INTRODUCTION

A complication to using the oxygen isotope composition (Δ18O) of vertebrate hydroxylapatite (HA) in paleoclimate studies is the need to distinguish variation due to temporal changes in the Δ18O of surface waters from that due to temperature-dependent fractionation during biomineralization. One solution is multiple-taxon comparisons using data from coexisting heterothermic (i.e., mammals) and heterothermic animals. Fossil emydid turtles have been suggested to be potentially useful as functional homotherms (Barrick et al., 1999) because 1) modern emyids employ behaviors, such as basking, to restrict skeletal growth a narrow temperature range, 2) their aquatic habitat constrains the isotopic variability of dietary inputs, and 3) emydids have a dense fossil record. However, because turtles lack teeth and therefore tooth enamel, sampling must focus on bone, which is potentially more susceptible to diagenetic alteration.

This study examines the oxygen isotopes from the carbonate (Δ18Oc) and phosphate (Δ18Op) fractions of hydroxylapatite from co-occurring emyids and two groups of known heterotherms (crocodilians and gar) from the Paleocene and Eocene (P-E) of the Clarks Fork Basin, Wyoming. Previous isotopic studies of this area provide an extensive dataset for comparison with the results of this study. Carbonate coulometry and X-ray diffraction measurements of bone carbonate content and apatite crystallinity were performed to examine the possibility of diagenetic alteration of turtle bone.

MATERIALS AND METHODS

Turtle, crocodilian, and gar fossils used in this study came from the collections of the U. Michigan Museum of Paleontology. Approximately 10-50 mg of powdered HA was obtained from each specimen using a hand-held rotary drill. For analysis of Δ18Oc, aliquots of HA powder were treated with 2-3% NaOH to oxidize organic matter and then treated with 1 M acetic acid buffered with 1 M Ca-acetate. The samples were then analyzed using a Kiel II automatic carbonate preparation device coupled to a Finnigan MAT-252 IRMS. For analysis of Δ18Op, 5-10 mg aliquots were each dissolved in 1 ml of 2 M HF distilled, deionized H2O. CaF2 precipitate was removed through centrifugation and decantation, and 1 ml of 2 M AgNO3 was added to each sample to rapidly precipitate finely crystalline Ag3PO4. The Ag3PO4 samples were then analyzed using a TC/EA coupled to a Finnigan Delta-Plus IRMS. The crystallinity index (CI) of the samples was measured through X-ray diffraction and Inorganic Carbon coulometry. The crystallinity index (CI) of the turtle bone samples was measured through X-ray diffraction and Total Carbonate content of the turtle bone samples was measured through Total Inorganic Carbon coulometry. The crystallinity index (CI) of the turtle bone samples was measured through X-ray diffraction and Total Inorganic Carbon coulometry. The crystallinity index (CI) of the turtle bone samples was measured through X-ray diffraction and Total Inorganic Carbon coulometry.

RESULTS

Figure 1: Unaltered bone and enamel from modern mammals exhibits a strong covariation (r² = 0.98) between Δ18Oc and Δ18Op (Bryant et al., 1996; Lacumin et al., 1996). A lack of covariation between Δ18Oc and Δ18Op for bone, enamel, and ganoine from this study suggests that carbonate or phosphate, or both, have been diagenetically altered.

Figure 2: Both high crystallinity and low carbonate content are thought to be indicative of recrystallization or replacement of primary HA (Person et al., 1995). Furthermore, diagenetically altered HA is generally 18O-depleted relative to unaltered HA (Zazzo et al., 2003), and previous studies suggest 18O-depleted waters in the P-E Bighorn Basin (Koch et al., 1999). However, neither high crystallinity (A) nor low carbonate content (B) is a good predictor of low Δ18Op values for turtle bone from this study.

Figure 3: Unaltered enamel and bone Δ18O from within an individual animal should be in equilibrium, and should therefore covary strongly. While intra-individual samples of crocodilian bone and enamel taken from jaw fragments with teeth preserved in situ exhibit a poor correlation for Δ18Oc (A), they exhibit a strong positive correlation for Δ18Op (B).

Estimates of mean annual temperature for the P-E Clarks Fork Basin are made by using two equations. First, the Δ18O of P-E meteoric/surface water (δ18Osw) is predicted from

\[ \delta^{18}O_{sw} = \delta^{18}O_p - 22.6 \]

Next, estimates of δ18Ow are used along with heterotherm (crocodilian or gar) δ18Oc in the phosphate-water temperature equation of Longinelli and Nuti (1973) to predict MAT:

\[ \text{MAT} (^\circ C) = 111.4 - 4.3(\delta^{18}O_p - \delta^{18}O_c) \]

CONCLUSIONS

The results of this study generally support the hypothesis of Barrick et al. (1999) that suggests the primary Δ18Oc of fossil emydid turtle bone may be preserved, and can be used along with Δ18Op from co-occurring heterotherms to quantify terrestrial paleotemperatures. This conclusion is supported by several observations. First, bone Δ18Op values generally fall within the range of Δ18O values of presumably unaltered mammal tooth enamel from previous studies of the same localities. Second, in contrast to Δ18Oc, intra-individual samples of crocodilian bone and enamel Δ18Op exhibit a fairly strong positive correlation. Finally, MAT estimates based on bone, enamel, and ganoine Δ18Op from this study are in general agreement with independent estimates based on LMA. The result testifies to the utility of both Δ18Oc and LMA approaches to estimating terrestrial paleotemperature, since each method provides an independent estimate through entirely different sample materials, assumptions, and taphonomic biases.

REFERENCES


