Shallow-water Excavation at Kenchreai

JOSEPH W. SHAW

PLATES 61-64

THE SUBMERGED AREAS AND THEIR EXCAVATION

Kenchreai, the eastern port of Ancient Corinth, has retained its ancient name up to the present day, even though only a few houses are now built near the ancient site.[1, 2] The Corinthia comprises a rough triangle with Corinth in the center, with the port of Lechaion upon the Gulf of Corinth to the west, the Isthmus of Corinth with its canal to the north, and Kenchreai upon the Saronic Gulf to the east. Kenchreai was known in ancient times primarily as the thriving port through which goods and passengers could be transferred overland from the Saronic to the Corinthian Gulf, or vice versa. It also provided Corinth with a base for her profitable commercial activities with the East.

Kenchreai has been visited and described by modern travelers and students. Greek archaeologists have even made some slight excavations on the site; but the first extensive exploration was undertaken beginning in 1963, through excavations of The American School of Classical Studies executed by The University of Chicago and Indiana University.[3] Several areas of the ancient town have been examined in four campaigns by means of trenches and by more extensive excavation, and efforts have been made to study the submerged foundations along the shore and other port facilities further out, including the moles, a pier, and superincumbent structures visible in the water.[4]

The harbor (pl. 61, fig. 1) consists of a natural cove in a projection of the coast, facing along a beach which extends a half-mile southward to a rocky promontory, at the base of which lie the so-called Baths of Helen. The harbor has the peculiar advantage in this area of the Corinthia of being deep and at the same time conveniently sheltered from what is now, and quite possibly was in ancient times, the prevailing northeast wind. The two promontories in pl. 61, fig. 1, close the harbor from the east and south. They are both partly natural, but it seems clear that they have been extended, raised, and built upon during Roman and possibly Greek times. The aim of such construction was to close the bay from the strong northeastern winds, which even now endanger ships coming to anchor within the harbor.

The northeastern promontory is composed of the lower slopes of one of the hillsides that descends from the plateau behind the harbor area. This hillside consists of rough conglomerate, poros limestone, and clay, which characterize native bedrock throughout this area. At its highest point, the hill is ca. 35m. above sea level. Upon reaching the sea below, the slope of the hill becomes more gradual, and then shelves out from the land until, at a point some 200m. from shore, it merges with the gently sloping sea bottom. At this point the

1 The author would like to thank Professors Robert Scranton and Edwin Ramage, co-directors of the Kenchrean expedition, for their kind permission to write this brief description of the underwater remains and of the means employed for their survey and excavation during the summers of 1963-1965. For their many helpful suggestions I am deeply indebted to Professor Scranton, Professor George Bass, and to my wife, who helped me improve my manuscript, though they are in no way responsible for any errors or omissions that remain. Photographs and plans are by the author unless otherwise specified.

2 Kenchreai is by road now about 85 km. from Athens, from Lechaion 18 km., from Ancient Corinth 15 km., and from the modern Corinth canal 7 km.

3 Scholars who have discussed the submerged remains in the harbor are A. Georgiades, *Les Ports de La Grèce dans L'Antiquité* (Paris 1907); H. Fowler and R. Stillwell, *Corinth* (Cambridge, Mass. 1932) I 71-75; K. Lehmann-Hartleben, "Die Antike Hafenanlagen des Mittelmeeres," *Klio* Beiheft (Leipzig 1923) XIV 259; T. H. Negris, "Vestiges Antiques Submergées," *AM* 29 (1904) 340ff; A. Orlandos, "'Η 'Βασιλική' τῶν Κεγχρεῶν" *Praktika tes Akademias Athenon* (1935) 55-57.

4 For preliminary report and plans of the first season's work see *Hesperia*, 33 (1965) 134-145, an article written by Professor Robert Scranton and Professor Edwin Ramage, the co-directors of the expedition. See also a general article by John Hawthorne in *Archaeology* 18 (1965) 191-200, a note by Robert Scranton in *AJA* 70 (1966) 195, and also by Scranton, "Discoveries at Kenchreai" in *Chicago Today* 3, No. 2 (University of Chicago, Spring 1966) 2-9. Members of the expedition responsible for the underwater work are Professor Robert Scranton, Director; Robert Hohlfelder and Alice Swift, graduate students and divers; Sanford Lowe, diver and photographer; James Russell, archaeologist; Nikos Kartelias, chief diver; Michael Valtinos, diver and engineer; Hariles Kotsovos, diver and boat captain; Ronald Jones, Angelos Pappas, Panayiotis Kondoyiannis, Georgia Kartelias, and Angelos Coutroumbakis, assistants, with the author of this article as supervisor of the underwater work and excavation-architect. Technical advisors were Peter Throckmorton (diving and excavation equipment) and Dimitri Rebikoff (photography).

water is from 35 to 45m. deep. The approximate line of juncture is represented by line AA on the harbor plan.

The west side of the northeastern promontory was adapted in ancient times for use as a mole, for the deep, sheltered water here was ideal for anchoring and mooring ships. This area extends some 130m. south of a tower, as yet of uncertain date, that is right on the shore. The southern end of the mole is over 4m. below sea level. Along its western and southern edges there is a sudden drop of 10m. or more down to the sea bottom, while the slope on the east is more gradual, conforming to the natural hill formation. An east-west section taken through the center of the mole (pl. 61, at 1-1 on fig. 1, and fig. 2A) shows rubble fill upon the slope, especially along its western edge, with foundations and paving laid into and upon the bedding thus created.

The promontory to the southwest has been more fully explored than that to the north. Still, little is known about the natural spit of land that may have existed there in earlier times, for it is now obscured by silting or later construction. The harbor current, running from northeast to southwest, has tended to clear the silt from the north promontory or mole, and to deposit it to the north and south of the South Pier.

The southwest promontory or, more simply, the South Pier, extends about 150m. beyond the shore. It comprises a large pier and its appended mole, and is 60m. wide at its broadest point. Our underwater excavations and survey were concentrated here. Both the pier and mole are composed of rubble fill that has been laid in varying depths either upon earlier ancient fill or directly upon natural sand or bedrock formation that existed before construction began. To the north, especially along the edge of the mole, there is a steep drop-off into deep water, while to the south the built area is more or less level with the present natural slope of the shore. Although excavation has not progressed to the point that dumped fill and natural formation can be separated, I believe that a north-south section of the mole would expose a core consisting almost entirely of rubble fill upon which the masonry foundations had been laid (pl. 61, marked 2-2 on fig. 1; also see fig. 2B). A conjectural section of the pier itself would show a greater mass of rubble fill to the north than to the south, with the masonry laid upon and into this rubble mass (pl. 61, marked 3-3 on fig. 1; also fig. 2C).

Upon first glance, the underwater remains are quite confusing. Indeed, to the newcomer who explores these 15,000 square meters of sunken ruins for the first time, either by swimming with a mask, or by peering from a boat through a sponge-diver's glass, or by viewing them from the shore when the water is exceptionally clear and unruffled by the wind, the ruins present a maze of rubble and ashlar walls often gutted by heavy seas and marine organisms, partially covered by rooftiles, sherds, and concretions. Although it is possible to view the general formations of the pier and moles from the surrounding hillsides upon which the ancient town once spread, close-up observation becomes difficult. Some of the remains have to be observed from as close as 1 to 3m., which is the height of the water above them. In such shallow water one can rarely see beyond a radius of 8m., and what he sees is distorted by the water. At the beginning of our survey, before fixed points had been established underwater, the swimmers often lost their bearings. For a time an overturned granite bowl on the South Pier was the only secure point of reference. Upon this bowl tired swimmers can still stand and have their heads just above the water. As work proceeded, however, the remains were entered bit by bit on a drawing, and finally the arrangements of walls became clearer. With such a frame of reference, work could proceed more smoothly.

Excavation and survey under water in the area of the North Mole have exposed a number of ancient constructions. Some heavy rubble and mortar walls and eroded cement floors appear under water along the eastern shore and seem to be extensions of a large Roman brick building of the second to sixth centuries after Christ, which stands on the shore to the northeast of the mole. Further to the east, away from shore, is a heavy pavement of large, cut limestone blocks placed irregularly and bordered at one point on the east by a wall which may represent the easternmost edge of an ancient "quai" now 1.63m. deep. South of this "quai," and extending out upon the North Mole itself, are lines of walls, probably building foundations, now partially buried under rubble and concretions. A wall, consisting of three courses of reused limestone blocks resting upon a heavy mortar and rubble foundation, begins near the tower and runs like a backbone along the center of the mole. Within this wall are built 13 reused column drums, average diameter 1.05m., arranged in a slight arc. Since only the tops of these drums are visible, their order has not yet been determined. What appears to be the end of this wall, 120m. from land, rests upon the brink of an underwater precipice that drops down abruptly from —6m. to —21m. below. The last block of the wall, ca. 2.50m. long by 1.50m. wide, is set into the rubble core of the mole.

Most interesting structures are to be found upon the South Pier. Here we have discovered three major building areas. These are upon the pier itself for, although the mole appended to the pier appears to have been at least partially paved and was supported along its edges by heavy retaining walls, no substantial building remains have been discovered upon it.

The first of these areas is along the northern edge of the pier, and consists of three buildings of which only the foundations and ground-level courses are preserved. These buildings are similar in plan, though of different dimensions, and share a common back wall. The buildings appear to have been separated by narrow roadways that certainly had access from the north, and quite possibly from the south. Facing northeast upon the bay, the buildings stood behind two heavy parallel retaining walls that reinforced a road running along the north side of the complex. The walls of the second and third building of this impressive group become more difficult to follow as they disappear on land below the aisles and nave of a church that has been superimposed above them. Basing our conclusions about these three buildings on their position on the pier, their size, their arrangement in relation to each other, and the roads connected with their use, we have tentatively called them warehouses.[5]

The second area is located south of the central warehouse. It contains four or more adjoining rooms, the walls of which sometimes project above water level. Amongst these is a large apsidal room which has been dug down to its well-preserved mosaic floor. Within the room were a great number of unusual finds, including perishable materials such as veneered wooden furniture.[6]

The third area, shown in pl. 62, fig. 3, occupies the southeastern end of the pier. Here, in a large 60m. by 40m. square area that appears to overlap part of the easternmost warehouse, appear extremely heavy poros block pavements and foundations, many still partially covered by rubble, in water ranging from 1.50m. to 3.00m. in depth. A series of six or more rooms or compartments were apparently bordered by these pavements. The rooms themselves were connected by curious doorways or channels, averaging 0.60m. wide, each opened or closed by means of two boards, stone slabs, or tiles fitted into pairs of opposite cuttings (pl. 63, fig. 4, II and III). Five examples of such boards and one slab are preserved *in situ*. The function of these interconnected rooms is still unknown, although, if water did flow through the channels described, the rooms could well have been used for the storage of fish or, for that matter, for bathing. For lack of a more suitable name, the area has been temporarily called the Channel Complex.

While excavation and survey of the submerged remains were concentrated upon the two great promontories described, a systematic exploration of the deeper waters outside of and within the harbor was made by means of magnetic compass. In these deeper waters, from —9m. to —40m., were found many unbroken coarse vessels, mainly cooking pots and large amphorae. At present they appear to have been dropped overboard from ships that were approaching, anchored in the harbor, or leaving it. So far the concentrations of pottery appear to indicate anchorage areas, rather than places where disabled or abandoned ships sank.

A number of trenches were dug alongside the moles and within the building areas of the South Pier in order to provide information for dating the structures, to investigate the depth of already half-exposed walls, and to probe for bedrock. During the course of the work, a variety of problems was encountered, ranging from purely archaeological ones to mechanical ones connected with excavations in shallow water. These experiments, I believe, are worth describing, to show that profitable results can be obtained from such work, and to provide useful information for future shallow-water excavators confronted with similar problems.

The types of fill we encountered varied consider-

[5] R. Scranton and E. Ramage, *op.cit.* (supra n. 4) 138. Although the size and uniformity of their regular plan seems to make them unique, they can still be compared with warehouses found at Ostia and Leptis Magna. See O. Testaguzza, "The Port of Rome," *Archaeology* 17 (1964) 173-180; A. Zanelli, "Il Porto Romano di Leptis Magna," *Bolletino del Centro Studi per La Storia dell' Architettura* 13, Suppl. (1958).

[6] Reported by J. Hawthorne *op.cit.* (supra n. 4).

ably. Thick, soft gray or black mud characterizes the sea bottoms in deep water, as well as in shallower areas below —3.00m., wherever there has been no rubble filling for mole or pier construction. Below the common eel grass which begins at an average depth of —1.50m. and continues down the slope to disappear in the —15m. zone, there is a deep layer of this mud. In Trench 4B, begun at —4.50m. there was found coarse brown beach sand which began below an almost solid layer of fine and coarse Roman ware of the first century after Christ. This sand continues to a still unknown depth, for digging operations were suspended after a maximum penetration of 2.50m. had been made. Of all the trenches dug, this was the deepest, although even here bedrock was not found (see pl. 61, fig. 2C, extreme left, also pl. 62, fig. 3, upper left, and pl. 64, fig. 5).

Two other probes were made in deeper water along the edges of the two moles. These trenches, both dug near the 15m. mark, burrowed into the sides of the precipitous moles at a point where their sides curve out to meet the gently sloping sea bottom. Our search here was limited, unfortunately, to about 1.50m. of horizontal and vertical penetration through thick gray mud containing broken coarse pottery of the first and second centuries after Christ. Further exploration of this kind, designed to determine the date of the construction and subsequent use of the moles, was hindered and finally stopped by the heavy rubble fill encountered. The heavy stones, undermined or loosened by digging operations, or lying precariously upon the mole's slopes above the trenches, threatened to avalanche down upon the working divers. Further work here would have entailed the difficult and dangerous work of shoring up the sides of the trenches and of stabilizing or removing the large stones lying upon the upper slopes, (see pl. 61, figs. 2A and 2B).

In Trench I, close up against the southeastern corner of the South Pier (pl. 62, fig. 3, lower right; pl. 63, fig. 4, I), we came upon substantial remains of wooden beams and planks, later identified as black pine,[7] that projected into the trench and proceeded to a still unknown distance into the rocky fill that provides a base for the pier buildings. This wood may belong to parts of a ship abandoned near the southern edge of the pier. The heavy rock fill here proved difficult to remove, for each large stone found had to be lifted by hand out of the trench, and then moved a safe distance away. Although this procedure is quite easily executed on land, and usually by unskilled workmen, in the water it must be performed by the one or two excavators who can fit into the trench. In this way the excavation process was slowed up considerably. If the excavation had been made in muddy or sandy areas, however, this problem would not have existed, for mud and sand are easily removed by a machine, the airlift, described below. In the case of Trench I, the heavy rubble and the limited amount of time that we could devote to this trench forced us to discontinue work. A plan was made of the wooden "ribs" and double planks *in situ*, and samples of the bronze nails and wooden pegs found were preserved.

In Trenches 2 and 3 (pl. 62, fig. 3, center; pl. 63, fig. 4, II, III), dug within rooms of the third building located upon the South Pier, we hoped to find stratified deposits. When we excavated these trenches, which were begun at levels varying from —1.70m. to —2.30m., we were particularly careful to record the levels and positions of the coins, lamp fragments, and sherds found. In both trenches there were soil layers, beginning with yellow gravel and sand lying over a still unanalyzed black, sooty layer which in turn overlay a deep deposit of soft, gray mud with whitish earth and rubble and limestone chips intermixed.

During our search for significant variations of fill and well-defined layers of deposit, we encountered an obstacle that troubled us in all of our underwater excavations, regardless of their depth: unless a retaining wall supported the loose fill along the side of the trench, the sides tended to crumble and slide down into the excavation. It was very frustrating that despite our efforts we could not maintain rectangular trenches with vertical sides, especially when excavating in mud or sand.[8] An allied problem was that, unless the trench was either very wide or very shallow, objects from higher strata might slide down into the working area. For this reason, data on stratification was obtained only from objects that could be proven to be *in situ*. Further complicating the matter was the fact that the underwater excavator, even more than one working on land, unconsciously tends to contract

[7] I am indebted to Peter Throckmorton for the identification.

[8] This problem has been discussed by F. Dumas in *Deep-water Archaeology* (London 1962) 17, and by H. Frost in *Under the Mediterranean* (London 1963) 19.

the size of the trench as he digs down. I attribute this to the fact that the excavator underwater does not stand above or sit in front of the excavation, as do most excavators on land, but lies instead over or alongside the working area, thus limiting his vision of the work being done. Threat of wall collapse was an allied problem. As a trench became deeper and more fill was removed, walls with shallow footings bordering or crossing the trench became undermined. While no walls actually collapsed, the danger of their doing so prevented us from gathering substantial amounts of materials which lay below them and would presumably furnish a *terminus post quem* for their construction.

Trench 4B was excavated outside the retaining walls that run along the north edge of the South Pier. Starting at —4.50m. depth, we first cleared away the deep-rooted eel-grass with knives, removed 0.30m. of mud and scattered Roman roof-tiles, and then came upon an extensive and surprisingly thick layer of fine and coarse Roman pottery and glass of the first century after Christ. This layer, over a meter thick in places, was so packed with large joining fragments of fine glass bowls and bottles, as well as clay amphorae, jugs, bowls, and lamps, that extremely slow and careful excavation was required. The very quantity of pottery removed during three weeks was surprising. For this reason, as soon as we realized that all of the pottery found belonged to one period and was apparently a dump, we limited our efforts to the removal of all the glass, coins, lamps, fine ceramic ware, and representative coarse ware. Below the layer described was a deep layer of sand containing earlier pottery. Unfortunately there was no time to investigate the areas to the sides of and below this point.

When underwater probing began in the second area of the South Pier, within the large room and apse mentioned, one could see a partially destroyed floor of concrete, enclosed by limestone walls, almost flush with the surface of the water. This floor, in places 0.20m. thick, rested upon a rubble fill, 0.80m. thick, which overlay a patterned mosaic floor. Sandwiched between these two floors, within the rubble and mud fill, was a treasure of small finds consisting of marble revetment, fragments of architectural marbles, sculpture, miniature ivory capitals and bases of the Corinthian Order, scores of curved ivory strips carved with varying patterns, and thin, engraved sheets of tortoise shell or ivory picturing male and female ritual figures. Upon the mosaic floor were many wooden planks and sections of veneered wooden furniture. Next to the furniture, stacked on edge upon the mosaic floor, and beside the north wall, was a series of panels, probably to decorate a wall, consisting of an elaborate and very beautiful glass mosaic in *opus sectile*.[9]

SURVEY TECHNIQUES AND EXCAVATION EQUIPMENT

Preliminary survey within the harbor of Kenchreai began in the summer of 1963, in order to explore the possibilities of excavation under water. The immediate aim was to learn the extent of the ancient remains in the shallow waters. As a result of this work, the importance of the North and South Moles and the South Pier became apparent, and their study became essential to our understanding of the harbor as a whole. Comprising some 15,000 square meters of built area, these vast areas had remained under water for over 1600 years but had been relatively gently treated by the sea, for the port is sheltered from the north by land, which cuts off the waves stirred up by the prevailing northwest wind. Since the remains merited further study, it soon became clear that a combined land-sea excavation should develop. As such it was one of the first of its kind and consequently involved a good deal of experimentation with equipment and techniques.

The basis for our preliminary survey was a topographical map drawn at a scale of 1:1000m.[10] This map had contours set at intervals of 5m. and it incorporated a series of linked points located on the shore and on the hills overlooking the harbor. These measured points became part of a survey grid that ran from south to north and from west to east over the surrounding area. The elevations of these points above mean sea level were also recorded. In time this system was extended into the harbor waters to include base or axis points useful for underwater surveys. Henceforth trenches and stray finds in any land or underwater area were located in terms of grid coordinates. Despite the difficulties encountered in the

[9] Further information about this interesting discovery can be found in Hawthorne *op.cit.* (supra n. 3) 197-199, and Scranton, "Discoveries at Kenchreai" (supra n. 4).

[10] Surveyed by John Bandekas, a topographer in Athens, in 1963.

recording of architecture and objects found in the water, this system allows such a degree of accuracy that errors could be reduced to as little as ± 0.02m. over two square kilometers of land and water.

For the initial survey of the South Pier, we first established, with a theodolite based on shore, a base line 150m. long marking the center of the longest warehouse foundation. In time, three permanent triangulation markers were used to extend these measurements out onto the mole. Using common skin-diving equipment of mask, snorkel, and fins, we laid down more than a mile of ¼″ rope to mark the centers of walls. These taut rope lines helped us determine the true direction and straightness of any wall and, because of the poor lateral visibility in such shallow water, they became an indispensable aid. To fasten these lines we dived down and hammered hardened 3″ steel nails (called concrete nails in the building trade) into ancient limestone blocks situated at wall intersections and building corners. We then attached numbered galvanized metal sheets to these nails. These markers were later replaced by numbered sheets of durable, laminated plastic. Beginning from the foundations on shore, we extended our reference points by direct measurements to the end of the South Mole, in 10m. of water. In all, there were about 100 markers distributed over an area 150m. long and 60m. wide. To help locate underwater points from the surface we used cork fishing floats into which we fastened numbered metal sheets. These buoys were tied from below with a heavy cord, the other end of which was tied to a nail that had been previously fixed in the foundation walls below.

At this point measurement from one nail to another could start. In instances where uneven bottom conditions or intervening obstacles made level measurement difficult, the swimmers used plumb bobs held over the measuring points, while a plastic Eslon tape, held level, gave the true distance. Though not perfect, this adaptation from land-surveying incorporated very little error when used over short distances.

Certain other measurements were taken during this survey. These included the dimensions and elevations of foundation walls. Many smaller details such as clamps and cuttings were also located, measured, and described. Elevation readings were taken by the excavation architect standing with his theodolite on shore, while a swimmer held a graduated pole, 6m. long, upon the spot to be measured. A helper in a nearby dory checked the readings and compared them with those of the architect by means of two-way radio. Another method for taking elevations consisted of stationing a helper on shore to read elevations and then to broadcast them with a portable electric megaphone to the surveyors swimming over the measurement points. The elevations obtained not only helped us to relate the structures to one another, but gave us the amount of slope of major pier areas.[11]

For the more specific measurements needed to make more detailed architectural plans, other methods had to be used. The excavation tools, diving equipment, and trained personnel that were added to the expedition in 1964, the second season, made this work possible. One method of drawing shallow water areas was found to be especially effective.[12] When the water was clear and unruffled, usually early in the morning, the boat was positioned over the area to be drawn, and pencil sketches were made upon large white plastic sheets, 0.35m. by 0.25m., cut from locally-made, rectangular dinner trays that had been slightly roughened by rubbing with steel wool. At times oil was sprinkled over the surface of the water, in order to improve its transparency. Sometimes, when the water was over 1.50m. deep, or was simply dirty from excavation or heavy seas, the architect had to spend seemingly endless, cold hours suspended just below the surface of the water while making the sketches (pl. 64, fig. 6).

The sketches themselves included triangulation and leveling points as well as symbolic and actual drawings of the foundations, floors, walls and fill visible. The drawings were made before actual measurement began, and were made at a scale judged by eye to be 1:70, that is, slightly larger in scale than that of the final 1:100 drawing (pl. 62,

[11] Some of these elevations may be valuable in ascertaining how the pier came to be underwater. We do know from Josephus that the Romans knew how to build foundations underwater (*The Jewish War* I, 408-414, Loeb), and from Vitruvius that walls now found underwater may well have been built on shore, then allowed to fall into the water (*De Arch.* 5.12ff). In the case of the Kenchreai port installations, however, the presence of floors, drains, clamp cuttings, and the complexity of the pavements and foundations in over a meter of water, strongly suggest that they were at one time on dry land.

[12] Methods of deep-water triangulation, leveling, and measurement are described by George Bass and Eric Ryan in "Underwater Surveying and Draughting," *Antiquity* 36 (1962) 252-261.

fig. 3). There was approximately 0.03m. overlap on the drawing sheets, so that when the sheets were fitted together a very good idea of the final plan could be obtained.

Actual measurements were made in a number of ways, depending upon the size, complexity, and depth of the area under study. For the basic 1:100 survey of the area in pl. 62, fig. 3, the original base-line mentioned earlier was used to establish graphically the axis lines of the Channel Complex. When these two axis lines were proven graphically to cross each other at right angles, the survey was completed. One diver held the 0.00m. point of the tape at right angles to one of the axis lines that had been marked by taut ropes stretched between nails or metal posts (pl. 63, fig. 7). The surveyor himself stood or floated above the point of measurement, while a helper behind him kept the tape taut and level. Communication between the trio was either by gestures or by a series of prearranged tugs on the 30m. tape. In some cases an extra swimmer would police the tape in order to make sure it was level, at the proper right angle to the axis line, and unimpeded by obstructions. Later, measurements were taken from the other base line to secure material for an adequate final drawing. In cases where greatest accuracy was desired, triangulation from corner or center posts was made, thus reducing the error to the point that it would not appear at 1:100 scale. As a double check, all wall terminations and room corners were triangulated from points on the axis lines.

Trench measurements were usually made from rope lines set up along their sides, or from the four corner posts to which the rope was attached. These corners were then triangulated from measured points along the base line.

Photographs supplemented the drafting work. In some cases the photographs helped the draftsman make or improve the underwater sketches. On the other hand, we often found very shallow areas difficult to photograph, and had to resort to the draftsman's plan as the best guide. A stereogrammetric photographic survey of the 70m. by 55m. area represented in pl. 62, fig. 3 was first tried. In this case, the photographer, pushing an I-shaped frame incorporating a Leica camera in its watertight case, made consecutive exposures between parallel ropes that had been laid previously on the bottom. About 1500 photographs were taken in this way. However, problems of inadequate depth control and the high cost of processing so many photographs in stereorestitution later proved discouraging. The single photographs taken, in combination with low-level aerial photographs and direct measurements, have nevertheless aided us in making the final plan.[13]

At Kenchreai we experimented with excavation tools and techniques that would safely remove sand, mud and rubble from foundations buried in shallow water. Many tools needed for this work were not readily available, and as a result we had to find skilled personnel to help order, make, and operate them. Since the operation of these machines often required knowledge of diving, these people had to be qualified divers as well.

During subsequent excavation, we used three tools to remove fill from underwater trenches. The first, used commonly throughout the Mediterranean by archaeologists, was the deep-water airlift, a kind of underwater suction pump made effective by compressed air rising and expanding within a vertical pipe.[14] The second tool, which we came to call the shallow-water airlift, was a modification of the first, the major difference between the two being that in the latter the pipe had a smaller diameter through which a great deal of air was forced (pl. 64, fig. 8). The third tool was a high-pressure water pump with a hose and an adjustable nozzle with a very small exit aperture (pl. 64, figs. 9 and 10).[15] When sea-water was pumped through this nozzle at high pressure, the force of the stream, ejected at 10 atmospheres pressure, became useful for clearing rubble and removing silt-laden waters from otherwise cloudy excavation areas. At a lesser, more controllable pressure the versatile hose was useful for the excavation of fragile remains.

[13] George Bass, of the University Museum of the University of Pennsylvania, has successfully experimented with stereogrammetric photography in deep water. See R. Karius, P. Merlfield, D. Rosencrantz, "Stereo-Mapping of Underwater Terrain from a Submarine," *Ocean Science and Ocean Engineering*, Transactions (Washington, June 1965) 1167-1177. Since the camera-subject distance in our case was so limited (1 to 3m.), a similar method would work best from a platform or, perhaps, from a helicopter or balloon.

[14] For additional information on the deep-water airlift, plus a bibliography tracing its origins, see Frederic Dumas, *op.cit.* (supra n. 8).

[15] The Galeazzi nozzle and hose have also been used in the deep-water recovery of the warship Vasa from Stockholm harbor, and also in the excavation of the Grand Congloué wreck. See A. Franzen, *The Warship Vasa* (Stockholm 1960) passim; and Y. Girault, *Les Fouilles sous-marines au Grand Congloué*, cited from J. Taylor, *Marine Archaeology* (London 1964) 69.

The deep-water airlift was most useful in areas over 10m. deep. Powered by a small compressor coupled with a volume tank, the airlift had sufficient suction at its lower end to extract surprising amounts of mud and sand, as well as small stones. Divers working with this machine were in pairs or alone, depending on their experience and the depth of the trench being excavated. Objects found were sent up to the fishing boat in baskets, to be subsequently transferred to land.

The shallow-water airlift was powered by a low-pressure air compressor, like that used for airhammers.[16] The compressor, supplying 100 cubic feet of air per minute (maximum), at an outlet pressure of 6 atmospheres, was stationed on the shore. From it stretched the rubber airhose, over 60m. in length and 0.03m. in diameter, made of detachable sections that were added or removed according to the distance from the shore to the excavation area. The airlift itself was a metal irrigation pipe 5m. long and 0.10m. in diameter. At the lower, working end, we attached a pipe of smaller diameter incorporating a tiller and the inlet for the airhose. The other end of the 5m. pipe was suspended from the surface by means of inner tubes or gasoline cans. While working, the excavator straddled the slanting pipe or worked alongside it. He placed small excavation tools and sherd baskets within reach.

This airlift worked best at depths ranging from 3-6m. At that depth almost any material not so big as to clog the pipe could be removed directly. There were problems encountered in the course of this work, however. One was the clogging of stones, sherds, or rooftiles at the mouth of the pipe or within it. This was alleviated somewhat by the addition of the smaller 0.08m. diameter pipe to the lower end of the airlift, which at least reduced clogging within the wider pipe. Another problem was the danger of the heavy pipe's gouging holes in soft deposits. This was offset, to some extent, by resting the sucking end upon convenient stones and then feeding fill excavated by hand into the mouth of the pipe. To catch desirable stray objects that might escape unnoticed up the pipe, we laid a 5 by 5m. canvas sheet on the bottom, under the downstream end of the airlift. As digging progressed, therefore, the mud and sand left in suspension were swept away by the current, while heavier objects, such as potsherds, pebbles, and coins, dropped onto the canvas sheet below.[17] In order to prevent the surrounding foundations from being covered by airlift waste we hung baskets from the exhaust end of the pipe. Each basket filled with waste was subsequently tied to inner tubes or Port-a-lifts (inflatable plastic balloons) and hauled away. Some 300 such basketsful of stone, sand, and rubble were deposited in nearby dumps. In some cases the contents of the baskets were searched by hand.

At less than 3m. depth, this airlift grew less effective due to the increasingly horizontal angle of the pipe and the decreased expansion of the compressed air, both lowering the suction effect. At —1.30m. the suction was barely sufficient to remove small pebbles, sand and mud. Moreover, we had the problem of directing the pipe into areas surrounded by walls. Since these walls impeded the pipe, they often limited the depth to which we could excavate. We found that, although good work could be done in such shallow water with this tool, the conditions of work were very tiring and awkward for divers burdened with heavy equipment and sometimes troubled by dirty water, sea swell, sea urchins, and other annoyances.

The third tool, the water hose assembly (pl. 64, figs. 9, 10), was composed of a 16 HP Jeep engine coupled with a bronze water pump, with a 30m. hose with nozzle that were manufactured by the firm of Roberto Galeazzi of La Spezia, Italy. By regulating the pressure of water we found that this tool could perform a number of important jobs. Thus, we could obtain a water jet sufficiently powerful to penetrate heavy mortar pavements or feeble enough to remove fill gently in 0.02-0.05m. *stroses*. It was particularly useful in the excavation within the apsidal building, where fragile objects were discovered. The fill from this excavation was washed into piles that were removed and then searched by workmen for small ivory, glass, bronze, or gold fragments that had been overlooked. In the lower strata, just above the mosaic floor, cleaning of the wooden furniture and *opus sectile* fragments was done by hand while the jet, lowered to 2 atmospheres pressure, supplied a current bringing in clear

16 On a long-term basis, diesel engines are more economical than the gasoline engines used by us. On the other hand, gasoline engines are generally lighter and involve a smaller initial expenditure.

17 In deep-water work, a screen or sieve is often attached to the upper end of the airlift. In some cases, the excavated fill is dumped directly into the boat or barge. In shallow water, however, especially when the fill is coarse, this method is difficult to put into effect.

water from outside the building. In loose mud, which becomes dissolved in a current of water, we could often excavate around objects without even touching them.[18]

Apart from the technical problems of ordering, making, or assembling equipment, one of the main concerns was the safety of the personnel involved in the diving operations. For this reason the 10m. fishing boat hired for the summer was always stationed over the deepest trench being excavated, with the captain or another diver ready to help, should something go wrong below. A recompression chamber was stationed on shore for extra safety. Of the twelve people diving, each had a diving schedule approximating what we judged to be a safe long-term exposure time. Depending on the depth and his resistance to the cold (the one girl in the group was the only one not heard to complain of the cold), each person was in the water from one to four hours per day for almost two months. Diving time in 1964 and 1965 totaled about 1000 hours, while surface skin-diving was probably double that. During 1964 some 60 cubic meters of coarse fill were removed from the trenches. Some 14,000 square meters of already-exposed area have been surveyed so far.

The work and the tools described were admittedly at an experimental stage, but we believe that there has been sufficient reward for the effort expended. Kenchreai and other partly-submerged sites in seismic zones are what archaeologists call areas of "fortunate catastrophes." These new sites, and others already under study, await our developing science.[19]

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[18] During the summer of 1965, Peter Throckmorton used the same water hose assembly to operate a successful dredge, which with a "venturi" at its working end, sucked silt out of the excavation through thirty feet of 0.15m. pipe laid on the bottom.

[19] Other surveys of partly submerged harbors include: N. Flemming, "Underwater Adventure in Apollonia," *Geographical Magazine* 31 (1959) 497ff; also see "Apollonia Revisited," *ibid.* 33 (1961) 522ff; E. Fritch and Ben Dor, "The Link Expedition to Caesarea," *Biblical Archaeologist* (1951) 50-59; E. Linder and E. Leenhardt, "Caesarea," *RA* (1964:1) 47-51; J. Leathan and S. Hood, "Submarine Explorations in Crete," *BSA* (1958-1959) 263-280; A. Maiuri, "L'Esplorazione archaeologica di Baia," *Atti del II Congresso Internazionale Sottomarina* (Albenga 1958) 108; A. Poidebard, *Tyr* (Paris 1939), and the same author with J. Lauffray, *Sidon* (Beyrouth 1952); J. Taylor, "Motya," *Archaeology* 17 (1964) 91-100. The above investigations sometimes included aerial photography, deep-water airlift work or the use of a water hose, and shallow-water search. Work at Motya and Caesarea is continuing. For further information on ancient harbors see H. Frost, *op.cit.*, esp. chs. v-vii, and J. Taylor, *Marine Archaeology* (London 1964) ch. 5; J. Rougé, *Recherches sur l'organisation du commerce maritime en Mediterranée sous l'Empire Romaine* (Paris 1966).

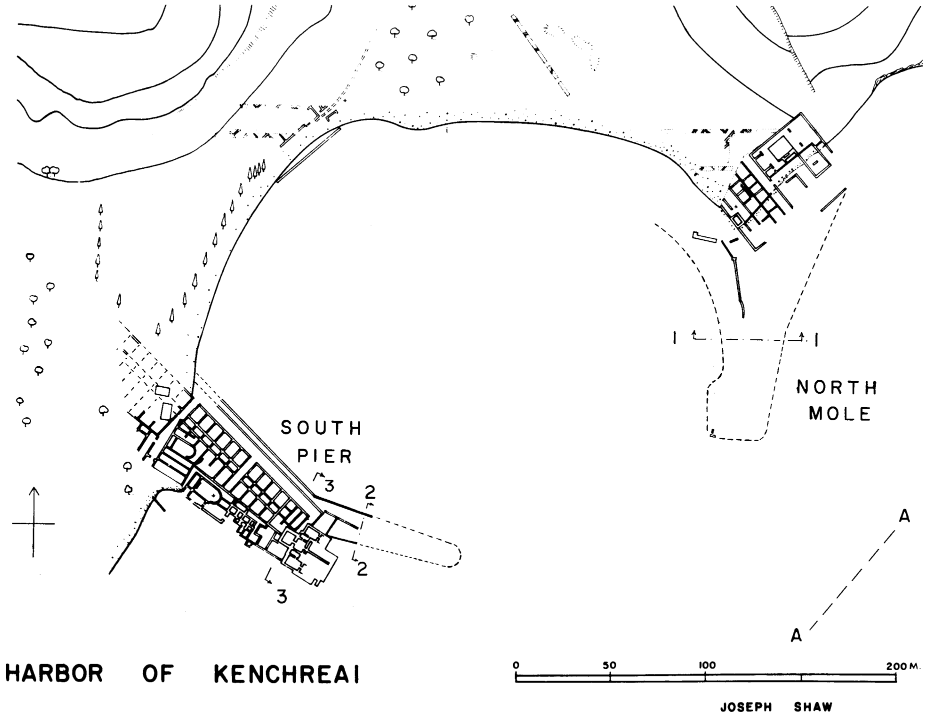

Fig. 1. General plan of harbor of Kenchreai

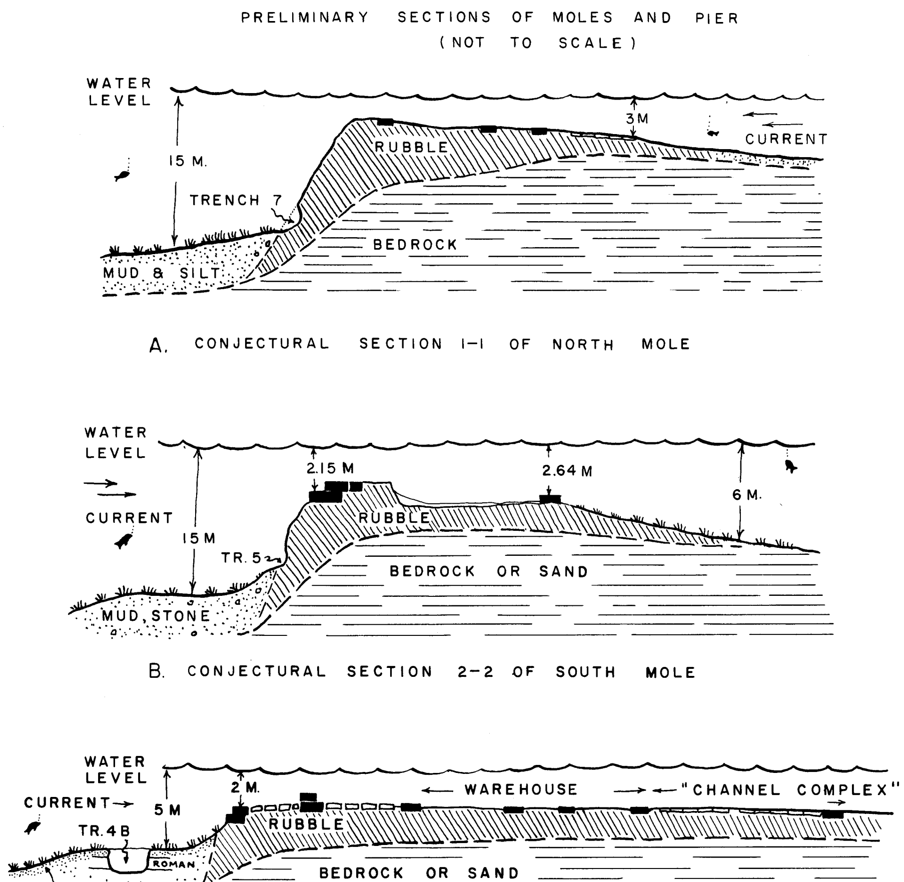

Fig. 2. Preliminary sections of North Mole, South Mole, and South Pier, at 1-1, 2-2 and 3-3, respectively, on fig. 1 (not to scale)

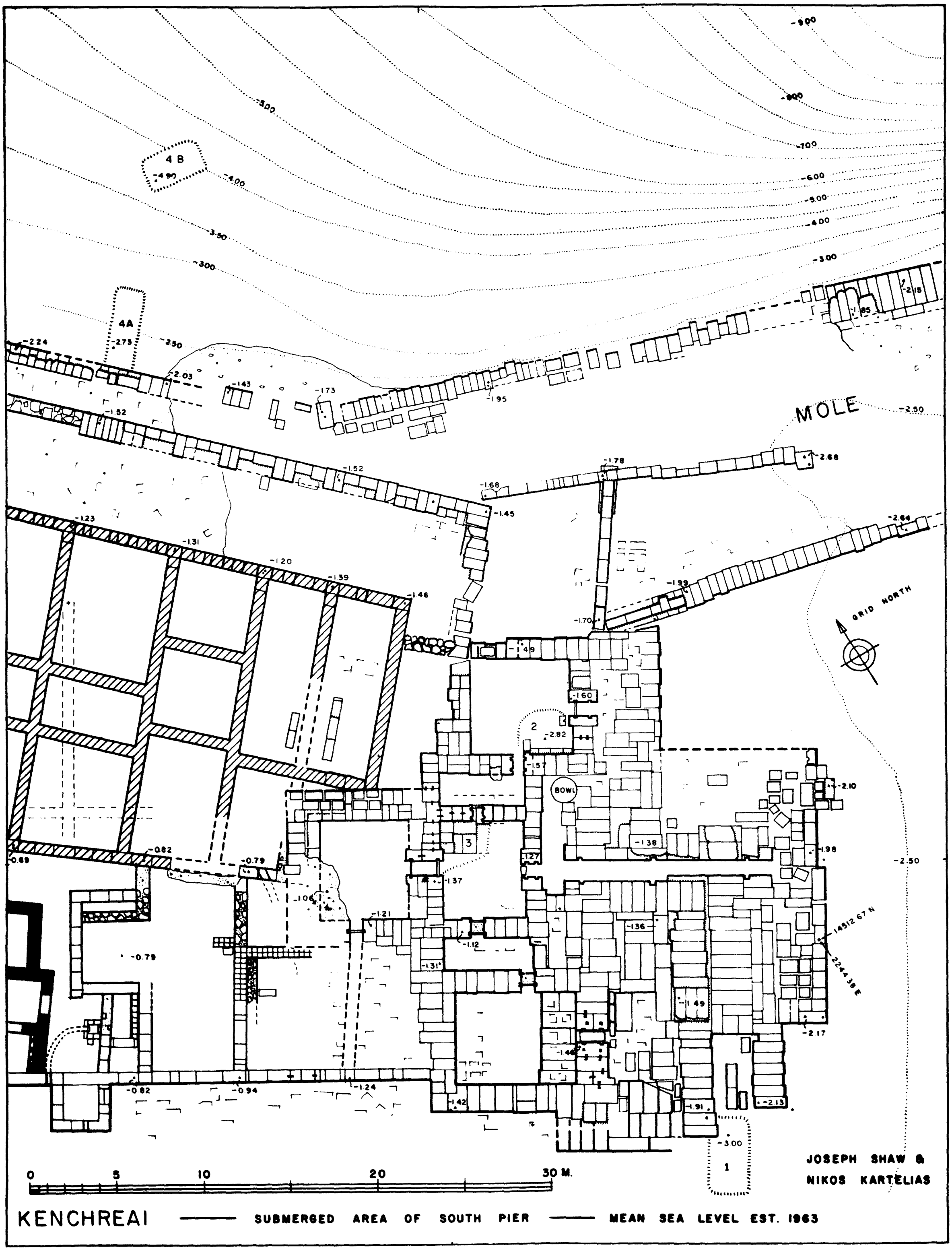

Fig. 3. This area of South Pier is entirely underwater. Upper left (hatched): easternmost warehouse; lower left (blackened): rooms related to apse to west; center: Channel Complex; upper right: mole

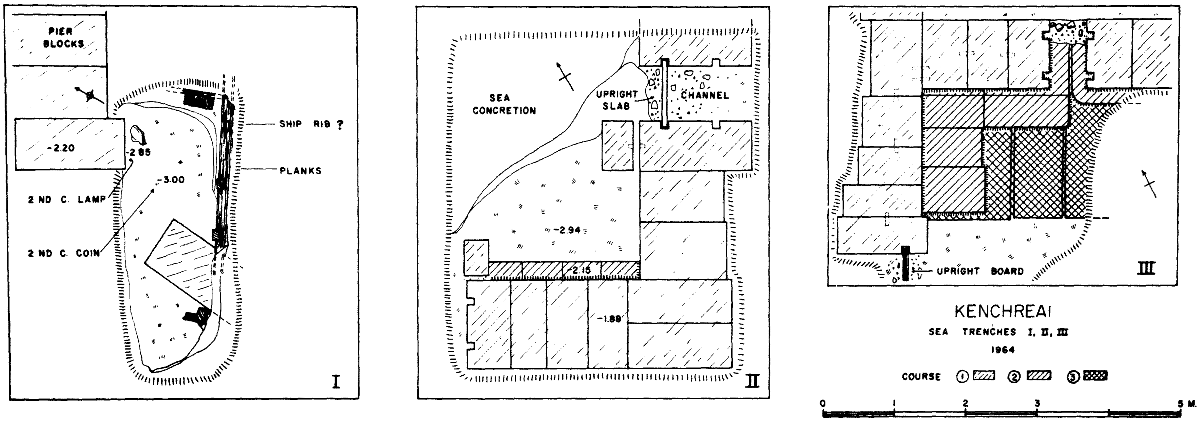

Fig. 4. Three of eight underwater trenches excavated in 1964. The first contained possible ship remains in Roman fill; second and third were in corners of rooms in Channel Complex

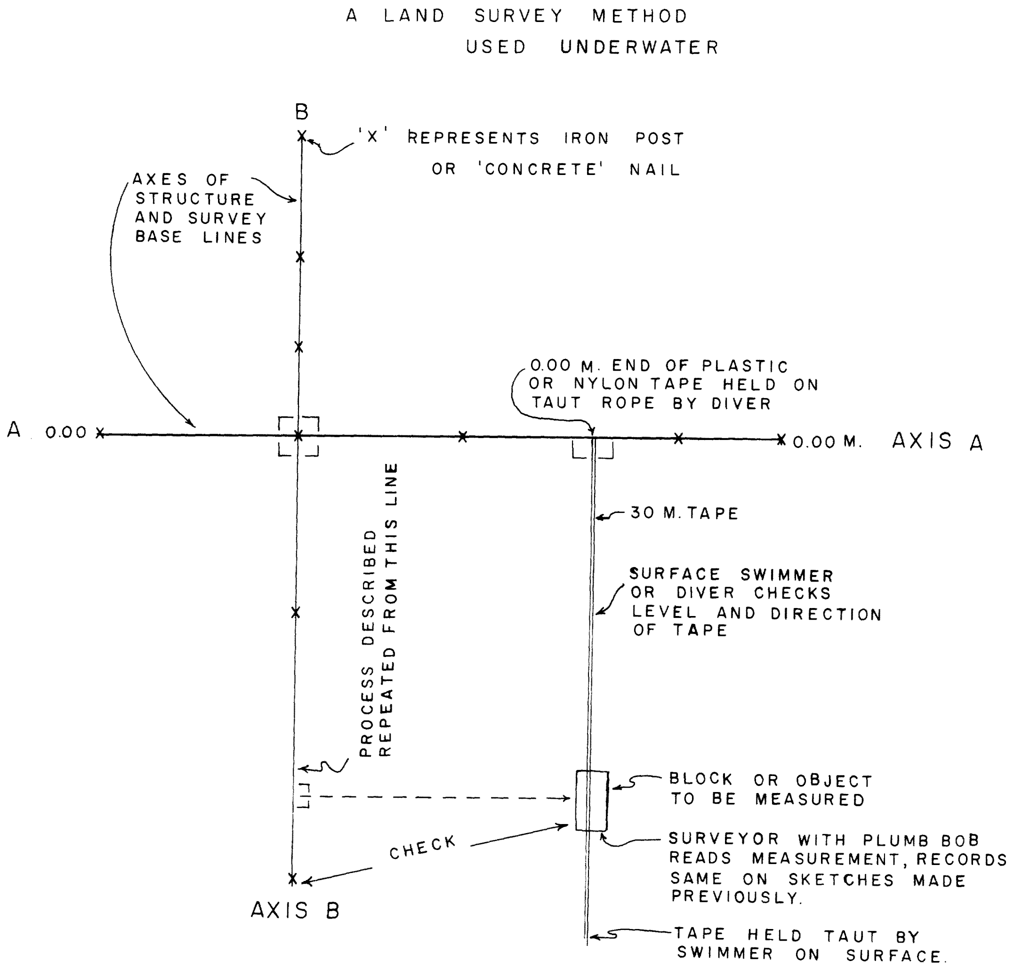

Fig. 7. A land survey method adapted for underwater use, useful for surveying large areas with same orientation

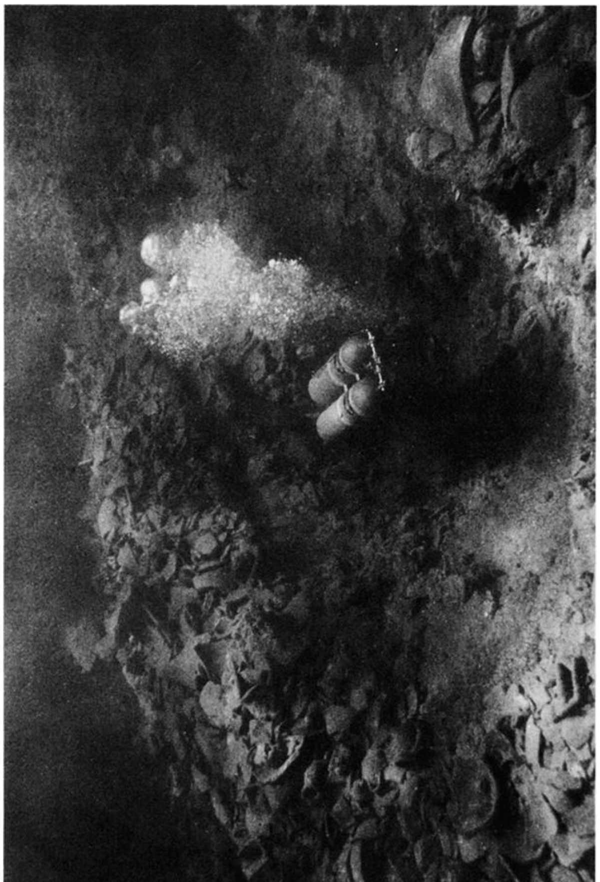

Fig. 5. Author in Trench 4B, just north of retaining walls of pier (photo N. Kartelias)

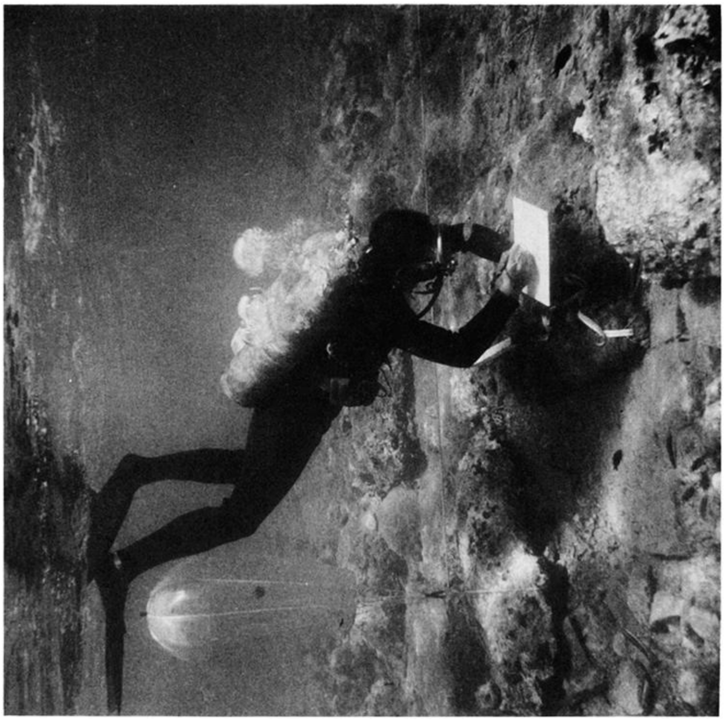

Fig. 6. Sketching submerged foundations. Limestone block is about to be removed (photo M. Valtinos)

Fig. 8. Excavating with shallow-water airlift (depth 1.50m.)

Fig. 9. "Galeazzi" on shore. Airlift in foreground

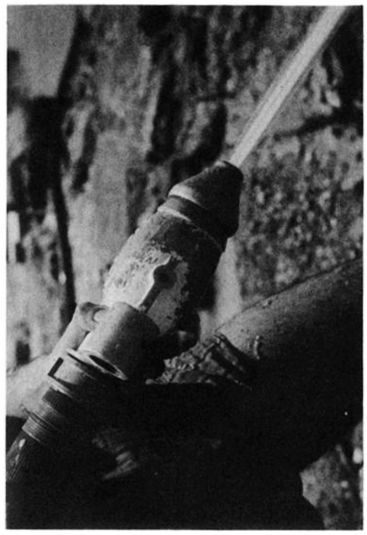

Fig. 10. "Galeazzi" nozzle with high-pressure water hose, for excavation under water