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A Revised Magnetic Polarity Time Scale for the Paleocene and Early Eocene and Implications for Pacific Plate Motion

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A REVISED MAGNETIC POLARITY TIME SCALE FOR THE PALEOCENE AND EARLY EOCENE AND IMPLICATIONS FOR PACIFIC PLATE MOTION

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Abstract. Magnetostratigraphic studies of a continental sedimentary sequence in the Clark's Fork Basin, Wyoming and a marine sedimentary sequence at Gubbio, Italy indicate that the Paleocene-Eocene boundary occurs just stratigraphically above normal polarity zones correlative with magnetic anomaly 25 chron. These data indicate that the older boundary of anomaly 24 chron is 52.5 Ma. This age is younger than the late Paleocene age assigned by LaBrecque et al. [1977] and also younger than the basal Eocene age assigned by Ness et al. [1980]. A revised magnetic polarity time scale for the Paleocene and early Eocene is presented in this paper. Several changes in the relative motion system between the Pacific plate and neighboring plates occurred in the interval between anomaly 24 and anomaly 21. A major change in absolute motion of the Pacific plate is indicated by the bend in the Hawaiian-Emperor Seamount chain at ~43 Ma. The revised magnetic polarity time scale indicates that the absolute motion change lags the relative motion changes by only ~3-5 m.y. rather than by >10 m.y. as indicated by previous polarity time scales.

A revised magnetic polarity time scale for Paleocene and early Eocene

The Cenozoic magnetic polarity time scale of LaBrecque et al. [1977] has been used extensively in the past few years. This polarity time scale was a modification of the time scale of Heirtzler et al. [1968] and primarily involved two calibration points: (1) an age of 3.32 Ma for the Gauss-Gilbert boundary and (2) an age of 64.9 Ma for the older boundary of magnetic anomaly 29 chron. (The suffix "chron" is used for time intervals of the magnetic polarity time scale in keeping with recommendations regarding magnetostratigraphic nomenclature, see Geology, 7, 578-583, 1979.) The latter calibration point resulted from placement of the Cretaceous-Tertiary boundary just preceding anomaly 29 chron [Sclater et al., 1974; Alvarez et al., 1977]. Mankinen and Dalrymple [1979] tabulated the changes in the LaBrecque et al. [1977] time scale required by revised constants for use in potassium-argon dating. Recently acquired biostratigraphic and magnetostratigraphic data indicate that further revisions of the Paleocene and Eocene portions of the magnetic polarity time scale are required.

Primarily from analyses of biostratigraphic ages of DSDP sediments, Berggren et al. [1978] concluded that magnetic anomaly 24 chron was basal Eocene rather than late Paleocene as on the time scale of LaBrecque et al. [1977]. Ness et al. [1980] have recently proposed a revised polarity time scale which incorporated the basal Eocene age of anomaly 24 and employed four calibration points: (1) an age of 3.40 Ma for the Gauss-Gilbert boundary, (2) 10.30 Ma for the older boundary of anomaly 5 chron, (3) an age of 54.90 Ma for the older boundary of anomaly 24 chron consistent with the placement of anomaly 24 chron as basal Eocene, and (4) an age of 66.70 Ma for the Cretaceous-Tertiary boundary just preceding the older boundary of anomaly 29 chron. Using these calibration points, Ness et al. [1980] obtained the ages of intervening polarity boundaries by interpolation and used the geologic time scale of Hardenbol and Berggren [1978] for geologic time boundaries in the Paleogene (with absolute ages recalculated using revised constants).

Magnetostratigraphic study of continental sediments spanning the Paleocene-Eocene boundary in the Clark's Fork Basin of northwestern Wyoming has recently been completed by Butler et al. [in press]. Results of that study indicate that the Paleocene-Eocene boundary occurs stratigraphically just above a normal polarity zone correlative with magnetic anomaly 25 chron. In the Clark's Fork Basin, the Paleocene-Eocene boundary is recognized on the basis of fossil vertebrate zonations. This same placement of the Paleocene-Eocene boundary within the magnetic anomaly sequence has also been found in the marine section at Gubbio, Italy by Napoleone et al. [1980]. The Paleocene-Eocene boundary in these marine sediments is recognized by foraminiferal zonations. These two magnetostratigraphic and biostratigraphic studies employed very different biostratigraphic systems in sedimentary sequences of vastly different sedimentary environment. Both magnetostratigraphic sections locate the Paleocene-Eocene boundary slightly younger than the younger boundary of anomaly 25 chron. The clear implication is that anomaly 24 chron is younger than the basal Eocene age used as a calibration point in construction of the Ness et al. [1980] polarity time scale.

The magnetostratigraphic data, in conjunction with the Paleogene geologic time scale of Hardenbol and Berggren [1978], indicate that the younger boundary of anomaly 25 chron is no older than ~56 Ma. From this revised age of anomaly 25 chron, it follows that the older boundary of anomaly 24 chron should be placed at 52.5 Ma rather than 54.9 Ma as used by Ness et al. [1980]. Thus the calibration point on the older boundary of anomaly 24 chron used by Ness et al. [1980] is too old by ~2.5 m.y. The effect of this change to the age of anomaly 24 chron on the Paleocene and early Eocene portion of the magnetic polarity time scale is tabulated in Table 1. Ages of polarity boundaries between the Cretaceous-Tertiary boundary at 66.7 Ma and the older boundary of anomaly 24 chron at 52.5 Ma were simply interpolated as done by Ness et al. [1980] but with 52.5 Ma (rather than 54.9 Ma) for the age of the older boundary of magnetic anomaly 24

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chron. Ages of polarity boundaries younger than 52.5 Ma were interpolated as by Ness et al. [1980] between the older boundary of magnetic anomaly 24 chron and the older boundary of anomaly 5 chron, but again using the revised 52.5 Ma age for the older boundary of anomaly 24 chron. The resulting ages of polarity boundaries were rounded to the nearest 0.1 Ma. A comparison of the magnetic polarity time scales of LaBrecque et al. [1977], Ness et al. [1980] and that derived in this paper is illustrated in Figure 1. We do not present results for younger portions of the magnetic polarity time scale because we feel that the validity of the interpolation between anomaly 5 chron and anomaly 24 chron may deteriorate as one proceeds more than 5 m.y. away from the calibration point at 52.5 Ma. Also, it is likely that magnetostratigraphic data may be forthcoming which will allow placement of calibration points between anomaly 5 chron and anomaly 24 chron.

As illustrated in Figure 1, the ages of magnetic polarity intervals between anomaly 21 chron and anomaly 24 chron are ~5 m.y. younger on the time scale reported in this paper as compared to the time scale of LaBrecque et al. [1977]. The age range from the younger boundary of anomaly 21 chron to the older boundary of anomaly 24 chron is 46 Ma to 52.5 Ma. As discussed below,the younger ages for these magnetic anomalies have some important implications regarding Pacific plate motion.

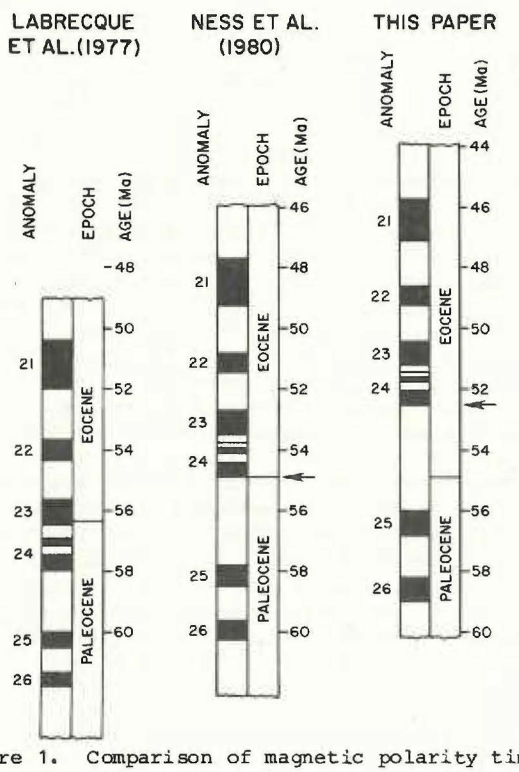

Figure 1. Comparison of magnetic polarity time scales in Paleocene and early Eocene. Ages on LaBrecque et al. [1977] time scale have been corrected as tabulated by Mankinen and Dalrymple [1979]. Arrows to the right of time scales of Ness et al. [1980] and this paper indicate the calibration point at the older boundary on anomaly 24 chron used in constructing these time scales.

Pacific spreading history and the Hawaiian-Emperor Seamount chain

Wilson [1963] proposed that the Hawaiian Seamount chain is a record of Pacific plate motion over a mantle magma source. This idea was expanded by Christofferson [1968] to include the Emperor Seamounts. Christofferson also introduced the term "hot-spot" and suggested that the bend in the Hawaiian-Emperor chain had been produced by a 60° change in motion of the Pacific plate over the Hawaiian hot-spot. Morgan [1971, 1972] then proposed that hot-spots were rooted in plumes of deep mantle origin and that this plume network provided a framework by which absolute motions of plates could be determined.

Many aspects of the hot-spot hypothesis are difficult to test. However, the required increase in age of seamounts from Hawaii to the bend and then northward on the Emperor Seamount chain is testable and has been the focus of much effort. Major contributions to knowledge of the ages of these seamounts have been made by Clague et al. [1975], Dalrymple and Clague [1976] and Dalrymple et al. [1980]. Presently, 27 volcanoes of the Hawaiian-Emperor chain have been dated by potassium-argon techniques [Dalrymple et al., 1980] and the age progression required by the hot-spot hypothesis is firmly established. The age of the bend in the Hawaiian-Emperor chain has been determined by Dalrymple and Clague [1976]. When converted to revised constants, the best age of the bend is 43.1 Ma (± 2.7 m.y. at the 95% confidence limit, Dalrymple, personal communication). If the bend in the Hawaiian-Emperor chain at 43 Ma reflects at 60° change in the motion of the Pacific plate, one would expect some changes in spreading or subduction to have occurred on the Pacific plate margins at or near the time of the bend.

A change in trend of magnetic anomalies in the northeast Pacific, near the magnetic bight off southern Alaska, occurred in the interval between anomaly 21 and anomaly 23 (Figure 2). This change in anomaly trend is evidence of a change in spreading along the Pacific-Farallon ridge. Byrne [1979] has compiled magnetic anomaly data in the northeast Pacific and concluded that magnetic anomalies 32 to 25 provide clear evidence of a Kula-Pacific-Farallon triple junction during that time interval. The southeast and northeast limbs of the triple junction show changes in orientation during the interval between anomalies 24 and 22 and the new orientations are established by anomaly 21 time. Byrne [1979] further suggested that the realignments of the northeast and southeast limbs require cessation of spreading on the Pacific-Kula ridge perhaps as early as anomaly 24 time, but no later than anomaly 21 time. The magnetic anomalies in the northeast Pacific are thus evidence of a major reorganization in Pacific-Kula-Farallon relative motion during the interval between anomalies 24 and 21.

The relationship between these changes in relative motion and the change in absolute motion of the Pacific plate as evidenced by the Hawaiian-Emperor bend at ~43 Ma has been addressed in several publications [e.g. Morgan, 1972; Gordon et al., 1978; Jackson et al., 1980]. Gordon et al. [1978] suggested that the change in Pacific plate absolute motion was a response to the development of subduction zones along the southwestern margin of the plate. These subduction zones were suggested to have developed because of northeastward motion of the Australian-Indian plate resulting from initiation of spreading between Australia and Antarctica. The oldest magnetic anomaly south of Australia is anomaly 21 [Weissel and Hayes, 1972] so that spreading between Australia and Antarctica must have been underway by anomaly 21 time. The implication is that the trench along the southwestern Pacific plate margin was also established at this time. Both changes in Pacific-Kula-Farallon relative motion along the northeastern margin of the Pacific plate and the development of subduction of the Pacific plate along its southwestern margin are thus thought to have occurred during the interval between anomalies 24 and 21. Anomaly 21 was placed at ~54 Ma on the Heirtzler et al. [1968] time scale and at ~52 Ma on the LaBrecque et al. [1977] time scale (adjusted for revised constants). Suggestions of causal relationships between the above outlined changes in relative motion and the change in absolute motion of the Pacific plate at 43 Ma have suffered because of the apparent ~10 m.y. age difference between these events. An important implication of the revised magnetic polarity time scale presented in this paper is that the ages of anomalies 24 and 21 are quite near to the 43 Ma age of the Hawaiian-Emperor bend.

As tabulated in Table 1 and illustrated in Figure 1, our revised magnetic polarity time scale places the older boundary of anomaly 24 at 52.5 Ma and the younger boundary of anomaly 21 at 45.7 Ma. The younger boundary of anomaly 21 is within the 95% confidence limits on the best age of the Hawaiian-Emperor bend. Anomalies 24 to 22 are significantly older than the bend. However,

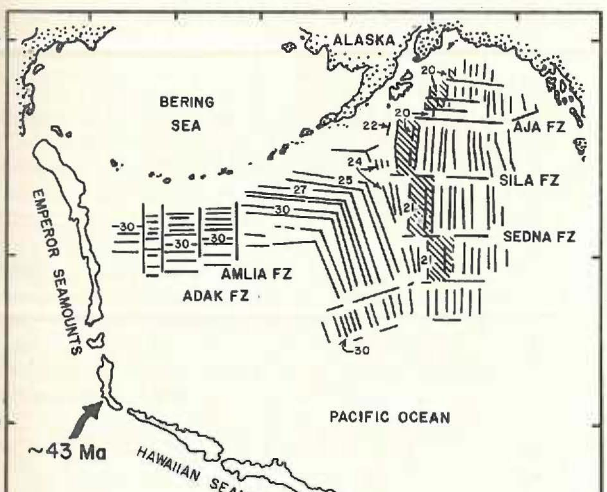

Figure 2. Late Cretaceous and Cenozoic magnetic anomaly distribution and Hawaiian-Emperor Seamount chain. Adapted from Byrne [1979].

TABLE 1. Ages of normal polarity intervals in Paleocene and early Eocene

Magnetic anomaly chron	Age (Ma)
21	45.7 - 47.1
22	48.6 - 49.2
23	50.4 - 51.2
24	51.6 - 52.5
25	56.0 - 56.8
26	58.2 - 59.0
27	62.2 - 62.9
28	63.9 - 65.1
29	65.6 - 66.5

the age difference between these anomalies and the bend in the Hawaiian-Emperor chain is much smaller than previously believed. For example, using the Heirtzler et al. [1968] time scale, anomaly 21 would appear to be ~11 m.y. older than the bend while this age difference would be ~8 m.y. using the LaBrecque et al. [1977] time scale. However, according to the time scale presented in this paper, the best estimate of the age difference between anomaly 21 and the bend would be only ~3 m.y.

The change in absolute motion of the Pacific plate at 43 Ma apparently followed the reorganization of the relative motion system which occurred in the interval between anomaly 24 and 21, but by a time lag of as little as 3 m.y. We believe that this time lag is small enough to strongly suggest a causal relationship between the relative motion changes and the (resultant?) change in absolute motion of the Pacific plate. A mechanism which we find especially attractive is that suggested by Gordon et al. [1978]. According to this mechanism, initiation of subduction of the Pacific plate along its southwestern margin at about anomaly 22 time resulted in a torque on the Pacific plate by the trench pull force [Forsyth and Uyeda, 1975]. Since the subducting slab must descend to ~200 km depth before the negative bouyancy required for trench pull will be fully developed, a time lag between initiation of subduction and the resultant change in absolute plate motion is expected.

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