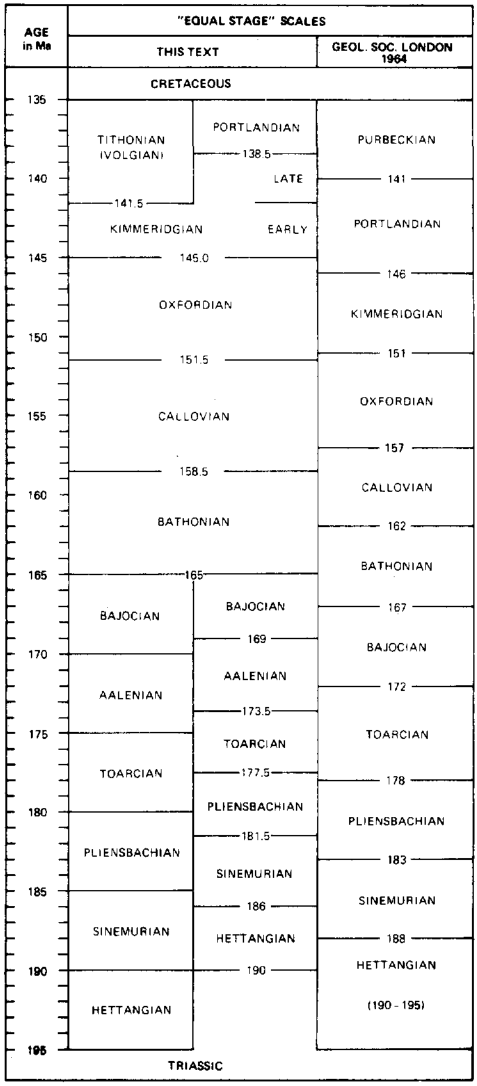
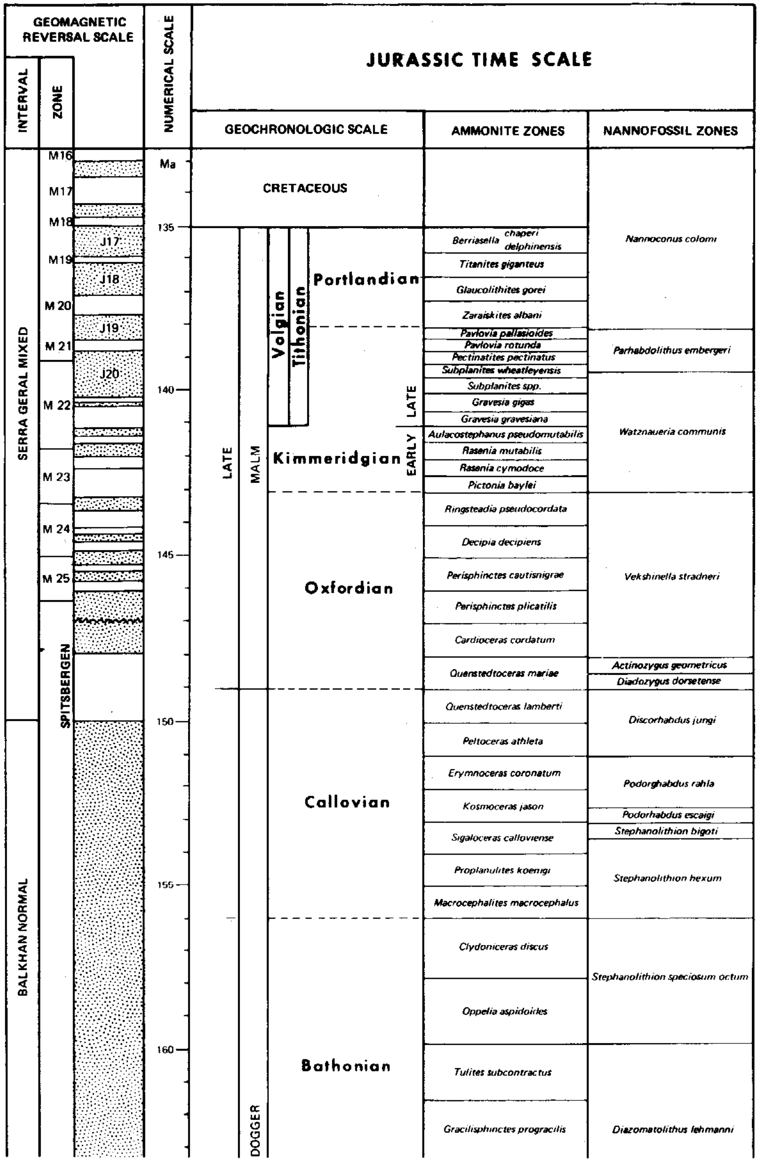


FIG. 2—Jurassic time scale proposed by Geological Society of London (1964) compared with scales derived on same assumptions but following chronostratigraphic subdivision proposed in Luxembourg in 1962 (Internat. Geol. Cong., 1964) and using −190 and −195 Ma as age of Jurassic-Triassic boundary.


JURASSIC TIME SCALE
GEOMAGNETIC REVERSAL SCALE
INTERVAL
ZONE
NUMERICAL SCALE
GEOCHRONOLOGIC SCALE
AMMONITE ZONES
NANNOFOSSIL ZONES
SERRA GERAL MIXED
BALKHAN NORMAL
SPITSBERGEN
M16
M17
M18
M19
M 20
M 21
M 22
M 23
M 24
M 25
J17
J18
J19
J20
Ma
135
140
145
150
155
160
CRETACEOUS
LATE
MALM
DOGGER
Volgian
Tithonian
Portlandian
Kimmeridgian
LATE
EARLY
Oxfordian
Callovian
Bathonian
Berriasella chaperi delphinensis
Titanites giganteus
Glaucolithites gorei
Zaraiskites albani
Pavlovia pallasioides
Pavlovia rotunda
Pectinatites pectinatus
Subplanites wheatleyensis
Subplanites spp.
Gravesia gigas
Gravesia gravesiana
Aulacostephanus pseudomutabilis
Rasenia mutabilis
Rasenia cymodoce
Pictonia baylei
Ringsteadia pseudocordata
Decipia decipiens
Perisphinctes cautisnigrae
Perisphinctes plicatilis
Cardioceras cordatum
Quenstedtoceras mariae
Quenstedtoceras lamberti
Peltoceras athleta
Erymnoceras coronatum
Kosmoceras jason
Sigaloceras calloviense
Proplanulites koenigi
Macrocephalites macrocephalus
Clydoniceras discus
Oppelia aspidoides
Tulites subcontractus
Gracilisphinctes progracilis
Nannoconus colomi
Parhabdolithus embergeri
Watznaueria communis
Vekshinella stradneri
Actinozygus geometricus
Diadozygus dorsetense
Discorhabdus jungi
Podorhabdus rahla
Podorhabdus escaigi
Stephanolithion bigoti
Stephanolithion hexum
Stephanolithion speciosum octum
Diazomatolithus lehmanni

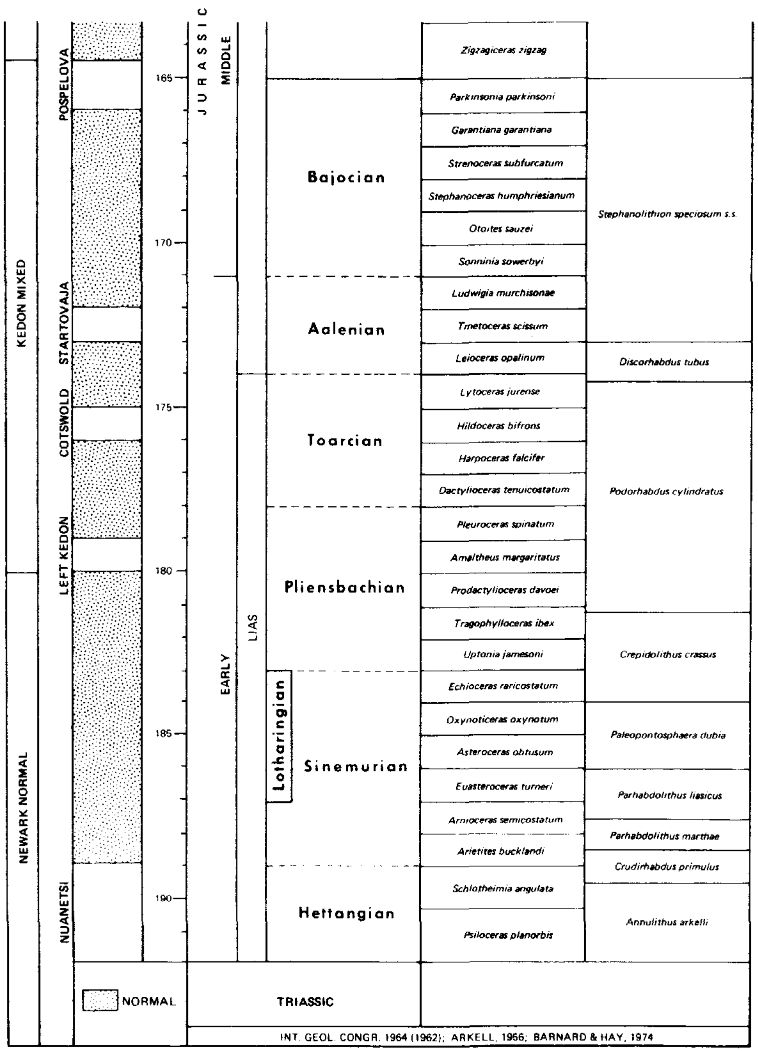


FIG. 3—Jurassic time scale proposed in this paper. Geomagnetic-reversal time scale is recalibrated after Larson and Pitman (1972) above wavy line at −147 Ma and after McElhinny and Burek (1971) and Pechersky and Khramov (1973) below.

ed (Oxfordian and Toarcian, 6 Ma; Hettangian, 4 Ma) for which no further reasons were given.

Howarth (1964), in an article which was the basis for the Jurassic part of the PTS, considered only 12 of all published radiometric dates of sufficient accuracy to be cited. These dates only broadly confirmed the proposed scale (Fig. 1).

Lambert (1971a, b) considered none of the glauconite ages cited by Howarth to be reliable and argued that the stratigraphic position of other radiometric dates is vague at best. His "most reliable" (1971a, p. 29) Jurassic radiometric age is 165 ± 4 Ma (K/Ar biotite) for the post-Bajocian Kelasury Granite. The second category of Lambert ("most reliable determinations without duplicate or supporting analyses," 1971a, p. 30) listed K/Ar biotite dates of −136 ±4 Ma for the post-early Kimmeridgian Horseshoe Bar diorite and −193? ±? for the Hotailuh batholith near the Jurassic-Triassic boundary. Lambert suggested rounding off to 5 Ma the ages of all major pre-Tertiary boundaries, proposing −135? Ma for the Cretaceous-Jurassic boundary but without deciding to −195? or −200? or −205? Ma for the Jurassic-Triassic boundary.

The present scale uses as basic points −135 Ma (Howarth, 1964; Lambert, 1971a, b) and −190 to −195 Ma (Howarth, 1964; Geol. Soc. London, 1964) boundaries and the 165 ±4 Ma (PTS, Item 90; Lambert, 1971a) mid-Jurassic age. Following the recommendations of the International Geological Congress (1964), the stage scheme of the PTS is altered in that Portlandian and Purbeckian are merged and Aalenian is added. Assuming equal-time representation of the stages, the Bajocian rather than the Bathonian becomes the middle stage of the Jurassic. The PTS conveniently could use the −165 ±4 Ma date (coincidentally the midpoint between −135 and −195) for the middle of their Middle Jurassic stage. Here it is placed as close to the middle as seems justified, the Bajocian-Bathonian boundary being drawn at −165 Ma (cf. Snelling, 1964).

A linear scale derived from the three calibration points in the PTS manner by assuming equal time (rounded to 0.5 Ma) for the stages would result in the scale of Figure 2. Another, equally hypothetical but perhaps slightly more meaningful, way to extrapolate a linear scale from calibration points is to assume time equivalence for biozones. Doing so for the 26 Arkell (1956) ammonite zones of the Jurassic older than 165 Ma gives each zone a duration of 1.15 Ma, if an age of 195 Ma is assumed for the base of the Jurassic and 0.96 Ma for a base 190 Ma old. Assignment of a duration of 1.0 Ma to each zone, therefore, seemed a reasonable approximation, and the scale of Figure 3 was the result.

For the post-Bajocian part of the scale, a few recent radiometric dates and Russian opinions (Fig. 1) suggest partial divergence from the "equal stage" and from the "equal zone" approach. Rounding the beginning times of the Portlandian and Tithonian (Volgian) to the younger whole number gives −138 and −141 Ma, respectively. Zonal equivalence within most of the Kimmeridgian brings its beginning to −143 Ma. Although highly artificial, these boundary ages seem to be confirmed by the available radiometric ages.

On the basis of radiometric age determinations, Russian authors (Perchersky, *in* Creer, 1971) drew the Callovian/Bathonian boundary at −147 Ma so that the Bathonian has a very long time span (Fig. 1). Consequently, Bathonian biochronozones would last disproportionately long, and Bathonian sediment-accumulation rates would be exceedingly low. On the proposed scale we stayed within Gygi and McDowell's (1970) radiometric age range of −146 ±3 Ma for the lowermost Oxfordian and uppermost Callovian by simply assigning a 1-Ma duration to the Oxfordian and Callovian ammonite zones. The resulting Oxfordian/Callovian boundary is 149 Ma old, and the Callovian/Bathonian boundary is 156 Ma old.

The older part of the geomagnetic-reversal time scale of Figure 3 is after the terrestrial scale of McElhinny and Burek (1971) and Pechersky and Khramov (1973). Sallomy and Briden (1975) found reversed polarity in the upper Toarcian Cotswold sands and Rosedale iron ore, confirming Girdler's (1959) results which had been incorporated in the McElhinny and Burek (1971) scale as the Cotswold Zone (=? Nuanetsi Zone of Pechersky and Khramov, 1973). Probably the Bajocian Startovaja Reversed Zone of Pechersky (*in* Creer, 1971) and Pechersky and Khramov (1973) is the same as the Mateke Zone of McElhinny and Burek (1971) and possibly was recognized by Sallomy and Briden (1975) in their Cephalopod Bed. Further included are the Bathonian/Bajocian Pospelova and the Domerian Left-Kedon Zones of the just-mentioned Russian authors; the fact that these reversed-polarity zones have not been recognized outside the Soviet Union may well be because of the scarcity of paleomagnetic analyses for this part of the stratigraphic column. The Finish Mixed Zone of Pechersky and Khramov (1973) probably falls within the Nuanetsi Reversed Zone of McElhinny and Burek (1971).

The younger part of the geomagnetic-reversal time scale is after the marine scale of Larson and Pitman (1972; "J" anomaly numbers after Vogt et

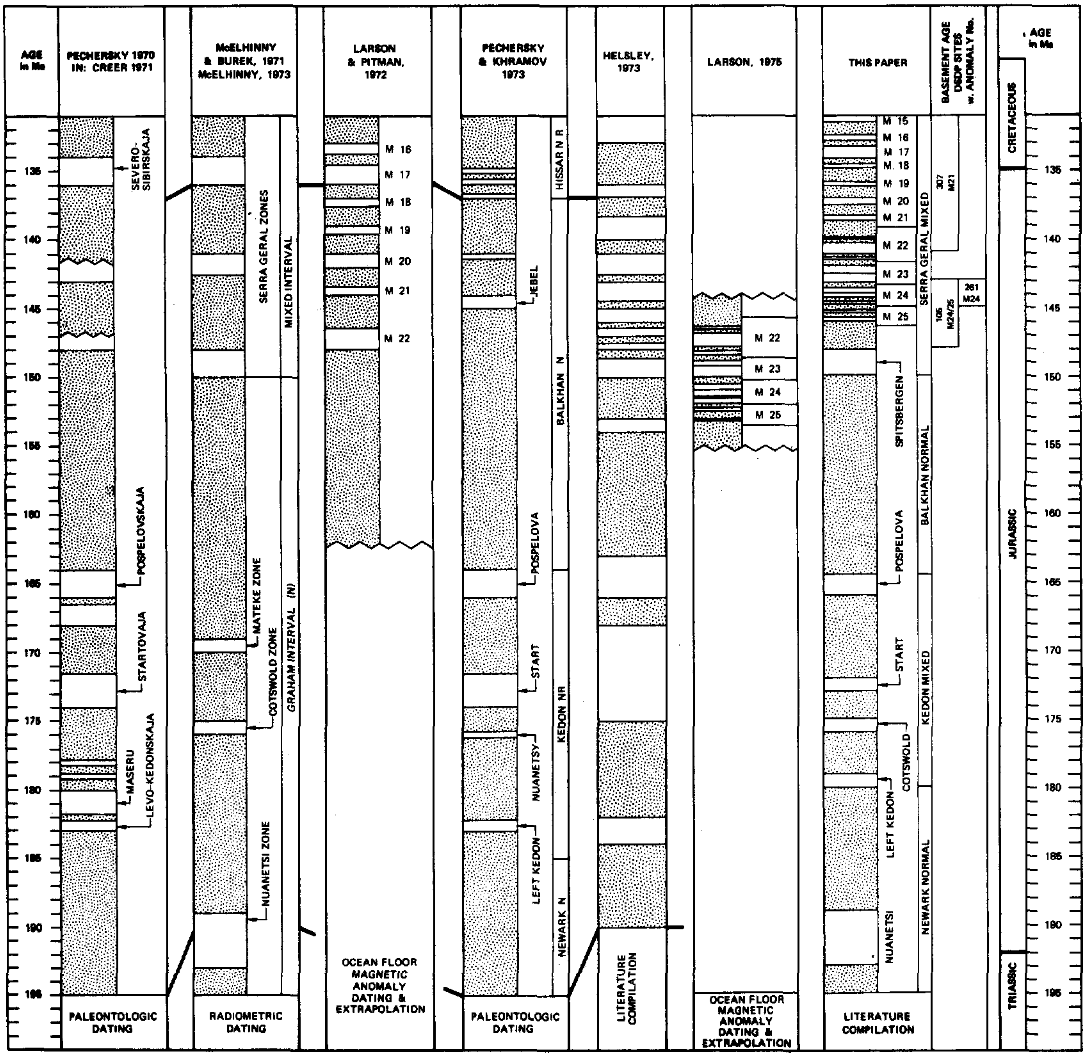


FIG. 4—Comparison of geomagnetic-reversal time scales published for Jurassic. Original Pechersky and Khramov (1973) scale is nonlinear; ages here have been estimated from Pechersky (1970, *in* Creer, 1971). Time intervals of normal field polarity are shaded. Russian radiometric ages have not been converted to accord with PTS constants.

al, 1971), but with 145 and 125 Ma instead of 155 and 120 Ma as the ages of the two calibration points used by Larson and Pitman—i.e., the age at the bases of Deep-Sea Drilling Project (DSDP) holes 105 and 166, respectively. The reasons for changing these estimates of basement age are given in the following.

Oceanic Basement Ages

Drawing the Cretaceous/Jurassic boundary (−135 Ma) at 550 m in DSDP hole 105 (calpionellids) and placing the base of the Kimmeridgian (−143 Ma) at 603 m (ammonite fragment; Hollister et al, 1972) means that a section 53 m thick was deposited in 8 Ma, a rate of 0.65 cm/1,000 years. This rate compares well with sites 100 (0.75 cm/1,000 years) and 99 (0.60 cm/1,000 years). The base of the sediment lies 19 m lower than the base of the Kimmeridgian and, extrapolating the rate of sediment accumulation, is 3.1 Ma older. The base of the Kimmeridgian could be lower in hole 105 than just assumed, which would increase the rate of sediment accumulation and make the base of sediment younger. On the other hand, the dinoflagellate biostratigraphy suggests that it could be somewhat higher with the reversed effect. To give the base of sediment an age range of 143-148 Ma seems justified, hence the use here of − 145 Ma.

The age of the lowest sediment at DSDP Site 166 (cores 27, 28) is "definitely Neocomian, probably Late Hauterivian" (Douglas, 1973, p. 684). In the core description for the site, two incompatible ages were given: "Late Hauterivian (Forams, Nannos)" and "Late Albian-Cenomanian (Rads)" (Winterer et al, 1973, p. 126, 127). Accepting a Hauterivian age for the lower cores means that the base of sediment lies 18 m below the Hauterivian-Barremian boundary (− 121 Ma) and probably is considerably older because the rate of sediment accumulation for the "zeolitic nannofossil marl" deposited near calcite-compensation depth (CCD) most likely is low, and because basement is 700 m higher than "normal" (Winterer, 1973), which further suggests minimal sediment-accumulation rates. It seems reasonable to assume an age range of − 122 to − 127 Ma for basement at Site 166, and to use − 125 Ma for the calibration point.

The use of − 145 and − 125 Ma brings the ages found during DSDP Leg 32 for the Early Cretaceous and Jurassic anomalies M4, M9, and M21 in accord with the prediction on the scale (123, 126, and 138.5 Ma, respectively), whereas with − 120 and − 145 Ma as calibration points, two ages would be older than predicted (117.5 and 121 Ma, respectively). If − 155 and − 120 Ma are used as calibration points, the found ages for M4 and M9 are older than predicted, and the found age for anomaly M21 is younger than predicted (118.5, 121, and 142 Ma, respectively). Anomaly M4 was dated at DSDP Site 303 as Valanginian to Hauterivian, 131-121 Ma old; anomaly M9 was dated at DSDP Site 304 as Neocomian, probably Valanginian, 135-121 (131-126) Ma old; and anomaly M21 was dated at DSDP Site 307 as probably Tithonian or Berriasian, 141-131 Ma old (Anon., 1973).

Results obtained at DSDP Site 261 further confirm the usefulness of the scale given in this study. The section between 508 and 526 m is of Tithonian age (Proto Decima, 1974); using − 135 and − 141 Ma as boundary ages gives an average rate of sediment accumulation of 0.30 cm/1,000 years. Downward extrapolation of this rate suggests that the top of the Oxfordian (− 143 Ma) is to be expected at 532 m, which is precisely where the boundary has been drawn on paleontologic evidence (top of *Stephanolithion bigoti*). A basement age of 143-145 Ma seems a reasonable estimate. Larson (1975) correlated the magnetic-anomaly pattern at site 261 with anomaly M24, the Atlantic DSDP Site 105 lying between M24 and M25. The preceding conclusions are summarized in Figure 4.

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