16

MEGALITHS AND MARINERS: EXPERIMENTAL ARCHAEOLOGY ON EASTER ISLAND

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*The monolithic stone sculptures (*moai*) of Easter Island (Rapa Nui or Rapanui) are world-renowned, considered to be the ultimate expression of ancient East Polynesian aesthetic and megalithic traditions.*[1] *The magnitude of pre-industrial technology required to make, move and erect them has long been a source of speculation and conjecture. Using Polynesian ocean-going canoe technology as our research model, in 1998 we designed and carried out the only genuinely replicable* moai *transport experiment attempted to date. Pre-tests to calculate the co-efficient of friction, determine the mechanical behavior of palm wood and evaluate pulling force capability were completed. A series of discrete but related transport experiments was then conducted in which a Rapa Nui crew successfully transported a concrete replica of the statistically average statue over variable island terrain to a replica ceremonial platform (image* ahu*) architecturally extrapolated from a single, dated site. The resultant time/energy observations are described here in full and support, with few revisions, Van Tilburg's (1994) previously postulated socio-political and economic model of the average Rapa Nui chiefdom.*

Rapa Nui (Easter Island) is a 160-171 km^2 (63-66 sq mi; maps vary) island, without a reef, isolated at the southern most limit of the tropics in an extreme windward position in the East Pacific (Figure 16.1). It was formed by the coalescing flows of three Pliocene to Holocene age volcanoes, the oldest of which is 3,000,000 years. Basalts and differentiated andesitic rocks are characteristic, and soils are predominately loams and clays. The Rapa Nui landscape is one of gently rolling hills and slopes irregularly punctuated by volcanic cones. Maximum elevation is 510 m above sea level.

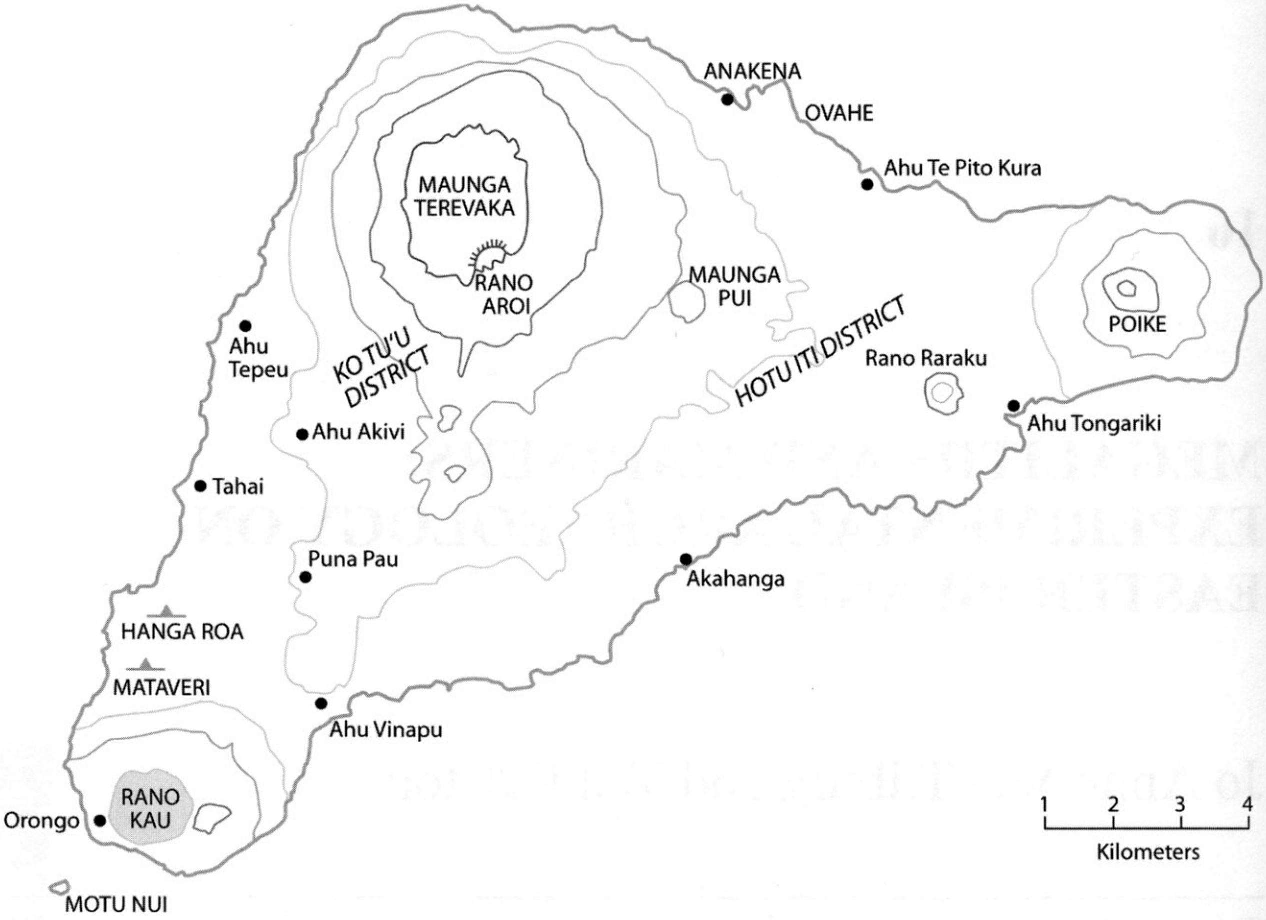


Figure 16.1 *Map of Rapa Nui (Rapanui) showing sites mentioned in the text.*

Lava plains are densely carpeted with loose rock cover.

Rano Raraku is the volcanic crater from which fully 95% of 887 monolithic statues documented by Van Tilburg in the context of the Easter Island Statue Project were carved (Figure 16.2). It is the island's most culturally significant geological resource. Consolidated *lapilli* tuff (compressed ash) is arrayed in horizontal bands exposed at the upper levels of the crater's interior and exterior. The tuff is yellowish-red when freshly cut (a color sought because of its cultural associations with the chiefly class), relatively easy to carve and capable of being smoothly finished. It varies in density, thus statues of the same size vary in weight, and readily absorbs water. Rano Raraku tuff weathers rapidly to a high degree of friability relative to site location and environmental factors, and has nodules of dark, dense metamorphic rock scattered randomly throughout.

Rano Raraku is connected to regional settlement zones in the north, west and southeast by roads 1 to nearly 20 km long and with truncated branches (Routledge 1919: fig. 74). Cleared of stones, the roads vary little in width, and in at least one instance a curb is present. They were used to transport *moai* to image *ahu,* although some *moai* near Rano Raraku may have been displayed upright in place. Prior to human settlement by Polynesian voyagers in the first millennium AD, Rapa Nui was forested with a species of palm tree similar to *Jubea chilensis* (early pollen analysis was conducted on cores collected by T. Heyerdahl; Flenley 1979; Flenley and King 1984).

The Rapa Nui megalithic tradition flourished from at least AD 1100 to ca.1500 when it overlapped with the emergence of another, related tradition at Orongo and fell into decline, continuing at some sites until the mid-1600s. Forest clearance and, ultimately, deforestation resulted from the need to provide living and gardening space to a growing population. Wood was also required to fuel the fires of human cremation, for house building and canoe construction, and for the timber and cordage used during statue transport and raising. European contact in 1722 was followed by a century of cultural devastation and broken traditions. Rapa Nui became part of modern Chile in 1888.

Industrial Arts, Tools and Division of Labor

Rapa Nui technology was stone based, producing an assemblage of portable artifacts similar to other high island East Polynesian societies. The stone adze (*toki*) shows considerable diversity in form, but most are quadrangular in cross-section with a secondary type category including trapezoidal or ovoid. Distinctive in the absence of a tang, these *toki* have a functionally analogous groove on the butt end. A *toki* in the form of a hand-held pick was used in the rough-out stage of statue carving.

David C. Ochsner

Figure 16.2 Rano Raraku statue quarry from the east.

Coral abraders (*punga*) were employed to finish the statue surfaces and it is probable that obsidian tools were used to incise fine details of the hands and ears.

Culturally dictated gender specialization circumscribed the performance of labor tasks, making some work spheres *tapu* (forbidden) to females. An expert in any craft was called *maori*. The carvers of monolithic statues were known as *tangata maori anga moai maea,* and were organized into a "guild" with insignia, gods and priests (Métraux 1940:137). "They were a privileged class, highly esteemed, and their profession was transmitted from father to son" (ibid.). Novices apprenticed themselves to masters (*tangata honui maori*) to learn basic skills or refine techniques. Commissioned by chiefs or lineage heads (*ariki*), master carvers were paid for the successful completion of their work in food, especially lobster, eels and large pelagic fish such as tuna (*kahi*) caught by expert fishermen called *vaka tangata*.

This reciprocal arrangement between chiefs, carvers and fishermen was made possible by large canoes that were the joint property of the families who contributed resources or labor to their construction and divided the catch (Métraux 1940:144). The paramount chief (*ariki mau*) owned the most magnificent vessel (*vaka vaero,* decorated with cock feathers). The only activities allowed the *ariki mau,* whose *tapu* hands were the source of sacred, rejuvenating spiritual power (*mana*), was "making fishing lines and nets and fishing in canoes" (Métraux 1940:131). At least five types of fish were *tapu* to all but him, and only the *ariki mau* was allowed to take tuna during the winter months. Megalithic tasks were certainly seasonal and related to the availability of preferred foods.

Social and Political Organization

The Rapa Nui system of social organization is typical of Polynesian hereditary chiefdoms, and the system's organizing principles were patrilinear and primogenital. Founding groups branched into local subgroups commonly formed through natural population increase, fission, and consequent land division along collateral lines of common ancestry. Hereditary status distinctions were made on the basis of genealogical distance from Hotu Matu'a, "Great Parent," the legendary founding ancestor, and territorial division corresponded with rank.[2] The paramount chief was the senior male in direct line of patrilineal succession and drawn from the Honga lineage of the Miru ramage.[3] He embodied the highest degree of sacred power. All Miru were considered aristocrats (*ariki paka*) and reserved the right to hold the title of chief (*ariki*). This presents a "striking parallel" between Rapa Nui and Mangaia in the Cook Islands "where only one tribe established *ariki* titles" (Métraux 1940:129).

Communal lands (*kainga*) were held by 10 major, ranked lineages (*mata*) and demarked by image *ahu*. Derived in form and function from Polynesian ceremonial sites (*marae*), Rapa Nui image *ahu* were enlarged and elaborated over about 500 years. All image *ahu* structures were built of locally quarried volcanic stone, and idiosyncratic design and site choices were made within a well-established, island-wide architectural pattern. Some seaward walls, such as those at Ahu Tahiri (Vinapu), were built with such great stone cutting expertise and time-intensive attention to careful joinery that they have been favorably compared to Inca stonework. However, image *ahu* scale and workmanship was dependent upon a range of variables, including resource availability, internal lineage organizational cohesion and access to artisan expertise as a function of social rank. All statues looked out over elite households that decreased in status from the coast and toward gardens and plantations. Lineages grew, prospered, divided and consolidated into two island-wide political alliances. These alliances facilitated or hindered statue transport over lineage lands.

The western alliance [Ko] Tu'u was the highest-ranked district, and its most prestigious site was 'Anakena, home to the Miru lineage and paramount chief, a divine being descended from the gods Tangaroa and Rongo through Hotu Matu'a. Potent spiritual power (*mana*) capable of increasing the fertility of the natural world was concentrated in the paramount chief's sacred head, loins and hands. All *moai* have exquisitely detailed facial features and hands, and traditions suggest that the statues themselves were phallic symbols. At Ahu Naunau (Nau Nau) pre-AD 1300 *moai* fragments are small, rounded forms with proportionately sized ears, chins and jaws. Re-erected *moai* on the restored Phase III of the same site fall within AD 1300-1400 (Martinsson-Wallin 1994; Martinsson-Wallin and Wallin 1998), and 55 other statues in their same type category on other sites probably do as well (Van Tilburg 1986; Figure 16.4).

The eastern, more populous, and lower-ranked district was Hotu Iti. It contained Rano Raraku, a fortuitous geographic situation that surely lent prestige, and Ahu Tongariki, the largest image *ahu* on the island and the most impressive megalithic structure in East Polynesia (Cristino F. and Vargas C. 1998). By about AD 1500 the third phase of Ahu Tongariki construction had been completed and fifteen *moai* 5.6 to 8.7 m tall and weighing up to 80 m tons surmounted the image *ahu*. Ahu Tongariki symbolizes the eastern district's highest level of political integration and its greatest challenge to traditional Miru authority. The two districts achieved parity, however, in the tallest *moai* transported to image *ahu*: one at Te Pito Kura (9.8 m) in the west and the other at Hanga Te Tenga (9.94 m) in the east.

Research Model

Our research model is drawn from well-documented Polynesian ocean-going raft and double-hulled canoe building technology and sailing tradition (Finney 1994; Haddon and Hornell 1975).[4] Experimental anthropology has reconstructed, tested and successfully established maritime methods for pre-contact Hawai'i and elsewhere in Oceania. Throughout Polynesia and on Rapa Nui, canoe builders and handlers were, like statue carvers, specialists who performed expert (and often sacred) work at the behest of powerful chiefs and for their communities. Canoe experts were socially and politically powerful, as were their gods.

In addition to the adze, the tool kit employed in canoe building contained the clamp, chisel, cordage and drill. Apprentices began by developing basic skills, including roughhewing and hauling massive logs. When wood materials were inadequate to build the desired size vessel, planks or logs were spliced and patched. Practiced methods of joinery provided strength, flexibility and protection of lashings from the sea, and finish details were carved with intricate artistry. Positioning, stepping, raising and rigging a canoe mast required precision timing and a well-coordinated work force. A canoe's survival in rough seas depended upon robust and durable cord lashing, which was required to withstand forces of many thousands of pounds per square inch. Complex methods of lashing outrigger components to both single and double hull canoes required such specialty tools as the *keke* (or *ke'ke*), a Y-shaped lash-tightening device that varied in size. Weaving patterns used in lashings had aesthetic and symbolic meanings in their own right. A common method of moving a canoe on land was over rollers. When rollers were lashed together to form a ladder a canoe could be transferred from sea to land over rocks or up steep cliff sides with relative ease.

Experimental Archaeology

Experimental archaeology is the systematic approach used to test, evaluate and explicate method, technique, assumption, hypothesis and theory at all levels of archaeological research (Coles 1968). This paper describes the replication of the statistically average Easter Island statue, derived through archaeological inventory and artifact analysis, and the use of it in a series of controlled tests within the documented Rapa Nui ethnological context (Van Tilburg 1986, 1993, 1994). Our transport hypothesis assumes that the skills required to build, launch and handle Polynesian double canoes have direct counterparts in the land-based technology of Easter Island. Further, we assume the probable transfer and adaptation of these skills to the task of moving the statistically average *moai*.

Previous Transport Theories and the Ethnographic Evidence

William Scoresby Routledge, co-leader of the Mana Expedition to Easter Island, 1913-15, made the first informed calculations of time and manpower required to quarry and then carve a *moai* (Routledge n.d., RGS WKR 1/14/20, 1/14, 1/14/11; Routledge 1919:179-180). Routledge estimated that a master carver and a crew of 54 men could carve “a medium size image of 30 ft. long” in 15.5 days using stone tools. He proposed that thirty men first isolated a rectangular stone block, then undercut it to balance on a stone “keel.” Simultaneously, 24 other men could sculpt details of the statue’s upper surface, sides, top and base. The amount of stone to be hewn was, by Routledge’s careful calculation, 1690 cubic ft., with each man able to remove 2 cubic ft. per diem. Even if the work force was reduced by 50%, Routledge noted, the task would still only require one month.

Our GPS mapping in Rano Raraku quarry validates Routledge’s “block system” of quarrying a sculpture “blank” (cf. Geiseler in Ayres and Ayres 1995:27,33; Skjölsvold 1961). Importantly, however, the workspaces in proximity to many statues are too narrow and cramped to allow more than a few men to work more or less simultaneously on any one statue (in the interior quarry, spaces average 30 to 50 cm wide; see also Skjölsvold 1961:367). Undercutting some sculpture did not take place until nearly the entire upper surface of the statue was detailed and, in a few cases, finished. However, there are many individual statues in discrete contexts within Rano Raraku that do not completely conform to these observations (Cristino F. et al. 1981; Van Tilburg 1986, 1994; Van Tilburg and Vargas 1998). Some early observers noted that the faces of many statues were carved first after the body was roughed out, but exceptions to that rule also exist. The point is that, while there was a general, patterned sequence of steps followed in quarrying, nothing was really “set in stone.” Clear evidence of methodological innovation or individual variation is present.

Englert (1974:95), Métraux (1940: 293), and Skjölsvold (1961:368) did not access W.S. Routledge’s calculations, but each believed that the estimate of “fifteen days” published by Katherine Routledge (1919:181) was either too low or improbable. In 1955 the Norwegian Archaeological Expedition to Easter Island and the East Pacific hired six Rapa Nui men to demonstrate quarrying techniques. Over the course of 3 or 4 days, they used stone picks to pound out a very awkward outline barely resembling a statue on a vertical rock face in Rano Raraku (Heyerdahl and Ferdon 1961:Fig. 60a; Heyerdahl et al. 1989:36; Skjölsvold 1961:366-372). On the basis of this incomplete demonstration, it was concluded that over a year was required to finish a 5 m tall statue. At the time, this estimate was thought to be "unreliable" by the investigators (Skjölsvold 1961:368), but was later accepted by them and, inexplicably, considered without explanation to be a viable experiment (Heyerdahl et al. 1989:36). Lavachery (1935:344-55), in sharp contrast, agreed with Routledge and felt that less than a month was required to carve a statue.

Routledge's precise estimate remains untested. However, it is unlikely that the numbers of people he suggests were ever involved as he describes, and the upper limit in many parts of the quarry could only have been about 15 carvers working at any one time. We documented the process of detailing and finishing the concrete replica of a statistically average statue that we used in the experiment described in this paper (Van Tilburg and Arévalo Pakarti 2002). That work suggests that the crucial issue in detailing *moai* was very definitely not numbers of people. Once "roughing out" is finished, a master carver and a willing assistant or apprentice can advance the work far more efficiently working alone. The numbers of people Routledge suggests would have certainly disrupted or made impossible the careful artistry required to apply details on *in situ* quarry statues.

There are five stages of statue production (Van Tilburg 1996; Van Tilburg and Vargas 1998). The first step is to create a shaped block on which *moai* details may be added in sequence, usually beginning with the head and face. Bilateral symmetry in torso, arms and hands was facilitated by a central line running from nose to navel. Specialists finished the undercutting and a larger work force, using ropes and levers, lowered the statue down slope where it was set upright in an excavated pit. Geiseler (Ayres and Ayres 1995:28) was the first to report in 1882 that round holes near the top of Rano Raraku cliff, according to "an old Rapa Nui native," were used to hold wooden posts for "sliding the completed stone idols down" to lower exterior slopes. Later investigators, including Routledge, could not corroborate this opinion. The exact purpose of the holes (and of two others like them in the quarry interior) remains undetermined, but using them in the manner Geiseler suggests would have been difficult. Many of these statues then became the focal points of ritual activity, including burials.

If the statue, complete except for carved eye sockets, was to be transported from Rano Raraku to an image *ahu*, ropes and logs were attached. Moving statues out of Rano Raraku exterior, interior and upper quarries and down slope to be readied for transport was best accomplished when they were in a supine position, either base first or headfirst. Levers were used throughout, and in some cases earth ramps may have been required (Englert 1974; Métraux 1940; Mulloy 1970; Routledge 1919; Thomson 1891). Finally, the *moai* was erected on image *ahu*. Eye sockets were carved and, during special ceremonies probably attended by the *ariki mau,* eyes made of coral and red scoria were placed in the sockets. In about 60 to 100 cases, red scoria cylinders (*pukao*) were placed on the heads of some statues and, very likely, erected with them.

In 1955 the Norwegian Archaeological Expedition to Easter Island hauled a real, 4 m tall supine statue an unknown total distance by dragging it either on its back alone or after being placed somehow on a "forked tree" sledge (Heyerdahl 1989:36; Skjölsvold 1961:366-372; Figure 16.3). Estimates of the number of persons required to pull the statue vary from 78 (E.N. Ferdon, Jr., pers. comm. 1996) to 180 (Heyerdahl et al. 1989:37). It was generally agreed by those involved that the method used was "cumbersome and not very convincing" (Ferdon, Jr., pers. comm.1996). In a later

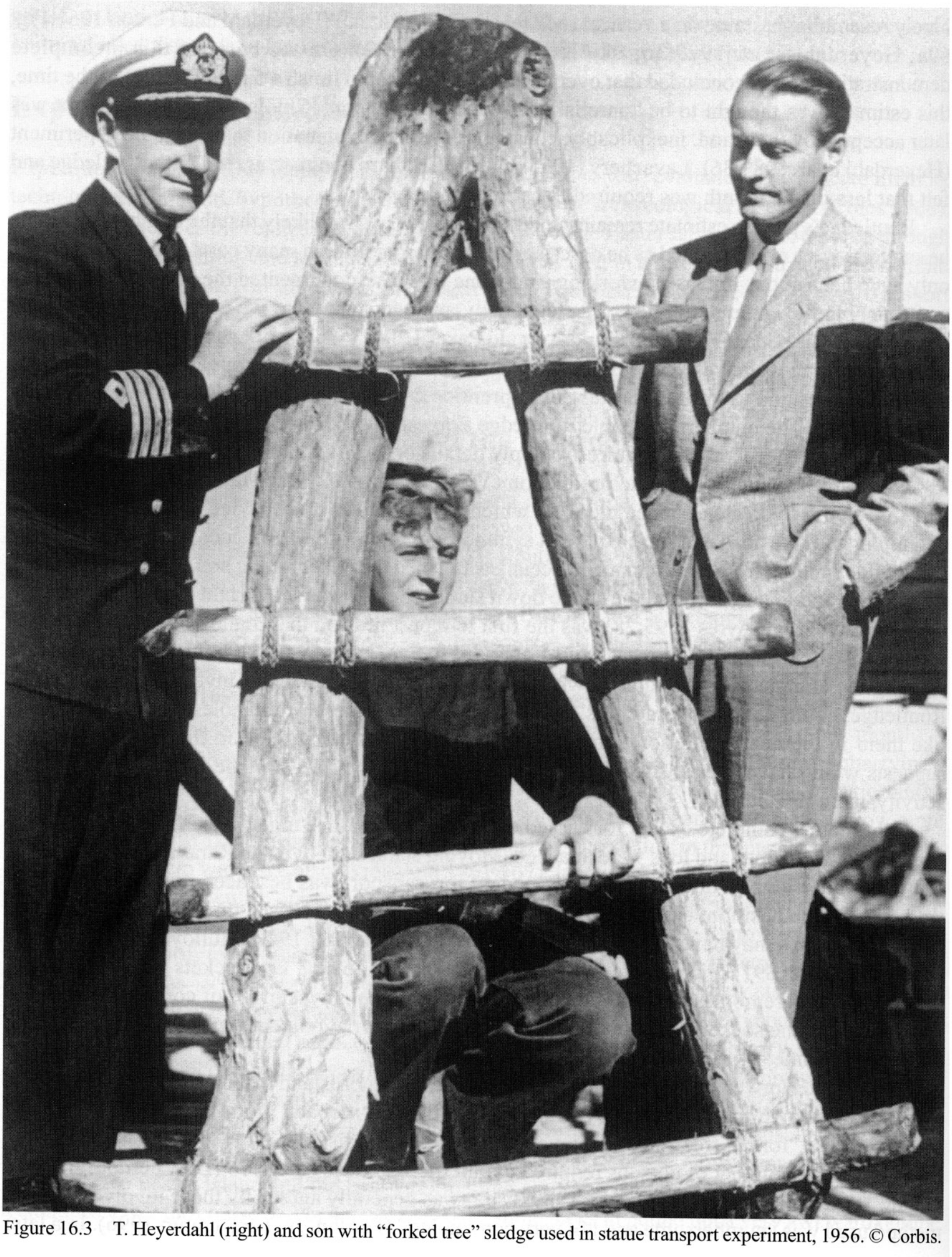


Figure 16.3 T. Heyerdahl (right) and son with "forked tree" sledge used in statue transport experiment, 1956. © Corbis.

variation of the horizontal method, a 12-ton concrete replica statue of awkward and inaccurate form was hauled a short distance on a wooden sledge (Pavel 1990).[5] A non-horizontal transport method was hypothesized in which a prone statue might be suspended from a bipod of logs (Mulloy 1970). Never tested, overly complex and with no basis in traditional Polynesian means and methods, it is improbable (Cotterell and Kamminga 1990).

All statues now found along transport roads from Rano Raraku quarry to ceremonial sites are in one of three positions: prone, supine or lateral (Van Tilburg 1986, 1994). Transport in prone or supine horizontal positions is strongly supported by logic and statue design (Van Tilburg 1993, 1994: fig. 123). History records that, between 1868 and 1935, four of six statues removed from the island to various museums were individually dragged prone or supine either as dead weights or on sledges pulled by attached ropes (Thomson 1891:498; Cooke 1899:700; Routledge 1919:257; Forment 1983; Van Tilburg 1986, 1992). Rapa Nui men and women participated in or directed the work of these modern transport events.

In 1868 the crew of H.M.S. *Topaze* hauled the basalt 2.42 m statue Hoa Hakananai'a (now in The British Museum) down Rano Kau for removal. Lt. C. M. Dundas (1868) said that it was placed "on a sledge of Captains bars" and dragged "broadside on over the softer ground & end on up the steep places." *Topaze* surgeon J. Linton Palmer inquired after transport methods but learned nothing. Twenty years later, Paymaster Thomson and the crew of U.S.S. *Mohican* dragged a 2.24 m basalt statue overland and removed it to the Smithsonian Institution. Thomson recorded hearsay about transport methods. Catholic missionaries told him that Rapa Nui people had said that statues were "endowed with power to walk about in the darkness" (Thomson 1891:497).

In fact, Pére H. Roussel, who arrived in 1866, reported in 1869 that transport information survived only in a "fable" in which "the great chief at that time, who was omnipotent like his predecessors, had commanded them to walk; on his command they had all begun to move while choosing sites to the best of their liking" (Heyerdahl 1961:71). A later variant of Thomson's tale is that chiefs and/or priests uttered charms and "the huge blocks walked for a distance and then stopped" (Métraux 1940: 304, quoting information from 1901; see also Heyerdahl et al. 1989:36). However, another Rapa Nui informant in the mid-1800s told the same missionaries that beach cobbles were used as rollers to transport statues in horizontal positions (Métraux 1940:304). Katherine Routledge (1919:182) was told that an old woman of Tongariki "moved the images by supernatural power." Routledge considered that story to be an "invention." Juan Tepano, the Rapa Nui consultant who worked with Routledge and who was largely responsible for her ethnographic success, accepted that the statues were moved by supernatural power, or *mana* (Routledge 1919:198; see also Englert 1974:79; Van Tilburg 2003).

To assume that actual transport methods are described correctly or literally in any of these oral traditions is to greatly oversimplify the metaphorical nature of Polynesian oral history and the complex concept of supernatural power (*mana*) clearly referred to in the "walking *moai*" traditions. Nonetheless, two researchers have independently conducted separate, off-island tests to move concrete replica statues in upright positions. One replica was placed upright on a small wood platform or "pod" and then pulled a short distance over flat ground (Love 1990). Another was manipulated to "walk" a few feet by tilting it alternately sideways with attached ropes (Pavel 1990). During an on-island variation on the latter test, two teams of Rapa Nui men pulled alternately on ropes attached to a real statue nearly 4 m tall, tilting it sideways to move it forward a short distance.

The test was abandoned rather quickly as dangerous and, unfortunately, the statue's base was unintentionally damaged in the process (Heyerdahl et al. 1989).

Katherine Routledge (1919:193-196), rightly perplexed by the patterns of breakage and weathering on statues lying along transport roads, "briefly considered" and then abandoned the possibility that some had been moved upright. Instead, she concluded that these statues were really "processional," and that they had once stood upright to mark the road between Rano Raraku and Rano Kau. Members of Captain Cook's 1774 crew sought shelter in the shade of a statue standing upright in the vicinity of Ahu Oroi (but not on the platform) that, some time afterward, fell and was broken. J. Linton Palmer, Lt. C.M. Dundas, R. Sainthill and Lt. M.J. Harrison all clearly state that a basalt statue removed from Hoa Hakananai'a by H.M.S. *Topaze* was originally upright and embedded in the earth at Mataveri, not on an image *ahu*. Excavation (Heyerdahl et al. 1989:50) lends substantial credence to Routledge's "processional" upright statue hypothesis, and some *moai* embedded upright on the slopes of Rano Raraku were never intended for image *ahu*.

The "walking" statue legends may be reliable descriptions of moving and erecting large wood, vegetable fiber and painted barkcloth human figures (*paina*) during historic time. The Spanish actually saw one of these figures in use in 1770, on the day they conducted a lavish ceremony annexing and renaming the island. The figure was eleven feet tall and white, with a fringe of black hair. Perhaps in imitation of the religious statues that Spanish priests carried in their impressive annexation procession, the Rapa Nui carried their figure "to the beach" where "they put it up on stones and sat cross-legged around it, howling all night by the light of flares" (Routledge 1919:233-4). The name of the Rapa Nui creator god Makemake was associated with this figure.[6] In 1786 the French saw a similar figure, also clothed in white, standing eleven feet tall on an *ahu* site. It represented a female, and a two-foot long figure representing a child was associated with it (Routledge 1919: 234).

Paina figures like that described above were essentially hollow, so that a person could climb inside and intone chants. One was described to Katherine Routledge as being clothed in white tapa with a crown of frigate bird feathers. They are said to honor deceased or living parents, both male and female, and were raised during image *ahu* ceremonies at which lavish amounts of food were provided. Memories of some of these ceremonies were quite vivid in Routledge's (1919:233) Rapa Nui consultants, and she noted that "at most, or all, of the large *ahu*, there can still be seen, in the grass at the foot of the paved slope, the holes where the *paina* have stood."

Katherine Routledge (n.d., RGS WKR 4/4/1, p. 72) was told by Utimio Rangitopa and either Juan Porotu or Nicolás Pakarati Urepotahi that they remembered a 35 ft. tall *paina* figure made of wood and plant fiber once erected in a hole 7 ft. in diameter at Ahu Mahatua. While this may be an exaggeration, the description of another such ceremony held at Ahu O'Pepe for one hundred people was certainly not (Van Tilburg 2001). *Paina* figures were burned or otherwise destroyed after the ceremonies were complete, but portable *tapa* figures of similar style have survived. A small pencil sketch depicting the raising of a *moai*-like image is in Routledge's unpublished fieldnotes. It was certainly made during a conversation she had about *paina* ceremonies. Four ropes are attached to the figure, two at the neck and two at the top of the head, and the sketch depicts erecting or manipulating the upright figure. The only logical conclusion, in our opinion, is that the "walking *moai*" tradition describes *paina*, figures, not stone *moai*.

Jo Anne Van Tilburg, 1992

Figure 16.4 Reference *moai* 01/53 at the target site of Ahu Akivi, an image *ahu* dated AD 1400 to mid-1600s.

Reference Statue and Target Site

Defined archaeological parameters for our experiment were first established through extensive field survey in which up to 55 discrete measurements were collected on each of 887 individual statues localized in 4 site types, including 5 archaeological zones of Rano Raraku (Cristino F. et al. 1981; Van Tilburg 1986, 1993, 1994). The statistically determined average statue was drawn from a subset of 134 statues possessing 10 crucial measurements of overall form. Total height of the average statue is 4.05 m. To determine volume of this and all other statues in the database, we presumed each statue to be a cube, and calculated head and torso dimensions separately. Using these data, the estimated weight of the average statue was then calculated on the basis of a specific gravity of 2.1, a value arrived at by averaging three previous estimates (Métraux 1940; Houston in Mulloy 1961:98; Mulloy and Figueroa 1978:38; Thomson 1891). Thus, we calculated (incorrectly, as it turned out) the weight of the average statue to be 12.5 m tons.

The "reference statue" that fits these formal parameters and also possesses as many stylistic details as possible is Statue 01/53 at Ahu Akivi, a restored coastal zone ceremonial site lying about 140 m above sea level on the southwestern slope of Maunga Terevaka (Mulloy and Figueroa 1978) (Figure 16.4). Ahu Akivi is reliably dated to after AD 1400 and before the mid-1600s (Ayres n.d.). In 1960 Statue 01/53 and 6 others nearly identical to it were re-erected during restoration of the site. Statue 01/53 was broken transversely across the neck and, during restoration, the head was replaced on the body slightly off-center and tilted.

Computer Modeling of Reference Statue

Photogrammetric data were collected on Statue 01/53 at Ahu Akivi (Van Tilburg 1993, 1994). These data were amplified through the creation of an accurate 1/10-scale figure modeled in clay by a professional sculptor.[7] The model was then used to formulate a wide variety of hypothetical transport configurations. Following that, it was laser scanned and the resultant three-dimensional computer image integrated and cross-checked with field data (Figure 16.5). Finally, the image was then

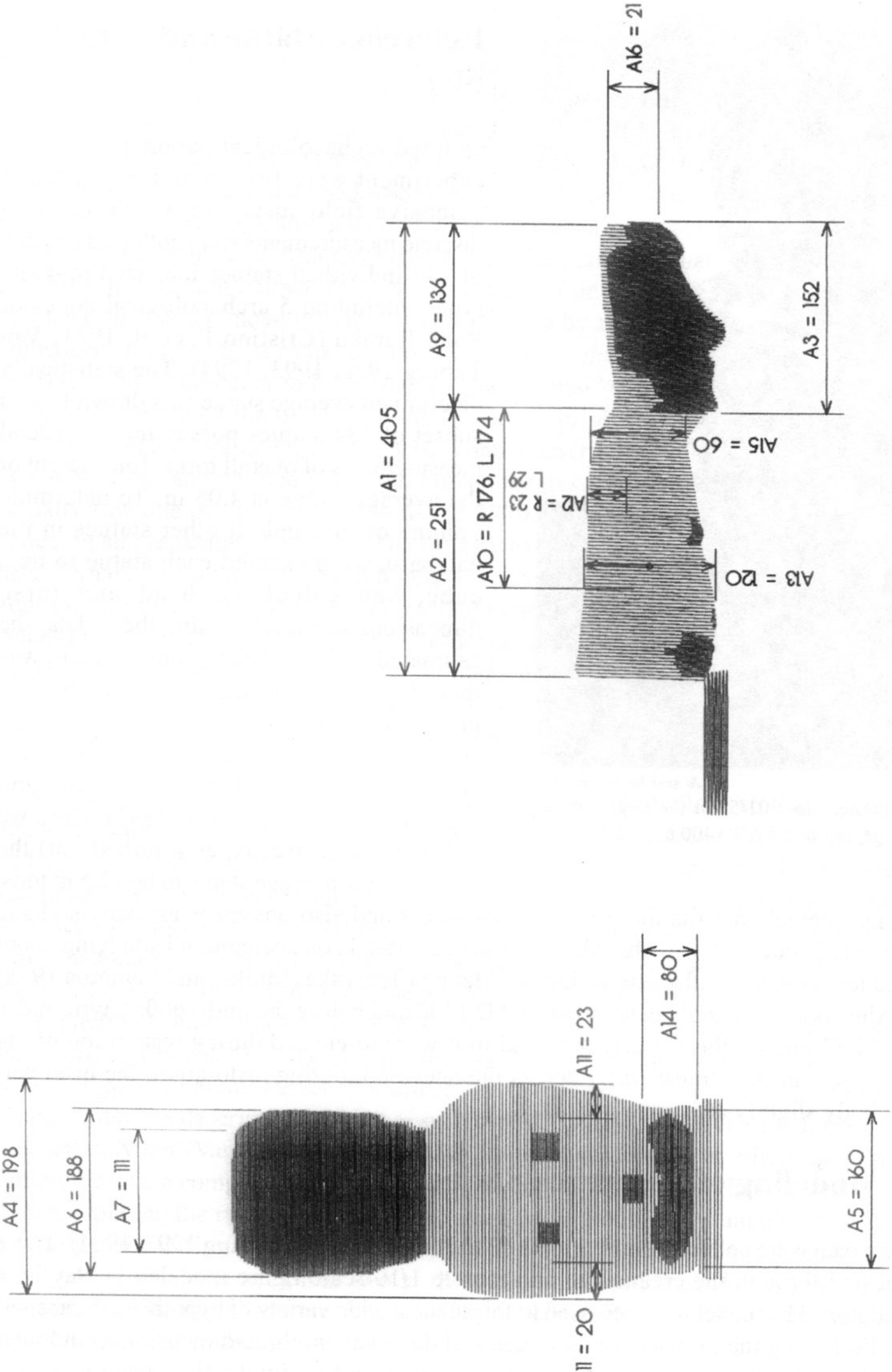


Figure 16.5 Computer generated image of *moai* 01/53. *Image © Jo Anne Van Tilburg.*

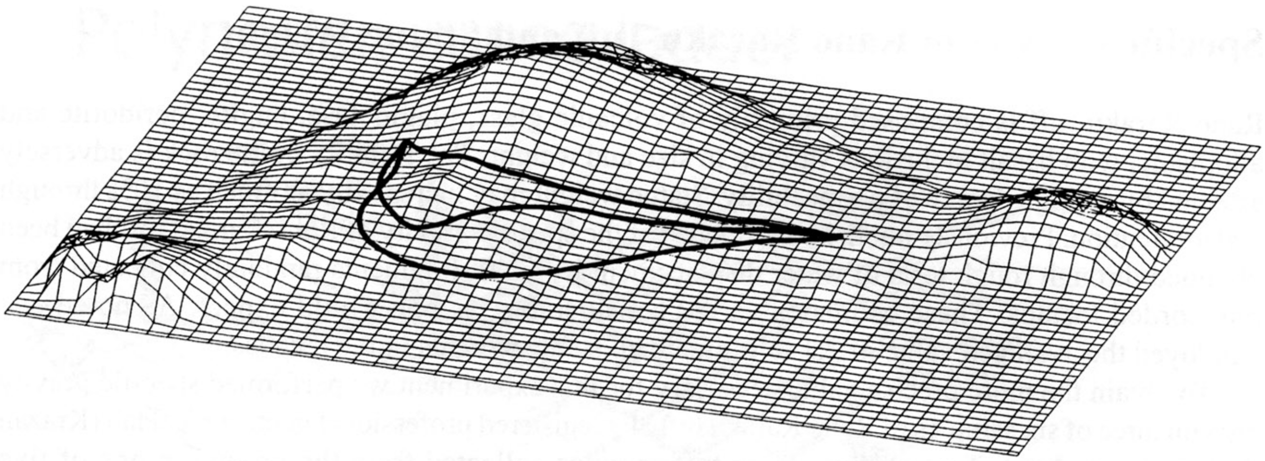


Figure 16.6 Optimal paths 1, 2, 3 (top to bottom) from Rano Raraku (right) to target site, Ahu Akivi (left). Diagram by Zvi Shiller.

employed in a series of digital tests designed to evaluate and refine our hypothetical transport configurations.

Optimal Path Calculations

Field data reveal that 42.6% of statues are in the prone position and 31.9% are supine. Most statues in transport are prone, and that position is required to erect a statue on most ceremonial platforms. To ensure a flexible application of our hypothesis, we developed methods that would allow us to transport a statue in either position. In the face up, headfirst position the statue lay on two beams that automatically assume a non-parallel form due to the distribution of statue weight, creating a semi-triangular sledge configuration. In the face down, base first position, however, the statue must be raised from the ground by placing crossbeams to support the neck and protect the protruding features of the face. In both variations on the horizontal transport hypothesis, wooden rollers and/or sliders were required, and pullers positioned along two ropes achieved locomotion.

UCLA's Laboratory for Robotics and Animation, directed by Dr. Zvi Shiller, participated in the next stage of the research. The first step was to digitize a rough terrain map of Rapa Nui. Robotics programs generated three alternative paths from Rano Raraku, where the statue would have been carved prehistorically, to Ahu Akivi, the "target site" 10-15 km away (depending upon the path) (Figure 16.6). While all were viable, Path 1 had the strongest archaeological support. It was also optimal in that it is the shortest and most direct route (10.1 km). Although it required the largest maximum number of people (70), the required energy expenditure was lower than the other two routes because it took the least amount of time (4.7 days). The projected number of people involved in the transport task varied slightly on all three routes, and depended on terrain difficulty. We concluded that the average pull crew required for Path 1 was 48 people, and the maximum force required to pull the statue was 2.5 tons.

Specific Gravity of Rano Raraku Tuff and Statue Weight

Rano Raraku tuff is composed primarily of volcanic glass, plagioclase, augite, peridotite and allophane, with basalt inclusions varying in size and weight. The stability of the rock is adversely affected by its high degree of permeability. Statue weight may increase by as much as 10% through water retention. Previously published estimates of the specific gravity of Rano Raraku tuff had been obtained through rough tests of water displacement by small fragments randomly collected from unrecorded locales. These estimates varied considerably, as one would expect. As noted, we employed the averaged value of 2.1 to estimate all statue weights in the database.

To obtain the more precise value necessary for this experiment we performed specific gravity tests on three of six samples of Rano Raraku tuff at a registered professional geotechnical lab (Krazan & Associates, Inc.). Two of three large tuff samples collected from the ground in one of five documented archaeological zones in Rano Raraku quarry were tested. In addition, tests were run on the largest of two core samples taken by Universidad de Chile archaeologist Claudio Cristino F. from the interior neck of one statue at Ahu Tongariki (Van Tilburg and Cristino F. n.d.[1997]). The core sample was heavier (more dense) at 114 (wet weight) lbs. per cu. ft. (1035g), and produced a reliable specific gravity of 1.57. This, of course, lowered the estimated weight of all statues in the database. The revised weight of the average statue is thus 9.86 m tons.

Pre-Tests: Characterizing Palm Wood and Determining Friction Coefficient

Our pre-tests at a California construction yard had three primary objectives: 1) to determine breakaway and steady friction coefficient for our hypothesized statue transport configurations bearing representative loads (i.e., 10-12 tons), 2) to determine the mechanical behavior of palm and eucalyptus wood under load, and 3) to determine the pulling force of 10 people. In addition, pre-test experience would give us insight into handling materials and organizing the workforce on Rapa Nui.

The trees of Rapa Nui's prehistoric palm forest had a theoretical ability to attain smooth, cylindrical but uneven trunks more than 1 m in diameter. There is no evidence, however, that they ever attained this maximum size, nor is it clear that, if they did, their trunks would have been useful in statue transport. Rather, many well-documented "prints" of palm trunks embedded in hardened lava on the northwest coast of Rapa Nui measure a less unwieldy 30 to 40 cm in diameter or less (G. Velasco in Van Tilburg 1994: Pl. 8).

Three separate test configurations were structured. We planned to test large diameter palm wood rollers and smaller diameter palm wood rollers (probably used in antiquity) on a hard surface, and then to slide the load directly on palm wood sliders. The tests would then be repeated with eucalyptus. A pair of concrete "Jersey barrier" highway lane dividers resting on a 2.5 cm steel road trench plate represented statue weight and size. This assembly, in turn, rested on a pair of 33 cm diameter palm trunks, 7 m long, arranged in a narrow "V" form, representing the transport sledge. Finally, the sledge was set directly on the rollers or sliders and the entire assembly pulled by a fork truck with a 10,000 lb. spring scale in place.

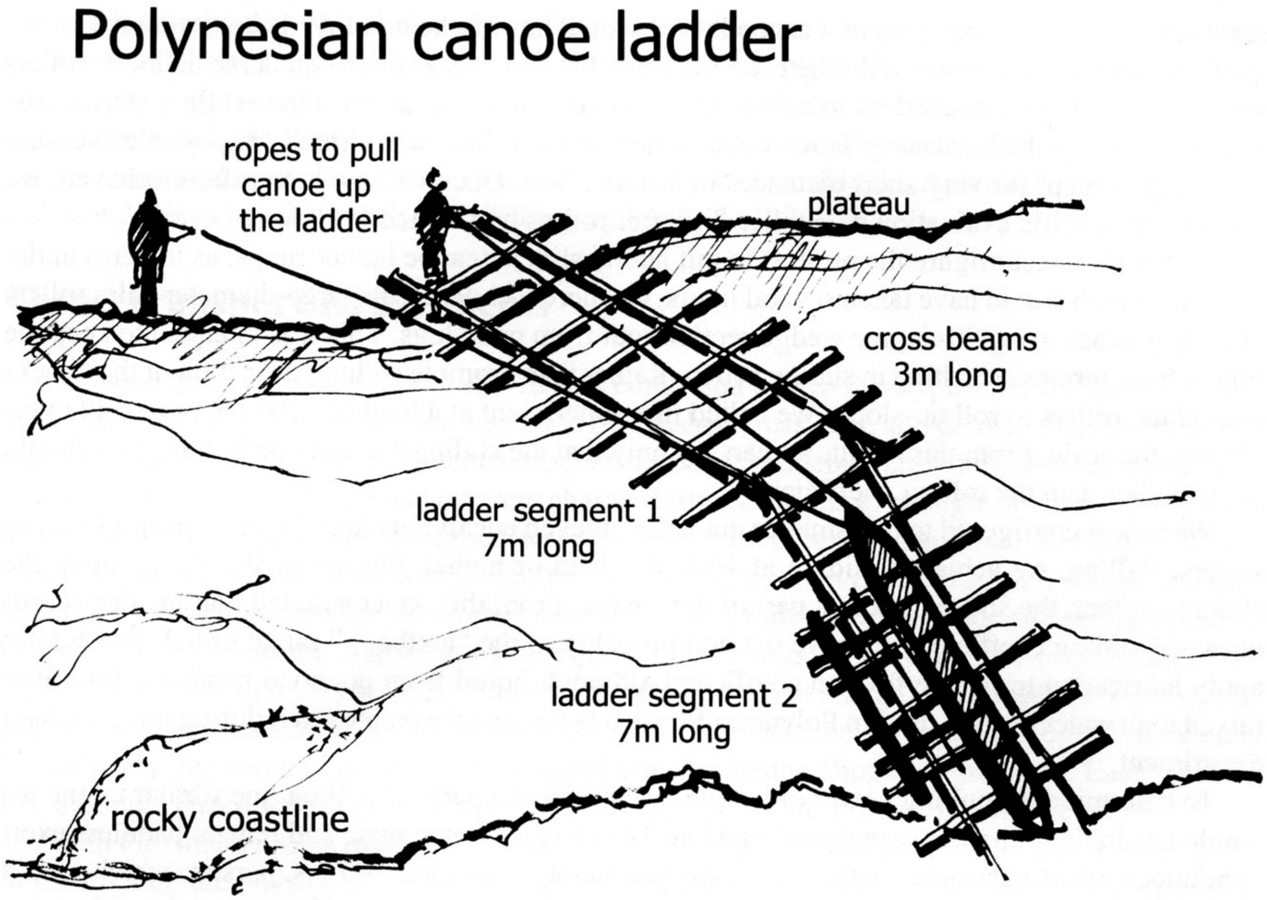


Figure 16.7 Polynesian canoe ladder prototype frame built and tested on Rapa Nui prior to the transport experiment. Drawing by Johannes Van Tilburg, 1998.

Results clearly demonstrate that palm wood is fully capable of bearing the requisite experimental load. Importantly, we learned that large diameter (33 cm) palm rollers allowed the loaded sledge to be moved, but because of irregularity in roundness the rollers did not stay true beneath the load. Instead, they tended to wander and jam into each other, resulting in only very limited progress before adjustment of the rollers with levers was required. To deal with this problem, we incorporated into our hypothesis the Polynesian concept of the canoe ladder (Figure 16.7).

A canoe ladder is made up of a series of ladder segments joined together and laid down over a rocky coastline, extending into the water. A skilled steersman can bring a canoe in line with the middle of the ladder, wait for a wave surge, and then paddle it up and onto the ladder. With enough hands, the canoe can then be pulled up out of the water onto land. The ladder provides support for the canoe on a compliant surface that will allow it to slide without gouging its hull over terrain that is uneven. Although pulling force requirements are higher with sliders such as a canoe ladder, greatly improved manageability of the load has resulted in its universal use throughout the Pacific. There are many places along the Rapa Nui coastline where a canoe ladder would have been useful to ancient fishermen, and it is certain that the concept was known. We rightly anticipated that during our full-scale statue transport experiment a canoe ladder would have to be employed.

Other useful results gained during pre-tests were that breakaway force with large diameter rollers was about 2800 lbs., equivalent to a friction coefficient of just over 0.1. Once rolling started, the load drops to half the breakaway. However, as stated above, rolling was virtually impossible to ensure or manage except for very short distances of 1m to 1.5 m. Once we saw how rollers behaved, we abandoned specific evaluation of smaller diameter rollers and turned to sliders.

Rather than reconfigure the pre-test to put lateral sliders (canoe ladder rungs, as it were) under the load, which would have taken several hours, we merely chocked the large-diameter palm rollers already in place using 30-degree wedge sections cut from palm logs. This was intended to keep the rollers from turning, resulting in sliding action. Rather than promote sliding, the action of the chocks caused the rollers to roll up-slope. We halted this experiment at a load of 8000 lbs., to avoid over-ranging the scale. From this result, we can say only that the sliding friction coefficient, as it should be, is higher than the rolling coefficient.

We now reconfigured to test smaller diameter, uneven eucalyptus logs for their ability to act as sliders. Pulling, we achieved sliding at 4000 lbs. load or higher, but not of the sledge upon the sliders—rather, the sliders acted as part of the sledge. From this we concluded that the dry wood-on-wood sliding coefficient is above 0.2 and probably in the "textbook" range of 0.4. We did not apply lubrication to reduce friction coefficient although liquid from pounded banana stump fiber mixed with water is often used in Polynesia for such tasks, and we employed it during our on-island experiment.

To determine the pulling power of people, we arranged a parallel pulling line similar to one we would use in the full-scale experiment and had 14 outrigger canoe male and female paddlers exert continuous effort measured by the scale. We reasonably estimated 100 lbs./person, which would be sustainable as long as footing was available. Analyzing everything, we drew several conclusions: rollers may work but managing them is difficult; eucalyptus is at least as strong as palm wood and can be used as a substitute for palm unavailable on modern Easter Island and, finally, that working with a large, heavy load requires a well-secured and robust support structure (sledge) and the ability to control motion in all directions.

Full-Scale Statue Replica

Cutting 75 full-scale paper sections from 3-D solid geometry digital data produced 75 7 cm thick foam layers that, when stacked and assembled vertically, created a full-scale statue. It became immediately obvious that the photogrammetric fieldwork had accurately recorded the slightly off-center position of the head on the torso of the real Statue 01/53 at Ahu Akivi, and that error was transferred to the paper patterns and then to the foam statue. Cutting and trimming the foam was necessary to recover the correct shape. This work was done by Rapa Nui sculptor Santi Hito under Van Tilburg's direction, and was incredibly difficult. The nose (which aligns and scales all dorsal features) was the biggest challenge.

Eventually, a satisfactory solution was achieved, and fiberglass was hand laid-up over the foam statue to create a mold that was then transported to Easter Island in four pieces and reassembled. A rebar cage for strength and ten tons of concrete (1-1-2 cement-sand-red scoria, 130 lb./3 ft. density) was machine-mixed and hand-placed into the mold, which was buried in sand. Four days of curing produced a 10-ton statue replica that then required 24 hours of finished carving by Arévalo P. and Hito. In this way, the *moai* was given some surface details and textures and the head and base shapes were modified. Additional corrections required to turn the statue into an accurate work of art would not be completed until after the experiment was over, and would take Arévalo P. and a part-time assistant 25 days to accomplish (Van Tilburg and Arévalo P. 2002).

Three Transport Experiments

The wooden transport sledge we designed was composed of two eucalyptus trunks laid in a tight-V modified to a semi-triangular configuration by a lashed crossbeam and derived directly from hull and outrigger forms of well-documented Polynesian canoe models (Van Tilburg and Ralston 1999). The pegged and lashed frame had inherent characteristics of balance, strength and flexibility, much as would a voyaging canoe designed to carry heavy loads great distances. For the first two experiments, the replica *moai* was placed face up and base down on the transport sledge. Parallel beams of eucalyptus were set out on the ground for use as rails on which wood rollers were placed. Forty persons pulled the statue on its sledge, with 20 stationed on each of two pull lines. Six additional men with levers were positioned on each side of the sledge to tend rollers. For the first pull, the statue on its sledge was hauled at a fast walk (approximately 5 mph) for about 5 m. Almost immediately, the rollers became so misaligned that the sledge slipped to one side. Each of these two attempts ended with rollers completely jammed, just as our pre-test had predicted.

With the rollers unsuccessful, the experiment halted and the transport sledge was re-configured to incorporate the physics of the Polynesian canoe ladder. Essentially, three rollers were lashed to the triangular frame of the sledge to keep them from going astray, in effect becoming sliders. The second experiment resulted in two quite successful pulls, one of 40 m and another of 70 m. Pulls were limited only by the available rail material laid out on the ground in the direction of travel and/or by rock outcroppings that impeded movement. Between pulls, the rails were repositioned. Coefficient of friction was established at 0.2, which surprised us with its low value, and about half that once sliding commenced. Sliding was greatly enhanced by the lubricity of the de-barked eucalyptus.

The third experiment was conducted with the statue face down, base first on the same transport sledge. To support the head and neck, the statue was raised slightly by placing a "triple stack" of lashed logs laterally across the sledge and lashed in place at the statue's upper torso level (Figures 16.8, 16.9). The slight concavity in the upper torso of the *moai* was located at exactly the required point and the statue quite naturally accepted this lateral beam. The statue was then pulled 50 m, 30 of which were along a road-path and 20m up an 8% grade ramp to the replica platform where it was to be erected. No rollers were used on the ramp. Instead, individual "rungs" of a "canoe ladder" were spaced up the ramp then lubricated with water/banana stump liquid. The 20 m distance was covered in an astonishing 15 seconds. The statue was then positioned for the raising experiment that followed.

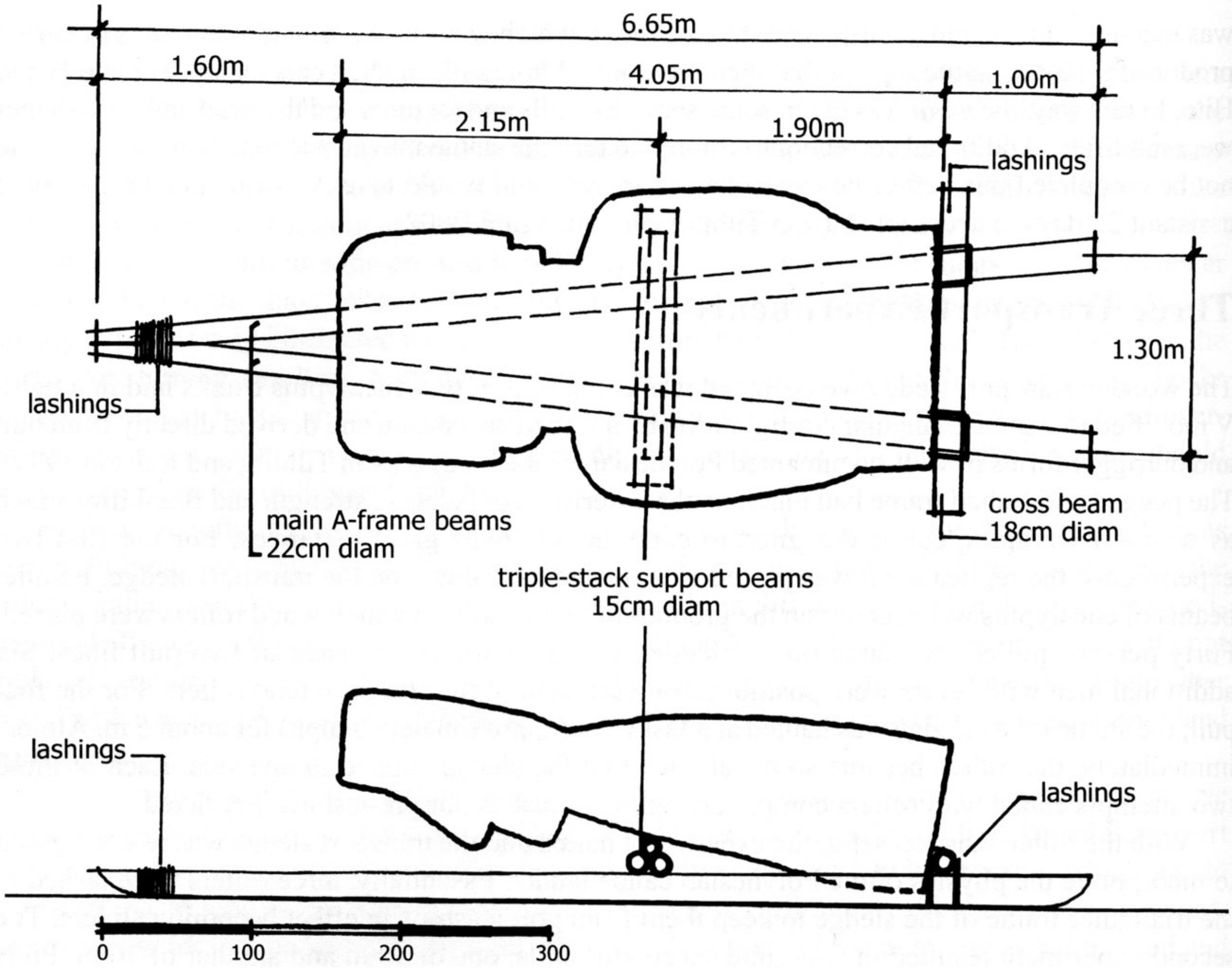
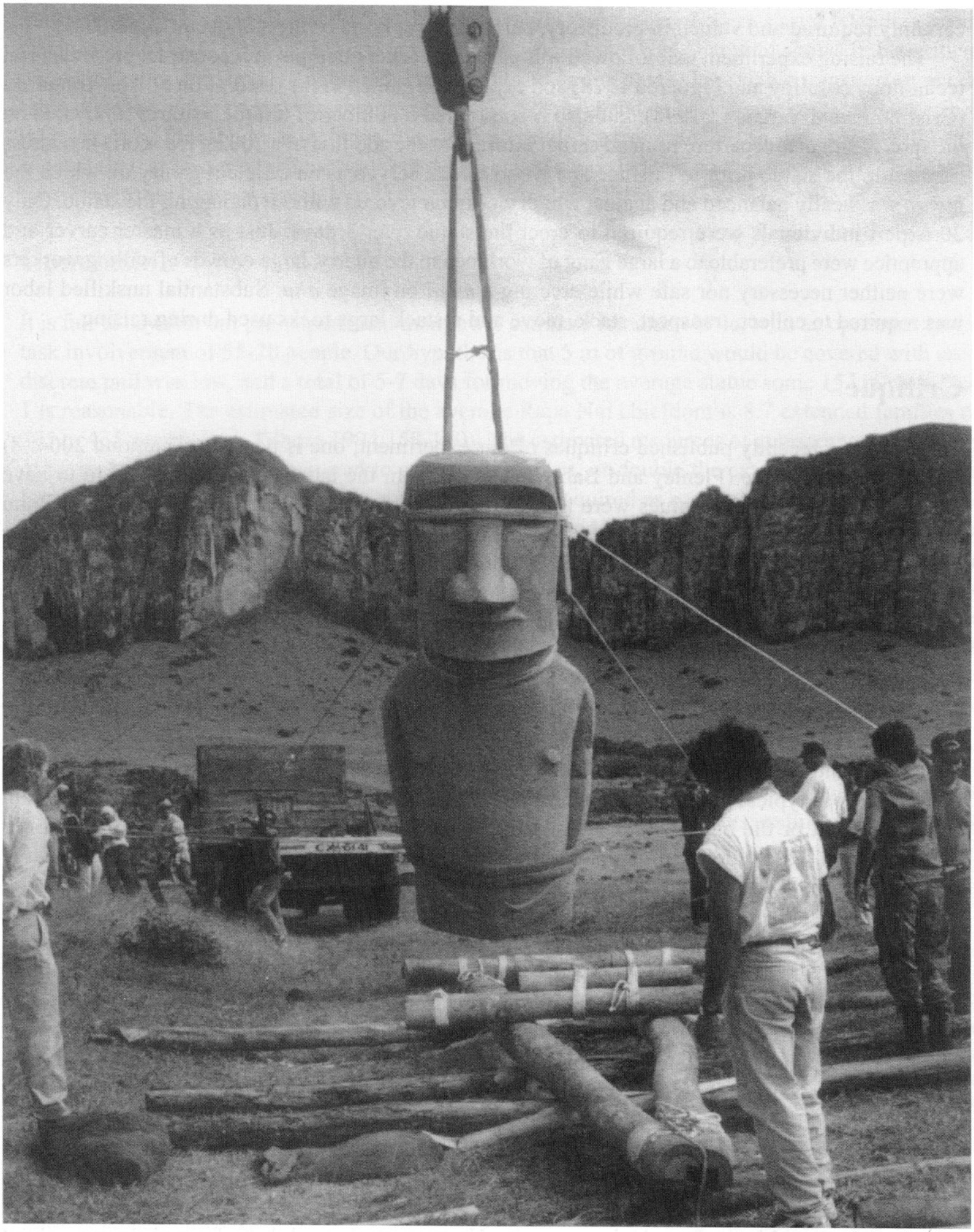


Figure 16.8 Configuration and dimensions of transport A-frame for third experiment, showing replica *moai* in face down position, supported by triple-stack of beams. Drawing by Johannes Van Tilburg, 1998.

Socio-Political and Economic Model

Computer modeling suggested that 55-70 people (or 48 average) were required to pull the average statue of 12 m tons over Path 1, and that their collective food requirement would have totaled 201,600 calories per day from agricultural staples such as sweet potatoes and bananas (Van Tilburg 1994:159). Our experiment demonstrated that 40 people were fully capable of pulling a 10 m ton statue. It is estimated that 65% of males and females between the ages of 10 and 65 are available for the average extended family "work force" in contemporary Polynesia (Van Tilburg 1994:158). Our hypothesis was that males performed the actual work, while females and children provided support. In fact, however, during the experiment women made up the larger part of the pull crews, while males only were allowed by the Rapa Nui crew chiefs to perform the heavy and far more dangerous tasks of levering in proximity to the statue. The pull crews generated a great deal of excitement, camaraderie and shared purpose during the transport experiment, and this sort of community participation was



Jo Anne Van Tilburg

Figure 16.9 Placement of replica *moai* on transport A-frame.

certainly required and valued in prehistory, part of the euphoria of the statue cult experience.

The raising experiment that followed was based on earlier attempts to reconstruct pre-industrial technology (Mulloy and Figueroa 1978) and experience gained in the restoration of Ahu Tongariki (Cristino F. and Vargas C. 1998), but also incorporated a number of unique features innovated on the spot. A singular departure from all earlier efforts was the addition of a 700 kg red scoria headdress (*pukao*) to the statue prior to raising. The wood sledge served as an efficient gantry on which the *pukao* was neatly balanced and against which workmen levered without damaging the statue. Only 20 expert individuals were required to erect the statue over 3 days. Just as a master carver and apprentice were preferable to a large gang of workmen in the quarry, large crowds of willing workers were neither necessary nor safe while erecting a *moai* on image *ahu*. Substantial unskilled labor was required to collect, transport, stack, move and restack large rocks used during raising.

Critique

There are two recently published critiques of our experiment; one is positive (Diamond 2004: 8) and the other negative (Flenley and Bahn 2003:125-7). In the latter, Van Tilburg is said to have "firmly believed that the statues were transported on their backs, feet first" (Flenley and Bahn 2003:125). Rather than "firmly" believing in any one transport method, Van Tilburg (1986:193) has consistently stated that "transport methods varied according to size and weight of the sculpture." Furthermore, this view was shaped into a hypothesis in which she employed computer simulations of highly accurate three-dimensional statue models to describe and illustrate conjectural methods of moving both supine and prone statues (cf. Van Tilburg 1994:155, fig. 123; 1995: 39, fig. 5). Computer simulations "are all very well, but moving huge rocks for real is a very different thing" (Flenley and Bahn 2003:125). Moving huge rocks for real, of course, is precisely what we did in our transport experiment.

Flenley and Bahn (ibid.) state that "the average platform selected for her experiments was Ahu Akivi, a very untypical platform specimen since it stands inland, and can thus be approached from either the front or the back." Their main point (which was made in the PBS Nova film of our experiment on which their critique is based) is that prone or supine statues approaching a large coastal platform head first had to be turned base first before being raised.

Just as our statue replica was based upon the statistically average statue, the platform used was a partial replica of one similar to Ahu Akivi (it was not Ahu Akivi). Far from it being "untypical," however, Ahu Akivi is very typical of nearly all large coastal platforms when, at their early building stages, they held average-sized statues. Furthermore, turning a prone or supine statue on the A-frame we designed is a relatively easy matter when viewed as part of the larger task. Our experiment actually raised more interesting questions about statues and platform architecture than these critics recognize. For example, how was a statue of any size raised on a platform when, approximately one meter from it, another was already standing upright and precariously balanced?

In sharp contrast, Diamond (2004: 8) views the statue transport question in the context of his own extensive research and personal experience of the islands near New Guinea. He grasps the "canoe ladder" concept we explore, and recognizes the effort that went into actually carrying out our experiment within the Rapa Nui community. He suggests that, while "informed guesses" about transport methods are easily made, Van Tilburg actually "persuaded modern Easter Islanders to put her theory to a test" (ibid.). This was no small accomplishment, as Diamond shows in his critical review of other, previously suggested, largely untried and certainly less viable transport methods (also sketched in this paper). He summarizes our experiment and its basic hypotheses, and describes its outcomes. Finally, he concludes that "the method most convincing to me is Van Tilburg's suggestion that Easter Islanders modified the so-called canoe ladders widespread on Pacific islands for transporting heavy wooden logs" (ibid.).

Conclusion

It is fair to say that our pre-experiment manpower estimate remains viable, with an optimum actual task involvement of 55-70 people. Our hypothesis that 5 m of ground would be covered with each discrete pull was low, and a total of 5-7 days for moving the average statue some 15 km over Path 1 is reasonable. The estimated size of the average Rapa Nui chiefdom is 8.7 extended families or 395 to 435 people (Van Tilburg 1994:158-160). The estimated resources of approximately 50 acres of agricultural crops were required to support this effort, or double the extended family norm for East Polynesia, with supplementary marine resources required as per oral traditions.

Projecting this estimate into the ultimately deforested island's ecological and cultural stage, however, creates a dramatic economic picture. Given the number and size of Rapa Nui image *ahu* and *moai,* their construction over about 300 years of peak activity added 25% to the total food requirements of the island's estimated population (see Diamond 2004). Such overexploitation explains, in part, the downward spiral of pre-contact culture. Moving statues that were larger than average, of course, required proportionately greater resources. Significantly, we estimate that the final building stages of large-scale ceremonial architecture moved appreciably more stone and demanded more resource investment than did transporting their associated statues.

This experiment suggests the revision of the specific gravity for Rano Raraku tuff. It also views the ethnographic descriptions of "walking" statues as referring to wood *paina* figures, not stone statues. We conclude that it is logical and reasonable to assume the successful transfer of basic elements of Polynesian maritime technology, expertise and tools to transporting (and erecting) monolithic *moai* of average size on Rapa Nui.

Acknowledgments

The authors wish to thank Keith L Johnson for inviting and editing this paper in honor of Clem Meighan, chairperson of Van Tilburg's doctoral committee. Clem took an always vital, questioning and profoundly encouraging interest in her work. Thanks especially to Johannes Van Tilburg, who was a driving force behind conceptualizing and carrying out three different transport strategies. UCLA Rock Art Archive digital artist Alice Hom assisted with image preparation. Gordon Hull accomplished statistical calculations of statue volume basic to the experiment. Core members of the transport team were Darus Ane, Cristián Arévalo P., Niko Haoa, Santi Hito, Margie Ralston, Rafael Rapu and Zvi Shiller. René Edmunds, Edmundo Edwards, Curtiss H. Johnson, Kent Sherwood and Ono Tuki were all especially helpful. Our deepest appreciation to former Rapa Nui governor Jacobo Hey Paoa, Mayor Pedro Edmunds Paoa, Fr. Joseph Navarette and José Miguel Ramírez. Above all, maururu korua to the Tepano and Hucke families and the kind and generous people of Rapa Nui.

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Notes

1. Rapa Nui is the apparently official and currently acceptable name of the island, used by the people on the island and on all Chilean maps. Linguists generally prefer Rapanui (cf. Van Tilburg 1994: 10).
2. Links between Hotu Matu'a as the traditional founding ancestor and "one of the same name" ('Atu Motua) in Mangareva are suggested (Green 1998:109; see also Buck 1938).
3. On Mangareva Miru and his brother Moa are the traditional first settlers who arrived from Hiva. The Miru were also associated with the western portion of the mythical Underworld (Buck 1938:20, 471). A drum called Miru was beaten continuously to accompany a chant called *ivitua* performed by *rogorogo* experts during ceremonies on *marae* associated with pregnancies and births in chiefly families (ibid. 1938:104). These are all provocative cultural parallels with Rapa Nui culture.
4. A recent non-instrument experimental voyage of *Hokule'a,* the Polynesian Voyaging Society's modern replica of a Hawai'ian voyaging canoe, traversed the open ocean from Mangareva to Rapa Nui in 19 days, making landfall on October 8, 1999.
5. The same replica statue was apparently also used to test the efficacy of lowering it down slope on timbers.

The timbers apparently scratched the back of the statue [but otherwise there is no published documentation of this test available] (Heyerdahl et al. 1989:40).

6. The Spanish thought they heard "Copeca," and that the image was "dedicated to [sexual] enjoyment". Métraux (1940:345) says that *kopeka* or *ati kopeka* "always refers to a slain man and implies the idea of vengeance"; see also Churchill (1912:306). On Mangareva, *kopeka* means "crossed" and refers to how two sprits are crossed at the deck of a raft to form the base of a triangular sail (Buck 1938:283). This suggests at least the possibility that the Rapa Nui term heard by the Spanish was being used to describe or refer to the Spaniards' crossed wooden uprights, which surely recalled ships' rigging.

7. Gary Lloyd sculpted the clay model to the field data specifications provided by Van Tilburg. A professional set designer then carved a full-scale statue that was used to create a fiberglass "shell" on which video images were projected. Entitled "Land of Projection," Bruce and Norman Yanomoto created the piece for an exhibition at the Japanese American Cultural Center, Los Angeles.