Awakening the Giant

Vincent R. Lee

This paper is an attempt to account for every detail of the process necessarily involved in the extraction, transport and placement of "El Gigante", the largest moai *on Rapa Nui. It is speculative, in that only full-scale testing of the techniques suggested could confirm their efficacy, an extremely costly and unlikely prospect. Nevertheless, the references show that every method has been shown to work at smaller scales and the notes address questions of scale at critical points. The author proceeds from the proposition that the islanders fully intended to move the statue upright from the quarry and erect it on a coastal* ahu *with an appropriately sized* pukao *atop its head. No explanation is offered for why that never happened. Rather, the assertion is that the Rapanui possessed the means and know-how to do so, despite the daunting magnitude of the project.*

Este artículo tiene la intención de dar explicaciones para todos los detalles del proceso necesario para extraer, transportar y colocar en sitio "El Gigante", el moai *más grande de Rapa Nui. Es un estudio especulativo, ya que solamente un análisis a gran escala podría confirmar la eficacia de los métodos propuestos – un prospecto muy caro y poco probable. Sin embargo, las referencias muestran que todos los métodos resultaron a escalas más pequeñas y las notas responden a preguntas importantes de escala. El autor asume el propósito de que los isleños tenían la intención, sin duda, de mover la estatua en una posición vertical de la cantera y colocarla en su posición final sobre un* ahu *costero con un* pukao *grande encima de la cabeza. No se presenta una explicación de por qué este nunca se ocurrió. En cambio se asume que los Rapanui tenían los recursos y los conocimientos para hacerlo, a pesar de la magnitud del proyecto.*

Introduction

Despite many years of research into the methods used by the Rapanui to move and erect *moai*, no one has yet accounted for every detail of the process necessary for the extraction, transport and placement of the statues, nor has anyone focused their analysis specifically on "El Gigante", the largest *moai* on Rapa Nui. What follows is a speculative attempt to accomplish both. Most of the ideas are not new, having been proposed and in many cases demonstrated by others using relatively small statues. I am indebted to all those who have preceded me in this work. My contribution here is to sort through all the existing theories, add several of my own and apply them to the most daunting project on the island, the 'awakening' of the Giant.

Some experts have doubted that the Rapanui ever intended to raise El Gigante from its bed. They may be right, though I doubt it. It is my hope that skepticism based solely on the magnitude of the undertaking – nearly four times that of "Paro", the largest *moai* actually erected on an *ahu*, with an estimated weight of 82 tons for the statue and an 11.5 ton *pukao* (Bahn & Flenley 1992; Flenley & Bahn 2002; Lee 1990; McLaughlin 2007) – will be offset by my analysis. If the Giant's carvers intended to finish the job, we must assume they thought they had the resources and know-how to do so, and can only speculate as to why they did not. A diminished workforce, resources, time, social stability, commitment – any or all of these might have been factors. I leave that analysis to others who are better qualified than I am. This paper is a study in rudimentary engineering, not archaeology. I take no position on any of the above issues, but simply address here how the Rapanui could have awakened the Giant, if they intended to, and circumstances had permitted it.

Assumptions

1. El Gigante is about 20 meters long and, extracted from the quarry, would weigh roughly 270 tons and exhibit a slender, straight-sided profile similar to that of the 11-meter *moai* excavated at the foot of the debris slope by Heyerdahl in 1987 (1989:234).
2. The Rapanui plan was to extract the statue from its bed, lower it to the toe of the debris slope, transport it in an upright position to a coastal *ahu*. According to Rapanui cultural tradition, the *moai* "walked" across the island with the aid of a supernatural force called *mana*. Upright transport is more consistent with this than any form of horizontal movement (Bahn & Flenley 1992; Flenley & Bahn 2002). The *moai* would be placed there facing inland with "eyes" installed and a 40-ton *pukao* balanced on its head.[1]

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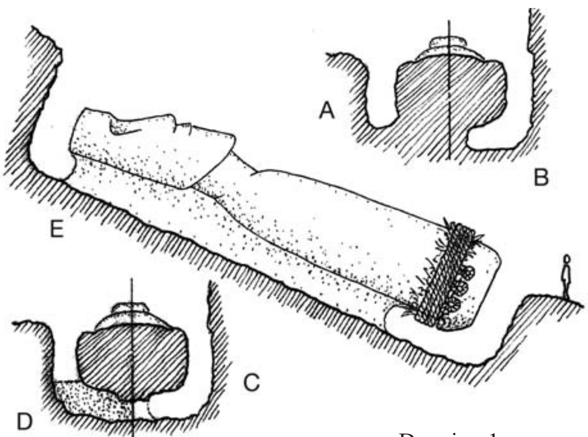
3. A workforce of several hundred laborers plus necessary logistic support was available as well as sufficient materials – *Jubaea* palm logs*, toromiro* poles*, hau hau* fiber for ropes and palm fronds, sweet potatoes and other lubricants, etc. – to get the job done.[2]
4. The methods proposed arise from knowledge reasonably attributable to the Rapanui in view of their presumed long experience with Polynesian maritime technology and the island's ubiquitous evidence of *moai* and *pukao* production and manipulation.
5. None of the methods proposed is contradicted by any evidence on the island or disproven by previous research.
6. The analysis that follows begins with El Gigante as it is found today, partially carved but remaining attached to bedrock along its entire back. The carving process itself is clear, with the pattern left by the *toki* (basalt adzes and chisels) still evident in the excavation and the *toki* themselves having been frequently recovered in the quarry.

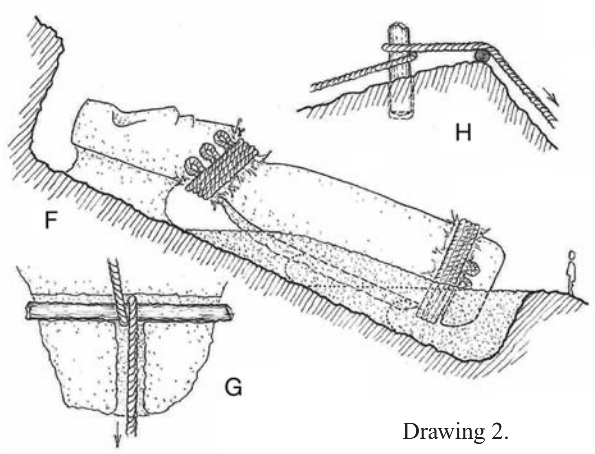
Extraction

The series of drawings that follows will illustrate every step in the proposed process, together with brief explanatory text for each image.



Drawing 1.

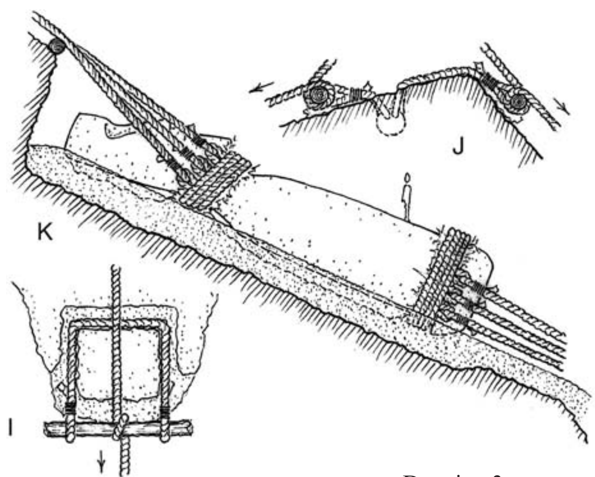
Cross-section 1A shows the statue as it is today. Detail 1B shows it undercut in preparation for detachment from bedrock, supported only by its keel. Detail 1E shows the statue completely undercut and ready for extraction. Removal of the keel will require simultaneous support beneath the statue as proposed in Drawing 2. Detail 1E, meanwhile, shows beginning removal of the keel from the base up, first cutting away just enough to permit attachment of a strong, tight, well-padded rope harness flush around the statue's base to facilitate all that follows, possibly leaving a small vestige of the keel below the harness as insurance to prevent it from slipping off.



Drawing 2.

Drawing 2F shows the keel being progressively cut away proceeding upward from the base while alternative support is simultaneously substituted by backfilling behind the cutters with stone chips beneath the statue. Detail 1C shows the keel cut away, leaving a vestige on the statue's back, but no trace on the floor of the bed.[3] In detail 1D, stone chips have been added for alternative support. With the cutters proceeding toward the head, the backfilling described above permits the attachment of another harness around the statue's neck prior to removing the last of the keel beneath the statue's head.

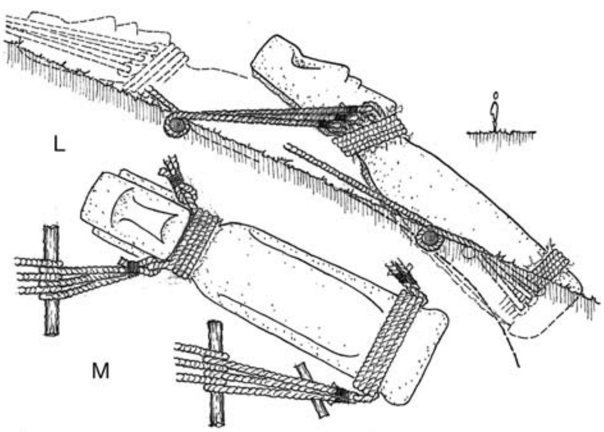
In Drawing 3K, the keel has been completely removed and the statue is supported entirely by the backfilled stone chips. Prior to removal of the last of the keel, however, head-ropes would be attached to the neck harness and snubbed tightly around anchors in the bedrock to prevent the statue from sliding uncontrollably once freed from its bed.[4] Details 2G and 3I are top views of anchor points carved into the bedrock high on the quarry cliffs and still clearly visible today. Details 2H and 3J are cross-sectional views of other types of anchor points still visible near the summit of Rano Raraku, the quarry cliff.



Drawing 3.

Head-ropes would be prudent, since the Rapanui had no way to be sure of the statue's behavior once freed, although the 25-degree slope at which it lies happens to be the precise angle at which an object's weight is effectively neutralized. Its tendency either to slide or remain stationary is roughly equal, with the friction against the slope deciding the issue.[5] This is a major benefit, since the debris slope below the quarry cliffs has about the same angle.[6] Despite its enormous weight, El Gigante is therefore relatively easy to move out of its bed and down the hill by pulling the foot-ropes for movement and snubbing the head-ropes around their anchors for control.

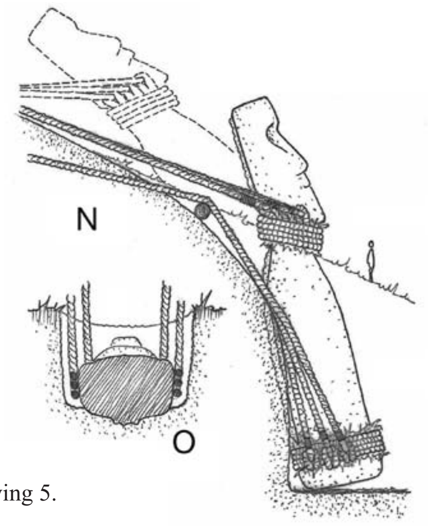
Test results[5] suggest that about 3% of an object's weight is needed to either move or restrain it on a 25-degree slope of loose gravel. To create such a track for the Giant, the bedrock below its base must first be cut away and covered with a deep layer of chips as shown in Drawing 3K. Next, a shallow groove is dug into the hillside below and lined with loose chips to guide and smooth the statue's descent. 3% of 270 tons, divided among 6 head-ropes, requires 2700 pounds of restraint per rope, easily provided by small crews taking advantage of the friction afforded by full wraps at the anchors. Working with gravity but without mechanical advantage, somewhat larger crews on the foot-ropes can easily nudge the statue downhill as necessary.



Drawing 4.

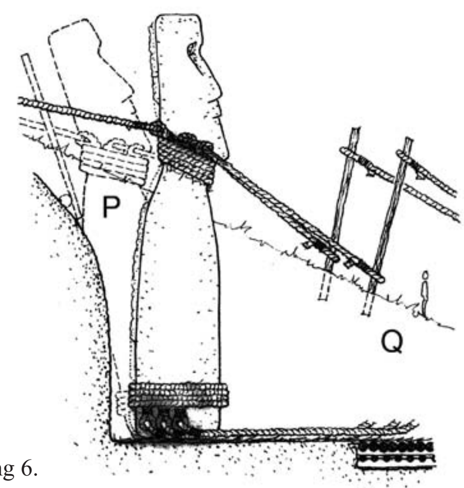
As the statue moves away from its bed and down the slope, intermediate anchors are easily established by digging "dead men" log anchors into the slope along both sides of the groove as outlined in Drawings 4L and 4M, limiting the lengths of the control ropes. As the statue nears the foot of the slope, the groove guides it into a pit, pre-dug to receive it in a standing position. Once the angle of descent steepens beyond 25 degrees, the foot-ropes, no longer needed for nudging the statue downhill, are re-rigged to assist in controlling the load from above as shown in Drawing 4M.

Nearing the bottom of the pit, the angle of descent steepens to nearly 90 degrees as shown in Drawing 5N, briefly allowing nearly the full weight of the statue to come onto the 12 control ropes. The strengths of both ropes and anchors would be critical in managing the load, and both were well within the capabilities of the Rapanui. As suggested in Drawings 4L and 4M, ropes were no doubt snubbed around anchor logs, reducing the force needed to control them to something less than 4% of the statue's weight.[7] Again, crew sizes would be correspondingly reduced.



Drawing 5.

To minimize the huge amount of excavation needed for a *moai* the size of El Gigante, the pit is only slightly larger than the statue, as suggested in Drawing 5O, with just enough space for workers to move around to its back for the final phase of finishing, the removal of the remaining keel.[8] Before this could begin, the statue was pulled upright onto its base by reorienting four of the head-ropes downhill for the pullers, possibly using levers as shown in details 6P and 6Q to minimize crew sizes. Two head-ropes would remain anchored uphill to guard against tipping the statue too far forward.

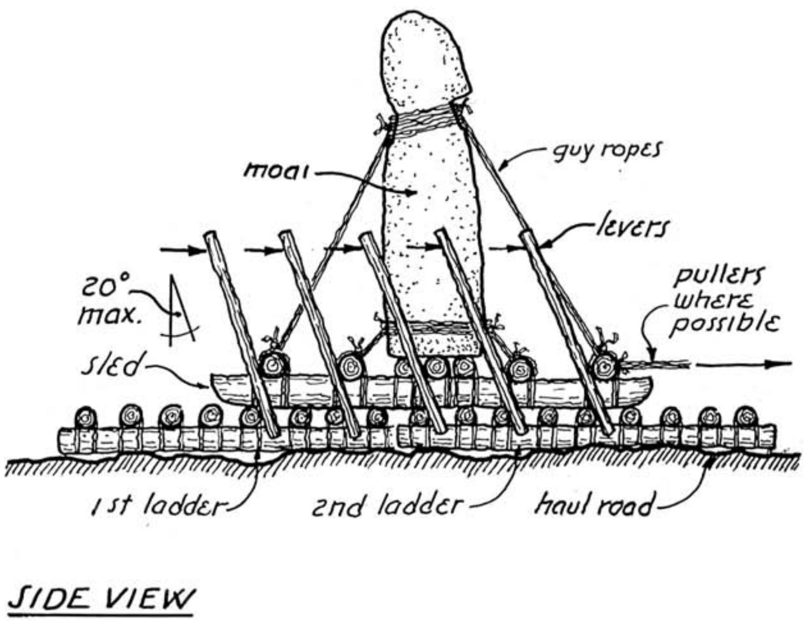


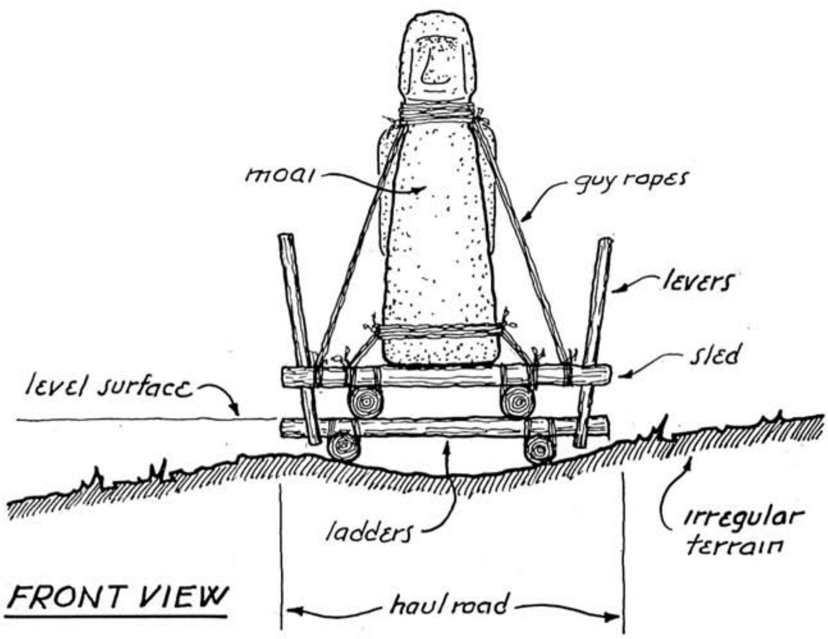
Drawing 6.

Drawing 6 shows the statue free-standing in the pit with sufficient space for cutters working from scaffolding able to remove all vestiges of the keel from its back[9] as well as complete any other finishing not possible in the quarry. A thick layer of palm fronds placed in the pit prior to lowering the statue pads its base and provides lubrication for the next, brief phase in moving the Giant. In addition, near the mouth of the pit, where less excavation was needed to enlarge its size, a sled and track have been set flush with the pit's floor in preparation for final transport of the statue across the island.

Transport

The decision to honor local tradition and move the statue upright leaves us only one proven option to accomplish the next move, given the restrictive space around the *moai* and evidence from previous excavations.[8] Several researchers, responding to the Rapanui tradition that the statues 'walked' across the island, have shown that alternately tipping and rotating a statue can indeed move it forward (see Bloch 2012; Love 2000b; MacIntyre 1999; Pavel 1995). El Gigante





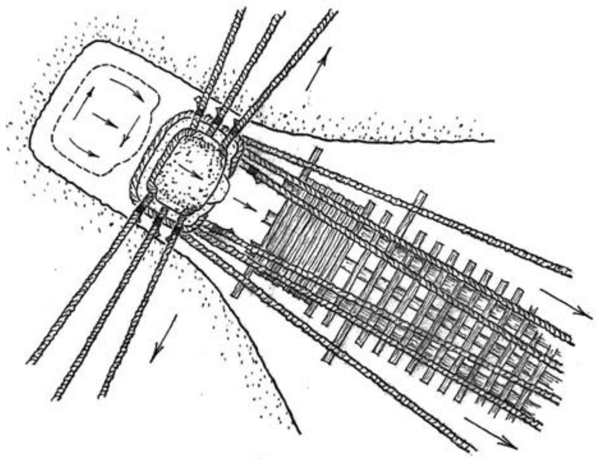
Figures 1 and 2 show the basic idea applied to a small, generic statue. For our purposes, the sled and ladder need to be greatly expanded and strengthened to accommodate the size and weight of the Giant, but the concept remains the same.

is far larger than those used in these experiments, and its slender profile renders the technique more demanding of care than in the earlier tests. Also, despite being done on smooth, flat terrain, those tests sometimes caused damage to the *moai*'s base not typically found on statues moved centuries ago by the Rapanui. Finally, excavations of the ancient haul roads have shown not smooth, flat roadways, but routes across rolling terrain with shallow, dished out profiles, neither of which are friendly to the method (see Love 2004). For all of these reasons, Drawing 7 shows it used here only to move the statue out of the pit a short distance onto a sled for continued movement across the island. Crews are alternately tipping the statue sideways using the head-ropes and coordinating with crews alternately rotating its base slightly forward with the foot-ropes.

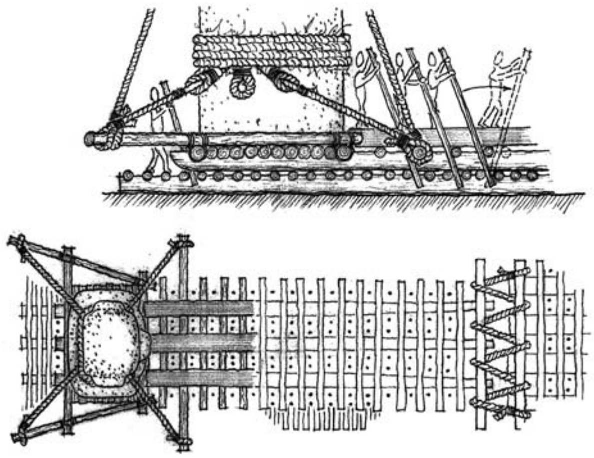
The sled design proposed here to continue upright movement of El Gigante on its journey is one the author devised during the 1998 NOVA project (see Lee 1998a, 1998b, 1999; Van Tilburg 1995, 1996) to solve a particular problem, but which has broader application here. In its simplest form, it mounts the standing *moai* on a sled offering numerous lever points, levered forward working against corresponding lever points on a "canoe ladder" (see Lee 1998a, 1998b, 1999), or track on the ground beneath the sled. Advantages of the method are enhanced stability of the upright statue, protection of its base from damage, reduction of crew size due to the mechanical advantage of lever-men vs. pullers, and elimination of any crew forward of the sled while moving onto a seacoast *ahu* with little or no space beyond the statue's pedestal for pullers to work.

Drawings 7, 8, and 9 show the specific elements of the expanded design. In theory, the loaded sled could simply be dragged over the ladder, with its crossbars acting as lubricated sliders. In the absence of the mechanical advantage of levers, however, the crew size in this case would be prohibitively large in comparison with the island's population.[10] And, as noted above, *only* lever-men can ultimately nudge the *moai* up onto a seacoast *ahu*, working alongside and behind the sled. Finally, some may wonder why rollers are not suggested here in lieu of sliders. The answer is complicated, but rollers are very difficult to manage under field conditions,[11] and once askew, would be virtually impossible to realign beneath anything like a 270-ton load.

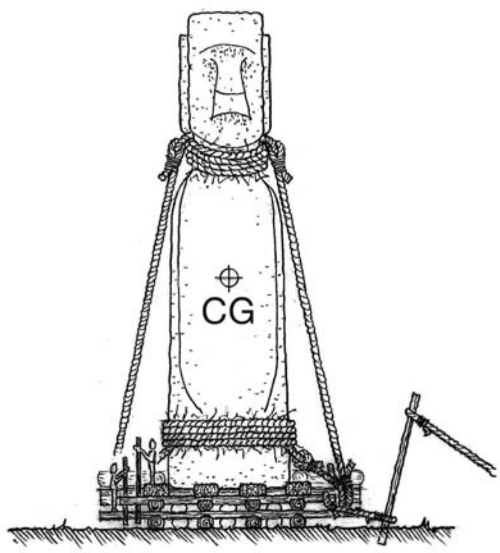
Drawing 7 shows the statue being walked out of the pit and onto a stout platform at the near end of the sled, prepositioned atop its ladder. In Drawing 8, the *moai* is loaded, lashed down with four tight foot-ropes and steadied by four tight head-ropes lashed to outriggers. Tightening is easily accomplished by twisting the ropes using the age-old "Spanish Windlass" method. The sled carrying the statue is about 20 meters long



Drawing 7.



Drawing 8.



Drawing 9.

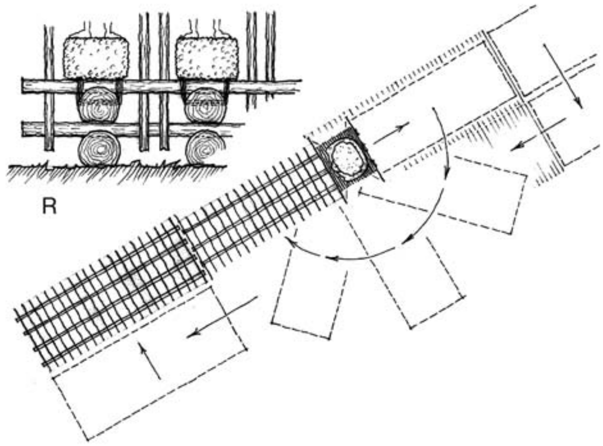
(roughly the length of a semi-tractor-trailer truck) and consists of stout crossbars about a meter apart, let into and lashed securely to three large longitudinal *Jubaea* palm log ‘runners’ spaced about a meter apart, with smooth, well lubricated surfaces bearing on the track below and beveled ends at both the front and rear to prevent hanging up on the sliders.

The ladder underneath is of similar design except that the crossbars extend beyond those of the sled about a meter at each side and are only 1/3 meter apart. They are notched deeply into longitudinal logs below, not lashed, but held in place by the weight of the sled above. Lubricating the ladder notches might encourage the sliders to rotate without going askew like free rollers, potentially further reducing friction between sled and ladder. Unlike the sled, the ladders can thus be easily disassembled, leap-frogged ahead of the sled in pieces and reassembled there, forming a continuous track using a minimum of trees. The spacing of the crossbars and other specifics of both the sled and ladder designs are important for maximum strength and utility, but easily determined by trial and error and well within the capabilities of the Rapanui (see Lee 1998a, 1998b, 1999).[12]

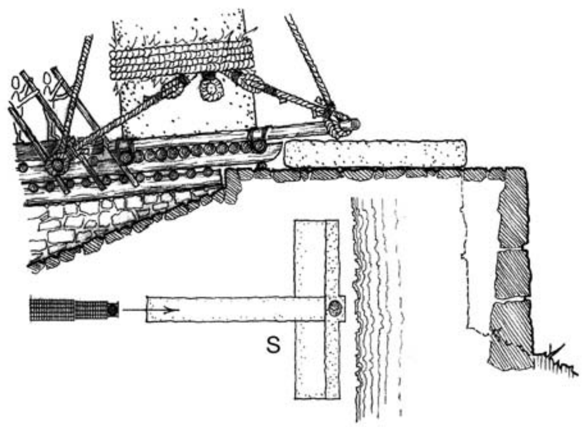
Each dot on the top view of the sled in Drawing 8 represents a lever-man, most of whom ride on the sled and add their weight to the load, as does the sled itself. As a result, the loaded sled weighs roughly 300 tons. The friction coefficient between the well-lubricated sled runners and sliders is about .2 (see Lee 1998a, 1998b, 1999), so moving the Giant will take a force of about 60 tons, or 120,000 pounds. Each worker can apply about 100 pounds to his lever. The longer the levers, then, the more of those 120,000 pounds each can provide.

Drawings 8, 9, and 10 show the design proposed here. Standing on long, raised platforms made of bundled reeds as shown in Drawing 10R, the lever-men on the sled have a mechanical advantage of about 5, accounting for 500 pounds of motive force each. Because of the limited length of available trees, the resulting crew of 240 can’t all fit on El Gigante’s sled and a second, larger sled is needed to help pull the load, much like the multiple engines hauling a freight train. To aid those working on the sleds, additional force can be applied by lever-men standing on the ladder and pullers on tow ropes, possibly aided by levers as suggested in Drawing 9.[13]

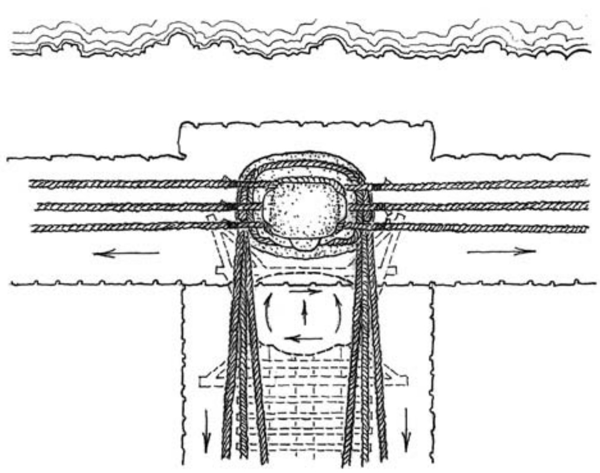
Using this method, a crew of fewer than 300 can move the Giant across the island, negotiating rough ground and uneven terrain without danger of toppling the statue or damaging its base, and consuming as few trees as possible. Before approaching its destination, however, one final move is necessary to reorient the statue so that it faces inland once placed on its *ahu*



Drawing 10.



Drawing 11.



Drawing 12.

platform: the train must be turned around. On flat, open ground, it might be possible to simply turn the track in a long sweeping turn until it is at a right angle to the direction of travel, and then do another sweeping turn back into line rear end first.

Drawing 10 shows an alternative method requiring much less space and travel. The sleds are separated and, by clever placement of several ladders, pullers rotate the statue sled 180 degrees around the axis of the *moai*. Then, the other unloaded sled is easily pulled over ladders into position behind the now-reversed statue sled. Workmen previously pulling El Gigante with their levers are now pushing it forward, taking advantage of sled designs that work equally well either way.

Placement

We are now ready for the final stage of the statue's journey, placement atop its pedestal on a seacoast *ahu*, with no workspace on its seaward side. Drawing 11 shows a generic *ahu* design not unlike many on the island, although with an especially low-angle approach ramp in response to the magnitude of our project. The platform's internal structure is not shown, but would need to be extra strong to support El Gigante's weight. The pedestal has been sized to match the height of the statue's sled for ease of movement from one to the other once the sled is levered as close to the pedestal as possible as shown in Drawing 11. The upper end of the approach ramp has been held lower than the *ahu* platform by the height of the ladder to make this possible.

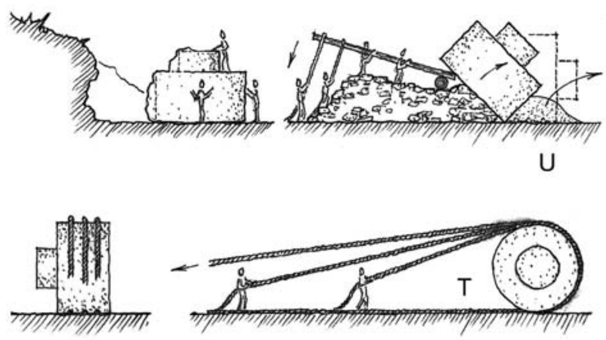
At this point, all that remains is walking the *moai* off its sled and onto its pedestal. Drawing 12 shows a process matching that used earlier to load the sled, except that in this case the foot-ropes are wrapped around behind the statue's back, reversing their direction of pull to permit backward movement while pulling from the front. The foot-ropes might also be pulled from the *ahu*'s wings, workspace permitting, like the head-ropes. The required movements being quite small, levers used per detail 6Q could greatly reduce crew sizes and save workspace.

Adding the *Pukao*

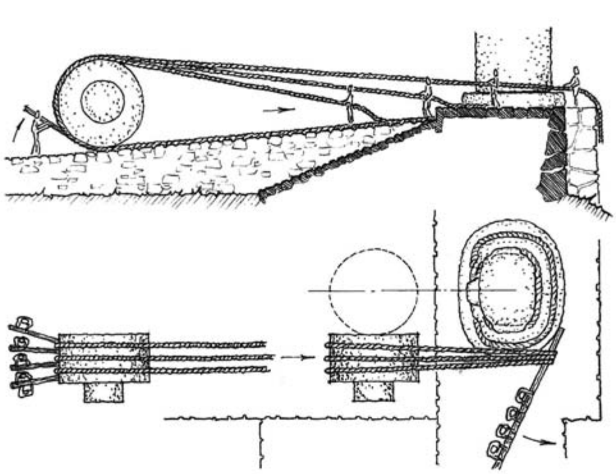
The next phase in awakening the Giant is balancing a red scoria *pukao*, or topknot, atop his head, and is thought by many researchers to be as daunting as placing the *moai* itself. Their concerns are magnified in this case by the size and weight of the *pukao* and the height of the *moai*, twice that of Paro, the tallest statue crowned with a *pukao* by the Rapanui. With Paro's statistics as a guide, El Gigante's *pukao* would weigh about 40 tons. Several ideas, including ramps of both stone and logs, have been proposed for installing a *pukao* atop a standing statue (see Mulloy 1970; Pavel 1995), but no evidence remains and none seem practicable here. Needed is an altogether new method, up to the task and within the capabilities of the Rapanui. First, however, we must carve the *pukao* and get it from the scoria quarry to the Giant's *ahu.*

Drawing 13 shows the beginning of this process. In detail U, the *pukao* is being tipped up, levered first up to 45 degrees and then lowered onto its edge by excavation of a sand pile.[14] Three ropes have been laid out under the sand so that once on edge, the *pukao* can be rolled like a huge wheel as in detail 13T. This is surprisingly easy, requiring a force equal to a very small percentage of the object's weight on level or gently sloping terrain.[15] Going gently downhill, the same system can be used to control the descent. Ropes must be staggered and laid under and out ahead of the *pukao*, such that several can always be wrapped over the top and on to the pullers.

In Drawing 14, the *pukao* has arrived at the *ahu* and is being rolled up the low-angle approach ramp. Lever-men working behind the *pukao* can help get it up the final grade and a clever use of levers can offset the lack of workspace as it approaches the *moai.* In anticipation of the next operation, the *pukao* is pulled up the edge of the ramp so that it can next be lowered into position on its base and centered on the *moai*, as



Drawing 13.



Drawing 14.

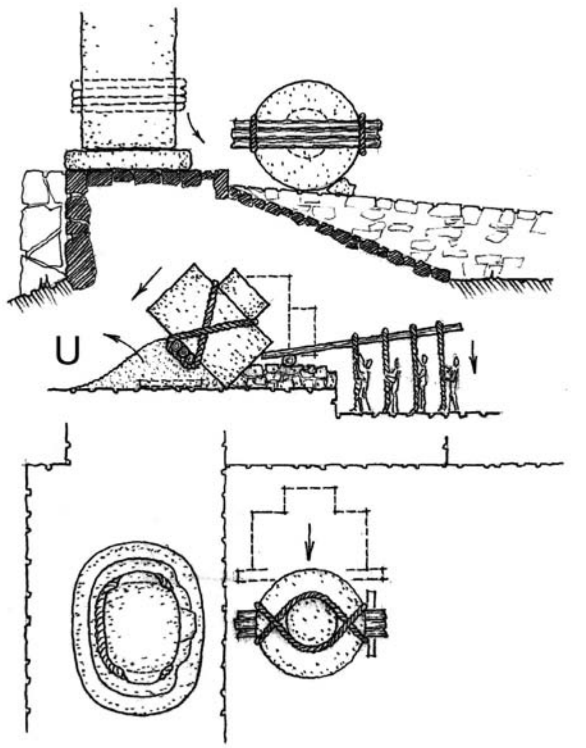
shown in Drawing 15. Before being lowered, however, it needs to be chocked with stones to prevent it from rolling away once the ropes are released. At this stage, the rope harness around the *moai*'s base is no longer needed and can also be removed. Finally, three stout logs are lashed onto the *pukao*'s base as shown and it is lowered into position for the next move, reversing the method described in detail 13U. Another log, buried in the sandpile, will offset the slope of the ramp such that the *pukao* is level once lowered.

Recalling that in Drawing 11, the top of the ramp was held lower than the *ahu* to compensate for the height of the ladder, the *pukao* must next be raised and a rough stone platform built beneath it to make up for this elevation difference. The method used is shown in Drawing 16. Using the logs lashed to its base as a pivot point, the *pukao* is rocked from side to side with flat stones placed alternately under the logs on the high side both raising the load and permitting construction of the platform. With most of the *pukao*'s weight being counterbalanced, the force needed to rock it is manageable.[16] Lever-men can be aided in this by a crew simply walking back and forth atop the *pukao*, as shown.

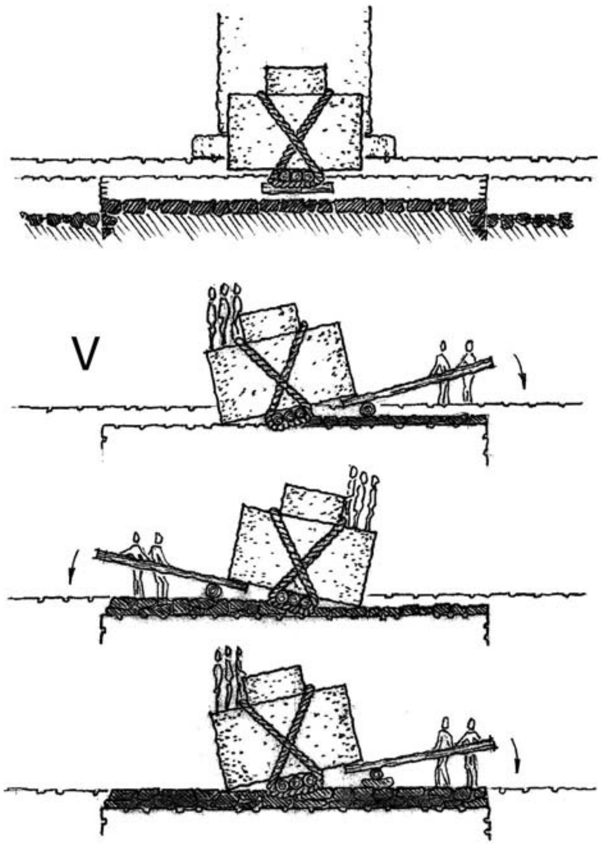
The *pukao* now rests on the raised platform, its surface level with the *ahu*. To continue lifting it, the same rocking method shown in Drawing 16 is used, with one exception. As the rock pile deepens, it must either expand laterally in the form of a rising, eventually enormous flat-topped pyramid or be contained somehow. Drawing 17 proposes containment by a rising log crib, notched at the corners like a rustic, two room log cabin, enclosing both the statue and the rock pile for stability and in preparation for moving the *pukao* finally into place atop the *moai.*

Many of the needed logs can be salvaged from the sleds and ladders, and the corner joints are securely lashed together. Most of the stones are temporarily borrowed from the steeply sloping inland face of the *ahu*, to be returned there later. To facilitate lifting both logs and stones, projecting log outriggers support platforms connected by ladders for the workers as well as periodic resting places for logs being raised as shown in detail 17W. Drawing 18 shows the process in action per details W and X, with the rocking crew continuing to raise the *pukao* per Drawing 16.

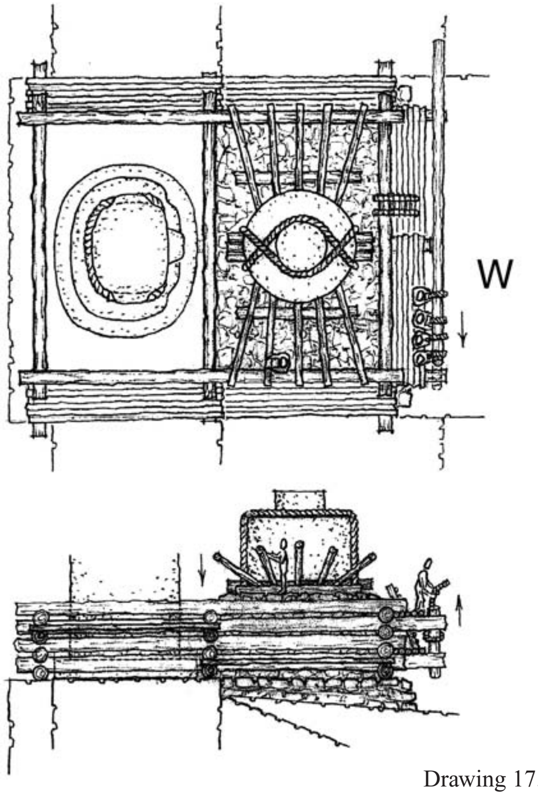
As the work surface approaches the *moai*'s neck, the harness there can be removed or, alternatively, lashed securely to the log work for mutual support. Once the base of the *pukao* is a bit below the top of the *moai*, short log rails and small rollers are inserted beneath the pivot logs to bring the base level with the top of the head. The ropes securing the pivot logs are then cut away, and the hat rolled into position atop the *moai* per detail Y, using the entire top of the log crib and rock pile as a work platform.[17]



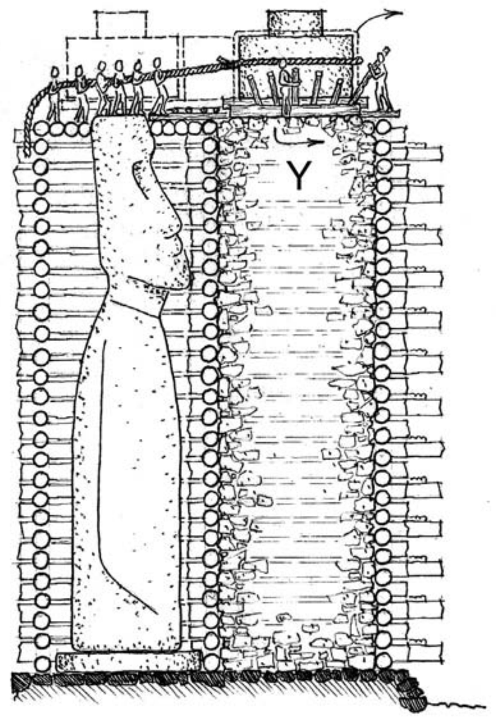
Drawing 15.



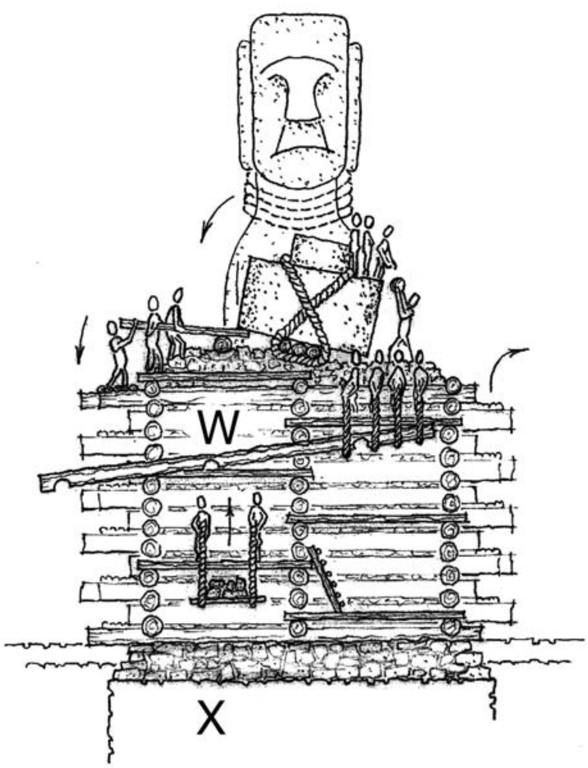
Drawing 16.



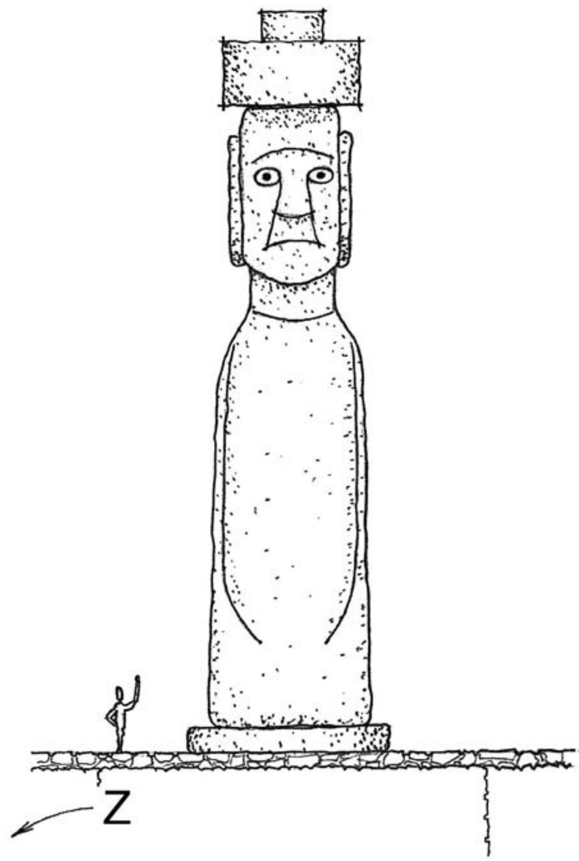
Drawing 17.



Drawing 19.



Drawing 18.



Drawing 20.

The Awakening

That done, the rock pile and log crib are dismantled, reversing the process by which they were raised, briefly halting to insert the *moai*'s eyes on the way down, thus 'awakening' the Giant as shown in Drawing 20. If still in place, the neck harness is removed, the rocks are returned to the steep inner face of the *ahu*, the logs recycled to other uses and the approach ramp taken down and added to those already buttressing the *ahu*'s inner face per detail Z. Thus might the carvers of El Gigante have completed a job well begun.

Conclusions

As stated at the outset, the proposed process is necessarily speculative, indicating only how the Rapanui could have completed the extraction, transport, and placement of El Gigante crowned by a *pukao*, since none of those things actually happened. Nevertheless, it is the author's thesis that the methods suggested were well within the capability of the Rapanui and would have worked if attempted. Major refinements would surely have resulted once the project actually got underway, but the basic ideas proposed are sound, un-contradicted by evidence on the ground and confirmed by the years of latter-day experimentation described in the references cited below. Applied to the hundreds of much smaller *moai* actually erected in antiquity, all of the proposed techniques would have been relatively easy.

Study of the quarry and the many *moai* still found at the base of the debris slope strongly suggest that extraction was accomplished more or less as suggested here. Variations on the 'walking' method for loading and unloading the sled have been well demonstrated (Bloch 2012; Love 2000a, 2000b). Applied to Paro, the lever-sled transport system proposed would have called for only 65 lever-men and a single sled about half as wide as those proposed for the Giant – a width corresponding to the actual haul-road widths reported by Love (2004). Using this method, the author has easily moved a 13-ton stone on a 1-ton sled over greased ladders on level ground with only 8 lever-men and up a 25% (1:4) grade with only 28 (Lee 1999). In two workdays, with only 10 helpers, the author has also raised a 12-ton stone lintel onto a pair of 3-meter (10 ft.) high uprights using much the same method suggested here for El Gigante's *pukao*. Returning to Paro, the crib needed to raise his 11.5-ton *pukao* would have been approximately as shown in Drawing 18. Although we may never know exactly how the Rapanui did what they did, it is clear that focused intelligence and determination were all that they needed.

Notes

1. In the absence of any other way to size an appropriate *pukao* for El Gigante, Paro's proportions have been copied. His *pukao* is about 14% of his weight. Applied to the Giant, this gives a weight of 37.8 tons, rounded off here to 40 tons.
2. The island's peak population has been estimated between two and ten or more thousand, divided into numerous clans. Whether clans cooperated on *moai* projects is unknown. Assuming not, El Gigante was almost certainly planned by a large, important clan, perhaps able to muster a workforce of several hundred, plus several hundred more in support. (Bahn & Flenley 1992; Flenley & Bahn 2002; Lee 1990; McLaughlin 2007).
3. No trace of severed keels has yet been found in any of the many empty beds still found in the quarry (G. Lee and C. Love pers. comm.).
4. The anchor points shown are examples from high in the quarry. They may have secured static lines from which snubbing logs were suspended far below, but creation of similar anchors lower down would have been a trivial matter for cutters able to carve a *moa*i. In any case, firm anchor points were abundant or easily established.
5. To test this, a 29-pound concrete block was set on a plank at an angle of 25 degrees. It remained stationary, but began sliding with less than a pound (3% of the block's weight) of force. The test was repeated with a layer of loose sand on the plank. When released, the block began sliding but was stopped by the same relatively small amount of force. 3% of 270 tons is 8.1 tons, or 16,200 pounds. Divided among 6 ropes, this puts 2700 pounds on each rope/anchor. By taking turns around the anchor logs, the forces felt by the restraining crews are easily manageable. See also note 7.
6. The slope is 25 degrees, or 55%, not 55 degrees as has been reported.
7. To test this, a 40-pound weight was suspended by a 1.5cm (5/8") diameter hemp rope around a smooth, 30cm (12") diameter horizontal log. With one complete turn around the log, a force of about 1.5 pounds (4% of the object's weight) prevented the rope from slipping around the log. Due to friction against the slope, no more than 90% of El Gigante's weight, or 240 tons, would likely come on the ropes during final lowering. The 12 anchor ropes would each carry about 20 tons, or 40,000 pounds, and require a 6.5 cm (2½") diameter hemp (or equal) rope. Three of these, snubbed around a .75m (30") diameter log about 5m (16ft) long, buried at least 1.2m (4ft) below the surface could readily handle the load. Aided by the mechanical advantage noted above, the lowering crews would need to control about 1600 pounds per rope, easily managed by 20 or so workers, or a total workforce of about 240.
8. *Moai* standing at the foot of the debris slope that have been completely excavated (Heyerdahl 1989:186-192 & 234-235; Routledge 2007 [1919]:185-189) disclosed that the pits into which they had been lowered were only slightly larger than the *moai*, especially where digging had been difficult, and no evidence was found of wooden sleds or other foreign material beneath the statues' bases.
9. Routledge 2007 [1919], Figure 68, facing page 189 shows this abandoned in progress, although on most *moai* standing at the base of the debris slope, keels have been removed.

10. The loaded *moai* sled, without lever-men aboard or a connected lever sled, would weigh about 280 tons, or 560,000 pounds. Pulled over well-lubricated ladders acting as sliders, the coefficient of friction is about .2, (see Lee 1998a, 1998b, 1999) requiring a force of 112,000 pounds to move the load. Assuming each worker can apply a maximum of 100 pounds of pulling force, a crew of at least 1120 would be required. While theoretically possible, this would constitute a large percentage of the island's total population, implying the cooperation of multiple clan groups. Even so, there is no way such a crew could possibly drag the *moai* up onto a seacoast *ahu* due to the disappearance of workspace once the front ranks reached the drop-off on the platform's seaward side. The method proposed here cuts the workforce by 75% and solves the *ahu* problem.
11. Substituting rollers for the sliders described above might theoretically reduce the workforce due to a presumably reduced coefficient of friction, except that rollers have been tried and found unmanageable (see Lee 1998a, 1998b, 1999; Van Tilburg 1995, 1996). To work properly, rollers must be uniformly cylindrical, straight and of matching diameters. They must roll over a smooth, flat surface. None of these conditions are readily provided in the field and failure of any results in rollers bunching together or going askew, both of which are difficult or impossible to remedy under load. Also, rollers are virtually impossible to manage going downhill or uphill, as on the *ahu*'s approach ramp. Finally, even a reduced workforce runs out of workspace as its front rank reaches the *ahu*'s seaward side.
12. All members in both the sleds and ladders and their connections have been designed strong enough to carry the loads and durable enough to complete the journey from quarry to *ahu.* Repairs or replacements along the way would be tedious, but possible (unlike righting askew rollers trapped beneath the loaded sled per Note 11) except directly beneath the *moai*, where the proposed design takes special care and members are oversized. All lashings are through holes bored through the runners to avoid obstructions between runners and ladders.
13. A detail reported by Love (2004), occasional post-holes alongside the roadway, may relate to the use of roped levers to assist sled crews in especially difficult places, as suggested in Drawing 9.
14. The most difficult move is the first, lifting one side of the *pukao* off the ground. Long, stout levers are inserted into holes dug under the edge to be raised, and fulcrums are set as close as possible to the edge. Only half the total load is needed at the outset, and progressively less as the angle increases. Chockstones are put under the base as it rises to maintain height gained. At the start, El Gigante's 40-ton *pukao* would require 20 tons, or 40,000 pounds of lifting force. Divided between 5 levers with a mechanical advantage of 10, each lever crew would have to apply 800 pounds of force, a manageable amount. As the load passes 45 degrees, its own weight completes the job. A sand pile to cushion the *pukao*'s descent is slowly excavated, allowing it to settle. By reversing the lever system, the last of the sand can be removed, completing the move.
15. To test this, a 40-pound pulley was set straddling a 1.5 cm (5/8") hemp rope, which was then wrapped up and over the pulley and attached to a spring scale. Over flat, level ground the force required to roll the pulley was negligible. Over slightly undulating ground the force needed to go uphill was less than a pound, or .25%. Applied to El Gigante's 40-ton *pukao*, the force required is 2000 pounds or less, easily applied by a crew of 20 or 30 workers.
16. Those portions of the *pukao*'s volume lying at either side of the pivot logs obviously counterbalance each other, leaving only the weight of the center portion, about 30% of the total, to be levered by the crew. Of the 40 tons proposed here, the workers need to rock 24,000 pounds back and forth, lifting only half this amount from each side. Divided among 5 levers, each has to account for 2400 pounds. With a mechanical advantage of about 8, and aided by a crew walking back and forth atop the load, this is well within the capabilities of several workmen per lever.
17. Here at last, is a situation appropriate for rollers. The *pukao* only needs to move several meters horizontally under easily controlled circumstances. Starting with the base of the *pukao* about 20cm (8") below the top of the *moai*, 20cm (8") diameter rails and small rollers are inserted under the pivot logs instead of stones so that the pivot logs end up supported on rollers atop rails flush with the statue's head. Taking advantage of a coefficient of friction of as little as .025, a crew of 20 or so applying a force of about a ton could then pull, push and lever the *pukao* into position and remove the rails, rollers and pivot logs by reversing the rocking method described in Note 15.

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References

Bahn, P. & J. Flenley. 1992. *Easter Island Earth Island*. New York: Thames and Hudson.

Bloch, H. 2012. If Only They Could Talk. *National Geographic Magazine* July:30-49.

Flenley, J. & P. Bahn. 2002. *The Enigmas of Easter Island.* New York: Oxford University Press Inc.

Heyerdahl, T. 1989. *Easter Island, The Mystery Solved*. New York: Random House.

Lee, G. 1990. *An Uncommon Guide to Easter Island*. Arroyo Grande: International Resources.

Lee, V.R. 1998a. *The Sisyphus Project: Moving Big Rocks Uphill or Into Small Places*. Cortez: SixpacManco Publications.

——1998b. Rapa Nui Rocks: Impressions from a Brief Visit. *Rapa Nui Journal* 12(3):69-72.

——1999. Rapa Nui Rocks Update. *Rapa Nui Journal* 13(1):16-17.

Love, C.M. 2000a. The Context and Structure of Ahu Kihikihi Rau Mea. *Rapa Nui Journal* 14(1):5-12.

——2000b. More on Moving Easter Island Statues, with Comments on the NOVA Program. *Rapa Nui Journal* 14(4):115-118.

——2004. Getting to Know You. *Rapa Nui Journal* 18(2):115-118.

MacIntyre, F. 1999. Walking Moai? *Rapa Nui Journal* 13(3):70-77.

McLaughlin, S. 2007. *The Complete Guide to Easter Island*. Los Osos: Easter Island Foundation.

Mulloy, W. 1970. A Speculative Reconstruction of Techniques of Carving, Transporting and Erecting Easter Island Statues. *Archaeology & Physical Anthropology in Oceania* 5(1):1-22.

Pavel, P. 1995. Reconstruction of the transport of the moai statues and pukao hats.*Rapa Nui Journal* 9(3):69-72.

Routledge, K. 2007 [1919]. *The Mystery of Easter Island*. New York: Cosimo Classics.

Van Tilburg, J. 1995. Moving the Moai, Transporting the megaliths of Easter Island: How did they do it? *Archaeology Magazine* Jan/Feb:34-43.

——1996. Mechanics, Logistics and Economics of Transporting Easter Island (Rapa Nui) Statues. *Rapa Nui Journal* 10(4):110-115.

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