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INTRODUCTION

In considering the subject of prehistoric earthmoving and the construction of monuments associated with it, there are many variables for which some sort of control must be achieved before any feasible demographic features related to the labor involved in such construction can be derived. Many of the variables that must be considered can be given support only through certain fundamental assumptions based upon observations of related extant phenomena. Many of these observations are contained in the ethnographic record of aboriginal cultures of the world whose activities and subsistence patterns are more closely related to the prehistoric cultures of a particular area. In other instances, support can be gathered from observations of current manual labor related to earth moving since the prehistoric constructions were accomplished manually by a human labor force. The material herein will present alternative ways of arriving at the represented phenomena. What is inherently important in considering these data is the element of cultural organization involved in such activities. One need only look at sites such as the Valley of the Kings and the great pyramids of Egypt, Teotihuacan, La Venta and Chichen Itza in Mexico, the Cahokia mound group in Illinois, and other such sites to realize that considerable time, effort and organization were required.

In this paper, the focus of attention will be on two sites, each of which provides information concerning the construction activity at each site. The Poverty Point site in northeastern Louisiana, 20 miles west of the Mississippi River, is one of the selected sites. The features of interest here are the earthen mounds (one of which is the second largest in North America) and the extensive, geometric system of earthen ridges that is associated with the largest mound. The other site that will be considered is Teotihuacan in Mexico. Emphasis here is upon the largest construction at the site, the Pyramid of the Sun.

TEOTIHUACAN

The Valley of Mexico in the Mesa Central of Mexico has been an important cultural center in Mesoamerica since man first arrived in Mexico. The Valley and surrounding areas witnessed the rise and fall of numerous native civilizations, climaxing with the destruction of the Aztec empire by the Spanish in the early 16th century. Among the civilizations which arose in the Valley was one centered in the small sub-valley of Teotihuacan. Although it was not the first civilization in the Valley, Teotihuacan, beginning in the last century B.C., grew to become the major political and cultural center of the Valley and, most likely, of a considerable area outside the Valley as well. Typically, Oaxacan remains appear at Teotihuacan as early as the first century A.D.; later, Teotihuacan influences are seen as far south as the Mayan site of Tikal. At present, Teotihuacan appears to be the Mesoamerican site at which true urbanism first appeared. During its heyday, Teotihuacan grew into a city with an estimated population of 85,000. The city was well-organized with a planned street pattern and districts. Present were large, airy homes for the powerful, crowded apartment complexes for the plebes, and an elaborate ceremonial and political center (Weaver 1972).

The ceremonial center, with its long, broad Avenue of the Dead and two large pyramids, is the better known part of the site; the larger of the two pyramids, the Pyramid of the Sun, is the second largest structure in the Americas. The site, especially its pyramids, has long fascinated men and has stimulated considerable research into its origins. Although the site had been abandoned for over 700 years, the Aztecs were still worshiping at the pyramids when the Spanish arrived. The Aztecs attributed the pyramids to the Toltecs, the legendary ancestors, who in fact did not achieve prominence until well after the city was abandoned. The Spanish, for lack of any other information, accepted the idea that the Toltecs were founders of Teotihuacan and that belief persisted into this century. Leopold Batres (1889), who directed the first "archaeological" excavations at Teotihuacan for the Mexican government at the end of the 19th and the beginning of the 20th centuries, described the site as the "Sacred City of the Toltecs".

It is now known that the occupation of Teotihuacan entirely predates that of the Toltecs, but much uncertainty remains concerning the site despite, and partly as a result of, the fact that it has been known and studied for so long. A major area of uncertainty concerns the Pyramids of the Sun and Moon. A major problem with the Sun Pyramid is that even its physical characteristics are in doubt. Batres' main project while he was working at Teotihuacan was the excavation and reconstruction of the Pyramid of the Sun. In the course of his work, Batres altered the original form of the pyramid and, because he did not record the excavation and reconstruction processes, he made it extremely difficult to determine what the pyramid looked like before he started or what he did to change its appearance. Apparently, when Batres started, the outer surface of the pyramid was a disintegrating mass of adobe and stone, as the Teotihuacanos used adobe rather than mortar to bind the face of the pyramid. Batres probably expected to find an earlier structure within the pyramid, as is the case with many other Mesoamerican temple mounds which were enlarged by accretion. Unfortunately for Batres and the pyramid, the

Pyramid of the Sun was basically built in one stage.* Before he realized his mistake, Batres had already removed several meters (probably 4-6 meters, although the exact amount is unknown) of mortar. The surface Batres had exposed when he stopped soon began to disintegrate because of the lack of lime mortar, so Batres had the surface rocks cemented together (Linne 1934; Weaver 1972). As it stands today, the pyramid has five major recesses or steps at various heights. On one side, the remains of brackets which helped hold the outer facing in place can still be seen. Linne states that Batres' reconstruction "obtained-with more or less accuracy- the original shape of the pyramid, albeit reduced in size". Others (J. Graham, personal communication) believe that Batres altered the appearance of the pyramid considerably, including changing the angle of the sides. Weaver (1972) states that the pyramid followed the typical talud-tablero style architecture of Teotihuacan: "a rectangular body (tablero) with recessed inset, which rests on an outward sloping basal element (talud)...at Teotihuacan, the tablero always was larger than the talud." The Pyramid of the Sun was faced with volcanic stones set in clay and plastered over with a coating of lime plaster, not ordinary lime and sand mortar (Linne 1934; Weaver 1972).

Because of Batres' methods of reconstruction, the exact original dimensions of the pyramid are not known. However, Alexander von Humboldt, a Frenchman who visited Mexico at the beginning of the last century, recorded in 1803 that the Pyramid of the Sun was found to have a base of 208 meters (682 feet) and a height of 55 meters (180 feet) (v. Humboldt 1811). These dimensions are at variance with those of Batres' (1886) who measured the pyramid as 224 meters square at the base and 68 meters high. Nevertheless, v. Humboldts' (1811: 64-7) observations about the pyramid are of some interest as they shed light on its original form and are more accurate in some respects than are modern observations:

> The nations whom the Spaniards found settled in New Spain attributed the pyramids of Teotihuacan to the Toltec nation; consequently this construction goes back as far as the eighth or ninth century;... The faces of these edifices are to within 52 feet exactly placed from north to south and from east to west. Their interior is clay, mixed with small stones. This kernal is covered with a thick wall of porous amydaloid. We perceive,

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* R. Millon (The Teotihuacan Map. Part I. University of Texas Press, 1973) says (Caption for Fig. 17b) that the pyramid was built in at least two stages. The earliest construction was in the Tzacualli Phase (A.D. 1-150) in Terminal PreClassic times when the structure reached to within about 2 meters of its present height. The uppermost 2 meters was added either in late Tzacualli or post-Tzacualli times. No reference is made to enlarging the outer shell of the pyramid.

> besides, traces of a bed of lime which covers the stones... They formed four layers of which three are only now perceivable,... A stair of large hewn stones formerly led to their tops... Each of the four principal layers was sub-divided into small gradations of a meter...
>
> It would be undoubtedly desirable to have the question resolved whether these curious edifices of which the one (the Tonatiuh Ytzaqual) (Pyramid of the Sun)... has a mass of 123,970 cubic toises (33,743,201 cubic feet) were entirely constructed by the hand of man or whether the Toltecs took advantage of some natural hill... Their situation in plains where no other hill is to be found renders it extremely probable that no natural rock serves for a kernal to these monuments.

Two tunnels, one dug by Manuel Gamio in 1917 and the other dug by Eduardo Noguera in 1933, were driven through the base of the Pyramid of the Sun to answer v. Humboldt's question. As he suspected, the pyramid is entirely man-made. Millon, Drewitt and Bennyhoff (1965) re-studied the tunnels to determine the nature and age of the fill of the pyramid and whether the pyramid was built in successive stages. While their investigation did uncover possible traces of earlier structures, these structures were insignificant in bulk when compared to the pyramid as a whole (Millon and Drewitt 1961). The single stage construction of this pyramid clearly demonstrates, despite arguments to the contrary, that Meso-American cultures did attain a level of social integration, be it officially a "civilization" or not, that permitted the construction of monumental public works. Further, the midden which comprises the vast majority of the interior of the pyramid indicates that it was constructed during the Tzacualli (or Teotihuacan I) phase, dating from the first century A.D. (Weaver 1972), 200 years before the official "Classic" period when Teotihuacan flourished.

It is frequently stated (cf. Weaver 1972; Linne 1934; Acosta 1963; et.al.) that the pyramid fill consists of "adobe brick." Millon, et.al. (1965) demonstrated that this assertion was incorrect. While they did find evidence of adobe brick within the pyramid fill, the major portion of the pyramid consists of midden, mainly in the form of loose soil that contains some rock and huge quantities of sherds. The adobe brick that does appear might have served as a structural feature designed to contain the loose fill while the pyramid was being constructed.

If the early reports of the pyramid's dimension are uncertain, present day measurements are only slightly more precise. The most recent measurement available from Millon, et.al.(1965) gives the pyramid's volume as 1,175,000 cubic meters, but does not include basal dimensions or height. Linne (1934) lists the most detailed dimensions: 211 m. by 207 m. by 215 m. by 209 m. at its base; and

64.5 m. high. He gives its mass at 2,980,000 (presumably) metric tons. His volume of 993,000 cubic meters is quoted by Cook (1947) and others and it agrees with the volumes listed by Acosta (1963) at 1.5 million cubic yards and by Judd (1948) at 35,067,596 cubic feet. Heizer (1966) gives a volume of 840,000 cubic meters, but does not provide any dimensions.

Another major question concerning Teotihuacan is the nature of the subsistence base of its population, especially at the time of the construction of the pyramids. Of course, agriculture was the foundation upon which Teotihuacan existed. But did the Teotihuacanos rely on natural rainfall for their farming or did they practice some form of irrigation, either via stream diversion and canal networks or via chinampa farming? The question is central to the understanding of the nature of Teotihuacan society. Irrigation that involved the thousands of people in and around Teotihuacan implies a high degree of centralized power capable of maintaining a large irrigation system. Irrigation also increases dramatically the potential production and reduces the risk of farming, the effects of which allow for an increase in population and/or the possibility of the maintenance of a body of non- (food) productive leaders, priests and craftsmen. That is, irrigation would have permitted the achievement of that level of social integration and diversification which has been labeled "civilization". Palerm (from Graham 1966) states:

> It seems rather obvious that a rainfall agriculture, never extensive in Mesoamerica, could not accumulate an adequate and constant surplus to maintain the urban centers... (p. 31)
>
> ...a strong socio-political organization seems to be the only way open to people with a poorly developed technology to have and run large-scale public works (p. 39).

Armillas (1948) states that rainfall in the Valley of Mexico today is sufficient for only one crop of maize; irrigation is necessary for a second crop. On the other hand, Gamio (1922) states that irrigation is now necessary for farming in the sub-valley of Teotihuacan. However, it is likely that a drop in rainfall has occurred since the pre-Classic because of man's activities in the area, including the deforestation of the sub-valley and the draining of most of the lakes in the region, a situation which does not obtain to as great an extent in the Valley of Mexico. The difference in rainfall is slight, but significant; it, therefore, seems at least possible that rainfall farming was possible at Teotihuacan before deforestation and land reclamation. Millon (1954) and others point to an analysis of pollen profiles from the Valley of Mexico by Sears (1951) which seems to indicate a dry period beginning in the late pre-Classic. This indicates to Millon that irrigation was necessary at Teotihuacan. Sanders (1962) states that Sears' data are "highly suspect".

Evidence does indicate that during the Tzacualli phase, when the Pyramid of the Sun was being built (A.D. 1 - A.D. 150), people were moving from the hills near Teotihuacan to the alluvial plains and piedmont (Weaver 1972) thus indicating a shift in agricultural pattern. But as of the present time, no direct evidence for irrigation during this period has been discovered (Sanders 1962). Sanders and Price (1968) believe that irrigation can be demonstrated for the Classic (A.D. 300 - A.D. 900). Weaver (1972) infers that irrigation was practiced at Teotihuacan by the late pre-Classic, though she admits to a lack of data. Regardless of whether there are data for that time period, the Pyramid of the Sun had already been built by a people for whom there is no evidence of irrigation. The Pyramid of the Sun is ample evidence of a high degree of sophistication and organizational ability for these same people. There is no evidence of a highly developed, tightly controlled irrigation system which Palerm and Sanders seem to require as a pre-condition for the construction of a public work as monumental in scale as the Pyramid of the Sun.

Assuming there was no irrigation during the Tzacualli phase at Teotihuacan, or at least not an extensive, centralized system, farming would have been limited to the rainy season from May through November, a period of approximately 200 days. For the purposes of this study, it will be assumed that the remaining 160 days were, more or less, "surplus" time that would have been available to some extent for public work. Erasmus (1965) cites a study by Ian Hogbin of the Wogeo chiefdom in New Guinea which states that each household averaged 40 to 45 days of community work per annum. The important fact there is that the Wogeo are not a "state" level society. The chief has no coercive power to force people to work. Erasmus' figure, then of 40 days per annum per household will be taken as the minimum number of work days in this study. At the other end of the scale, 200 days per annum per household will be used as the maximum number of days of community work; this figure assumes that members of the households other than that of the adult male head would also perform community service, thereby raising the number of work days per family. One hundred days a year will be used here as an intermediate figure; 100 days a year seems a likely amount of community service, given a project as great and compelling as the construction of the Pyramid of the Sun. Weaver (1972) gives a population of 30,000 for the end of the Tzacualli phase; using this population as the maximum population available for the construction of the pyramid, 6,000 households would be contributing work to the community (accepting five as the average family size).

As the Mesoamericans were without draft animals or vehicles and relied entirely upon human labor for all construction tasks, factors affecting the output of manual labor become important in any time-labor estimate. Factors which must be considered are the manpower required for excavation and transportation of fill materials (loose, sandy earth, clay, rock, and lime for the pyramid), the manpower (mp) required for construction of special sections of the structure (i.e., the stone-faced outer layer), the manpower for the production of lime plaster; length of the work day; distance raw materials had to be transported; density of materials transported; weight carried on each trip; available work-force; and number of work days per year.

For this study, the man-days necessary for excavation was calculated using data Erasmus (1965) collected from a study of the Mayo Indians of Sonora. Using a hardwood digging stick, Erasmus' informants could excavate 2.6 cubic meters of earth a day. The rate of excavation would necessarily depend upon the type of soil. A loose soil is assumed for the pyramid as a midden full of sherds would not be expected to pack. Erasmus' figure, then, is probably too low for the rate of fill excavation; however, the same figure is used for the rate of the exterior clay, which would probably require more manpower to excavate. The two rates are assumed to average to the 2.6 cubic meters of output per day given by Erasmus.

Manpower required for transportation was calculated using the daily output and manpower formulas and tables in United Nations publication ST/-ECAFE/SER.F/17 (Earthmoving by Manual Labour and Machines, hereinafter referred to as UN) and the Economic Commission for Asia and the Far East publication E/EN.11/WRD/Conf.3 L.1 (Manual Labour and Its More Effective Use in Competition with Machines for Earthwork in the ECAFE Region, hereinafter referred to as ECAFE). Manpower for transportation on the level, with a loading height of 0, equals $q \dfrac{1}{\frac{L}{V} + \frac{L}{V'}} H$, where H = work hours per day, q = capacity of the container used for transportation expressed in cubic meters or kg, L = average transport distance, and V and V' = average velocity, of the basket carrier, loaded and unloaded, respectively. The loading and unloading time are not considered, nor is the time lost per trip. It was assumed to be five hours as the most likely average time actually spent per day (see Erasmus 1955, 1965); nine hours was used as a maximum work day. A seven hour work day was also used in the calculations as an intermediate figure. However, a nine or even a seven hour work day was probably unlikely. The warm temperatures of the Valley of Mexico during the middle part of the day would probably have precluded such long work days, particularly for such strenuous work as voluntary earth moving. Indeed, when Erasmus (1965) conducted his experiment, he found that productivity dropped so dramatically that he eliminated the sixth hour of work from his calculations. In this paper, seven and nine hour days were used to compute the time necessary for construction only for the volume of the Pyramid of the Sun given by Linne (1935) and others to illustrate the range of variation in estimates when different length work days are introduced into the calculations. When expressed as a volume, q (capacity of container) is calculated by multiplying the density of the transported material times the weight of a basket load of material. For the fill, Erasmus' density of sandy Sonoran earth of 1.3 was used; for the clay, a density of 1.7 for light clay (taken from UN Table 45) was used. The rock in the adobe and rock outer coating was native basalt that is abundant in the Teotihuacan area and need not be excavated or broken up (cf., Castaneda 1925, footnote on p. 53). A density for basalt of 3.0 was taken from Braumeister's Standard Handbook for Mechanical Engineering (1958).

Three values for the mass of basket loads were used: 15 kg. as a minimum mass (based on Shetrone's (1930) measurement of preserved basket loads from Monk's Mound). Forty kg. was used as a maximal value, as suggested by the ECAFE value for weight carried by Indian workers who were affected by heat. Twenty-two kg. was used as an intermediate and most likely value as suggested by Ford (1955a), Fowke (no date) and Erasmus' 1965 experiment. Values for L (average transport distance) vary with each substance used. The fill was assumed to have been excavated within a 1 kilometer radius of the pyramid, with an average transport distance of 750 meters. Clay was assumed to have been excavated within 750 meters of the pyramid, with an average lead (transport distance) of 500 meters. Rock was assumed to have been collected within a 3 kilometer radius of the pyramid, with an average lead of 2.25 kilometer. Lime, with a density of 1 (from Braumeister) was arbitrarily assumed to have been manufactured 5 kilometers from the pyramid. All materials were assumed to have been transported in two stages: Stage one--from source to a stockpile at the base of the pyramid, with no lift; and Stage two--from the stockpile to the pyramid with an average lead of 30 m. and an average lift of 18 m. (18 m. is the height of the first layer of the pyramid which contains approximately half the total volume, (c.f. Millon 1965). Lift introduces an additional manpower factor; an average, constant value of .342 manpower (mp) per cubic meter for a five hour day was extrapolated from ECAFE. Man-days necessary for the manufacture of lime was taken from Erasmus (1965). Again using Erasmus' 1965 data, an extra component of required man-days was added to the total manpower requirement to take into account the work needed to fit the stones in the outer layer of the pyramid. Work force was calculated at 6,000 (one per household) for all equations, except for the manpower requirement for rock transportation. Since the rock is ubiquitous and is available in various sizes, it was assumed that other members of a household would contribute some time to its collection, thereby yielding an estimated two additional workers per family or a work force of 1,200.

The details of the calculations using the above variables and formula are presented in Appendix 1. Table 1 below gives a portion of the final results. The estimates range widely from a maximum time of 61 years to a minimum time of 4.4 years. As was mentioned previously, 22 kilogram per load probably best approximates the ancient load size. If 100 days per year is taken as the time spent on such a major project as the Pyramid of the Sun, the estimated time for construction for the pyramid ranges from 10 to 20 years, with the

Table 1. Time in Years Necessary to Build the Pyramid of the Sun.

load size Volume	15 kg			22 kg			40 kg		
days work	40	100	200	40	100	200	40	100	200
$1.17 \times 10^6 m^3$	61.8	24.7	13.4	51.8	20.7	10.3	43.9	17.6	8.8
$9.93 \times 10^5 m^3$	48.2	19.3	9.7	42.5	17.0	8.5	26.1	14.4	7.4
$8.40 \times 10^5 m^3$	20.4	12.2	6.1	26.3	10.5	5.2	22.3	8.9	4.4

Workday = 5 hr.

inconsistencies in pyramid size from modern reports remaining as the only uncontrolled variable.

The time and labor estimates given in Table 1 and in Appendix 1 were calculated on the basis of the assumption that labor was voluntary, or at least not coerced physically. People would be expected to be motivated to work by "the desire for public approval and prestige, duty to the community, religious sentiment, pleasure, and pride in craftsmanship" (Erasmus 1965). The size of the pyramid, the complexity of organizing such a long term project, and the amount of time involved (most likely around 15 to 20 years) strongly suggest that some specialists were present at Teotihuacan in the opening century of this millenium, probably in the person of priests who also functioned as architects, organizers, and engineers. The estimates derived here do not, however, suggest the presence of full-time craft specialists. If Weaver's (1972) population estimate of 30,000 for the Teotihuacan locale by the end of the Tzaculli phase is accepted, then construction of the pyramid by the number of specialists which could have been supported by such a population would have taken vastly longer than by community effort. Cook (1947) estimated that 300 full-time specialists worked on the Pyramid of the Sun. To support such a population of non-subsistence workers and the other functionaries associated with the project, Cook estimated a population of 150,000, a much greater number than the evidence suggests. Further, 300 specialists working even 300 days a year would still have required 10 to 12 years to construct the pyramid (assuming 22 kg. loads and a five hour work day). As can be seen in Table 1, such a time for construction is only slightly less than that possible for a citizen work force (using Linne's volume and 22 kg. as the load size).

Brainerd (1954) and Erasmus (1965), on the basis of very crude data, estimate the man-days of labor necessary for the construction of the pyramid at roughly three million. The data and controls presented in this paper yield a man-day estimate of 5 to 15 million, with an estimate of 10 million man-days as the most probable figure.

POVERTY POINT

Of the three mounds at Poverty Point, the largest is the Poverty Point mound. It has an elevation of 70 feet and overall basal measurements of 640 feet north to south by 710 feet east to west. From the summit, a flattened area about 15 feet in diameter, running east to west on both the north and south side of the mound, are several narrow stepped ridges 180 feet long. On the east side of the mound summit is a gently graded slope that Ford and Webb (1956) suggest could have been used as a platform that provided easier access to the summit, since the west side of the mound is extremely precipitous. This slope drops to a flat rectangular portion of the mound that is 23 feet high and measures 240 by 300 feet. Ford and Webb (1956) later note that this mound "is aligned rather closely to the cardinal directions" and that it lies directly west of the octagonal ridges of the site, all of which may reflect the organization and planning necessary to construct the earthworks. From what can be determined by a core drilling of this mound and by excavation of the other mounds at the site, Poverty Point Mound was constructed mostly of brown and yellow clay with some occurrences of loam and whitish topsoil.

Of the information available on the Poverty Point site at the time of this report, none revealed any excavation that had been carried out on the Poverty Point Mound itself, other than the drilled core taken by Ford and Neitzel in 1953. The precise nature of the mound is, therefore, in question. It is not known definitely whether the mound is an effigy mound or a burial mound, though its artificial nature is not in doubt. The core drilled to a depth of 61 feet from the mound summit showed continually changing soil color (and texture) and a flint chip at 56 feet. Later investigations of eroded cuts in the lower platform on the east side of the mound showed evidence of basket loading. Impressions of basketry were found here (Ford and Webb 1956; Ford 1954, 1955a, 1955b, 1955c). Ford gives the volume of the Poverty Point Mound as 185,000 cubic yards (141,221 cubic meters).

The second largest of the three mounds at the Poverty Point Site is the Motley Mound, about 1-1/2 miles north of the Poverty Point Mound and the octagonal ridges. It is similar in shape to the Poverty Point Mound, but is considerably smaller. Ford and Webb (1956) say of the two mounds:

> If the peculiar shape of the Poverty Point Mound is considered to be oriented towards the west, away from the center of the octagonal arrangement of ridges, then the Motley Mound is oriented towards the north, always away from the center of this figure. The summit is formed by a high, narrow, east-west ridge. Again, a small flattened platform lies at the highest point, near the center of the ridge. The crests of the ridges on either side of the platform descend by poorly defined steps, and a slight sinuosity of the ridge line is observable.

The Motley Mound has basal dimensions of 400 feet by 600 feet and is 56 feet high. This mound and the small 21.5 foot high conical mound 740 yards north of the Poverty Point Mound contain 265,000 cubic yards (202,291 cu. m.) of earth (Ford 1955a).

The small conical mound, though not nearly so large or structurally impressive as the other two, disclosed some important information on mound construction when several test trenches were run through it by Ford and Webb. Upon excavation it was found that this mound had been built in stages and contained four floors, one of which held the remains of a number of containers of earth. From these "basket-loads" preserved on this floor, Ford was able to determine the average size of the load (50 pounds), the weave of the basket and the basket design, thus providing good evidence as to how the earth was transported to the mound. Later, Ford and Webb state that "the containers full of clay found on Building Level 4 clearly were intentionally placed. In this stoneless alluvial valley they are possibly analagous to the layers of gravel or stone that cap primary stages of many of the Hopewell Cultural Mounds of Ohio". Impressions of basketry came from other areas at the Poverty Point Site also and it is assumed that they were considered in Ford and Webb's conclusion that 50 pounds was the average load size.

The Geometric ridges contain over half the total volume of earth in the mounds at the site. There are six ridges, concentrically arranged, that form half of an octagon, with four "aisles" radiating out from the center, cutting across the ridges. The ridges are, on the average, six feet high, although the original height is difficult to determine because of erosion and cultivation. These ridges, approximately 80 feet across, stretch to the very edge of a 15 foot bluff that overlooks Bayou Macon. Webb and Ford (1956) later say that they "think that the excavations in the concentric ridges that form the portion of an octagonal figure three quarters of a mile in diameter have demonstrated that the dwellings of the inhabitants were arranged along the crests of these ridges, although no direct evidence of the dwellings was found". Following this, they make a statement regarding population size at Poverty Point;

> In the absence of evidence as to the size and arrangement of houses at this site, an estimate of the population is difficult. If the octagonal figure were symmetrical and complete in the eastern portion, which is now erased, about 11.2 miles of artificial ridge was built and occupied. If houses were arranged along these ridges at 100 foot intervals, there would have been about 600 houses in the town. There were probably several times this number. In any event, a population of several thousand people is indicated.

The archaeological record seems also to indicate that the 530,000 cubic yards (404,581 m^3) contained in these ridge structures came from the spaces between the ridges, in which case the work required for construction of the ridges would have been sufficiently less than if the soil had been transported any distance.

A consideration of some cultural phenomena and the subsistence pattern is necessary here as they are directly related to the work force and organization that would have been necessary in the construction of the earthworks at Poverty Point. Ford and Webb (1956) say of the Poverty Point peoples:

> Culturally the Poverty Point Complex seems to belong at the end of the Eastern Archaic phase. The diagnostic traits that define its cultural position are: cooking with heated stones (artificial stones of baked

> clay), crude adzes or hoes, celts, tubular pipes of clay and stone, steatite vessels, two-baled flat gorgets, bar atlatl weights, bannerstones (rare), plummets of hematite and magnetite, copper (two pieces), stone beads, and a substantial proportion of corner-notched projectile points.

They also note similarities between certain Poverty Point traits to some of those from the Adena and Hopewell cultures of the Upper Mississippi Valley. The subsistence pattern would had to have been based on agriculture to insure a staple food source for the large population necessary for the construction that was performed at Poverty Point.

There is no evidence of any other staple food source at Poverty Point, such as the shell middens that have accumulated in some areas of the Southeast. The only direct evidence for agriculture at the site is the one bit of fired clay into which a corn cob was pressed, leaving an impression (Ford 1955a). Possible indirect evidence of agriculture is the celts and adzes or possibly hoes. These people most probably depended on hunting and gathering for a good part of their diet as did most agricultural groups of the east. There was no mention of faunal remains in the site report; however, tools related to a hunting economy were found that included cutting, scraping and perforating tools and substantial number of projectile points.

The first element considered in the discussion of time and labor involved with mound construction at the site is population. Using Ford's figure of 600 houses that were built on the geometric ridges at the site, a population of 3,000 people can be assumed in the vicinity of the Poverty Point mound. Quite possibly a population was distributed in the outlying areas around the site. Taking this into consideration, using the average maximum family size as five and assuming all of the houses were occupied at the same time, a maximum population at the Poverty Point site at any one time is set at 6,000 people. Accepting S.F. Cook's figures of 173,000 for the population of the Teotihuacan area and requiring 25,800 acres of corn at 40 bushels an acre yield, a population of 3.5 per cent (6,000) of Cook's total would only require around 900 acres of corn to support themselves (Cook 1947). There is adequate land available for cultivation on Macon Ridge, the site of Poverty Point, and the required acreage may have been even less if the people had a secondary dependency on hunting and gathering. An alternative, smaller population figure will be considered, assuming that only half of the houses were occupied at any one time and assuming that an equal sized population existed in the outlying area around the mounds. This yields a figure of 300 household heads in the ridge area and 300 in the outlying area. Using a minimum family size of five (any lower would result in a decreasing population or ZPG), the total population in this alternative situation would be 3,000.

In determining the cubic content of the structures at Poverty Point, the figures Ford (1956;1955a) gives were accepted and used in computations. The cubic contents of the features at Poverty Point are:

Poverty Point Mound-----------------185,000 cubic yards
Motley Mound
Conical Mound (Mound B)-------------265,000 cubic yards
Octagonal Ridges--------------------530,000 cubic yards

Total 980,000 cubic yards
(748,092 cubic meters)

The total weight of the earth in these structures is 3,305,817,585 pounds (1,502,644,357 kg.), using a weight of 2.0 metric tons per cubic meter of heavy clay (UNESCO 1961). It is assumed that the bulk of the soil used in construction was of a clay-like nature, since this was the case in Mound B which was more extensively tested than any of the other mounds. The soil in the mounds was extremely hard packed; this is another reason for using the weight and density of heavy clay.

The time required to construct the mounds at Poverty Point must have been considerable. The time the people had available for non-essential labor would have largely been dependent on the labor requirements for subsistence. Erasmus (1965), in reviewing the literature on primitive technologies and agricultural societies derived an average minimum figure of 40 days of work contributed by each head of family in pre-state societies. This figure will be used for one set of time-labor calculations.

In the area around Poverty Point, the average growing season, determined by the earliest killing frost in the fall and the latest killing frost in the spring, is 220 days (USDA 1944). If the assumption, that some agricultural activity was going on during this time, is accepted, 145 days remain to be devoted to other activities. Bowen (1961) says there are six basic requirements for all agriculture. They are:

1. Ground must be broken up
2. A seed bed prepared
3. Animals kept away from the growing crops
4. The harvest taken
5. Crops prepared for storage use
6. Crops stored

Considering all of these activities, it seems that there would have been adequate time to devote to other activities during the growing season. The artist DeBry, in 1564, noted that a group of Florida Indians, after planting their crops, left the fields alone from the twenty-fourth of December until the fifteenth of March (Fundaburk

1958). Here is a case in the southeastern United States where, for an 81 day period, no agricultural maintenance was necessary at all. Waddell (1972), in his study on the Aruni, an agricultural people of the New Guinea highlands, states that 49 percent of the Aruni's time at home is spent in food production. Here, too, considerable time would have been available during the growing season to devote to other activities. The 49 percent figure included activities such as fencing and the care of pigs, a factor that would not have been involved in food production at Poverty Point. Taking into account the above mentioned information and realizing that there were other tasks also to be done, such as hunting and gathering, house maintenance, socializing and religious activities, a maximum of 150 days contributed by each house-head is used here. This figure is used in a separate calculation of time-labor. In yet another set of calculations, a figure of 100 days contributed by each house-head is used. This figure was reached very arbitrarily and is used to show a medium range in the effort required on construction of the earthworks. It will also represent a figure that is between Erasmus' minimum man-days and the maximum man-day figure.

Erasmus (1965) also conducted experiments with the Mayo Indians of Sonora in Mexico concerning manual labor that was involved in excavating and transporting earth. He found that a five hour work day was the most efficient when a man is involved in the fairly strenuous work of excavation and transportation. Also in his observations of the Mayo, Erasmus noted a maximum nine hour work day. The reason that efficiency was reduced after five hours of earth moving, Erasmus feels, was due to the effects of the extreme heat of the Sonora region which rose from 84 degrees at 6:30 A.M., the beginning of the work day, to 110 degrees at 11:30 A.M. However, the temperature in northeastern Louisiana should not have been much of a problem since the temperature rarely goes above 100 degrees and usually does so only in the late summer months. Both work-day figures (5 and 9) are used in our calculations, as is a median day of seven hours.

The soil of Macon Ridge, upon which Poverty Point is built, was formed from earlier stages of the Mississippi and Arkansas Rivers and seems to be the source for the soils contained in the mounds (Webb and Ford 1956). As mentioned earlier, the soil used for the construction of the geometric ridges was obtained from the area between the ridges, according to evidence disclosed by excavation of several test areas among these ridges. The soil for the mounds must have come from the plains surrounding the site as there is no single "quarry" source. There would have been a considerable depression made in the landscape if 450,000 cubic yards of soil had been removed from one spot. In 1591, DeBry (Fundaberk 1958) observed preparation for the construction of an earthen altar by some Florida Indians, which included leveling the land. In leveling an area for mound construction, not only was the surface prepared for the structure, but the soil removed from the leveling could also be used in construction. A maximum limit of 600 yards distance for transporting soil to the mound sites will be used. Any distance further than this would have reduced efficiency greatly. The average speed of a laborer carrying a load of soil has been determined by a UNESCO study on manual labor as 3 km. an hour (UNESCO 1957). At this rate, it would take 10 minutes just to transport a load 600 yards. It is improbable that the soil sources would have been located much further away. Using a radius of 600 yards for a soil source around the three mounds, the average transport distance would be 400 yards. This distance is computed by taking the radius of a smaller circle containing half the volume of the larger circle and half the volume of the soils in the mounds. An area of this size would have yielded enough soil for construction of the mounds by removing only 1.2 feet of the soil covering.

To establish the labor involved in the transporting of the soil, the average basketload size must be determined. As mentioned earlier, Ford and Webb (1956) determined an average load size of approximately 50 pounds for the Poverty Point site. They arrived at this figure by noting the basketloads and impressions that were exposed during excavation. Shetrone (1930) says that he carefully observed and measured basketloads in his investigations into primitive mounds and found that workers seldom carried over 20 to 25 pounds in a load. Jewell's (1963) experiment, in which English students actually constructed a mound using primitive tools, pointed to 30 pounds as the most economical load. Fowke (n.d.) says a man can easily carry half a bushel or 5/8 of a cubic foot in one load. The weight of 5/8 cubic foot of common soil is between 45 and 50 pounds (Braumeister 1958). Erasmus, whose experiments with earth moving were mentioned earlier, determined that the average load for the Mayo Indians in that experiment was approximately 20 kilograms or 44 pounds. The three figures used in the calculations show a range of effort that includes the loads discussed above. The three basket sizes used are: 15 kilograms (33 pounds), 22 kilograms (48.4 pounds) and 40 kilograms (a maximum load of 88 pounds).

There are two basic processes that occur in mound construction and for these processes several equations are used. Atkinson (1961) says:

> All earthwork building processes can be broken down into two parts: loosening of subsoil and the filling of baskets in the ditch, and transport to and dumping of basket loads on to the bank. In the former, rate of production is independent of size and varies only as to hardness of material being dug; the latter is related directly to the size of the earthwork being built.

Erasmus' figure of 2.6 cubic meters of soil excavated per man per day was used. The Erasmus observations were mentioned earlier in the paper. This figure of 2.6 was obtained by observing Mayo Indians excavate and fill containers using a digging stick and their hands to perform the activities during a five hour work day (Erasmus 1965). This figure provides only for excavation and not for transportation.

The time-labor figure for transportation of earth is determined by the use of an equation obtained from a UNESCO (1961) study on manual labor. This formula is given in the data on Teotihuacan elsewhere in this paper. The formula is based on the soil being transported and then stockpiled to be carried up later and placed on the mound. A separate figure is used to determine the work necessary to carry the loads up onto the mound. This figure is mentioned next.

The labor required for lift (vertical distance) in transporting the soil is determined from a table obtained from a study carried out by the Economic Commission for Asia and the Far East (1957). The study included calculations on the manpower required for 40 kilograms at various lifts and leads. These figures are obtained by interpolating from this table and calculating ratios for the other basket sizes used in this paper. The figure presented in the table is given in terms of the manpower required for the lift of one cubic meter in one work day. The table includes figures for the various types of soil, including hard clay, that are used in these calculations. The lift figures are average lift heights determined by the percentage volume contained in the mounds at that particular height (height at which half of the volume is contained). The average lift height for all the mounds is 6 meters and for the ridges 1 meter.

A summary of all the variable used in calculations for time-labor involved in the Poverty Point earthworks is tabulated below.

	Volume	
	Cubic Yards	Cubic Meters
Poverty Point Mound	185,000	141,221
Motley Mound Mound B	265,000	202,291
Geometric Ridges	530,000	404,580
Total	980,000	748,092

Total Soil Weight - 3,299,085,720 pounds 1,496,184 metric tons

	Proposed Population	
	Total	Number of Workers
a.	6,000	1,200
b.	3,000	600

DAYS OF MOUND LABOR/MAN/YEAR

a. 40
b. 100
c. 150

LENGTH OF WORK DAY

a. 5 hours
b. 9 hours
c. 7 hours

TRANSPORT DISTANCE FOR BASKET LOADS

For All Mounds Excluding Ridges

Maximum distance	600 yds.	(545 meters)
Average distance	400 yds.	(360 meters)

For Ridges

No transport distance - lift-lead figure 1 m. lift 12 m. lead

VELOCITY

Loaded - 3 km./hr.
Unloaded - 5 km./hr.
Average - 4 km./hr.

LIFT HEIGHT (VERTICAL TRANSPORT DISTANCES)

Mounds - 20 ft. (6 m.) average
Ridges - 3.3 ft. (1 m.)

BASKET SIZES

a. 15 kg. (.008m^3) = 33 lbs.
b. 22 kg. (.011m^3) = 48.4 lbs.
c. 40 kg. (.020m^3) = 88 lbs.

CALCULATIONS

A. Mandays required for excavation of all soil at Poverty Point =

$$\frac{\underline{\text{Total volume of earthworks}}}{\text{output (m}^3\text{)/day}} \qquad \frac{748{,}092\ \text{m}^3}{2.6\ \text{m}^3\ \text{(from Erasmus' study)}} =$$

278,728 man days

B. Output/man/day for transporting soil (P.P. Mound, Motley Mound and Mound B only) = $q \dfrac{1}{\frac{L}{V} + \frac{L}{V'}} H$: where q = basket capacity in m^3, L = transport distance in kms., V = velocity loaded, V' = velocity with no load and H = hours in work day:

$$\text{output} = q \frac{1}{\frac{.360}{3} + \frac{.360}{5}} H = q \frac{1}{.192} H = \underline{q\ (5.2)\ H}$$

(a) $.008\text{m}^3(5.2)5$ = .008(26) = $.208\text{m}^3$/day/man = 1,651,500 man-days
(b) $.008\text{m}^3(5.2)7$ = .008(36) = $.288\text{m}^3$/day/man = 1,192,750 man-days
(c) " " 9 = " (47) = .376 " " " = 913,595 " "
(d) $.011\text{m}^3$ " 5 = .011(26) = .286 " " " = 1,201,091 " "
(e) " " 7 = " (36) = .396 " " " = 867,455 " "
(f) " " 9 = " (47) = .517 " " " = 664,433 " "
(g) $.02\text{m}^3$ " 5 = .02 (26) = .520 " " " = 660,600 " "
(h) " " 7 = " (36) = .720 " " " = 477,100 " "
(i) " " 9 = " (47) = .940 " " " = 365,438 " "

Man days in each of the above calculations was determined by dividing total volume of the mounds (not ridges) by the output/man/day.

C. Manpower required for removal from stockpile and placement in mounds and ridges at Poverty Point (lift and lead): (figures determined from ECASFE study)

a. Mounds (P.P. Mound, Motley Mound, Mound B) - 6 m. lift - 12 m. lead for hard clay requires .252 manpower/m^3/day

b. Ridges (Octagon) - 1 m. lift - 12 m. lead for hard clay requires .170 manpower/m^3/day

c. Total manpower for lift and lead of all soils from stockpiles = Ca + Cb = .422 mp/m^3/day

d. Output/man/day for lift and lead = $\frac{1}{.422}$ = 2.4m^3/m/day can be removed from stockpiles and placed in mounds.

e. Total Man-Days required for lift and lead from stockpiles at Poverty Point = $\frac{\text{Total Volume in Earthwork } (m^3)}{\text{output/man/day (Cd)}}$ =

$$\frac{748{,}092\ m^3}{2.4\ m^3} = 311{,}705 \text{ mandays}$$

D. Total Man-days required for excavation of earth and removal from stockpiles to mounds = Ce + A = 599,433 man-days

E. Total Man-days work in Poverty Point Earthworks, with alternate basket size and length of work day:

	Basket Size	Day Length	Total Man-Days
a	15 kg	5 hours	Ba+D = 2,250,933
b	15 kg	7 hours	Bb+D = 1,792,183
c	15 kg	9 hours	Bc+D = 1,513,028
d	22 kg	5 hours	Bd+D = 1,800,524
e	22 kg	7 hours	Be+D = 1,466,888
f	22 kg	9 hours	Bf+D = 1,263,866
g	40 kg	5 hours	Bg+D = 1,260,033
h	40 kg	7 hours	Bh+D = 1,076,533
i	40 kg	9 hours	Bi+D = 964,871

F. Total Work Days Contributed by Poverty Point Alternative Population Figures:

	N No. Family Heads	n Work-Days/Year	N.n Total Man-Days/Year
a	1200	40	48,000
b	1200	100	120,000
c	1200	150	180,000
d	600	40	24,000
e	600	100	60,000
f	600	150	90,000

G. Time (in years) for completion of Poverty Point Earthworks with alternative populations, work days, and basket size =

$$\frac{\text{Total Man Days}}{\text{Man Days Per Year}}$$

Man-Days/Year	Fa 48,000	Fb 120,000	Fc 180,000	Fd 24,000	Fe 60,000	Ff 90,000
Total Man-Days						
Ea=2,250,933	46.9	18.8	12.5	93.8	37.5	25.0
Eb=1,792,183	37.3	14.9	10.0	74.7	29.9	19.9
Ec=1,513,028	31.5	12.6	8.4	63.0	25.2	16.8
Ed=1,800,524	37.5	15.0	10.0	75.0	30.0	20.0
Ee=1,466,888	30.6	12.2	8.1	61.1	24.4	16.3
Ef=1,263,866	26.3	10.5	7.0	52.7	21.1	14.0
Eg=1,260,033	26.3	10.5	7.0	52.5	21.0	14.0
Eh=1,076,533	22.4	9.0	6.0	44.9	17.9	12.0
Ei= 964,871	20.1	8.0	5.4	40.2	16.1	10.7

Webb and Ford state in their site report for Poverty Point excavations in 1952 that:

> The few examples of chronological information that have been secured from excavations in various parts of the earthwork suggest that probably all of it was built and inhabited at about the same time. The same conclusion might be drawn from a casual view of the air photograph, for it is obvious that the figure was constructed according to an integrated plan that probably would not have prevailed if the town had grown by accretion over a long span of time.

It seems that, in view of this statement, the most probable rate of construction for the Poverty Point earthworks falls in the ranges given for a population of 6,000 with the head of each household working 150 days. As shown by the table accompanying calculation (G), the range in time for construction of the mounds is from 5.4 years for a population of this size. The range, of course, arises out of consideration of variables that include basket size and length of working day. In considering the smaller population of 3,000, the work could have been accomplished under optimum working conditions presented in this paper with a completion time of between 10.7 years and 25 years.

It is unnecessary to mention any more about the organization and planning necessary for constructing a site such as Poverty Point. It is interesting to think about the dates of the site, tentatively placed at between 800 B.C. and 600 B.C., an estimate that is 1,000 years earlier than the greatest mound complex in North America at Cahokia in Illinois. Very little is known of the Poverty Point peoples as compared to the extensive picture that is available for Hopewellian and Adena peoples who left a rich record for archaeologists to associate with cultural phenomena. Until more archaeological evidence is obtained from the few Poverty Point type sites, there is little that can conclusively be stated concerning their level of integration and type of organization. Webb and Ford speculate on possible influence from the Upper Mississippi Valley by a group that may have evolved later into Hopewell and Adena cultures. Other than that, little can be said specifically about how the Poverty Point peoples may have accomplished such a major engineering and construction feat.

Research carried out on this paper revealed very little concerning specific methodology for arriving at time-labor figures for some primitive architectural features that quite obviously represent major and remarkable engineering feats. At the most others have mentioned cubic content (there is even variability on a matter as fundamental as this) and have suggested the amount of work a man can do in a day and correlated that to cubic content. The work a man can do in a day is not a constant. There was very little discussion on the variables of time-labor in the data investigated during research for this report.

Demography is a matter that is better treated in Meso-America where there exists a current population that lives on a relatively primitive subsistence level. From this living population and from the extensive ethnographic record accumulated through history, a valid population figure can be determined for Teotihuacan. In eastern North America there was very little ethnographic material collected on the aboriginals until after they were dominated and their cultures modified by Europeans. The Meso-American data on demography lends itself to the Poverty Point discussion on population when the assumption is that both areas were engaged in some level of pre-state horticulture.

Once the labor force is established the element of working time must be established to carry out time-labor calculation. The major factor affecting time available for non-essential labor (monument building) is subsistence pattern. There are interacting phenomena that make up subsistence regimes and allot time to tend to other matters. These phenomena were investigated and controlled.

There are also interacting elements that affect work output involved in the construction process. Although many of these elements vary from culture to culture and area to area, it is felt that the energy expenditures and construction processes were similar enough at the two discussed sites to allow use of some of the same equations and figures to establish control. The list of variables has by no means been exhausted; however this paper is a step towards ending mere speculation on how prehistoric peoples, such as those at Poverty Point and Teotihuacan, accomplished engineering and construction feats represented by monumental architecture.

Time-labor studies as those presented in this paper are far removed from the romantic aspects of archaeology such as finding ancient treasures or speculating as to possible extraterrestrial origins of various civilizations. However, they do yield useful information as to the social and political integration of a society, based upon existing archaeological and experimental data. Time-labor studies can also serve as tests of other hypotheses. This study, for instance, indicates that monumental public works need be either a sure sign or the exclusive domain of state level societies. This study demonstrates that the construction of the Pyramid of the Sun and the Poverty Point complex was possible for a society which was not necessarily rigidly organized, nor did its construction necessarily depend upon coerced labor. Further, this study yields a picture of a people who believed in their own power to undertake and complete such a task and who were dedicated enough to their ideals to bring it to fruition.

In conclusion, this paper suggests a range of possibilities for time and labor consumption by considering variables over which some degree of control can be achieved. There are some elements that could conceivably affect working time about which we can only speculate; these include for instance, such factors as illness, mourning, socializing, inclement weather, and religious festivals. Perhaps when more is known of the respective peoples, an entirely different and more valid time-labor calculation method can be developed.

APPENDICES 1 AND 2

FOR

TEOTIHUACAN

APPENDIX 1: Calculations of the manpower and time requirements for the construction of the Pyramid of the Sun.

1. A. Volume of Pyramid:

Millon: $1.17x10^{6}m^{3}$; Linne: $9.93x10^{5}m^{3}$; Heizer: $8.40x10^{5}m^{3}$

Load Size Material s	15 kg	22 kg	40 kg
fill 1.3	.015 m^{3}/load	.017 m^{3}/load	.031 m^{3}/load
clay 1.7	.008	.013	.024
basalt 3.0	.005	.007	.013
lime 1.0	.015	.022	.040

Volume of outer shell removed by Batres; = 25% volume

M: $2.8x10^{5}m^{3}$; L: $25x10^{5}m^{3}$; H: $2.1x10^{5}m^{3}$

M = Millon; L = Linne; H = Heizer

Volume of clay; if clay = 25% to outer layer

M: $7.0x10^{4}m^{3}$; L: $6.3x10^{4}m^{3}$; H: $5.3x10^{4}m^{3}$

Volume of rock in outer shell

M: $2.1x10^{5}m^{3}$; L: $1.9x10^{5}m^{3}$; H: $4.6x10^{5}$

Volume of lime coating, assuming 30 cm. thick = 1%

M: $1.17x10^{4}$; L: $9.93x10^{3}$; H: $8.40x10^{3}$

2. A. Man-days required for excavation of fill, using $2.6m^{3}$/day from Erasmus (1965)

M: $4.1x10^{5}$ days; L: $3.8x10^{5}$ days; H: $3.2x10^{5}$ days

B. Assuming a work force of 6,000; required man-days =

M: 68 days; L: 63 days; H: 53 days

C. Assuming a 6,000 man work force; days required for clay excavated =

M: 18 days; L: 16 days; H: 14 days

D. Erasmus states that 300 man days of labor, including excavating limestone, cutting firewood, transporting firewood and limestone, and stacking wood, yields 8,140 kg. lime which .037 man-days per kg. of lime.
of lime = 1000 kg/m^3. Mass of line covering =

M: $1.17\text{x}10^7$kg; L: $9.93\text{x}10^6$kg; H: $8.40\text{x}10^6$kg

Man days for lime plaster preparation =

M: $1.17\text{x}3.7\text{x}10^5 = 4.3\text{x}10^5$ days; L: $9.93\text{x}3.7\text{x}10^4 = 3.7\text{x}10^5$ days;
H: $2.0\text{x}10^5$ days

E. Assuming a work force of 6,000 days required for lime preparation =

M: $\frac{4.3\text{x}10^5}{6\text{x}10^3} = 72$ days; L: $\frac{3.7\text{x}10^5}{6\text{x}10^3} = 62$ days;

H: $\frac{2.9\text{x}10^5}{6\text{x}10^3} = 48$ days

F. Total days required for all materials before transport = 2(B+D+F)

M: 158 days; L: 141 days; H: 115 days

3. A. If fill collected within 1 km. with av. lead = 75 km.; output =

$$.015 \quad \frac{1}{\frac{.75}{3} + \frac{.75}{5}} \quad 5 \quad \text{or} \quad .017 \quad \frac{1}{.25 + .12} \quad 5 \quad \text{or}$$

$$.031 \quad \frac{1}{.37} \quad 5 \text{ and } 40 \text{ kg.} = .418 \text{ m}^3/\text{day}$$

B. Days required for transport of fill to stockpile = volume ÷ output per day

	Load Size Volume	15 kg	22 kg	40 kg
M	$1.17\text{x}10^6$	$5.8\text{x}10^6$ days	$5.1\text{x}10^6$ days	$2.8\text{x}10^6$ days
L	$9.93\text{x}10^5$	$4.9\text{x}10^6$	$4.4\text{x}10^6$	$2.4\text{x}10^6$
H	$8.40\text{x}10^5$	$4.2\text{x}10^6$	$3.7\text{x}10^6$	$2.0\text{x}10^6$

C. Assuming 6,000 workers, required day for fill transport =

	15 kg/load	22 kg/load	50 kg/load
M	9.70 days	8.50 days	4.70 days
L	8.20	7.30	4.00
H	7.00	6.20	3.30

D. Manpower for transport of fill from stockpile to pyramid with an average lift of 18 m., which yield an mp factor of .342 mp/m^3, and average lead of 30 m., which yield

$$mp = {}^{1}/_{c}\ \frac{1}{\frac{.03}{3}+\frac{.03}{5}}\ 5 = {}^{1}/_{5c}\ (63.5) = {}^{1}/_{312.5c}\ \frac{.0032}{c}$$

for

c = .015; .017; .031m^3, (for 15 kg. = .213 mp; for 22 kg. = .189; for 40 kg. = .103) equals mp for lift + mp for transportation = for 15 kg. = .655; for 22 kg. = .531; for 40 kg. = .445

E. Output per man per day for transport from stockpile to pyramid =

$$\frac{1}{\text{total mp}} = \frac{1}{.655};\ \frac{1}{.531};\ \frac{1}{.445}$$

for 15 kg. = 1.5 m^3/day; for 22 kg. = 1.9 m^3/day;

for 40 kg. = 2.2 m^3/day

F. Days required for transport of fill from stockpile to pyramid =

$$\frac{m^3}{m^3/\text{day}}$$

	Load Size Volume	15 kg.	22 kg.	40 kg.
M	$1.17\text{x}10^6$	$7.1\text{x}10^5$ days	$6.2\text{x}10^5$ days	$5.3\text{x}10^5$ days
L	$9.93\text{x}10^5$	$6.6\text{x}10^5$	$5.2\text{x}10^5$	$4.5\text{x}10^5$
H	$8.40\text{x}10^5$	$5.6\text{x}10^5$	$4.4\text{x}10^5$	$3.8\text{x}10^5$

G. Assuming 6,000 available workers, required days =

	15 kg.	22 kg.	40 kg.
M	120 days	100 days	90 days
L	110	90	75
H	90	70	60

H. If clay collected within .75 km. of pyramid with an average load of .5 meters, output =

$$c \; \frac{1}{\frac{.5}{3} + \frac{.5}{5}} \; 5 = 5c \; \frac{1}{.17+.1} = 16.50c$$

for c = .008 m^3/load; c = .013 m^3/load; c = .024 m^3/load for 15 kg. = .132 m^3/day; for 22 kg. = .214 m^3/day; for 40 kg. = .406 m^3/day

I. Days required for transport of clay to stockpile = volume ÷ daily output

	Load Size Volume	15 kg.	22 kg.	40 kg.
M	$7.0\text{x}10^4$	$5.3\text{x}10^5$ days	$3.3\text{x}10^5$ days	$1.7\text{x}10^5$
L	$6.3\text{x}10^4$	$4.8\text{x}10^5$	$2.9\text{x}10^5$	$1.5\text{x}10^5$
H	$5.3\text{x}10^4$	$4.0\text{x}10^5$	$2.4\text{x}10^5$	$1.3\text{x}10^5$

J. Assuming 6,000 available workers; days required =

	15 kg.	22 kg.	40 kg.
M	90 days	55 days	28 days
L	80 days	50 days	25 days
H	67 days	40 days	22 days

K. Manpower required to transport clay from stockpile to pyramid w/average lift of 18 m. and average lead of 30 m. Lift factor = .342 mp/m^3; lead component = $\frac{.0032}{c}$ - (c.f. 3D) for 15 kg. = .400 mp/day; for 22 kg. = .245 mp/day; for 40 kg. .133. Total mp = .342 + $\frac{.0032}{c}$ = for 15 kg. = .742 mp; for 22 kg. = .587 mp; for 40 kg. = .475 mp

L. Output per man per day for transport from stockpile to pyramid =

$$\frac{1}{\text{total mp}} = \frac{1}{.742\text{ mp}} ; \frac{1}{.587\text{ mp}} ; \frac{1}{.475\text{ mp}} =$$

for 15 kg. = 1.3 m^3/day; for 22 kg. = 1.7 m^3/day; for 40 kg. = 2.1 m^3/day

M. Days required to transport clay from stockpile to pyramid = $\frac{\text{volume}}{\text{output}}$

	Load Volume	15 kg.	22 kg.	40 kg.
M	$7.0\text{x}10^4$	$5.4\text{x}10^4$ days	$4.1\text{x}10^4$ days	$3.3\text{x}10^4$ days
L	$6.3\text{x}10^4$	$4.8\text{x}10^4$ days	$3.7\text{x}10^4$ days	$3.0\text{x}10^4$ days
H	$5.3\text{x}10^4$	$4.1\text{x}10^4$ days	$3.1\text{x}10^4$ days	$2.5\text{x}10^4$ days

N. Assuming 6,000 workers; required days =

	15 kg.	22 kg.	40 kg.
M	9.0 days	7.0 days	5.5 days
L	8.0 days	6.0 days	5.0 days
H	7.0 days	5.0 days	4.0 days

O. Assume basalt collected within 3 km. of site, with average

lead of 2.25 km. output = $5c \frac{1}{\frac{2.25}{3} + \frac{2.25}{5}} = 5c \frac{1}{.75 + .45} =$

$5c \frac{1}{1.20}$

for 15 kg. = .021 m^3; for 22 kg. = .029 m^3; for 40 kg. = .054 m^3

P. Days required for transport of basalt to stockpile = volume ÷ output

	Load Volume	15 kg.	22 kg.	40 kg.
M	2.1×10^5	1.0×10^7 days	7.2×10^6 days	4.0×10^6 days
L	1.9×10^5	9.0×10^6 days	6.5×10^6 days	3.5×10^6 days
H	1.6×10^5	7.6×10^6 days	5.5×10^6 days	3.0×10^6 days

R. Assume 1,200 workers; required days =

	15 kg.	22 kg.	40 kg.
M	830 days	600 days	330 days
L	750 days	540 days	290 days
H	630 days	470 days	250 days

S. Manpower required to transport rock from stockpile to

pyramid = .342 mp for lift + $\frac{.0032}{c}$ for mp for transport

with 30 m. lead
transport mp = .640 for 15 kg.; .457 for 22 kg.; .262 for 40 kg.
total mp = .982 for 15 kg.; .799 for 22 kg.; .604 for 40 kg.

T. Days required = mp · Volume =

	Lead Volume	15 kg.	22 kg.	40 kg.
M	2.1×10^5	2.06×10^5 days	1.68×10^5 days	1.27×10^5 days
L	1.9×10^5	1.88×10^5 days	1.52×10^5 days	1.15×10^5 days
H	1.6×10^5	1.57×10^5 days	1.28×10^5 days	9.70×10^4 days

U. Assume lime transported 5 km.

$$\text{output} = 5c \, \frac{1}{\frac{5}{3} + 1} = 5c \, \frac{1}{2.67} = 5c\,(.375) = 1.88c$$

for 15 kg. = .029 m^3/day; for 22 kg. = .041 m^3/day; for 40 kg. = .075 m^3/day

V. Assume 6,000 workers for rock

	15 kg.	22 kg.	40 kg.
M	34 days	28 days	21 days
L	31 days	24 days	19 days
H	26 days	21 days	16 days

W. Days required for lime transport = volume ÷ output

	Load Volume	15 kg.	22 kg.	40 kg.
M	1.17×10^4	4.0×10^5 days	2.8×10^5 days	1.6×10^5 days
L	9.93×10^3	3.4×10^5 days	2.6×10^5 days	1.3×10^5 days
H	8.40×10^3	2.9×10^5 days	2.0×10^5 days	1.1×10^5 days

X. Assume 6,000 workers for lime transport

	15 kg.	22 kg.	40 kg.
M	67 days	47 days	27 days
L	57 days	43 days	22 days
H	50 days	33 days	18 days

Y. Manpower for transport of lime from stockpile to pyramid =

$$.342 \text{ mp} + \frac{.0032}{c} = .342 + (.213 \text{ or } .145 \text{ or } .080)$$

total mp = .555 for 15 kg.; .487 for 22 kg.; .422 for 40 kg.

Z. Days required for transport lime from stockpile to pyramid

	Load Volume	15 kg.	22 kg.	40 kg.
M	$1.17\text{x}10^4$	$6.5\text{x}10^3$	$5.7\text{x}10^3$ days	$4.9\text{x}10^3$
L	$9.93\text{x}10^3$	$5.5\text{x}10^3$	$4.8\text{x}10^3$ days	$4.2\text{x}10^3$
H	$8.40\text{x}10^3$	$4.7\text{x}10^3$	$4.1\text{x}10^3$ days	$3.5\text{x}10^3$

AA. Assume 6,000 workers

	15 kg.	22 kg.	40 kg.
M	1.1 days	1.0 days	.8 days
L	.9	.8	.7
H	.8	.7	.6

BB. Total days required to transport pyramid materials.

	15 kg.	22 kg.	40 kg.
M	2222 days	1678 days	972 days
L	1857	1485	837
H	1571	1260	701

4. A. Using Erasmus' (1965) figure of 10 hr/m^3 of masonry = 2 $days/m^3$ rock and adobe exterior of pyramid would require M: $5.6x10^5$ days; L: $5.0x10^5$ days; H: $4.2x10^5$ days

B. Assuming 6,000 workers, outer coat would require M: 93 days; L: 73 days; H: 70 days

5. A. Total days required to construct pyramid with a 5 hr. day

	2F + 2BB + 3B 15 kg.	22 kg.	40 kg.
M	2473 days	2071 days	1756 days
L	1929	1699	1445
H	1223	1051	886

B. Total time in years assuming 40, 100, 200 days of community labor per year

	15 kg.			22 kg.			40 kg.		
	40	100	200	40	100	200	40	100	200
M	61.8	24.7	13.4	51.8	20.7	10.3	43.9	17.6	8.8
L	48.2	19.3	9.7	42.5	17.0	8.5	26.1	14.4	7.4
H	20.4	12.2	6.1	26.3	10.5	5.2	22.3	8.9	4.4

C. Total time in years required when work day varied but load kept constant at 22 kg. (the most likely carrying load) for 5, 7, and 9 hours.

	40 days/yr.			100 days/yr.			200 days/yr.		
	5 hr.	7 hr.	9 hr.	5	7	9	5	7	9
M	51.8	36.6	29.0	20.7	14.5	11.6	10.3	7.2	5.8
L	42.5	29.8	23.8	17.0	11.9	9.5	8.5	6.0	4.8
H	26.3	18.4	14.6	10.5	7.4	5.9	5.2	3.6	2.9

APPENDIX 2: Some dimensions, volumes, and weights for the Pyramids of the Sun and Moon at Teotihuacan.

Acosta, 1963
Pyramid of the Sun: 735 ft. at base; 210 ft. high
volume = 1,500,000 cubic yds.

Pyramid of the Moon: 490x390 ft. at base; 135 ft. high
volume = 252,000 m^3

Batres, 1889
Pyramid of the Sun: 224 m. square at base; 68 m. high

Cook, 1947
Pyramid of the Sun: volume = 993,000 meters cubed

Heizer, 1966
Pyramid of the Sun: volume = 840,000 cubic meters

Humboldt, 1811
Pyramid of the Sun: 208 m. square at base; 55 m. high
volume = 33,743,201 cubic feet

Pyramid of the Moon: 44 m. high

Judd, 1948
Pyramid of the Sun: 692 ft. square at base; 212 ft. high
volume = 35,067,596 cubic feet

Linne, 1934
Pyramid of the Sun: 211 m^{x}207m^{x}211m^{x}209m at base
64.5 m. high
volume = 993,000 cubic meters
weight = 2,980,000 tons

Pyramid of the Moon: 150mx120m at base; 42 m. high

Millon, 1960
Pyramid of the Moon: 500 ft. x 400 ft. at base; 100 ft. high
volume = 250,000 cubic yards

Millon, 1965
Pyramid of the Sun: volume = 1,117,000 cubic meters
volume of 1st stage = 600,000 cubic meters

Weaver, 1972
Pyramid of the Sun: 700 ft. square at base; 200 ft. high

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