The Middle and Late Bronze Age Climate of Ya'amoun in Northern Jordan Using Oxygen Isotope Analysis from Human Tooth Enamel

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Abstract*. The purpose of this study is to determine the climate of the Middle and Late Bronze Age of the Ya'amoun in northern Jordan. Through the use of Stable oxygen isotope composition of human tooth enamel from the site, the mean value for oxygen isotope in the Middle and Late Bronze Age was measured and analyzed using ANOVA. The results indicate that climate during the Middle Bronze Age was drier than the Late Bronze Age but with sufficient amount of precipitation that enabled, to some extent, the practice of dry farming.*

Introduction

Changing environmental conditions have long been considered major factors in shaping human behavior and in diversifying people's adaptive strategies (Henry, 1985; Issar, 1995; Gasse, 2000; Weiss and Bradley, 2001). For this reason, archaeological studies should not be treated in isolation from climate change because cultural change is triggered by climate fluctuations (Bar-Yosef, 1996). In Jordan, for example, archaeological studies have not extensively focused on such issues, and the history of climate change remained to be explored, especially during the Bronze Age.

Proxies for past climate are growing year after year, but the most reliable ones are those that can reveal quantitative measures obtained by stable isotope analysis. Stable oxygen isotopes exist in water molecules in three different forms; the most abundant are $H_2{}^{16}O$ and $H_2{}^{18}O$. The vapor pressure of $H_2{}^{16}O$ is higher than $H_2{}^{18}O$ and consequently the evaporation of water from a body results in a vapor that is poorer in ^{18}O than the initial water. During condensation, the lower vapor pressure of $H_2{}^{18}O$ changes it to liquid more readily than water made of lighter isotope (Dansgaard, 1964). The continuing condensation of the vapor will continue removing the heavier isotopes, leaving it more depleted in $H_2{}^{18}O$. So, low temperature depletes water in ^{18}O and high temperature enrich water in ^{18}O (Dansgaard et al., 1971; Robin, 1977, Rozanski et al., 1992). This means that cool climates are attributed to higher ^{16}O, and warmer climates are attributed to higher ^{18}O. The measurements of the ratio of $^{16}O/^{18}O$ in fossil water can thus determine the relative temperature during the time of fossilization. There are temporal and geographical variations in the isotopic composition of water due to latitude, altitude, and distance from source of moisture (Rosanski et al., 1993). But unless we know the entire local variations, oxygen isotopes in local meteoric water should be considered a reflection of average surface temperature.

Human tooth enamel is precipitated in equilibrium with body water at a constant temperature (Frick et al., 1995), so except for higher body temperature in cases of diseases, the isotopic signature of water remains static. The oxygen isotope composition of water is, in

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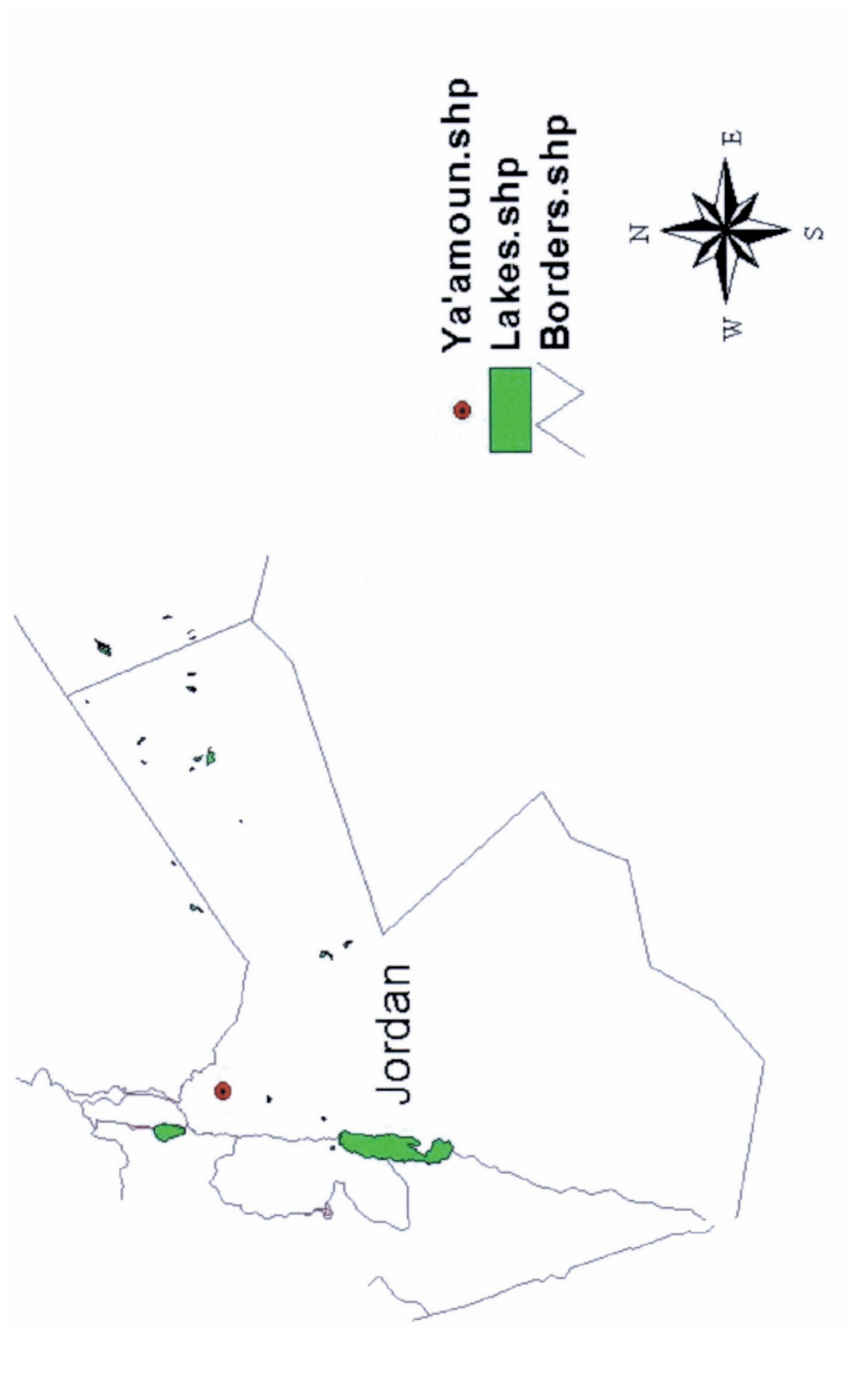

Fig. 1: The archaeological site of Ya'amoun.

turn, a reflection of oxygen isotope composition of the water ingested by the person (Luz et al., 1984; Luz and Kolodny, 1985; D'Angela and Longinelli, 1990; Kohn et al., 1996) and consequently the water ingested by a person is an indicator of ? ^{18}O of local water and then an indicator of climate.

In this paper, the isotopic composition of local meteoric water is reconstructed from the isotopic composition of the tooth enamel. This paper then investigates and explores the climate during the Bronze Ages in Jordan using oxygen isotope analysis from human tooth enamel in Ya'amoun-- one of the important sites in northern Jordan that witnessed continuous occupation since the Middle Bronze Age.

The Site

Having been dated to the Middle Bronze Age, and extended to the Islamic Period, Ya'amoun is located 25km south of the city of Irbid and occupies a very large area at about 828m above sea level (fig. 1). Excavation in the site has started in 1999 by a joint project between the University of Arkansas in the US and Yarmouk University in Jordan, led by professors Jerome Rose and Mahmoud El-Najjar respectively. Middle Bronze Age tombs in the site are carved in rock, the most significant of which is Tomb I that was dated (based on scarabs, ca. 1630-1522 BCE) by Burke and Rose (2001). The Late Bronze Age tomb (158) was carved in rock too and was dated on the basis of pottery count. Tomb I and Tomb 158 were selected for the sampling procedure.

The Samples

The number of teeth in each sample group was estimated following the power equation $Ø = (n)^{1/2}(\sum ?\ ^{2}/P)/\ ?\ ^{2})^{1/2}$. By hypothesizing that P is 0.9 and the standard deviation is .56 at ? = 0.05, the number of teeth in each group is calculated to be 14. I sampled 36 Middle Bronze Age second premolars and 34 Late Bronze Age second premolars. Previous studies show no systematic differences in ? ^{18}O values among tooth positions (Wright and Schwarcz, 1998; Frick et al., 1995). Second premolars start to form at the age of 2.5 years after birth (after weaning) and fully develop at the age of 7 years after birth (Hilson, 1996), so the enriched breastfeeding milk in ? ^{18}O does not precipitate in tooth enamel.

Materials and Methods

Enamel was prepared for isotopic analysis using a modified method (Wright and Schwarcz 1998). The teeth were cleaned with distilled water and then dentine and cementum were physically removed using a diamond bit. Enamel then was finely ground to a size of less than 50 µm. Organic components of the enamel were removed by soaking enamel powder in 1.5% sodium hypochlorite for 24 hours; then rinsed by distilled water. Carbonate minerals were removed by soaking the enamel powder in 0.1 M acetic acid for 20 hours then rinsed with distilled water. Samples then were freeze-dried for four days.

Using an off-line technique (Al-Shorman, 2002a), the dry enamel powder was reacted with 100% phosphoric acid at 90 $^{\circ}$C for 30 minutes and the pump-out time between samples was set to another 15 minutes to ensure completion of the reaction before the next sample was admitted. The resulting reaction products were frozen using liquid nitrogen, and then CO_2 gas was liberated using dry ice and then was collected in glass fingers that were used to be run in the Finnegan mass spectrometer at the stable Isotope lab/University of Arkansas.

Results

The researcher examined the enamel layer of ancient teeth to determine isotope use in assessing climate changes. The results have enabled the determination of the relative temperature changes during the Middle and Late Bronze Ages. The results were calibrated for the fractionation factor (?1 = 1.00798) after Swart et al. (1991). This fractionation takes place during the reaction of enamel with phosphoric acid at 90 (C. The second fractionation factor (?2, between enamel and drinking water) used in calibrating tooth enamel results was used after Al-Shorman (2002a), which is 1.023618. The mean ? ^{18}O value for tooth enamel from the Middle Bronze Age is 19.29% and the standard deviation is 1.22%, while the mean ? ^{18}O value for the Late Bronze Age is 18.28% and the standard deviation is 1.16%. After applying the statistical analysis of variance (ANOVA) between the two sample groups (Middle and Late Bronze Age), ? ^{18}O values show significant variation at the 0.05 level between the two groups.

Discussion

Considering ? ^{18}O as a proxy for air surface temperature, the results indicate that the Late Bronze Age in northern Jordan enjoyed colder temperature and higher amounts of precipitation compared to the Middle Bronze Age. After the application of the second fractionation factor, it is estimated that the isotopic composition of the local meteoric water during the Middle Bronze Age is -4.23% and -5.22% during the late Bronze Age. Based on the data presented by Al-Shorman (2002a), the relationship between the amount of precipitation and ? ^{18}O of local meteoric water in northern Jordan is expressed as y = -0.0477x - 0.749, where y is the value of ? ^{18}O and x is the amount of precipitation. Based on the previous regression equation, the amount of precipitation during the Middle Bronze Age is estimated to be around 75mm for each winter month (~300mm annually) and 110mm for each winter month (~ 450mm annually) during the Late Bronze Age. Though the amount of precipitation during the Middle Bronze Age was low, it was enough for the practice of dry farming. In Jordan, dry farming succeeds when the amount of precipitation does not drop below the range of 170-200mm a year (Kirkbride, 1985). This means that the people of Ya'amoun during the Middle Bronze Age would have been able to practice dry farming.

The two groups of samples possess higher intra population variation (1.22 during the Middle Bronze Age; 1.16 during the Late Bronze Age), which could be the result of human migration and that certain subgroups might have accessed different water sources with different oxygen isotopic composition in their destinations. It is known that during the Middle Bronze Age, big waves of the Hyksos people immigrated from Jordan and Palestine to the Nile Delta (Coogan, 1998) seeking better water resources.

Other studies in Jordan and the region support these isotope results and show that Jordan was experiencing droughts at the end of the Early Bronze Age and the beginning of the Middle Bronze Age (Callway, 1978; Horowitz, 1979; Kenyon, 1979; Harlan, 1982; Rosen, 1986; Hole, 1997; Issar et al., 1992).

As a response to droughts, the people during the Middle Bronze Age established their settlements in areas that currently receive more than 300mm annual rainfall (Al-Shorman, 2002b) and diversified their subsistence strategy between dry farming (Zohary and Spiegel-Roy, 1975; Zohary and Hopf, 1988; Neef, 1990) and animal husbandry (MacDonalds, 2001).

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ملخّص: باستخدام نظائر الأُكسجين المستقرة في ميناء الأسنان، من الموقع الأثري "يعمون" شمالي الأردن، تبيّن ان المناخ خلال العصر البرونزي الأوسط، كان اكثر جفافاً، مقارنة بالعصر البرونزي المتأخر؛ ولكنَّ كميات الأمطار المتساقطة، آنذاك، كانت كافية لمارسة الزراعة الجافة، الى حدٍ ما. واستجابة للظروف المناخية القاسية، وفترات الجفاف الطويلة، هاجر سكان المنطقة إلى أماكن أخرى، ذات وفرة في مصادر المياة، كدلتا النيل في مصر. إنَّ نتائج النظائر المستقرة هنا، تتوافق مع الدراسات الأخرى، التي عُنيت بالبيئة القديمة.

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