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ARCHAEOLOGY IN NEW ZEALAND

THE DEVELOPMENT AND APPLICATION OF NEW ZEALAND OBSIDIAN HYDRATION DATING, 1996-1998

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INTRODUCTION

This article is to inform readers of the continuing development of New Zealand obsidian hydration dating, which has been funded by the Foundation of Research, Science and Technology. This research seeks to date Aotearoa/New Zealand's past on the basis of refinement and strategic application of obsidian hydration dating (OHD), which was successfully developed during 1993-94. It has four objectives. These are: to improve the accuracy and precision of hydration rim measurement using a non-destructive technique; to control and reduce other sources of dating error; to evaluate recently published alternative models of initial Maori colonization and dispersal along the east coast, North Cape to the Bluff; and, to carry out a high resolution dating of the archaeological evidence of pre-European Maori settlement and fortification in the Hauraki Gulf. The rationale of each of these objectives, and the methods used, are outlined below.

GENERAL OVERVIEW

New Zealand archaeological sites contain a very limited range of temporally diagnostic artefacts (Davidson 1984). Therefore, archaeologists here have been reliant on radiocarbon dating as the principal means of age determination. Archaeology in New Zealand has been substantially compromised by the cost and imprecision of radiocarbon dating. High quality Accelerator Mass Spectrometry (AMS) dates cost NZ$800 each and yet they routinely suffer from problems of inbuilt age (Anderson 1991), marine reservoir effect (McFadgen and Manning 1990) and perturbations in the calibration curves for the period 1050 to 1150 AD and 1680 to 1840 AD (McFadgen, Knox and Cole 1994; Stuiver and Pearson 1986; Stuiver and Becker 1993) which are fundamentally important in the New Zealand context, as the first spans the interval in which colonization may have occurred and the second relates to a period of major economic and ecological change.

The imprecisions associated with radiocarbon dating mean that problems exist in the development of coherent regional chronologies and in the interpretation of dates (Anderson 1991; Anderson and McGovern-Wilson 1990; Sutton 1987a,b, 1994). This seriously limits the precision with which sites can be dated, and it impedes the development of hypotheses capable of explaining the considerable cultural and economic change which occurred in prehistoric and early historic Maori Society.

This situation prompted Sutton and Sheppard to initiate a research project with Chris Stevenson in 1993 which was directed towards developing obsidian hydration dating as an alternate chronometric technique. OHD is based on the fact that obsidian absorbs water over time, forming a hydration band on its exposed surfaces. Band width can be measured. Temperature dependent rates of hydration can be established experimentally. Therefore, time elapsed since an obsidian surface was exposed by flaking can be calcuated. The outputs from the 1993 project (see Appendix 1) have established that obsidian hydration dating is less expensive than radiocarbon dating and that it does not suffer from the problems inherit in radiometric methods, mentioned above. Therefore, it is capable of providing an absolute time scale against which to set the events of New Zealand's pre-European and early historic past.

SCIENTIFIC BACKGROUND

The procedure for calculating an obsidian hydration date involves three steps: hydration rate determination; hydration rim measurement; and, effective hydration temperature modelling.

Hydration Rate Determination

The development of hydration rates for New Zealand obsidians received only limited attention (Ambrose 1976; Leach and Naylor 1981) prior to 1993. Conventional methods of hydration rate definition for specific obsidian sources have included the correlation of hydration rim widths with associated radiocarbon dates and by high temperature induced hydration on geological samples. The hydration rims formed at high temperature were then measured and used to calculate the hydration rate constants (A, E). These constants were used to estimate archaeological hydration rates at ambient conditions with the Arrhenius equation:

$$K = Ae^{-E/RT}$$

where: K = archaeological hydration rate
A = high temperature hydration rate
E = activation energy
R = universal gas constant
T = temperature

The dependence of hydration rate on obsidian chemical composition has been addressed through theoretical considerations (Ericson 1981) and by correlation of high temperature hydration rates with glass chemical constituents (Friedman and Long 1976). Recent work by Mazer *et al.* (1992), Stevenson *et al.* (1993), and Stevenson *et al.* (in press) has shown a strong interdependence between the structural water content of the glass and the hydration rate at high temperature (A) and the activation energy (E). With this calibration established, it is now possible to estimate archaeological hydration rates for individual artifacts from the concentration of OH- contained within the glass.

During the development of the hydration rate calibration, structural water concentrations were precisely determined using Fourier transform infrared spectroscopy (FTIR) on clear obsidian specimens (Stevenson and McCurry 1990; Newman *et al*. 1986). During the application of these calibrations to New Zealand archaeological obsidians and others, it became clear that the lack of glass clarity in the majority of artifacts was a significant hinderance in the use of infrared methods. To counter this limitation, Ambrose and Stevenson (Stevenson *et al*. in press) developed an additional calibration curve demonstrating the relationship between structural water content (OH-) and the density of the obsidian, as part of the 1993 project. High density obsidians will have low quantities of structural water and hydrate slowly while low density glasses will have higher OH- concentrations and faster hydration rates. With this relationship water values, and thus hydration rates, for virtually all New Zealand archaeological obsidians can be estimated.

In the research objectives listed below we propose to identify through density measurement those New Zealand obsidians which hydrate rapidly and are therefore the most suited for hydration dating. In addition, density measurement prior to hydration analysis will be used to establish hydration rates for each analysed artifact.

Hydration Rim Measurement

A variety of non-destructive high precision depth profiling techniques exist for measuring the width of the hydration rim (Lee *et al*. 1974; Tsong et al. 1978; Duerden *et al*. 1982) but optical measurement continues to be the most frequently used method. However, optical techniques require a high level of skill in the field of microscopy and blind tests conducted between different laboratories (Jackson 1984; Stevenson *et al*. 1989b) have shown that the amount of variation in measurement values on the same specimen can vary by more than the optical resolution of the microscope. This suggests that factors such as sample preparation, image quality, focusing techniques, and image boundary definition by the operator were all factors that contributed to measurement variation.

To overcome these difficulties, the obsidian dating laboratory at the Centre of Archaeological Research has implemented the computer-based imaging measurement system proposed by Ambrose (1994; in press). This procedure gives an integrated measurement of the hydration rim surface which suppresses small differences in sample surface planeness and diffusion front variation thereby giving an average width value for the measured area. Under these conditions a measurement with a precision of 0.075 um may be made (1 pixel = 0.075 um). Application of this procedure has produced dates which agree well with radiocarbon dates (Stevenson *et al.* 1995).

The optical measurement of hydration bands is a destructive process which requires the preparation of a geological thin section. This technique will always be a part of the laboratory procedure and one which is used to date artifacts taken from potentially chemically or physically destructive environments such as sand dunes or high alkaline soils - the former of which contain a significant number of prehistoric sites in New Zealand. In these situations the external surfaces of the artifact may have been eroded and interior fissures must be examined to assess the true age of the artifact (Ambrose 1994). The use of this technique on New Zealand sites has met with considerable success (Stevenson *et al.* 1995). However, finer measurement resolution, and thus more precise age determinations, is desirable for the colonization and dispersal research (Objective 3) and the high-resolution settlement pattern analysis (Objective 4) proposed here.

A non-destructive technique of rim measurement using Nuclear Resonance Reactions is valuable for several reasons: a) it preserves information on use-wear, style, and technological attributes; b) has a reported precision of 0.02 um - 0.04 um thereby producing dates with small standard errors (Tsong *et al.* 1978; Leach and Naylor 1981); and c) measures individual locations of 2 mm in diameter, thus permitting multiple measurements at different locations on the artifact. All of these features are advantageous from the standpoint of conservation and analytical flexibility and will serve to improve future applications. We propose to capitalise upon this analytical advantage by integrating nuclear resonance profiling methods (Objective 1) into application of OHD within this research programme (Objective 3 & 4).

A control study of observer accuracy using the optical method in conjunction with nuclear resonance profiling will occur, between the OHD laboratory at the Centre for Archaeological Research and Archaeological Consultants Inc, of Columbus Ohio, by arrangement with Dr Chris Stevenson.

Soil Temperature

Research during 1993-1994 at 60 locations using zeolite diffusion cells to monitor soil temperature (Ambrose 1980) indicated that hydration temperature has a large influence on OHD (Jones *et al.* nd) accuracy. This follows from the substantial variation in soil temperature which occurs with depth, aspect, matrix composition and vegetation cover which was documented during 1993-1994. Therefore we intend to control for temperature variation very carefully while building on our previous experience. Innovative techniques, described under

Objective 2, will be used to determine effective hydration temperatures (EHT's) for locations on the East Coast of the South Island, and in the Hauraki Gulf and Auckland. The EHT's defined in this manner will be used in the analysis of colonisation and dispersal (Objective 3) and the Hauraki Gulf settlement pattern study (Objective 4). They would also have broader applicability, allowing OHD age determinations to be made reliably for most of New Zealand. At present applicability is limited by sparse EHT data. In addition, the combined experimental and field data on EHT will be used as the basis of a guide and sample collection protocol to be used by those wishing to have the OHD laboratory at the Centre for Archaeological Research produce age determinations for their purposes.

Models of Colonisation

Maori colonisation of New Zealand has been a long-standing preoccupation in both Maori korero and academic debates. The Great Fleet Tradition (Smith 1898-9) is now widely discredited (Simmons 1976; Simmons and Biggs 1970). Since its demise, and particularly within the last five years, there has been a proliferation of accounts of Maori colonisation and dispersal. First, and this is a continuation of ancient practice, iwi recount their individual canoe origins. Significantly, the iwi accounts attest to multiple arrivals over several centuries with some canoes having successive landfalls, many of their crews encountering established inhabitants. These elements - multiple arrivals and many recolonisations spread over time - are very close to the most recent archaeological synthesis on this topic (Sutton 1994), as noted by Bayard (1994). Meanwhile, archaeologists have come up with five different accounts (Bulmer n.d. [1988]; Sutton 1994; McFadgen n.d.b [1992]; Caughley 1988; McGlone **et al**. 1994). Each of them specifies a region and time interval within which first landfall occurred, and some clearly indicate rate and direction of dispersal following colonisation while others do not.

These alternatives can be reduced to a small number of propositions. They are:

1. first Maori presence was early or late; i.e., before or after 700 BP (Anderson 1991);

2. the earliest identified settlement occurred in the subtropical north, Coromandel- Bay of Plenty, the central or southern parts of the east coast;

3. dispersal from that earliest identified settlement was instantaneous, or it took time; and,

4. if the latter, its direction and rate will be discoverable, within the limits of accuracy which are addressed in Objectives 1 & 2 of this application.

Each of these propositions can be tested by the research design contained in Objectives 3 and 4, below.

PROGRAMME OBJECTIVES

The purposes of Objective 1 are to implement non-destructive band measurement as obsidian artefacts are taonga, and to improve the accuracy of hydration band measurement in order to maximise the accuracy of OHD age determinations. These goals will be achieved by increasing the resolution and reliability of archaeological hydration rim measurement using nuclear resonance depth profiling in order to lower the associated dating error and measuring 250 archaeological samples using nuclear resonance depth profiling procedures. Once established through experimental work in Year I (1995-1996) this facility will provide 150 high precision measurements per year as part of Objectives 3 and 4.

Method

The successful pioneering work of Leach and Naylor (1981) will be substantiated and extended with the aim of improving the reproducibility and spatial resolution of hydration rim determinations using the $'H(^{7}Li, \gamma)\ ^{8}Be$ nuclear resonance reaction. This method involves measuring the hydrogen content of the obsidian at increments moving into the surface of the artefact. This will provide a profile of the hydrogen content of the glass which will decline markedly at the interior edge of the hydration band, allowing measurement of band width.

The steps will be to:

(a) Establish the intrinsic response of the system (at the AURA II accelerator, The University of Auckland) by examining the hydrogen depth profile of a uniform, thin sample, probably of a hydrogenated titanium layer on a gold substrate.

(b) Repeat the procedure above (a) using a layer around 1 micron thick.

(c) Use the results of (a) and (b) to interpret the resonance response of sample obsidian artefacts.

(d) Examine 250 artefacts from the Objective 3 and 4 series in an adapted existing semi-automatic scanning nuclear target chamber.

Very large sodium iodide detectors (up to 250mm X 250 mm) and intense ^{7}Li nuclear beams will be used if necessary.

The purpose of Objective 2 is to reduce OHD error by:

1a. Determining effective hydration temperatures (EHT) for locations on the East Coast of the South Island, in the Hauraki Gulf and Auckland.

1b. Determining EHT and relative humidity for East Coast and sand dune locations.

2. Developing a protocol for collecting obsidian from archaeological sites which minimizes the error associated with estimation of effective hydration temperature. This will be submitted for publication in **Archaeology in New Zealand**.

3. Determining the hydration rates of all major obsidians used archaeologically in New Zealand and isolating those which hydrate fastest.

4. Evaluation of operator error in optical hydration rim measurement by conducting yearly blind tests of 20 samples with American OHD laboratories.

Method

1a) Select four, archaeologically significant project areas from within physiographically distinct regions of the East Coast of the South Island. Beginning November 1995 place temperature cells at multiple locations for 12 months to cover all variation with regard to soil type, topography and vegetation.

1b) Beginning July-August 1995 revisit the locations of key East Coast archaeological sites to be dated by the obsidian method (20+ sites) and plant a column of temperature/relative humidity cells for 12 months.

1c) Beginning August 1995 place 60 temperature/relative humidity cell pairs in the Auckland/Hauraki Gulf region for 12 months to investigate archaeological sites, sand dune environments and provide comparative data for thermocouple studies, designed to isolate factors involved in intrasite variation. The latter will be carried out on a test site in Auckland.

1d) Compare the fit of measured temperatures in 1a to 1c to those determined by a soil temperature model based on soil temperature data from meterological stations after the methods of Aldridge (1982) and Aldridge and Cook (1983).

2a) Develop and publish written guidelines for obsidian sample collection so as to minimize variation in the EHT history of the sample and maximize its storage EHT.

3a) Obtain samples from existing collections (University of Auckland, Auckland

Museum, University of Otago) of the 10 most extensively utilized obsidian quarries on North Island New Zealand and select a total of 40 small samples (2 cm x 2 cm) for a total of 400 samples.

3b) Perform a glass density measurement to four significant digits on each sample using a Mettler density kit. The buoyancy method will be implemented using an organic heavy liquid (Perfluro Methadecalin) in order to increase the analytical precision to its highest possible level using this method (+/- 0.0002).

3c) Plot the density ranges for each of the quarries and rank order the quarries as to hydration rate. Faster hydrating obsidians will provide finer chronological resolution.

4. Have 20 slides read yearly by the OHD lab at Archaeological Consultants Inc., Columbus Ohio, in association with Dr Chris Stevenson.

Objective 3 is intended to be the first thorough-going application of OHD to a fundamental issue in New Zealand prehistory; colonisation and dispersal. It is designed to assess the age and occupational ranges of a statistically compelling number of archaeological sites along the East coast of both islands, from North Cape to the Bluff, which are known to contain moa bone, or bone of other extinct and extirpated species and/or early artefact forms and stone materials. Further, it will determine the direction and rate of population dispersal along that coastline. It will discriminate between the 5 alternative archaeological models of colonisation and dispersal which exist at present, see discussion above. A statistically robust number of samples will be dated from each site. Colleagues suggest a number in excess of 20 per site will be necessary, and may be significantly greater in some instances. A total of 40-50 settlements dated at more than 600 years BP exist (Anderson 1991; Anderson and McGlone 1993) and all of these will be included in the research, if possible.

Our intention is that approximately 1000-1400 obsidian artefacts will be dated for Objective 3 within the second and third years of the programme (1996-7 & 1997-8). This will substantially increase the scientific accuracy of dating the early settlements and make it possible to discriminate between the five current models of colonisation and dispersal and to present a well-attested account which may be one of the five or a substantially new model.

Method

This research comprises six consecutive steps. These are:

1. review the published archaeological literature to find and collate accounts of the maximum number of suitable previously excavated sites.

2. visit museum collections throughout New Zealand to establish which of these sites are well-represented in the curated collections and how specifically obsidian flakes from each of them can be associated with layers and features within the stratigraphy, dated structures, diagnostic artefacts and indicative faunal material, such as the bone of extinct bird species or extirpated marine mammals. This will involve museum staff and *kaumatua* from *iwi* of the regions being discussed.

3. select 20-50 obsidian flakes from each of the appropriate archaeological sites. The number dated per site will vary with both abundance of obsidian and site complexity, as an attempt will be made to sample vertical and horizontal stratigraphy, and to make OHD age determinations from each of the radiocarbon dated contexts.

4. measure the obsidian hydration rims non-destructively, using the method developed under Objective 1 above, where appropiate. Microscopic thin sections will be used to define hydration bands in precussion fissures (after Ambrose 1994) wherever surface attrition may have occurred.

5. calcuate OHD dates using hydration rates and temperature calibrations, defined on the basis of research described in Objectives 1 and 2, respectively.

6. Examine the fit of the OHD data to the models of colonisation and dispersal using the methods of regression, trend surface analysis and spatial autocorrelation.

Objective 4 is the first thorough-going application of OHD to a second fundamental issue in New Zealand prehistory: an intensive regional study of the developing pattern of pre-European Maori settlement and society as revealed in archaeological settlement patterns. Only the high-resolution dating capability of OHD brings this objective within practical reach.

It will establish a detailed chronology for sample areas of the Hauraki Gulf to examine settlement intensity from colonisation to 1840 and evaluate changing patterns of occupation of the Gulf islands in combination with a GIS study of land use. Specific hypotheses include the following:

1. The Gulf islands were settled by at least 600 years ago.

2. Archaeological evidence of settlement and subsistence reveal developing and systematic environmental and social relationships.

3. The earliest fortified pa may be 3-500 years old and a number of major episodes of fortification occurred more recently.

4. Pa and associated undefended sites reflect local ecological, demographic and

political factors.

5. In late pre-European times, intensifying intertribal relations are implicated in increasing political integration and regional defensive events.

Method

Over the past 5 years much of the background work of archaeological site survey and recording has been done, in consultation with *Tangata whenua*. The inner Hauraki Gulf islands are now the most thoroughly-investigated landscape of this kind in New Zealand. At the same time, an independent GIS survey is in progress and data will be in hand to assist interpretation of the OHD results.

Research method comprises six consecutive steps. These are:

1. Select 30 sites for high-resolution OHD investigation.

2. Conduct substantial test excavations and record stratigraphic information and precise site plans using an electronic alidade.

3. Select 10 obsidian flakes from each archaeological sites as appropriate.

4. Measure hydration rims non-destructively, by the method developed under Objective 1, above, where appropriate. Otherwise microscopic thin sections will be used to measure hydration bands in percussion fissures (after Ambrose 1994) where surface attrition may have occurred.

5. Calculate OHD dates using hydration rates and temperature calibrations, defined on the basis of research described in Objectives 1 and 2, respectively.

6. Examine the fit of the OHD data to the models of emerging patterns of ecological and social change in pre-European Maori history as inferred from settlement pattern study.

CONCLUSION

Obsidian hydration dating offers some possibility of refining the chronology of New Zealand's pre-European and early historic past. However, great care must be taken to avoid various pitfalls which have caused problems in other parts of the Pacific, and elsewhere. The thorough development of a protocol for sample collection and its careful use following a reconsideration of the physics of effective hydration temperature may be the single most important methodological innovation offered by the present research. Applications of OHD to the contested issue of colonisation and dispersal and to the Hauraki Gulf programme will be sufficiently thorough to establish the merit of the method in our most circumscribed sequence.

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Appendix 1: Outputs from the 1993-94 Obsidian Hydration Dating research comprise:

1. a data file of New Zealand Obsidian Hydration Dates, produced at the Centre for Archaeological Research, as of 1 August 1994;

2. a data file of Foreign Obsidian Hydration Dates, produced at the Centre for Archaeological Research, as of 1 August 1994;

3. 'Estimation of Hydration Rates from Obsidian Density Measurements' by Stevenson and Ambrose (For *American Antiquity*);

4. 'Advances in the Hydration Dating of New Zealand Obsidian' by Stevenson, Sheppard, Sutton and Ambrose. (In press, *Journal of Archaeological Science*);

5. 'Obsidian Sourcing by PIXE Analysis at AURA2' by Neve, Barker, Holroyd and Sheppard (In press *New Zealand Journal of Archaeology*);

6. 'Measuring Soil Temperatures for Obsidian Hydration Dating in Northern New Zealand' by Jones, Sutton, Jones and McLeod (In *Archaeology in New Zealand*).

7. Effective Hydration Temperature and Obsidian Hydration Dating. by Jones, Sheppard and Sutton. (submitted *Journal of Archaeological Science)*.

8. 'Exploitation of the Mayor Island Obsidian Source' by Neve, Barker, Sheppard and Sutton (In preparation, for *Geoarchaeology*).

9. 'Dating New Zealand Prehistory using Obsidian Hydration', by D.G. Sutton and P.J. Sheppard, (In *Archaeology In New Zealand*, September 1994,