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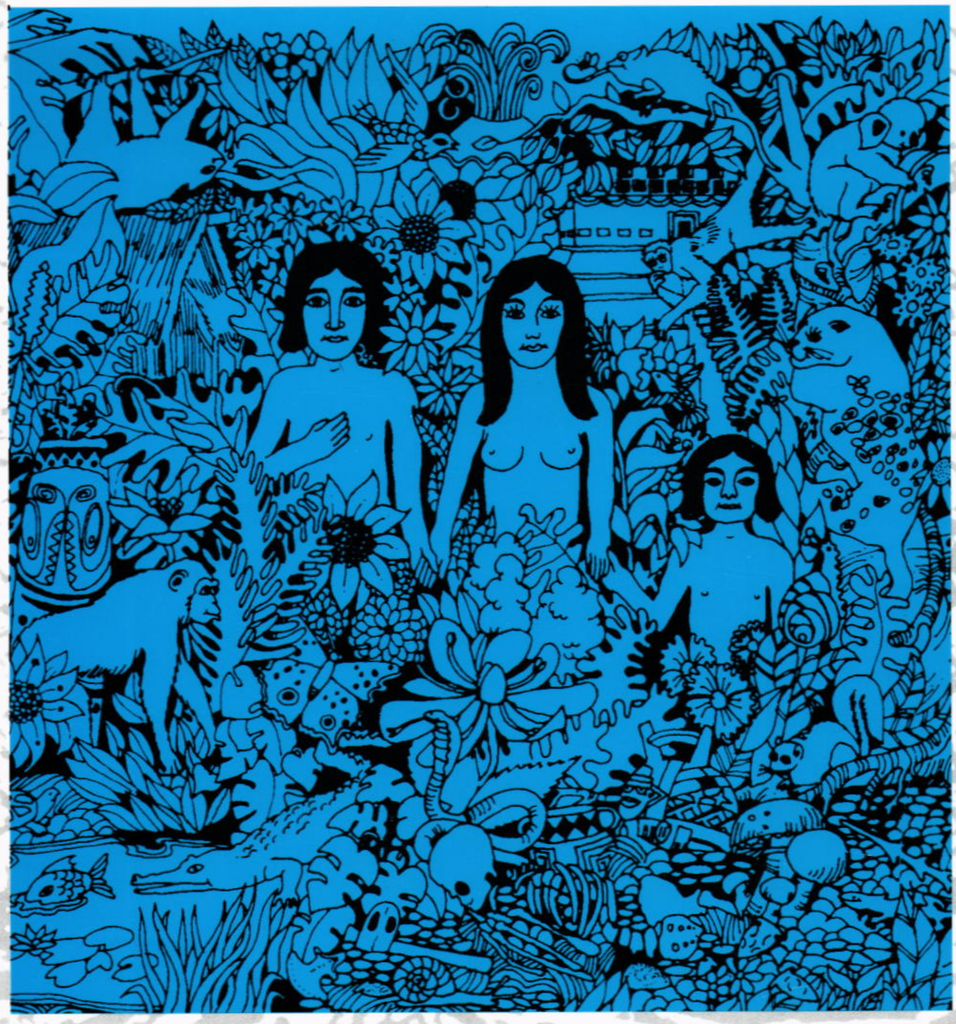
Stuart Bedford, Christophe Sand and David Burley (eds), ***Fifty Years in the Field: Essays in Honour and Celebration of Richard Shutler Jr's Archaeological Career***



FIFTY YEARS IN THE FIELD. ESSAYS IN HONOUR AND CELEBRATION OF RICHARD SHUTLER JR'S ARCHAEOLOGICAL CAREER

Edited by Stuart Bedford, Christophe Sand and David Burley

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NEW ZEALAND ARCHAEOLOGICAL ASSOCIATION MONOGRAPH

STATUS ARCHITECTURE AND STONE RESOURCES ON POHNPEI, MICRONESIA: EXPERIMENTS IN STONE TRANSPORT

William S. Ayres and Christopher J. Scheller

INTRODUCTION

Research on Micronesian prehistory has been greatly furthered by the work of Richard Shutler Jr. and co-researchers over several decades. Early archaeological examination of colonisation centred on ceramics recovered from Melanesia and western Micronesia and Shutler was active in these endeavours (e.g. Gifford and Gifford 1959; Gifford and Shutler 1956). He later helped formulate a general prehistoric sequence for the Central Caroline Islands based on ceramics from Chuuk Island (Shutler *et al.* 1977; Takayama and Shutler 1978; see also, Sinoto 1984). A related aspect of work by Shutler and co-researchers concerns provenance of pottery based on petrographic analysis to determine whether they were of local or foreign manufacture based upon their mineralogical character (Descantes *et al.* 2001; Dickinson and Shutler 1979, 2000). This research has inspired a range of other provenance studies including ones on Pohnpei, Micronesia, that extend the issues of long-distance pottery transport to distribution and use of stone as a resource material (Ayres *et al.* 1997). The particular application addressed in this paper is with stone building materials, intra-island distribution patterns, and transport methods.

EXPERIMENTAL ARCHAEOLOGY

Experimental archaeology represents a long tradition of exploring material culture correlates of human behaviour through the re-enactment of behaviours linked to the acquisition, shaping, and use of raw materials that occur as part of the archaeological record. The research discussed here addresses some basic questions about stone transport for construction and tool use through experiments in a living cultural context that is often unavailable for archaeological inquiry. Our study is designed to improve understanding of stone transport methods used in traditional technology contexts in general and to participate in the process that people in the Micronesian islands now are engaged, that of maintaining knowledge of their own past, deciding which information is significant and reliable, or even recreating it. This has become a salient feature of island life in much of the Pacific brought about by the rapid transformations accompanying the emergence of internationally-involved Pacific microstates.

Archaeological experiments have been conducted either in the laboratory (e.g. Keeley 1980), at archaeological sites (Coles 1979), or in cultural settings where indigenous practices can be observed and recorded in a controlled fashion. The latter include projects such as flake stone tool manufacture in New Guinea (White and Thomas 1972) and stone tool use in Venezuela (Carniero 1979). While the laboratory offers the advantage of being able to control selected variables precisely, the existing cultural setting offers insight into "real life" or living culture contexts in which other parameters can be established. In these cultural contexts applicability to direct historical contexts often can be postulated and a variety of factors can be considered that are pertinent for archaeological interpretation. However, archaeologists have debated the value of cultural-setting experiments and have raised questions about the extent to which the contemporary activities are part of a living, continuing tradition or simply a "memory culture" reconstruction possibly inconsistent with actual prehistoric or traditional practice. In many cases these have been carried out as a supplement to other investigation and perhaps were not controlled or recorded as completely as would be optimal for a scientific experiment. Also, in most cases these have been conducted in cultural contexts where the pre-metal technology itself had totally or largely passed out of use. Thus, as in Carniero's (1979) experiment in which a local person who had never used a traditional stone tool was asked to fell a tree with a ground stone axe, the ability to control critical cultural and technical variables is drawn into question. In these cases, while it is possible to document various aspects of the materials themselves, e.g. the kind of stone or shell or thatching materials, the material culture itself is no longer within a functioning systemic context. Thus, care must be taken in formulating a research design suitable for extracting archaeologically relevant data from experimental efforts; this is true for both laboratory cases as well as "field" experiments. Here,

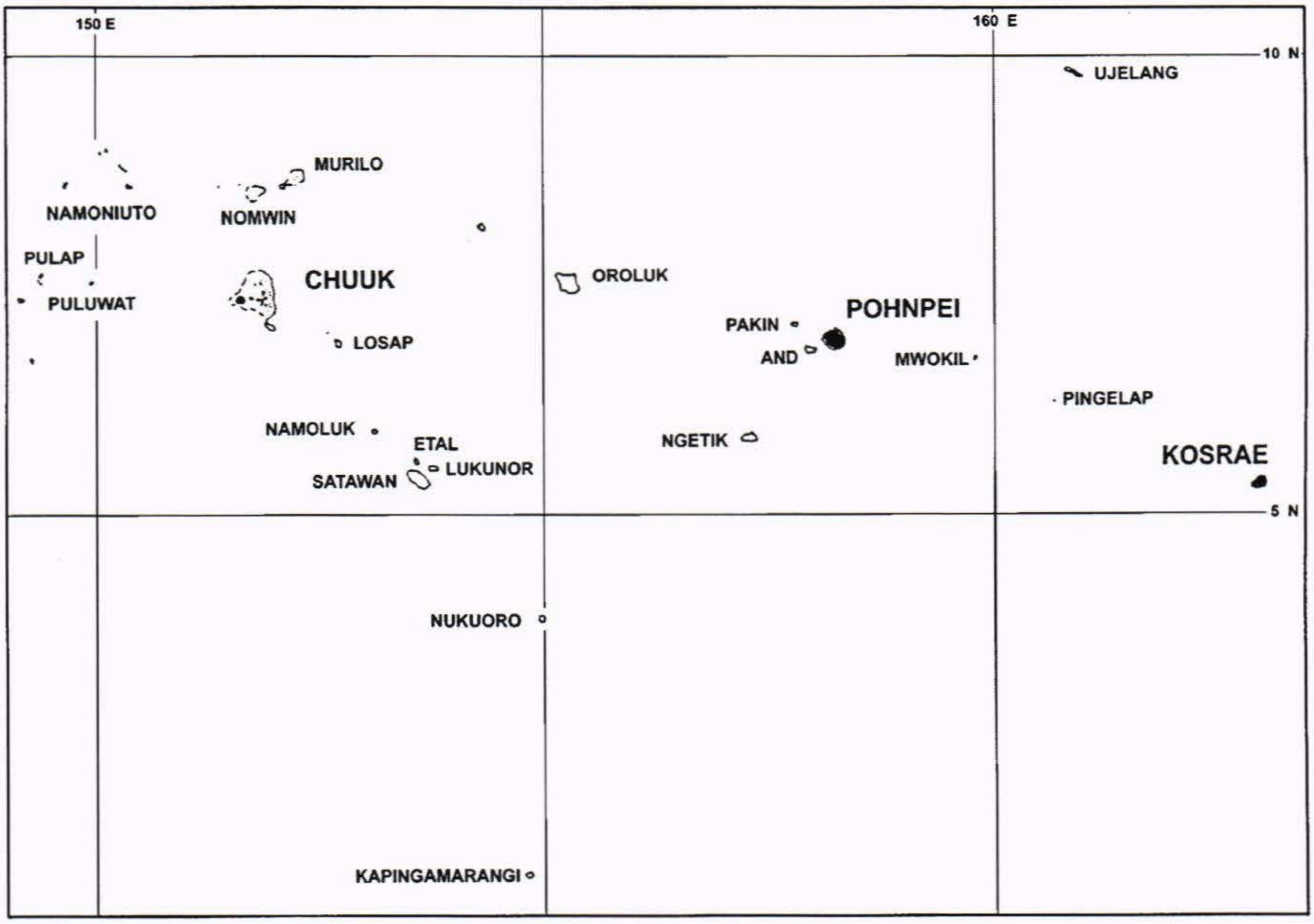

FIGURE 1. Map of the Pohnpei region of central Micronesia.

for Pohnpei, ethnoarchaeology provides models and parameters for experimentation. Both aid in developing more systematic linkages between material culture and human behaviour (Schiffer and Skibo 1987).

THE EXPERIMENTAL SETTING AND LOCAL ENVIRONMENT

Within the Pacific Islands, previous experiments carried out in cultural context – and with varying degrees of control – have examined stone and shell adze manufacture and use, shell fishhook manufacture, transporting stone images (e.g. Mulloy 1970; Van Tilburg 1994:151-158), and replication of traditional crafts made from perishable materials. Relatively little attention has been paid to transport of building materials despite its importance in Polynesia and Micronesia (but see Kolb 1994).

The experiments reported here offer detail about the transport of stone on Pohnpei Island, Central Caroline Islands, Federated States of Micronesia (Figure 1). While these preliminary experiments are modest and were in effect scaled (Coles 1979:42), they were conducted in the context of a functioning cultural system in which stone is still used in social and ritual ways. Boulders of up to 50-60 metric tons were moved in prehistoric times and some up to 500 kilos have been transported regularly from quarries to feast houses up until the present. The experiments discussed here include efforts to transport massive blocks and columns used in construction and other stones employed as heavy duty tools, especially as pounding anvils to prepare kava (*Piper mythisticum* or *sakau* as it is called) used in ritual feasting on Pohnpei.

Pohnpei represents a classic chiefdom that continues to function with redistribution supervised by ranked chiefs serving to provide access to both status and distribution of basic foodstuffs (Hughes 1983; Petersen 1982). Historically, stone construction of varying scales on Pohnpei helped to define and differentiate social status and political rank differences. Thus, in this analysis, monumentality is viewed as a key element in the identification of power (De Marrais *et al.* 1996) and the

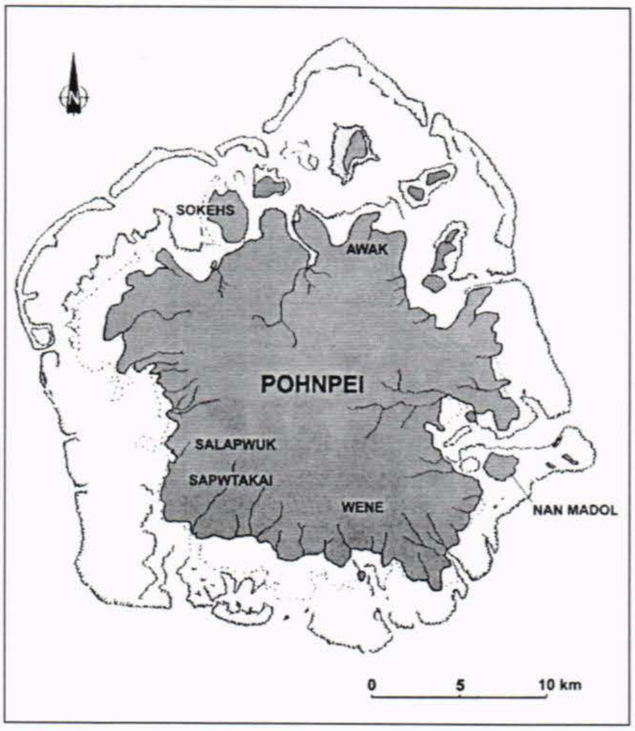

FIGURE 2. Map of Pohnpei Island showing major research areas, including Awak, Sapwtakai and Nan Madol.

research is part of an effort to define political inclusiveness through comparative quantification of architectural remains (see Abrams and Bolland 1999; Kolb 1994). Traditionally, the sizes of the foundations of Pohnpeian dwelling houses and meeting houses were carefully related to the status of the occupants, and tombs, which employed large and special kinds of stones in their construction, seem to have varied in similar ways (Ayres and Haun 1980; Ayres, Haun and Mauricio 1981). This status-linked use of megalithic architecture is most clearly represented at the Nan Madol site, the seat of the Sau Deleur ruling line on Pohnpei's east coast which united much of the island's estimated population of 25,000 in late prehistoric times (Athens 1980; Ayres 1983; Hambruch 1932). Nan Madol covers over 75ha and is comprised of approximately 300,000m^3 of stone building materials with a total mass of 0.5 to 0.75 million metric tons (Ayres 1990).

Research at Nan Madol shows a general pattern of construction style evolution determined from evidence derived from individual structures among the 100 artificial islets and from comparisons of various sections of the complex. Nan Madol appears to have a pre-construction occupation phase followed by an initial artificial islet stage where boulders were used with few or no columnar materials to form low, and generally small, islets. Dating of the oldest Nan Madol artificial islets continues to be complicated but they appear probably as early as A.D. 500-800. A later stage emphasising columnar basalt and free standing walls, some of which are up to 8m high, dates at least as early as A.D. 1200 and extends up to A.D. 1500. Following this, megalithic construction seems to wane throughout Pohnpei.

A volcanic landmass of somewhat over 310km^2 (120 sq mi), Pohnpei is the largest island in eastern Micronesia (Figure 2). As a high island it has a rugged, mountainous interior with elevations rising to nearly 800m (2600ft) above a fringing coral reef and a lagoon with scattered, small volcanic and coral islets. Stone resources were limited to a rather narrow range of volcanic rock types forming mostly over the last 5 to 9 million years. Most of these are considerably altered, as no recent volcanic activity is recorded. Coral available around the island's reef was also used extensively for building.

The use of stone for implements in Micronesia was restricted because of the few high islands offering suitable stone. Thus, within Micronesia most archaeological studies thus far have concentrated on shell tools and ceramics because stone implements are rare, especially in the eastern Carolines, the Marshalls, and Gilberts. Ayres and Mauricio (1987) have examined the rare Pohnpeian ground stone adzes, but other stone tools include primarily small pounders made from stream cobbles. Only Kosrae in eastern Micronesia shows developments in stone architecture comparable to Pohnpei (e.g. Cordy 1982).

NAN MADOL ROCK TYPES

The rock specimens moved in the experiments discussed here are prismatic columns and boulders of lava. These and other building rock types have been described by geologist Gordon Goles (Ayres *et al.* 1997) as follows:

One of the common kinds of columnar lava used in Nan Madol construction is a crystal-rich ankaramitic lava (Code CR) which commonly forms elegant columns (Aydin and DeGraff 1988). It has a pronounced, dense distribution of phenocrysts and microphenocrysts of black, glassy augite that stand out in positive relief on weathered surfaces, while brownish, negatively-weathering olivine phenocrysts accompany the larger augite ones. Other column forms that are common include two kinds of sparsely porphyritic basalt, one with predominantly augite microphenocrysts (approximately one per 5 to 10cm^2; Code SA) and one with predominantly olivine microphenocrysts (approximately one per 10-15cm^2; Code SO). These typically have a surface colour ranging from dark grayish brown to olive gray (Munsell 10YR4/2 to 5Y5/2; Geol. Soc. Amer. classif. N3 as a fresh exposure).

Studies are underway to determine the quarries for these material types, but geological mapping is very preliminary for Pohnpei and only a few of many potential quarry areas have been identified.

Massive boulders used in construction – most notably at Nan Madol – include ones of flow-banded xenolithic basalt (Code FB) and less commonly, tuffs (Codes BT and XT). The flow-banded basalt has common exfoliative weathering and highly weathered surfaces that are micro-cavernous. This rock type is common near the inland side of Nan Madol on the southern shore of Temwen Island, where it constitutes one of the lowermost lavas in the local stratigraphic succession. Collection localities for it, presumably used by the builders of Nan Madol, are close to the site in the form of prominent fault scarps along which the rock type is exposed as large blocks. A yellowish-brown weathering colour is common (Munsell 10YR5/4). Less commonly, tuffs were used as boulder building material; these include both bedded tuff (Code BT) and xenolithic tuff (Code XT).

Another distinctive rock type used as construction material and for tools was a trachyte, particularly from the Takaiuh plug, or a putative quarry near it in Madolenihmw District close to Nan Madol (Code TR). This shows a greenish weathering colour and the sugary, aphanitic texture is easily seen on weathered surfaces.

Other rocks recorded at Nan Madol as construction material include aphanitic basalt, which forms blocky, angular pieces (Code AB) and platy-jointed basalt (Code PB). Less common, but also widely found are breccia, vesicular basalt, diktytaxitic basalt, microprismatic basalt, and iron-mineralised rock. Studies underway on lithology and petrology and resultant stone structural characteristics should improve our understanding of stone selection and use.

POHNPEI TRADITIONS OF STONE MOVING

Massive stones are still moved today on Pohnpei, most commonly to acquire the flat slabs (called *peitehl*) used as a surface to pound kava roots (*sakau*) in feast houses (the *nahs*). However, tombs, feast house foundations, and large artificial islets on the coral reef, such as at Nan Madol, no longer are constructed using massive stones as they were in the past; now, instead, many smaller stones are collected for building meeting houses and dwellings and finishing is usually aided by use of cement. Cement has become important for providing a smooth floor surface which was made in earlier times with wooden floors and woven mats over coarse gravel surfaces. The prehistoric practice is best known from Nan Madol where massive boulders up to 50-60 tons and thousands of stone columns measuring up to 60cm across and up to nearly 8m long were transported for

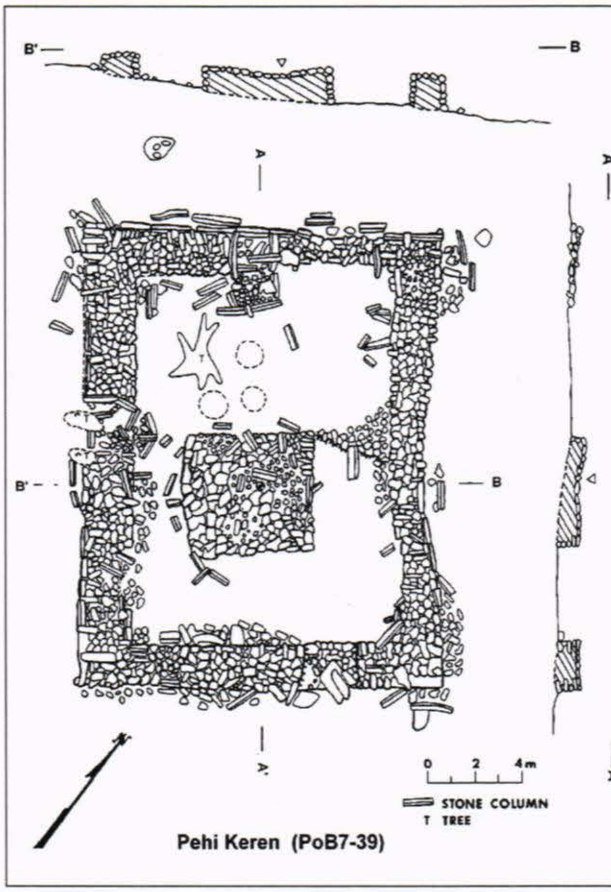

FIGURE 3. Plan of stone walled-tomb, Awak, Pohnpei (Site B7-39), showing use of small boulders and limited columnar rock. Age approximately A.D. 1500.

construction of foundations and walls. Most of the columns fall into the 0.5 to 2.5 ton range, but some weigh up to 6-8 metric tons. It is clear that most columns were transported from quarry areas located more than 10km, and some up to 30km, away from Nan Madol. There are no traditions of carving or shaping stone on Pohnpei other than for making some small tools.

Pohnpeians have oral traditions that speak to how the columns were transported; one widely quoted one is that the columnar rocks "flew" through the air to Nan Madol at the request of priests (Hambruch 1932). In addition, rafts of bamboo are said to have been used to float the rock from around the island through the lagoon to Nan Madol. While undoubtedly columnar rock was being transported and used in construction during the period of early outside Western contact when a number of direct observations were being written down, no reports of columnar stones being transported for construction are available.

THE ARCHAEOLOGICAL QUESTIONS

Several questions were considered in planning and conducting these experiments: 1) whether stone materials used in ritual context have different characteristics and transport requirements compared to non-ritual construction materials; 2) if experiments can help us determine the requirements and practical limitations of stone transport in the traditional context with regard to labour and other organisational logistics; and 3) how stone use, especially megalithic stonework, relates to the changing social and political status of corporate groups and of individuals. The first step in answering these is to review the kinds of stone available on Pohnpei and their known uses.

Kinds and Uses of Stone

Columnar lava pieces represent the most obvious and unusual stone shape and material type at Nan Madol and many other sites having religious or ritual significance. While columnar is rock is known from architectural sites, especially tombs (*lolong*), all around the island, the specific sources for such stone have been difficult to pinpoint (Figure 3). All the building stone materials do appear to be from Pohnpei itself rather than imported from another island; Pohnpei's nearest neighbouring volcanic high island offering suitable building stone, Kosrae, where columnar rock was used in similar ways, is over 400 kilometres away. Several general areas are known on Pohnpei where columnar rock is available, but other than massive columnar-jointed outcropping boulders that appear to have served as quarry faces, no extensive rock quarries for production of the tremendous quantities of columns required for the Nan Madol constructions have been confirmed. Because the rock extraction was done not by cutting the rock but by separating the columnar pieces at the joints few direct traces of the quarrying activity, other than broken pieces of columns, remain today. Hambruch (1932) did identify a few general localities based on oral history. What are interpreted as trans-shipment pier or dock facilities have been found at three sites and several quarries for columnar rock have been located and field studies initiated (Ayres *et al.* 1997).

Massive boulders were essential in the construction of Nan Madol and many other ritual architectural complexes on the island (Figure 4). These are used in less systematic ways compared to columns and appear in a variety of architectural types with no known ritual significance. The columns and the boulders were not shaped by the builders but used in forms that were selected from naturally occurring rock forms.

The source of the largest boulders used at Nan Madol appears to be the adjacent Temwen Island east coast and shoreline, in particular at what appears to be a fault line forming the coast just back of the old reef flat on which Nan Madol was constructed. The oldest Nan Madol islets have foundations and retaining walls constructed of boulders that are often 1.0-1.5 by 0.5 by 0.75m in size, all thus relatively small compared to the largest ones moved for later islet foundations. Our geological study suggests that most, if not all, of these stones come from Temwen (G. Goles, field report). The archaeological questions have to do with how the boulders were moved and the evidence is somewhat different than that for transporting the columnar stone. There is no specific oral tradition report of how boulders were moved and no massive ones have been included in construction in historic times. Because of their shape they would be more difficult to lift – but less likely to break from transverse stress – than the columnar rock. In most cases we believe these could have been dragged on wooden runners rather than being lifted. While there is no preserved record of stone or earth causeways extending across the reef that would have facilitated the movement of massive boulders from Temwen or other coastal locations, a rail-like support system of logs could have been used and have left no recognisable trace.

One of the very few known archaeological indicators of how possibly the larger stones were lifted and positioned in building comes in the form of carved grooves in the underside of a massive rounded column of trachyte, which is considerably softer than the standard lava stone forming the columnar construction material. This special, grooved stone was found at the NE corner of Peikapw Islet, Nan Madol, an artificial island measuring approximately 110 by 100 metres and standing 2 metres high. The stone now sits partially submerged in the mangrove swamp. As noted, the trachyte material is known from Takaiuh peak, a vertical volcanic plug located on north shore of Temwen Bay approximately 3 kilometres from Nan Madol. The stone measures 3m long, has a diameter ranging from approximately 0.6 to 0.8m and tapers to rounded ends; it weighs an estimated 3 metric tons. A few other similarly rounded columns of trachyte are known from other Nan Madol islets, but they are rare and they appear to lack the carved grooves. The pecked and ground grooves on the Peikapw boulder are approximately 6 to 8cm wide and up to 4cm deep and extend around approximately one fifth of the circumference of the column. The grooves are interpreted as points for lashing on a wooden beam. This beam may have been used just for carrying the piece to Nan Madol, in which case it may have been considered necessary because the column is rounded and would be difficult to control compared to the standard pentagonal or hexagonal column shapes. Pohnpeians worked trachyte as a raw material by pecking and grinding to form various grinding and sawing tools, and it is likely that they recognised in making the grooves that it would greatly improve the security of lashings.

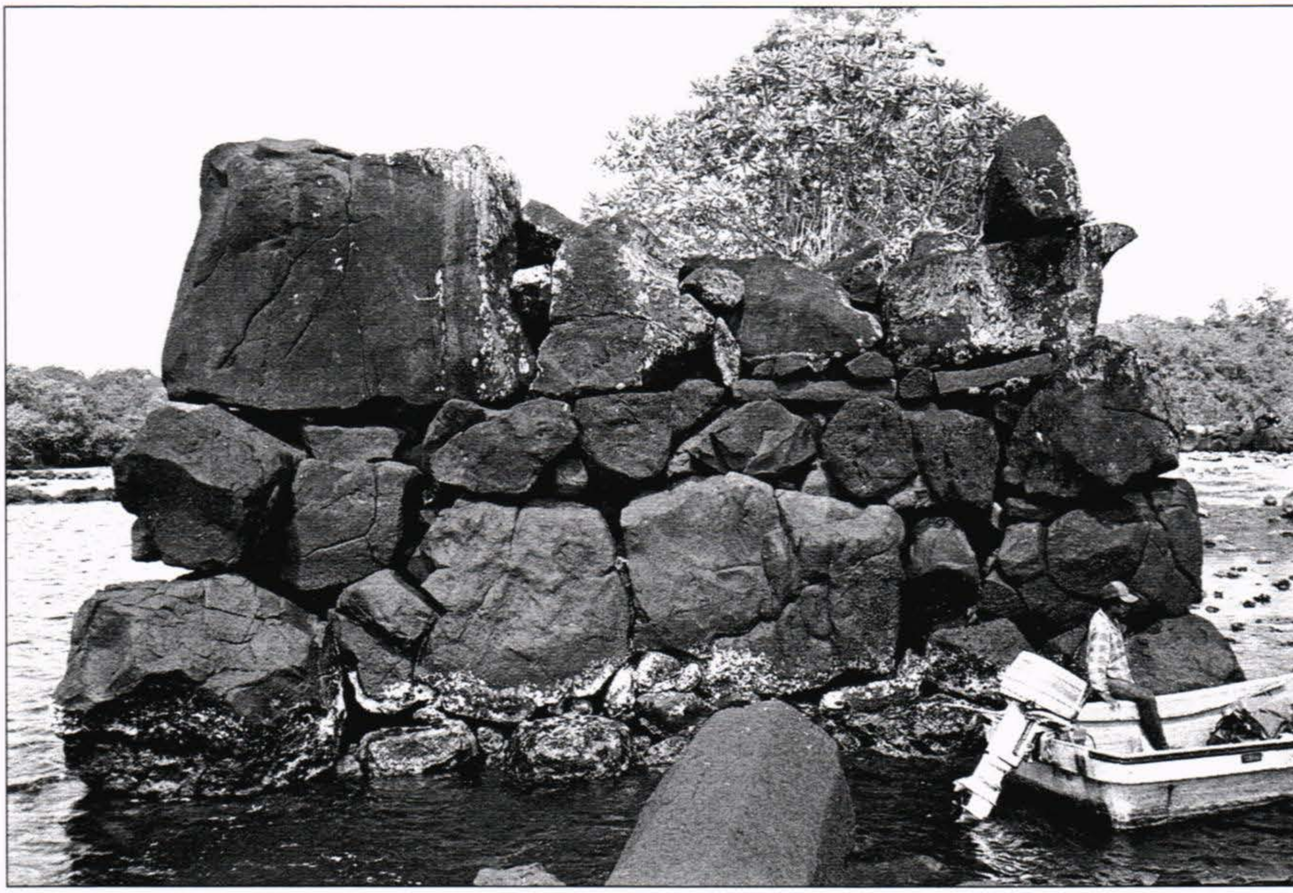

FIGURE 4. View of boulder construction at Nan Madol. Entryway at Nan Mwoluhsei seawall, Pohnpei (W. Ayres).

An hypothesis specifically related to the use of this unusual rounded column is that it was actually part of a machine for lifting columns or boulders used in the construction. The stone could have been an effective counterweight when fastened to a massive beam placed across a column or other rock used as a fulcrum. Thus a simple, but potentially effective, crane might have been used in lifting building materials from the rafts used to bring the stone in through Nan Madol's channels. A crew of men could have controlled the movement of the crane to lift and carefully position the larger boulders and columns. One of the basal corner boulders of Peikapw weighs an estimated 25 metric tons and presumably could not have been lifted with such a device. However, many other construction stones used in building the islet base, which is 1.5-2.0m high, and the enclosing wall, another 2m high, are on the order of 0.5 to 4 metric tons.

Based on the archaeological record and ethnographic context, it seems clear that stone materials used in ritual context have different characteristics and transport requirements compared to non-ritual construction materials. The relationship of special kinds of stone to status-linked architecture throughout the entire island makes experimental study of its transport and distribution of interest for addressing questions of changing social and political status of corporate groups.

EXPERIMENTS IN AWAK AND AT NAN MADOL

At the start of this project, then, some information was available about the archaeological and cultural context of megalithic and other stone construction on Pohnpei from studies extending back to the late 19th century. Still, the transport of stone building material was largely unrecorded and the specific techniques mentioned in oral history for handling large stone columns had not been directly observed. Two experiments were carried out to develop some basic information.

Kava Stone Transport in Awak

The first experiment in transporting stone using traditional techniques was carried out in Awak, Uh District, Pohnpei. We asked local residents to move a *sakau* stone using their usual methods. The process was recorded on film by

Odyssey Productions of Portland, Oregon, and through field notes. A flat slab of stone 20cm thick and approximately 1.2 by .75m in size was selected at Duwe Reirei quarry in Kepin Awak, which is known to have good *sakau* pounding stones. The stone slab has a mass calculated at 380 kilos. The quarry, which was recorded in earlier archaeological survey, is still used today and stones have been moved using the same methods described below for the experiment (Ayres and Haun 1980; Ayres *et al.* 1981). The tops of buried, vertically oriented rocks in locations such as this one tend to break off in thin segments as the stone alters and the jointing separates. In selecting a stone for use as a kava pounding surface (*peitehl*), size is a major factor as it should be large enough in its flat working face so that two to four people can sit around it comfortably when pounding the kava root; but it should also be of a size that a few men can move it around in the feast house after it is installed. That is, it often needs to be moved out from a temporary storage position at one side of the feast house's central open work area when it is needed for use in the floor pit where the kava pounding takes place. Thus, only stones within a certain size range, approximately 200 to 500 kilos, typically would be selected for transport to the meeting house (*nahs*). An important consideration in selecting the stone is whether it produces a distinctive bell-like sound when struck in a rhythmic way (*tempel*) with the stone pounder (*moahl).*

After the stone was selected for transport to the meeting house, it was fitted with an armature or frame of poles of hibiscus wood (*Hibiscus tiliaceous, kalau*) that were cut with machetes for the purpose so that a crew of 12 men could lift the stone and carry it to the *nahs* located approximately 150 metres away (Figure 5). The stone was shifted by hand into a position where it could be tilted up on one edge and then tipped over on top of two short poles 12cm in diameter and 1.3-1.5m long. These were later lashed on to two poles 10-12cm in diameter and 2.5 and 2.8m long that were tied parallel onto the top of the flat stone, thus cradling it within four poles. The two long poles formed the main lifting handles. All lashing was done with the traditional Pohnpeian rope, hibiscus bark strips. Approximately 15m of bark strips ranging from 3-5cm in width was used. The straps were wrapped around the intersections of the stone and the supporting poles five to six times and tied with simple square knots; main joints were re-knotted several times. Individual participants differed in how they made the lashing secure. Note that no pulleys, inclined planes, or even levers were used in moving this stone. The 12 crewmen discussed the arrangements and the positioning of the poles and also the route to carry the stone out of the quarry. A rough trail existed for part of the distance to the meeting house, but no special effort was expended in preparing a path or walkway for carrying the slab. The work was difficult because the quarry outcrop is exposed on a steep hillside and the route to the meeting house was uphill and across a small stream.

The entire process of making arrangements and transporting the stone took approximately six hours. The time required to actually carry it from the quarry to the meeting house after the poles were lashed on was one and a half hours, including two rest stops and one required re-lashing after thin hibiscus straps failed.

This transport was done in exactly the same way that *sakau* stones have been moved in Awak in recent times and was in no sense a "re-creation". Two weeks after the stone was moved, a feast was held in the meeting house and the stone surface was cleaned and *sakau* was pounded on it for the first time.

Experiments with Columnar rock at Nan Madol

Moving the raw materials for construction at Nan Madol represents a set of significantly more complex transportation problems than moving a *sakau* stone because most of the building stones were much larger, they often were selected because of their special shape, and they were transported from various locations around the island and across the coral reef flat by the tens of thousands. Note that none of the stones was carved or shaped; selection provided the only means of getting the needed shapes and sizes for construction.

The stones selected for the transport experiment were found in the destroyed East corner of Nahningi Islet, an artificial islet forming part of the massive complex of stone architecture at Nan Madol, but one lying outside the core complex called Nan Madol Central. A stone column at Nahningi Islet measuring 2.01m long by approximately 45 x 30cm across was the object of the first effort. This column, located at the north edge of Nahningi Islet, is hexagonal in cross-section shape with faces of 11,14,42,25,22, and 37cm, weighs approximately 1 metric ton, and is made of sparsely porphyritic lava (SA code). This column, which is approximately twice as heavy as the second column described below, could be just barely lifted by the assembled crew, so we shifted our attention to a somewhat smaller column.

The column transported was 1.43m long by approximately 36cm in diameter and had faces of 11, 20,13,18,10,22,15, and 16 cm on the octagonal end; its shape grades into a hexagonal shape at the other end. The stone material is sparsely porphyritic lava (SA code) and the column weighs approximately 422 kilograms (930 lbs).

This stone was fitted with an armature of poles of hibiscus wood (*Hibiscus tiliaceous*) – which is relatively

FIGURE 5. Transporting kava-pounding stone (*peitehl*) lashed to hibiscus (*Hibiscus tiliaceous*) poles, Awak, Pohnpei. This stone was carried using traditional techniques to a local meeting house (W. Ayres).

light wood – so that it could be lifted by a crew of 14 to 15 men. These men came from lands on Temwen Island, adjacent to Nan Madol, and the poles and bark strips were acquired there as well. One pole 12-14cm in diameter and 8m long was tied to the length of the column and then two shorter poles of 14cm diameter and 5m length were lashed on crosswise to form the main lifting supports. All lashing was done with the traditional Pohnpeian rope, the hibiscus bark strips. Approximately 12m of bark strips ranging from 4-6cm in width was used. The straps were wrapped around the intersections of the stone and the supporting poles five to six times and tied with simple square knots.

In order to determine what kind of raft size and construction would be effective for transporting columnar rocks across the reef or through canals in the mangrove swamp to get them to Nan Madol, we prepared a raft so that the crew could place the stone column on it to see how well it would float and how it could be manoeuvred. The raft was constructed of three single layer floats, each consisting of six to eight bamboo poles ranging in diameter from 4.5 to 12cm, that were lashed together on top of one another. The three single layer bamboo floats or rafts had been constructed previously for the use of families living on nearby Temwen Island. The raft poles ranged from 7 to 9m in length and in total the 21 pieces formed a raft approximately 75 to 80cm wide and 35cm high. Large bamboo pieces are somewhat difficult to find today and are considered quite valuable so we were unable to acquire materials to make a larger raft construction.

The experiment was conducted when the tide depth was approximately 0.8 metre above the sand covered reef surface around Nahningi (Figure 6). This afforded an optimum working depth for persons trying to lift and move a heavy stone when they were standing in water. The total time for making arrangements and moving the column was approximately one day. Once the poles and bark straps were available, the process of lashing the poles, lifting the stone, and placing it securely on the raft (Figure 7) and then determining the raft's manoeuvrability took only approximately 2 hours. It was clear that the loaded raft could be poled by one or two persons almost as rapidly as a canoe.

FIGURE 6. Preparing to lift a stone column at Nan Madol (Naningi Islet) for experiment with rafting as a transport method. Bamboo raft is at left centre (S.Heiser).

In sum, the experiments aided in establishing the requirements and practical limitations of stone transport in the traditional context with regard to labour and logistics. As a scaled experiment, we were able to demonstrate the feasibility of using rafts for transporting stone columns across the reef to the building sites.

CALCULATIONS AND COMPARISONS

Stone Transport Issues

As a way to quantify the labour effort; we calculated the weight/person lifted in the experiment. While we expected that it might be as much as 50 kg/person, it was determined to be only approximately 31-33 kg/person in each case (this includes the weight of the poles/frame). Thus, without formal planning the appropriate number of individuals was arranged for each transport project to allow for a similar effort on the part of each person. Pohnpeian task leaders understood how many people would be required to lift and move the stones.

There have been several archaeological experiments with carrying stones on the order of 1 to 2 tons. For example, at La Venta, Mexico, where studies of early chiefdom architecture were done (Drucker *et al.* 1959), 35 men were required to lift and move a 1.5 ton (1363kg) column a short distance. The weight/person ratio here would be 39 kg/person (presuming that the weight reference is in English tons rather than metric tons; Heizer 1966:825). Another pertinent case of stone transport by carrying also shows a similar weight/person ratio to that reported for Pohnpei. Lehmann (in Heizer 1966) had 35 local workers transport a 1.0 ton (presumed metric ton) stone sculpture on a litter over a distance of 7 kilometres through jungle and wet, rugged terrain in Colombia. This took 7 days. Including an approximate weight of 100 kilos for the litter, the weight/person ratio would be 31 kg/person.

The summary statistic of weight lifted/person masks the difficulty of moving the stones over rough terrain where irregular footing and access to poles to lift against results in considerable variation in the actual weight any

FIGURE 7. Floating stone column of 0.5 metric tons on a bamboo raft, Nan Madol, Pohnpei (W. Ayres).

individual would have to support in moving the stones. Thus the shifting amount of lifting support, perhaps from 0 to 75kg, required of individuals is an important consideration in successful transport; cooperation in responding quickly to shifts in the stone's position relative to the bearers is essential. This difficulty associated with carrying compared to dragging a stone represents different problems for transport.

The use of litters, ropes and slings, sledges, earth or stone ramps, and water transport to facilitate moving massive stones is widely reported (Heizer 1966). However, there seems to be a practical limit to lifting a stone on a litter as the stone approaches 5 tons; that is – depending on the shape of the stone – it is usually easier to drag rather than lift such a heavy piece. While we do not yet have experimental data for dragging stone related to Nan Madol, there is evidence from other areas. An interesting report of moving an 11 ton tomb capstone in Sumba, Indonesia, describes the block being dragged on a sledge for more than 3km by 525 men in only 2 days (ref. in Heizer 1966:827). This rather rapid transport is unusual. Evidence suggests that most of the stone used in Nan Madol construction could have been carried on a litter/poles and rope slings, but that a significant portion of the building materials and boulders and probably the very largest stone columns would have to have been dragged.

Pohnpei's Relative Status Ranking

The comparisons below (Table 1) suggest that even though columnar rock was available in Awak, non-local columns were brought in for construction of ceremonial architecture (especially *lolong*, stone walled tombs) where in one case (Site PoB7-2) a massive column 2.5m long was the only large one used in the entire structure covering some 150m². Comparable and more numerous columns were transported to build the tomb B7-39 (see Figure 3). No local columnar rock is known in the vicinity of the Sapwtakai Centre (Bath 1984) or of Nan Madol and this confirms the long-distance transport of this basic building material. Boulders appear to have been available locally for stonework created in all of these complexes, but the maximum sizes of these vary, in general, with the status of the centre.

CONCLUSIONS

The experiments were successful because they allowed us to record in detail some of the parameters – including the kinds of materials and personnel organisation required – for transporting massive stone blocks and columns. That stone materials used in ritual context have different characteristics and transport requirements compared to non-ritual construction materials is documented in their type, shape and size and site associations. All the materials observed in use, except for the steel machete which replaced earlier cutting tools made of shell and stone, represent traditional materials. An alternative to hibiscus bark rope is cord woven from coconut fibres; this is widely used for construction and may have been required for more massive boulders. We were able to demonstrate and record on film the actual process of moving the stones and to show that it is feasible, as Pohnpeians have recounted in oral tradition, to transport large stones by raft across the reef flat.

While the sizes of stones used in the experiments were small compared to the largest ones moved to Nan Madol in prehistoric times, the general principles and especially the potential of rafting for moving columnar rock through the lagoon from around the island were demonstrated. Certainly not all variables pertinent for moving a stone of 20 tons can be addressed by organising a lift and floating a 0.5 metric ton column, still, the experiment verifies that this method represents a feasible way to easily transport columns, especially the thousands of relatively small ones used at Nan Madol, over long distances. This could have been accomplished by mass loading on large rafts. We have no direct evidence from these experiments regarding the largest rock that could be lifted using the techniques described above. Given the mean weight/person values reported from various experiments noted above of 34 kg/person, 100 persons could carry a stone weighing 3.2 metric tons on a pole frame weighing approximately 0.2 metric tons, or a total 3.4 metric tons. Although crews of up to 200 bearers have been reported carrying an exceptional heavy boulder (Heizer 1966), the logistics of positioning such a large number of workers close to a massive stone seem insurmountable. More experiments could be helpful to refine the parameters for this but organisation of such an experiment would take substantial resources. Based on all these experiments, however, we believe that dragging and levering a massive boulder – or the rare columns over 6 to 8 metric tons – seems the most likely alternative to lifting for building stones of over 5 tons primarily because of the limitations of the number of men who could lift on armature poles.

Our experiment demonstrated that water depth of greater than one metre and probably closer to 1.5 metres would be required to support effectively the larger raft necessary for more massive stones; the raft thickness also would need to be considerably greater than the one used in the experiment. This suggests that loading from a constructed stone pier or dock would be advantageous to get the right combination of raft size and water depth required for transporting the larger columns and boulders. An alternative to lifting columns to place them on top of a raft would be to tie the raft to the stone at low tide so that the incoming tide would lift both; the stone column could be suspended from the floating raft or placed on top. This technique also is known to Pohnpeians (E. Eperiam, pers. comm.).

The Pohnpei case of moving stones of up to 50 to 60 metric tons fits into the upper range for prehistoric chiefdoms around the world. Yet Pohnpei is different from many other Pacific and Southeast Asian cultures that represent pre-state "megalthic cultures" in that the known stone transport is of *menhirs* or tomb capstones that rarely weigh more than 10-15 tons. These "individualised" megalithic enterprises (Heizer 1966:828) where single stones were moved to mark ancestral status or tomb chambers contrast with building a Nan Madol type complex, because the latter required far more organisation and direction in construction and planning. This perspective is sharpened by noting the amount of stone, probably three-quarters of a million metric tons (basalt and coral), brought into Nan Madol, the island's main centre. Pohnpei also differs from other chiefdoms in the extensive use of columnar rock and the lack of emphasis on shaping or carving the stone.

The recording of the traditional transport of a *sakau* stone and the experimental moving of a columnar building stone represent the first such attempts on Pohnpei to examine systematically the basis for transporting hundreds of thousands of tons of rock during the prehistoric period for ceremonial structures. While Nan Madol represents the most elaborate result of stone transport for megalithic construction, the practice of moving large stones represents a core feature of the prehistoric technology found throughout the island. In all areas, residential structures for the elite, tombs, and other sacred areas show the use of massive stones for distinctively marking special function, a common feature of many Pacific Island and other prehistoric societies. Stone materials differ considerably with regard to their significance for status marking in Pohnpei architecture; most important are columnar basalt, massive boulders, and special use stones such as kava pounders. Megalithic stonework can be documented over a period of more than 1000 years reflecting the development of major centres as they changed in social and political status.

POHNPEI CHIEFLY AREAS AND LEVELS

STONE TYPE	Awak - Local Chiefdom	Sapwtakai - Regional Centre	Nan Madol - Paramount
Largest Stone Type Transported	Boulder/Column	Boulder	Boulder
Type 1. Columnar Rock: Upper Limit of Natural Local Columns	1.00m x 0.4 dia. = 0.12 cu m or 350 kg*	none known	none known
Type 1. Largest Column Used in Construction	2.5m x 0.6 dia. = 0.71 cu m or 2,060 kg	2.5m x 0.5 = 0.49 cu m or 1,420kg	8 m x 0.75 = 3.53 cu m or 10,240kg
Type 2. Boulder Rock: Upper Limit of Natural Local Boulders	2x3x3m (48,600kg)	2x3x4m (64,800 kg)	3x4x4m (129,600kg)
Type 2. Largest Boulder Used in Construction	1.0 x 0.75 x 0.50m = 0.38 cu m or 1,030 kg	1.5 x 1.25 x 1.0m = 1.88 cu m or 5,080 kg	2.15 x 2.5 x 4m = 21.5 cu m or 58,050 kg

*note: mass is calculated at 2900 kg/cu m for the crystal-rich lava columns and 2700 kg/cu m for the flow-banded basalt boulders (the range is on the order of 2400 to 3100 kg/cu m for the basalt stone used in building; values rounded to the nearest 10 kg). Columns range from nearly perfect prismatic forms that are neatly pentagonal or hexagonal for their entire length to ones with one end showing a hexagonal cross-section and then grading into an octagonal shape on the other, thus a close approximation of diameter is measured and this is used to calculate volume.

TABLE 1. Comparison of maximum sizes of two stone types transported on Pohnpei for three levels of chiefly centres.

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