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A Cost-Surface Analysis of the Exchange of Obsidian in Prehistoric New Zealand

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ABSTRACT

The movement of obsidian from chemically distinct sources within New Zealand provides an opportunity to trace exchange. This paper explores the possibility of using the GIS technique of cost-surface analysis to establish possible routes of obsidian exchange, as well as aiding in the identification of those sites that may have played a centralised role in exchange. The correspondence between the position of South Island sites and the generated paths suggests that these sites could have been located for ease of communication. Fall-off in obsidian along sequences of sites along least-cost paths suggests that down-the-line exchange was occurring during the middle period of this analysis. This research has shown that realistic modelling of ocean travel should be an immediate goal of future research to ensure that cost-surface analysis is utilised to its full potential in the Pacific context.

Keywords: COST-SURFACE ANALYSIS, EXCHANGE, GIS, OBSIDIAN, LEAST-COST PATHS, CENTRALISED SITES, NEW ZEALAND.

INTRODUCTION

A variety of evidence indicates that extensive communication and trade networks existed in prehistoric New Zealand. This is demonstrated through early historic and ethno-historic documents. For example, when Captain Cook made initial contact with the Māori people of Palliser Bay in Cook Strait he was asked for nails. However his previous contact with Māori had extended only as far south as Cape Kidnappers, 270 km north of Palliser Bay (Leach 1978: 301). Examinations of prehistoric sites in New Zealand have consistently revealed quantities of foreign raw materials in virtually every context. A recent study of the obsidian assemblage from the late prehistoric North Island site of Kohika suggests that caching of obsidian was occurring at the site (Holdaway 2004: 191). Such evidence suggests that some sites may have played an important or centralised role in exchange networks within pre-contact New Zealand.

A substantial amount of work has gone into sourcing foreign lithic material in archaeological contexts in New Zealand. This paper attempts to improve understanding of the exchange mechanisms operating within prehistoric New Zealand, which resulted in the transfer of this material. This is done using the GIS spatial technique of cost-surface analysis. This type of analysis allows factors such as topography or the presence of water-bodies, which would have affected the transfer of materials, to be accurately quantified and factored into the study. The source data to be analysed is the information from the obsidian assemblages sourced by Seelenfreund and Bollong (1989). There are two main goals behind

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these analyses: firstly to establish possible routes for obsidian distribution, and secondly to establish whether some sites played a centralised role in obsidian exchange. The results obtained in the cost-surface analysis are compared to the archaeological records of the analysed sites in order to consider whether or not they support such an interpretation.

STUDYING EXCHANGE IN ARCHAEOLOGY

Exchange is the transference of materials, information and services between groups and individuals (Braswell and Glascock 2002: 34). In an archaeological context, exchange has a dual status; it both acts as an indicator that cross-cultural contact was taking place and would have been a prime motive amongst prehistoric groups for such contact (Renfrew 1969: 151). A great deal of work has been conducted in archaeology over the past 40 years in considering such movement of goods and materials.

In order to describe exchange the archaeologist has three interrelated jobs. The first of these is to determine the geographic source of the supposed exchanged goods (Schwartz and Hollander 2006: 323). The development of a method to characterise the artefactual material meets only half of this requirement, as there is also a need to establish that there exists some qualitative or quantitative chemical or mineralogical difference between sources, which is distinct from differences within each source (Glascock 2002: 2). The second task is to describe the spatial patterning of the materials and is usually undertaken with regional point scatters, regression analysis and trend-surface analysis (Earle 1982: 5). The third task is to reconstruct the organisation of the exchange. This has also been undertaken with regression analysis to interpret the spatial patterning. This approach was pioneered by Renfrew and his associates (Renfrew *et al*. 1965, 1966, 1968) in their work on exchange in the Near East.

This led to the development of the law of monotonic decrement which states that when a material is only available at a highly localised source, its distribution frequently conforms to a general pattern, finds are abundant near the source and there is a fall-off with growing distance from the source (Renfrew 1977: 72). It was noted that this fall-off did not really take effect until 300 km from the source. The area inside this distance is called the supply zone and the area outside it is known as the contact zone (Torrence 1981: 51). The suggested explanation for this phenomenon was that in the supply zone people were willing and able to visit the sources themselves, whereas those in the contact zone obtained smaller quantities by exchange with trade partners in the supply zone. This law can act as a base-line from which to compare different exchange mechanisms (Torrence 1981: 54). Thus it is a useful starting point when considering exchange mechanisms.

THE STUDY OF EXCHANGE IN NEW ZEALAND

New Zealand has an extensive history of work on tracing exchange, though this has been concerned primarily with sourcing lithic materials rather than trying to identify possible mechanisms of exchange. Although most of this work has been concerned with obsidian, there has been a substantial amount done on other lithic material, including chert (Moore 1977) and nephrite (Beck 1981, 1984; Reed 1957; Ritchie 1976, 1984; White 1984). Obsidian is a useful medium for considering exchange because it can be chemically sourced, is common in archaeological sites and was of value to prehistoric peoples in most contexts.

An early interest in obsidian studies in New Zealand can be attributed to Green (1962, 1964), who suggested that variations in percentages of obsidians from different sources inter-regionally and through time could be interpreted as evidence for patterns of trade. He further suggested that the distribution of find spots of obsidian could help identify actual trade routes in less densely occupied portions of the country. In addition he called for the adequate sampling of obsidian sources. This resulted in the creation of large reference collections at both the Universities of Auckland and Otago (Sheppard 2004: 154). The collection at Auckland was established by Green and members of the New Zealand Archaeological Association with additional aid coming from the New Zealand public. The collection at Otago was primarily developed through the efforts of Ward and Leach. Archaeologists have now identified 27 geographically distinct sources of obsidian in New Zealand within the four distinct source regions of Northland, the Coromandel/Great Barrier/Hauraki group, Mayor Island and the Taupo volcanic zone (Sheppard 2004: 151). It now seems likely that most if not all of the archaeologically significant sources of obsidian in New Zealand have been discovered (Jones 2002: 131).

Methods for the sourcing of obsidian recovered from archaeological contexts can be divided into two types; physical and geochemical characterisation methods. The most notable example of the former are methods proposed by Moore for sourcing samples on readily observed physical characteristics. These were presented in a conference paper in 1987 and although it is unpublished (Moore n.d.), it is a widely distributed manuscript. Colour in transmitted and reflected light is Moore's key characteristic for a rapid sort of assemblages. Jones (2002) has also developed methods for the physical characterisation of obsidian. Like those suggested by Moore, Jones' primary splitting attribute is also colour in transmitted light, which he defined using RGB band intensities to discriminate green from all other colours. This enabled samples from Kaeo, Waihi and Mayor Island to be differentiated from all other source types (Jones 2002: 341).

A host of geochemical sourcing methods have also been tested. The use of such methods was initially promoted by Green, who conducted the earliest experiments with emission spectroscopy in New Zealand (Green *et al*. 1967). Ward (1972) experimented with wave length dispersive XRF and this allowed him to discriminate among his source regions with only some overlap. Various other chemical characterisation methods have been tried, including atomic absorption (Armitage *et al*. 1972), energy dispersive XRF (Bollong 1983; Leach 1977a, 1977b), PIXE-PIGME (Coote *et al*. 1972; Duerden *et al*. 1979, 1984) and neutron activation analysis (Leach 1996, Leach and Warren 1981).

Using the above methods, a considerable number of obsidian artefacts have been sourced over the years but there has been only one large-scale country-wide project (Seelenfreund and Bollong 1989). The majority of projects have focused on individual sites and hardly any research has been invested into defining exchange networks and systems. However, it should be noted that Seelenfreund-Hirsch (1985) conducted a comparative analysis on the Mayor Island components of a number of assemblages from both the North and South Islands, Anderson (2000) considered the distribution and implications of Mayor Island obsidian on outlying island groups in southern Polynesia and Moore (2005) recently looked at the cultural distribution of obsidian from the Waihi source.

Comparatively little work has been conducted on identifying mechanisms of exchange. A notable exception was a highly important paper by Leach (1978), who noted that both historical and ethno-historical records indicated that complex exchange and communication networks had existed in New Zealand. Leach suggested that trade and exchange could be regarded as agents of communication and that an effort should be made to describe the structure and channels of that communication in addition to the content which passes through it. In order to do this Leach further suggested the use of communication theory in studying exchange. He demonstrated his ideas by analysing the lithic component of the assemblage from Palliser Bay. He also noted that concepts of interaction and costs are most useful when considering exchange (Leach 1978: 399).

COST-SURFACE ANALYSIS AND ITS APPLICATION IN ARCHAEOLOGY

Cost-surface analysis is the generic name for a series of GIS techniques based on the ability to assign a cost to each cell in a raster map and to accumulate these costs by travelling over the map (Van Leusen 2002: 101). Cost-surface analysis developed out of earlier spatial allocation methods such as Thiessen polygons and Xtent modelling. Cost surface, unlike earlier methods, moved beyond the assumption of a homogeneous and featureless plain and allowed the assignment of weights to individual locations according to landscape variables (Kvamme 1999: 175).

There are a number of slightly different algorithms for developing cost surfaces in different GIS but they largely fall into two categories, namely isotropic algorithms and anisotropic algorithms. Isotropic algorithms take account of the cost of movement across a surface but take no account of the direction of movement (Wheatley and Gillings 2002: 151). To calculate an isotropic cost surface, the algorithm requires two inputs: a file which contains the cost of travel across each cell, called a friction surface, and a file containing the location of the features, called the seed locations. The majority of algorithms expect the friction surface to contain a proportional cost of crossing each cell relative to a nominal base cost of 1 (Wheatley and Gillings 2002: 152). For example, a location coded 0.5 would incur half the effort to cross as one coded with the base cost.

In an anisotropic algorithm, the direction of travel is considered to affect the cost of movement across the terrain. This method is important in cases such as slope when movement across a friction surface makes a difference to the cost incurred (Wheatley and Gillings 2002: 152). One suggested approach is to create inputs for both the magnitude of the friction and the direction in which the friction has its greatest effect.

Usually cost surface has been employed to model either the energy expended or the time taken in moving from one cell to another. The creation of the friction surface greatly influences the nature of cost-surface analysis and thus requires careful consideration (Wheatley and Gillings 2002: 154). Van Leusen (1999) has published an extensive review of the algorithms that can be used to derive friction values.

Differing cell sizes, different algorithms and the number of directional moves allowed all influence the outcome of a cost-surface analysis and are thus extremely important (Harris 2000: 121). Arguably the most important application of cost-surface analysis is the generation of least-cost paths. In least-cost paths the algorithm regards the cost surface as an elevation model whose lowest point (zero) is the target location (Wheatley and Gillings 2002: 157). In effect it simulates the effect of a drop of water being placed on each of the remaining cells and plots their passage to the target location.

There are three main areas where cost-surface analysis has been used in archaeological research; namely economic and political boundary definition, establishing possible colonisation routes, and considering the relationship between historically known paths and associated monumental features.

In the first major archaeological application of the methodology, Limp (1990) used cost-surface analysis to assess the agricultural potential, as reflected by soil conditions, that fell within the Rush site's territory. He noted that this differed significantly from the traditional site catchments he had constructed around the site earlier. Gaffney and Stancic (1996) conducted a similar analysis on the island of Hvar. First they constructed site catchments of 5 km around the Iron Age hill forts but saw that there was a large degree of overlap between these catchments. Thus they instead constructed catchments based on a cost surface and this eliminated the majority of the overlap. Gaffney and Stancic then pointed out that most of the productive soil fell within these catchments and suggested that there was a correlation between building hill forts and controlling the most productive land.

Hare (2004) utilised cost surface in estimating polity boundaries in the Post-Classic Yautepec Valley, Mexico. This was done by assigning territory to each polity centre with the smallest cost distance. During this analysis, cost surface was also used to modify the Xtent and interaction models (Hare 2004: 803).

Studies by both Anderson and Gillam (2000) and Glass *et a*l. (1999) attempted to identify and evaluate possible colonisation routes in the Americas using cost-surface analysis. The main problem with such analyses is that since a colonising population would not have known what lay ahead of them, the application is hampered by the requirements of having particular starting and ending points. A solution to this problem has recently been developed and put forward in Field and Lahr's (2006) attempt to identify a southern dispersal route out of Africa and eventually into Australia. This solution entailed placing 60 km search radiuses around a starting point in a cost surface. Following each calculation, the search radius was moved to the latest end point. Thus the route was the culmination of 60 km segments.

The most notable case of considering a historical known path with associated monuments is Bell and Lock's (2000) analysis of the prehistoric Ridgeway in Oxfordshire, England. A least-cost path was constructed on the local topography and it was found that it fitted the existing Ridgeway remarkably well, with interesting deviations occurring at the hill forts (Bell and Lock 2000:93). The authors interpreted this pattern with the suggestion that the Ridgeway originated before the hill forts were constructed.

Such studies have made a significant contribution to the use of cost-surface analysis in archaeology. The main contribution is of course that the topography has been realistically modelled for analyses. Additionally, they have demonstrated the value of cost-surface analysis in considering a diverse range of issues such as colonisation and boundaries between settlements. However, cost-surface analysis has not yet been used to deal with exchange routes, something it is hoped this study can rectify. Moreover, most studies have not had to deal with the possibility of extensive water-based travel. It is also a goal of this research to contribute to the accurate factoring of this form of travel into cost-surface analysis.

MODELLING

In order to answer specific 'how' and 'why' questions, archaeologists commonly build models (Kohler and van der Leeuw 2007: 1). These models may be informal and implicit but they still exist. For this study I have attempted to model possible obsidian exchange routes through transportation based on the environmental variables of the cost of crossing different slope types and waterways. This model, as will be seen later in the paper, has generated a number of possibilities for obsidian exchange that can be tested against the archaeological record, both in this paper and in future studies. These variables were chosen because they would have affected transportation costs throughout New Zealand prehistory and can be effectively modelled. However, these are not the only variables that could have affected the transportation, as social costs and indeed other environmental variables would have played an important role. Thus it is important to remember that the results produced by the model are dependent on the variables chosen for this study.

Unfortunately social costs cannot be factored into this model at this stage. Such social costs are likely to be fairly dynamic and to have changed throughout the New Zealand sequence. In addition, several studies have highlighted the existence of non-residential sodalities, such as hapū, in historic and contemporary Māori society (Marshall 2004: 82). These are difficult to identify in the archaeological record and would be almost impossible to model in this study.

DATASET

The sites that were analysed in this study were taken from Seelenfreund and Bollong's (1989) paper in which they sourced obsidian artefacts from 58 archaeological sites using X-ray fluorescence (XRF) spectroscopy. These sites had been dated directly by radiocarbon or indirectly through comparison of a site's diagnostic artefacts with those of other sites in the immediate area, which had been dated directly (Seelenfreund and Bollong 1989:170). The sites had been separated into three approximately contemporaneous groups in order to make comparisons on a local and regional basis. These groups were as follows: Group 1 (early period), older than 630 BP; Group 2 (middle period), 630 BP–350 BP; Group 3 (late period), younger than 350 BP. These groups were largely retained in the present study, although it is recognised that recent chronological revisions have challenged the dating of some of the sites.

The sites had been plotted on a map (Seelenfreund and Bollong 1989: 171). Upon examining the map it was noted that the South Island Group 2 site of Clarence had not been included and it was therefore excluded from the current study. It was decided to include the South Island site S20/2 Tahunanui near Nelson, which had been dated to between AD 1200 and 1300, in Group 1 as well as Group 2. The site of S131/6 near Lake Te Anau, dated to between AD 1600 and 1700, was added to Group 3, as this group contained only three South Island sites. The sites included in this study are shown in Figure 1.

Digital elevation maps for the North and South Islands of New Zealand at a scale of 1:50 000 were obtained from the Geography Department at the University of Auckland. It was decided to include a river layer in this analysis as the importance of water bodies as major arteries for transport and exchange is widely acknowledged in the New Zealand context (e.g., Irwin 2004: 239). The river data layer was obtained from ESRI world base map data available from the ESRI website.

METHODS

The DEM data was imported into ARCGIS 9; cell size was 25 km by 25 km. The majority of the following analyses were carried out with the spatial analyst tools in ARCGIS. The DEM data was reclassified into eight relative values based on elevation using the reclassify tool. The North Island and South Island layers were then combined into a single layer using the mosaic tool.

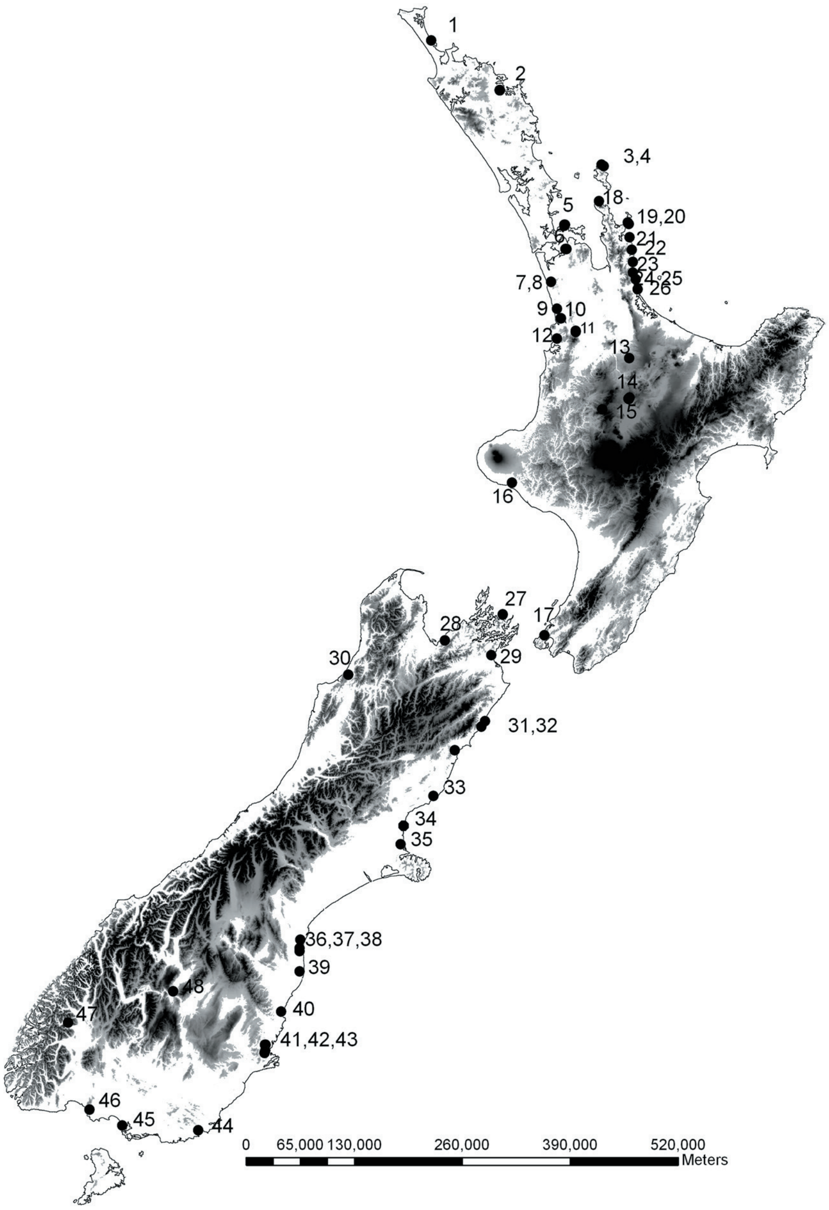

Figure 1: Location of sites in this study. 1: Houhora, 2: Pouerua undefended sites, 3: N30/3, 4: N30/4, 5: N38/30 & 37, 6: Elletts Mountain and Hamlins Hill, 7 and 8: Maioro, 9: Koreromaiwaho, 10: Raglan, 11: Mangakaware and Ngaroto, 12: Aotea, 13: Tokoroa, 14: Whakamoenga, 15: Waihora, 16: Hingaimotu, 17: Paremata, 18: Port Jackson, 19 & 20: Skippers Ridge sites, 21: Hahei, 22: Hot Water Beach, 23: Tairua, 24 & 25 Whangamata sites, 26: Kauri Point Swamp, 27: Titirangi, 28: Tahunanui, 29: Wairau Bar, 30: Heaphy River, 31: Avoca, 32: Peketa, 33: Timpendean, 34: Hohoupounamu., 35: Redcliffs, 36: Waitaki River, 37: Tai Rua, 38: Waimataitai, 39: Shag River Mouth, 40: Shag Point, 41: Long Beach, 42: Murdering Beach, 43: Purakanui, 44: Pounawea, 45: Tiwai Point, 46: Pahia, 47: Lake Te Anau, 48: Hawksburn.

The river layer was added to the map and reclassified to give the rivers a relative value of 1 while all other cells were coded 0. Another layer was then created in which the cells containing rivers were given a value of 0 and all other cells were given a value of 1. This second layer was multiplied with the reclassified DEM layer with the raster calculator, which effectively gave the cells containing river data a value of 0. This new layer was added to the initial reclassified river layer using the raster calculator. This ensured that cells containing rivers were assigned a value of 1 instead of a slope value.

Wheatley and Gillings (2002) have suggested a number of ways to map barriers, terrain and transportation routes into a cost surface. These include representing a river as a central corridor of very low friction, with a suitable value to represent quick low-energy transportation up and down the river, but then surrounding the river with a thin buffer of high cost to represent the cost of acquiring a means of transport (Wheatley and Gillings 2002: 157). However, in a New Zealand context where canoe transport would have been fairly common, this cost of acquiring transport would not apply and therefore has not been included in this analysis.

All cells with no data were then assigned a value of 1. This was done in order to code the ocean with a value of 1. Although assigning the ocean such a value may seem simplistic, it was assumed that regardless of the value it would interact realistically with the coastline, as the cost paths would probably use a low-lying area or a river to come inland.

The five source areas of obsidian, namely Coromandel, Northland, Inland, Mayor Island and Great Barrier Island, were plotted in from an estimation of their position from the map included in Seelenfreund and Bollong's (1989) article. This was done using the editor tool. Where more than one sub-source existed, the midpoint was chosen to plot the source. It was decided to include Fanal Island with Great Barrier Island because of their close proximity. The sites were then plotted in using the same method. The site of Lake Te Anau was plotted in based on an estimation of a map included in Clout (1996).

Cost-weighted distance was calculated using the cost dataset for each of the sources. This created both a direction and a distance output raster for each of the sources. Least-cost paths were then created using the shortest path tool from each of the sources to all the relevant sites for each time period. Since some of the obsidian could not be assigned to a single source, but only narrowed down to a few sources, least-cost paths were created for all those sources. A distinction was made between certain paths and possible paths by representing the former as solid black lines and the latter as dotted black lines. A second set of paths was created from each source to the relevant sites, but this time the ocean was assigned a value of 6 instead of 1.

Buffers of 20 km radiuses were then created around each of the sites using the buffer wizard. The buffers were used to determine which least-cost paths ran within 20 km of each site. Buffers of this size were chosen because economic boundaries of 10 km and 5 km have been suggested for sedentary farming groups and hunter-gatherer societies respectively (Gaffney and Stancic 1996: 48). Both kinds of society are represented by sites in this study. However the territory controlled by these groups would have been much larger, and doubling the economic boundary seems like a fair estimate.

RESULTS

The characteristics of the least-cost paths will now be presented. The paths are shown in Figures 2 to 7.

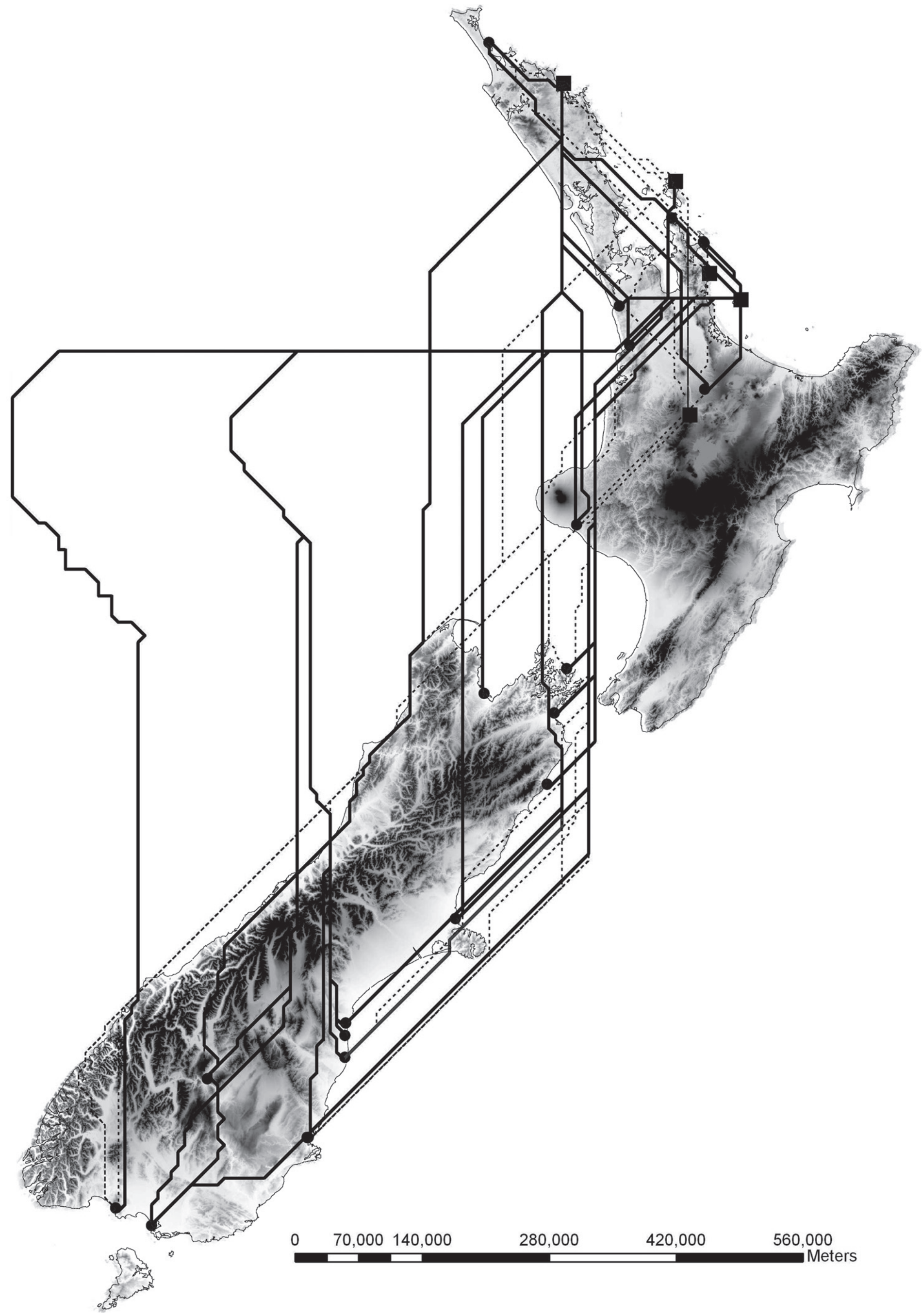

Figure 2: Map of Period 1 low cost marine travel.

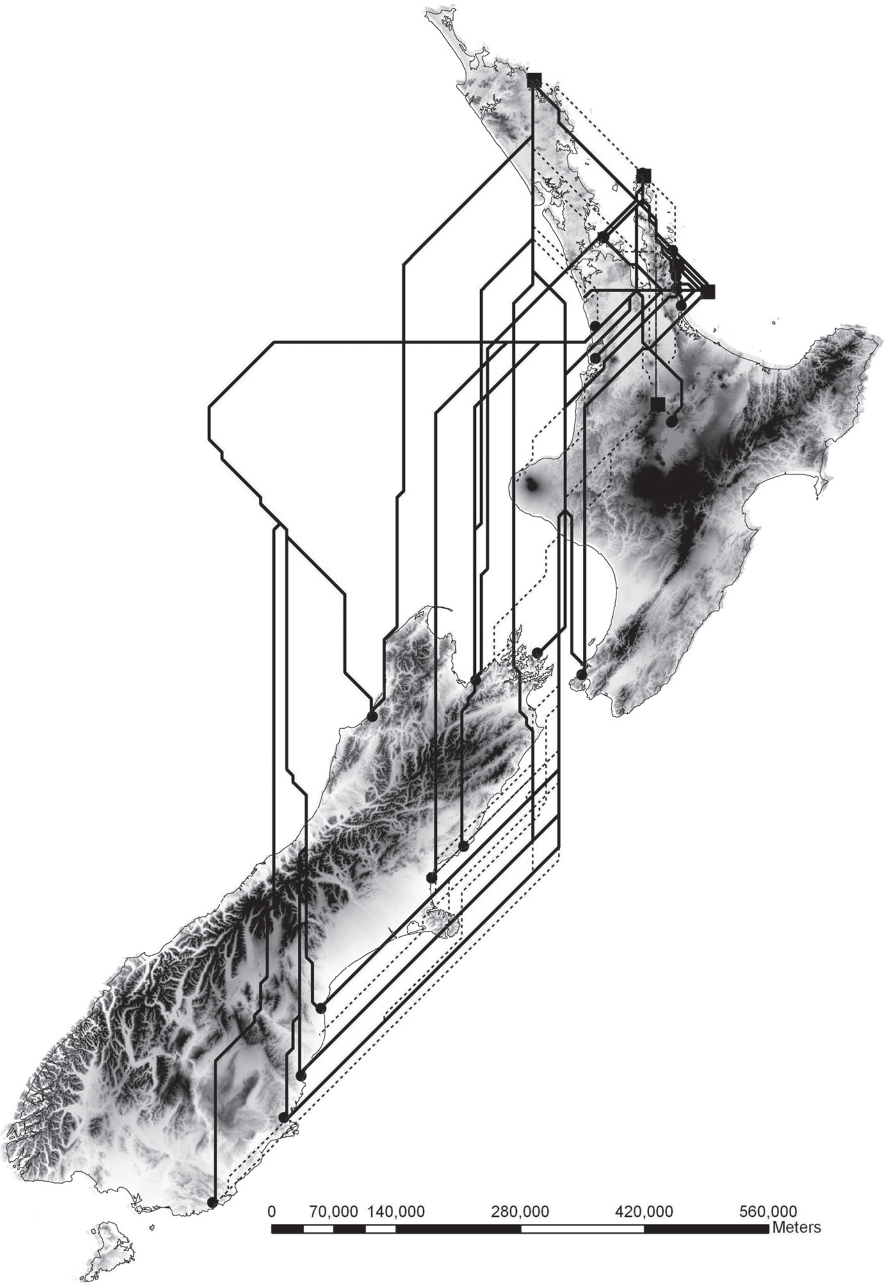

Figure 3: Map of Period 2 low cost marine travel.

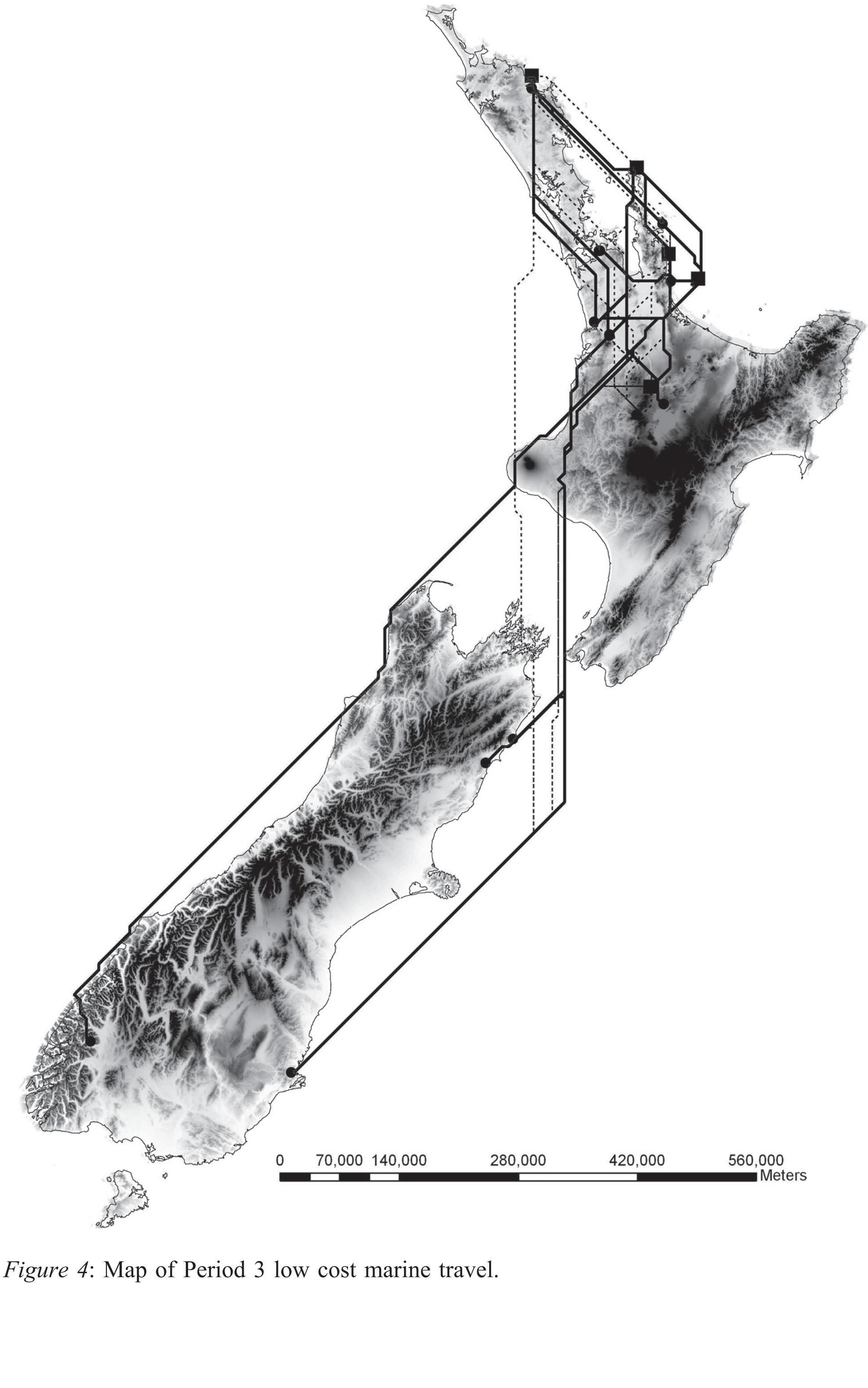

Figure 4: Map of Period 3 low cost marine travel.

Figure 5: Map of Period 1 high cost marine travel.

Figure 6: Map of Period 2 high cost marine travel.

Figure 7: Map of Period 3 high cost marine travel.

Period 1 low cost marine travel (Fig. 2)

For the North Island sites, the least-cost paths are almost exclusively land-based. The paths from Mayor Island and Great Barrier Island head inland almost immediately. The rivers are not utilised extensively. The only paths to make use of the Waikato River are those that go to the site of Tokoroa. For the South Island, there is a rather different situation. For the sites located on the east coast up to the Otago Peninsula, the paths from Great Barrier Island, Inland, Coromandel and Mayor Island travel from the east to west coast on the North Island and then head out to sea around Hingaimotu. They then travel around Cook Strait and stay out to sea before coming in to their respective sites. For the sites of Waitaki River, Long Beach and Waimataitai, the paths from Coromandel go 372.37 km out to sea on the west coast of the North Island, then travel down to the South Island and cross it to their respective sites. The cost path from the Coromandel to Tiwai Point travels along the west coast of the South Island and then uses the Clutha River to arrive at the site. The paths from the Coromandel and Mayor Island to Pahia travel 695.9 km out to sea from the North Island before travelling down to the bottom of the South Island and use the Waiau River to reach the site.

Period 2 low cost marine travel (Fig. 3)

For this period, the North Island paths are predominantly land-based with only paths to Whakamoenga utilising the Waikato River. The paths to the sites on the east coast of the South Island travel just west of Wanganui before going out to sea and around to the east coast of the South Island, although paths from the Northland source head out to sea well before this point. Paths to the Heaphy River site on the west coast of the South Island head to sea sooner and generally travel 372.37 km out to sea before travelling south to the site. The same applies to paths from the Coromandel to sites further south on the east coast, namely Pounawea, Purakanui and Shag Point.

Period 3 low cost marine travel (Fig. 4)

In period 3, the paths to the North Island sites are still land-based. To reach sites on the east coast of the South Island, the paths also travel a similar route as in the previous periods, but none travel across substantial portions of the South Island. To reach Lake Te Anau, the paths travel close to the coasts of the North and South Islands for the entire journey.

Period 1 high cost marine travel (Fig. 5)

The change in ocean values does not significantly affect the North Island sites' cost paths, which are again land-based. However, the paths to the South Island sites are significantly affected. The paths from all sources all arrive at the Inland source and travel down to where modern day Wellington is located and then cross the short stretch of water to the South Island. The paths then split between those going to sites on the west coast and those going to sites on the east coast. The paths on the east coast pass through the majority of the subsequent sites. The path to Hawksburn travels along the west coast before moving inland to the site.

Period 2 high cost marine travel (Fig. 6)

The period 2 paths are essentially similar to those of the earlier period. Of special interest is that all the paths heading to the South Island pass through the North Island site of Paremata. These paths also pass through most sites on the east coast of the South Island.

Period 3 high cost marine travel (Fig. 7)

The paths of period 3 are essentially similar to those of the previous two periods.

Summary

For the first group (low cost marine travel), assigning the ocean a value of 1 has greatly affected the paths from the sources to the South Island sites, as the paths look to utilise this low corridor of friction extensively and avoid as much land as possible to reach their destinations. Thus it appears that in this scenario, ease of travel was preferred to the overall distance covered. This is demonstrated by some paths going considerable distances out to sea. The same situation did not apply to the paths to the North Island sites, where sites were much closer to the sources.

In the second group (high cost marine travel), paths from the sources to the South Island sites use the flat coastal areas extensively. Because the ocean no longer has such a low value, ocean travel is no longer as advantageous. Travel to the North Island sites is essentially similar in both groups.

Tables 1 to 6 show how many sites the paths from each obsidian source travel through for each scenario and period. The paths have been divided into those going to North Island and South Island sites, as indicated by S and N in the tables.

Discussion

The results from the cost-surface analysis models indicate that regardless of whether ocean travel was easy or difficult, it did not play a major role in exchange systems in the North Island. However, this is not the case for the South Island, as changing the ocean value drastically affects the least-cost paths produced. It appears that if ocean travel was easy, the majority of South Island sites could have by-passed most other sites and obtained obsidian directly. However, there appear to be some problems with assigning the ocean such a low value. A number of paths head several hundred kilometres out to sea, which seems highly unrealistic. A host of factors, including currents and swells, would have affected ocean travel to varying degrees. These will need to be factored into future work. Thus in order for cost-surface analysis to be utilised to its full potential in a Pacific context, accurate ways of modelling ocean travel into a cost surface will need to be developed. Much more realistic results appear to have been obtained when the ocean was assigned a high value. Of special interest is the fact that the majority of South Island sites are located along the least-cost paths to most other sites; this was apparent even before the buffers were drawn. Thus it is possible that these sites were purposely located in areas conductive to communication with other sites.

TABLE 1
TOTAL LEAST-COST PATHS THROUGH SITES PERIOD 1
LOW COST MARINE TRAVEL

Sites	Mayor Island	Northland	Gt Barrier	Inland	Coromandel	Total
Raglan	10 (1N 9S)	0	8 (1N 7S)	1 (0N1S)	3 (0N 3S)	22 (2N 20S)
Port Jackson	1 (1N 0S)	2 (2N 0S)	11 (11N 0S)	1 (1N 0S)	1 (1N 0S)	16 (9N 7S)
Skippers Ridge L.2	2 (2N 0S)	0	0	1 (1N 0S)	1 (1N 0S)	4 (4N 0S)
Skippers Ridge L.3	2 (2N 0S)	0	0	1 (1N 0S)	1 (1N 0S)	4 (4N 0S)
Tokoroa	0	0	0	2 (2N 0S)	0	2 (2N 0S)
Maioro1	0	1 (1N 0S)	0	0	0	1 (1N 0S)
Hingaimotu	3 (0N 3S)	0	5 (0N 5S)	5 (0N 5S)	4 (0N 4S)	17 (0N 17S)
Wairau Bar	0	5 (0N 5S)	0	1 (0N 1S)	0	6(0N 6S)
Waimataitai	1 (0N 1S)	1 (1N 0S)	0	1 (0N 1S)	1 (0N 1S)	4 (0N 4S)
Waitaki River.	2 (0N 2S)	2 (0N 2S)	0	1 (0N 1S)	1 (0N 1S)	6 (0N 6S)
Redcliffs	0	2 (0N 2S)	0	1 (0N 1S)	1 (0N 1S)	4 (0N 4S)
Hawksburn	1 (0N 1S)	1 (0N 1S)	0	0	0	2 (0N 2S)
Long Beach L.4/misc.	0	0	1 (0N 1S)	0	0	1 (0N 1S)

TABLE 2
TOTAL LEAST-COST PATHS THROUGH SITES PERIOD 1
HIGH COST MARINE TRAVEL

Sites	Mayor Island	Northland	Great Barrier.	Inland	Coromandel	Total
Port Jackson	0	0	13 (N 9S)	0	0	13 (4N 9S)
Maioro 1	0	13 (3N 10S)	0	0	0	13 (3N 10S)
Raglan	0	11 (1N 10S)	0	0	0	11 (1N 10S)
Tokoroa	0	0	0	2 (2N 0S)	0	2 (2N 0S)
Skippers Ridge L. 2	1 (1N 0S)	0	2 (1N 1S)	1 (1N 0S)	1 (1N 0S)	5 (4N 1S)
Skippers Ridge L. 3	1 (1N 0S)	0	2 (1N 1S)	1 (1N 0S)	1 (1N 0S)	5 (4N 1S)
Wairau Bar	11 (0N 11S)	8 (0N 8S)	7 (0N 7S)	4 (0N 4S)	4 (0N 4S)	34 (0N 34S)
Tahunanui	1 (0N 1S)	1 (0N 1S)	1 (0N 1S)	1 (0N 1S)	1 (0N 1S)	5 (0N 5S)
Avoca	8 (0N 8S)	7 (0N 7S)	6 (0N 6S)	4 (0N 4S)	4 (0N 4S)	29 (0N29S)
Redcliffs	7 (0N 7S)	6 (0N 6S)	5 (0N 5S)	4 (0N 4S)	4 (0N 4S)	26 (0N 26S)
Waitaki River	6 (0N 6S)	6 (0N 6S)	5 (0N 5S)	4 (0N 4S)	4 (0N 4S)	25 (0N 25S)
Waimataitai	6 (0N 6S)	6 (0N 6S)	4 (0N 4S)	4 (0N 4S)	4 (0N 4S)	24 (0N 24S)
Long Beach L4/misc.	2 (0N 2S)	2 (0N 2S)	2 (0N 2S)	1 (0N 1S)	1 (0N 1S)	8 (0N 8S)
Shag River Mouth	4 (0N 4S)	4 (0N 4S)	4 (0N 4S)	3 (0N 3S)	3 (0N 3S)	18 (0N 18S)

FALL-OFF ANALYSIS

One of the goals of this research was to better understand the mechanisms operating in exchange in New Zealand. As mentioned earlier, fall-off analysis is a useful starting point for considering such mechanisms. The generated cost paths often ran through similar sequences of site buffers. Since a few combinations of sites reoccurred in many least-cost paths in all three periods, it was decided to test the fall-off of obsidian with increasing distance using both the number and overall mass of the obsidian pieces recovered at these sites. This was done in two ways. Firstly, the fall-off of all obsidian types along the generated paths was tested, starting with the first site in the sequence. Secondly, the fall-off of obsidian definitively attributed to Mayor Island by Seelenfreund and Bollong (1989) was tested. For Mayor Island, only number of pieces was included. The sequences used in this analysis are all for high cost marine travel.

The results produced in the fall-off analysis should be treated with caution, as the excavations varied greatly in scale and the same recovery techniques were not used on all sites. These factors may have created considerable bias. In the graphs, both a straight line and an exponential curve were used.

TABLE 3
TOTAL LEAST-COST PATHS THROUGH SITES PERIOD 2 LOW COST MARINE TRAVEL

Sites	**Mayor Island**	**Northland**	**Great Barrier**	**Inland**	**Coromandel**	**Total**
Whangamata.	15 (8N 7S)	0	0	0	7 (2N 5S)	22 (10N 12S)
Kauri Point Swamp.	2 (2N 0S)	0	0	0	1 (1N 0S)	3 (3N 0S)
Tairua	15 (7N 8S)	1 (1N 0S)	1 1N 0S)	1 (1N 0S)	7 (2N 5S)	25 (13N 12S)
Hot Water Beach	2 (2N 0S)	5 (5N 0S)	3 (3N 0S)	1 (1N 0S)	10 (5N 5S)	21 (16N 5S)
N30/3	0	0	17 (13N 4S)	0	0	17 (13N 4S)
Koreromaiwaho	7 (0N 7S)	0	4 (1N 3S)	0	0	11 (1N 10S)
Aotea	0	0	4 (1N 3S)	0	5 (1N 4S)	9 (2N 7S)
N38/30 & 37	0	2 (2N 0S)	1 (0N 1S)	0	0	3 (2N 1S)
Timpendean	0	1 (0N 1S)	1 (0N 1S)	2 (0N 2S)	2 (0N 2S)	6 (0N 6S)
Purakanui	0	0	0	1 (0N 1S)	1 (0N 1S)	2 (0N 2S)
Shag Point	1 (0N 1S)	0	0	0	0	1 (0N 1S)
Hohoupounamu	1 (0N 1S)	0	0	0	1 (0N 1S)	2 (0N 2S)
Tahunanui	1 (0N 1S)	0	0	0	0	1 (0N 1S)

TABLE 4
TOTAL LEAST-COST PATHS THROUGH SITES PERIOD 2
HIGH COST MARINE TRAVEL

Sites	**Mayor Island**	**Northland**	**Great Barrier**	**Inland**	**Coromandel**	**Total**
Kauri Point Swamp	13 (4N 9S)	0	0	0	0	13 (4N 9S)
Hot Water Beach	2 (2N 0S)	0	2 (2N 0S)	1 (1N 0S)	10 (4N 6S)	15 (9N 6S)
Tairua	3 (3N 0S)	0	2 (2N 0S)	2 (2N 0S)	8 (2N 6S)	15 (9N 6S)
Whangamata	8 (8N 0S)	2 (2N 0S)	1 (1N 0S)	2 (2N 0S)	8 (2N 6S)	21 (15N 6S)
N30/3	0	0	18 (13N 5S)	0	0	18 (13N 5S)
Hahei	1 (1N 0S)	0	3 (3N 0S)	0	1 (1N 0S)	5 (5N 0S)
Maioro 2	0	9 (3N 6S)	0	0	0	9 (3N 6S)
Koreromaiwaho	0	7 (1N 6S)	0	0	0	7 (1N 6S)
Aotea	0	7 (1N 6S)	0	0	0	7 (1N 6S)
Paremata	9 (0N 9S)	6 (0N 6S)	4 (0N 4S)	7 (0N 7S)	7 (0N 7S)	33 (0N 33S)
Tahunanui	1 (0N 1S)	1 (0N 1S)	0	0	0	2 (0N 2S)
Timpendean	5 (0N 5S)	4 (0N 4S)	3 (0N 3S)	5 (0N 5S)	5 (0N 5S)	22 (0N 22S)
Hohoupounamu.	4 (0N 4S)	3 (0N 3S)	3 (0N 3S)	4 (0N 4S)	4 (0N 4S)	18 (0N 18S)
Tai Rua	3 (0N 3S)	2 (0N 2S)	2 (0N 2S)	3 (0N 3S)	3 (0N 3S)	13 (0N 13S)
Shag Point	2 (0N 2S)	1 (0N 1S)	1 (0N 1S)	2 (0N 2S)	1 (0N 1S)	7 (0N 7S)
Purakanui	1 (0N 1S)	0	0	1 (0N 1S)	1 (0N 1S)	3 (0N 3S)

TABLE 5
TOTAL LEAST-COST PATHS THROUGH SITES PERIOD 3
LOW COST MARINE TRAVEL

Sites	**Mayor Island**	**Northland**	**Great Barrier**	**Inland**	**Coromandel**	**Total**
Whangamata A	2 (2N 0S)	0	0	0	8 (5N 3S)	10 (7N 3S)
Pouerua	0	13 (11N 2S)	0	0	0	13 (11N 2S)
N30/4	0	0	15 (13N 2S)	0	0	15 (13N 2S)
Elletts Mountain	0	4 (4N 0S)	0	0	0	4 (4N 0S)
Hamlins Hill	0	4 (4N 0S)	0	0	0	4 (4N 0S)
Skippers Ridge II	5 (5N 0S)	1 (1N 0S)	1 (1N 0S)	0	1 (1N 0S)	8 (8N 0S)
Mangakaware	1 (1N 0S)	2 (2N 0S)	5 (2N 3S)	1 (1N 0S)	0	9 (6N 3S)
Ngaroto	1 (1N 0S)	2 (2N 0S)	5 (2N 3S)	1 (1N 0S)	0	9 (6N 3S)
Whakamoenga 4	0	0	0	1 (1N 0S)	0	1 (1N 0S)
Murdering Beach.	1 (0N 1S)	1 (0N 1S)	1 (0N 1S)	0	1 (0N 1S)	4 (0N 4S)

TABLE 6
TOTAL LEAST-COST PATHS THROUGH SITES PERIOD 3
HIGH COST MARINE TRAVEL

Sites	**Mayor Island**	**Northland**	**Great Barrier**	**Inland**	**Coromandel**	**Total**
Whangamata A	9 (8N 1S)	0	0	1 (1N 0S)	8 (6N 2S)	18 (15N 3S)
Pouerua	0	14 (11N 3S)	0	0	0	14 (11N 3S)
N30/4	0	0	18 (14N 4S)	0	0	18 (14N4S)
Skippers Ridge II	1 (1N 0S)	1 (1N 0S)	0	0	0	2 (2N 0S)
Elletts Mountain	4 (4N 0S)	11 (8N 3S)	0	1 (1N 0S)	1 (1N 0S)	17 (14N 3S)
Hamlins Hill	4 (4N 0S)	11 (8N 3S)	0	1 (1N 0S)	1 (1N 0S)	17 (14N 3S)
Raglan	0	6 (3N 3S)	0	0	0	6 (3N 3S)
Mangakaware	1 (1N 0S)	2 (2N 0S)	0	1 (1N 0S)	0	4 (4N 0S)
Murdering Beach	1 (1N 0S)	0	2 (0N 2S)	2 (0N 2S)	2 (0N 2S)	7 (0N 7S)
Peketa	0	0	1 (0N 1S)	1 (0N 1S)	1 (0N 1S)	3 (0N 3S)
Waihora	0	0	0	3 (0N 3)	1 (0N 1S)	4 (0N 4S)

Period 1 sequence 1 (Fig. 8): Wairau Bar (11 pieces, 48 g); Avoca (20 pieces, 20 g); Redcliffs (99 pieces, 534 g); Waitaki River (25 pieces, 270 g); Waimataitai (2 pieces, 0.4 g); Shag River (35 pieces, 233 g). As can be seen from Figures 8A and 8B, the fall off curves are not descending in a straight line, which indicates that down-the-line exchange was not taking place. The site of Redcliffs is well above the curve in both graphs, which may indicate that it acted as a centralised site for the distribution of obsidian. The same occurs in Figure 8C, when only Mayor Island obsidian is considered.

Period 1 sequence 2 (Fig. 9): Maioro 1 (795 pieces, 604 g); Raglan (15 pieces, 67 g); Wairau Bar (11 pieces, 48 g); Avoca (20 pieces, 20 g). The sequence is rather different from the first. When considering both number of pieces and mass, a straight fall-off curve is produced, suggesting that down-the-line exchange was occurring. A similar result is produced by the Mayor Island graph.

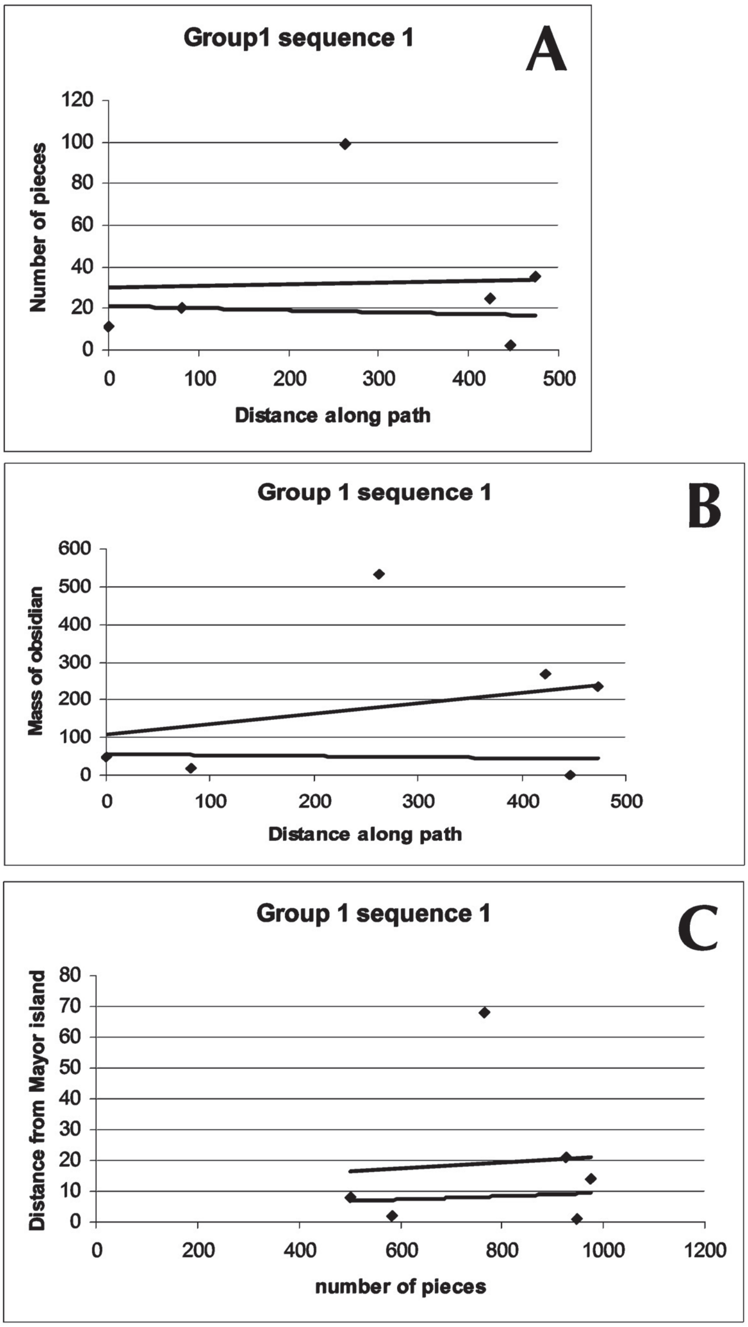

Figure 8: Group 1 sequence 1 fall off of obsidian. A: by number of pieces, B: by mass, C: Mayor Island obsidian by number.

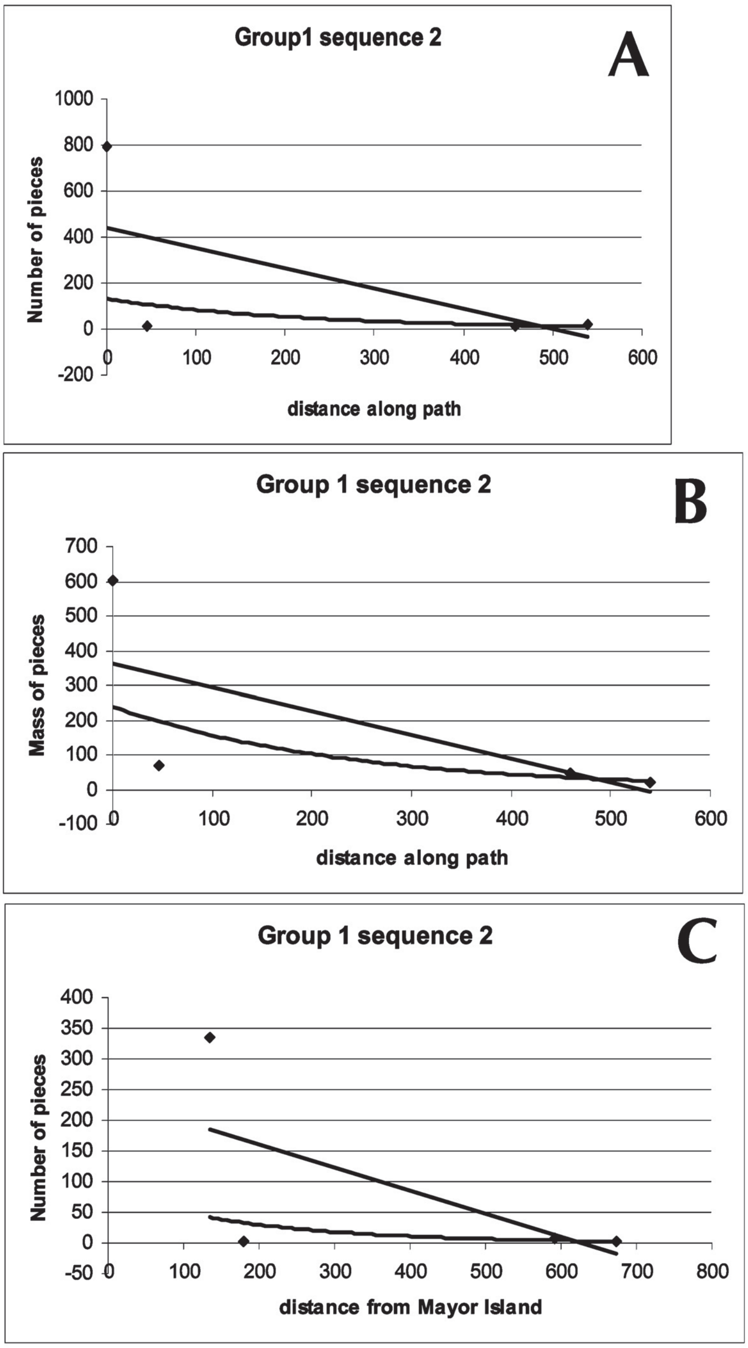

Figure 9: Group 1 Sequence 2 fall off of obsidian. A: by number of pieces, B: by mass, C: Mayor Island obsidian by number of pieces.

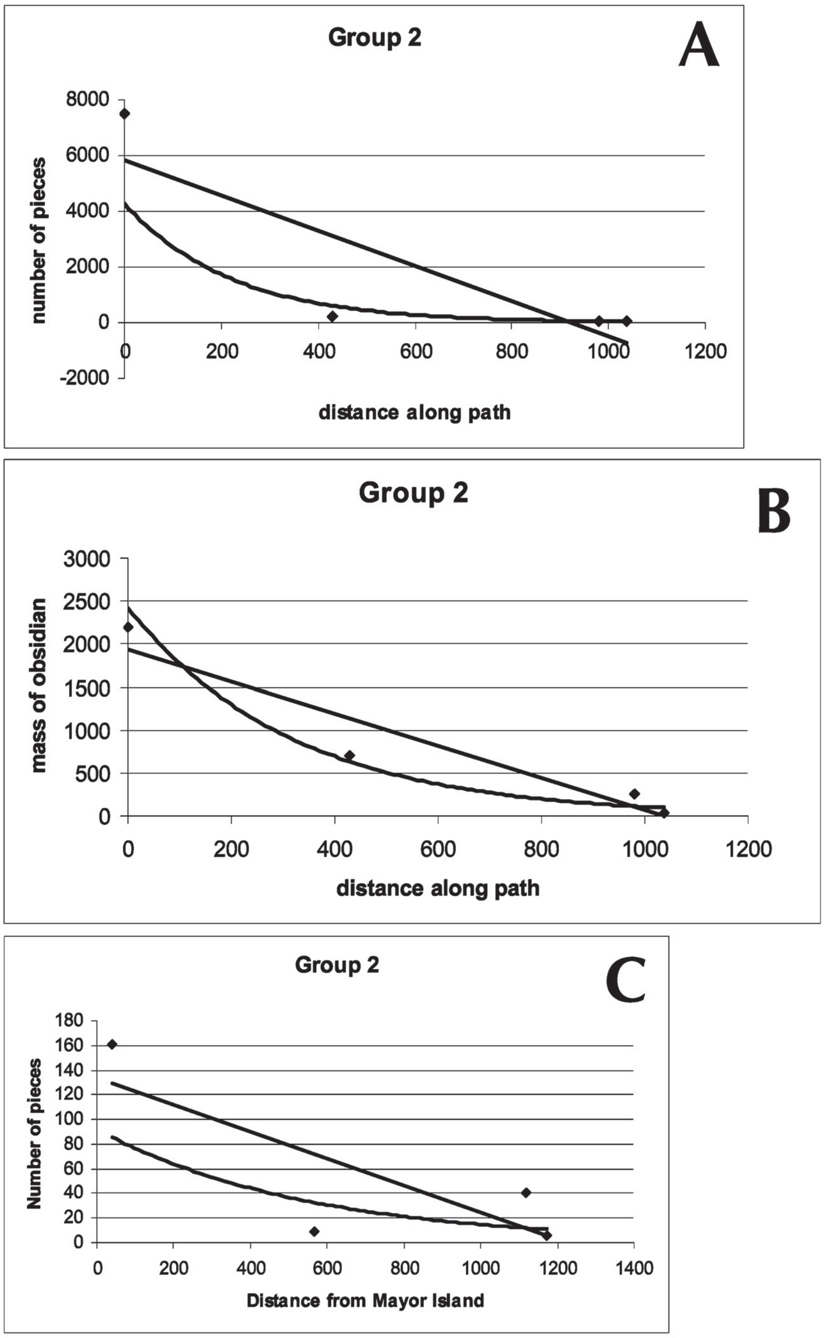

Figure 10: Group 2 fall off of obsidian. A: by number of pieces, B: by mass, C: Mayor Island obsidian by number of pieces.

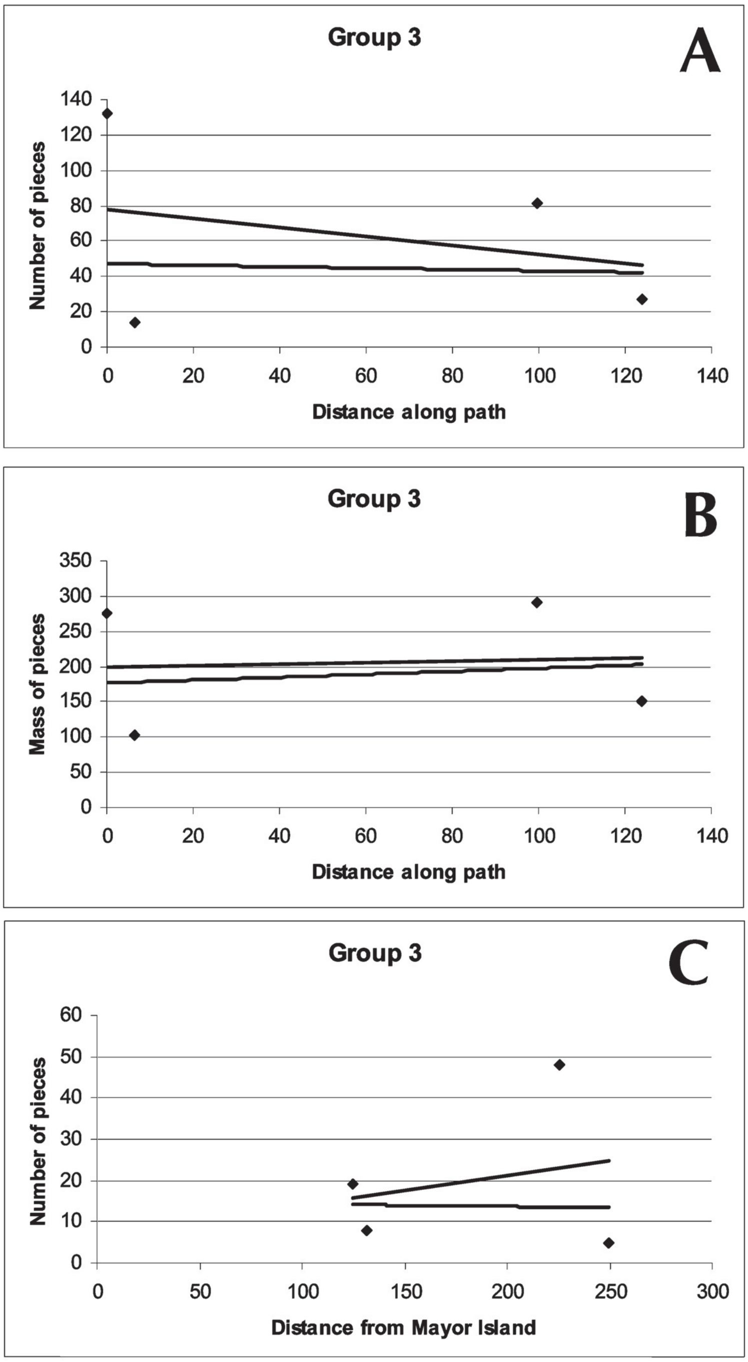

Figure 11: Group 3 fall off of obsidian. A: by number of pieces, B: by mass, C: Mayor Island obsidian by number of pieces.

Group 2 sequence 1 (Fig. 10): Kauri Point swamp (7,500 pieces, 2,187 g), Paremata (226 pieces, 700 g); Shag Point (78 pieces, 260 g); Purakanui (38 pieces, 41 g). This sequence also produces a direct fall-off when considering raw count, mass and only Mayor Island obsidian.

Group 3 sequence 1 (Fig. 11): Elletts Mountain (132 pieces, 275 g); Hamlins Hill (14 pieces, 103 g); Raglan (81 pieces, 292 g); Ngaroto (27 pieces, 152 g). This sequence does not produce a direct fall-off. However, Elletts Mountain and Hamlins Hill are situated in very close proximity to each other and so if the two are combined or Hamlins Hill is ignored, there is a direct fall-off, although this is less straight forward when considering mass. These graphs also suggest that Raglan may have acted as a centralised site. When only the Mayor Island pieces are considered, no direct fall-off is indicated, although this graph also suggests that Raglan may have acted as a centralised site or redistributive centre.

These results suggest that there may have been a number of different mechanisms of exchange operating at the same time across different regions and from different source types. It appears that down-the-line exchange was operating during the middle period but the situation is less clear for the other two periods.

CENTRALISED SITES

Several sites from each of the three periods had a number of least-cost paths running through them or through their buffers. This may suggest that these sites played a centralised role in exchange. The archaeological records of these sites were considered to assess whether or not they support this suggestion. The factors that were considered relevant were as follows. 1: the amount of obsidian, as it would be expected that if large amounts of obsidian were passing through a site there would be substantial amounts on site. 2: the presence of other imported lithic materials, if exchange was moving in both directions. However, it should be noted that perishable items could have filled this role and would not have been recovered archaeologically. 3. Site type and, more specifically, if a site was defended. A number of Māori oral traditions mention battles for control of greenstone sources (Brailsford 1996: 31). Thus it could be expected that in order to maintain control of a source or route of an important stone material, defensive structures may have been necessary. This information, as well as the numbers of paths passing through the sites, is presented in Table 7.

It can be seen that the archaeological records do offer a degree of support to the notion that these sites acted as centralised sites, although none of them meet all three criteria. It is noteworthy that Redcliffs has 99 pieces of obsidian (which is very large compared to other South Island sites), as it is one of the two sites which the fall-off analysis identified as possible redistributive centres.

TABLE 7
CHARACTERISTICS OF POSSIBLE CENTRALISED SITES

NB: Other Lithics = Other foreign lithic materials. Low Cost Paths = No. of paths with low marine transport costs. High Cost Paths = No. of paths with high marine transport costs.

Site Name	Raglan
Site type	Defended settlement
Obsidian N	16
Other lithics	Unknown
Low Cost Paths	22
High Cost Paths	13 (all from Great Barrier Island)
Notes	Very large numbers of obsidian chips had been found in sites around the Raglan area (Hunt 1962)
Site Name	Port Jackson
Site type	Open settlement
Obsidian N	15
Other lithics	Unknown
Low Cost Paths	16
High Cost Paths	13 (all from Great Barrier Island)
Notes	Diamond (1962) noted the presence of many pits and terraces on steep ridges which were well adapted to defence
Site Name	Hingaimotu
Site type	Open settlement
Obsidian N	99
Other lithics	Unknown
Low Cost Paths	17
High Cost Paths	0
Site Name	Avoca
Site type	Open settlement
Obsidian N	20
Other lithics	Unknown
Low Cost Paths	0
High Cost Paths	29
Site Name	Whangamata
Site type	Open settlement
Obsidian N	82
Other lithics	Unknown
Low Cost Paths	22
High Cost Paths	21
Site Name	Pouerua
Site type	Open settlements
Obsidian N	231
Other lithics	Adzes of greenstone found in the vicinity (Leahy and Nevin 1993: 53)
Low Cost Paths	13
High Cost Paths	14
Notes	Four known obsidian sources within 40 km of Pourerua (Brassey and Seelenfreund 1984: 39

Table 7 continued

Site Name	Maioro 1
Site type	Open settlement
Obsidian N	795
Other lithics	Unknown
Low Cost Paths	1
High Cost Paths	13
Notes	Fox and Green (1982) noted the presence of an obsidian working floor that indicated the presence of a craftsman and the settlement was placed in a strong defensive position
Site Name	Redcliffs
Site type	Open settlement
Obsidian N	99
Other lithics	Argillite from Nelson-Marlborough and orthoquartzite from South Canterbury or Otago (Trotter 1975: 199)
Low Cost Paths	0
High Cost Paths	26
Site Name	Hot Water Beach
Site type	Open settlement
Obsidian N	1182
Other lithics	Contains a considerable amount of Tahanga basalt (Leahy 1974)
Low Cost Paths	21
High Cost Paths	15
Notes	Percentage of Coromandel obsidian increases in the site over time (Leahy 1974)

CONCLUSION

Results of a cost-surface analysis provide archaeologists with the opportunity to determine how the natural features of the landscape would have affected exchange. The routes of the paths generated from the obsidian sources to the South Island sites differed considerably according to whether ocean travel was assigned a low or high cost. This is in part due to an inability to factor in such travel realistically. Rectifying this problem should be an immediate goal of future research. Until it has been rectified, the full potential of cost-surface analysis in a Pacific context cannot be realised. Despite this setback, this analysis has generated a considerable amount of useful information from which tentative conclusions can be drawn.

The correspondence of South Island sites with the generated least-cost paths appears to indicate that their placement was in part due to maintaining communication links with other sites. The results of fall-off analysis of sequences of sites generated through the least-cost paths indicate that down-the-line exchange was taking place in the middle period. However, the situation appears to be more complex for the other two periods, and more than one mechanism of distribution could have been taking place. The archaeological evidence does provide some support for the notion that sites with a number of paths running through them may have acted as centralised sites. The most noteworthy of these is Redcliffs.

It is hoped that this paper has effectively demonstrated the usefulness of GIS techniques for considering exchange mechanisms in New Zealand, although much work remains to be done. It would be interesting to use the same techniques to consider the exchange of other lithic materials, such as chert and pounamu. When Roger Green initiated the study of obsidian in New Zealand, he believed that it had the potential to allow patterns of trade and exchange to be inferred. It now appears that GIS spatial techniques can go a long way towards fully realising this potential.

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