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A Late Pleistocene to Holocene Record of Precipitation Reflected in *Margaritifera falcata* Shell $\delta^{18}O$ From Three Archaeological Sites in the Lower Salmon River Canyon, Idaho

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Oxygen-18 ($\delta^{18}O$) concentrations in *Margaritifera falcata* shells preserved in three archaeological sites in the Lower Salmon River Canyon of Idaho are compared with modern mussel shells. Shell $\delta^{18}O$ records show that Late Pleistocene and Early Holocene climates were drier with occasional periods of increased precipitation. After *c.* 4000 years BP, precipitation is higher in the Salmon River basin than at present and trends toward modern conditions after *c.* 1800 years BP. The climatic conditions reflected by fluctuations in shell $\delta^{18}O$ are matched by regional palaeoenvironmental records, including pollen, glacial and palaeohydraulic proxy sources, and are compared with major changes in Plateau prehistoric cultural patterns. Studies of late Quaternary records of freshwater bivalve shell $\delta^{18}O$ are useful for reconstructing climatic conditions and complement geoarchaeological studies in riparian contexts.

Keywords: OXYGEN-18, *MARGARITIFERA FALCATA*, IDAHO, STABLE ISOTOPES, GEOCHEMISTRY, PALEOENVIRONMENTS.

Introduction

Shells of freshwater bivalves are a common occurrence in archaeological sites located along rivers, having been an important food resource for many societies. In the Pacific Northwest, three mollusc taxa, *Margaritifera falcata*, *Gonidea angulata* and *Anodonta* sp. typically dominate the bivalve assemblage of sites. Stable isotope geochemistry of molluscs, which is used extensively in geological and palaeoenvironmental studies (Kerr-Lawson *et al.*, 1992; Krantz, Williams & Jones, 1987; Jones, Williams & Arthur, 1983; Romanek & Grossman, 1989; Wefer & Berger, 1991), has been employed in archaeological studies in marine settings (Baily, Deith & Shackleton, 1983; Emiliani *et al.*, 1964; Glassow *et al.*, 1994; Herz, 1990; Kennett *et al.*, 1997; Killingley, 1981; Killingley & Berger, 1979; Koerper, Killingley & Taylor, 1985). Archaeological studies of freshwater bivalve shell stable isotope geochemistry are less common, however (e.g. Kennett & Voorhies, 1995). The first part of this paper discusses the theoretical and methodological bases for employing the stable isotope geochemistry of freshwater bivalve shells in archaeological research. This discussion is followed by a presentation of a Late Quaternary $\delta^{18}O$ record from *M. falcata* shell carbonate constructed from faunal collections in three archaeological sites in the Lower Salmon River Canyon of Idaho.

In this isotope record, greater aridity is seen in the Late Pleistocene and Early Holocene, while after *c.* 4000 years BP precipitation rates are higher than today, continuing on toward modern conditions in the Late Holocene. Comparisons made between the Lower Salmon River shell $\delta^{18}O$ record and regional palaeoenvironmental records supports the use of this geochemical method to investigate palaeoclimate patterns. Taken further, the $\delta^{18}O$ record of Salmon River mussel shell carbonate can be used to help interpret palaeoenvironmental aspects influenced by rainfall regimes such as processes of soil formation, vegetation patterns, and conditions of faunal habitats and to evaluate the ecological context of prehistoric hunter–gatherer adaptations.

Research with Freshwater Bivalves

Two major methodological approaches are present in palaeoenvironmental studies of river mussels in North

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American archaeology. The first involves studies of species occurrence in archaeological sites, while the other addresses processes of shell production. Both studies aim to interpret aspects of invertebrate faunal assemblages in terms of their specific autecological requirements as a means of establishing proxy records of palaeoenvironmental conditions.

In the first approach, aquatic conditions are inferred from the relative abundance of certain mussel species found in an archaeological assemblage. Differences in species abundance are interpreted to indicate the effects of climatic conditions on their habitats, as one species increases its population over the other under conditions that favour its autecological requirements (Landye, 1973; Chatters, 1986; Chatters *et al.*, 1991, 1995).

The usefulness of this method has been questioned by Lyman (1980: 127), who cautions that while the two species have different microenvironmental requirements, they can both be found within a linear kilometre of river in some areas. Also, since the presence of bivalve shells in archaeological sites is typically seen as the result of subsistence gathering activities in these studies, the level to which shell assemblages represent natural conditions, and not a culturally-biased sample, is unclear. For these reasons, the results of river mussel species abundance studies appear to provide ambiguous statements about climatic or hydrological conditions of the past.

The second approach is represented by the work of Chatters *et al.* (1995), who reconstructed ancient stream environments in the Wells Reservoir region of the Columbia River Basin of northern Washington. Annual stream temperatures are inferred through an investigation of the relationship between modern river bivalve growth and water temperatures, which is based on an unpublished study (Chatters *et al.*, 1995: 491). Chatters claims to have discovered a linear function between the number of days where water temperatures are between 6–10°C and the thickness of modern mussel shell growth bands. Since a comprehensive report on this method and its relationship to ambient Columbia River conditions is not available for review, and given the uncertainties of whether growth patterns among modern mussel populations in a hydroelectric dam reservoir provides a "natural" perspective on mollusc growth response to habitat conditions, it may be premature to use this approach as a way to derive palaeothermometry data. A more appropriate method of this kind would involve a study of mussels in a natural habitat, such as a free-flowing stream largely unaffected by human activities, or in a controlled laboratory setting.

Stable Isotope Geochemistry of Freshwater Bivalves

The application of stable isotope geochemistry to freshwater bivalves has mainly been used to infer lacustrine hydrology (Hodell *et al.*, 1991, 1995; Kerr-Lawson *et al.*, 1992), although studies of riverine molluscs have been made (e.g. Dettman & Lohmann, 1993). The isotopic signature of shell carbonates in freshwater invertebrates reflects the isotopic composition of ambient environmental water (Fritz & Poplawski, 1974; Kerr-Lawson *et al.*, 1992; Dettman & Lohman, 1993).

Two models are available to interpret the $\delta^{18}O$ signature of riverine bivalve shell carbonate. Dettman & Lohmann (1993) define these models as "temperature-dominated" and "water-based". In the first model, variability in shell $\delta^{18}O$ is a reflection of changes in surface water temperature. In fluvial systems dominated by groundwater input, variation in the isotopic concentration of meteoric water at seasonal scales is overwhelmed by the isotopic effects of seasonal changes in water temperature.

Under a "water-based" model, the effects of temperature-dependent $\delta^{18}O$ fractionation is greatly diminished relative to seasonal changes in the $\delta^{18}O$ of precipitation. Of greater importance is the influence of regional climate on the isotopic composition of meteoric water. Changes in the $^{18}O/^{16}O$ ratio in river water are driven by variations in the isotopic character of meteoric water, produced as atmospheric water vapour moves inland from its oceanic source (Craig, 1961; Dansgaard, 1964) (Figure 1). Thus, in a "water-based" model, isotopic changes in meteoric precipitation reflect variability in "the condensation of atmospheric water vapour, at the prevailing air temperature, with isotopic equilibrium maintained between vapour and condensate" (Welhan, 1987: 134). Unlike the first model, $\delta^{18}O$ data interpreted through the "water-based" model can be viewed as a proxy record of regional precipitation regimes.

A Model of Salmon River Bivalve Shell Geochemistry

The fluvial behaviour of the Salmon River is typical of other Columbia River basin streams, in that the pattern of annual discharge is determined by the timing and rate of runoff from melting snowpack in the upper reaches of the basin. Inputs of water from rainfall events produce only minor alterations to river flow and rates of discharge closely follow the melting of the snowpack (Paulsen, 1949). This pattern of discharge strongly suggests that the hydrology of the Salmon River is not dominated by groundwater inputs. Since the reservoir of water that makes up the Salmon River discharge largely comes from atmospheric precipitation accumulated in the snowpack, it is expected that the $\delta^{18}O$ signature of freshwater bivalve shell carbonate will mirror changes in regional climatic effects on meteoric water and not from temperature effects on groundwater inputs.

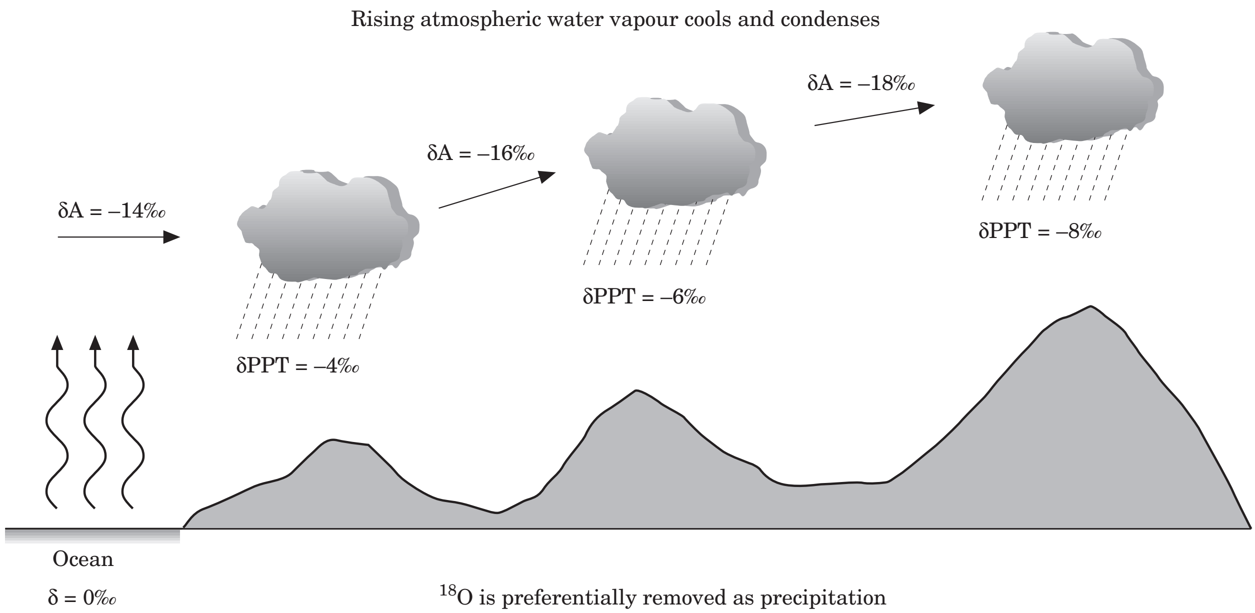

Figure 1. Isotopic changes in atmospheric water vapour (δA) and preferential rainout of ^{18}O-enriched water (δPPT) with inland movement from oceanic sources (adapted from Welhan, 1987).

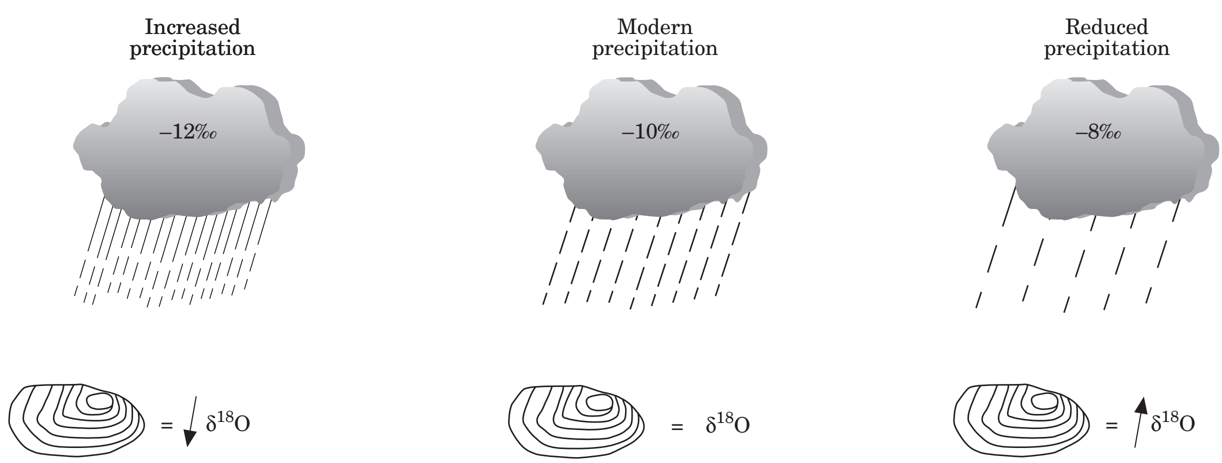

Figure 2. Expected trends in $\delta^{18}O$ of freshwater mussel shell carbonate formed under differing precipitation regimes.

Given these considerations, periods of heightened aridity are expected to produce an increase in the concentration of $\delta^{18}O$ in meteoric water, which is also reflected in mussel shell carbonate geochemistry (Figure 2). During periods of increased precipitation, the $\delta^{18}O$ signature of meteoric water will become more negative, producing similar trends in the $\delta^{18}O$ of freshwater bivalve shells.

By using the $\delta^{18}O$ signature of modern riverine bivalve shells as an isotopic baseline, comparisons can be made with the $\delta^{18}O$ of bivalve shells from archaeological sites to provide a means of evaluating isotopic changes in the regional meteoric water that has entered the basin. This record can be considered to represent a proxy for palaeoprecipitation regimes, with changes in the $\delta^{18}O$ signature of shells interpreted as representing variability in regional climates. We assume little to no diagenetic effects from soil water have altered shell geochemistry, as shell samples were collected from buried contexts beyond the limits of soil wetting depth in the local semi-arid environment.

Methods

Modern *M. falcata* shells were collected from active flood zones in several locations along the Lower Salmon River. Fossil samples of *M. falcata* shell were obtained from faunal collections of three archaeological sites excavated along the Lower Salmon River. Shell samples were submitted for X-ray diffraction and revealed an aragonite mineralogy. All shell carbonate

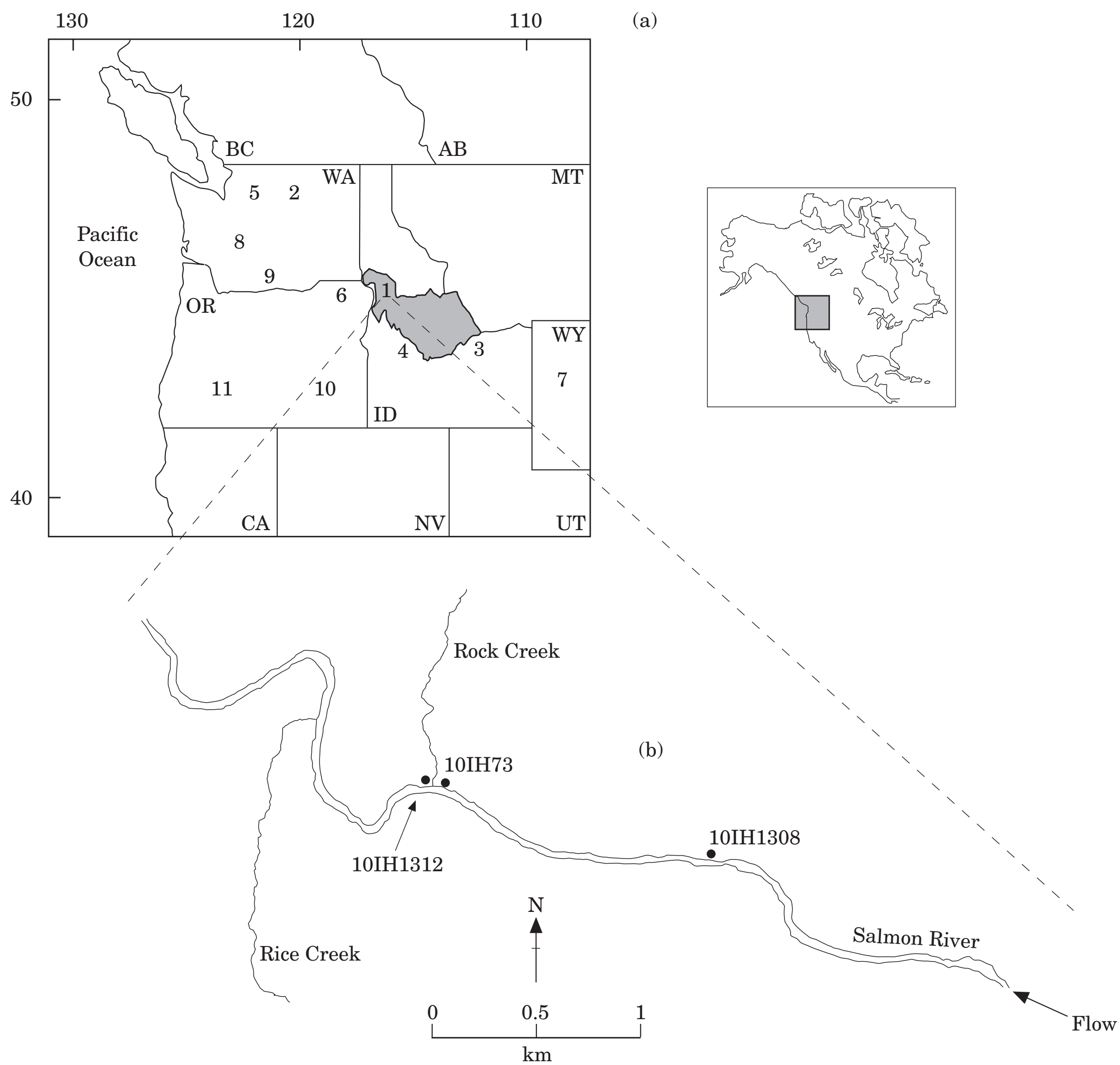

Figure 3. Map of study area showing (a) location of the Salmon River basin in relation to regional palaeoenvironmental sites discussed in text: (1) Lower Salmon River Canyon study area and Salmon River basin (shaded portion); (2) Wells Reservoir; (3) Lemhi Mountain Range; (4) Pioneer Mountain Range; (5) Glacier Peak; (6) Wallowa Mountains; (7) Wind River Range; (8) Mount Rainier; (9) Carp Lake; (10) Diamond pond; (11) Mount Mazama (Crater Lake). Exploded map at bottom (b) shows Lower Salmon River Canyon study area with position of archaeological sites used in this study.

samples were initially bleached with NaOCl(aq) and oven dried. Bulk carbonate samples representing homogenized portions of entire shells were individually reacted *in vacuo* at 25·3°C with H_3PO_4. The evolved CO_2 gas was cryogenically isolated and analysed with a Finnigan MAT 252 mass spectrometer, which has an internal error of $\pm 0{\cdot}1$‰ for carbonates. $\delta^{18}O$ and $\delta^{13}C$ signatures are compared to standard mean ocean water (SMOW) (Baertschi, 1976) and Peedee Belemenite (PDB) (Craig, 1957), respectively; all results are reported in parts per mil (‰).

Context of the study area

The Salmon River originates in the mountains of central and eastern Idaho in the Pacific Northwest of the United States (Figure 3). Melting winter snowpack and rainfall during the spring months produces a pronounced increase in annual fluvial discharge. Temperatures and precipitation vary with elevation, with reduced rainfall and greater aridity in the lowland canyons and mesic conditions in the uplands and mountains. Climatological data for several localities in and around the Salmon River basin are presented in Table 1.

Vannote & Minshall (1982) reported the modern distribution of *M. falcata* in the Salmon River. They note that the best-developed river mussel communities are found in those areas with large stable cobble and boulder channel gravels. Since most of the Lower Salmon River flows over a bedload comprised of

Table 1. Climatological data from selected stations in and around the Salmon River basin, Idaho (Western Regional Climate Center, 1999). Annual (Ann) and seasonal (DJF=December, January, February; MAM=March, April, May; JJA=June, July, August; SON=September, October, November) temperature shown in °C. Annual and seasonal precipitation shown in cm

	Temperature					Precipitation				
Station	Ann	DJF	MAM	JJA	SON	Ann	DJF	MAM	JJA	SON
Cottonwood	13·2	2·6	12·4	24·3	13·6	56·9	12·7	18·3	13·5	12·5
Lewiston	17·4	5·5	16·9	29·7	17·3	32·5	8·4	9·7	7·1	7·6
Boise	17·2	4·4	16·7	30·2	17·7	30·2	10·2	9·4	3·8	7·1
Nezperce	13·8	2·8	12·8	25·3	14·2	53·9	11·9	17·5	11·7	12·7
Grangeville	8·0	− 0·7	7·0	17·5	8·2	60·7	11·2	21·6	13·7	14·2
Riggins	19·2	6·9	18·8	31·7	19·3	42·7	9·4	14·2	9·1	10·2

coarse clastic material, *M. falcata* locally dominates the genera of river mussels found in local archaeological sites (Drake, 1963; L. G. Davis, unpubl. data).

M. falcata shells from three archaeological sites located along the Lower Salmon River were used in this study (Figure 3). To place the samples in a stratigraphic and temporal context, a brief review will be provided of the site stratigraphy.

The Cooper's Ferry site (10IH73) produced *M. falcata* shells associated with cultural occupation in stratified aeolian and alluvial sediments. Two radiocarbon dates from the Cooper's Ferry site were used in this study: 11,410 years BP and 8430 years BP (Table 2). Although other radiocarbon dates have been produced from the Cooper's Ferry site, only a selected number are used to build a temporal framework for this study due to issues of possible contamination of bone collagen dates and vertical displacement of charcoal samples in rodent burrows. The stratigraphic record of this site and the positions of radiocarbon dates used in this study are shown in Figure 4(c).

The Gill Gulch site (10IH1308) was excavated by the Bureau of Land Management (BLM) and produced evidence of later Holocene cultural occupation on an aggrading alluvial fan surface (Dickerson, 1997). Shells were collected from two test excavation units (Figure 4(b), (d)), which produced radiocarbon ages between 4940 and 3340 years BP (Table 2).

The last site included in this study is the Nipeheme Village site (10IH1312), where shells were associated with intensive cultural occupation on a floodplain (Figure 4(a)) with radiocarbon dates ranging between 1780 and 1140 years BP (Table 2). Relative age markers are provided in the upper portion of the site by the presence of protohistoric artefacts, including a glass trade bead. The protohistoric period in west-central Idaho is considered to fall between *c.* 450 years BP and *c.* 150 years BP (AD 1500 to 1805) (Sappington, 1994: 337). At the Nipeheme Village site, a terminal protohistoric date of 150 years BP is placed on the context of the glass bead.

Establishing a temporal scale

The stratigraphic position of radiocarbon ages and protohistoric artefacts in the three sites were used to establish a temporal scale for mussel shell geochemistry. The isotopic results of shell samples were organized as a time series by normalizing rates of deposition between the position of radiocarbon ages.

Presentation of data

The results of isotopic analyses on river mussel shell carbonates from modern and archaeological samples are presented in Table 3. Modern *M. falcata* shells returned $\delta^{18}O$ values near 13·6‰, while $\delta^{13}C$ values were more variable. Shell $\delta^{18}O$ values ranged from 12·6 to 15·3‰ in all archaeological samples, with a mean of 13·5‰ and a standard deviation of 0·5‰. The $\delta^{13}C$ values of archaeological shells spanned − 2·9‰ to − 7·5‰, averaging − 5·2‰ with a standard deviation of − 1·0‰. Comparisons between archaeological shell $\delta^{18}O$ and $\delta^{13}C$ fail to reflect a strong correlation in all cases (Figure 5).

Interpretation

Modern *M. falcata* shell $\delta^{18}O$ is used as a baseline value (13·6‰) for comparison with the isotopic concentration of archaeological shell samples (Figure 6). $\delta^{18}O$ values exceeding 13·6‰ reflect lower atmospheric precipitation rates relative to modern climate conditions while $\delta^{18}O$ values lower than the baseline reflect periods of increased atmospheric precipitation. Mussel shell $\delta^{13}C$ reflects the dissolved carbon present in the river water during shell construction (Kerr-Lawson *et al.*, 1992). As the origin of this carbon can be attributed to many sources (e.g. C_3 and C_4 plant matter, carbon-bearing bedrock) in the basin, the overall meaning can be obscure. This consideration helps to explain the poor fitness between shell $\delta^{18}O$ and $\delta^{13}C$ concentrations shown in Figure 5. Because of the ambiguity between $\delta^{13}C$ and $\delta^{18}O$ variability in Lower Salmon River *M. falcata* shells, the carbon-13 signature is not considered to clearly represent palaeoenvironmental conditions.

During the Late Pleistocene and Early Holocene, $\delta^{18}O$ values in *M. falcata* shells fluctuate relative to modern mussels, indicating that Late Pleistocene and Early Holocene precipitation in the Salmon River

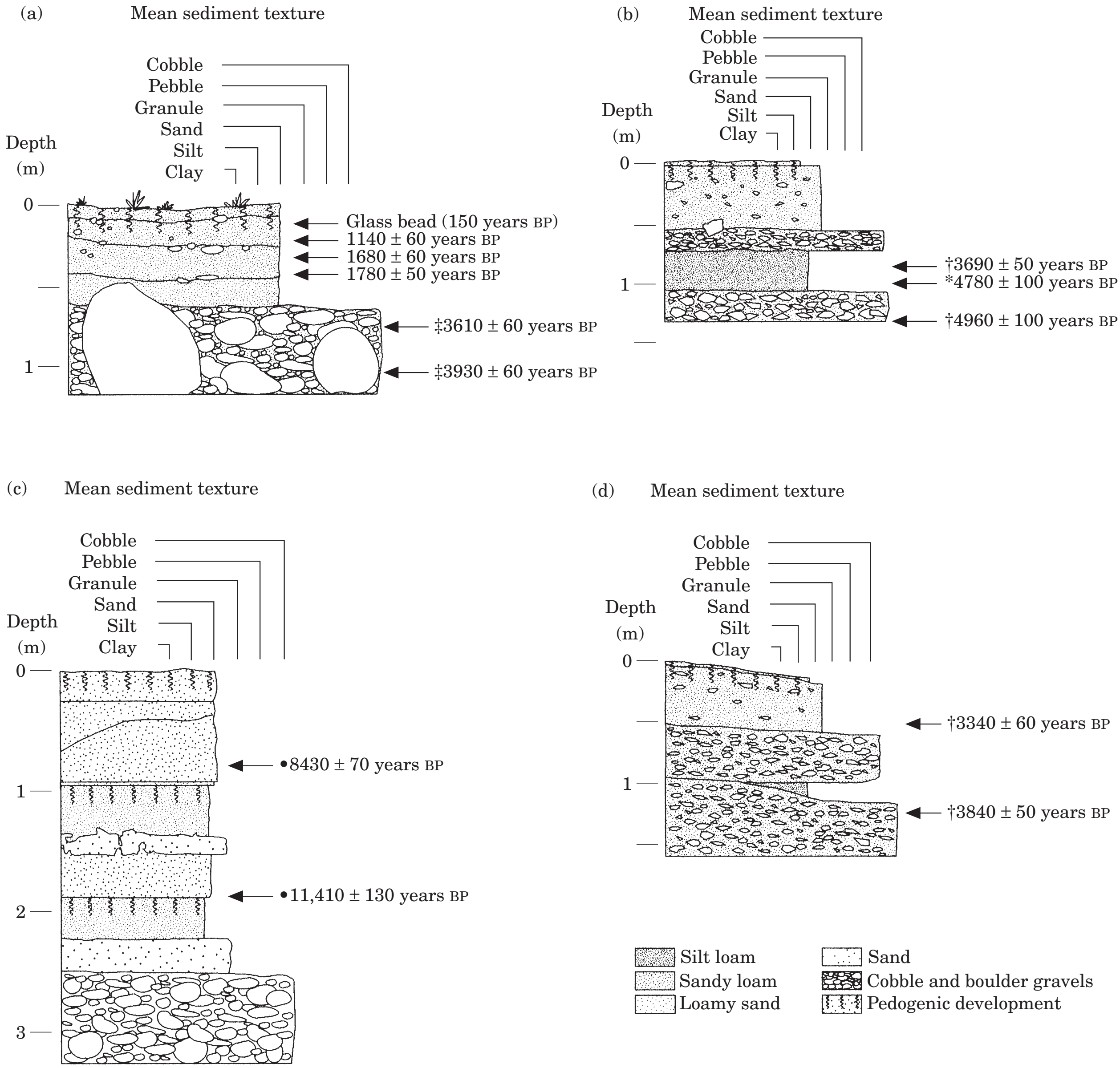

Figure 4. Stratigraphic profiles from the Nipehéme Village site (10IH1312) Unit A and B composite (a), the Gill Gulch site (10IH1308) Unit 2 (b), the Cooper's Ferry site (10IH73) Unit A (c), and the Gill Gulch site (10IH1308) Unit 1 (d) showing positions of lithostratigraphic units, pedostratigraphic units and radiocarbon dates relative to depth in m. Radiocarbon dates shown are in uncalibrated ^{14}C years BP. Stratigraphic profiles from the Gill Gulch site are based on descriptions made by Dickerson (1997). * AMS bone collagen date; ● AMS wood charcoal date; † AMS mussel shell carbonate date.

basin was not stable. Three notable periods of aridity are seen, with the first at 11,400 years BP and the second event rising after 11,000 years BP, culminating immediately before 10,000 years BP and the third at 9000 years BP. During the first arid period, $\delta^{18}O$ concentrations shift from 13·3‰ to 14·4‰ between *c.* 11,800 to 11,500 years BP. Between *c.* 11,200 to 10,100 years BP, $\delta^{18}O$ values vary between 13·2‰ and 15·3‰, marking the driest period in the past 12,000 years BP. A change to arid conditions is seen again between *c.* 9500 and 9000 years BP, represented by a change in $\delta^{18}O$ from 13·5‰ to 14·0‰. Lastly, precipitation decreases between *c.* 8600 to 8100 years BP, marked by an increase in $\delta^{18}O$ concentration from 13·1‰ to 13·8‰.

Early trends toward wetter conditions are seen at 11,700 years BP (13·3‰), from 11,500 to 11,200 years BP with an $\delta^{18}O$ change from 14·4‰ to 13·2‰, between *c.* 10,000 to 9500 years BP associated with a shift from 15·3‰ to 13·5‰, and from *c.* 9000 to 8600 years BP, where $\delta^{18}O$ values change from 14·0‰ to 13·1‰.

Table 2. Radiocarbon dates from Lower Salmon River Canyon archaeological sites used in this study. Depth is reported in cm BD (below datum)

Site	Depth (cm BD)	Material	Lab number*	Age (RCYBP)§
10IH1312	25	Wood charcoal	TO-7350†	1140 ± 60
10IH1312	35	Wood charcoal	TO-7354†	1680 ± 60
10IH1312	39	Wood charcoal	TO-7355†	1780 ± 50
10IH1308/1	40–50	Mussel shell	Tx-9271‡	3340 ± 60
10IH1308/2	80–90	Mussel shell	Tx-9272‡	3690 ± 50
10IH1308/1	80–90	Mussel shell	Tx-9373‡	3840 ± 50
10IH1308/2	90–100	Bone collagen	Beta-11657†	4780 ± 100
10IH1308/2	120–130	Mussel shell	Tx-9275‡	4940 ± 100
10IH73	75	Wood charcoal	Beta-114952†	8430 ± 70
10IH73	180	Wood charcoal	TO-7349†	11,410 ± 130

*Beta refers to Beta Analytic; TO refers to Isotrace Radiocarbon Laboratory, University of Toronto, Tx refers to University of Texas, Austin (†AMS date, ‡conventional radiocarbon date). §uncalibrated ^{14}C age in radiocarbon years before present.

Between *c.* 4500 and 4100 years BP, δ^{18}O values change from 12·7‰ to 14·7‰, reflecting a rapid and major shift to arid conditions. This trend is quickly reversed by a return to wet conditions between 4100 and *c.* 3950 years BP marked by a change in δ^{18}O from 14·7‰ to 13·1‰. From *c.* 4000 and 2950 years BP δ^{18}O values fall between 13·1‰ and 13·7‰, showing the presence of wetter conditions that gradually decrease through time. After a sharp but short decrease in δ^{18}O concentration to 13·3‰ after *c.* 2950 years BP, which is interpreted as a brief return of wetter climates, values increase under conditions of decreasing precipitation to 13·7‰ by *c.* 1950 years BP. Another abrupt shift toward increased rainfall is seen at *c.* 1800 years BP with δ^{18}O values at 12·6‰, the lowest of the entire record. By *c.* 1700 years BP, precipitation is much reduced, with δ^{18}O concentrations at 13·5‰. After *c.* 1700 years BP, rainfall appears to have been close to modern conditions.

Carbon-13 values of mussel shell carbonates are interpreted to reflect the nature of inorganic carbon dissolved in river or stream water during shell formation (Kerr-Lawson *et al.*, 1992). A lack of agreement between trends of shell δ^{18}O and δ^{13}C is expected in riverine bivalves, since much of the dissolved carbon may come from plants that grow in different habitats throughout the basin.

Since the Salmon River basin is large in area and contains a diverse plant population, the distribution of which is largely controlled by elevation effects on temperature, precipitation and evaporation, different δ^{13}C values are expected among shells that live in the main Salmon River water as compared to lowland tributary basin stream water. While the δ^{18}O of the water from both of these basins is expected to be the same under a water-based model of isotope geochemistry the plant populations in each will be different and are expected to produce different δ^{13}C values in their waters.

Comparisons with Regional Palaeoclimatic Records

Records of Late Pleistocene to Holocene palaeoclimatic conditions have been constructed from several areas in the Pacific Northwest. These records are derived from pollen and organic carbon deposition in lakes and bogs, and fluvial geomorphology histories are reflected in depositional and erosional events in fluvial basins. Histories of glacial advances are present in Pacific Northwest mountain ranges and the Rocky Mountains from the Wind River Range of Wyoming, as synthesized by Davis (1988). Palaeoclimatic records summarized in the sections below are compared against the Lower Salmon River Canyon *M. falcata* shell δ^{18}O record in Figure 6.

Late Pleistocene and Early Holocene

Butler (1984*a*, *b*, 1986) marks the timing of late Wisconsinan deglaciation of east-central Idaho's Lemhi Range prior to 11,200 years BP due to the presence of Glacier Peak set B tephra in alpine meadow sediments. Cotter, Bloomfield & Evenson (1986) also place late Wisconsinan glacial retreat in the Pioneer Mountains of central Idaho by at least 11,200 years BP based on the presence of Glacier Peak set B tephra within bog sediments deposited in a kettle hole feature. Butler (1984*a*, 1986) reports periglacial wedges and deformed bedding structures dating between 10,130 years BP and 7560 years BP, which are interpreted as bracketing a return of cold conditions.

At Glacier Peak, in the northern Cascade Range of Washington, the distribution of the Glacier Peak set B tephra points to the local retreat of glaciers before 11,200 years BP (Porter, 1978). Increased organic sedimentation in alpine lakes on Mt. Rainier at 10,000 years BP is interpreted as evidence of Early Holocene climatic warming (Heine, 1998).

Table 3. Stable isotope geochemistry data from M. falcata *shells collected at Lower Salmon River Canyon beaches and archaeological sites 10IH73, 10IH1308 units 1 and 2, and 10IH1312. Depth is reported in cm BD (below datum)*

Site	Depth (cm BD)	$\delta^{18}O_{SMOW}$‰	$\delta^{13}C_{PDB}$‰
Pine Bar 1	Surface	13·60	− 8·08
Pine Bar 2	Surface	13·58	− 8·33
Apricot Bar	Surface	13·50	− 9·28
10IH1312	15	13·47	− 4·12
10IH1312	25·5	13·40	− 3·92
10IH1312	26	13·56	− 5·65
10IH1312	29	13·42	− 5·25
10IH1312	32	13·52	− 4·31
10IH1312	35	12·60	− 7·48
10IH1312	39	13·74	− 4·25
10IH1312	45	13·61	− 5·48
10IH1312	55	13·30	− 6·12
10IH1312	65	13·72	− 5·58
10IH1312	75	13·41	− 5·06
10IH1312	85	13·29	− 5·34
10IH1308/1	15	13·04	− 3·84
10IH1308/1	25	13·08	− 5·52
10IH1308/1	35	13·11	− 5·11
10IH1308/1	65	13·20	− 5·75
10IH1308/1	85	12·78	− 5·58
10IH1308/1	95	13·09	− 5·68
10IH1308/1	105	14·71	− 5·89
10IH1308/1	125	14·15	− 6·92
10IH1308/1	135	12·70	− 7·17
10IH1308/1	155	12·82	− 5·33
10IH1308/2	15	13·56	− 4·14
10IH1308/2	25	13·55	− 4·69
10IH1308/2	35	13·43	− 4·71
10IH1308/2	45	13·74	− 3·23
10IH1308/2	65	13·52	− 4·67
10IH1308/2	75	13·17	− 5·01
10IH1308/2	85	13·27	− 4·18
10IH1308/2	115	13·33	− 3·39
10IH1308/2	135	13·04	− 5·47
10IH73	40	13·26	− 5·55
10IH73	50	13·80	− 6·08
10IH73	80	13·09	− 5·05
10IH73	90	13·98	− 5·17
10IH73	110	13·46	− 5·15
10IH73	120	13·77	− 5·60
10IH73	130	15·33	− 2·90
10IH73	160	14·27	− 6·62
10IH73	170	13·22	− 5·37
10IH73	180	14·38	− 3·91
10IH73	190	13·31	− 5·39

Zielinski (1987) and Zielinski & Davis (1987) date the rapid retreat of glacial ice in the Temple Lake valley between *c.* 11,000 years and 12,000 years BP on the basis of radiocarbon-dated organic material from Temple Lake and Rapid Lake cores (Davis, 1988). Warmer conditions are seen to prevail in the Temple Lake valley by 10,340 years and 11,370 years BP, as reflected in an increase in organic sedimentation in lakes and between moraines (Davis, 1988).

Pollen records point to warmer and drier conditions in the Pacific Northwest between 10,000–9,500 years BP (Sea & Whitlock, 1995), while general post-glacial

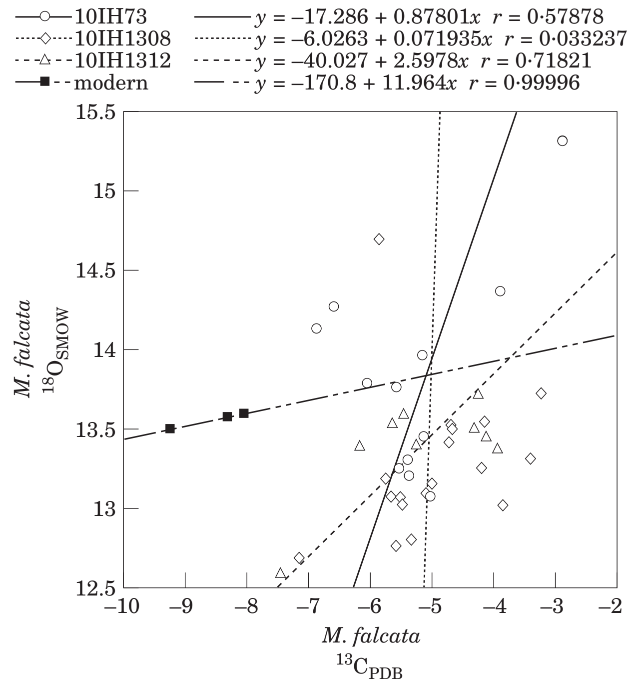

Figure 5. Cross plot of $\delta^{18}O$ versus $\delta^{13}C$ from *M. falcata* shell samples in Lower Salmon River Canyon archaeological sites; samples from the Cooper's Ferry site (10IH73) shown as open triangles; samples from the Gill Gulch site (10IH1308) presented as open diamonds; samples from the Nipeheme Village site (10IH1312) shown here as open circles; samples from modern beaches shown as closed boxes. Patterns of regression lines for site data shown above cross plot correspond to line patterns shown in key.

warming is observed throughout most of the Pacific Northwest by 10,000 years BP (Mehringer, 1985). Between 9800 and 8950 years BP, glaciers readvance on Mt Rainier, suggesting a return to cooler and wetter conditions (Heine, 1998). Barnosky (1985) reports a shift towards increased humidity at *c.* 8500 years BP, interpreted from increasing pine pollen at Carp Lake in south-central Washington. Kiver (1974) identified a period of advance for the Glacier Lake moraine in the Wallowa Mountains of northeastern Oregon between *c.* 9000 years BP and before the eruption of the Mazama set O tephra at 6800 years BP (Bacon, 1983). Confirmation of this general scheme comes from rates of boulder weathering and pedostratigraphic data provided by Burke (1978). Mehringer (1985) notes that inland Pacific Northwest pollen records show decreased effective moisture and warm conditions by 7000 years BP, resulting in the desiccation of lakes in some lower elevations areas.

Chatters & Hoover (1992) report alluvial aggradation events on the middle Columbia River of eastern Washington between 9000–8000 years BP, 7000–6500 years BP, 4400–3900 years BP, and 2400–1800 years BP. The timing of these aggradation periods are attributed to transitions from cold, moist climate conditions to drier, warmer conditions (Chatters & Hoover, 1992:

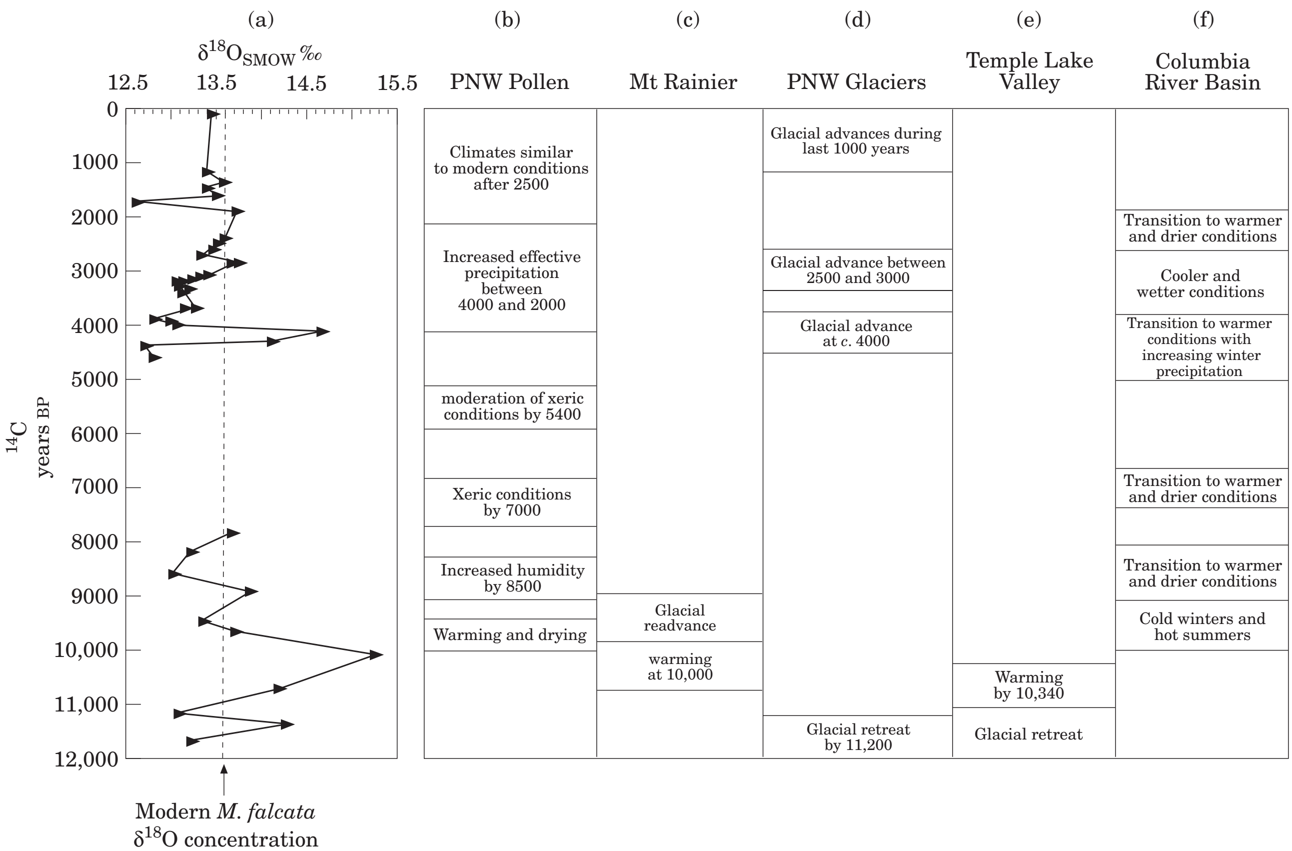

Figure 6. Comparison of Lower Salmon River Canyon *M. falcata* $\delta^{18}O$ record with regional palaeoenvironmental proxy records. Composite record of $\delta^{18}O$ values reported from each site (see Table 3) are plotted against an interpolated time curve presented in uncorrected radiocarbon years BP (a); $\delta^{18}O$ values from archaeological sites are projected relative to the modern *M. falcata* shell $\delta^{18}O$ signature, shown as a vertical dashed line. Summarized palaeoenvironmental conditions derived from Pacific Northwest pollen (b), Mt Rainier (c), Pacific Northwest glaciers (d), Temple Lake Valley glaciers (e), and Columbia River basin proxy conditions (f) follow aforementioned sources in text.

54). Drawing upon a number of proxy palaeoclimate sources (Chatters, 1991), Chatters & Hoover (1992) infer palaeoclimatic conditions for several early Holocene periods: cold winters and hot summers with a possibility of spring precipitation is posited for the period 10,000–9000 years BP, while climates change to warmer winters and hot summers with winter-dominant precipitation between 9000–8000 years BP.

Middle to Late Holocene

Palaeoenvironmental records show a general trend toward cooler and wetter conditions during this period. Earlier xeric conditions appear to have become more moderate by 5400 years BP throughout much of the region and change to wetter, cooler conditions with increased effective precipitation by 4000 years BP (Mehringer, 1985). Neoglacial readvances are posited at *c.* 4000 years BP and within the last 1000 years in the Lemhi Range (Knoll, 1977; Butler, 1984*b*, 1986) and Lost River Range (Cluer, 1987) of Idaho on the basis of relative ages on glacial features. Three Late Holocene glacial advances are seen in the Wallowa Mountains, with events dated to between *c.* 2500 years BP and 3000 years BP, at *c.* 1000 years BP and within the last 500 years BP on the basis of the tephrostratigraphy (Kiver, 1974), boulder weathering rinds and soil development (Burke, 1978). Tephrostratigraphy and dendrochronology are used to date the maximum extent of two glacial advances at Glacier Peak between 5100 to 5500 years BP, at *c.* 3400 and before AD 1650 (Beget, 1984).

On the basis of proxy palaeoclimate data synthesized from multiple sources in the Columbia River Basin, Chatters (1991) infers warming winter conditions and hot summers with winter-dominant precipitation between 8000–4400 years BP, while a brief shift to cooler and moister conditions may have occurred between 7800–6500 years BP. Wigand's (1987) work at Diamond Pond in southeastern Oregon shows a record of increased effective precipitation between 4000–2000 years BP. Increased quantities of mesic plants are seen at Carp Lake after 5000 years BP, suggesting climatic amelioration (Barnosky, 1985). Cold winter and cool summer conditions with winter-dominant precipitation are thought to have prevailed in the Columbia Basin between 3900–2400 years BP, shifting to warmer winter and summer climates with a reduction in winter-dominant precipitation from 2400–1800 years BP (Chatters, 1991). Pollen records reflecting climatic conditions similar to today appear to have become widespread after 2500 years BP (Mehringer, 1985).

Comparisons with Isotopic Record

Patterns of $\delta^{18}O$ concentration in *M. falcata* shell carbonate show many similarities with regional palaeoclimate records. Retreat of glacial ice in the Wind River Range between 12,000 and 11,000 years BP may be coincident with increased aridity suggested by shell $\delta^{18}O$. General warming and drying of regional climates by 10,000 years BP is reflected by increased concentrations of $\delta^{18}O$ in Lower Salmon River Canyon shells between *c.* 11,000 and 10,000 years BP. Variability in pollen records during the Early Holocene is matched in the isotopic record, particularly at *c.* 8500 years BP, which is marked by decreased $\delta^{18}O$ values in Lower Salmon River Canyon shells and increased humidity at Carp Lake (Barnosky, 1985). Warmer and drier conditions reported from the Columbia River Basin between 9000 and 8000 years BP (Chatters, 1991) are seen at *c.* 9000 years BP in the isotopic record; however, wetter conditions are seen afterwards until *c.* 7900 years BP. Early Holocene periglacial conditions reported by Butler (1984*a*, 1986) in the Lemhi Range may be associated with the decrease in shell $\delta^{18}O$ between 9000 and 8000 years BP.

Late Holocene conditions also correlate well between isotope and regional proxy records. Warmer, drier conditions seen in the Columbia River Basin between 4400–3900 (Chatters, 1991) are matched by increased $\delta^{18}O$ values briefly from *c.* 4200 to 4000 years BP. Decreased $\delta^{18}O$ concentrations after 4000 years BP, reflecting increased precipitation rates, compare favourably with a cooler and wetter climate interpreted from Pacific Northwest pollen records and alluvial cycles of the middle Columbia River Basin from the same time period (Mehringer, 1985; Chatters, 1991). This increase in mesic conditions is also correlated to neoglacial advances in many areas of the Far West. Inland Pacific Northwest pollen records reflect climatic conditions similar to today by *c.* 2500 years BP, while *M. falcata* shells show near modern $\delta^{18}O$ signatures during this time. The sharp, rapid decline in shell $\delta^{18}O$ at *c.* 1850 years BP correlates to the end of alluvial aggradation in the middle Columbia River Basin by 1800 years BP (Chatters & Hoover, 1992), both suggesting a shift to cooler and wetter conditions. Climate conditions associated with renewed activity in regional glaciers during the last millennia is not reflected in the shell $\delta^{18}O$ record, due to its low temporal resolution after *c.* 1100 years BP.

Comparison with Regional Archaeological Record

Traditionally, palaeoenvironmental records have been given a great deal of attention by Plateau archaeologists, who value these data as a means of providing a contextual basis for model building in prehistory. While causal comparisons of cultural and environmental records do not necessarily explain the cultural behaviours themselves, they are an important starting point for developing research questions in regional archaeology. Here, brief comparisons are made between southern Plateau archaeological records and the *M. falcata* shell $\delta^{18}O$ record of the Lower Salmon River Canyon in order to illustrate its usefulness in archaeological research.

Fluctuating Early Holocene environmental conditions are cited as influencing the availability and productivity of natural resources in the southern Plateau, which are mirrored in hunter–gatherer adaptive strategies and demographic patterns (Ames, 1988). Low populations spread thinly across the landscape used technological and logistical approaches well-suited to a high level of resident mobility. Population densities were controlled by the carrying capacity of the landscape, driven, in turn, by effective temperature and precipitation regimes and their influence on biological populations. During periods of climatic moderation and increased resource productivity, early hunter–gatherers might congregate in higher numbers to exploit rich resources in selected places, leaving a distinct archaeological signature for a limited time. As environmental conditions deteriorated, early populations would have scattered once again, shifting back to adaptive strategies better suited to the use of natural resources with lowered productivity and spatial density.

The *M. falcata* shell $\delta^{18}O$ record shows several distinct periods of climatic fluctuation, which might be used to predict the general nature of early hunter–gatherer adaptive strategies in the southern Plateau under Ames' (1988) model. Early Pacific Northwest populations might be expected to show higher levels of resident mobility during the period between *c.* 11,000 and 10,000 years BP, due to a projected decrease in regional precipitation rates reflecting heightened aridity, which may have resulted in decreased biological productivity in the southern Plateau. Between *c.* 9800 and *c.* 8000 years BP, precipitation regimes show some fluctuations between arid and mesic conditions with amplitudes much reduced from the previous period. This may have produced regional environmental conditions that were amenable to increased biological productivity and higher density hunter–gatherer populations. The latter period of environmental change also corresponds to the transition from Palaeoarchaic to Archaic cultural traditions in the region. By *c.* 8000 years BP, important cultural changes are seen in southern Plateau archaeological sites, represented by new technological and logistical innovations (Leonhardy & Rice, 1970; Ames, 1988; Sappington, 1994).

The latter half of the *M. falcata* shell $\delta^{18}O$ record also corresponds to fundamental changes in southern Plateau prehistory. Cultural complexity, marked by the increased use of camas roots and salmon and increased settlement along major rivers and tributaries, is seen throughout the region after *c.* 5000 to 4000 years BP (Ames *et al.*, 1998; Brauner & Stricker, 1990; Chance *et al.*, 1989; Leonhardy & Rice, 1970; Roll & Hackenberger, 1998; Sappington, 1994). This period corresponds to increased rainfall and mesic conditions reflected in the *M. falcata* shell $\delta^{18}O$ record. Although the exact link between environmental changes and these cultural developments is not clear, and have been dated earlier in some areas (e.g. Brauner, 1976), the correlation of hunter–gatherer cultural and environmental change is widespread in the archaeological literature of the region.

Identifying the role of precipitation change associated with these post-5000 years BP climate conditions adds yet another degree of resolution to our understanding of the environmental context of Late Holocene cultural behaviours in the Plateau. Clearly, however, the correlations discussed here are of a first-order approximation and serve only to highlight potential avenues for further, more detailed, archaeological and geoarchaeological research seeking to elucidate the relationship between prehistoric societies and their environmental contexts. Increasing the database of shell samples will also help to increase the clarity and resolution of this palaeoprecipitation record.

Conclusions

Oxygen-18 and carbon-13 values from *M. falcata* shell carbonate samples collected from three archaeological sites located along the Lower Salmon River Canyon of Idaho show several periods of increased and decreased rainfall over the last 12,000 years BP. Greater aridity is observed during the Late Pleistocene and early Holocene, while after *c.* 4000 years BP precipitation rates increase relative to modern conditions. After *c.* 1800 years BP, precipitation trends toward modern values. The isotopic record compares closely with numerous regional palaeoenvironmental records, reflecting specific conditions of relative humidity. Stable isotope records from freshwater mussels provide a new perspective on Late Quaternary palaeoclimate conditions and archaeological records in the Pacific Northwest, and are a useful addition to investigations of human–environmental interactions in prehistory.

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