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Oxfordian and Lower Kimmeridgian Magnetic Polarity Time Scale

J.G. Ogg[1] and J. Gutowski[2]

[1]Department of Earth and Atmospheric Sciences,
1397 Civil Engineering Building, Purdue University, West Lafayette, Indiana 47907, USA

[2]GEOPOL, ul. Pulawska 18, PL-00-975 Warszawa, Poland

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ABSTRACT

The magnetic polarity zonation for each ammonite zone through the Oxfordian and Kimmeridgian stages has been assembled using a series of approximately 25 outcrops. The observed suite of approximately 20 pairs of normal- and reversed-polarity zones is correlated with the Pacific marine magnetic anomaly sequence from M23 through M35. The relative durations and approximate ages of Oxfordian and Kimmeridgian ammonite zones can be estimated from a seafloor spreading model that incorporates radiometric ages on these anomalies from Ocean Drilling holes.

INTRODUCTION

Magnetostratigraphic correlation of biostratigraphic events to marine magnetic anomalies has enabled both high-resolution global stratigraphy and estimates of absolute ages within the Cretaceous and Cenozoic [e.g., 1, 2, 3, 4, 5]. The Jurassic portion of the marine magnetic anomaly record ("M-sequence") extends into the Callovian [6, 7, 8], but only the Jurassic-Cretaceous boundary interval has been directly correlated to biostratigraphy [e.g., 9, 10, 11, 12]. Prior to the Late Kimmeridgian, the increased frequency of magnetic reversals, coupled with difficulties in obtaining reliable primary magnetization in continuous stratigraphic sections having good biostratigraphic control, has hindered development of a standard magnetic polarity time scale. Portions of the Oxfordian and Callovian have yielded a reproducible magnetic polarity pattern [e.g., 13, 14, 15], but these intervals have been too limited to allow correlations to the marine magnetic anomaly pattern.

In this paper, we summarize the magnetostratigraphy of approximately 25 sections that provide multiple coverage of most ammonite zones within the Oxfordian and Kimmeridgian. The composite magnetic polarity pattern from this array appears to correlate to the main features of the marine magnetic anomaly M-sequence.

STRATIGRAPHIC SECTIONS

The suite of sections in Poland and Spain were within the Submediterranean Faunal Province during most of the Oxfordian and Kimmeridgian, therefore the ammonites in both regions can generally be correlated. However, the subdivision of the Oxfordian into ammonite zones is still evolving [e.g., table in 15], therefore nomenclature and assignment of zonal boundaries varies slightly according to region and date of publication. In particular, the lower subzone, "Tenuicostatum" of the Plicatilis ammonite zone in Poland probably encompasses the "Vertebrale" subzone and lower portion of the Antecedens subzone as currently defined in Spain and France [e.g., 16, 17, and table in 15].

In general, the successions are developed on shelves that experienced a general progressive transgression during the Oxfordian. The basal Oxfordian, if present, is very condensed. The bulk of the Oxfordian is represented by sponge-bearing micritic limestones. The lower Kimmeridgian in Poland is represented by oolitic to marly limestone; in contrast to the sections in Spanish Prebetic and Subbetic regions of condensed nodular limestones. Within the Oxfordian-Kimmeridgian are some discontinuities that appear to correlate to regional changes in sea level [18].

Poland

Lower Oxfordian sections of Zalas, Podleze (3 sections) and Rudno within the Krakow-Wielun Uplands have a published magnetostratigraphy [14]. The lower extent of the succession at Zalas has been revised by Marchand and Tarkowski [19].

The two Gniezdziska quarry sections of lower to middle Oxfordian in the Holy Cross Mountains have been described by Matjya [20] and Drewniak and Matyja [21]. The middle Oxfordian in Wola Morawicka quarry in the same region can be correlated to Gniezdziska using lithostratigraphy. The Wysoka quarry in the Polish Jura is described by Glowniak and Matyja [22].

Niegowonice quarry in the Polish Jura has a detailed middle Oxfordian ammonite stratigraphy by Matyja and Wierzbowski [23, 24]. Zawodzie quarry in the eastern suburbs of Czestochowa has a detailed ammonite succession spanning the Bifurcatus Zone [25, 26, 27]. Syborowa quarry in the Polish Jura has a well-defined Bifurcatus-Bimammatum zone boundary [28, 24].

The lower Kimmeridgian quarries at Malogoszcz and Bukowa in the Holy Cross Mountains have a biostratigraphy and lithostratigraphy by Kutek [29, 30, 31]. The Sobków-Wierzbica quarry in the same region spans the Oxfordian/Kimmeridgian boundary ([32].

Spain

Four Oxfordian sections near Aguilón (Iberian Chain) have a published magnetostratigraphy by Steiner et al. [13]. Juárez et al. ([15] duplicated two of these sections and added two new sections. G. Meléndez was the lead paleontologist for both of these studies, but his ammonite zonal scheme and boundary placements had changed during the intervening 8 years [e.g., 17]. Therefore, the results of Steiner et al. [13] have been adjusted for the revised biostratigraphy. The composite polarity patterns of each of these two studies (6 sections total) are nearly identical.

Middle to upper Oxfordian successions in the Prebetic paleogeographic zone at Segura de la Sierra and at Cazorla are from sections #1 and #4 in García-Hernández et al. [33]. The Oxfordian/Kimmeridgian boundary sections at Cehegin and Sierra Gorda #2 have ammonite stratigraphy by F. Olóriz and J.M. Tavera (personal communications, 1982).

Lower Kimmeridgian portions of the sections at Carcabuey and Sierra Gorda are reinterpreted from the original data included in Steiner et al. [13]. These sections continue through the Tithonian (not shown), and provided the basis for the present Tithonian ammonite zone correlation to magnetic polarity chrons [9].

MAGNETOSTRATIGRAPHY

A total of approximately 500 samples from this suite of sections were thermally demagnetized to obtain characteristic directions of magnetization. Samples from Spain were commonly reddish in color and generally displayed well-defined directions of dual polarity from 350°C to 500°C or 600°C. The pole positions are consistent for the expected paleolatitudes of Spain during the late Jurassic [e.g., 13], and indicate differential amounts of rotation.

Samples from Poland generally had weak intensities of magnetization. Commonly above 350°C, the magnetization was too weak to accurately measure or would acquire unstable directions induced by formation of new magnetic phases from oxidation of pyrite or decomposition of iron-bearing clay. For most of the Polish samples, demagnetization at 200°C was adequate to unblock normal and reversed polarity. The bulk of the samples were useful for polarity, but the high scatter of most characteristic directions precluded computation of precise poles. Those subsets of samples that yielded stable directions had a paleolatitude consistent with the expected late Jurassic position of Poland [e.g. 14].

COMPOSITE POLARITY PATTERN AND CORRELATION TO M-SEQUENCE

The correlation of the suite of magnetostratigraphic sections depends primarily upon the assignment of ammonite zones and subzones (Figures 1 and 2). A composite polarity pattern is constructed for each ammonite zone according to duplication of polarity features in multiple sections with allowance for recognized discontinuities in sedimentation (columns on right side of Figures 1 and 2). In some cases, especially within portions of the Plicatilis and lowermost Transversarium zones and at the Oxfordian/Kimmeridgian boundary, the composite polarity column is based upon a single magnetostratigraphic section. The Poland and Spain composite polarity patterns were rescaled using (1) an arbitrary assumption of equal-duration for ammonite subzones within the Oxfordian and

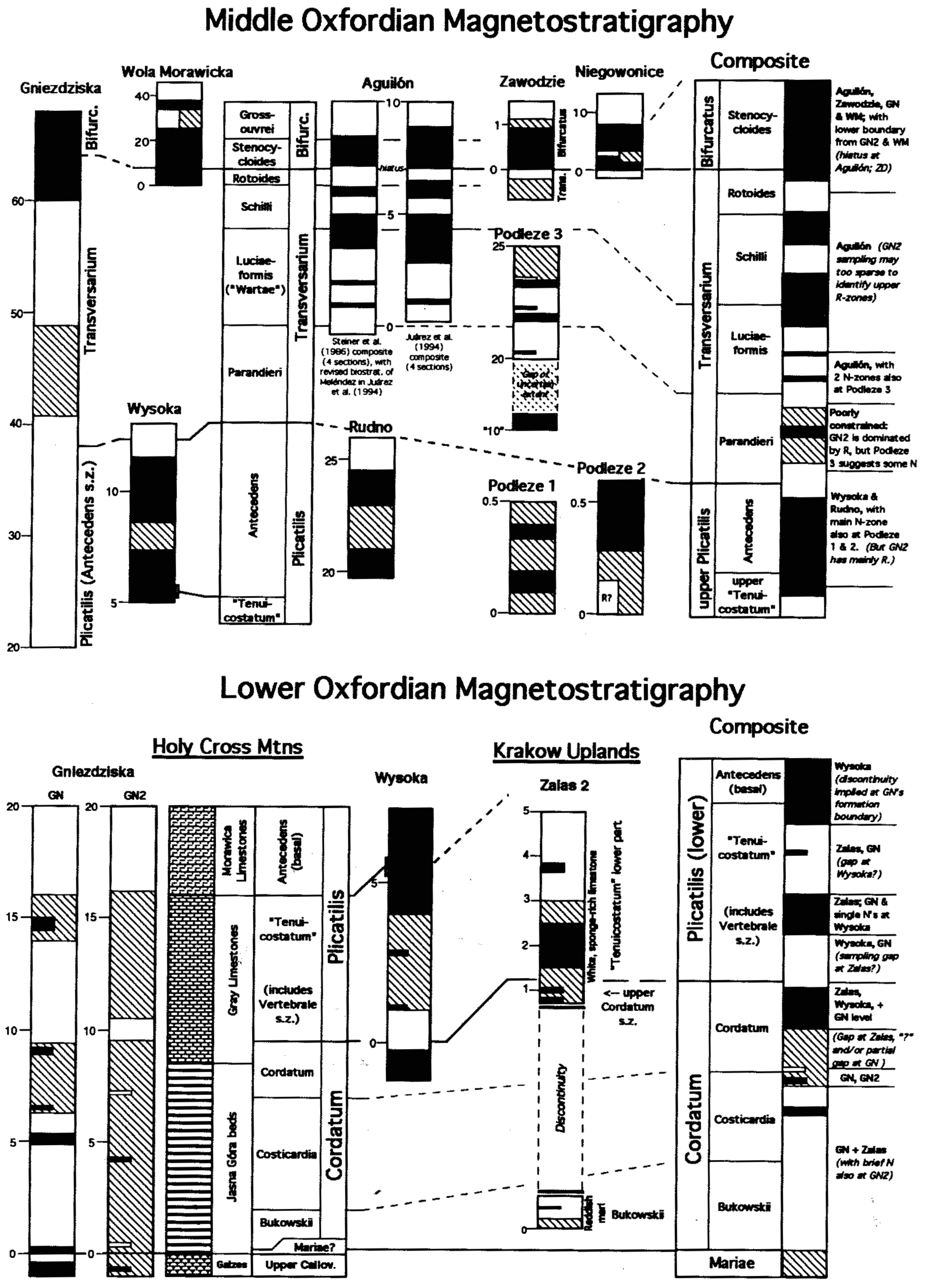


Figure 1. Magnetostratigraphy of Lower and Middle Oxfordian sections and the composite magnetic polarity pattern. On the magnetostratigraphy columns, black portions are normal-polarity zones, white portions are reversed-polarity zones, and diagonal-lined portions are stratigraphic intervals that were not sampled or failed to yield reliable paleomagnetic polarities. Meter levels of each section are on the left side. Ammonite zone correlations are shown by solid or dashed lines. Derivation of composite polarity pattern is explained in notes on the right side.

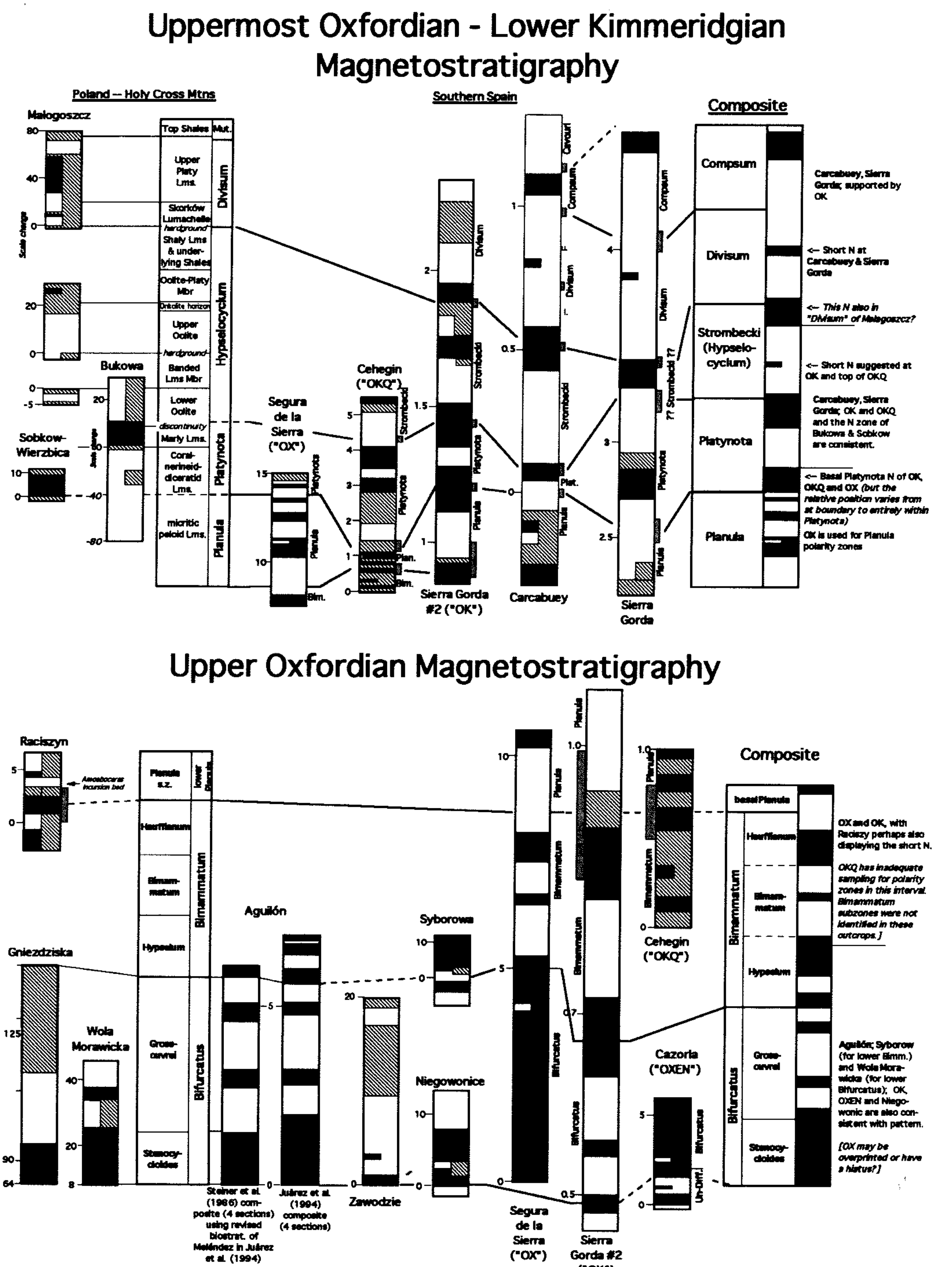


Figure 2. Magnetostratigraphy of Upper Oxfordian and Kimmeridgian sections and the composite polarity pattern. Magnetic polarity column format is similar to Figure 1. Ammonite zone correlations are shown by solid or dashed lines, with uncertainties in placement of ammonite zonal boundaries, if known, indicated by a gray band adjacent to the polarity column.

within the Early Kimmeridgian, and (2) an age scale of 150.7 Ma for the Kimmeridgian/Tithonian boundary and 154.1 Ma and 159.4 Ma for the boundaries of the Oxfordian Stage [5] (leftmost column in Figure 3).

An approximate age scale for the Jurassic portion of the M-sequence of marine magnetic anomalies [7] was based on two calibration points: (1) Ocean Drilling Program (ODP) Site 765, drilled on marine magnetic anomaly M26r in the Argo Abyssal Plain, has an Ar-Ar age on the basement basalts of 155.3 ± 3.4 Ma [34]; and (2) ODP Site 801, drilled into Pacific crust older than magnetic anomaly M39, has basement basalts interbedded with radiolarian assemblages of latest Bathonian or earliest Callovian [8] and an Ar-Ar age of 166.8 ± 4.5 Ma [35] (middle column of Figure 3).

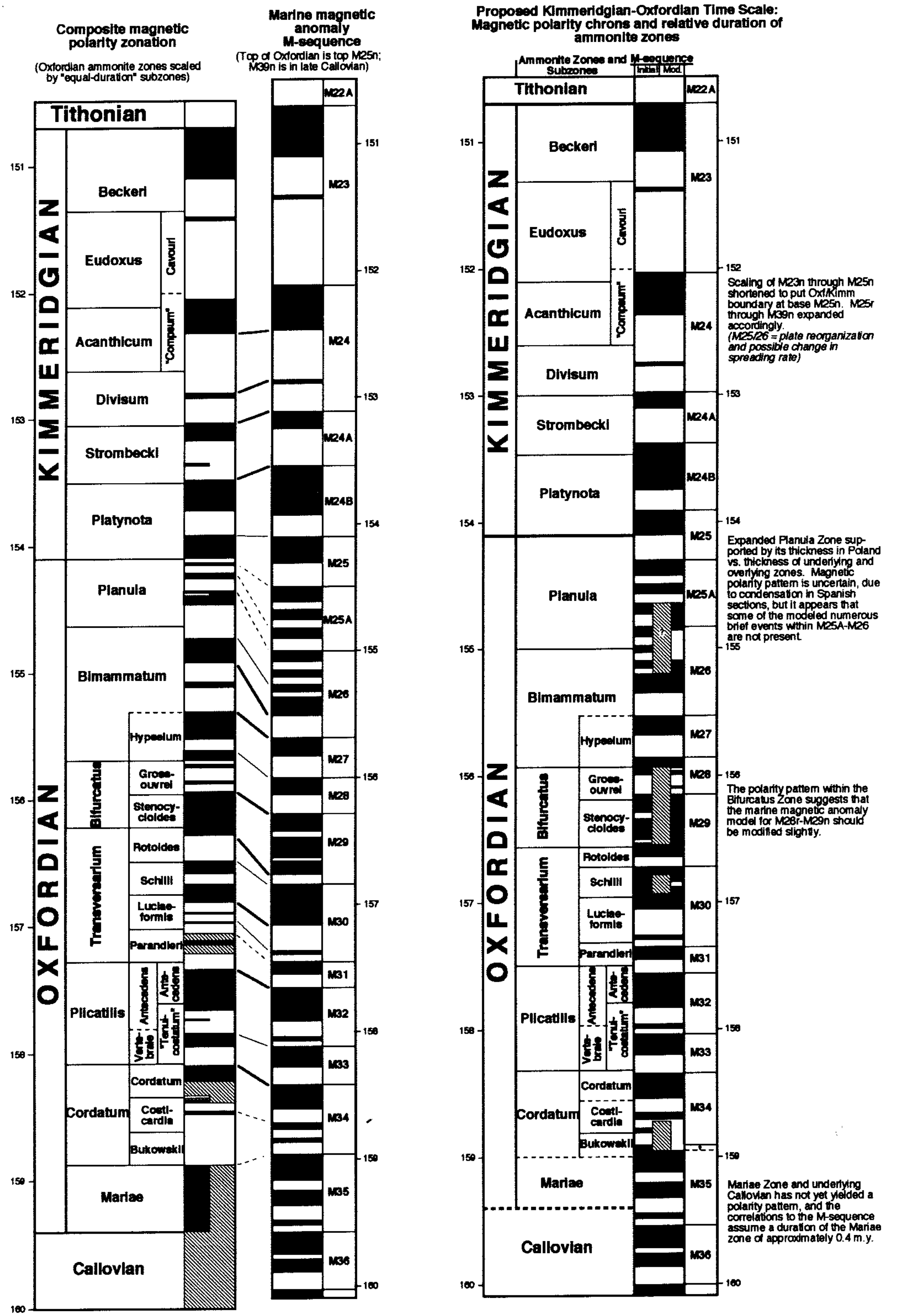
When these two independent scales -- magnetic polarity zones for ammonite zones and the marine magnetic anomaly pattern -- are compared, the approximate frequency of reversals are similar (Figure 3). A set of correlations can be made using the following logic: (1) the Kimmeridgian polarity zones are equivalent to magnetic polarity chrons M23 through M25 [9], (2) the normal polarity zone in the lower part of the Platynota Zone is polarity chron M25n, implying that the projected M-sequence ages should be moved slightly younger (e.g., a more rapid spreading rate) than was initially assumed, (3) all major polarity zones have been identified in the Oxfordian above the Mariae Zone and these have a counterpart in the M-sequence, (4) the M-sequence model for the low-amplitude Japanese magnetic lineations may have included brief "reversals" that are artifacts of natural intensity fluctuations or topography (e.g., the clusters of brief events modeled within anomalies M26, M29n and M34r), and (5) the relative scalings of ammonite subzones or zones and their associated polarity zones are approximately correct, except for rare exceptions, such as the Rotoides Subzone, which span only a thin stratigraphic band in the measured sections.

Under this set of constraints and assumptions, a consistent suite of correlations is possible. The Oxfordian stage appears to be equivalent to magnetic anomalies M25r through M35. If a constant spreading rate is assumed for the formation of this magnetic anomaly set in the Japanese lineations, then these correlations yield a relative duration of ammonite zones and subzones and a few postulated revisions in the magnetic anomaly model (right column in Figure 3).

The resulting composite scale of magnetic polarity chrons and associated ammonite zones provides a revised Oxfordian and Early Kimmeridgian time scale (Figure 3). The abundance of magnetic polarity reversals will cause ambiguity in broad correlations unless either detailed biostratigraphy, sequence stratigraphy, or isotope stratigraphy is available. However, once the approximate ammonite zone is known, then the magnetic reversals will provide a set of time horizons for high-resolution correlation on a global scale.

Figure 3. (opposite page)

The left pair of columns are the composite magnetostratigraphy zonation and the M-sequence of marine magnetic anomalies using a constant spreading-rate model. Proposed major correlations are in heavy lines and lesser correlations are in light or dashed lines. Rescaling of the ammonite zones to fit this marine magnetic anomaly model yields a composite magnetic polarity time scale for the Oxfordian-Kimmeridgian (columns on the right) with estimates of relative durations of the associated ammonite zones and subzones. The magnetostratigraphy suggests that the initial magnetic anomaly model (left side of polarity time scale) may require minor revision of brief polarity intervals (right side of polarity time scale).


Composite magnetic polarity zonation
(Oxfordian ammonite zones scaled by "equal-duration" subzones)
Marine magnetic anomaly M-sequence
(Top of Oxfordian is top M25n; M39n is in late Callovian)
Proposed Kimmeridgian-Oxfordian Time Scale: Magnetic polarity chrons and relative duration of ammonite zones
Ammonite Zones and Subzones
M-sequence
Initial
Mod.
Tithonian
KIMMERIDGIAN
OXFORDIAN
Callovian
Beckeri
Eudoxus
Cavouri
Acanthicum
"Compsum"
Divisum
Strombecki
Platynota
Planula
Bimammatum
Hypselum
Bifurcatus
Grossouvrei
Stenocycloides
Transversarium
Rotoides
Schilli
Luciaeformis
Parandieri
Plicatilis
Antecedens
Antecedens
"Tenuicostatum"
Vertebrale
Cordatum
Cordatum
Costicardia
Bukowskii
Mariae
M22A
M23
M24
M24A
M24B
M25
M25A
M26
M27
M28
M29
M30
M31
M32
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Scaling of M23n through M25n shortened to put Oxf/Kimm boundary at base M25n. M25r through M39n expanded accordingly.
(M25/26 = plate reorganization and possible change in spreading rate)
Expanded Planula Zone supported by its thickness in Poland vs. thickness of underlying and overlying zones. Magnetic polarity pattern is uncertain, due to condensation in Spanish sections, but it appears that some of the modeled numerous brief events within M25A-M26 are not present.
The polarity pattern within the Bifurcatus Zone suggests that the marine magnetic anomaly model for M28r-M29n should be modified slightly.
Mariae Zone and underlying Callovian has not yet yielded a polarity pattern, and the correlations to the M-sequence assume a duration of the Mariae zone of approximately 0.4 m.y.

Figure 3

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