Magnetostratigraphic correlation of the Lincoln Creek Formation, Washington: Implications for the age of the Eocene/Oligocene boundary

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ABSTRACT

Paleomagnetic studies of the upper Eocene to Oligocene Lincoln Creek Formation, southern Olympic Peninsula, Washington, produce a polarity pattern spanning Chrons C15r to C6C. This allows direct correlation of the provincial foraminiferal and molluscan biostratigraphy with the global marine chronology. A high-temperature basalt date of 38.5 ± 1.6 Ma correlates with a position just below Chron C15, placing Chron C15r at about 38 Ma. This suggests that the age of the Eocene/Oligocene boundary within Chron C13r is younger than 38 Ma, probably about 37–36 Ma.

INTRODUCTION

Correlation of the Pacific Coast biostratigraphic stages with other chronologies has been hampered by the provinciality of the northeast Pacific fossil assemblages, by the scarcity in coastal sediments of more cosmopolitan oceanic taxa, and by the dilution of assemblages by high rates of sediment accumulation. A few radiometric dates are associated with these Pacific Coast sequences, but they are generally not associated with reliable biostratigraphic control (Armentrout, 1981). The difficulty of correlating Pacific Coast biochronologies with the global marine standard has led to other controversies, such as varied age estimates for the Eo-

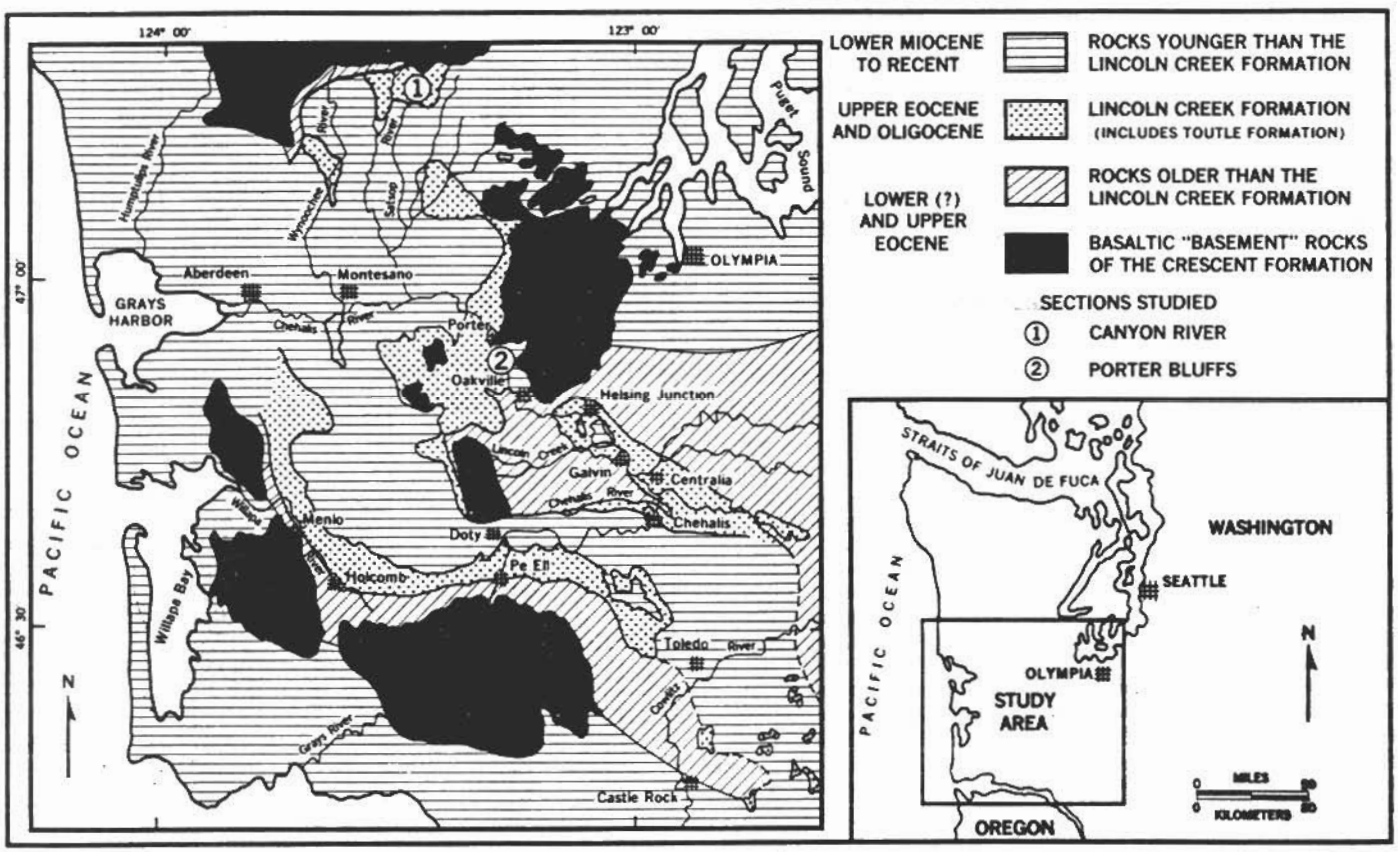

Figure 1. Geologic map of southwest Washington showing outcrop area of Lincoln Creek Formation and study areas Canyon River (1) and Porter Bluffs (2). Geology modified from Huntting et al. (1961).

cene/Oligocene boundary (cf. Armentrout, 1981; Prothero et al., 1982). In this paper we use magnetostratigraphy as a means of correlating a local section with the magnetic polarity time scale, thus improving interregional correlations.

We sampled a nearly continuous river-bottom section in the Canyon River tributary of the Satsop River, Grays Harbor County, Washington (Fig. 1). The Canyon River section has been studied for benthic foraminifers (Rau, 1966), mollusks (Armentrout, 1973, 1975), and calcareous nannoplankton (Armentrout and Worsley, 1980). These data sets allow correlation of the stratigraphic sequence with the provincial benthic foraminiferal (Rau, 1981) and molluscan (Armentrout, 1975, 1981) stages (Fig. 2), and a first attempt at correlating the stratigraphic sequence provides a means of correlating the provincial chronologies with the global time scale.

We collected three oriented blocks of rock using simple hand tools at 97 sites spanning about 2900 m of section (Fig. 2). Samples were trimmed down on a band saw and measured on a CTF Systems cryogenic magnetometer at the South Dakota School of Mines and Technology. Mean natural remanent magnetization (NRM) intensity for the samples was 11.7×10^{-7} gauss. Pilot studies of alternating field and thermal demagnetization showed that reversed samples were best recognized at cleaning temperatures of 300 °C. Many samples were reversed at NRM. Further details of the laboratory procedure, magnetic behavior, and biostratigraphic correlation are being prepared for publication elsewhere (Armentrout and Prothero, in prep.).

RESULTS

The polarity pattern provides a clearly defined sequence of normal and reversed events (Fig. 2). Correlation of the local pattern with the magnetic polarity time scale is based on the following considerations:

1. The magnetic polarity pattern of the Lincoln Creek Formation shows a lower interval of two thick reversed events (LR11 and LR10) and an upper interval characterized by relatively thin normal and reversed events (LR9 through LR2). As a working hypothesis, we suggest that the two thick reversed intervals correlate with Chrons C13r and C12r, which are unique in their duration during the mid-Tertiary (Prothero et al., 1982). This hypothesis suggests that the reverse-normal event of the lower Lincoln Creek Formation correlates with Chron C15r-C15.

2. Rock samples from the reversely polarized interval in the lowermost Lincoln Creek Formation (LR14) yield calcareous nannoplankton assigned by Armentrout and Worsley (1980) to Martini's (1971) zones NP19/20 (sample B0253) and NP21 (sample B0254). Both assignments are tenuous due to the low diversity, high-latitude near-shore assemblage. J. E. Hazel and S. F. Percival (1984, written communs.) suggested that the nannofossil assemblages of samples B0253 and B0254 correlate best with the interval of NP19/20 through NP21, which correlates with Chrons C15r through C12r (Berggren et al., 1984). This correlation suggests that the reversed-normal interval of the lower Lincoln Creek Formation could be either Chron C15r-C15 or Chron C13r-C13.

3. The Astoria(?) Formation, the uppermost unit studied, contains faunas assigned to the Saucesian Foraminiferal Stage (Rau, 1966) and the Pillarian Molluscan Stage (Addicott, 1976), which are assigned to the early Miocene (Armentrout, 1981; Armentrout et al., 1984). Those correlations suggest that the magnetic polarity events of the Astoria(?) Formation of the Canyon River section (LR1 through LN2) correlate with lower Chron C6C.

4. If we correlate the lower Lincoln Creek Formation reverse-normal event (LN13–LR14) with Chron C15r-C15 and assume the section is continuous, the entire sequence of Canyon River section magnetic

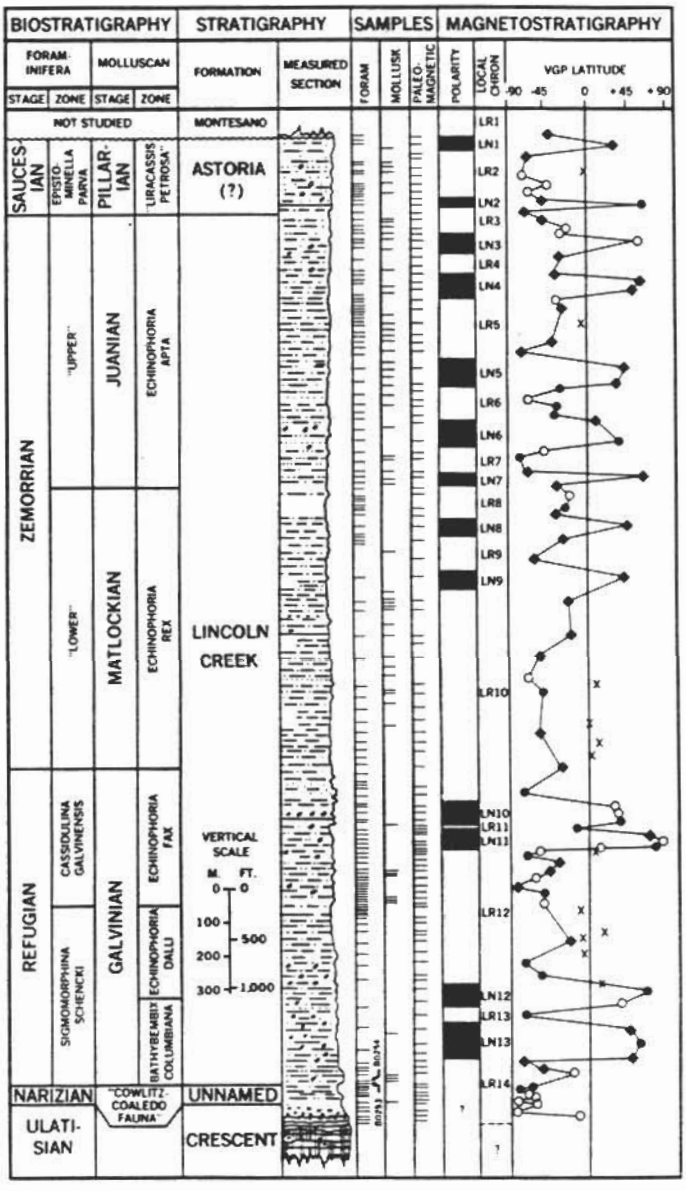

Figure 2. Biostratigraphy, stratigraphy, and magnetostratigraphy of Canyon River section. Foraminiferal stages and zones follow Rau (1966, 1981); molluscan stages and zones follow Armentrout (1975, 1981). Stratigraphy follows Rau (1966): unnamed unit is Rau's "sedimentary rocks of late Eocene age." Classification of magnetostratigraphic sites follows Opdyke et al. (1977). Solid circles = Class I sites significant at 95% confidence level; open circles = Class II sites that failed signficance test because one or more samples were lost during preparation; diamonds = Class III sites that failed significance test because one sample was divergent from mean direction; X denotes sites with virtual geomagnetic pole (VGP) latitudes less than 10°, which were considered indeterminate. All determinate sites are plotted and connected, even in the case of single-site magnetozones, since limited outcrop reduced sample density in these intervals. VGP latitudes are corrected for tectonic tilt of about 15° shallower inclination. Local intervals of normal polarity are numbered LN1 through LN13; local intervals of reversed polarity are numbered LR1 through LR14.

polarity correlates well with the magnetic polarity time scale of the late Eocene–Oligocene–early Miocene and is consistent with previous biostratigraphic assignments of the lower Astoria(?) to the basal Miocene. The resulting correlation to the magnetic polarity time scale is shown in Figure 3.

DISCUSSION

Recent studies of Paleocene magnetostratigraphy and biostratigraphy (Poore et al., 1982; Lowrie et al., 1982) place the Eocene/Oligocene boundary in the middle of Chron C13r, which Berggren et al. (1984) dated at about 36.5 Ma (Fig. 3). According to our correlation of the Lincoln Creek Formation magnetic polarity sequence with the magnetic polarity time scale, the Eocene/Oligocene boundary falls within the Refugian Foraminiferal Stage and Galvinian Molluscan Stage. The Eocene/Oligocene boundary approximates (within the resolution of sample density) the *Sigmomorphina schencki/Cassidulina galvinensis* Benthonic Foraminiferal Zone boundary of Rau (1966, 1981) and the *Echinophoria dalli/Echinophoria fax* Molluscan Zone boundary of Armentrout (1973, 1975, 1981) (Fig. 2).

High-temperature K/Ar data on a basalt (mapped as Crescent Formation) underlying lower Refugian/lower Galvinian Stage strata of the Lincoln Creek Formation at Porter Bluff section (Fig. 1) yield a date of 38.5 ± 1.6 Ma (Armentrout et al., 1980) (age calculated using decay constants recommended by Steiger and Jäger, 1977). A possible age of 38.5 ± 1.6 Ma for the base of the Refugian/Galvinian Stages and the magnetostratigraphic correlation of the lower Refugian/Galvinian Stages with Chron C15r is in agreement with the time scale of Berggren et al. (1984), who placed Chron C15r between 37.68 and 38.10 Ma (Fig. 3).

Armentrout (1981), using data from Oregon and Washington, suggested placement of the Eocene/Oligocene boundary at 32 Ma. That interpretation was based on two sets of data: (1) Wolfe (1981) correlated the "Goshen Flora"/Angoonian Megafloral Stage boundary with the Refugian/Zemorrian Foraminiferal Stage boundary and dated the boundary at 32.5 Ma using radiometric ages from rocks associated with the megafloras. (2) Armentrout (1981) correlated the Refugian/Zemorrian Foraminiferal Stage boundary with the NP20/21 Calcareous Nannoplankton Zone boundary and the P16/P17 Planktonic Foraminiferal Zone boundary, approximately coeval with the Eocene/Oligocene boundary of Hardenbol and Berggren (1978).

Armentrout (1981) interpreted these correlations to suggest that the Eocene/Oligocene boundary of Hardenbol and Berggren (1978) was approximately coeval with the "Goshen Flora"/Angoonian Megafloral Stage boundary at 32.5 Ma. The paleontologically calibrated magnetostratigraphic data presented here show that the Eocene/Oligocene boundary is within the Refugian Foraminiferal Stage of the Pacific Northwest, not at the Refugian/Zemorrian Stage boundary. Placement of the Eocene/Oligocene boundary to a position within the Refugian/Galvinian Stages in the Pacific Northwest results in the correlation of Wolfe's "Goshen Flora"/Angoonian Megafloral Stage boundary within the early Oligocene, a correlation in agreement with the time scale of Berggren et al. (1984) and Prothero et al. (1982).

The new magnetostratigraphic data presented here result in improved precision of the placement of the Eocene/Oligocene boundary within the local stratigraphic sequence of western Washington and provide another high-temperature K/Ar date supporting the 36–37 Ma estimate for the Eocene/Oligocene boundary.

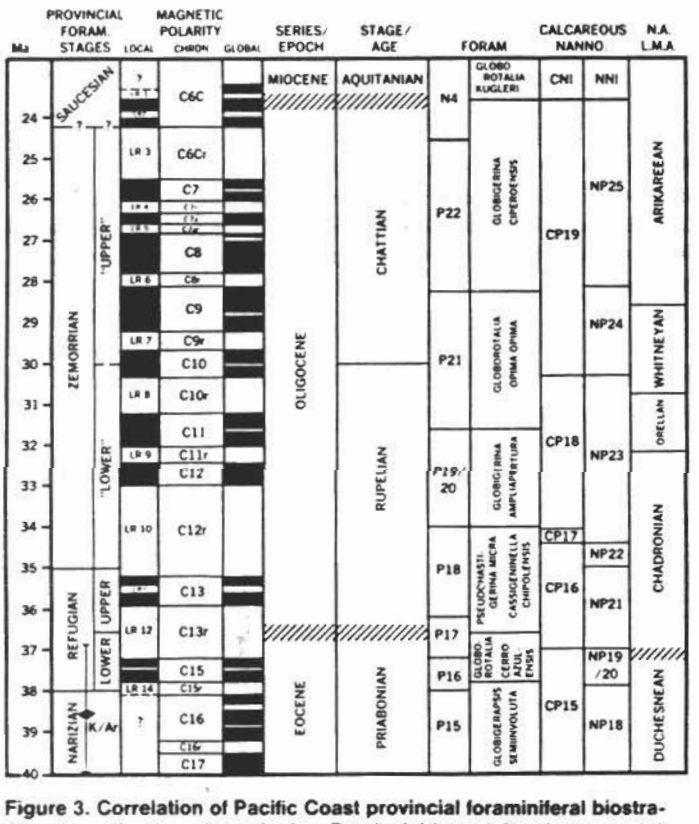

Figure 3. Correlation of Pacific Coast provincial foraminiferal biostratigraphy with other chronologies. Provincial foraminiferal stages and local magnetic polarity sequence from Figure 2. Global time scale components after Berggren et al. (1984); Chron terminology after Harland et al. (1982). N.A.L.M.A. indicates North American Land Mammal Ages after Prothero et al. (1982). Diamond with error bars shows chronostratigraphic position of radiometric date just below Refugian/Narizian Foraminiferal Stage boundary, Porter Bluff section (Fig. 1).

CONCLUSIONS

A polarity pattern correlated with Chrons C15r through C6C was obtained from samples of upper Eocene/Oligocene–lower Miocene marine siltstone of the Lincoln Creek and lower Astoria(?) formations. The Narizian/Refugian Foraminiferal Stage boundary occurs in Chron C15r at about 38 Ma on the time scale of Berggren et al. (1984). A high-temperature basalt K/Ar date of 38.5 ± 1.6 Ma at or just below the Narizian/Refugian boundary corroborates the time scale of Berggren et al. (1984).

On the basis of the magnetostratigraphic correlation presented here, *the following calibration is proposed for provincial Oregon–Washington* Eocene through Oligocene biochronologic boundaries:

1. The Narizian/Refugian Foraminiferal Stage boundary and the boundary between the unnamed stage represented by the molluscan assemblage of the Cowlitz and Coaledo Formations and the Galvivian Molluscan Stage correlate with upper Chron C15r at about 38 Ma, slightly younger than the middle/late Eocene boundary of Berggren et al. (1984).

2. The Refugian/Zemorrian Foraminiferal Stage boundary and the Galvinian/Matlockian Molluscan Stage boundary correlate with lower Chron C12r at about 35 Ma, within the early Oligocene.

3. The "Lower"/"Upper" Zone boundary of the Zemorrian Foraminiferal Stage and the Matlockian/Juanian Molluscan Stage boundary correlate with Chron C10 at about 35 Ma, within the early Oligocene.

4. The Zemorrian/Saucesian Foraminiferal Stage boundary and Juanian/Pillarian Molluscan Stage boundary probably correlate with the base of Chron C6C at about 24.3 Ma, but this interval requires further study before a definite calibration is proposed.

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Reviewer's comment

Presents the first magnetostratigraphic data that allow correlating the Pacific west coast provincial "stages" with standard chronostratigraphy. This, plus the radiometric data, provide support for one of several contending points of view on the chronology of the Eocene/Oligocene boundary.

William Berggren