Sourcing the Megalithic Stones of Nan Madol: an XRF Study of Architectural Basalt Stone from Pohnpei, Federated States of Micronesia

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– RESEARCH REPORT –

Sourcing the Megalithic Stones of Nan Madol: an XRF Study of Architectural Basalt Stone from Pohnpei, Federated States of Micronesia

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ABSTRACT

Nan Madol is a massive 81 hectare prehistoric administrative and ceremonial complex made up of 93 constructed islets on the high volcanic island of Pohnpei. Built between AD 900 and 1650 over earlier settlement remains along the southern coast of Temwen Island within the fringing reef, the site is noted for its distinctive use of columnar basalt and large boulders. XRF analysis presented here suggests the site's builders favoured columnar basalt from the island's main shield building stage (7–8 mya) over post-shield material. Boulders incorporated in the architecture are primarily from post-shield stage Temwen Island but supplemented by some main shield boulders from mainland Pohnpei. Preliminary findings further suggest that there were shifts in the relative frequency of quarries used to construct different structures. These shifts could relate to exhaustion of accessible stone from specific sources or perhaps changing preferences for stone from different sources due to social or political imperatives.

Keywords: basalt sourcing, monumental architecture, Nan Madol, Pohnpei

INTRODUCTION

The archaeological site Nan Madol, sometimes called the 'Venice of the Pacific' has captured the imagination of visitors to Pohnpei for generations (see Athens 1981, for an account of early observations). The site has a long history of occupation (Athens 1990). However, it did not start to become an elaborate administrative and ceremonial centre until about AD 900, with major expansion and megalithic building starting around AD 1200–1300, followed by its decline after about AD 1500–1600 (Athens 2007). Consisting of 93 named artificial islets constructed over a fringing reef on the southern coast of Temwen Island just off the coast of Pohnpei, Nan Madol is noted for its distinctive architectural use of columnar basalt and large boulders (Figs. 1 & 2). Over the past thirty years, investigations include those of Athens (1980, 1983, 1990, 2007), Ayres (1985, 1990, 1993), Ayres *et al.* (1997), Bath & Athens (1990), and Saxe *et al.* (1980), some of whom have speculated on the sources of architectural stone. Ayres *et al.* (1997), for example, used petrography to identify different phases of construction of one of the larger islets, Pahndipap, and also attempted to match possible quarry stone to a handful of architectural stones and ceremonial kava (*sakau*) pounding stones.

We report on the geologic classification of 49 individual architectural elements derived from 38 columns and 11 boulders from 10 islets located across the complex (Table 1). This represents only a small portion of the stones used to build the site, but is nonetheless the largest such database published to date. We refrain from interpretations relating to larger social and political issues but note the potential of future research to yield chronological information on the construction, and re-construction, of different parts of Nan Madol by tracking the use of individual sources, or geological source areas. This type of methodology has potential not only to tell us more about Nan Madol, but many other of the largest structures in the region and thus put us one step closer toward a comprehensive understanding of megalithic structures in Oceania on a landscape scale (e.g., Shepardson 2005).

METHODS

Pohnpei, located in the Federated State of Micronesia, is a high tropical volcanic island (338 km²) surrounded by a wide fringing reef and offshore barrier reef (Fig. 3). The island evolved in three stages: (1) a main shield building stage occurring around 8–7 mya, (2) an initial post-shield

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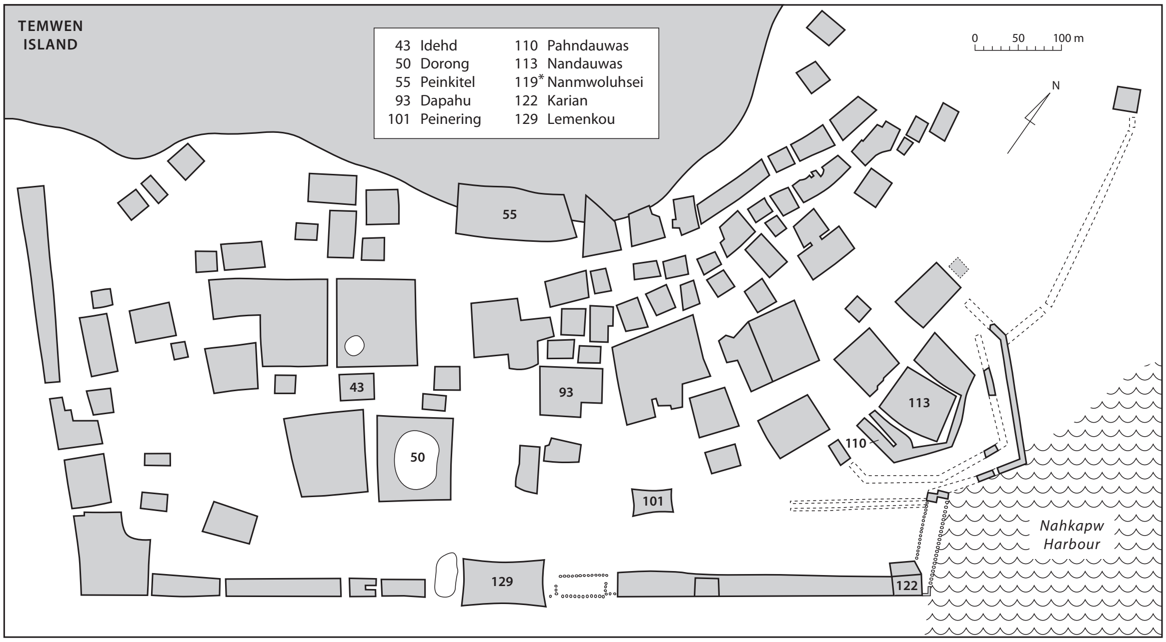

Figure 1. Map of Nan Madol (Source: Morgan 1988). Nanmwoluhsei islet (#119) not shown.

Figure 2. Columnar basalt wall construction using typical header-and-stretcher architectural style. Note use of large boulders as foundation stones. Photo by J.S. Athens.

stage represented by Awak Volcanics about 7–3 mya, and (3) a more recent post-shield stage represented by the Kupwuriso Volcanics from 2 to less than 1 mya, with Temwen Island (adjacent to Nan Madol) being Pohnpei's most recent geological feature (Dixon 1984; Keating *et al.* 1984; Mattey 1982; Spengler *et al.* 1994). Spengler *et al.* (1994) report on the geochemistry from each of these stages using XRF laboratories at the University of Hawaiʻi and Washington State (see Spengler *et al.* 1994: Table 1). Washington State XRF trace element data was normalised to the University of Hawaiʻi values (maximum difference of 4–8%) (see Spengler *et al.* 1994: 8, for further detail).

For this study, we used a Bruker AXF portable energy dispersive XRF at the Department of Anthropology & Archaeology, University of Otago. Instrument settings, optimized for mid-z elements, were similar to previous studies (McCoy 2011; McCoy *et al.* 2010, 2011; Mosley & McCoy 2010). Samples were run on a 300 second count time (40 eV per channel, filament ADC = 8 amp) with a filter (12 mil Al + 1 mil Ti + 6 mil Cu). CalProcess software was used for quantification drawing upon international standards used to calibrate peak intensities (standards: AGV-2, BCR-2, BHVO-2, BIR-1a, DNC-1a, GSP-2, QLO-1, SRM-278, W-2a); 500 second run time was used for standards. A pelletized USGS basalt standard (BHVO-2) was used as a control. These represent current best practices with regard to the use of p-XRF (Shackley 2010). Geological samples run at the University of Otago were first compared with published data on the chemical composition of Pohnpei basalts and architectual samples were matched to stage by principle component analyses (PCA) based on mid-z elements.

Table 1. *Locations of architectural stone and geological samples, Pohnpei*

Sample No.	Islet	Location on Building	Type
NM_09_1	Nandauwas #113	N wall	boulder
NM_09_2	Nandauwas #113	N wall	boulder
NM_11	Nandauwas #113	E wall	column-like boulder
NM_12	Nanmwoluhsei #119	Outer wall	boulder
NM_14	Nanmwoluhsei #119	Outer wall	boulder
NM_16	Nandauwas #113	Seawall	boulder
NM_17	Nandauwas #113	Seawall	boulder
NM_18_1	Pahndauwas #110	NW end	boulder
NM_18_2	Pahndauwas #110	NW end	boulder
NM_50	Peinering #101	basal foundation stone	boulder?
NM_02_1	Idehd #43	W enclosure wall	column
NM_02_2	Idehd #43	W enclosure wall	column
NM_03	Idehd #43	W enclosure wall	column
NM_04	Idehd #43	SE wall	column
NM_05_dark	Idehd #43	NE wall	column
NM_06	Idehd #43	N corner	column
NM_07	Idehd #43	NW wall	column
NM_10_1	Nandauwas #113	N wall	boulder
NM_10_2	Nandauwas #113	N wall	boulder
NM_13	Nanmwoluhsei #119	Outer wall	boulder
NM_15	Nandauwas #113	Seawall	boulder/very eroded column
NM_19	Lemenkou #129	E wall	column
NM_20	Lemenkou #129	N wall	column
NM_21	Lemenkou #129	N wall	column
NM_22	Lemenkou #129	N wall	column
NM_23	Lemenkou #129	NE enclosure, W wall	column
NM_24_dark	Lemenkou #129	SE enclosure, N wall	column
NM_25	Lemenkou #129	SE enclosure, E wall	column
NM_26	Peinkitel #55	NW wall	column
NM_27	Peinkitel #55	N corner	column
NM_29	Peinkitel #55	Main enclosure, NE corner	column
NM_30	Peinkitel #55	Main enclosure, S wall	column
NM_51	Dorong #50	N corner	column
NM_52	Dorong #50	N corner	column
NM_53	Karian #122	E wall, inner	column
NM_54	Karian #122	Entrance, N side	column
NM_55_1	Karian #122	top of central crypt	column
NM_55_2	Karian #122	top of central crypt	column
NM_56	Karian #122	E wall, inner	column
NM_57	Nandauwas #113	N wall	column
NM_58	Nandauwas #113	central crypt	column
NM_59	Nandauwas #113	N of front entrance	column
NM_60	Nandauwas #113	E wall, inner	column
NM_61	Nandauwas #113	S wall	column
NM_62	Nandauwas #113	S wall	column
NM_63	Nandauwas #113	S wall	column
NM_64	Nandauwas #113	N corner	column
NM_65	Dapahu #93	SW wall	column
NM_66	Dapahu #93	NE wall	column
NM_67	Dapahu #93	SW wall	column
NM_68	Peinering #101	S wall	column
NM_69	Peinering #101	E wall	column

Table 1 *continued*

Sample No.	Islet	Location on Building	Type
NM_70	Peinering #101	NE corner	column
NM_71	Peinering #101	N corner	column
Q2	geological sample	Sokehs Island, east side of Takain Ripkapehd basalt from base of outcrop *ca.* 100 metre contour	
Q3	geological sample	Pusehn Malik volcanic plug, Palikir columnar basalt	
Q4	geological sample	Net Point next to road on east side, at place called Nangeomara, columnar basalt attached to large boulder with columns that had fallen from mountain top	
Q5	geological sample	Sokehs Island, east side of Takain Ripkapehd basalt from base of outcrop *ca.* 150 metre contour	
Q7	geological sample	Oa; Merei en Yap, outcrop of columnar basalt at side of road near Oa. Location called Merei en Yap. Sample specimen had 5 sides; length could not be determined	
Q8	geological sample	Temwen Island, next to house of Masao Silbanuz boulder outcrop	
PNI-1	geological sample	Ipwal, columnar basalt collected from top of modern quarry *ca.* 1 km west of Sokehs Rock	
PNI-5	geological sample	Ohwa, columnar basalt collected near Ohwa Christian High School	

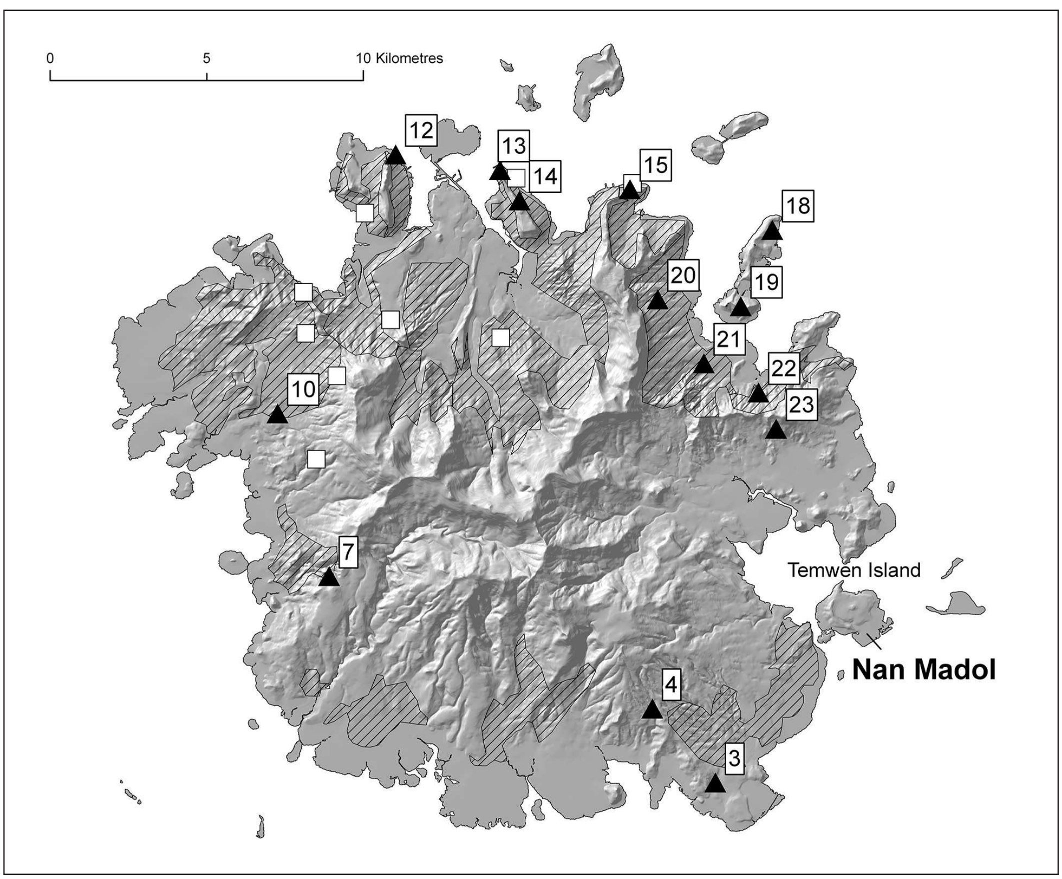

Figure 3. Sources of Columnar Basalt, Pohnpei. While most of the island's surface geology is post-shield basalt, there is a band of main shield stage basalt (marked with lines) exposed at mid elevations which includes notable topographic features such as Sokens Island and Pwusen Malek volcanic plug on the northwest portion of the island. For full list of locations of natural sources of columnar basalt (triangles), see Ayres *et al*. (1997:Figure 4.2). Relevant for this study are 10=Pwusen Malek, 12=Sokens (Ipwal is located *ca.* 1 km due west of here), 13=Nett Point, 14=Nett; 22=Oa and 23=Paliapailong (near Ohwa). Locations of published data on chemistry of main shield basalt shown as squares (after Spengler *et al*. 1994).

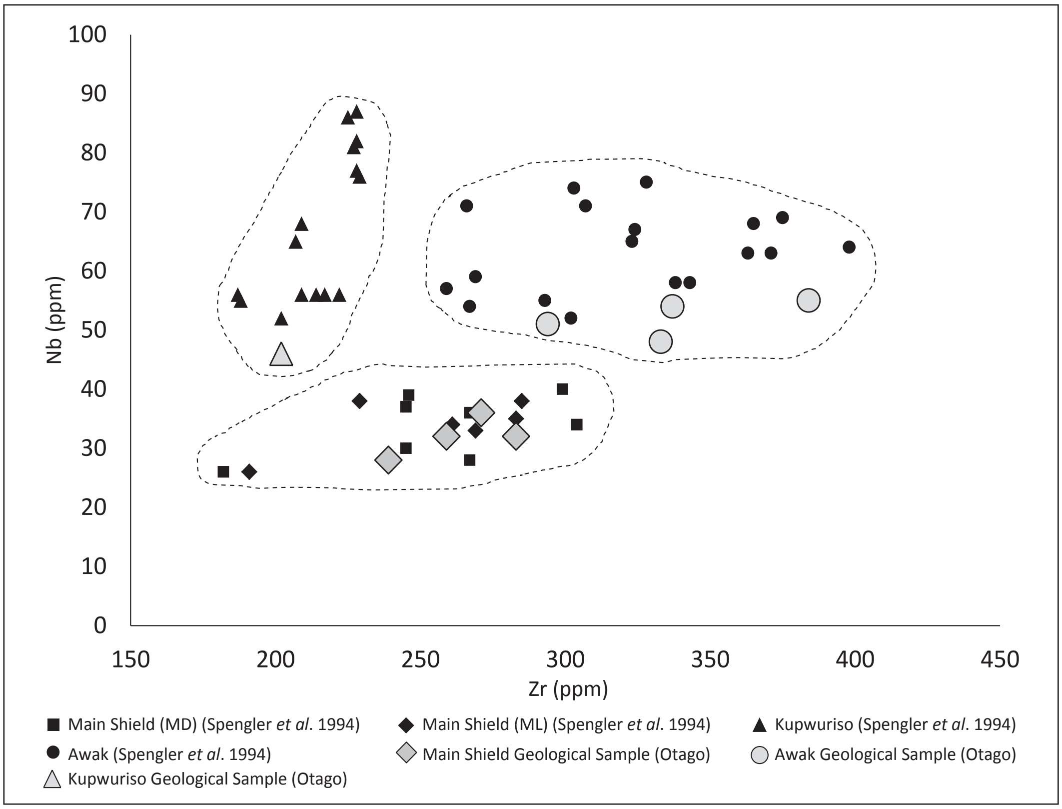

Figure 4. Classification of Geological Samples by Stage. Geological samples from Pohnpei run at the Univeristy of Otago fall within expected values for three stages defined by Spengler *et al*. (1994). Two examples of Q3 included in study.

Geological Samples

We analyzed 8 geological samples, most collected by the second author in 1982, 1984 and 1987 ('Q' samples), at possible sources of architectural stone, with a few additional samples collected in 2011 by the first author ('PNI' samples). These were classified based on Spengler *et al.*'s (1994) method of distinguishing between geological stages using Nb and Zr (Fig. 4). Samples included examples from all three stages: two locations with main shield sources (Pwusen Malek, Q3; and Sokehs Island, Q2 & Q5); four Awak post-shield sources (Nett Point, Q4; Ipwal, PNI-1, Ohwa, PNI-5, and Oa, Q7); and one Kupwuriso post-shield potential source of boulders (Temwen Island, Q8). Ayres *et al.*'s (1997) report the locations of 14 potential sources of columnar basalt that may have been used to construct Nan Madol; thus, the baseline geologic data presented here represents only a fraction of potential sources (Fig. 3).

Architecture Samples

The locations of analysed architectural stone samples from Nan Madol ('NM' samples) are described using the traditional islet name and numbering system of Hambruch (1936; see Hanlon 1988: 11 for updated orthography provided by Rufino Mauricio and used herein). The samples were collected by the second author in 1982 and 1984. The location of the architectural stone is noted in Table 2. We further summarise results below in terms of the size of these stones based on length and approximate weight calculated by their volume and an estimated density of basalt (2.65 tonnes per m^3).

RESULTS

The results show that architectural stones tested pertain to main shield and post-shield stage volcanics (Fig. 5 & Table 3).

Main Shield Stage Volcanics

Nearly all columnar basalt (n=36) and some large boulders (3 out of 11) come from main shield stage volcanic sources. It is possible to further divide these into three subgroups (Fig. 6). We annotate the subgroups below, but it is important to keep in mind that these represent a small subset of the larger site and we have a limited range of appropriate geological samples to compare them with.

Subgroup 1. This group includes most columns tested (n=30). Columns average 2.5 meters in length and weigh between 3 to 0.1 tonnes, with an average weight of just

Table 2. *Mid-z Elements for Architectural Stone and Geological Samples, Pohnpei*

Sample No.	Rb	Sr	Y	Zr	Nb	Geological Stage	Geochemical Subgroup
NM_09_1	28	1125	32	201	54	Kupwuriso	
NM_09_2	12	723	35	262	62	Kupwuriso	
NM_11	39	886	33	205	48	Kupwuriso	
NM_12	42	918	31	193	50	Kupwuriso	
NM_14	36	1879	32	122	57	Kupwuriso	
NM_16	39	891	34	206	49	Kupwuriso	
NM_17	26	1529	30	171	55	Kupwuriso	
NM_18_1	37	993	35	194	54	Kupwuriso	
NM_18_2	35	894	35	225	54	Kupwuriso	
NM_50	28	622	32	227	56	Kupwuriso	
NM_02_1	12	387	24	165	20	Main Shield	Subgroup 3
NM_02_2	14	417	23	181	22	Main Shield	Subgroup 3
NM_03	39	755	30	272	39	Main Shield	Subgroup 1
NM_04	17	436	21	175	19	Main Shield	Subgroup 3
NM_05_dark	34	882	32	271	41	Main Shield	Subgroup 1
NM_06	30	659	27	228	30	Main Shield	Subgroup 1
NM_07	21	631	26	222	26	Main Shield	Subgroup 1
NM_10_1	28	587	32	181	35	Main Shield	Subgroup 2
NM_10_2	18	565	33	173	28	Main Shield	Subgroup 2
NM_13	24	549	29	178	29	Main Shield	Subgroup 2
NM_15	18	574	29	173	28	Main Shield	Subgroup 2
NM_19	23	677	25	222	28	Main Shield	Subgroup 1
NM_20	27	791	34	278	38	Main Shield	Subgroup 1
NM_21	18	548	28	220	28	Main Shield	Subgroup 1
NM_22	19	559	26	204	26	Main Shield	Subgroup 1
NM_23	31	728	32	279	39	Main Shield	Subgroup 1
NM_24_dark	34	709	28	240	37	Main Shield	Subgroup 1
NM_25	18	689	26	242	33	Main Shield	Subgroup 1
NM_26	44	930	34	273	40	Awak	
NM_27	24	653	25	198	23	Main Shield	Subgroup 1
NM_29	27	685	22	211	28	Main Shield	Subgroup 1
NM_30	45	1067	34	271	46	Awak	
NM_51	26	720	22	214	28	Main Shield	Subgroup 1
NM_52	22	625	28	231	26	Main Shield	Subgroup 1
NM_53	33	780	33	277	37	Main Shield	Subgroup 1
NM_54	26	630	30	236	29	Main Shield	Subgroup 1
NM_55_1	22	606	25	209	27	Main Shield	Subgroup 1
NM_55_2	33	805	31	272	38	Main Shield	Subgroup 1
NM_56	25	644	25	221	28	Main Shield	Subgroup 1
NM_57	25	704	31	244	34	Main Shield	Subgroup 1
NM_58	28	680	27	253	32	Main Shield	Subgroup 1
NM_59	36	864	33	261	43	Main Shield	Subgroup 1
NM_60	34	848	31	266	37	Main Shield	Subgroup 1
NM_61	24	466	23	182	20	Main Shield	Subgroup 3
NM_62	26	692	31	242	35	Main Shield	Subgroup 1
NM_63	26	641	27	225	35	Main Shield	Subgroup 1
NM_64	28	494	27	157	26	Main Shield	Subgroup 2
NM_65	31	849	30	241	32	Main Shield	Subgroup 1
NM_66	22	653	25	223	28	Main Shield	Subgroup 1
NM_67	13	384	19	163	19	Main Shield	Subgroup 3
NM_68	32	798	32	249	33	Main Shield	Subgroup 1

Table 2 *continued*

Sample No.	Rb	Sr	Y	Zr	Nb	Geological Stage	Geochemical Subgroup
NM_69	22	592	25	216	24	Main Shield	Subgroup 1
NM_70	24	533	32	162	26	Main Shield	Subgroup 2
NM_71	28	594	26	198	25	Main Shield	Subgroup 1
Q2	23	594	30	239	28	Main Shield	Subgroup 1
Q3_1	27	727	31	259	32	Main Shield	Subgroup 1
Q3_2	28	816	29	271	36	Main Shield	Subgroup 1
Q4	49	1087	35	337	54	Awak	
Q5	42	653	35	283	32	Main Shield	Subgroup 1
Q7	37	1182	37	294	51	Awak	
Q8	30	771	31	202	46	Kupwuriso	
PNI-1a	47	898	39	384	55	Awak	
PNI-5a	34	915	38	333	48	Awak	

under a tonne (0.8 tonnes). Geological samples within this group include Sokehs Island and the Pwusen Malek volcanic plug. Nonetheless, architectural stone likely comes from many chemically similar sources. Examples of this subgroup are found on each islet tested.

Subgroup 2. This subgroup includes boulders (n=3) and large columns (n=2) that based on their size, 9.5 to 1.8 tonnes, may be boulders that resemble columns rather than true columnar basalt and may represent a single main island source of boulders. Examples were found among columns on two islets, Peinering #101 and Nadauwas #113, and among boulders on two of four islets tested (Nadauwas #113, Nanwoluhsei #119).

Subgroup 3. This group includes a small set of columns (n=4). While their sizes are within the range of other columns, there are no examples under 2 meters in length; average length and weight are 3.1 meters and 1.3 tonnes (range, 1.9 to 0.4 tonnes). Examples were found on three islets Dapahu #93, Idehd #43, and Nadauwas #113.

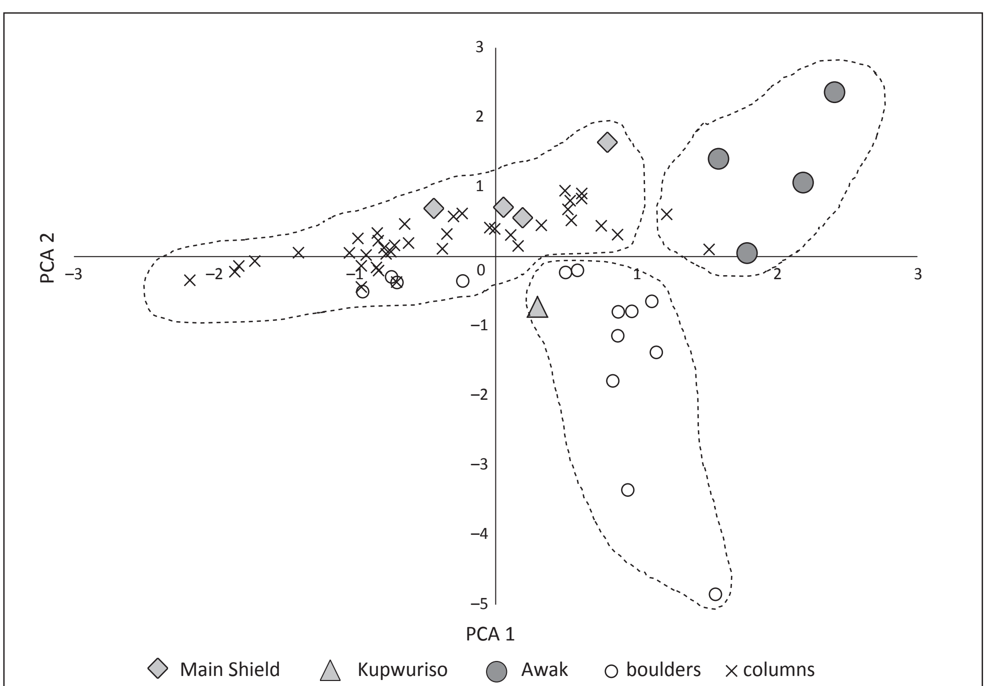

Figure 5. Classification of Architectural Samples by Stage.

Table 3. *Summary of stone source by islet, Nan Madol.*

Columns	Main shield			Post-shield
	Subgroup 1	Subgroup 3	Subgroup 2	Awak
Dapahu #93	2	1	–	–
Dorong #50	2	–	–	–
Idehd #43	4	2	–	–
Karian #122	4	–	–	–
Lemenkou #129	7	–	–	–
Nandauwas #113	6	1	1	–
Nanmwoluhsei #119	–	–	–	–
Pahndauwas #110	–	–	–	–
Peinering #101	3	–	1	–
Peinkitel #55	2	–	–	2
Totals:	**30**	**4**	**2**	**2**

Boulders	Post-shield	Mainshield
	Kupwuriso	Subgroup 2
Dapahu #93	–	–
Dorong #50	–	–
Idehd #43	–	–
Karian #122	–	–
Lemenkou #129	–	–
Nandauwas #113	4	2
Nanmwoluhsei #119	2	1
Pahndauwas #110	1	–
Peinering #101	1	–
Peinkitel #55	–	–
Totals:	**8**	**3**

Post-Shield Volcanics (Awak Stage)

Only two post-shield columns were found and each belong to the Awak stage. They represent the same range of sizes as other columnar basalt sources, 3.0 and 0.10 tonnes, and were both found on the same islet (Peinkitel #55).

Post-Shield Volcanics (Kupwuriso Stage)

While no Kupwuriso stage post-shield examples of columns were found, most boulders belong to this stage (8 out of 11). These boulders were all sizable, including very large boulders (*ca*. 25 tonnes) weighing more than the biggest columns, to large boulders (1.3 to 0.8 tonnes) on par with columnar basalt. Clearly, potential sources for post-shield stone could be widespread over Pohnpei, but the high values of yttrium (Y) in these samples makes it likely that, as previous researchers have suspected (Ayres *et al*. 1997), Temwen Island is the source of Nan Madol's largest boulders (see also Spengler et al. 1994). Examples were found on all four islets where boulders were tested (Peinering #101, Pahndauwas #110, Nadauwas #113, and Nanwoluhsei #119).

DISCUSSION

It is unsurprising that the architects of Nan Madol chose local columnar basalt stone from Pohnpei in the construction of the site, or that for the largest stones – the massive foundation boulders – they turned to adjacent Temwen Island. What is of interest here is how even in this small sample we can start to see how specific types of sources were chosen over others. On the largest scale, the rarity of post-shield columnar basalt in the architectural stone tested here is remarkable given it is widely available on Pohnpei and includes potential quarries quite close to Nan Madol. In our view, it seems unlikely that these sources were ignored and further research will show more examples of post-shield columnar basalt.

The rarity of a certain class of sources in our sample is more understandable when we consider the frequency of sources present in different sectors of Nan Madol (Table 4). Oral traditions explicitly point to a general trend of earlier islets in the central area (#43, #93), followed by those in the northeast (#113, #101), with the latest being an outer structure build partially on Temwen Island (#55) and possibly the seawall (#122, #129). If these structures were built in the relative order suggested by oral traditions, then the

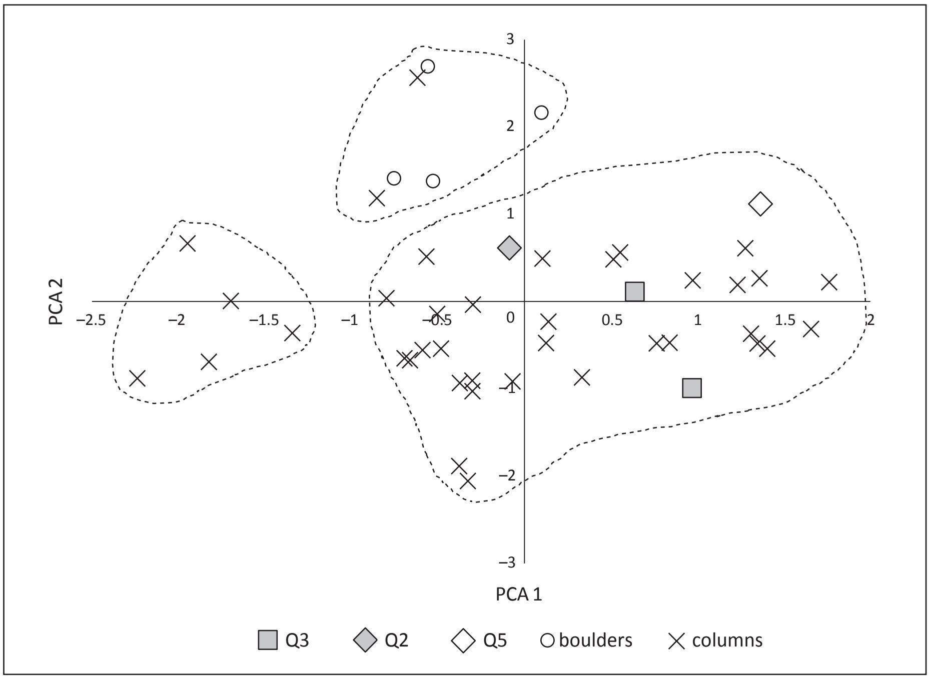

Figure 6. Subgrouping of Main Shield Stage Basalts. Subgroup #1 (right) includes only columns and includes geological samples from Sokehs Island and Pwusen Malek, Subgroup #2 (top) includes boulders and columns, and Subgroup #3 (left) is comprised of columnar basalt greater than 2 meters in length.

results reported here may allow us to detect when certain sources go in-and-out of fashion over time.

The spatial distribution of Main Shield Subgroup 3 suggests a steadily declining use over time; precisely what would be expected in a source that was mined to exhaustion. There appears to have been a progression in the use of Main Shield Subgroup 3 (+2 meter long columns) that follows from being relatively commonly used, accounting for a quarter of samples, to being rarely used, and finally to being absent from samples tested. Interestingly, Main Shield Subgroup 2 only appears in samples from the northeastern area, suggesting it may have been in favour for a brief time in the middle of this sequence. The final structure (#55) was built using Main Shield Subgroup 1 and rare examples of Awak stage post-shield columnar basalt, while other outer features returned results from Main Shield Subgroup 1 only. The lack of other shield building basalts points to source exhaustion as having been a factor in stone choice, and more importantly, this may be a useful tool for teasing apart a detailed history of the construction, and re-construction, of individual portions of the site.

There are of course a number of other explanations for this patterning, including the very real possibility that this progression purely reflects changing preferences of the builders responsible for the different stages of construction of the site rather than source exhaustion. It could also reflect changing social and political imperatives in the procurement of stone. Future research at Nan Madol combined with oral traditions should help clarify these initial results.

Table 4. *Summary Sources by Geographic Sector of Nan Madol*

	Main Stage Subgroup 1	**Main Stage Subgroup 3** (+2 m long columns)	**Main Stage Subgroup 2** (columns & boulders)	**Post–shield Awak**	**Islets**	**n**
Central	Major source(s) (75%)	Common source (25%)	–	–	#43, #93	9
Northeast	Major source(s) (75%)	Rare (8%)	Common source (17%)	–	#113, #101	14
Outer	Major source(s) (87%)	–	–	Rare (13%)	#122, #129, #55	15

SUMMARY

The results of this XRF study of architectural stone from Nan Madol suggest several basic insights into the construction of the site:

1. There appears to be a preference for some columnar basalt sources (Main Shield, Subgroup 1) over post-shield (Awak or Kupwuriso). There are no indications thus far that stone from outside of Pohnpei was used.
2. There may have been a single source of columnar basalt where pieces greater than 2 meters were regularly mined (Main Shield, Subgroup 3). Current evidence suggests that it may have been mined to exhaustion.
3. Boulders are mainly from Temwen Island (Post-shield, Kupwuriso), but were also brought from another source (Main Shield, Subgroup 2). This later source produced large boulders and columnar basalt, or long boulders that mimic the shape of columnar basalt.

The spatial distribution and frequencies of these sources suggest shifts in quarry use reflecting exhaustion of columnar basalt at some locations, cultural preferences, or other social and political imperatives for use of different sources.

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