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– ARTICLE –

Quantification of Stone Artefact Assemblages in Aotearoa New Zealand

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ABSTRACT

Many of the popular models of pre-European Māori settlement rely on the quantification of stone artefact abundance when made from different raw materials. Relative proportions of these materials provide the basis for inferences about mobility, trade and exchange, and social interactions. However, a number of methods for calculating artefact abundance exist with these reflecting different aspects of artefact completeness, fragmentation, and artefact assemblage formation. Using examples of artefact assemblages made from basalt, chert, and obsidian, from two sites in Te Ika-a-Māui, Aotearoa (North Island, New Zealand), different methods of calculating raw material proportions are explored including those based on frequency, size, and the technology of flake production. Measures of stone artefact assemblage completeness are then considered using artefact size distributions and comparisons with the Weibull and fractal power law distributions. We emphasise the differing goals of abundance measure calculations and the assumptions their uses entail.

Keywords: stone artefacts, assemblage analysis, quantitative archaeology, Aotearoa New Zealand

INTRODUCTION

Flaked and ground stone artefacts are the most common material culture items found in archaeological sites in Aotearoa. Locations with abundant stone artefacts made from different raw materials are argued to indicate prolonged occupation and vice versa, and the presence and abundance of different artefact types are assumed to indicate site function (Anderson & Smith 1996; Furey 2002). Equally, the relative proportions of different raw materials are thought to represent variability in access to sources, occupation duration, and mobility, and are related to changes in economising strategies over time (*e.g.* McCoy & Carpenter, 2014, Walter *et al.* 2010). Such variance in turn allows inferences about other facets of social organisation and interaction (*e.g.* Ladefoged *et al.* 2019). Yet despite the centrality of arguments about abundance of artefacts and therefore relative proportions of raw material use, considerations of how to quantify this abundance, particularly for stone artefacts, are rare in archaeological reports and publications. If current understandings of what constitutes an abundant or varied stone artefact assemblage are not based on quantitative criteria then the certainty of inferences concerning occupation duration and social interaction based on these measures should be called into question.

In its simplest form, abundance refers to the number of objects aggregated together in some manner however comparing abundances as frequencies treats each object, and indeed the units of aggregation as equivalent. With stone artefacts this raises issues since different forms will vary in abundance as a result of some combination of manufacture, use, and breakage. The nature and extent of the unit used to group artefacts together as assemblages will also have an impact on the results of relative abundance calculations. For example, archaeologists often distinguish stone artefacts as flakes, cores, and tools, assuming that when found together, the assemblage reflects the act of core reduction and tool production. However, flaking a raw material nodule may produce many flakes but only one (or at least a small number) of cores. Subsequently, one, or a small number of flakes may be retouched into tools, and of course in adze flaking, the core may itself become the finished tool. Quantification therefore may require an understanding of aspects of stone artefact technology but it also may involve considering aspects of mobility since some combination of the raw materials, the products of flaking, and the tools produced may be moved to any number of locations. Abundance calculations are therefore potentially influenced by a number of processes and these need to be considered when using different measures and when interpreting the results.

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STONE ARTEFACT ANALYSIS IN AOTEAROA

Unfortunately assessing the impact of these processes on Aotearoa stone artefact assemblages is made difficult since technological studies are few and far between, with those that consider the issues surrounding the quantification of abundance rarer still. This partly relates to the history of stone artefact studies in Aotearoa. For example, after the initial work of von Haast and Best (1912), early 20th century literature focused on documenting the forms of tools found, creating typologies, and proposing functional classification (Knapp 1924, 1928, 1941) together with only limited consideration of the methods of manufacture (McCully 1941). McCully commented on connections between raw material use and tool type and the general expediency of some flaked stone technologies. However, this initial interest quickly declined except for adze typologies (most recently the Shipton *et al.* 2016 assessment of the Duff (1977) typology) with focus instead shifting to the sourcing of raw materials. Studies on the technology of stone artefact manufacture in the latter half of the 20th century were intermittent and include B.F. Leach (1969), Jones' (1984) morphological analysis of flake assemblages, and Leach and Leach's (1980) study of reduction. Kooyman (1985) studied usewear from various sites, and other edge-use papers appeared intermittently (Leach 1979, Frederickson & Sewell 1991, Walter *et al.* 2010). Turner and Bonica's (1994) work studied the relationship between flake size and reduction stage based on cortex and dorsal scarring using results to infer aspects of mobility. Holdaway's (2004) detailed study of the obsidian assemblage from Kohika presented a method for investigating intensity of lithic reduction and tool retouch and Phillipps *et al.* (2016) followed Holdaway's (2004) method examining core reduction, tool use, and discard combined with detailed raw material sourcing to investigate mobility. More recently Jorgensen (2018) considered multiple aspects of stone artefact technology, including potential markers of reuse.

The advent of geochemical sourcing of materials such as obsidian has provided an additional avenue of inquiry. These studies initially focused on understanding the diversity of obsidian sources and methods for effectively ascribing geological source location. Once such methods were established, with most practitioners using portable x-ray fluorescence and comparison with reference samples to establish source (McAlister 2019; Sheppard *et al.* 2011), research focused on the implications of sourcing raw materials. Linked to developments elsewhere, data were related to the movement of materials in the past, and in Aotearoa focused on procurement, communication networks, trade and exchange, and resource pressure, seeking to document change in these over time (Leach 1978; Seelenfreund-Hirsch 1985, Sheppard 2004, Sheppard *et al.* 2011; McAlister 2019, McCoy & Carpenter 2014, Walter *et al.* 2010, Ladefoged *et al.* 2019). While these advances were extremely useful, as noted above comparatively less time was invested in understanding technological aspects of procurement, use, and discard of obsidian. This included considerations of how best to quantify relative proportions of stone materials. As a result, aside from the studies noted above, most often stone artefacts appear in publications as counts and/or weights, and are compared as relative proportions using these quantities. In some cases, assemblages are broken down into flakes, cores, and tool types, however, the only publication to report fragmentation within an Aotearoa assemblage to our knowledge is Holdaway (2004). There is partial recording of fragmentation in Smith *et al.* (1996) for Shag River Mouth assemblages, but it is not consistent between flake forms. There are also no explicit discussions around issues of stone artefact quantification in Aotearoa and therefore no standards or consistency in reporting. We acknowledge some reporting of quantification issues and artefact fragmentation may exist in graduate student work, including that of our own students (*e.g.* Gaylard 2018; Young 2019; McBride 2019; Middleton 2021). But as discussed below, given that much weight is placed on the ability to quantify abundance or material assigned to a specific geological source, the lack of consideration of issues of quantification is surprising and potentially problematic. Therefore in this paper we consider different ways of quantifying stone artefact abundance and the relationship of these measures to stone artefact manufacture and assemblage definition as a way of encouraging greater attention to stone artefact classification and assemblage characterisation.

STONE ARTEFACT QUANTIFICATION

Does the lack of discussion of quantification of stone artefacts pose a problem for Aotearoa archaeology? Figure 1 helps answer this question by providing an example of some of the issues that arise using different abundance measures from two sites; Te Mataku and Tauroa Point (Figure 2). Both assemblages consist of stone artefacts manufactured from obsidian, chert, and basalt. The assemblage from Te Mataku (T10/358) was collected over a series of field work periods from 2013 to 2015 (Furey *et al.* 2017; Phillipps *et al.* 2014). In addition to stone artefacts, Te Mataku contains remains of fish, shellfish, bird, moa, and mammals including dog and marine mammals (Furey *et al.* 2017, Phillipps *et al.* 2014). A series of features were also excavated and include a series of pits containing faunal material, fire features containing fire cracked rocks, and postholes. Radiocarbon determination results suggests occupation prior to the 16th century.

The Tauroa Point assemblage derives from site N05/302, excavated in 1992, with further test pitting and systematic collection of eroding surface materials in 2003 (Allen 2006a, 2006b). The excavation uncovered a number of large and small fire features, post holes, pits, stone artefacts, and faunal remains. This early occupation, dated to late 14th century CE by radiocarbon, is interpreted to relate to a variety of activities, including gathering of marine resources, food processing, production of fishhooks, and stone flaking. Processing and consumption of seal, bird, and a small whale took place, while remains of domesticated dog suggested its use as a food as well (Allen 2006b). Tauroa Point is interpreted as a temporary occupation for procuring these resources.

Both sites would be (and have been) interpreted as shorter term occupation procurement camps within a traditional logistical model of settlement, often described as part of settlement models more generally in Aotearoa. We do not describe these in detail here, but have recently discussed them elsewhere in publication (Phillipps *et al.* 2022). We briefly return to this interpretation in the discussion.

Identification of artefacts followed the method outlined in Holdaway (2004) and Phillipps *et al.* (2016). Flaked stone artefact classes were drawn from definitions provided in Holdaway and Stern (2004). Complete and broken tools include flaked and ground stone tools (*e.g.* scrapers, adzes). Measurement procedures outlined in Holdaway and Stern (2004) were used in the analyses which follow and the R script for the generation of data presented in graphs and tables is included as supplementary data.

One of the simplest methods for stone artefact quantification is to count the number of objects present, providing an artefact frequency (Number of Archaeological Specimens, NAS, Table 1). However, what classes of artefact are to be counted? Because of the nature of conchoidal fracture, striking a flake from a core will produce many small fragments sometimes referred to in stone artefact studies as shatter in addition to one or more larger flakes. Are all these fragments included in the frequency determinations? Answering this question involves posing others, for example, were all the fragments in different size classes collected? This involves consideration of the consistency of such things as screen sizes, a topic much discussed in faunal analysis (*e.g.* Allen 2014) but less often for stone artefacts. For Table 1, NAS frequencies report artefacts with a maximum dimension of 20 mm or above, a size related to potential for small stone artefacts to be moved by water flow (Fanning & Holdaway 2001).

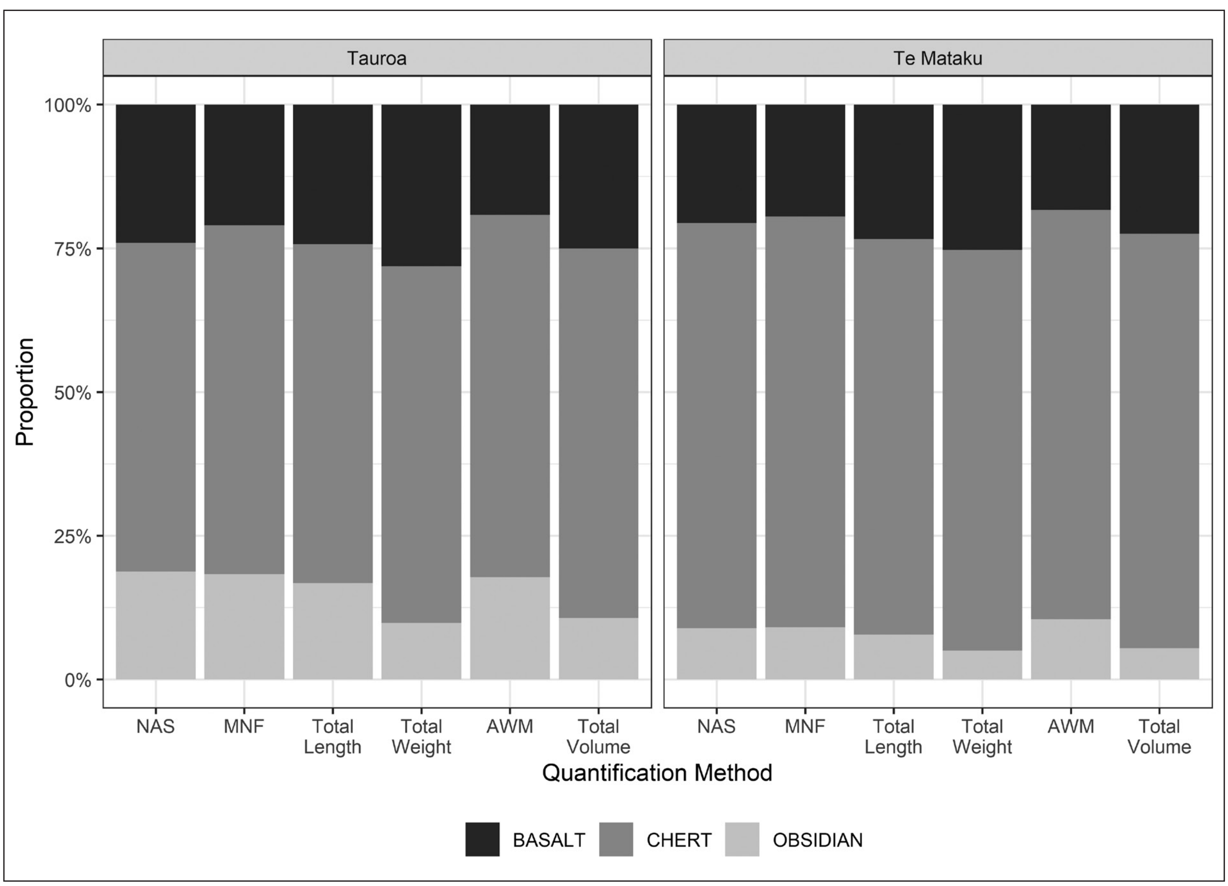

Figure 1. Cumulative stone artefact proportions manufactured from basalt, chert, and obsidian from Te Mataku and Tauroa Point calculated by summing the number of artefacts (Number of Archaeological Specimens, NAS), minimum number of flakes (MNF), total artefact maximum length (mm), total artefact mass (g), MNF by average weight (average weighted method, AWM, Jayez and Nasab 2016), and total artefact volume (cm³). Details of each method are provided in the text.

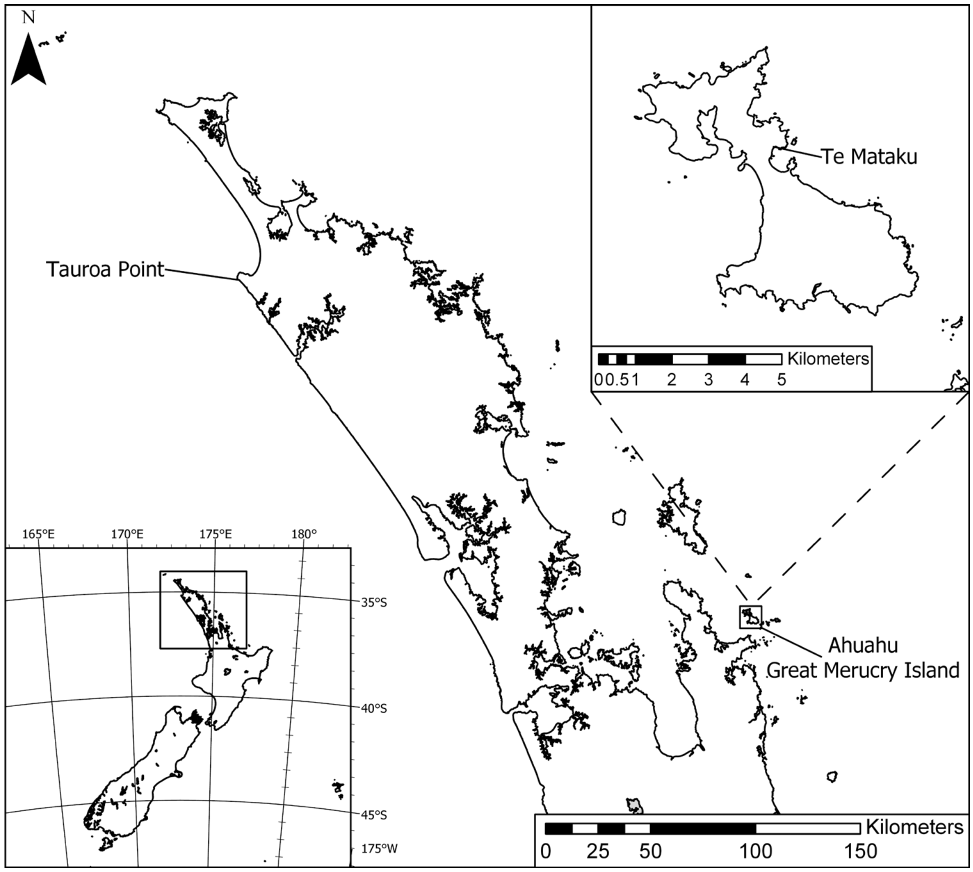

Figure 2. Location of the two sites from which stone artefacts are derived.

Table 1. *Abundance measures for Tauroa and Te Mataku stone artefact assemblages. See text for details of how these are calculated.*

Material	NAS	MNF	Total Length (mm)	Total Weight (g)	AWM	Total Volume (cm^3)
Tauroa						
Basalt	156	87.5	4631	1116.39	98	384.96
Chert	371	253.0	11,249	2460.79	322	988.27
Obsidian	122	76.5	3195	391.05	91	164.31
Total	**649**	**417.0**	**19,075**	**3968.23**	**511**	**1537.54**
Te Mataku						
Basalt	508	357.0	15,979	5316.70	428	1833.35
Chert	1737	1311.0	47,149	14,660.20	1662	5887.63
Obsidian	219	166.5	5349	1053.60	244	442.69
Total	**2464**	**1834.5**	**68,477**	**21,030.50**	**2334**	**8163.66**

NAS provides frequency but is agnostic about artefact size, other than the 20 mm size cut off used in the current study. Large artefacts have the same value as smaller artefacts. If artefact size is considered important, an alternative is to consider artefact mass rather than artefact frequency since this obviously includes artefact size. Following this approach, Figure 1 shows a difference in proportion calculated by summing the mass of artefacts formed from different materials compared to the proportions determined by calculating artefact frequency. This difference suggests that basalt artefacts are larger, and therefore heavier, than chert or obsidian artefacts, possibly related to the size of the cobbles from which flakes were struck. However, some of this difference also relates to material density. In Aotearoa, prior experiments on the density of obsidian indicate a range of values within and between sources ranging from

2.32 to 2.42 g/cm³ (Armitage 1971; Reeves & Armitage 1973; Reeves & Ward 1976; Stevenson *et al.* 1996). Recent work on the density of raw material found obsidian reports an average density of 2.38 g/cm³ and chert an average density of 2.49 g/cm³ (Middleton 2021). Basalt has an average density of 2.9 g/cm³, although further work on basalts from Aotearoa may reveal variability in sources used by Māori. Artefact size also depends on processes that lead to fragmentation. All other things being equal, broken artefacts will be smaller than complete examples and while this will be captured by overall assemblage mass, fragmentation will affect the relationship between artefact frequency and mass. Large numbers of small artefacts (the shatter mentioned above) will increase the total mass of artefacts below the cut-off point.

As an alternative to mass, geometric dimensions might be used to characterise artefact size, and therefore proportions, bypassing the impact of different material densities (but not the size cut-off). Taking multiple measurements allows calculations of artefact volume (Phillipps & Holdaway 2016) although the variety of flake and core shapes can make some geometric approaches imprecise. Laser scanning or photogrammetry provides more precise measurements (Lin *et al.* 2010) but is time consuming using current technologies. Middleton (2021) suggests volume derived from artefact weight and material density corresponds well. We include volume calculated on weight and material density, using the above values. We also adopt a simpler approach, using only a measurement of the maximum dimension of each artefact greater than or equal to 20 mm, summed by raw material, and expressed as a cumulative proportion. This method obviously quantifies artefact size only in one dimension.

A different way to think about stone artefact abundance relates this to the manufacture of flakes from a core. As each flake is struck, it is complete in the sense that it has a platform and a termination. However, breakage may occur either as a consequence of flake manufacture, that is breakage as the complete flake is struck, or after manufacture is complete through mechanical snapping brought on by any number of actions. Such flakes may be broken into two or more fragments. Thought of in relation to the location of the flake platform, that is the surface struck to form the flake, breakage may occur in one of two planes: either a lateral snap across the body of the flake or a longitudinal split though the platform. Experiments suggest that the later occurs most often during flake manufacture whereas the former may reflect post-manufacture damage. Because flakes struck as a result of conchoidal fracture share a common set of attributes it is possible to quantify breakage in relation to these attributes and thereby estimate the number of flakes originally struck from the core taking account of the frequency of flakes, and therefore in our example, the proportion of flakes struck from different materials.

Portnoy (1987; Mayer-Oakes & Portnoy 1993) is cited as the first analyst to report stone artefact fragmentation, and is credited with developing the Minimum Number of Individual Tools (here taken to mean 'artefacts', not just retouched tools) measure, expressed in Figure 1 as MNF, Minimum Number of Flakes. This measure combines the total number of complete artefacts and the greatest number of either proximal, centre (medial), or distal fragments to provide an estimate of the number of complete artefacts in an assemblage as originally manufactured. There are different ways of calculating minimum artefact numbers (Hiscock 2002; Holdaway & Stern 2004; Shott 2000) but all follow a similar logic of counting only one fragment per flake struck. In Figure 1, we show results for minimum numbers calculated using two methods, one based on the method discussed in Holdaway and Stern (2004) and another based on artefact mass (discussed below). However,

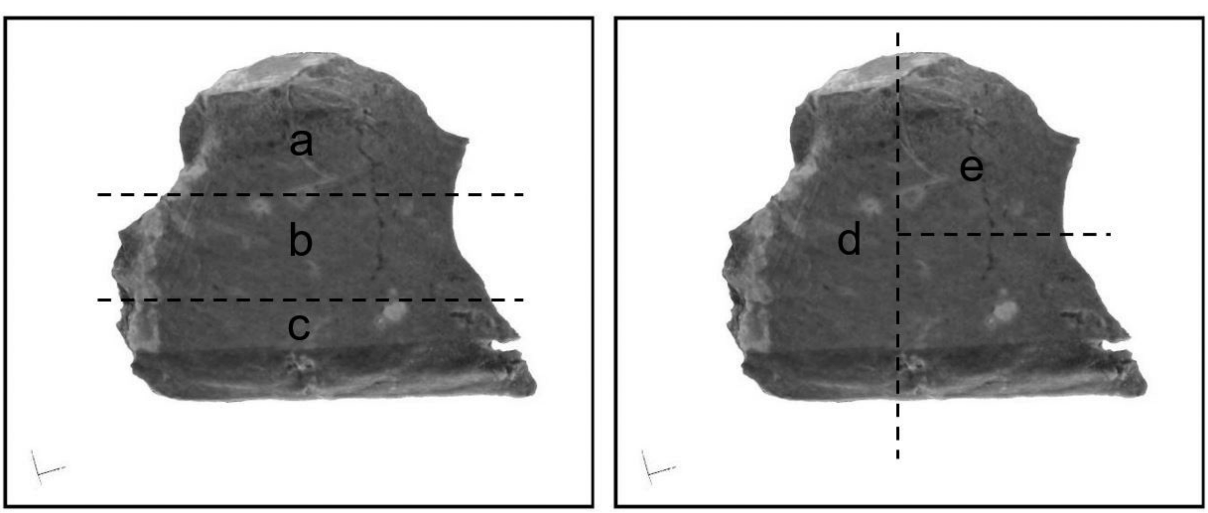

Figure 3. Flake fragmentation types showing a proximal (a), medial (b) and distal (c) break on the left, and complete (d), and proximal (e) splits on the right.

Table 2. *Tauroa and Te Mataku artefact frequency (and proportion) by raw material.*

	Tauroa				Te Mataku			
Artefact Type	**Basalt**	**Chert**	**Obsidian**	**Total**	**Basalt**	**Chert**	**Obsidian**	**Total**
Angular fragment	26 (16.7)	34 (9.2)	12 (9.8)	**72 (11.1)**	23 (4.5)	102 (5.9)	13 (5.9)	**138 (5.6)**
Angular fragment tool	3 (1.9)	5 (1.3)	8 (6.6)	**16 (2.5)**	1 (0.2)	2 (0.1)	2 (0.9)	**5 (0.2)**
Complete flake bipolar	0 (0.0)	1 (0.3)	0 (0.0)	**1 (0.2)**	–	–	–	–
Complete flake	62 (39.7)	158 (42.6)	45 (36.9)	**265 (40.8)**	260 (51.2)	1047 (60.3)	142 (64.8)	**1449 (58.8)**
Complete split	13 (8.3)	22 (5.9)	9 (7.4)	**44 (6.8)**	23 (4.5)	184 (10.6)	7 (3.2)	**214 (8.7)**
Complete split tool	0 (0.0)	0 (0.0)	2 (1.6)	**2 (0.3)**	1 (0.2)	3 (0.2)	1 (0.5)	**5 (0.2)**
Complete tool	4 (2.6)	33 (8.9)	13 (10.7)	**50 (7.7)**	19 (3.7)	43 (2.5)	4 (1.8)	**66 (2.7)**
Core	3 (1.9)	10 (2.7)	7 (5.7)	**20 (3.1)**	6 (1.2)	26 (1.5)	2 (0.9)	**34 (1.4)**
Distal flake	10 (6.4)	31 (8.4)	9 (7.4)	**50 (7.7)**	59 (11.6)	121 (7.0)	14 (6.4)	**194 (7.9)**
Distal tool	3 (1.9)	16 (4.3)	2 (1.6)	**21 (3.2)**	6 (1.2)	1 (0.1)	1 (0.5)	**8 (0.3)**
Medial flake	6 (3.8)	15 (4.0)	3 (2.5)	**24 (3.7)**	48 (9.4)	102 (5.9)	15 (6.8)	**165 (6.7)**
Medial tool	1 (0.6)	3 (0.8)	0 (0.0)	**4 (0.6)**	0 (0.0)	2 (0.1)	4 (1.8)	**6 (0.2)**
Proximal flake	21 (13.5)	29 (7.8)	7 (5.7)	**57 (8.8)**	57 (11.2)	90 (5.2)	10 (4.6)	**157 (6.4)**
Proximal split	4 (2.6)	7 (1.9)	4 (3.3)	**15 (2.3)**	2 (0.4)	11 (0.6)	3 (1.4)	**16 (0.6)**
Proximal split tool	0 (0.0)	1 (0.3)	0 (0.0)	**1 (0.2)**	–	–	–	–
Proximal tool	0 (0.0)	6 (1.6)	1 (0.8)	**7 (1.1)**	3 (0.6)	3 (0.2)	1 (0.5)	**7 (0.3)**
Total	**156 (100.0)**	**371 (100.0)**	**122 (100.0)**	**649 (100.0)**	**508 (100.0)**	**1737 (100.0)**	**219 (100.0)**	**2464 (100.0)**

all minimum number methods require information on the frequency or size of different artefact fragments, like the frequency data provided in Table 2. In this classification, complete artefacts are distinguished from those broken fragments that retain a platform or a termination, or neither. Flakes are differentiated from tools with retouch, and these are also separated into broken and complete forms. Broken artefacts with longitudinal splits are differentiated from those with lateral breaks and there is a class of artefacts without platforms or terminations that cannot be identified as medial fragments of complete flakes (angular fragments). If these have a retouched edge they are classified as angular fragment tools. Flakes struck using a bipolar technique are classified separately from those struck from a single platform. Finally, there are classes for cores differentiated from flakes because they retain only negative flake scars. Holdaway and Stern (2004) provide extended definitions of these categories.

Dividing flakes into complete and broken fragments therefore allows estimates of the number of flakes originally struck based on artefact frequency, however Jayez and Nasab (2016) go one step further by proposing a method using mass whereby the number of complete flakes are added to an estimate based on the total mass of segments (broken fragments) divided by the average weight of the complete flakes (Table 1). Figure 1 also shows the relative abundance of flake minimum numbers calculated using this method for each of the three raw materials.

Finally, differentiating complete from broken flakes (Table 2) also allows the calculation of a fragmentation ratio, that is the relative proportion of complete to broken flakes (Table 3). In this case we compare the frequency of complete flakes and tools with the frequency of broken flakes and tools that retain a platform (proximal flake, proximal tool). Results indicate differences in fragmentation between the sites with Tauroa showing increased fragmentation levels across all three materials compared to Te Mataku. The causes of fragmentation are varied but include such activities as trampling (*e.g.* Weitzel & Sánchez 2021) either by people in the past or animals (and of course people) in the present. Differentiating among these can be important for inferences about aspects of occupation not related to stone artefact manufacture. For example, heightened levels of fragmentation may reflect greater concentra-

Table 3. *Fragmentation ratio calculations for Tauroa and Te Mataku complete and proximal flakes and tools.*

	Tauroa			Te Mataku		
Material	**Complete**	**Proximal**	**Ratio**	**Complete**	**Proximal**	**Ratio**
Basalt	66	21	3.14	279	60	4.65
Chert	191	35	5.46	1090	93	11.72
Obsidian	58	8	7.25	146	11	13.27

tions of activity leading to breakage in one site compared to another. One could also adopt Jayez and Nasab's (2016) approach and calculate a fragmentation ratio incorporating artefact mass.

What can be concluded from Figure 1? For the Tauroa and Te Mataku assemblages considered here, measures of abundance indicate the predominance of chert artefacts from both sites followed by basalt then obsidian. However, there are differences in relative proportions based on frequency, mass, maximum length, and the two MNF methods. Not all of these methods are very different, for example NAS and MNF, but when weight and volume are considered, differences are more pronounced. None of these abundance measures illustrate the differences in fragmentation between the two sites indicated by the fragmentation ratio calculations. The lesson from Figure 1 is that there is no one 'correct' means of determining abundance, but that different measures may produce somewhat different results. It is important to understand the basis for these differences when drawing conclusions from the relative abundance of artefacts made from different materials. Size, degree of fragmentation, and technological component matter but so does assemblage completeness, a topic that we now consider.

ASSEMBLAGES AND ABUNDANCE MEASURES

Measures of artefact abundance and fragmentation that use MNF calculations make assumptions about the intended form of the object and its manufacture, for example a tool like an adze, seeking to quantify the complete assemblage that presumably existed at some point as a consequence of this manufacture. Such analyses generally treat artefact fragmentation as damage incurred during or after manufacture that was not intentional. However, stone artefact fragmentation was not always accidental, as shown for example in the production of microliths in many places around the world where snaps were used to create particular forms. Nor need accidental breakage during manufacture render the resulting fragment undesirable since broken fragments frequently retain usewear on broken edges indicating that broken artefacts were selected for use after fragmentation occurred. If broken artefacts were selected for use, and then abandoned, assemblage size and composition may not represent the residue of one artefact manufacturing sequence but several different forms of activity. This raises questions about the intent of stone artefact assemblage analysis. Archaeologists study artefact assemblages because of the behaviour such analyses may reveal but to which aspect of behaviour does assemblage composition refer? The sequence of flake removals culminating at the point of tool manufacture? The accumulation of manufacturing products to the point after a phase of artefact use? Or indeed, accumulation to the point after items from earlier manufacturing episodes were reworked and reused? Ethnographic accounts of stone artefact manufacture and use cast doubt on the efficacy of assemblage composition resulting from simple, linear, manufacturing sequences resulting in the creation of single products by individual knappers. Instead, these accounts describe frequent selection, reworking, and reuse of stone artefacts by multiple individuals at different times such that assemblage composition may reflect the outcome of actions by multiple individuals over prolonged periods often for a variety of purposes (*e.g.* Holdaway & Douglass 2012). Given these complexities, what do abundance measures seek to reconstruct? Should we attempt to quantify an original number of 'complete' objects? Were people in the past concerned with whether an artefact had a bulb of percussion or not and was therefore complete or broken in a technological sense, or was the existence of a cutting edge more important? Our (archaeological) notion of completeness, whether an artefact or assemblage, therefore needs careful consideration lest only one aspect of the historical process of assemblage formation becomes the focus (Rezek *et al.* 2020).

Shott (2000: 727) provides an example of this issue when he draws a distinction between stone artefacts originating from tool production versus those derived from tool resharpening. Both actions result in the creation of numbers of artefacts however he suggests that the latter relates to tool quantification in the sense that knowing the quantity of flakes removed in the process of tool resharpening provides an indication of original tool size. However, because stone tools are easily transported, such resharpening may occur in many places, therefore artefacts derived from resharpening are easily combined with those derived from unrelated episodes of manufacture. Shott also comments that tools may change considerably in size and form as a result of use with some discarded intact if reduced in size beyond certain thresholds. Like the retouch from resharpening events, such discard may not always occur at the locations where the tool was used. Therefore, tool resharpening, for example the reworking of an adze damaged during use, may add material to a stone artefact assemblage even when the tool itself is absent. With good evidence for adze reworking in Aotearoa (Turner & Bonica 1994) the issues Shott raises need consideration.

If the focus is shifted from stone artefact assemblages as the outcome of a single manufacturing sequence and instead focusses on the history of assemblage accumulation, assemblage completeness may be approached without assuming the existence of a single cobble reduction sequence. Flaking is a reductive process with flakes produced necessarily no larger than the core that they are struck from. As flaking progresses, the core becomes smaller and so therefore do the flakes removed from that core. This leads to characteristic flake size distributions that are asymmetric with high frequencies of small flakes and fragments and relatively few larger artefacts. Figure 4 shows histograms of artefact size distributions for the Aotearoa site assemblages divided by raw material type with all having the expected asymmetrical distributions.

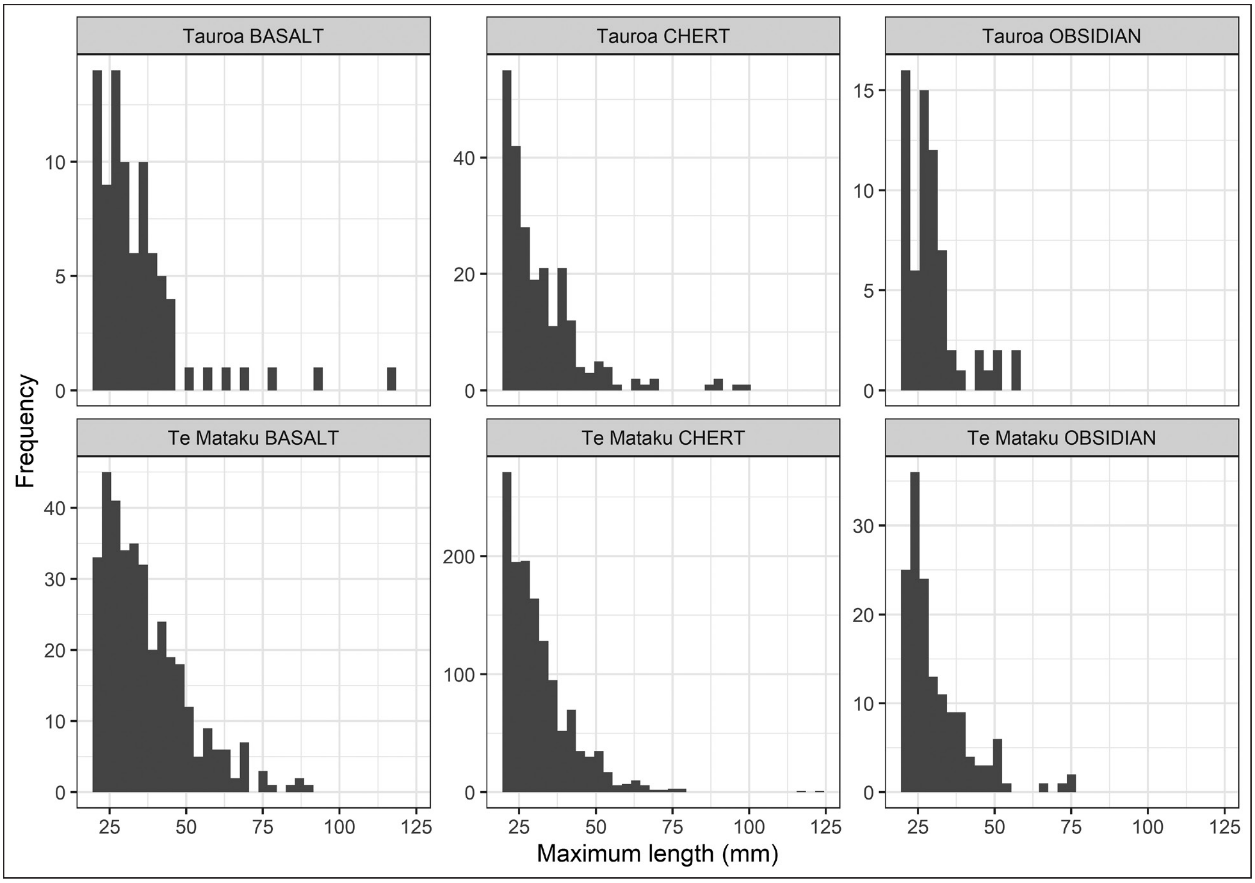

Figure 4. Histograms of stone artefact maximum length measurements for complete and proximal flakes and tools and complete and proximal longitudinal splits by raw material type for the Tauroa and Te Mataku assemblages. Note y-axes vary between plots.

Larger cores, derived from larger blocks of raw material will obviously allow the production of larger flakes but an experimental study by Lin *et al.* (2016) shows that core size and reduction intensity have little impact on the shape of flake size distributions like those shown in Figure 4. The same forms of asymmetric distribution result even when both core size and reduction intensity are varied. What does have an impact on the shape of flake size distributions is the removal of flakes of particular sizes or indeed their addition. This relates to the types of activities recorded in ethnographic studies of flake manufacture described above (Holdaway & Douglass 2012). Observations in this study showed that flakes manufactured and abandoned by one knapper became the source of useful flakes for another with selected flakes often transported to other locations in several ethnographic cases. Therefore, it might be expected that flake size distributions would show differences in shape as a result of varied artefact transport activities.

There are a number of ways of measuring flake transport based on the geometry of the original cobble (*e.g.* Dibble *et al.* 2005; Douglass *et al.* 2008; Phillipps & Holdaway 2016) but where cobble shape and size is not known, assessing changes in the shape of the artefact size distribution plots provides an alternative method. Following Lin *et al.* (2016), flake removal or addition rather than reduction intensity will change the shape of the artefact size distributions therefore it should be possible to compare the distribution of flake sizes. The distribution can be used to determine if the distribution suggests all the products of core reduction are present, or if the history of assemblage accumulation is more complicated indicating the removal and potentially the addition of artefacts from different locations. Lin *et al.* used the Weibull distribution to model flake size distributions since Stahle and Dunne (1982, 1984) suggested this form of distribution has the closest fit to the observed distribution of flakes produced as a result of core reduction. Brown (2001) suggested in addition that a fractal distribution, a power law distribution quite similar to the Weibull distribution in certain cases could be used since this distribution successfully predicts a rock's fragmentation in a number of natural settings. In the following we employ both distributions to consider the size distributions of the artefacts in the Aotearoa assemblages.

As Lin *et al.* (2016) explain (see also Shott 2002; Morales 2016), the Weibull function can be expressed using what is referred to as shape (β) and scale (λ) variables, where shape indicates the slope of the distribution and scale the spread of values. Figure 5 plots histograms for complete and broken flake sizes and the resulting Weibull plot based on these data. All plots save that for Te Mataku basalt show distributions reflecting low Weibull λ values. Compared to the other five assemblages, the histogram for Te Mataku basalt has a more dispersed set of artefact size values and therefore a higher λ (Figure 5).

Lin *et al.* report β and λ values for an experimental assemblage created by six individuals, knapping 14 flint nodules treated here as the equivalent of chert flaked in the Aotearoa examples. Each nodule was reduced in three stages, removing between 20% and 96% of nodule mass, producing as a result 42 separate assemblages. Maximum dimensions were recorded for flake products that retained a platform with sizes greater than or equal to 25 mm in these assemblages and these data were generously made available by Sam Lin for the comparison with the Aotearoa assemblages reported here. Also made available were data collected as part of the study that defined the Cortex Ratio (Dibble *et al.* 2005). These data included the experimental reduction of 26 cortical obsidian nodules by what is reported as a variety of knappers. The Dibble and colleagues obsidian assemblage provides data to compare to the Aotearoa obsidian assemblages. The same size criteria were applied to the obsidian experimental assemblage, with flake products with a platform both complete and fragmented and having a maximum dimension greater than or equal to 25 mm analysed to maintain consistency with the flint experimental assemblage.

Figure 6 plots Weibull β and λ values for the two sets of experimental assemblages together with results calculated for the six Aotearoa assemblages. Data used for the Aotearoa examples matched those measures used for the experimental assemblages. Comparison shows that the Aotearoa assemblages cluster together with low values of both β and λ. This result is very similar to that which Lin *et al.* (2016: Figure 3) obtained when they plotted flint archaeological assemblage results from Pech de l'Aze IV, a French Middle Palaeolithic site. As is the case with their study, the Aotearoa archaeological assemblages show much less spread (λ) than the experimental examples. This means that relative to the experimental assemblages, in the archaeological cases small artefacts are abundant and large artefacts less so. As shown in Figure 5, relative to the other Aotearoa assemblages, the Te Mataku basalt assemblage has a larger λ value but this is smaller than the majority of the experimental assemblages (acknowledging that none

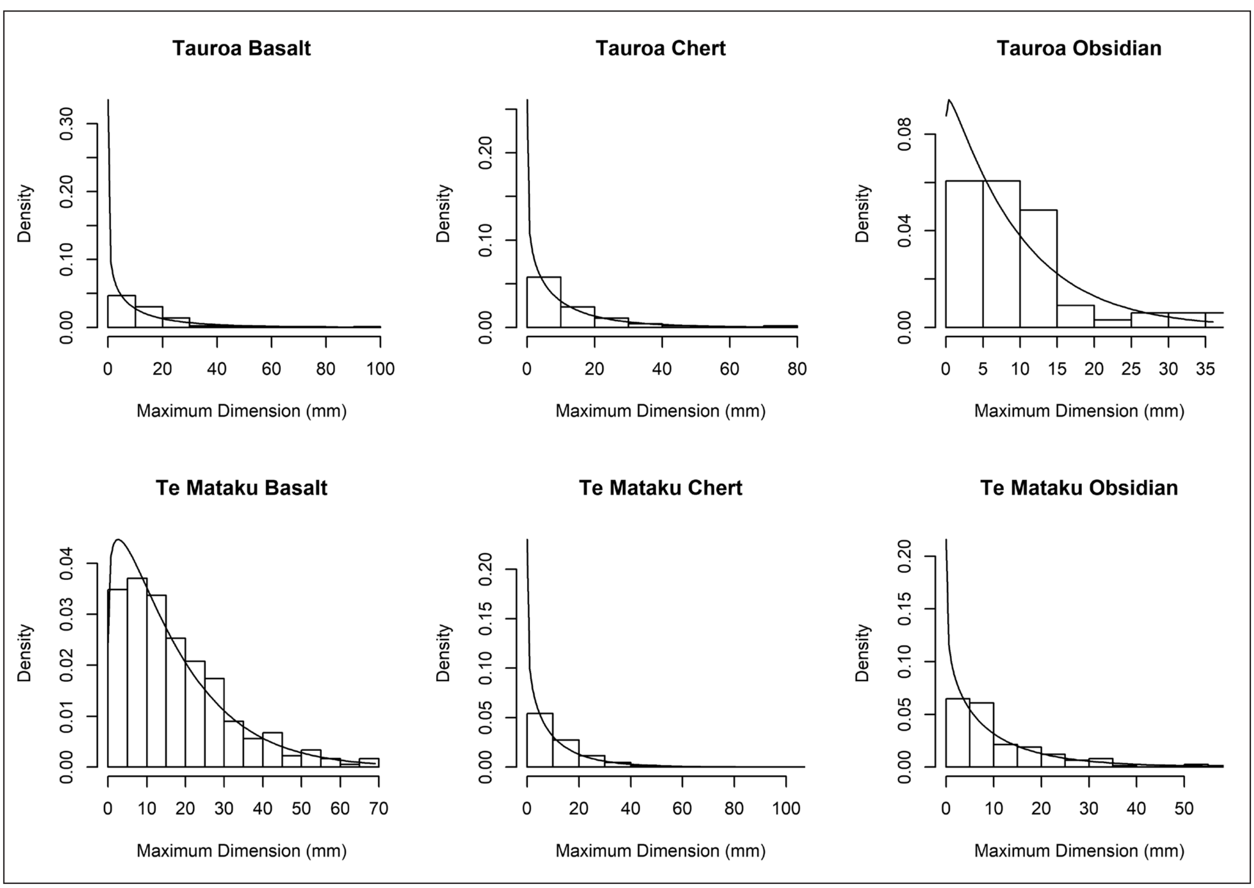

Figure 5. Complete and proximal flake and tool and complete and proximal longitudinal splits maximum length histograms with calculated Weibull plots fitted. Note the axes vary between plots.

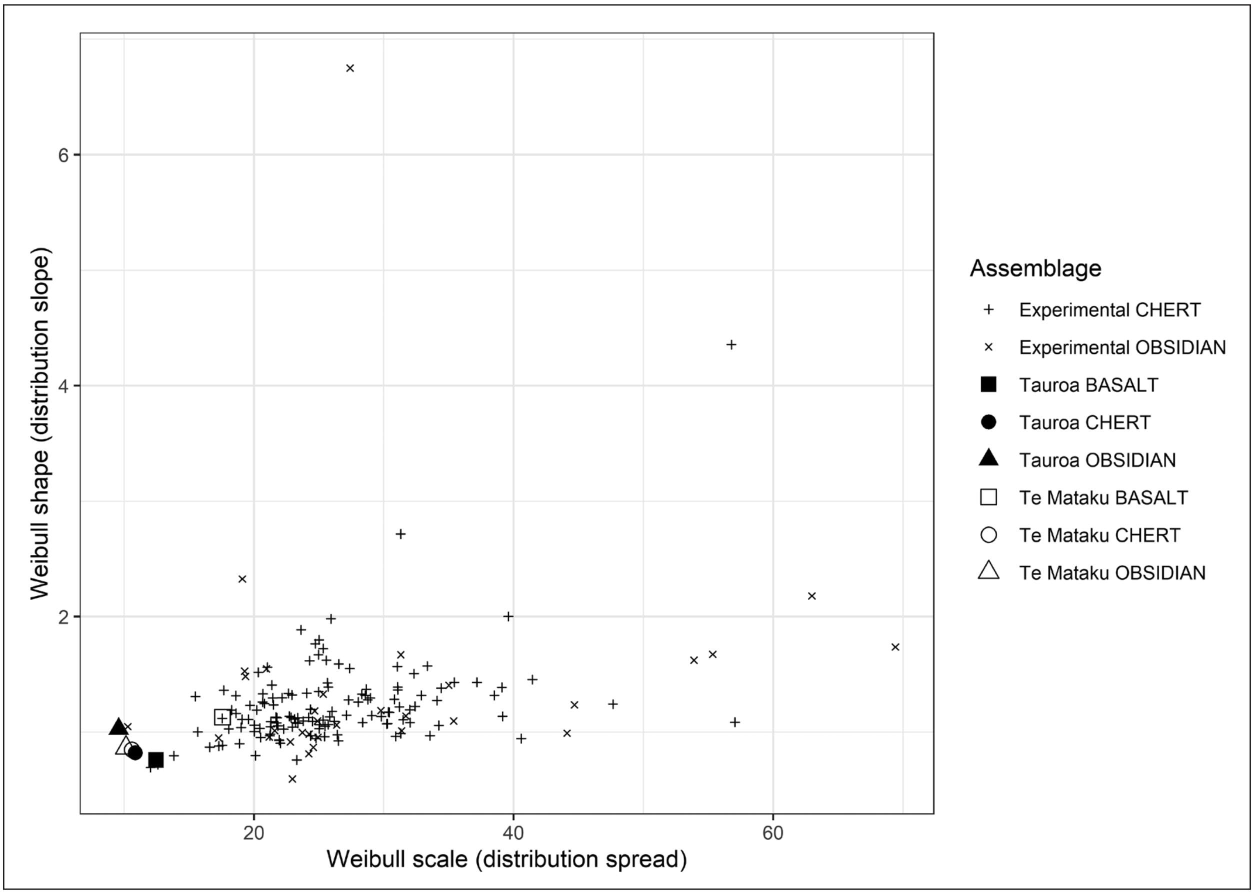

Figure 6. Shape and scale plot of experimental chert and obsidian assemblages together with shape and scale values for the six Aotearoa assemblages.

of these are made of basalt). As Lin *et al.* note, this pattern highlights the difference between archaeological assemblages that at times result from complex sets of activities including but not limited to artefact manufacture, leading to the removal or addition of artefacts, and the ordered flake sizes generated in experimental core reduction. The presence of flake fragments with grinding facets in both the Te Mataku (n = 3) and Tauroa Point (n = 29) assemblage indicates the presence of the products of resharpening that Shott (2000) discussed, however neither of the basalt assemblages contains the numbers of flakes needed to indicate extensive adze manufacture although Te Mataku contains minor evidence of adze manufacture in the form of adze roughouts (n = 4).

Brown (2001) cites the work of Turcotte (1997) who showed that rock fragmentation leads to a size frequency distribution of fragments that follows a fractal power law relation,

$$N(>r) = r^{-D} \qquad (1)$$

where $N(>r)$ is the number of fragments with a dimension greater than r (here this is maximum length) and D is the fractal dimension, a measure of the relative abundance of objects of different sizes. Taking the logarithm of both sides of equation (1) provides a means of calculating D,

$$D = -\frac{ln(N(>r))}{ln(r)} \qquad (2)$$

Table 4 shows how $ln(r)$ and $ln(N>r)$ are calculated for Tauroa chert artefacts. For the size intervals that characterise the variance in flake maximum length, artefact frequency in each size bin is calculated. The value of r is taken as the lower bound for each size interval bin and the cumulative artefact frequency for bins greater than that r value bin is calculated. $ln(r)$ is the natural log of lower bound bin value while $ln(N>r)$ is the natural log of the cumulative artefact frequency with sizes larger than the bin range. Values of $ln(r)$ and $ln(N>r)$ are then calculated for r determined as the lower bound for the next bin range with this repeated for the range of bin values. Plotting $ln(r)$ versus $ln(N>r)$ as a scatter plot allows a linear regression line to be fitted with the slope of this line approximating the value of D. In the archaeological examples that Brown discusses, a higher value of D corresponding to a steeper regression line reflects high concentrations of relatively

Table 4. *Fractal size interval calculations for the Tauroa chert assemblage.*

Size interval (mm)	Frequency	Lower bound *(r)*	Cumulative frequency *(N>r)*	*ln(r)*	*ln(N>r)*
20–30	136	20	236	2.995732	5.463832
30–40	55	30	100	3.401197	4.605170
40–50	25	40	45	3.688879	3.806662
50–60	10	50	20	3.912023	2.995732
60–70	5	60	10	4.094345	2.302585
>70	5	70	5	4.248495	1.609438

small artefacts and correspondingly, lower proportions of large artefacts. Brown provides as an example of a high *D* value, an assemblage dominated by small flakes derived from biface flaking. Lower values of *D* are seen when analysing dense flake assemblages located at raw material sources where test flaking of large cobbles is indicated.

Figure 7 shows the scatter plots for *ln(r)* against *ln(N(>r))* for the Aotearoa assemblages with linear regression lines fitted. The slope of these regression lines provide an approximation of *D* (*e.g.* 2.7 for Tauroa basalt). Overall, values for *D* are relatively high, approaching those that Brown (2001: 627–628) associates with biface reduction ($D = 3.7$ to 4.45), and higher than the values of 1.3 to 1.4 that Brown (2001: 625) associates with initial large cobble reduction. Thus the Aotearoa assemblages suggest a relatively high proportion of small artefacts at the expense of larger artefacts, a result similar to that reported in the Weibull analysis above. Using either of these techniques, the artefact size distributions suggest that the archaeological assemblages have lost numbers of larger sized artefacts compared to the size range of artefacts created when cobbles are completely flaked.

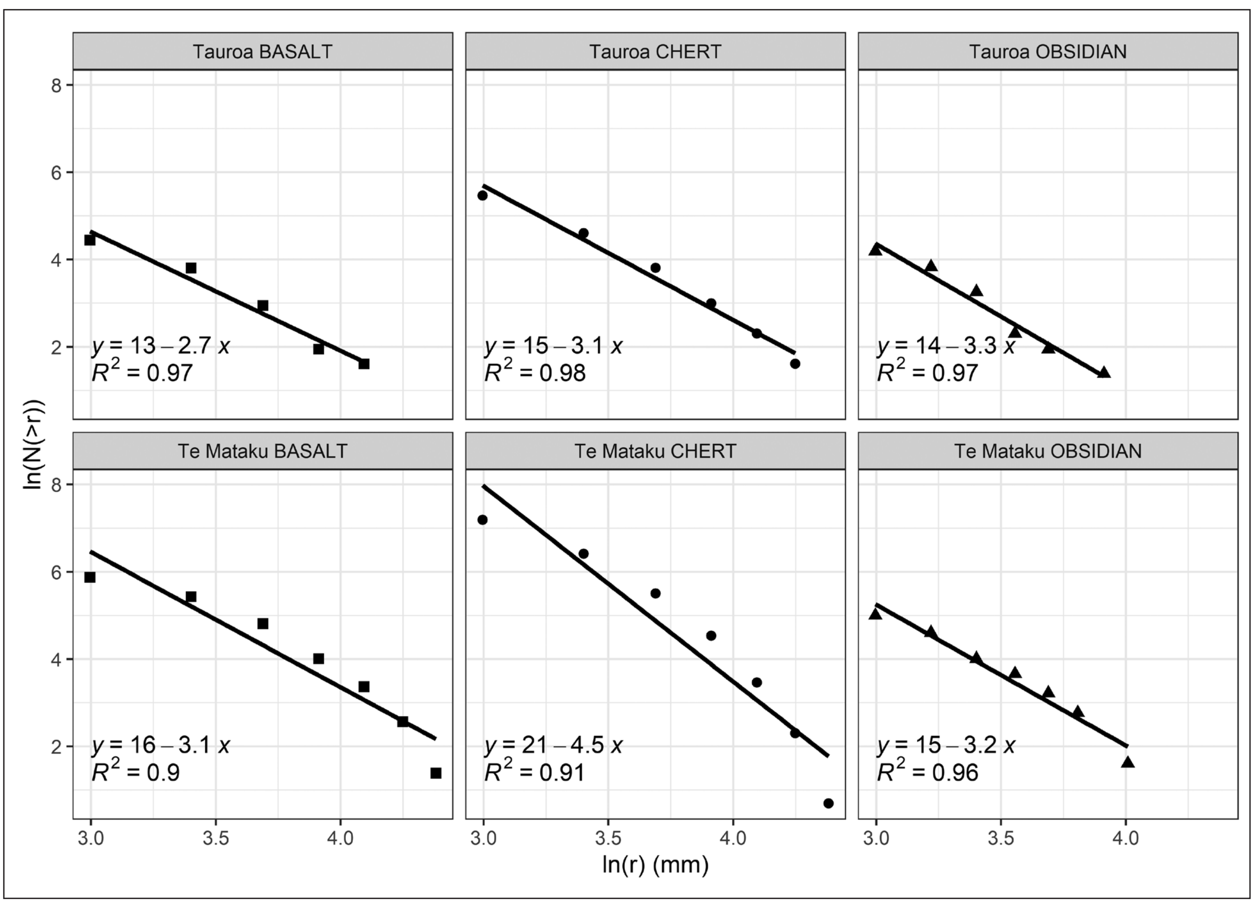

Figure 7. Scatter plots for the fractal distributions for each of the six Aotearoa assemblages together with regression lines and equations. Distributions are based on maximum dimensions of complete flakes and tools, proximal flakes and tools, plus complete and proximal split flakes and tools.

DISCUSSION

Depending on how artefact proportions are calculated, raw material proportions will differ within sites therefore complicating comparisons among assemblages between sites. Results will vary depending on how raw material was flaked but also levels of fragmentation. This means that there is no one 'correct' way to calculate artefact abundance but rather studies need to consider the range of processes that led to artefact accumulation within a site. Many stone artefact analyses are predicated on the notion that assemblages represent the product of single core reduction sequences however such situations are more the exception rather than the rule both ethnographically and archaeologically. Ethnoarchaeological studies describe multiple individuals working the same suite of artefacts as well as different individuals selecting and moving artefacts many of which were manufactured by others (Holdaway & Douglass 2012). Reuse is rife, with what might be considered as archaeological materials frequently repurposed. Archaeologically, nodules, chunks, and blocks of raw material were moved for use or as material reduced further to produce more flakes and tools (*e.g.* Coco *et al.* 2020; Turq *et al.* 2013). The results of the Weibull and fractal analyses presented here to describe artefact size distributions indicate the removal of large artefacts from assemblages representing all three raw materials, suggesting removal of artefacts was common at both Tauroa and Te Mataku. Thus assemblages at these sites are 'incomplete' as measured against size distributions expected from the complete flaking of cobbles in a single sequence.

These results suggest how different measures of artefact and assemblage abundance and completeness might relate to different research questions. If questions seek information on procurement and transport of raw materials, then carrying weight (gross mass) might be a useful measure. If questions relate to access to resources and economising behaviour, then reduction intensity measured by such things as flake to core ratios (Holdaway & Stern 2004), dorsal scar density on cores and flakes (Clarkson 2013), use intensity (Young 2019), and reuse intensity reflecting resharpening/recycling (Coco *et al.* 2020; Jorgensen 2018; Morales *et al.* 2015) might be useful. Use of an index of fragmentation is also likely important if it is thought that assemblages from sites were subject to different taphonomic processes, and this may be divided into different types of fragmentation based on assumptions about patterns of breakage (*e.g.* longitudinal, transverse). The point here is that multiple measures and methods of quantification are needed to develop an understanding of assemblage formation and artefact use-life. As the analyses presented here demonstrate, assemblages analysed in the present are the outcome of a variety of processes, both 'natural' and 'cultural', that unfold over time, reflecting such activities as artefact transport and reuse. To document these processes requires detailed study to understand what contributes to assemblage size and composition.

Measuring the Minimum Number of Flakes assumes a relationship between complete and broken artefacts. But are all broken flakes or tools necessarily useless? Is fragmentation always 'post-depositional' or 'accidental' or are there instances where fragmentation may be deliberate as shown by some global examples? Flaking experiments suggest breakage during manufacture is common, but it does not mean these objects were not used. Analysis should also consider the potential for reuse and recycling. This certainly suggests complete assemblage analysis (taking into account size cut-offs in what was retrieved) but also indicates that technological analysis including flake classification and related measures of fragmentation needs to be approached with care. Artefacts and the assemblages that formed as a consequence of artefact deposition reflect use-lives, sometimes long ones so quantification that essentialises one aspect of manufacture, for example core reduction, may not be that useful. Examining assemblage composition through other means such as size distribution or geometric measures of surface area and volume depletion may be better indicators of behavioural processes such as recycling and movement across landscapes that play out over the long term.

These considerations result in the need to think carefully about the types of questions that can be asked of assemblages. Simply 'dating' an assemblage to a particular period, for example, does not preclude processes of assemblage formation continuing in later times. What are today classed as archaeological sites, may in the past have acted as raw material deposits available for reuse by later inhabitants (Holdaway & Phillipps 2020). Some synchronic or even diachronic comparisons about social organisation, trade, or mobility at times rely on assumptions that underplay the significance of assemblage formation over time. As Shott (2010) notes, assemblages are always in a state of becoming. The same is true of artefacts in that they can change over time via a variety of processes such as reuse or stock trampling. If we accept these realities simple, functional classifications of artefacts, for example the identification of 'flaking floors' become questionable. Rather we should consider the utility of temporally broader understandings of landscape and resource use, and apply different abundance measures accordingly.

In the case of the two assemblages presented here results suggest that a variety of behavioural processes contributed to the accumulation of stone artefacts, but the removal of large artefacts across raw material types likely occurred suggesting the onward transport of artefacts for use at later times in other locations. A variety of alternative approaches to studying artefact movement have been presented in the literature (*e.g.* Close 2000; Douglass *et al.* 2008; Middleton 2021; Phillipps and Holdaway 2016; Turq *et al.* 2013) and this study confirms the utility of Weibull and fractal analyses as alternative methods (Lin *et al.* 2016). Future work could use and compare the results from the alternative methods described here among Aotearoa sites and assess their potential for understanding movement, mobility, and landscape use in the past, along with a consideration of the complexities of assemblage formation. Comparisons between assemblages provide the ability to construct more detailed regionally based understandings of landscape use that may contribute to existing broader models.

CONCLUSION

How do we best quantify stone artefacts and assemblages in Aotearoa? There is no single, definitive answer to this question. Rather as this study highlights, assemblages need to be interrogated to understand their composition. Does artefact fragmentation have an impact on the quantification of Aotearoa assemblages? The short answer is yes, potentially, and when examining relative proportions of different raw material sources, this must be considered. When using some measures, high degrees of fragmentation may overestimate or indeed underestimate the presence of certain stone materials depending on the size of the resulting fragments. There is value in analysing stone artefact assemblages in detail and combining measures to understand how assemblages have formed, both as the result of manufacture and use, and a variety of post depositional processes. However assemblages rarely reflect the outcome of single activities, the flaking of a cobble to create a desired tool all in the same place. Therefore, artefact abundance measures need to be combined with other measures that inform on assemblage completeness, either geometric approaches calculating surface area and volume (*e.g.* Phillipps & Holdaway 2016), or as illustrated here, measures of artefact size distribution. All provide information on how the process of artefact accumulation leads to assemblage composition found archaeologically.

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