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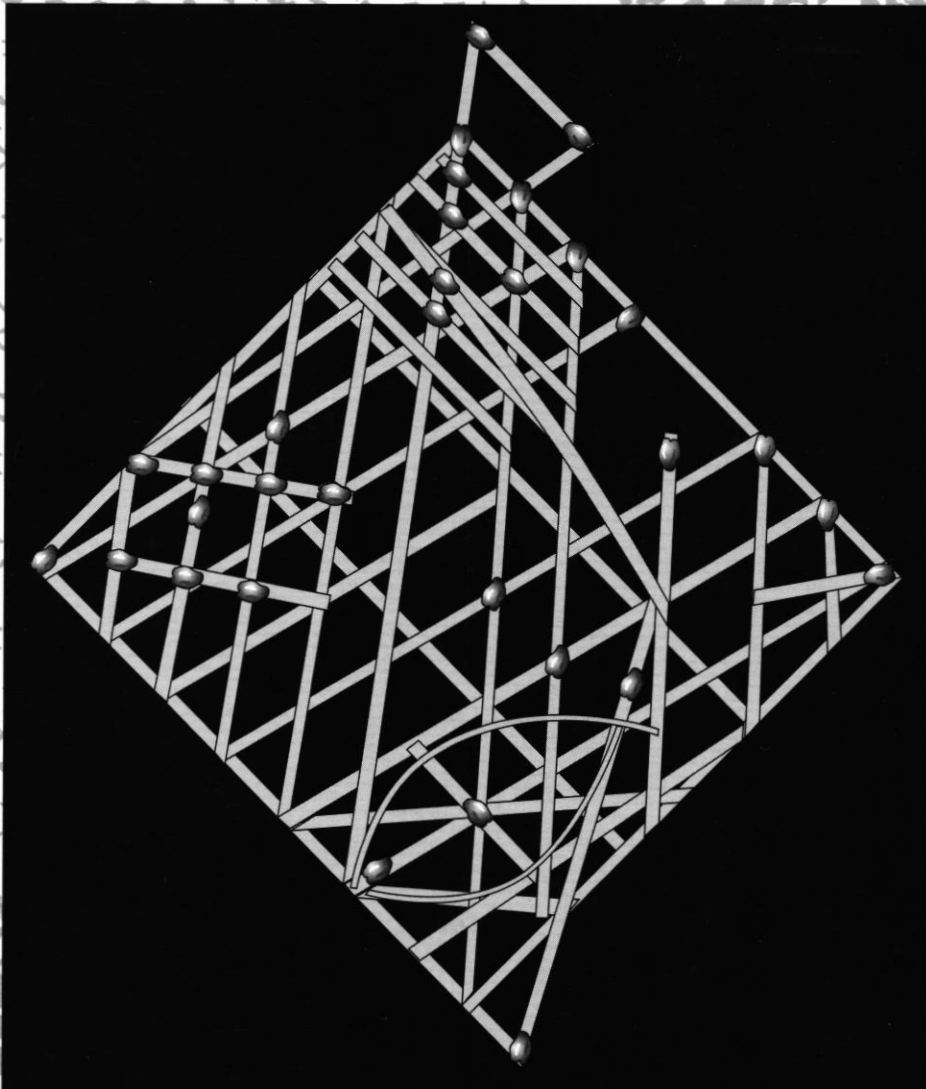

# PREHISTORIC LONG-DISTANCE INTERACTION IN OCEANIA: AN INTERDISCIPLINARY APPROACH

Edited by Marshall I. Weisler

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NEW ZEALAND ARCHAEOLOGICAL ASSOCIATION
MONOGRAPH

# PROVENANCE STUDY OF LITHIC MATERIALS IN MICRONESIA

William S. Ayres, Gordon G. Goles and Felicia R. Beardsley

Lithic material distributions in the Pacific Islands provide significant evidence for long distance movement of stone artefacts and pottery that includes rock sand. Stone transport and provenance studies in the Pacific have concentrated on volcanic glass and high quality axe/adze stone within Melanesia and Polynesia (e.g., Best *et al.* 1992; Burton 1984; Cleghorn *et al.* 1985; Green *et al.* 1967; Leach and Witter 1990; McCoy 1977; Smith *et al.* 1977; Weisler 1990a, b, 1993a). This paper offers an overview of long distance stone procurement within Micronesia in the western Pacific and, as a specific regional level case, examines stone building material use on Pohnpei, a volcanic island in the eastern Carolines.

Micronesia is a geologically and lithologically complex area of the western Pacific because it includes landforms on either side of the Andesite Line, which separates the predominantly andesitic volcanism to the west from the basaltic formations in the central and eastern Pacific. Rock from both areas was transported within the region and exchange occurred locally and over long distances. However, within Micronesia stone tends to be a very limited component of the traditional technological assemblages compared to the ubiquitous marine shell implements and production debitage, and in many areas ceramics may provide the only useful indicator of trade links during the early prehistoric period. Although provenance studies involving systematic use of chemical and mineral composition analyses are at present uncommon, the far reaching inter-island contacts known historically indicate that it should be possible to identify archaeological signatures of both stone artefacts and pottery with further study.

## ARCHAEOLOGICAL STUDY OF LITHIC PROCUREMENT AND EXCHANGE

Developing and testing hypotheses related to stone transportation begins with confirming that such materials, either stone tools or building materials, were moved over long distances (Howe 1910; Kempe 1983). Inter-island transport can commonly be asserted from a few artefacts (even one if distinctive); intra-island transport patterns can be more difficult to establish. First, one must recognise that a distributional pattern exists for a class of imported material; once established, identification of actual sources follows. Unfortunately, most Pacific island landforms and dense vegetation make it difficult to locate source areas or quarries, particularly because our collective preconceptions of what an ancient quarry might look like compound the difficulties in finding the archaeological traces. Local traditions, particularly those linked to prestige uses of stone, may assert that specific sites were quarries when in fact logistics and the character of the raw material precludes such uses. For these and other reasons one does not usually begin a search for quarries until the archaeological record strongly suggests that finding them would provide important insights.

Considering stone provenance and exchange mechanisms that facilitated moving essential or valued raw materials requires an analysis of the full range of stone acquisition and use. The 'efficiency' of lithic technology organisation has been a significant issue for archaeologists examining hunter-gatherer systems; this has been interpreted as being part of the organisational structure or basic mobility strategy (Binford 1979) and as mediated by culturally defined 'suitability' (Gould and Saggers 1985). This issue is significant also for stone transport within food producing, politically complex Pacific societies such as those in Micronesia. Here, however, status related aspects of stone use assume much greater prominence and it is useful to distinguish two basic kinds of transported stone: (1) those principally non-utilitarian in use, especially exotic rock types (e.g., volcanic glass imported into Pohnpei or limestone [aragonite] disk 'money' shipped into Yap from Palau); and (2) those utilitarian in function that have become elements of the local technological system (e.g., non-oceanic, silicate-rich stone for flaked implements, pottery from Yap brought into the Caroline atolls, or building stone transported within the Pohnpei region). Both kinds of lithic materials are part of the archaeological record in Micronesian chiefdoms, where organisational structures reflecting complex regional administration are expected to determine a more formalised exchange system than for hunter-gatherers (Ericson 1984).

Efficiency is not viewed as a simple constant; it was maintained via a variety of strategies. However, distinguishing the role of direct procurement versus trade often presents a problem. Many different kinds of social interaction may be represented by the movement of raw materials and finished products and therefore the exchange relationships are complicated (Hunt and Graves 1990), especially as viewed in an archaeological context. Distinct modes of transport and efficiency maintenance have been distinguished and basic among these is a pattern where procurement or access is directly linked to distance, that is, a simple distance-decay process; this often has as compensatory behavioural patterns the extension of material life and material substitution (see, e.g, Ricklis and Cox 1993). Once stone materials can be differentiated as to geologic source, spatial inter-site analysis offers a viable way of deciphering the organisation of lithic technology and of inferring site function and overall settlement patterns. Accounting for differences in suitability of different resources and their distribution across the landscape is an aim of this research.

Among the most important insights that can be derived from a study of lithic procurement and production are those related to changes in social and political systems. In some situations, changes in sociopolitical integration are predicted when shifts in the distribution of stone artefacts and ceramics (and potentially other artefacts) can be documented at the local or regional level. For example, on Pohnpei, stone building materials documented only at a local level should contrast with evidence of building materials brought into island centres from other regions; that is, materials derived from distant sources on or off the island. It should be noted that increases or shifts in materials transported may reflect changes in sociopolitical complexity but not necessarily in levels of political centralisation or an extension of hegemony (see Roscoe 1993; Ayres 1993). Long distance systems for moving stone raw materials or products in the high island-atoll interaction spheres in Micronesia do not necessarily indicate direct political integration.

Case studies of stone resource use within specific cultural and environmental contexts are a necessary first step for developing a theoretical model that can systematically relate such production systems and their products to a wide range of cultural, environmental and technological variables. Pohnpei and other Pacific islands provide an unusual opportunity for testing such models of stone technology and exchange relationships. Their insularity, environmental circumscription and limited range of available resources together permit better control over some of these variables than is commonly the case in continental situations, and the study results have important implications for analysis of provenance and production systems in other prehistoric societies, insular or continental.

An interdisciplinary study drawing on perspectives and methods from archaeology, anthropology, geology and geochemistry is underway at the University of Oregon. The focus is on stone materials in archaeological sites from the Pacific Islands, with a long term goal of identifying changes in island exchange patterns and sociopolitical transformations. Complementary to lithic provenance determination is an examination of the petrographic, elemental and technological attributes of ceramics. These goals are part of a larger materials compositional analysis and provenance project at the University of Oregon's Geo-Anthropological Laboratory. This work has included field study and collection of prehistoric building stone, ceramic manufacturing materials and quarry samples from several Pacific islands as well as detailed laboratory analyses.

## THE MICRONESIAN CONTEXT

Compared to the southwest Pacific or Polynesia, the scale of inter-atoll and atoll-high island interactions in Micronesia was great. Some long distance interaction spheres are shown in Figure 4.1. However, the use of stone for implements was far more restricted because of the very limited number of high islands offering suitable tool stone. Thus, within Micronesia most studies thus far have concentrated on ceramics, including geochemical assay (for example, Ayres and Bryson 1989; Bryson 1989; Dickinson and Shutler 1979, 1982; Graves *et al.* 1990; Intoh 1982, 1990; Intoh and Leach 1985; Pavlish *et al.* 1986; Takayama 1981) because of the paucity of stone implements, especially in the eastern Carolines, the Marshalls and Gilberts (Kiribati). Ayres and Mauricio (1987) have examined Pohnpeian stone adzes; however, their study was not based primarily on geochemical data. More recently, geochemical study of Pohnpeian stone was completed by Goles and Ayres (Ayres and Goles 1990) with results indicating significant opportunities for provenance study in the area of non-ceramic cultural material.

### *Characteristic patterns and regional variation*

Carved rectangular limestone columns with capstones were used widely for house pillars (*latte)* in the Marianas.

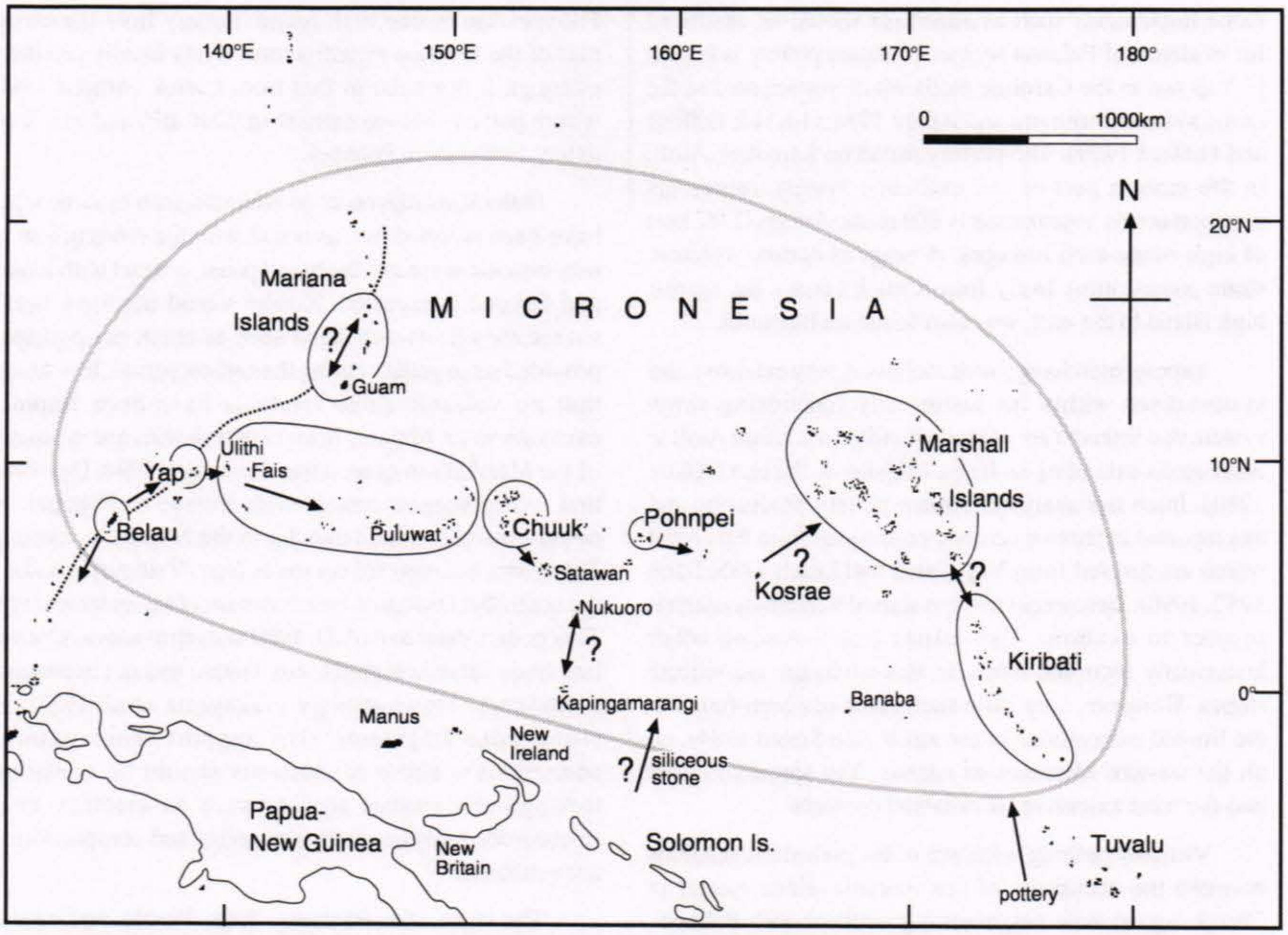


FIGURE 4.1. Map of Micronesia showing suggested lithic transport interaction spheres.

Exposed, tectonically elevated reef sections as well as inland limestone outcrops were used for quarrying these slabs; a few such areas are known but no provenance study has yet been done on the stone in either the quarries or the columns. Silicate-rich stone, which was not uniformly available, must have been transported inter-island as well; stone adzes and axes should fit into this pattern of stone use in western Micronesia. Given the complex geology of the Marianas, localisation of stone and clay resources suggests that inter-island exchange was likely. Few studies attempting to determine provenance of these materials have been undertaken (Beardsley 1993; Craib 1983), but some successful ceramic analysis have been initiated (Butler 1988; Graves *et al.* 1990).

The Palauan archaeological record shows evidence of contact with the Philippines, at least late in the cultural sequence, which points to important extra-regional interaction for all of western Micronesia. Within Palau itself, recent surveys of the distribution and styles of stone images (Van Tilburg 1991) suggest that there may be opportunities for characterising and determining the provenance of these artefacts. Also, the widespread use of basalt in the architectural features within the traditional stone platform villages, the artefact assemblages associated with these prehistoric habitations and the sites in Palau's coral islands (Rock Islands), point to the rich store of information awaiting provenance research (Beardsley 1995).

Another feature of western Micronesian exchange involves the stone and pottery moved between Palau and Yap - especially, the stone disks or 'money' quarried in Palau - which has been known for some time based on historical accounts and attribute comparison (Beauclair 1963; Osborne 1966, 1979). No geochemical study has been done to specifically address the complexity of this exchange. These large perforated disks were quarried in Palau's Rock Islands and transported to the Yapese communities in Palau and Yap, but it is not known at present if Palau is the sole source for all of these stones. Trace element comparisons also using Sr isotopic ratios and other possible discriminants could well determine if this is the case. Additionally, Yapese stone implements such as adze/axes should be examined for evidence of Palauan sources. Palauan pottery is known in Yap and in the Caroline atolls which participated in the *sawei* system (Fujimura and Alkire 1984:110-113; Gifford and Gifford 1959). The pottery found on Lamotrek Atoll, in the eastern part of the exchange system, represents transport across approximately 800 nautical miles (1482 km) of high-island-atoll linkages. A range of oceanic volcanic stone pieces, most likely from Chuuk (Truk), the nearest high island to the east, was also found on Lamotrek.

Yapese interchange with atolls was very extensive and systematised within the historically functioning *sawei* system that linked Yap's Gagil chiefdom via Ulithi Atoll to other atolls extending as far as 1200 km to the east (Alkire 1980). Intoh has analysed Yapese pottery production and has reported extensive ceramic collections from Fais Atoll which are derived from Yap (Intoh and Leach 1985; Intoh 1982, 1990). Descantes (ms) has started a ceramics analysis project to examine Yap-Ulithi links. Among other historically recorded items in this exchange are silicate stones. However, very little such stone has been found in the limited excavations in the atolls (see Sinoto 1984). Of all the western Micronesian islands, Yap appears to have had the most extensive extra-island contacts.

Virtually nothing is known of the prehistoric relations between the occupants of the volcanic island cluster in Chuuk lagoon with neighbouring atolls or with Pohnpei, the nearest high island to the east. The early Chuukese pottery (King and Parker 1984; Shutler *et al.* 1984; Takayama and Shutler 1978) seems unlike that found on Pohnpei, other than being tempered with calcareous sand, an ubiquitous tempering agent across this region of the Pacific, and thus suggests no contacts that would provide a platform for the exchange of lithic materials.

Kosrae, the easternmost Micronesian high island, presumably had contacts with neighbouring atolls in the Marshalls, but these are not historically documented as in the case of the *sawei*. The only archaeological traces of these putative contacts are non-oceanic rocks found by Weisler on Maloelap Atoll (pers. comm. 1994) and at least one example of a basalt stone pillar reported from Namu Atoll (Mason 1947:10). As both Kosrae and Pohnpei have extensive sources of columnar rock used extensively in constructing ritual centres, either could represent the source of the stone observed by Mason. Neither Cordy (1982, 1983, 1993) nor Athens (1990) report exotic materials in their Kosrae assemblages, but it is possible that Kosrae fulfilled a function for adjacent atolls similar to that held by Pohnpei for its neighbouring atolls. And, while as yet undocumented, it is also possible that stone building materials as well as other materials were exchanged between Kosrae and Pohnpei, the nearest high island. Pottery from the earliest part of the Kosraen record is most likely locally produced, although it is similar to that from Chuuk (Athens 1990), where pottery dates to more than 2000 BP, and to a lesser extent to that from Pohnpei.

In the Marshalls no stone artefacts, such as stone adzes, have been reported but, as noted with the reference to the non-oceanic stone and the basalt pillar, contact with Kosrae and beyond is expected. Kosrae would not have been a source for silicate-rich stone such as chert, but perhaps it provided some pottery during the earliest period. It is striking that no volcanic stone artefacts have been found in excavations on Majuro, Arno or Kwajalein, nor in surveys of the Marshalls in general (see Beardsley 1994; Dye 1987) that would suggest contact with Kosrae or Pohnpei. No pottery has been found thus far in the Marshalls, although Takayama has reported ceramics from Vaitupu, Tuvalu, to the south that Dickinson concludes are of Fijian temper type. This pottery dates to *ca* A.D. 1000 and represents a relatively late trade ceramic brought into Tuvalu and not necessarily a settlement era technology (Takayama *et al.* 1987:1,8); stone adze fragments also support these external connections. These connections should be confirmed through provenance studies such as electron beam microprobe analyses of temper grains and comparisons of adze material.

The stone adze fragments from Tuvalu represent an interesting potential connection to the long-distance movement of stone implements in eastern Micronesia, including those found on Pohnpei. A rare stone adze shaped in a form typical of West Polynesia was found on Pohnpei (Ayres and Mauricio 1987). As expected, instrumental neutron activation analysis (INAA) data on the adze showed it to be different from existing Pohnpei samples as well as from samples processed from Tutuila, Samoa, a very important source of high quality basalt used extensively for adze production (Ayres and Eisler 1987; Best *et al.* 1992; Leach and Witter 1990; Weisler 1993b; see Table 4.1 and Chapter 5, this volume).

In general, the opportunities for lithic provenance study in Micronesia have only recently been recognised and only a few systematic studies have been conducted. Given the known distribution of exotic rock materials, the potential is great, especially in the case of the Yap-atoll links, the Yap-Palau connections and, we believe, the unusual opportunity to study building stone provenance in the eastern Carolines.

| Element | Adze<br>Pohnpei<br>Sample<br>P-26 | PPN Quarry<br>Pohnpei<br>Sample<br>P-3 | PPN Quarry<br>Pohnpei<br>Sample<br>P-9 | Volcanic Glass<br>Pohnpei<br>Sample<br>P-27 | Nan Madol<br>Pohnpei<br>Sample<br>NDS-CR | Tataga-matau<br>Samoa<br>Sample<br>S-2 | Maloata<br>Samoa<br>Sample<br>S-6 |
|---|---|---|---|---|---|---|---|
| Fe% | 9.49 ± 0.12 | 0.14 ± 0.09 | 8.47 ± 0.09 | 0.93 ± 0.06 | 10.1 ± 0.2 | 9.99 ± 0.11 | 9.34 ± 0.10 |
| Na% | 2.67 ± 0.15 | 2.76 ± 0.07 | 2.64 ± 0.07 | 3.4 ± 0.3 | 1.69 ± 0.07 | 2.66 ± 0.10 | 1.72 ± 0.17 |
| Co | 44.4 ± 1.1 | 33.5 ± 1.3 | 32.4 ± 0.5 | n.d. | 62 ± 2 | 45.6 ± 0.6 | 48.2 ± 0.6 |
| Sc | 16 ± 0.15 | 11.7 ± 0.12 | 11.38 ± 0.11 | 1.95 ± 0.08 | 26.2 ± 0.6 | 16.91 ± 0.18 | 20.1 ± 0.2 |
| Cr | 12 ± 2 | 60 ± 2 | 56.9 ± 1.3 | 12+3 | 411 ± 13 | 7.8 ± 0.9 | 181 ± 3 |
| Ta | 3.5 ± 0.3 | 6.2 ± 0.4 | 4.7 ± 0.2 | n.d. | n.d. | 2.92 ± 0.12 | 2.41 ± 0.10 |
| Hf | 6.9 ± 0.3 | 9.4 ± 0.2 | 8.7 ± 0.14 | 4.1 ± 0.3 | 5 ± 0.2 | 7.96 ± 0.15 | 6.54 ± 0.14 |
| Th | 2.57 ± 0.17 | 6.38 ± 0.16 | 6.12 ± 0.11 | 7.1 ± 0.3 | 2.5 ± 0.14 | 3.21 ± 0.09 | 2.58 ± 0.08 |
| U | n.d. | n.d. | n.d. | n.d. | 0.71 ± 0.08 | n.d. | n.d. |
| Ba | 320 ± 30 | 660 ± 30 | 640 ± 20 | 940 ± 70 | 250 ± 20 | 230 ± 20 | 190 ± 20 |
| Rb | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| La | 25.7 ± 0.9 | 52.9 ± 1.0 | 51.5 ± 0.7 | 21.1 ± 1.4 | 25.1 ± 1.3 | 27.2 ± 0.6 | 20.9 ± 0.5 |
| Ce | 72.4 ± 1.5 | 133.3 ± 1.7 | 124.6 ± 1.4 | 42 ± 2 | 56.3 ± 1.8 | 76 ± 0.9 | 59.8 ± 0.8 |
| Nd | 49 ± 3 | 83 ± 2 | 83 ± 5 | 21 ± 4 | 25.3 ± 1.7 | 46.1 ± 1.3 | 41.4 ± 1.2 |
| Sm | 9.78 ± 0.12 | 12.79 ± 0.13 | 12.29 ± 0.12 | 2.62 ± 0.08 | 7.4 ± 0.3 | 10.82 ± 0.11 | 9.34 ± 0.10 |
| Eu | 3.3 ± 0.2 | 3.6 ± 0.2 | 3.76 ± 0.14 | n.d. | 2.34 ± 0.19 | 3.38 ± 0.10 | 2.92 ± 0.09 |
| Tb | 1.6 ± 0.12 | 1.4 ± 0.10 | 1.42 ± 0.07 | 0.62 ± 0.18 | n.d. | 1.48 ± 0.06 | 1.36 ± 0.06 |
| Yb | 3 ± 0.2 | 2.54 ± 0.08 | 2.52 ± 0.06 | 1.8 ± 0.3 | 1.43 ± 0.09 | 3.16 ± 0.08 | 2.49 ± 0.08 |
| Lu | 0.47 ± 0.02 | 0.377 ± 0.012 | 0.351 ± 0.008 | 0.27 ± 0.03 | 0.182 ± 0.009 | 0.439 ± 0.011 | 0.345 ± 0.011 |

TABLE 4.1. Pohnpei geochemical data: key rock samples from Experiment 89.

## POHNPEI DATA AND ANALYSIS

Our primary interest is in regional level interactions as reflected in exchange systems marked by the distribution of ceramic and stone building materials on Pohnpei. Columnar lava pieces and boulders were transported within a Pohnpei-wide system and to nearby atolls, and some exotic stone specimens are known. Based on a peer polity interaction model (e.g., Renfrew and Cherry 1986), changes in sociopolitical integration - not necessarily to higher levels - are predicted when shifts in the distribution of building materials and ceramics (and potentially other artefacts) can be documented. The Nan Madol complex of artificial islets on Pohnpei's east coast represents the administrative centre for an island-wide polity controlled by the Sau Deleur ruling line and dating to *ca* A.D. 1200 to 1500. Stone building materials with distributions documented only at the local level for pre-Nan Madol polities should contrast with evidence of building materials brought into Nan Madol from other Pohnpei regions during the Sau Deleur era; that is, construction stone at the complex during the Deleur chiefdom era is expected to have been derived from multiple locations, in some cases far removed from the site. This predictive model is constrained only by the realities of materials availability and transport logistics. In particular, transport of single stone columns weighing many tonnes would seem to require rafts and perhaps lifting cranes. Thus, lagoon margin quarries probably were greatly preferred by ancient builders. Leaving aside these constraints for the moment, we agree with Ericson (1984:7) who notes that in complex societies the form and degree of regional administration is expected to determine the exchange system. However, the use of secondary sources of stone may not be affected in these contexts, and differentiating primary from secondary sources is a significant issue for all studies of lithic production systems.

The long term goal of the current project is to tie the Nan Madol complex and related sites together graphically, structurally and ideologically. The present analysis builds on earlier work, principally by Hambruch (1932-36), Riesenberg (1968), Saxe *et al.* (1980), Athens (1980) and Bath (1984), as well as that of Ayres since 1977 (Ayres 1985, 1990, 1993; Ayres and Haun 1980). Additionally, understanding Nan Madol should aid in interpreting the significance of the architecturally similar Leluh complex on Kosrae to the east (see Cordy 1982, 1993; Graves 1986). It is quite possible that these two complexes represent a broader interaction sphere involving at the very least an exchange of ideas and perhaps of artefacts and raw materials as well.

Pohnpei presents an unusual opportunity to determine the provenance of building stone because columnar rock was widely used in constructing tombs, house foundations, meeting houses and walled enclosures. For the Nan Madol project, two immediate and complementary objectives are: (1) to locate quarries that provided the unusual columnar volcanic stone and the massive boulders used in constructing the Nan Madol artificial islets and architectural complexes; and (2) to examine the stone from the standpoint of its transport, use in construction and structural strengths. Sampling done to date is represented in Figure 4.2. Figure 4.3 illustrates basic stone forms and building styles.

Our initial null hypotheses are that: (1) Nan Madol construction stone is all local, that is, derived from the adjacent landscape; (2) Nan Madol construction boulders are all from adjacent Temwen Island; and (3) columnar basalt materials are all from one source. Our predictions are: (1) one quarry providing approximately 50 percent of the Nan Madol columnar material will be identified; (2) not all boulder material is from nearby Temwen Island; and (3) columnar stone material will show the greatest number of discrete quarry areas.

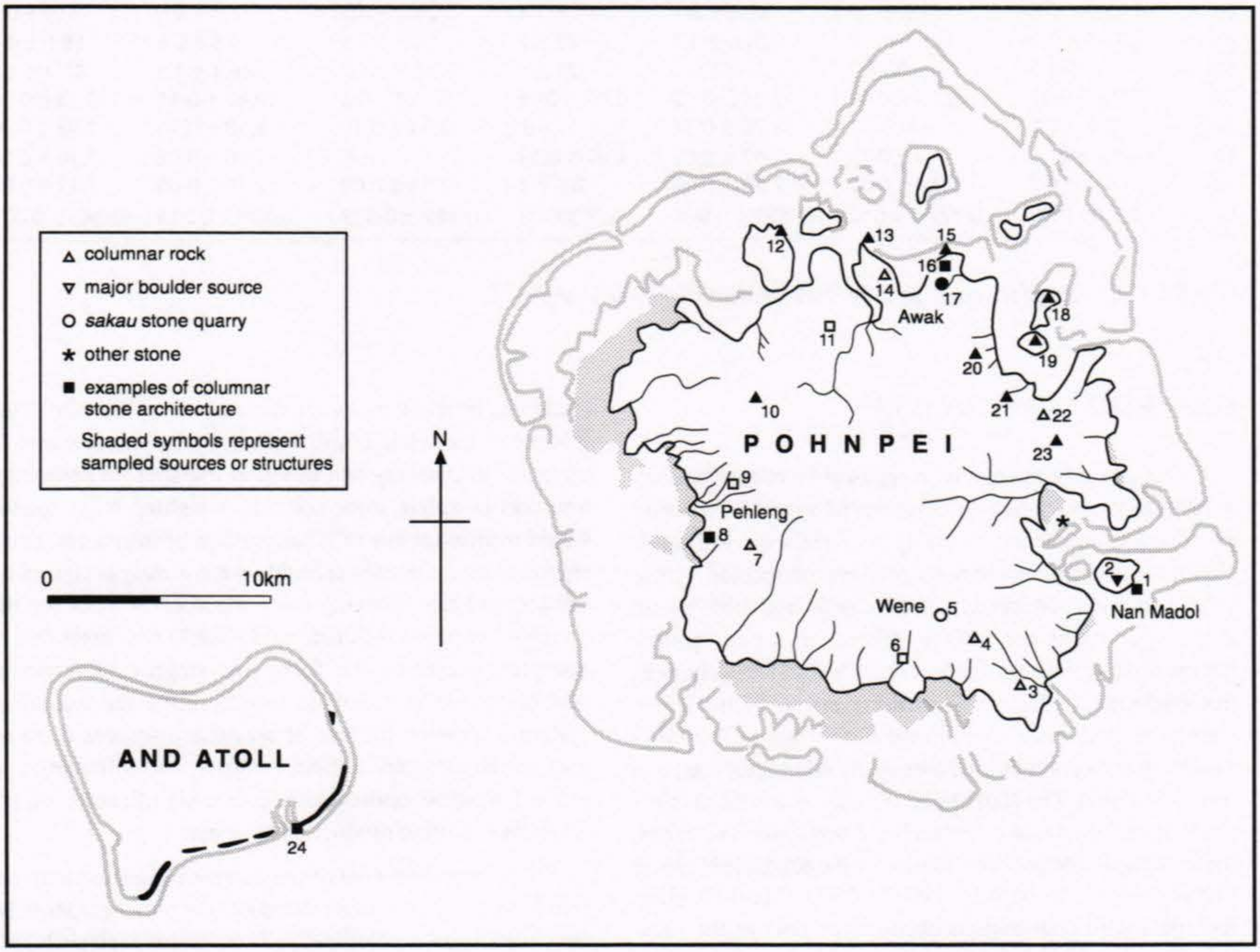


FIGURE 4.2. Pohnpei map showing stone sources and selected archaeological sites. 1 = Nan Madol; 2 = Temwen; 3 = Lohd Pah; 4 = Rentu; 5 = Olapel; 6 = Wene; 7 = Toamwoaroahlong; 8 = Pwudoi; 9 = Pehleng; 10 = Pwusen Malek; 11 = Likinlolam, Nett; 12 = Sokehs; 13 = Nett Point; 14 = Nett; 15 = Awak Pah; 16 = Peinais; 17 = Kepin Awak; 18 = Depehk; 19 = Takieu; 20 = Nanuh; 21 = Saladak; 22 = Oa; 23 = Paliapailong; and 24 = Pehi en Pwok, And Atoll.

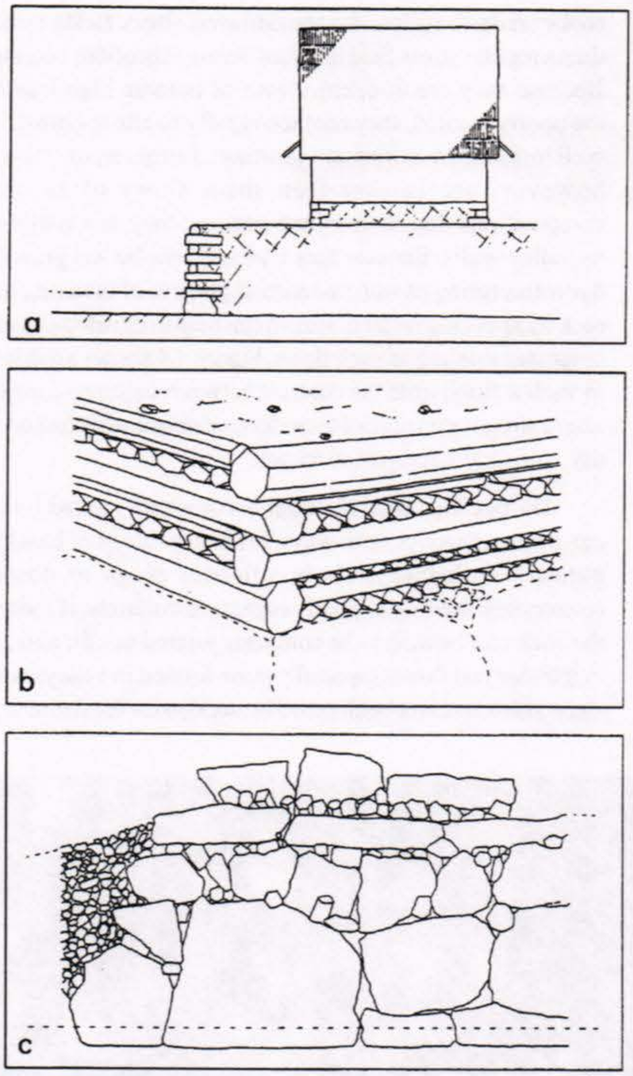

FIGURE 4.3. Illustrative Pohnpei stone building styles: (a) generalised cross-section of artificial islet with pole and thatch house structure; (b) header and stretcher construction; and (c) wall section of Pahnwi Islet (PWI) showing construction style with boulder base and columnar header and stretcher above. The largest boulder in the wall base is approximately 3.5 m across.

*Geology of Pohnpei Island and the region*

The volcanic island lineament of Truk, Pohnpei and Kosrae in the western Pacific has been proposed as a hot-spot trace (Mattey 1982, and references cited therein). The arguments by Mattey are not entirely convincing, especially in view of the known complexity of tectonic relationships along and near the Caroline Ridge. Pohnpei, the largest volcanic island in the eastern Carolines, was represented in Mattey's study by only 30 samples, all from relatively young rocks of the post-shield building stage. Although his work provides a valuable initial database, both Goles and S. Spengler (with whom Goles is collaborating on a broad study of Pohnpei) believe that extension of Mattey's work and re-examination of his major conclusions are necessary.

Pohnpei and Kosrae are both high volcanic islands with lagoon bounding reefs and some nearshore fringing reefs. Thus, they provide a notable diversity of resources and ecological microenvironments. Among the resources, lithic materials for large scale construction and tools, and clays suitable for pottery are of major concern. Distribution of these resources on Pohnpei as well as general features of the island's geology are known to some extent, while Kosrae remains largely unknown geologically. Little geological work has been done on Pohnpei and thus Goles's field studies so far have been largely reconnaissance and mapping of selected areas (also see Spengler 1990). The volcanic geology is known to be complex with numerous areas that could potentially be sources of columnar lavas and tuffs which might have been exploited by the builders of Nan Madol and other sites around the island. While the recent geological age (*ca* 9 to 4 million years; Mattey 1982; Yagi 1960) and topography do not suggest the presence of extensive clay deposits for pottery production, high quality smaller deposits have already been located - some have been sampled by Ayres, Goles and Robert Bryson in 1988 and 1989 - and secondary clays are widespread throughout the island's lower elevations.

Availability of geological and other resources contrast markedly between high volcanic islands and low coral atolls. Certain geologic features of Pohnpei are, however, both unusual (perhaps even unique) and relevant to our present concerns. Extensive use of columnar-jointed rock (see, for example, Aydin and DeGrafe 1988) in archaeological contexts is a remarkable feature of the island. We must consider whether resource availability has played an important role in encouraging such uses.

Oceanic volcanic islands possess excess gravitational potential energy, of which they rid themselves by slowly sinking beneath the sea, as for instance the older volcanic edifices of the Hawaiian-Emperor Seamounts chain have done. In part also, most of them respond by spalling off sections of their flanks along circumferential normal fault systems, so that large blocks (in some instances many kilometres in typical lateral dimensions) slowly slide into the sea around the margins of the islands. As long as at least one of the principal shield volcanoes of the island is active, the half-graben-like features formed by this large-scale mass wastage tend to be filled in by fresh volcanic products. When the shield-building stage is over, both erosion of the shield(s) and detachment of large blocks along circumferential faults act to develop valley systems and marginal plains. Typically, after a period of quiescence, the shield-building stage is followed by eruptions of small-volume alkalic magmas, many from parasitic vents scattered about the perimeter of the shield or on the alluviated plains that now surround the eroded shield. As these vents in turn become inactive, they tend to be plugged by the last batch of magma to approach the surface. Such vent plugs typically form masses of columnar-jointed lava upon cooling.

But there is another, relatively uncommon, way in which columnar-jointed igneous rock can be formed on oceanic high islands. Most lavas of such islands, whether of the shield-building stage or the later alkalic eruptions, tend to form rather thin flows. Important exceptions are the highly silicic lavas and domes formed as part of the late stages of volcanism on most such islands. These typically form very steep-sided rock masses, but tend to be very irregularly jointed because of their large viscosities, which cause the rock to 'remember' stresses imposed while its parent magma was slowly flowing. Thus, jointing in such rocks tends to follow the remembered stress fields rather than a regular stress field imposed during subsolidus cooling. Because they are thin, most lavas of oceanic high islands are poorly jointed; they cool too rapidly to allow growth of well organised columnar jointing. Intracanyon flows, however, are thicker than sheet flows of similar compositions and temperature because they are confined by valley walls. Because they typically overlie wet gravels, hydrofracturing (a well understood process of breaking hot rock by applying water or steam) can help to develop elegant columnar jointing in such flows. Figure 4.4 shows a roadcut in such a flow; note the contrast between columns formed above stream gravels and those formed above what had been dry land (left hand part of view).

On oceanic volcanic islands columnar jointed rocks can form in three general ways: (1) as vent plugs of basaltic parasitic volcanoes; (2) in siliceous plugs or domes (commonly leading to poorly organised columns, if indeed the rock can be said to be columnar jointed at all); and (3) in intracanyon flows, especially those formed in valleys with steep sides and wet bedloads. The conditions for formation

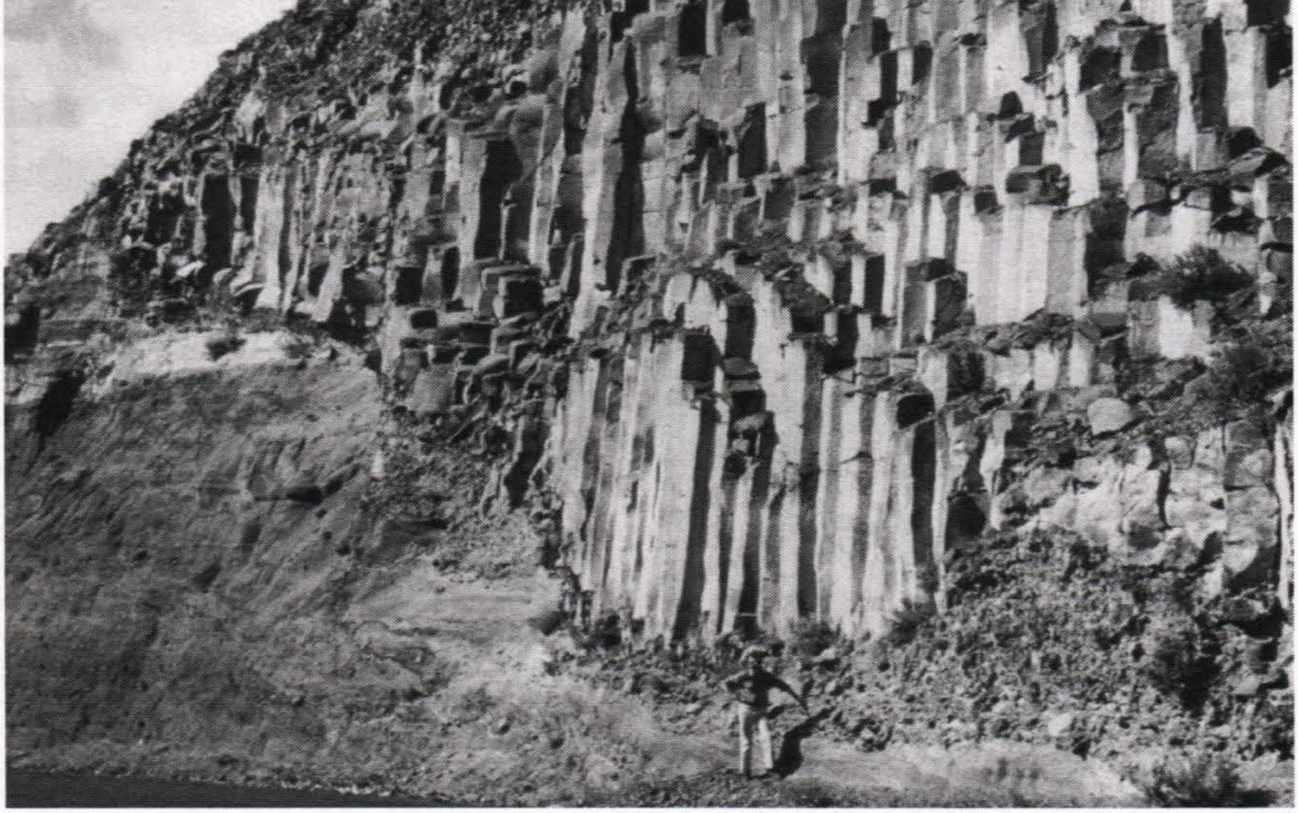

FIGURE 4.4. View of columnar basaltic lava. This shows a roadcut in an intra-canyon "Rimrock" lava of the Deschutes Formation in central Oregon. Elegant columns formed in and near the centre of the lava by hydro-fracturing because water held in stream gravels; jointing of the margins of the lava, where it flowed over dry land, is much less elegant. Geologist shown for scale is about 1.80 cm tall (G. Goles).

of columnar-jointed intracanyon flows are rarely encountered on most high islands. On Pohnpei, however, it is known that normal faulting radial to the centre of the shield was a characteristic response to excess gravitational potential energy during much of the later tectonic and volcanic history of the island, for reasons not presently well understood. Spengler (1990) has suggested that large scale mass wastage facilitated by as much as 1300 m of soft foraminiferal ooze and cherty limestone beneath the Pohnpeian shield was a factor in the post-shield structural deformation at Pohnpei. This thick, soft sediment layer was penetrated by a Deep Sea Drilling Project drillhole about 290 km south of Pohnpei; Spengler suggests that it continues north beneath Pohnpei. We concur and speculate that it may lie beneath Kosrae as well. Post-shield structural deformation of Kosrae has not been studied. Whatever the cause(s) of the style of faulting seen on Pohnpei, it has formed a number of valleys with relatively steep walls radiating away from the high ground near the present centre of the island. Evidently, such valleys existed in the geologically recent past as well, and were typically narrower than those seen now, because Pohnpei possesses an unusually large number of intracanyon lava flows, many with margins now exposed by erosion and most with very well developed columnar jointing. (Pohnpei also possesses several notable vent plugs, although all of these known to us are located at some distance from the present seacoast, so that columnar rock from them cannot be easily transported to building sites such as at Nan Madol.) The island apparently has been slowly sinking, as expected, so that several of these strikingly columnar jointed rock masses are now located within easy reach of water transport.

Goles has spent two field seasons on Pohnpei and has mapped in moderate detail the Temwen Island subsidiary volcano, on the southeastern shore of which the Nan Madol complex is built. The Temwen volcano has some intriguing features: it began to form as a tuff ring, with seawater evidently having access to the magma column at a shallow level. The centre of this tuff ring, however, is occupied by subaerial lavas, apparently comagmatic with the earlier pyroclastic material. Both the tuff and the lavas have been used as part of the construction materials for the Nan Madol sites. Thus, detailed compositional characterisation of these (in part already completed) will be of interest in the context of the main thrust of this research, that is, provenance of Nan Madol building materials. The results, including geochronology and studies of isotopic ratios, are likely to help in understanding changes in erupted material as the style of eruption shifts from phreatic to a relatively quiet effusive one.

## METHODOLOGY

Determining the provenance of stone building materials, combined with artefact distributional data and associated architectural styles, aids in documenting relationships among social and political centres. Recent University of Oregon INAA (instrumental neutron activation analysis) characterisation of columnar building materials from Nan Madol demonstrates sufficient differences in elemental composition among the samples for determining quarry specific provenances. This finding is encouraging because it can be extended to pottery and localised clay resources, although differences in these materials are not expected to be as striking as those for the volcanic rock building materials, especially as the clay sources appear to be much more numerous.

### *INAA and provenance studies*

As was demonstrated by Randle *et al.* (1971) and by many others since, instrumental neutron activation analysis is a powerful technique for 'fingerprinting' rock, tephra, clay and soil samples. Both because INAA has favourable characteristics for use in provenance studies, and because Goles has extensive experience in applications of the technique (he led the team that first developed INAA in its modern guise, for use on lunar samples), this was the analytic technique of choice for this research project. INAA allows accurate and relatively rapid determination of abundances of many minor and trace elements which can be highly diagnostic in geological materials. Some of the most useful of these elements, such as Sc (scandium), La (lanthanum), Sm (samarium), Lu (lutetium) or Hf (hafnium), can be determined by INAA with imprecisions (single relative standard deviation level) of about 1-2%, and comparable accuracies. This capability allows one to make very reliable characterisations of artefacts and source rocks and determinations of provenance, and to distinguish sources that differ only slightly in composition.

In addition, we have already made some use of x-ray fluorescence (XRF) (courtesy of Prof. Peter R. Hooper, Washington State University) in studies of rocks from Pohnpei and plan to continue using this technique. XRF provides very accurate data for elements such as Ba, which makes the technique a useful adjunct to INAA. (For a discussion of XRF techniques, see Chapter 10.)

Control over intra-source variability is fundamental to successfully fingerprinting construction material (see Chapter 10). Given the range of determined values and the sorting done to date, it seems possible to systematically develop these data for most regional quarries. The research plan calls for systematic sampling to map in detail the discrete geochemical compositional occurrences across quarries, especially one main quarry representing probably the largest source exploited on the island, Saladak in Uh. But just finding the building stone quarries is a long term project; however, at least the limited number of potential quarries on the island makes it feasible to sample for regional sources. Grid and transect sampling was successfully used on Rapa Nui (Easter Island) obsidian quarries (see Beardsley *et al.* 1991) and we expect to employ this technique further in Pohnpei.

Our efforts are interdisciplinary in nature, integrating perspectives and methods from geology and anthropology to address questions of prehistoric resource exploitation and processes of sociopolitical transformation that may be reflected in changes in use related patterns.

## RESULTS OF POHNPEI LITHICS STUDY

### *Geological mapping*

Goles mapped the major geological features of Temwen island adjacent to Nan Madol and did a reconnaissance in other parts of Pohnpei. These efforts are essential for both the stone building and the clay/ceramic materials research. Because we now have some chronological control over the age of construction of many islets, Goles is analysing additional rock samples from stone used in construction.

### *Lithology*

Based on lithologic characteristics, Goles has identified 13 types of rocks used in Nan Madol construction and has employed these data in descriptions of various archaeological features. Goles and Ayres mapped the occurrence of these rock types in one major architectural face of the site's major tomb (Nan Douas, 60 m long by up to 8 m high); this work demonstrated that the wall had either been built using different source materials or that sections were rebuilt (Sample shown in Fig. 4.5). In a second case, mapping the stone distribution exposed in an artificial islet surface, Pahndipap, helped to illustrate construction and stone type differences at *ca* A.D. 800 for the earliest artificial islet compared to an expansion completed at *ca* A.D. 1200 (Fig. 4.6). This type of detailed mapping is an invaluable aid in site description while the lithological data complements the geochemical results for provenance determination.

### *Geochemistry*

Three groups of stone samples from Pohnpei have been analysed using INAA techniques. One completed in 1987 demonstrated a marked compositional variation among samples. The results showed that the investigation of artefact provenance was feasible. The second group analysed in 1988 fully confirms that the building rocks can be geochemically fingerprinted. A third group was processed in 1990. The results from samples processed thus far show that scandium and barium elemental ratios are good traits for distinguishing columnar rock building materials according to quarry. A

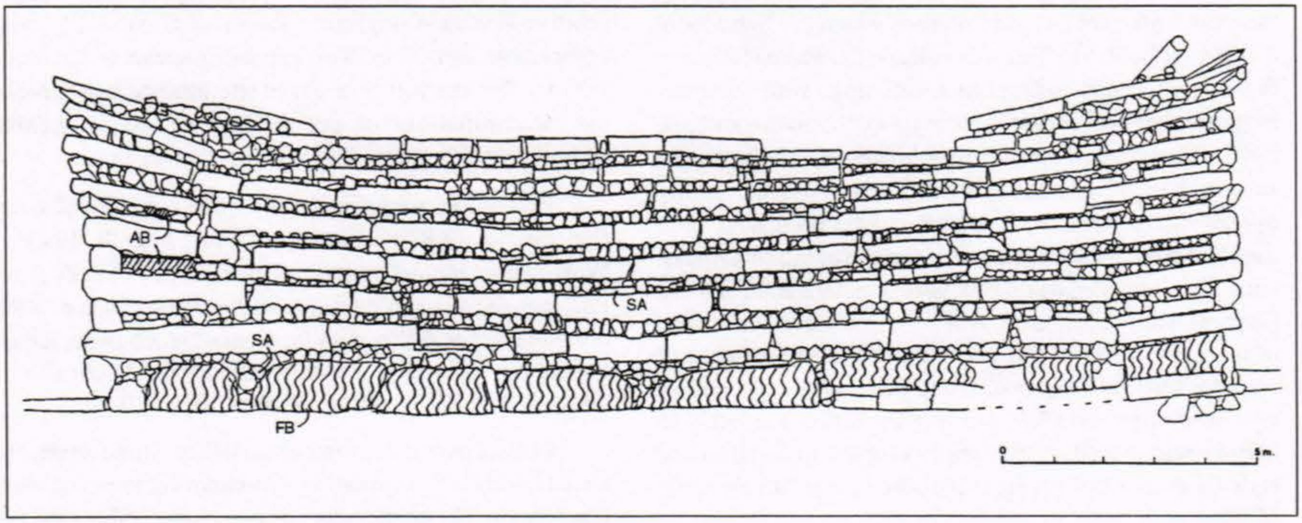


FIGURE 4.5. Face view of columnar lava construction in the southwest side of the main entry wall, Nan Douwas tomb, Nan Madol. Rock type codes are the same as in Figure 4.6.

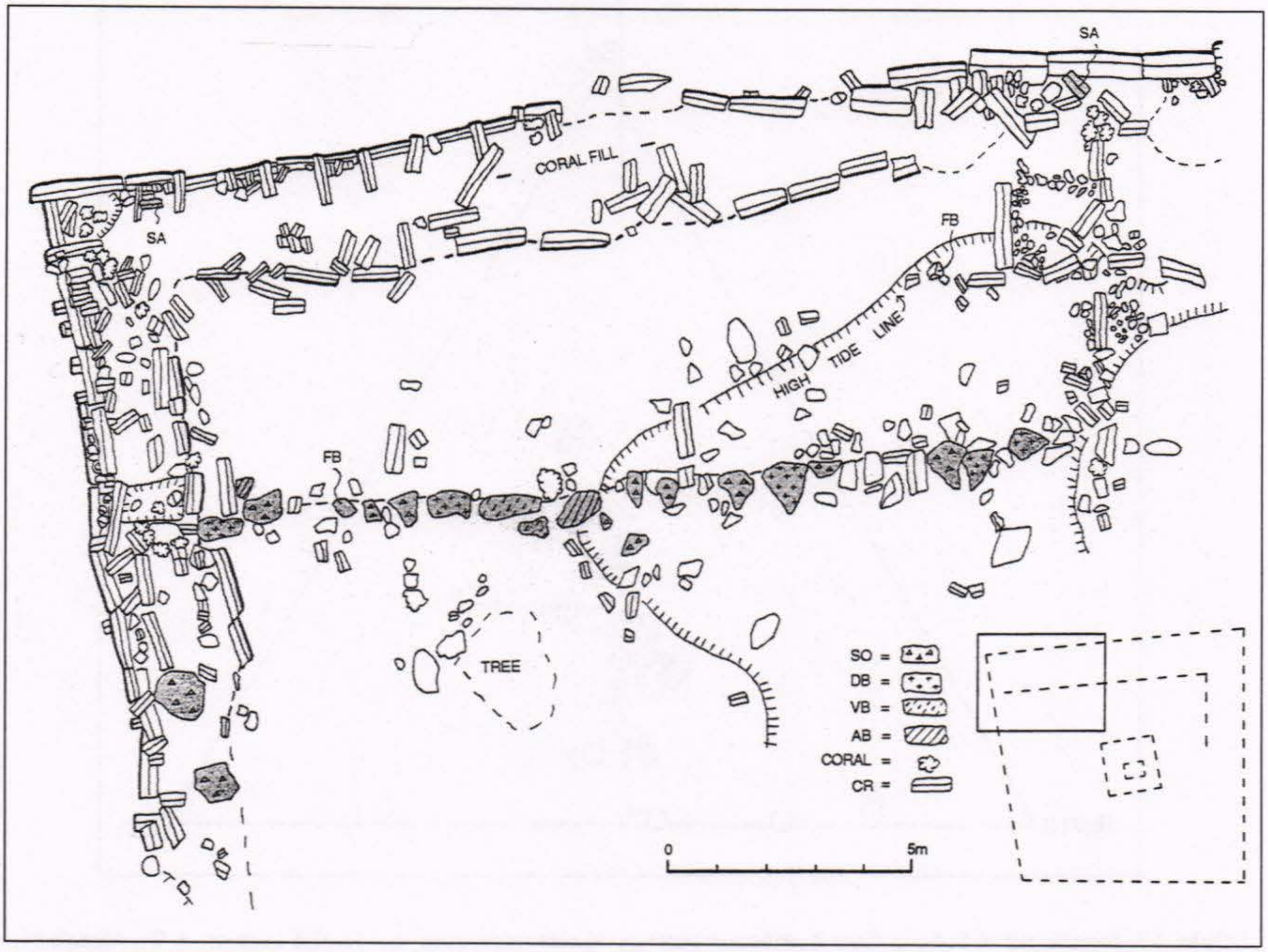


FIGURE 4.6. Distribution of stone building materials in the northwest corner of Pahndipap Islet, Nan Madol. Inset shows location of corner of Pahndipap Islet shown at 1:100 scale to illustrate variation in building stone types. Unshaded rocks represent CR code (Crystal-Rich); shaded ones include AB = Aphanitic Basalt; DB = Dense Basalt; FB = Flow-Banded; SO = Sparsely Porphyritic Olivine Basalt; SA = Sparsely Porphoritic Augite Basalt; VB = Vesicular Basalt. The alignment of boulders of varied building materials represents the earliest part of the construction.

ternary plot (Fig. 4.7) shows distributions reflected in Sc-Ba-La (scandium-barium-lanthanum) data. Evidently, most specimens exhibit a nearly constant Ba/La ratio of about 5.5, with a wide variation in Sc contents so that points on the diagram are spread out from that for (Sc-poor) *sakau* stone from Pahnwi islet to that for one of the Nett sources, Sc-rich (no. 13). Superimposed on that trend is a subsidiary one of variation in Ba contents with only slight changes in Sc/La ratios, from the Ba-rich (nos. 15-17) to relatively Ba-poor stone from Nett (no. 14). Note that preliminary interpretation of geochemical data on the volcanic glass (no. 27) strongly suggests that it is not from Pohnpei but was imported from a source located to the south, possibly in the Solomon Islands volcanic arc. Because Sc, unlike Ba and La, is hosted in mafic minerals (especially clinopyroxenes) in these rocks, the main trend is entirely expected from well established considerations of trace element distributions in igneous rocks. It suggests that some of the distinctions seen in Figure 4.7 might be detected by petrographic studies alone, without the effort and expense of INAA analysis. No rationale can at present be given for the subsidiary trend. Overall, distributions of points on Figure 4.7 imply that INAA directed at accurate determination of only three elements, La, Ba and Sc, would discriminate clearly among sources of archaeologically important lithic materials on Pohnpei.

## CONCLUSIONS

Provenance work on lithic materials in Micronesia has just started, but research in the region to date indicates that this is a very promising approach toward the understanding of the social, political and economic interaction spheres on both the local and regional scales. Within the broader regions

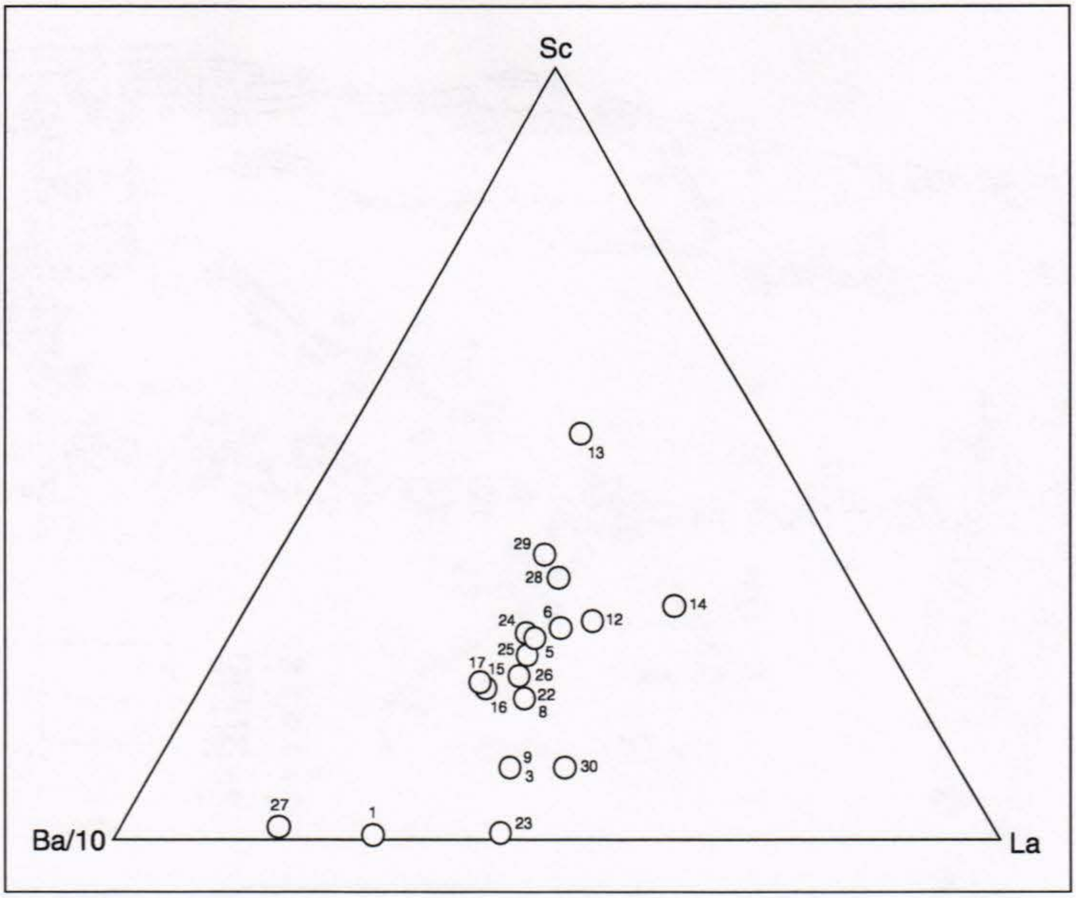


FIGURE 4.7. Ternary plot of Sc-Ba-La (Scandium-Barium-Lanthanum) elemental ratios. 1 = Takaiuh trachyte; 3, 9 = Madolenihmw source (Paliapailong); 5, 6 = Madolenihmw source; 8, 22 = Awak columnar stone (in construction); 12-14 = Nett sources (3); 15-17 = Awak sakau stone quarry; 23 = sakau stone, Pahnwi islet, Nan Madol; 24, 25 = Pusen Malek, Palikir source; 26 archaeological stone (adze specimen); 27 = archaeological stone (volcanic glass); 28 = Nan Douwas CR columnar lava building stone; 29,30 = possible quarry sample.

of western Micronesia and central-eastern Micronesia there are quite different questions and research problems related to long distance movement of lithic materials. These require significantly different methods to interpret local level exchange, principally intra-island, compared to inter-island regional exchange across linguistic and cultural boundaries. Successful studies of exchange must necessarily examine such activity on a regional scale as well as link the study of resource availability with provenance determination of archaeological materials. Ceramics could complement the examination of non-ceramic exchange items as well. And any provenance studies within the diverse regions of Micronesia must take into account that long distance exchange or trade has taken place within the context of three levels of island interaction, as documented from oral history, archaeological remains and compositional analysis: (1) high island-atoll interaction; (2) high island-high island; and (3) extra-Micronesian contact.

Specific conclusions regarding the Nan Madol building materials are limited in present scope because of the massive scale of the quarrying and transport efforts. An estimated 750,000 tonnes of stone were brought into the site complex and based on lithological and geochemical examination these are from diverse sources. Given that the population of Pohnpei during the Nan Madol construction period was probably no more than 25,000, the 100 artificial islets and associated stone features must have required a substantial per-capita effort, perhaps comparable to that of constructing the Egyptian pyramids. Preliminary results of the geochemical study to determine the provenance of the Nan Madol building materials are promising and will be extended when data analysis from the most recent experiments is completed; it is clear that at least four geochemically distinct sources for columnar basalt can be distinguished. Source distribution suggests a complex regional administration and there was stone transport even to nearby atolls (And Atoll).

There is a clear trend towards increased standardisation of building materials with time, based on lithological characteristics. Also, as the centralised sociopolitical system collapsed it is apparent that the size of building materials of even the most complex structures created after *ca* A.D. 1500 decreased substantially and that extensive re-use of building materials was taking place, thus fitting the expectation of compensatory behavioural patterns providing for extension of material life and material substitution as sociopolitical change made access to massive stone columns difficult. Determination of provenance for stone boulders and slabs used at Nan Madol is underway in parallel with the studies of columnar basalt and suggests that several additional sources were used. Once possible quarries are located, studies of intra-quarry geochemical and lithological variability will be undertaken and should provide additional insights into use of stone by ancient Pohnpeians.

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