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Ancient Heavy Transport, Methods and Achievements

Transport of heavy stones provides evidence of the socio-economic types of ancient societies.

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Modern engineering and energy resources are so great that the task of transporting a 1000-ton weight today would constitute no particular problem. But in times before the wheel and steam or internal-combustion engines were known, such transport could have been accomplished only with human or animal energy aided by such simple friction-reducing devices as sledges, gliders, or rollers, and equally uncomplicated lifting or raising devices such as inclined ramps and levers. That great stones weighing hundreds of tons were moved by some ancient societies is well known, but the means which were employed are less well understood.

Recent histories of technology and engineering (*1*) usually mention only in passing the remarkable examples of long-distance moving of stones weighing scores or hundreds of tons in both the Old and the New World in ancient times. Perhaps this is either because historians of engineering are unaware of the information buried in the anthropological literature (*2*) or because they are reluctant to enter into an investigation which involves so much speculation.

Physical and Historical Evidence

Several kinds of information are available. First are the great stones themselves which still lie unfinished in the quarry, such as the 1168-ton unfinished granite obelisk at Aswan (*3*) and the uncompleted volcanic tuff statues on Easter Island (*4, 5*). There are many known examples of large stones which were abandoned along the route between their source and intended destination. A good example is the great red porphyry blocks weighing from 2 to over 100 tons that lie between the cliff of Cerro Buena Negra, Peru, where they were cut, and the fortress of Ollantaytambo, 5 kilometers away (*6*). The unfinished fortress was unsuccessfully attacked by the Spaniards under Hernando Pizarro, brother of Francisco Pizarro, in 1534, and what can be seen today marks the point to which the Inca construction activity had progressed at the time of the Spanish Conquest. Unfinished or arrested projects such as these provide particularly useful information, since an interrupted project is usually easier to interpret than a completed one.

The main source of evidence for heavy transport in antiquity is, of course, stones that were successfully moved to their intended destinations and placed in their intended positions. Into this category in the New World fall the score or more of colossal sculptured human heads, stelae, and "altars" of basalt weighing up to 36 tons and assignable to the Olmec culture of the southeastern lowland of Mexico of the 1st millennium B.C. (*7, 8*); the multiton andesite statues associated with the early phases of Teotihuacán in Mexico, among which are the 217-ton Idolo de Coatlinchán, the largest stone sculpture attempted by the prehistoric peoples of the New World, and the 24-ton Diosa de Agua (*9*); the ignimbrite jambs and lintels, weighing up to 26 tons, employed in the temple constructions at Mitla in the state of Oaxaca, Mexico (*10*); the 60-ton Stela F and the several 30-ton zoomorphic altars at the Maya site of Quiriguá, Guatemala; and the largest of the Aztec-period sculptures of Mexico, such as the famous "calendar stone" weighing 24 tons. In South America are the 200- to 300-ton stones used in constructing the Inca fortresses at Sacsahuaman above Cuzco (Fig. 1) (*11, 12*) and at Ollantaytambo, about 50 kilometers from Cuzco, in the valley of the Urubamba (Vilcanota) River (*6*). In the Old World, the number of ancient stone monuments weighing 50 tons or more (some as much as 1000 tons) is so large that they cannot be listed here. Examples are the granite obelisks of the 18th and 19th dynasties at Luxor, quarried at Aswan and brought down the Nile on boats (*13, 14*); the two 1000-ton Colossi of Memnon (the Greek name for Amenhotep III) brought up the Nile from quarries at Silsileh, near Cairo (*13*, pp. 96–97), which stand on the plain of Thebes; the huge stones in some of the tomb chambers, passageways, and relieving arches over the chambers (*15*); in Greece, the jambs, lintels, and sills of the Lion Gate at Mycenae, and at the same site the stones weighing 120 tons, used as doorway lintels in some of the tholos tombs, especially that of the Tomb of Agamemnon (*16*); in France, Spain, and the British Isles, the hundreds of huge stones, some weighing over 100 tons, used as menhirs or walling (orthostats) and roofing (capstones) in the megalithic tombs (variously called dolmens, chambered tombs, passage graves) (*17–19*); and in England, the impressive megalithic constructions at Avebury and Stonehenge (*20, 21*). The largest stone transported by the megalithic peoples of western

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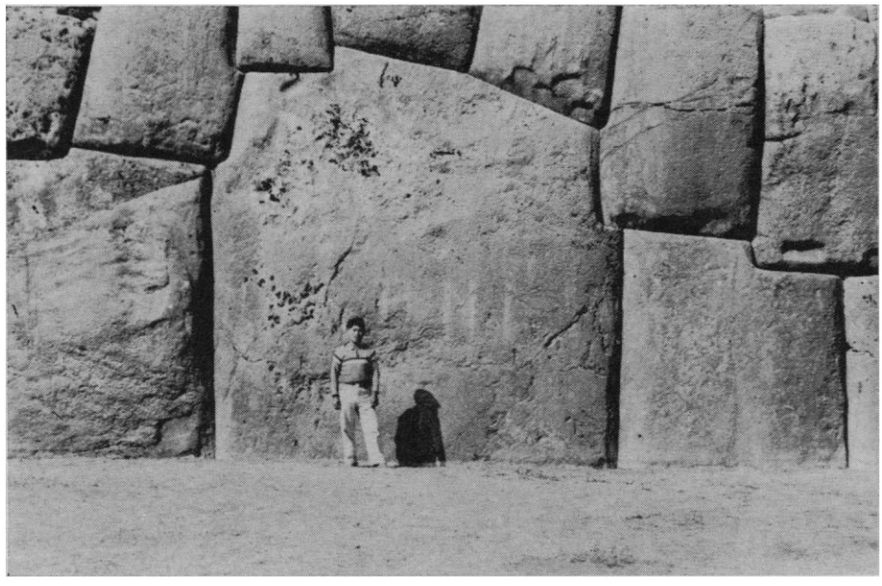

Fig. 1. One of the large, closely fitted limestone blocks in the fortress of Sacsahuaman, near Cuzco, Peru. Weight exceeds 200 tons. [Photo by author]

Europe is the 382-ton Grand Menhir Brisé at Locmariquer, Brittany.

Other sources of information, of great importance but limited in quantity, are pictorial representations of great stone sculptures being transported by water or dragged on land by gangs of men. These are known from Egypt and Assyria, and most of these paintings or low-relief sculptures are well known because they have been often reproduced and discussed. In addition, written records from Egypt and the eastern Mediterranean area provide useful, brief accounts of particular feats of heavy transportation, and there are documents in which reference is made to a particular aspect of the process, such as numbers of men employed, the use of a ship or sledge for transport, or the employment of slave labor.

Still another source of information is ethnographers or early chroniclers who have recorded the techniques employed for extracting large blocks of stone from the quarries and the means by which recently living primitive peoples (who are, in effect, modern megalithic culture groups) have transported large blocks of stone and raised them into position. Such accounts are available for some still-living peoples of the Himalayan provinces, Indonesia, and Madagascar, as well as for the Aztecs of Mexico and the Incas of Peru at the time of the Spanish Conquest (see Fig. 2).

Some hints of how the problems of moving and raising extremely heavy pieces of stone were solved in ancient times also come from modern experiments. Atkinson, for instance, attempted to move replicas, weighing up to 4 tons, of the "blue stones" used at Stonehenge (*20*), and Heyerdahl organized a work crew of 180 Easter Islanders and recorded their success in dragging a 12-ton statue and in setting up a 25-ton fallen statue by levering it gradually and building up under it, as it was raised, a blocking of small stones (*4*, *22*). Other investigations have involved scale models, as in the erection of Egyptian obelisks (*23*) and raising upright the sarsen shafts of Stonehenge (*24*).

Observations of this sort must be distinguished from purely hypothetical suggestions such as that of Posnansky (*25*), who believed that the two 100-ton blocks of red sandstone at "Puma Punka," a section of the site of Tiahuanaco on Lake Titicaca, Bolivia, were pushed on stone balls acting as ball-bearings running over a prepared roadbed of dressed stone blocks (Fig. 3). This theory may have been suggested by the transport from Karelia to St. Petersburg of a 600-ton pedestal of a statue of Peter the Great placed on top of iron cannonballs running in grooved iron tracks (*26*, *27*). Another example of a highly improbable theory is Wolff's suggestion (*28*) that the statues of Easter Island, some of which weigh 70 tons, were transported not by men but by periodic volcanic eruptions, a suggestion rather like that made in the 18th century by Deslandes (*17*, p. 16), who did not believe ancient peoples could have moved the stones for megalithic tombs and wrote,

> These stones are a consequence of disturbance that the land has suffered as a result of the many floods, tremors, inundations and volcanic eruptions by which its entire surface has been disfigured.

Another belief, which according to Camby (*29*) was held by several 18th-century students of megalithic remains, was that the Druids possessed a highly advanced knowledge of mechanics, the facts of which were later lost, which enabled them to move megaliths. Earlier explanations had postulated transport by giants of superhuman strength or by fairies (*17*, pp. 16–18; *30*). For instance, Saxo Grammaticus wrote, about A.D. 1200,

> That the country of Denmark was once cultivated and worked by giants is affirmed by the enormous stones which are in the barrows of the ancients. Should any man question that this was accomplished by superhuman force, let him look to the tops of certain mountains and say, if he knows how, what man has carried such immense boulders up to their summits. For anyone considering this marvel will note that it is inconceivable how a mass, scarcely, or but with difficulty, movable upon a level, could have been raised to so mighty a peak of so lofty a mountain by mere human effort, or by the ordinary exertion of human strength.

Another prescientific explanation was that the stones could will themselves to move or to remain immovable on the ground, as was believed in Europe and Polynesia (*4*, p. 369; *31*), as well as in Mexico (*32*) and Peru (*33*), where stones abandoned between the quarry and their destination are called *piedras cansadas* (tired stones).

The perfect fitting together by the Incas of irregularly shaped stones with as many as ten joints was done by a process which is not understood today. Since blocks of stone weighing many tons could not have been lifted up and taken down repeatedly to test their fit, it seems probable to me that some sort of template was used, but no evidence or report of such devices is known. The stone joining is so remarkable that it aroused the interest of the Spaniards, and in response to their inquiries in the 16th century they were told that the stones were "softened" and thus made easy to work by application of the juice of certain red leaves. This explanation is surely folkloristic, notwithstanding the fact that polyhydroxypolycarboxylates of certain plants can serve as chelating agents to weather stone and thus make it easier to work (*34*).

Recent and Ancient Transport

Examples of the moving or erection of large stone sculptures or obelisks from recent times can provide useful hints of the kinds of problems that were faced and solved in ancient times. Reference here is to the removal from Luxor, Egypt, to the Place de la Concorde, Paris, of a 230-ton granite obelisk by the French marine engineer Le Bas, which required 6 years (1830–1836) of labor (Fig. 4) (*26*, chapter 3); and to the dragging for 3 kilometers and the erection at Seringapatam, India, in 1895, of the 20-meter granite obelisk weighing 35 tons (*13*, p. 103; *35*).

Egyptian obelisks were moved efficiently to London by Dixon in 1877 and to New York by Gorringe in 1879 (*26*, chapters 2, 4; *36*). The Paris obelisk was transported in a specially built ship, the *Louqsor*, which had a removable bow. The shaft was run into the ship lengthwise and the bow bolted on. The London obelisk was encased in a watertight steel cylinder which was towed behind a steamer from Alexandria. The New York obelisk was taken into the hold of the ship through a hole cut in the iron plate bow.

The desire of foreigners to acquire these outstanding examples of Egyptian stone-working is not limited to the last century, as is indicated by the dozen Egyptian obelisks taken to Rome by the emperors Augustus, Caligula, and Constantine II (dimensions, weights, and locations of all known Egyptian obelisks are given in *26*, p. 145). The remarkable engineering accomplishments of the Romans are evidenced not only by their transport of the Egyptian obelisks but also by the 1000-ton blocks employed in the temple of Jupiter at Baalbek, and the 350-ton granite capstone of the tomb of Theodoric at Ravenna (*37*). The largest existing finished Egyptian obelisk now stands before the Basilica of St. John Lateran. It weighs 510 tons, and about A.D. 357 it was brought by Constantius to Rome from Alexandria, where it had been left in A.D. 330 after having been moved down the Nile from Thebes by Constantius's father, Constantine the Great. There are Roman records of the trans-Mediterranean shipping and erecting of obelisks (*26*, p. 156; *38*). Assurbanipal (the Sardanapalus of the Greeks), an Assyrian emperor who captured and sacked Thebes in 663 B.C., brought from there two obelisks which together

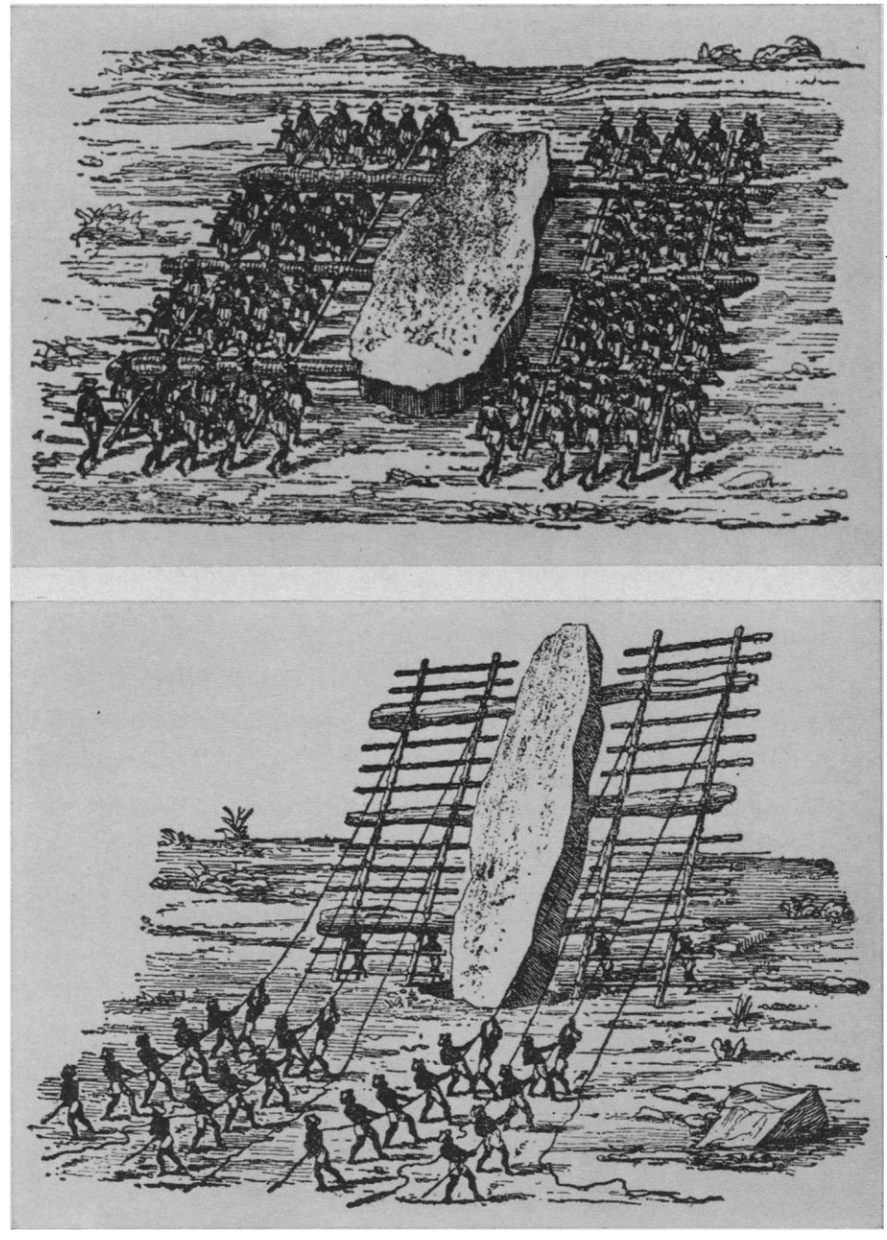

Fig. 2. Two stages of litter transport of a large stone in the Himalayan area. [From *51*]

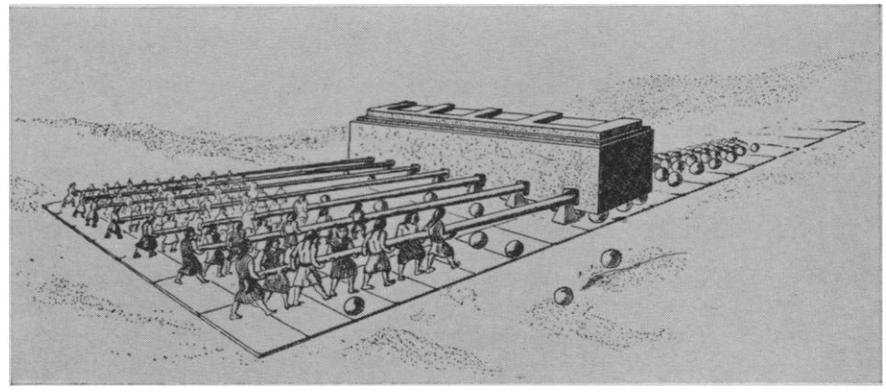

Fig. 3. Hypothetical means of transport of the 100-ton block of sandstone at Tiahuanaco, Bolivia, with the use of stone "ball-bearings." [From *25*]

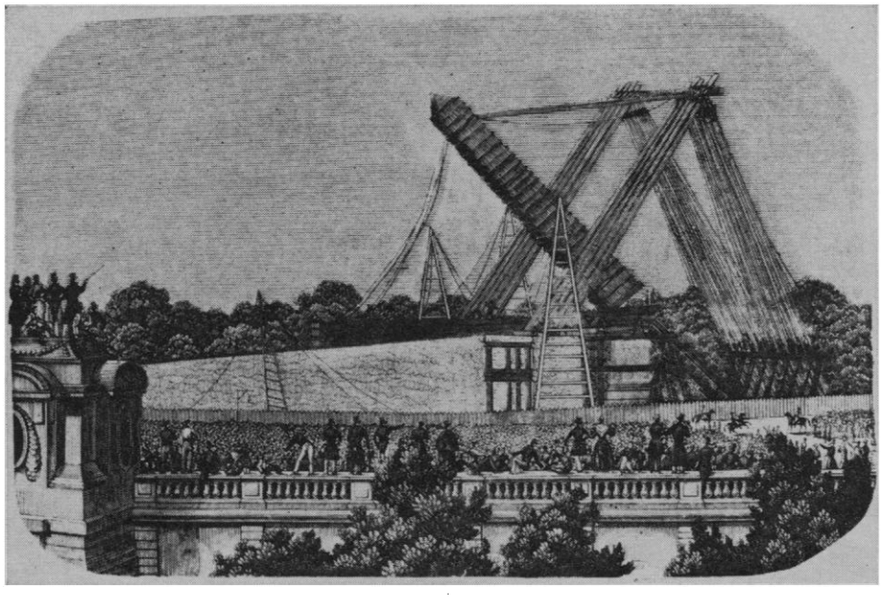

Fig. 4. Erection of the 230-ton Paris obelisk in 1837. [From *Magasin Pittoresque*, 1837]

weighed 75 tons, and set them up outside a temple at Nineveh (*26*, p. 154).

Classical authors wrote about the moving of stone monuments of such weight that the accounts must be either wholly imaginary or great exaggerations of actual events. Herodotus, for instance, reports a monolithic chapel weighing about 5000 tons brought from Aswan to the temple of Latona at Buto in the Nile delta (*39*). Diodorus Siculus, who wrote in the middle of the 1st century B.C., tells of Queen Semiramis of Assyria (probably to be identified as Sammuramat, wife of Adad-Nirari III, 810–782 B.C.) who "quarried out a stone from the mountains of Armenia which was 130 feet long and 25 feet wide and thick," and which she caused to be brought to Babylon on a raft. An 18th-Dynasty Egyptian inscription mentions an obelisk of Queen Hatshepsut which was 108 cubits (about 65 meters) long. It has been calculated that such a stone, to withstand the internal stress when moved, would have had to weigh 11,000 tons (*23*, p. 106; *40*). No evidence of this obelisk exists now, however, and the report is either an error or a gross exaggeration.

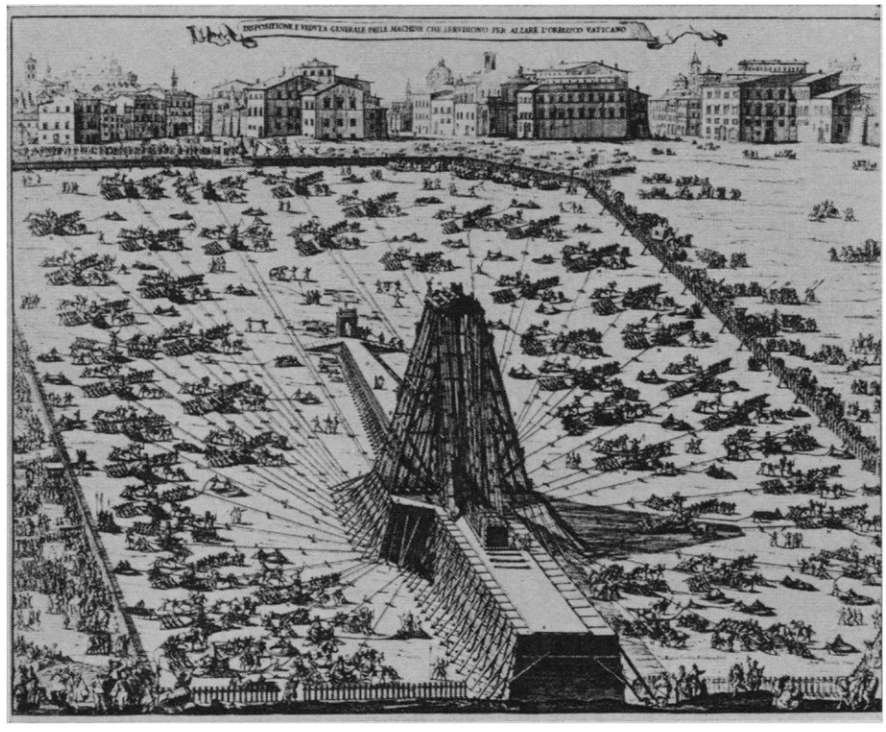

Fig. 5. Erection, directed by Fontana, of the 510-ton Vatican obelisk in 1585, with the use of 40 windlasses, 907 men, and 75 horses. [From *41*]

The difficulties of moving and erecting obelisks even with the advantages of steel cables, heavy ropes, windlasses, and pulley blocks are amply demonstrated by the illustrated accounts of Fontana (*26*, chapter 5; *41*), who in 1585 moved and set up the 510-ton Vatican obelisk which had been brought to Rome by Caligula (Fig. 5); by Layard's spirited description of the removal of the colossal bull and lion sculptures from Nimrud to the banks of the Tigris (*42*); by Major Bagnold's raising and transport of the 600-ton statue of Rameses II at Memphis (*43*); and by the moving of the 217-ton Idolo de Coatlinchán to Mexico City in 1964 on a specially built trailer, weighing 45 tons, supported by 112 pneumatic-tired wheels and powered with four tractors (*44*).

The methods anciently employed for raising very heavy stones such as column drums, wall blocks, or architraves were probably simple ones whose execution depended primarily upon a large human labor force. In Peru, inclined earth ramps were employed on which heavy stones were dragged, and there is a record that the cathedral in Cuzco was built by Inca workmen using such ramps (*45*, vol. 92, p. 262). It is supposed that the imposing Hypostyle Hall at Karnak, with its immense columns and heavy stone spans, was erected by filling the interior of the hall with earth as the construction grew in height, and that the stones were raised by drawing them up inclined ramps laid against the exterior (*15*, p. 91). The same method for raising the 2.5-ton limestone blocks that form the hearting of the Giza pyramids is mentioned by Herodotus, who wrote that the ramp which extended from the Nile to the pyramids was 1000 meters long, 10 meters wide, and 16 meters high (*46*). The techniques believed to have been used to set the 50-ton Stonehenge sarsens upright (*21*) are remarkably like those reported from recent times for setting up in their sockets the cedar logs used in the large houses of the Clayoquot tribe of Vancouver Island (*47*).

Human Energy Expenditure

Probably there is a limit to the weight of a stone which can be carried on a litter of poles or with shoulder poles and rope slings. A 5-ton stone would require such a heavy and cumbersome litter that it would be more practical to drag the stone with ropes on a sledge (that is, a modified litter). At La Venta, Mexico, in 1955, we found that basalt columns weighing between 1.5 and 2.0 tons could be carried, though with difficulty, by 35 men using shoulder poles and rope slings supporting the stones (Fig. 6; *48*, plate 9). In 1943, in the mountains of Colombia, 35 men under the direction of H. Lehmann managed, with difficulty, to transport on a litter a stone sculpture weighing 1 ton (Fig. 7) (*49*). A week was required to carry this stone 7 kilometers, the slowness being due to rain and the need to cut a trail through the forest. In Madagascar, stones weighing more than 2 tons were dragged, and smaller ones were carried on a litter of poles borne by 50 men (*50*). Stones on the island of Nias and in the Himalayan area appear, from descriptions of the litters and reports that 300 or 400 men were engaged as bearers, to have been somewhat heavier, but their weights and dimensions are unfortunately not recorded (*51*, *52*). Here the mountainous terrain must have precluded, or at least discouraged, the dragging of large stones.

It has been proved that heavy stones were transported by water. Wall reliefs in the temple of Queen Hatshepsut at Thebés show two huge granite obelisks laid base to base on a lighter that had been specially built for the purpose. The lighter was towed by a flotilla of 30 smaller craft (*53*). It is believed that these obelisks, which were quarried at Aswan and weigh 370 tons apiece, were loaded on a lighter floated into a canal leading from the Nile. After the canal was blocked off, the lighter was packed in earth, loaded from the bank, and then, after the earth packing was removed, floated off again (*23*, p. 64; *13*, pp. 94–95). Another possible method of loading an obelisk onto a ship was employed by Ptolemy Philadelphus (286–247 B.C.), who dug a canal under the obelisk, leaving it suspended with each end resting on the bank of the canal. Two boats, each loaded with stone blocks, were brought beneath the stone shaft, the blocks were removed, and as the boats rose in the water they supported the obelisk (*26*, pp. 154–155). The two colossi of Memnon at Thebés were moved on the Nile, and, in the words of the sculptor, "I caused to be built eight ships whereupon the statues were carried up the river" (*13*, p. 96). The earliest Egyptian pictorial records of heavy transport by water are the reliefs from the causeway of Wnis (Unas), dating from the 5th Dynasty (about 2400 B.C.), which show large planked barges bearing two granite columns about 1 meter in diameter, 5 meters long, and each weighing about 100 tons, lashed to sledges (Fig. 8) (see *54*).

Fig. 6. Carrying a 1.5-ton stone column with poles and rope slings at La Venta, Mexico, in 1955. [Photo by author]

Another pictorial example of water transport is that of the colossal human-headed bull sculptures which stood at the gates of the palace of Sennacherib in Nineveh. These great limestone blocks, weighing over 30 tons, are shown resting on heavy wooden sledges sitting on large rafts which were towed on the Tigris from the quarries at Balatai (now Eski Mosul), some 35 kilometers away. In other reliefs, gangs of slaves (prisoners of war) draw the

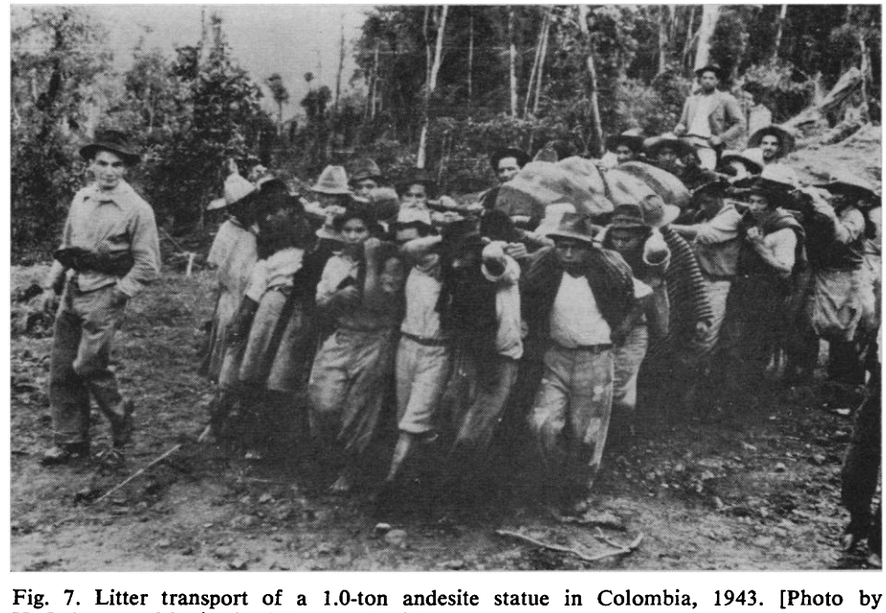

Fig. 7. Litter transport of a 1.0-ton andesite statue in Colombia, 1943. [Photo by H. Lehmann, Musée de l'Homme, Paris]

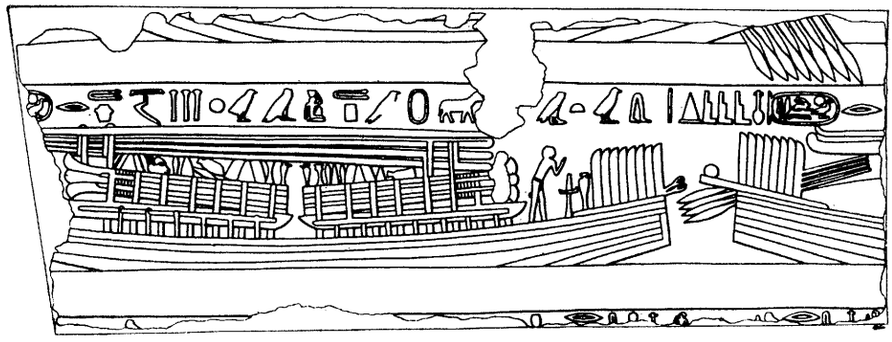

Fig. 8. Barge carrying granite columns for the pyramid complex of Wnis at Saqqara, Egypt. Fifth Dynasty, about 2400 B.C. [From *54*]

sledge with a breast sling or bricole attached to the heavy ropes fastened to the sledge, which runs on the ground over short logs laid lengthwise as stationary gliders, not as moving rollers (Fig. 9). From the time of Layard, who discovered and first published these reliefs over a century ago (*39*, *55*), most scholars have accepted the view that cylindrical wooden rollers were used to move the bull statues, but this interpretation is questioned by Davison (*56*), who believes that the round wooden pieces are friction-reducing sleepers laid beneath the runners in the direction of the sledge movement.

Much has been said about the use of wooden rollers for moving heavy stones in prehistoric times, but most of this seems to be conjecture. Wooden rollers require a firm surface to move upon, and very heavy weights would crush such wooden pieces. The use of wooden rollers cannot be demonstrated for any stone-moving culture in the New World, and at best the evidence is weak for pre-Roman Old World societies. The blue stones of the inner circle of Stonehenge were almost certainly brought by water from their source in the Prescelly Mountains in Wales (*20*, p. 99; *57*), and transport by water is considered practically certain for the La Venta monuments in Mexico, some of which weigh nearly 40 tons (*7*).

A well-known tomb painting, now destroyed, from El Bersheh, Egypt, dating from the 12th Dynasty, shows 168 men dragging a 60-ton alabaster statue of a noble named Djehutihetep on a sledge (Fig. 10) (*58*). Opinions differ as to how accurate the painting was intended to be, some students believing that an impression of a great crowd of men drawing on the ropes was intended (*13*, p. 92; *59*), and others (*56*, *60*) arguing that the exact number of draggers is shown and that the sledge was running on greased wooden planks which were "the beginnings of a modern technique, namely, lubricated flat machine-surfaces." Egyptian and Assyrian records of heavy transport are abundant, and are illustrated by one example (*61*, p. 73) referring to the Assyrian king, Sennacherib (704–681 B.C.):

> Hittite people [Syrians], plunder of my bow, I settled in Nineveh. Mighty ships after the workmanship of their land, they built dexterously. Tyrian, Sidonian and Cyprian sailors, captives of my hand, I ordered to descend the Tigris with them [bull statues] and come to land at the wharves of Opis. From Opis where they drew them up on land, they dragged them on sledges.

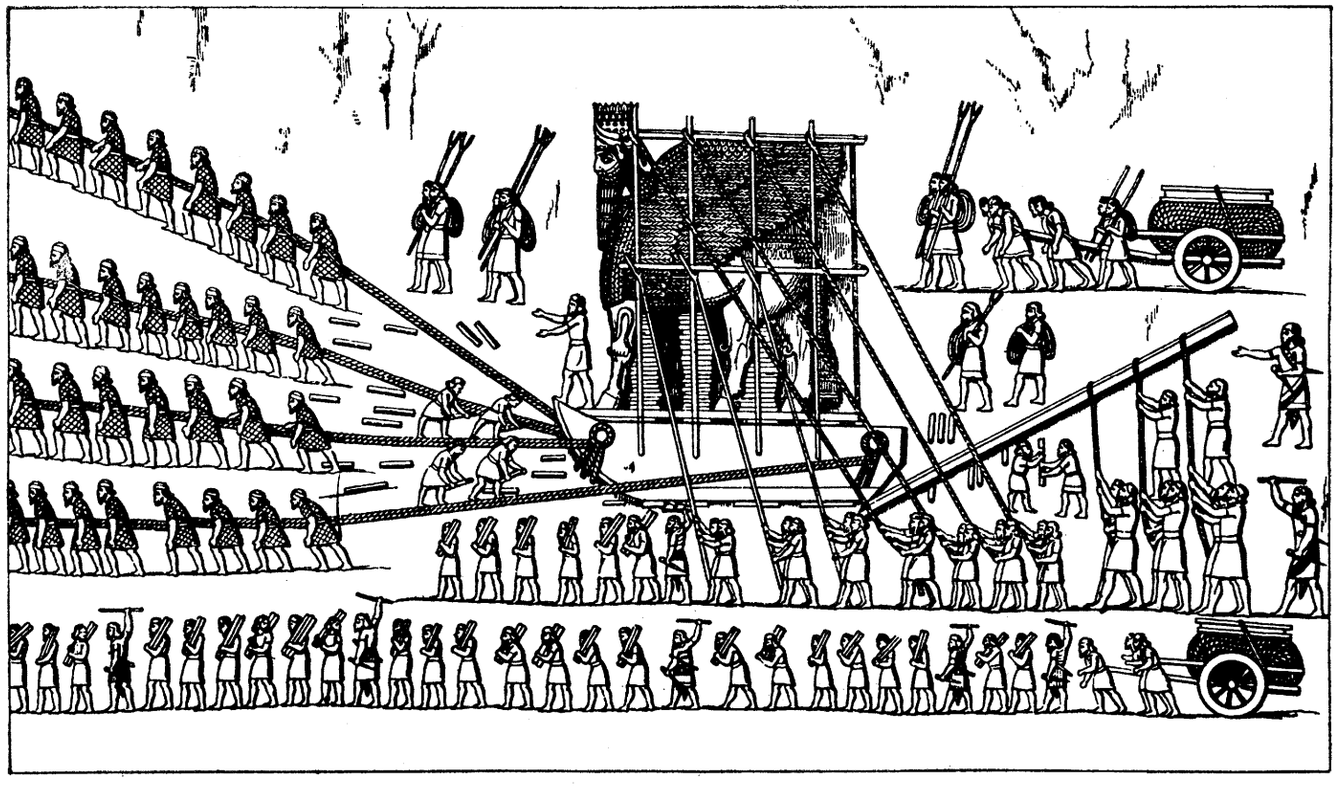

Fig. 9. Assyrian transport of a winged bull statue weighing about 30 tons. From a sculptured limestone panel dating from the 8th century B.C. discovered at Nineveh by Layard. [From *42*]

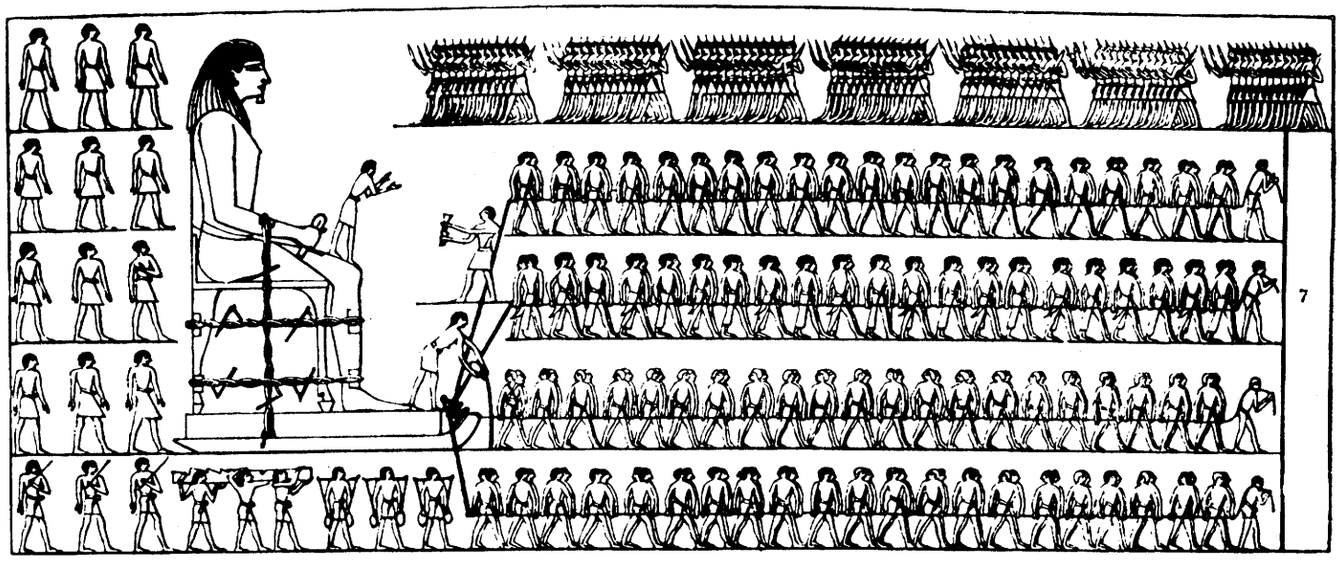

Fig. 10. Dragging the 60-ton alabaster statue of Djehutihetep. From a 12th-Dynasty tomb painting at El Bersheh, Egypt, about 1800 B.C. [From J. G. Wilkinson, *The Manners and Customs of the Ancient Egyptians* (London, 1878)]

A number of groups in southeast Asia, Africa, and Oceania have, until recent times, moved large stones which they set upright as memorials for the dead or built into tombs similar to the megalithic graves (dolmens) of western Europe. Good accounts of the placing of stones weighing several tons on a heavy sledge made of a forked tree which was dragged by ropes or vines attached to it have been published for the Nagas (*62, 63*), the Khasis (*64*), and for the people of Malekula and Tonga (*65, 66*), Madagascar (*50*, pp. 63–64; *67*), Nias (*68*), and Sumba (*69*). One of the best of these accounts (*69*) describes how an 11-ton block of stone was dragged on a heavy wooden sledge over a distance of 3 kilometers by 525 men in 2 days. The slab was then pulled up an inclined plane made of heavy logs and brought into final position as the capstone of a tomb.

Ramps of earth, known to have been widely employed in ancient times both in the Old and New Worlds, are usually thought of as the simplest and most commonly used means of elevating heavy stones serving as upright columns, stelae, tomb covers, or architraves.

Calculations of numbers of men required to pull the ropes attached to a sledge running over the ground depend upon the kind of sledge used, the weight of the stone being borne, the use of log or plank sleepers laid either at right angles—like railroad ties—or as gliding rails in line with the direction of movement, the slopes encountered, and the distance from the quarry (*7, 8, 10, 70*). By considering examples provided by modern megalith movers and using known data on human energy (*13, 71, 72*), attempts have been made to determine how many men were required to move certain multi-ton stones (*73*). Animal power was not used for drawing heavy weights in ancient times because, it is believed, adequate harnessing methods were not developed until the 10th century A.D. (*74*). Although a horse has 15 times the pulling power of a man, the pre-10th-century neck harness choked the animal so that it could exert only about one-quarter of its strength (*71*, pp. 82–86). In Roman times it had been determined that the ratio of food consumed by the horse and man was 4:1, and because this was about the same ratio as the relative power output of the horse and man, the use of draft animals rather than men would have had no economic advantage if, as was the case, there was a plentiful supply of manpower (*71*).

Socio-economic Implications

An important but difficult problem in connection with preliterate or prehistoric civilizations is whether public works in which great stones were employed can be taken as evidence of the existence of a class-differentiated society. I believe that in those societies which engaged in transport of substantial numbers of stone monuments of colossal size there existed a developed system of superordinate authority, and that these tasks were performed through the exercise of control over the population by the ruling group. The evidence from Assyria from the 7th and 8th centuries B.C. supports this interpretation (*75*), and the same is true of the absolute authority exercised by the Egyptian pharaohs, at whose orders the obelisks, tomb chambers, colossal statues, temples, and other constructions were quarried, shaped, transported, and erected. For Mycenae, with its cyclopean walls, great tholos tombs, and the deep shaft graves excavated in the last century by Schliemann (*16*), the evidence points to the existence of powerful leaders. For the megalithic Europeans of the 2nd and 3rd millennia B.C., the actual evidence for all-powerful leaders is less clear, but some authorities (*20*, p. 165; *18*, p. 32; *76*) have interpreted the megalithic tombs and "temples" such as Stonehenge as evidence of a strongly class-structured society.

Similar arguments, although admittedly not based on direct evidence, are proposed for the Olmec culture of the 1st millennium B.C. in southeastern Mexico (*77, 78*) and the culture of Teotihuacán, Mexico, during the first five centuries A.D. (*79, 80*). There is no doubt that the Aztecs (*81*) and the Incas (*11, 82*) had strongly differentiated class structures. Agriculturists are, or have been in the past, movers of multi-ton stone monuments. This practice is lacking among preagricultural hunting, fishing, and plant-collecting societies. An established farming economy permits and en-

courages—through an assured food supply, long periods of leisure between crop harvesting and planting, population expansion, and craft specialization (V. G. Childe's "Neolithic Revolution")—development of civilization to a degree which is impossible in food-collecting societies (*83, 84*).

The transport of huge stones most often has a religious or memorial purpose (*85*), for such stones commonly are sculptured to represent actual persons or deities or are integral elements of religious structures. La Venta, with its stone monuments, was a sacred ceremonial center, and the Olmec colossal heads there are believed to be portraits of great chiefs or priests; colossal statues of the 18th and 19th dynasties in Egypt represent Amenhotep III and Rameses II, personifications of the sun god; the human-headed colossal bull statues of Assyria show the face of the emperor and were demonstrably located at the gates to serve as supernatural protectors of the palace; and most of the stones which today are dragged by troupes of villagers in the Himalayas, Melanesia, Madagascar, and Indonesia are erected as memorials to the dead. These southeastern Asiatic groups can scarcely be characterized as class-structured societies. When they move and set up a stone as a memorial to a dead ancestor (the stone serves the secondary purpose of influencing the spirits to bring big harvests), the work is done by members of men's organizations (clubs) or by large numbers of coresident villagers, and although these stones are relatively large, they seem rarely to weigh more than 10 or 12 tons. There is no compulsion to provide help in moving stones, and everyone who aids is fed by the family whose ancestor is being honored. Cases are reported where the amount of food required was so great that the project had to be abandoned, or where as much as 5 or 6 years were needed to move a large stone because the surplus food required had to be periodically regathered (*65*, p. 362; *67*, p. 103; *69*). Thus these stone-transport events in southeastern Asia and Madagascar are family-oriented, cooperative projects which are paid for in food given to the workers. This is an "individualized" activity where a single stone is moved and is different from the much more complex organized work involved, for example, in the building of the fortress of Sacsahuaman in Peru or Stonehenge in England. Where great numbers of very large stones are transported to one place, presumably some direction is being exercised. The giant sculptured phallic monuments at Dimapur—in what is now Naga territory—were made by "skilled labour which only a powerful prince in the plains could command" (*63*). Dimapur monuments are larger than the stones moved by Naga villagers in recent times.

Kaplan (*86*) argues that huge constructions such as the earth- or rubble-filled stone-faced pyramids of Mesoamerica are not necessarily evidence of centralized authority and the exercise of labor direction and control of large populations. On the other hand, the magnitude and quantity of stone and earth required for some of these pyramids (*87*) and indications that the Pyramid of the Sun at Teotihuacán was built as a single, short-term project imply that more than casual volunteers showed up for the stone-cutting, earth-carrying, and odd duties, that a well-planned engineering program was devised and prosecuted by a large labor force of specialists (stonemasons, earth-bearers, engineer-overseers), and that the work was carried out on a planned and regular basis. I do not suggest that there was actual compulsion in the form of gangs of laborers working under the lash, but rather that some strong persuasion—perhaps unquestioning obedience to an authority which indicated what it wished and expected to be done—resulted in successful large-scale cooperative work projects (*79, 88*). The old view that the pyramids of Egypt were built by slaves toiling under the whips of overseers has given way to the belief that farmers and craftsmen performed the work, the farmers "working on the job in payment of taxes during the season of the [Nile] inundation when agricultural work was impossible anyway" (*89*).

A similar view of the theocratic society of the La Venta Olmecs in the New World has been proposed (*78, 90*). Lopez de Gomara's account of the Cortesian conquest of Mexico (*91*) presents evidence of the unquestioning obedience [Linné (*92*) felicitously called this the Mexican trait of "submissive religiosity"] displayed by the Aztecs, whose heroic and hopeless defense of their city of Tenochtitlán for more than 3 months ranks as one of the most remarkable examples of voluntary and unbending allegiance to a ruler in all human history. Perhaps this undeviating acceptance of authority is the key to understanding the nature and strength of the motivating idea referred to above, which has long characterized the aboriginal societies of Mesoamerica. This kind of relationship between the general population and those who held the power may have also been characteristic of some, perhaps most, of the ancient Old World civilizations. Slaves or prisoners did serve in some societies (Egypt, Assyria, Persia) as the main source of human labor, but these were the exception and not the rule.

A generally acceptable definition of civilization has not yet been achieved. S. Piggott defines civilized societies as "those which worked out a solution to the problem of living in a relatively permanent community, at a level of technological and social development above that of a hunting band . . . and with a capacity for storing information in the form of written documents or their equivalent." Sanders (*93*) has recently written that "archaeologists define civilizations in terms of excellence of technology, and especially by the presence of monumental architecture. . . . More significant, however, are the social and economic implications of these technological achievements. They are always the product of a large, organized human society with marked occupational specialization and social stratification." Within the general purview of these definitions, one can argue that transport and use of multi-ton stones in architecture and sculpture are the palpable evidence of the exercise of authority in socially stratified populations, and, whether those societies were literate or not, that these impressive monuments were often intended to memorialize the person or deity represented, or in whose name the construction was erected, the point here being that with civilization there comes a desire, as well as a means, of leaving a record for the future (*94*). If it is to be maintained, power must be exercised and demonstrated, and one of the ways which certain societies devised toward this end, from Neolithic times on, was to secure, transport, and erect stones weighing many tons.

Conclusions

That more and larger stones were transported over a much longer time span in the Old than in the New

World is obvious. The earlier arrival of the peoples of the Old World at the level of cultural development generally termed "civilization," accompanied as it was by a superior technology (*95*), goes far to account for this fact. Similarities, even identities, in techniques employed in transporting heavy stones (for example, sledge, ramps) or beliefs about stones (for example, that stones can will themselves to move or remain fixed) are taken to be fortuitous and independent convergences of the same genre as those cultural parallels recently pointed out by Caso (*96*) and Rowe (*97*).

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Multiple Causes and Controls in Differentiation

The variety and interdependence of these causes may be essential to the stability of morphogenesis.

Barbara E. Wright

Entities are not to be multiplied without necessity.—OCKHAM

The correct hypothesis for the solution of a problem often turns out to be the least complicated one that can be thought of at the time. Experience has taught us that "nature operates in the shortest way possible," and that the least complex explanation usually corresponds to reality. This, of course, depends on how complicated the problem really is, and on how close we are to its solution. The investigator may be unaware that the shortest way possible is in fact long and tortuous, and may cling to the security of an oversimplified interpretation which interferes with a search for relevant new facts and avoids recognition of the complexity of the problem. In dealing with complicated phenomena which are brought about by varied and independent forces, searching for a single cause or trigger mechanism can only delay our eventual understanding of the problems involved. Differentiation appears to be such a phenomenon and, with Ockham's permission, we shall now proceed, out of necessity, to multiply entities; show that they are *all* required; and even suggest that their very number is an essential aspect of differentiation.

Relatively few processes of morphogenesis are both simple enough and at present, well enough studied to allow an analysis of more than one of the responsible entities (or causes) involved. Many investigators have stressed the importance to differentiation of changes in (i) enzyme activities (*1*); (ii) RNA metabolism (*2*); (iii) gene activation (*3*); (iv) levels of specific substrates (*4, 5*); or (v) inhibitors (*6*). At any of these levels of control the rate of a reaction critical to morphogenesis may be influenced. Since disagreement and confusion frequently arise from unexpressed (and usually unknown) discrepancies in the definitions of the words *differentiation, morphogenesis*, and *development*, they are used interchangeably in this discussion for the sake of variety; their meaning in the particular context should be clear. If differentiation were always so complex as to simultaneously involve each of the types of control summarized above, it would indeed be difficult to analyze them all at this stage of our knowledge. For example, in view of the role of the gene in controlling the rate of an enzymic reaction necessary to differentiation, it is clear that its action is distant and indirect, being mediated through RNA templates, through enzymes, and through substrates. Since partial control of morphogenesis could (and does) occur independently at these "lower" levels, the extent of their contribution must be understood before we can clarify the role of selective gene activation.

As an example of the dependence of one level of control upon another, let me summarize two cases in which interpretation of data at the enzyme level was completely dependent on knowledge of alterations at the substrate and inhibitor level.

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