

MCMAHON COPY

APPENDIX C
SSRS TEST DEPOSIT SAND LEVEL OBSERVATIONS/
KAHALUU AND DISAPPEARING SANDS BEACH
OBSERVATIONS

BY
JON ROACH
HILO MARINE OPTION PROGRAM

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INTRODUCTION

Under the supervision of Dr. James Maragos, five Hilo College Marine Option Program student divers participated in the Environmental Monitoring Program accompanying the Submarine Sand Recovery System (SSRS) pilot test at Keauhou Bay, Hawaii.

Three months prior to commencement of the SSRS mining operations, the five students completed the field work portion of the Offshore Aggregate Survey (OAS) . The survey, which specifically investigated the nearshore area between Kawaihae Bay and Mahaiula Bay on the Kona Coast of the island of Hawaii, constituted a continuation of the State of Hawaii's offshore sand inventory program.

OBJECTIVES

The following objectives were undertaken by the OAS team in the "before/during/after" observation periods spanning the monitoring program at Keauhou Bay:

- I. Observe sand fill rates and impletion patterns associated with equilibration of the conical depressions resulting from sand mining
- II. Observe deepening effects of deposit
 - A. in relation to crater degeneration
 - B. in relation to undermining of original coral boundaries
- III. Observe for possible erosion in response to offshore mining operations at nearby beaches
- IV. Observe possible sand migration in or out of defined boundaries of test deposit resulting from mining operations or other causes

All categories of observations dealt with changes in the natural topography of the submerged deposit and nearby beaches in response to the SSRS mining operations in which over 10,000 cubic yards of sand were excavated.

The actual process of sand excavation was accomplished via insertion through water jetting of the recovery probe into the sand deposit to a pre-

determined depth below the existing sand level. Sand surrounding the inserted probe was subsequently elevated to the surface barge through hydraulic suction action.

This type of sand retrieval formed conical depressions or craters, with the recovery probe situated in the apex position. As stated in the preliminary draft of the SSRS project Environmental Impact Statement (EIS), removal of in excess of 10,000 cubic yards of sand was predicted to leave numerous craters or inverted cones at the various probe locations on the deposit surface.

Those craters formed from a single recovery probe location were characterized by an identical wall slope throughout the full 360° of crater. Due to variations in sand particle composition and therefore hydraulic properties, some minor exceptions were observed in the lower regions of each crater (refer to Figure E).

Usage of a fluidizing pipe by the test crew increased the maximum recovery efficiency of a single probe location. The PVC fluidizing pipe was 10 meters in length and 1.5 centimeters in diameter. The pipe was perforated with numerous small drill holes arranged in a single straight row. Coupled to the main recovery probe's water stream with small diameter flex hose, the fluidizing pipe had its own isolated water flow and subsequent jetting action.

Water streams issuing from the pipe perforations eroded limited sections of the crater wall and fluidized the sand, carrying it to the crater apex where recovery via hydraulic suction took place.

An originally symmetrical crater underwent various transformations involving diameter extension, decrease in wall slope, etc. through usage of the fluidizing pipe. In one instance, the fluidizing pipe generated depressions which connected and subsequently incorporated several isolated craters into a single irregularly shaped, asymmetrical, conglomerate crater

(see photo A).

As indicated in the preliminary draft of the project EIS, wave action was expected to fill in the probe craters with an estimated overall vertical deepening of the deposit of two meters. Depressions or deepened areas of approximately four meters below the original sand level were predicted to remain in the immediate locale of each recovery crater position. It was uncertain as to whether this levelled area would remain deepened or gradually fill with sand migrating from adjacent deeper water deposits or on-shore sand reservoirs.

Also initially predicted was the exposure of new rock and/or dead coral surfaces along the coral boundary of the deposit in response to the overall deepening in the area. Also outlined was the potential advantage found in this exposure of fresh solid substrates. It was suggested that these could serve as colonization areas for corals and other solid-substrate requiring organisms.

In close association with the new substrate exposure, another possible effect to be monitored was any undermining activity of the original coral boundary of the test deposit. It was suggested that such undermining action might cause cracking and collapse of the fragile reef framework, especially in areas abundant in the finger coral Porites compressa.

The third category of observations dealt with the possible erosion of nearby beaches in response to the offshore sand mining operations at the Keauhou site. Following the concept that sand would be lost from nearby beaches in order to take the place of the excavated offshore sand, or that mining might otherwise interrupt the natural sand conflux of these beaches with offshore deposits, those beaches of closest proximity to the work site were monitored. These were Kahaluu Park and Disappearing Sands Beaches. As illustrated on the master map #1, Kahaluu and Disappearing Sands Beaches are respectively 1.25 and 2.8 kilometers north of the test deposit.

The fourth category of observations dealt with the possible migration of sand in or out of the test deposit boundaries in response to mining operations or other causes. The resultant effects of eliminating more than 10,000 cubic yards of sand from the integrated nearshore sand budget via excavation were uncertain. Such an excavation might impose an imbalance on the overall system and trigger an incoming migration of sand from exterior sources, such as onshore beach systems or deeper water deposits. This potential response to the sand deficit created by mining operations was suggested in the preliminary draft of the SSRS EIS as a possible mode of deposit adjustment.

METHODS

The first category of observations concentrating on sand fill rates required two types of measurements. The first was concerned with the rate of sand fill into the individual craters left by the recovery probe; primarily from the immediate area surrounding each crater. The second not only investigated changes in the surface level of the deposit, but also monitored boundary changes in response to sand migration from all points of the original deposit boundaries to the crater positions.

Sand levels were monitored periodically using the following technique: 20 rebar stakes 1.5 meters in length were secured at regular distance intervals along the perimeter of the deposit (see Figure A). Stakes were positioned in coral structures that appeared firmly fixed to the bottom and thus resistant to possible undermining effects of shifting sand.

A line of standard 210 centimeter length was extended from the top of each stake horizontally out over the sand. A groove was engraved on top of each stake in order to standardize the angle of line extension. Once properly extended over the deposit edge, the line was levelled with an

attached line level. From the tip of the levelled line over the sand, another calibrated line with a brass plumb bob attached to one end was used to measure the vertical distance between the levelled line and the deposit surface (see Figure and photo B).

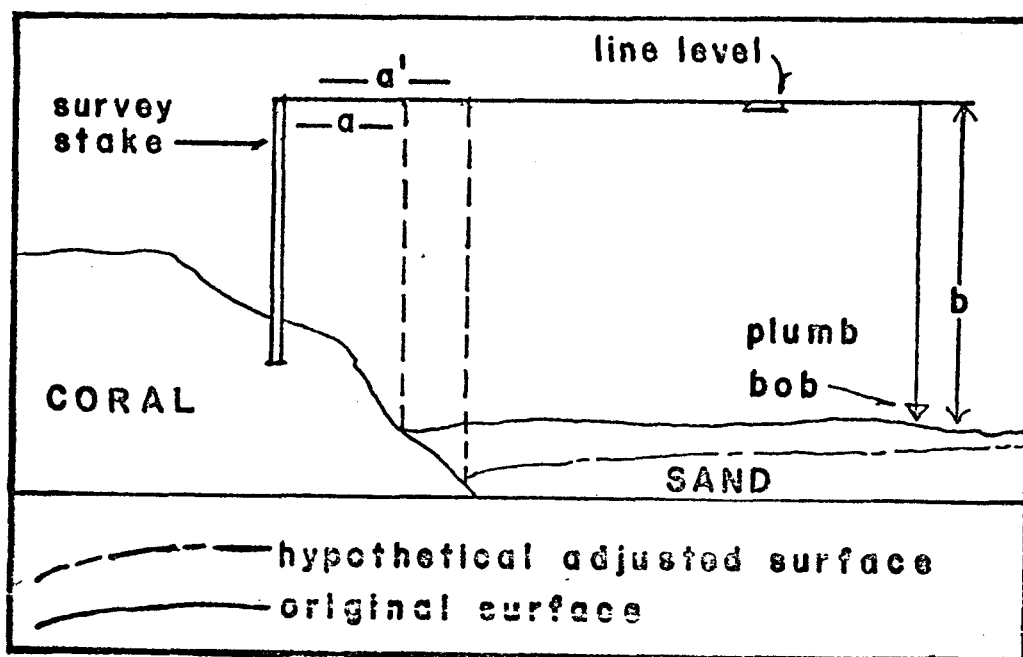


Figure B : sand level measuring scheme

In addition to the vertical measurements, horizontal measurements, "a" and "a'", along the calibrated levelled line, were taken to identify any variations in distance between the immovable stake and the coral/sand interface, or deposit boundary.

Such lateral or horizontal sand shift measurements were predicted to reveal minor if any alterations in sand/coral interface location. This preliminary suggestion was made based on the extreme isolation of the deposit as perpetuated by the coral arena surrounding nearly the full perimeter of the test deposit. An average slope of 35° was observed for the majority of the coral wall encompassing the deposit.

The importance of horizontal line measurements would surface if a given test deposit was characterized with little or no solid substrate

boundaries, and thus closely intertwined with adjacent sand deposits. In this suggested case, lateral sand shift and subsequent alterations in the aerial configuration of the deposit could easily occur.

The second group of sand fill rate observations utilized a less quantitative procedure and relied more on visual diver observations obtained the same day that stake measurements were taken. Divers inspected each crater or conglomerate crater, and recorded the condition of the walls and rim, reporting any evidence of sand migration from the immediate area surrounding each crater. If sand migration was evident, the distance from the existing crater rim to the outer boundary of migrating sand was measured and recorded.

The fourth major group of deposit observations dealt with possible sand migration in or out of the deposit boundaries in either suspended or otherwise mobile form. These observations also relied on the less quantitative diver visual investigation method. If particle migration was observed, the amount and relative velocity of movement was estimated and recorded. Velocity was estimated with a time component based on consecutive monitoring dates as reference points.

Photographic documentation of the deposit surface was included at various stages of the mining operations, especially in the immediate locale of the recovery craters.

The last major category of observations dealt with the periodic evaluation of the nearby beaches, Kahaluu and Disappearing Sands. The beach profile method described by Moberly and Chamberlain (1964) was utilized to determine the periodic morphological condition of each beach.

Profiles were taken perpendicular to the major axis of each beach; usually one profile at both ends, in the center, and at any other position of the beach where the major axis deviated noticeably. It was assumed that each tract of beach facing the open sea in a different direction would be

affected differently by a prevailing swell condition; thus the necessity for multiple profiles (see Figures C and D).

For Kahaluu Beach, three such profile stations were secured, each facing a different prevailing swell direction. Only one station was marked off for Disappearing Sands Beach due to the brevity of beach length and estimated volume. The profile station was secured in the center of the beach where the major concentration of sand was located.

In addition to beach profiles, photographic documentation accompanied each monitoring visit so to obtain a more complete description of each beach's periodic condition (see photos F through I).

RESULTS

Observation dives were taken at the Keauhou site on 8/27, 8/29, 9/10, 9/21, 10/27-28, 11/30-31, and 3/15-16, providing comparison surveys throughout the mining operations. In addition to the sand level measurements, various physical parameter estimates such as wind velocity, sea conditions, underwater visibility, and sand ripple formations were also recorded.

Sand level measurements were taken on 9/10, 9/21, and 3/15. On the 9/10, 9/21, and 3/15 dives, the full compliment of 20 stakes were measured, (see Table 1).

Diver observations taken early in the monitoring program indicated sand movement into the probe recovery craters was limited to the immediate neighborhood of each crater. For this reason, only those stakes in the direct vicinity of the recovery positions were measured on the 10/27 dive. However, on each dive, the full perimeter of the deposit was examined using additional steadfast bottom structures as estimation standards. These primary 9/10, 9/21, and 10/27 inspections yielded no appreciable influx of sand into the excavation area at any deposit location other than the immediate

locale of the recovery craters (refer to Figure A).

This trend of localized crater impletion is portrayed in the $\Sigma\Delta$ or summation of change values listed in Table 1 in which stakes bordering the approximate crater positions show the most significant change in level. Small movements in location of the bubble in the line level resulted in a ± 4 centimeter range of values for one "b" vertical distance measurement. Therefore measurements were assumed within a ± 4 centimeter range of accuracy and significance.

In disagreement with the assumed trend were $\Sigma\Delta$ values for stakes 5, 7, and 10 which also revealed a significant decrease in sand level. Observations taken on the last 3/15 visit did not perceive any noticeable sloping or other indications of gross sand migration over the 125 meter stretch of deposit between these deeper water stakes and the excavation craters located in shallower water. Such a deposit sloping was prominent for stake positions 13-14, 19-20, and 3-4.

The distinction between significant $\Sigma\Delta$ values for the excavation-zone, shallow water stakes and the deeper water stakes was not accurately defined by the utilized methods of investigation. It is suggested that the sand level decrease in the deeper portion of the deposit represented mostly localized sand movements, or movements expressing a current influence on sand bordering the sand/coral interface; comparable to the constant metamorphosis taking place at a bank in a river bend. Although unlikely, sand migration may have taken place from even this remote section of the deposit to the probe craters. This assumption was not substantiated by any diver observations during the monitoring. However, with adequate passage of time, such a process would undoubtedly occur to some degree.

Observations of crater equilibration revealed a general decrease in crater slope accompanied by a decrease in crater apex depth. Sand fill appeared endemic of areas immediately adjacent to each individual crater.

A migration zone of up to three meters in width was observed on the 9/10 and 9/21 dives. Increasing in size with elapsed time, the zone progressively widened to a maximum of 15 meters encompassing the rim of the largest conglomerate crater. This crater is ideally illustrated along with the migration zone in Figure E.

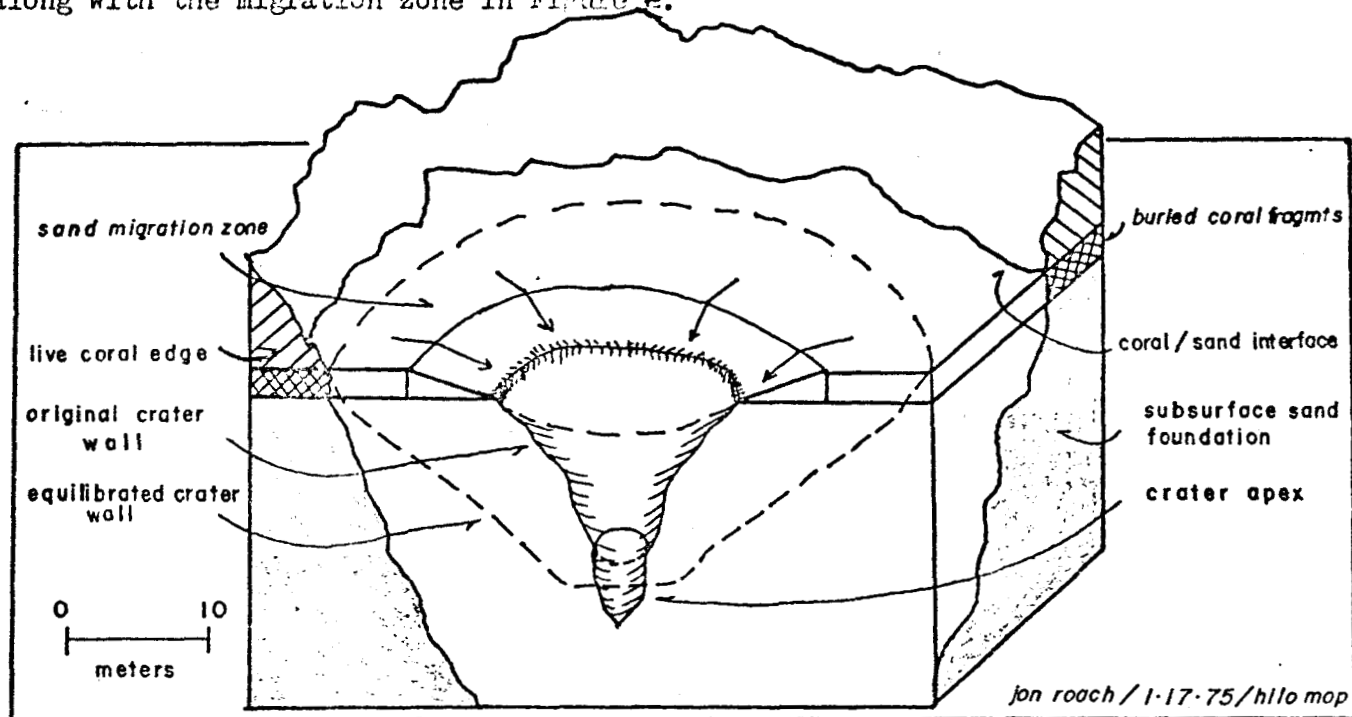


Figure E : Ideally illustrated excavation crater and sand migration zone

Several indicators were presumed to denote the migration zone of impleting sand. A gentle sloping of the sand surface into the craters coupled with the variation in color between freshly-uncovered, grayish or poorly oxidized sand and the lighter-shaded, well oxidized surface material proved significant indications of the migration zone.

Another sign of freshly uncovered sand was the presence of small, well-defined ripples or rills in the migration zone encompassing each crater rim. The original sand level adjacent to this area did not display this pattern, but was distinguished by irregular indentations and subtle contours assumed to characterize relatively undisturbed portions of sand. Any well defined ripple sets found in the undisturbed sand areas encompassing

each migration zone were usually oriented at an angle different than that of the well defined rills within the migration zone.

Degeneration of newly formed crater walls was expressed in changes of crater slope and diameter. With further passage of time, the underlying degeneration pattern observed for all nine craters was an increase in diameter, a decrease in wall slope, and a decrease in crater apex depth.

By the 9/21 observation dive, the recovery probe had been relocated in the second recovery, for two days, allowing the first crater to adjust for this length of time. ^{position} The wall of this original crater appeared uniform in degree of ~~slope~~ slope except for an increase in steepness at the apex where material of a greater compactness was presumed to exist. By the 3/15 dive, crater slope decreased to such a degree that the entire southeastern end of the shallower portion of the deposit angled into a large conglomerate depression, or what was previously the general location of the well defined excavation craters.

The general pattern of overfall softening of crater rim and wall slope with further passage of time was observed in all successively produced craters. The maximum distance from which sand migrated towards a crater rim approached 15 meters, as observed on the 3/15 dive. It should be noted that this observation was dependent upon rim location and crater diameter; both of which changed with passage of time.

Observed on the 9/10 and 9/21 dives was a 15-25 centimeter layer of semi-fluidized, fine grain sand covering the full 360° of each crater wall. This segment of somewhat "elastic" sand proved uniform in thickness and homogeneous in consistency. Upon penetration of the entire band, a foundation of coarser, more compact sand was always encountered underneath.

The upper band of "elastic" sand was assumed to represent the finer-sized remnants of what had once comprised the moving layer of fully fluidized sand previously generated during actual recovery operations. Termination of suction action in the crater apex allowed the fluidized layer to part-

ially settle out and gel into the observed stationary suspension.

Observations regarding possible undermining of the original coral boundaries in response to the overall deepening effect of the deposit were broken down into two categories; preliminary and secondary. As substantiated by the lack of significant changes in the horizontal line measurements, the preliminary 9/10 and 9/21 observation dives revealed no appreciable movement of sand from any of the coral boundaries in response to crater impletion (see Table 2). Some localized variations were noticed in isolated instances where depressions below the average coral/sand interface level were observed (see photo C).

The secondary observation dives taken on 10/27, 11/30, and 3/15 revealed a progressive enlargement of each crater's migration zone towards the coral edges of the deposit (refer to photo A). By the final 3/15 dive, movement of the conglomerate crater's migration zone had progressed to the point of exposing previously deposited, dead Porites compressa fragments, (see photo D). Encroachment of the coral edge by the migration zone approached a maximum in the vicinity of survey stake # 3 (see photo E).

A dual assumption was formulated to explain the presence of the coral fragments in this stretch of deposit ^{adjoining} the coral boundary. The assumption was based on a sequence of two events; exposure of the previously deposited dead coral fragments via sand shift, followed by undermining and toppling of coral at the original sand/coral interface. The second event was assumed dependent upon completion of the first because exposed coral fragments undoubtedly served as foundation material for the living coral. Once the migration zone reached the sand and buried coral fragments, the shifting sand served to transport the fragments away from the coral edge towards the recovery depressions.

The assumption of previously deposited dead coral fragments was further validated by an observation made by the SSRS test crew. It was soon

realized that useage of the fluidizing pipe in the area adjacent to the coral edge proved impractical because of frequent encounters with buried coral fragments which halted the desired jetting action.

It was noted that the mixture of coral fragments observed on the sand surface consisted predominantly of dead P. compressa, with a small proportion of living P. compressa and P. lobata included. P. compressa was the major part of the living species of coral fragments observed moving towards the recovery depressions.

Kahaluu and Disappearing Sands beaches were profiled on 7/24 and 10/28, providing before and after survey material respectively (see Figures F, G, and H). Comparative photos were taken on both monitoring dates for each beach (see photos F through I).

Single profiles taken on separate dates of Disappearing Sands Beach are comparitively illustrated in Figure C. A definite increase in horizontal length of the backshore or berm with the row of coconut palms as a reference point occured (see Figure F). This makai increase in beach volume successfully concealed what boulders were previously exposed in the foreshore and swash zones of the 7/24 profile. Using the Mean Lower Low Water Datum (MLLW) provided by the National Ocean Survey Tide Tables (1974 and 1975) as a base of estimation, the overall volume of the beach increased during the mining operations.

Profiles of the three Kahaluu Beach stations are depicted in Figures G and H. Profile "C", the northernmost station on the beach, revealed no significant erosion. Morphological changes for the station were limited to relocation of runnels and ridges in the foreshore/backshore; estimated beach volume remained constant. Profile station "A" for Kahaluu constituted the only profile to reveal an estimated decrease in beach volume. The two profiles were identical except for a 2.75 meter shortening of the backshore area which was observed on the 10/28 visit.

Not indicated on Figure D of Kahaluu Beach was a small intermittent breakwater running from the shoreline at the southern park boundary to approximately 75 meters offshore of the profile station "C".

Horizontal underwater visibility estimates were recorded during each dive. Distances varied depending on previous swell conditions and the diver's position in the water column. The following estimates were taken on the bottom at the crater positions to attempt correlation between any turbidity and the recovery operations. On the 10/27 dive, underwater visibility approached 10 meters, presumably a response to the 8-10 foot NW swell which peaked out three days previously. Swells decreasing to four feet were recorded for the actual 10/27 dive. The maximum visibility observed on any of the dives approached 25 meters.

While in operation, the recovery of sand created some turbidity in the crater region bounded by the apex and one half the crater depth. Particle suspension above the crater rim was never observed by the OAS team although Maragos identified limited migration of suspended sediment during one diving visit (see photo).

A concrete relationship between sediment migration in or out of the test deposit boundaries and subsequent volume modifications of the onshore beaches could not be formulated based on the non-quantitative visual observations secured at the Keauhou test site. Such a statement could be made only when based on data collected from a longer monitoring program utilizing a more statistically valid approach to submarine sand movement. The use of radioactive sand tracers over a minimum of 12 months as described by Ingle (1966) would produce the desired significant data required of such statements.

At the Keauhou site, no appreciable submarine migration of sand was observed between the onshore beaches and the offshore deposit. It was noted that both beaches were at a minimum of 1.25 kilometers from the test site. Noticeable material transport over the full distance within the limited time of monitoring was assumed most unlikely.

CONCLUSIONS

A numerical rate of sand fill into the recovery craters was not determined on the basis of the data collected. Greater emphasis was placed on the patterns of sand fill into the individual craters with passage of time. Sand fill into the craters originated from a maximum of 15 meters from any of the crater's rims. This area of impleting sand was denoted as a sand migration zone. Such a zone was observed for each recovery crater.

By the final 3/15 observation dive, sand movement within the migration zone encompassing the largest conglomerate crater reached the original coral boundary of the deposit between survey stakes 2-4, or a limited section of 60 meters in comparison to the full 800 meter perimeter of the deposit. Previously buried coral fragments adjoining the original sand/coral interface at this location were exposed. The exposure was followed by a small undermining of the living coral boundary.

The overall process of crater adjustment was likened to the movement of sand in the upper chamber of an hourglass when released to the lower chamber. As crater diameter increased, rim circumference increased, and the total volume of sand migrating into the crater depressions increased logarithmically. It was predicted that, given enough time, sand would recede to varying degrees from every section of the deposit's coral perimeter. With further passage of time, an overall "softening" of the newly, sharp-edged recovery craters was observed.

Undermining of the original coral boundary was observed only in the section of coral edge bounded by survey stake locations 2-4. Survey stake #3 stood out as the area of maximum undermining activity, with a one meter decrease in sand level adjacent to the coral edge. Undermining came about in two steps. Buried coral fragments previously serving as foundation material to the existing live coral boundary were first exposed by sand

receding from the coral edge into the recovery depressions. This band of shifting sand was the sand migration zone described earlier. Secondly, after the shifting sand or migration zone transported the fragments a distance away from the coral edge, small amounts of live Porites compressa and Porites lobata, both found in the living coral boundary, were undermined and toppled onto the receding sand surface.

The localized undermining between stakes 2-4 was the most advanced stages of coral collapse observed a response to mining operations. Future undermining of the same intensity was not predicted for the remaining coral perimeter. The nearer the coral boundary to recovery depressions, the faster and more advanced the undermining activity; thus the predicted maximum coral edge damage at stake positions 2-4, which border the excavation area. ^{not} _{closely}

Beach profile observations indicated no significant erosion of either Kahaluu or Disappearing Sands beaches. It was finally ^{concluded} ~~assumed~~ that offshore sand mining and volume modifications of adjacent beaches could not be correlated based on the non-quantitative investigation method used. Such a relationship could be made only when based on data collected over a longer monitoring span in which a more statistically valid approach to measurement of submarine sand movement was utilized.

No appreciable migration in or out of the deposit boundaries of suspended or otherwise freemoving sand was observed. Water turbidity resulting from recovery operation was observed confined to the limits of each recovery crater. However, Maragos identified sediment suspension exterior to a particular recovery crater on one occasion.

It was concluded that equilibration of recovery craters formed by SSRS mining operations would eventually effect every section of the test deposit's coral/sand interface with some degree of sand shifting away from the original coral edge. The degree to which undermining proceeded was

predicted greatest at perimeter locations of least distance from the recovery depressions.

Future mining operations employing the SSRS technique are recommended to locate recovery positions as far away from existing coral boundaries as possible. The farther away from the boundary, the lesser the degree of crater wall slope and thus diminished the sand transporting ability of the migration zone. The greater the angle of repose into the recovery depressions, the greater the movement of coral fragments from beneath and away from the coral boundary; with subsequent intensified coral undermining a result.

It is suggested that a future radioactive sand tracer study be initiated to observe a setup of control craters dispersed in reference to a coral perimeter over various locations of a test deposit. Perhaps an average distance from which sand recovery no longer significantly effects a coral edge can be determined. Possibly ^{the} a same sort of standardized number can be formulated for the crater apex depth; a depth that when coupled with the safe distance from a coral boundary, will minimize undermining activity.

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Gratitude is extended to the following divers of the Offshore Aggregate Survey team for their expert diving assistance during the monitoring program:

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Pat Omeara
John Paul Jones

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Herb Mann
Robert Kim

Captn. Ed Bilderback, Jim Vansant, and the remaining crew of the Valiant Maid are heartily thanked for their constant professional help and encouragement. John Healy of the Hilo College Geography Department provided the cartographic equipment, lab space, and guiding expertise required for map construction.

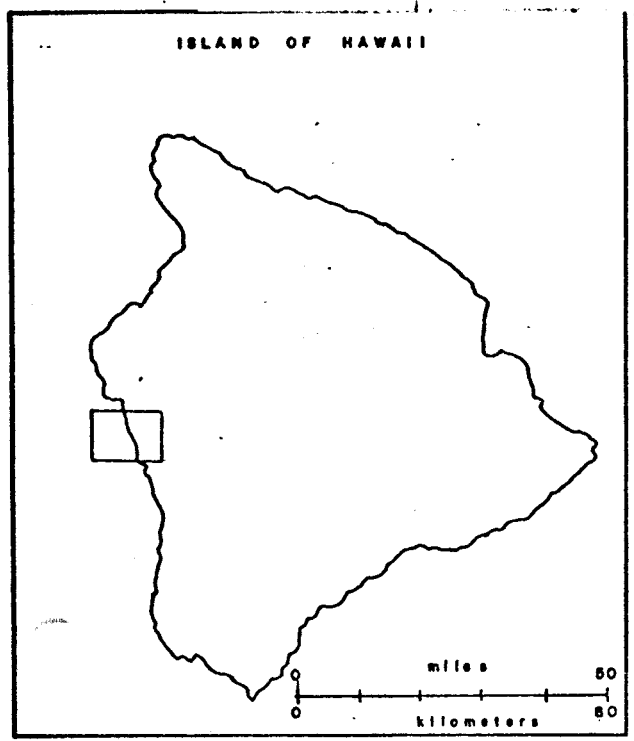
Final mahalo is given to Barry Hill and Chick Durbin, former Director and Hilo Coordinator of the Marine Option Program, respectively. Without the pioneering leadership and foresight of both individuals, the preceding "hands-on" learning opportunity would have never materialized.

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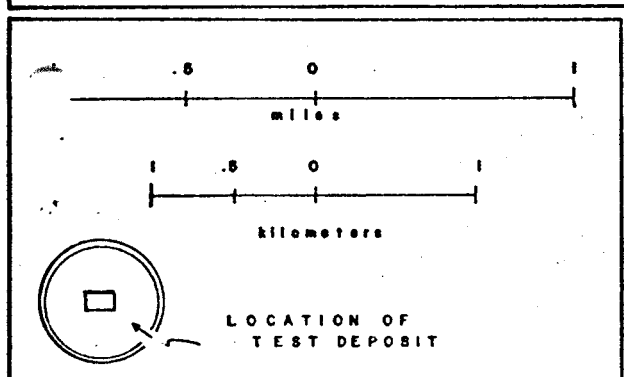
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master map #1

(2)



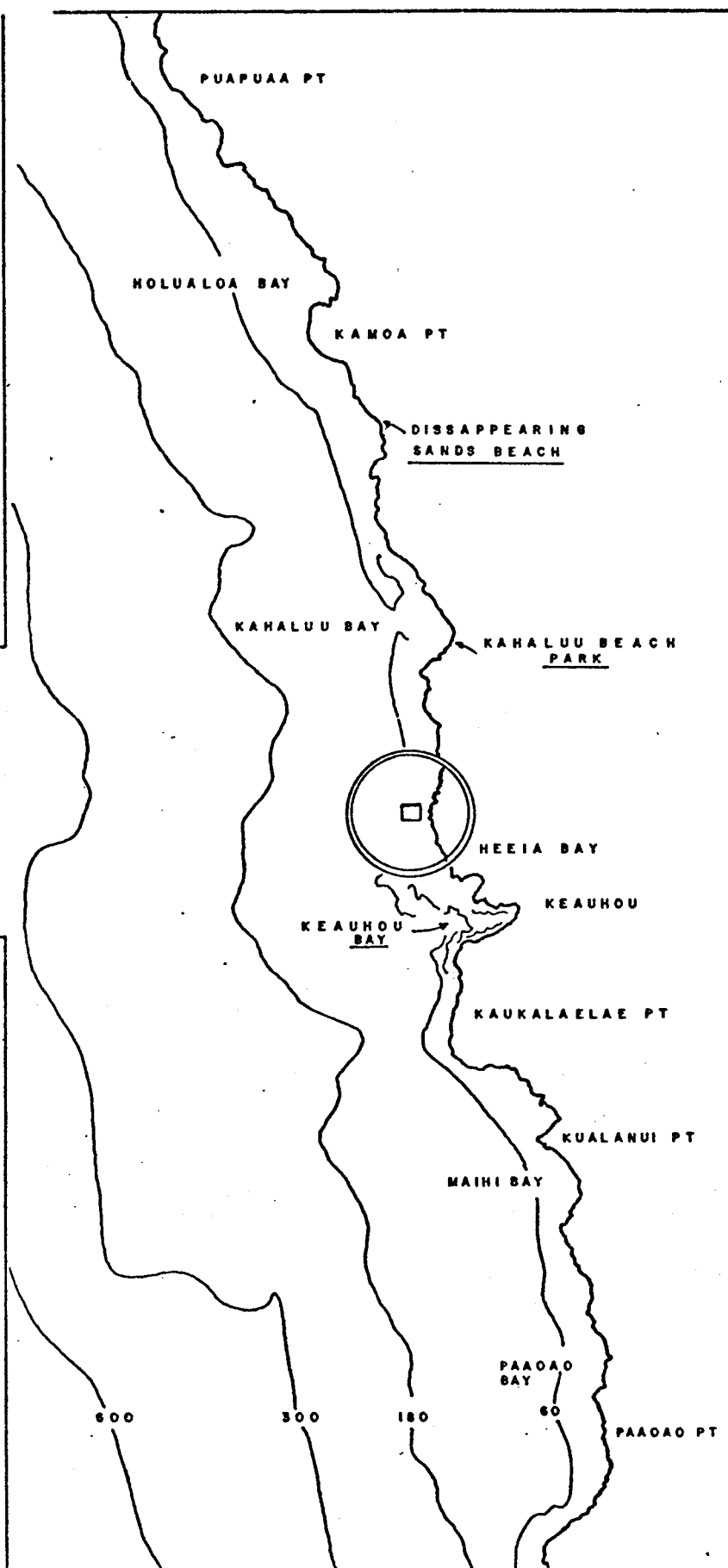
N
↑
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S



SUBMARINE SAND RECOVERY
SYSTEM TEST SITE

KEAUHOU BAY
ISLAND OF HAWAII

JON ROACH
1-17-75
HILO MARINE OPTION
PROGRAM



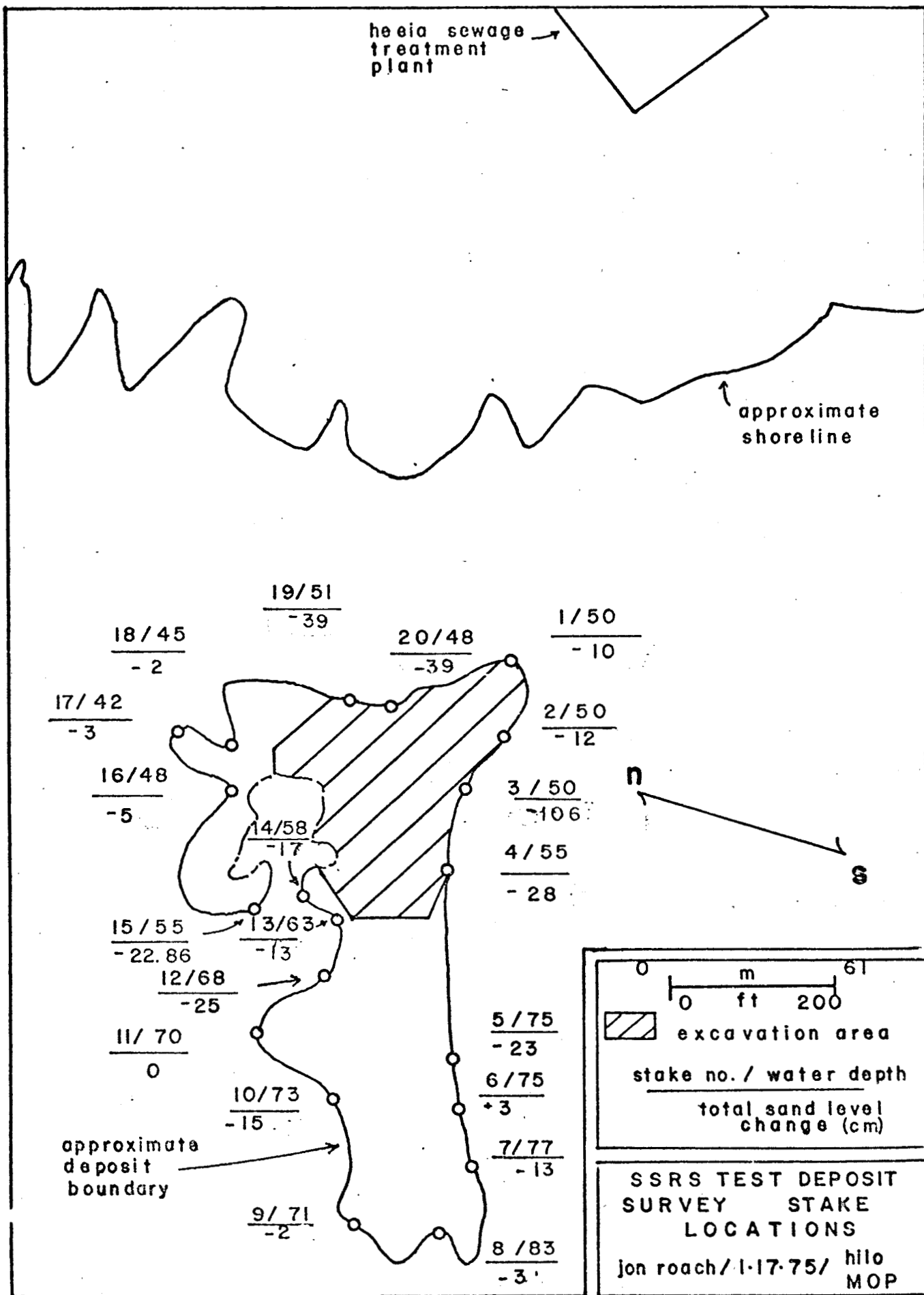


Figure A
(11)

Figure 1
(1111)

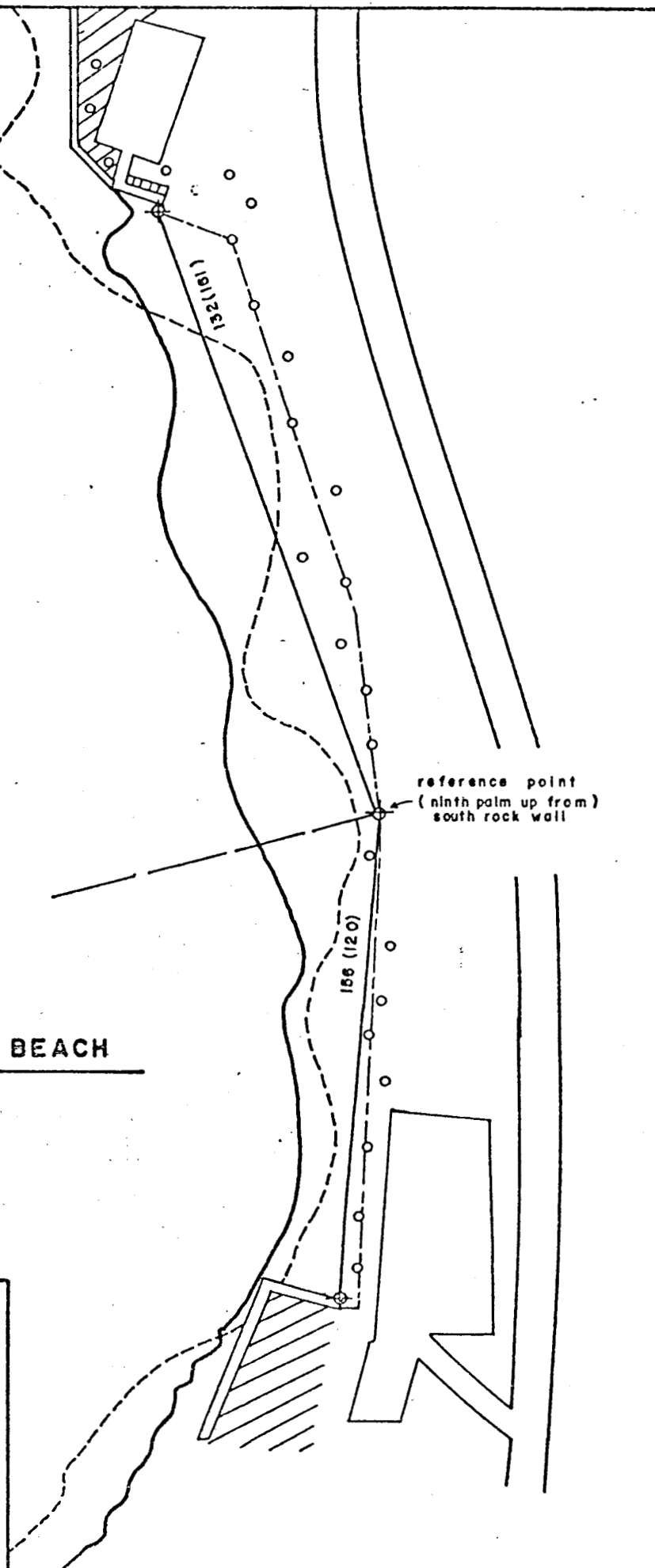


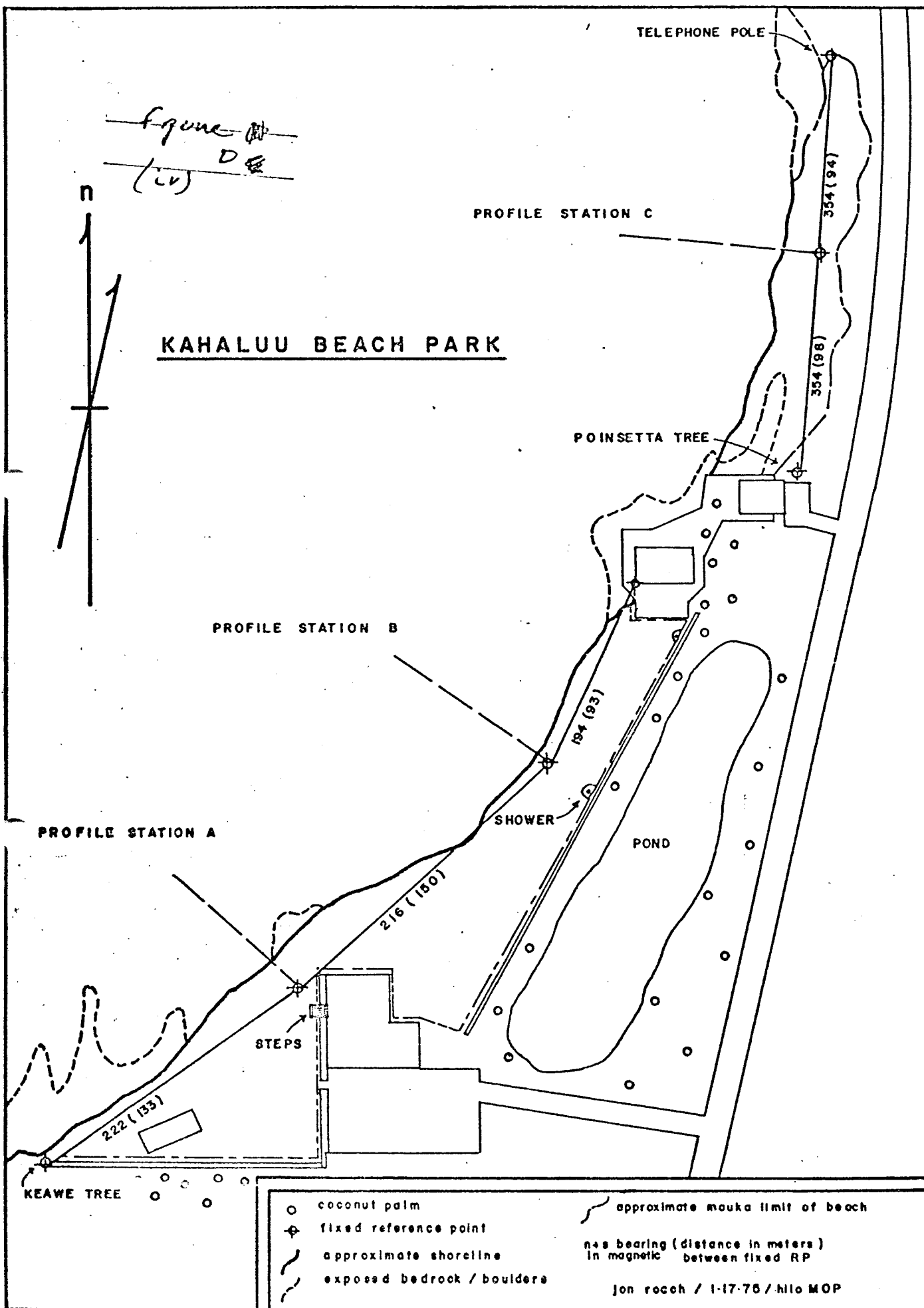
PROFILE STATION A

DISAPPEARING SANDS BEACH

- coconut palm
- ⊕ fixed reference point
- approximate shoreline
- - - approximate mauka limit of beach
- - - exposed bedrock / boulders
- magnetic (distance in meters)
bearing between fixed RP

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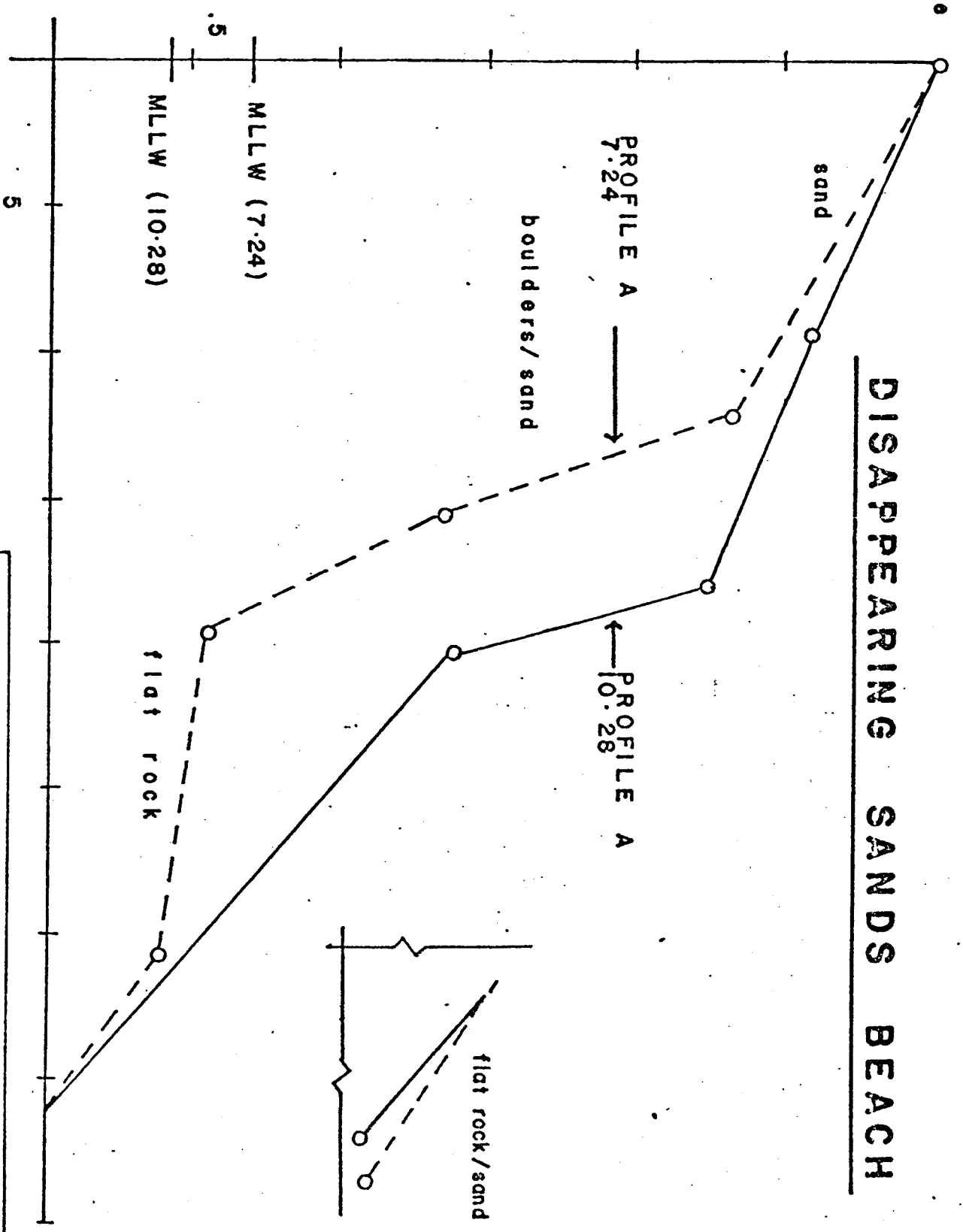


(5)
Figure 10

reference
point

SCALE · meters (vertical X 10)

DISAPPEARING SANDS BEACH



measurement
station
MLLW mean lower
1900 water

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KAHALUU BEACH PARK

SCALE: meters (vertical X 10)

reference point

PROFILE B

10-28

PROFILE A

7-24

PROFILE B

7-24

PROFILE A

10-28

MLLW (7-24)

.5

MLLW (10-28)

coral edge

5

○ measurement station
MLLW mean lower low water

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fig. 2-46

(v2)

KAHALUU BEACH PARK

SCALE · meters (vertical X 10)

reference
point

PROFILE C
7.24

PROFILE C
10.28

cobbles

MLLW (10.28)

MLLW (7.24)

5

5

○ measurement
station
mean lower
MLLW low water

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Figure 2
(vii) H

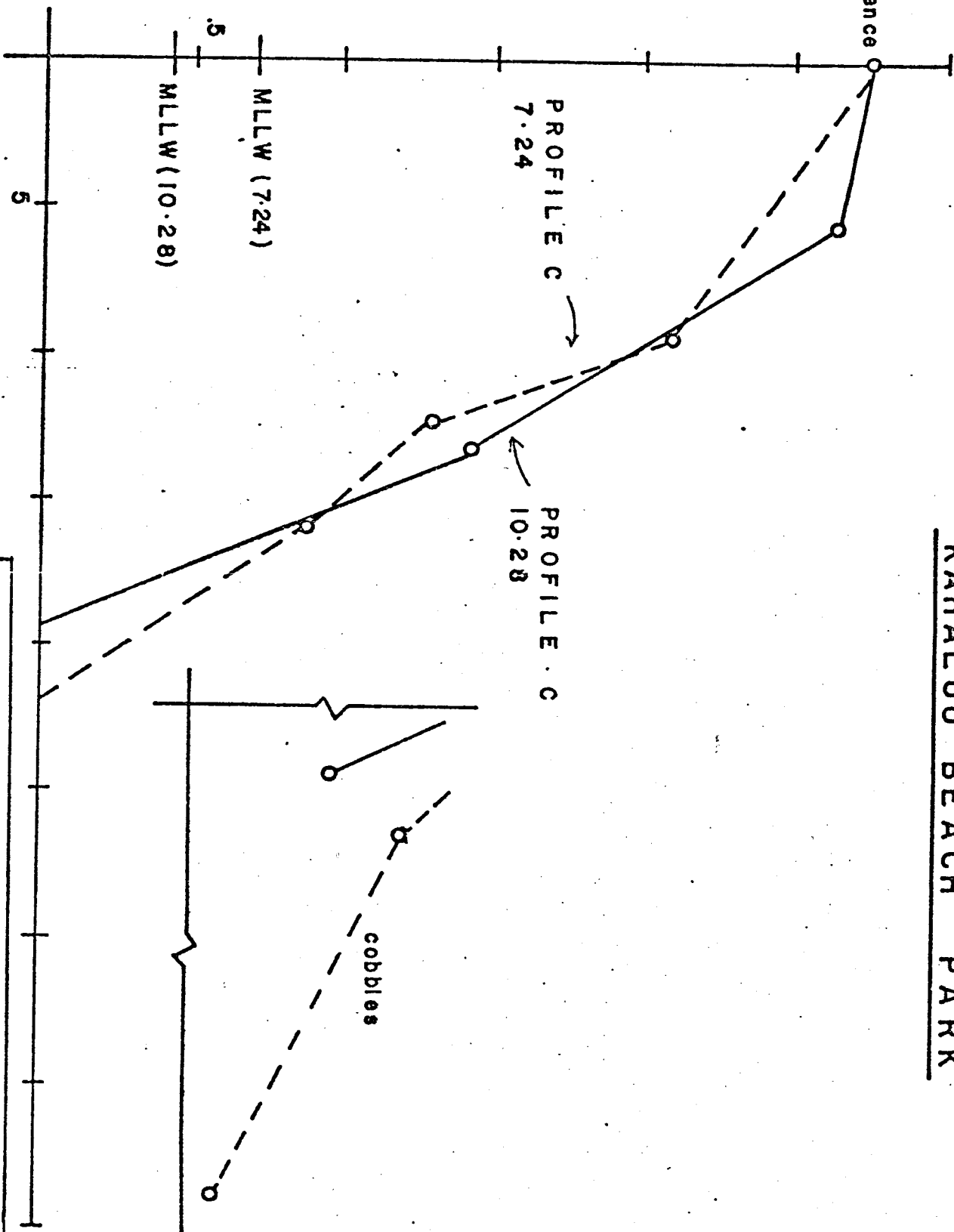


TABLE 1 : comparative survey stake measurements *

stake number	measurement on 9/10 dive	measurement on 9/21 dive	$\Delta 1$	measurement on 10/27 dive	$\Delta 2$	measurement on 3/15 dive	$\Delta 3$	$\Sigma \Delta$
(1)	132	132	0	127	+5	142	-15	-10
(2)	102	98	+4	104	-6	114	-10	-12
(3)	135	157	-22	221	-64	241	-29	-106
(4)	114	109	+5	114	-5	142	-28	-28
(5)	117	112	+5	-	-	140	-28	-23
(6)	135	137	-2	-	-	132	+5	+3
(7)	155	163	-8	-	-	168	-5	-13
(8)	88	91	-3	-	-	-	-	-3
(9)	84	81	+3	-	-	86	-5	-2
(10)	76	-	-	-	-	91	-15	-15
(11)	124	-	-	-	-	124	0	0
(12)	130	127	+3	-	-	155	-28	-25
(13)	84	86	-2	-	-	97	-11	-13
(14)	97	99	-2	-	-	114	-15	-17
(15)	76	81	-5	-	-	99	-18	-23
(16)	152	150	+2	-	-	157	-7	-5
(17)	157	163	-6	-	-	160	+3	-3
(18)	135	132	+3	-	-	137	-5	-2

* note: all distances measured in centimeters/ (-) value denoted level decrease/(+) value denotes level increase

TABLE 1 : comparative survey stake measurements (cont.)

(19)	124	127	-3	-	-	163	-36	-39
(20)	137	141	-4	135	+6	163	-28	-26

TABLE 2 : comparative horizontal
line measurements*

stake number	measurement on 9/10 dive (a)	measurement on 3/15 dive (a')	$\Sigma \Delta$
(1)	61	61	0
(2)	94	183	-89
(3)	30	43	-13
(4)	36	36	0
(5)	38	38	0
(6)	25	25	0
(7)	160	160	0
(8)	-	-	-
(9)	41	41	0
(10)	28	28	0
(11)	91	135	-44
(12)	152	152	0
(13)	38	38	0
(14)	18	18	0
(15)	15	15	0
(16)	51	51	0
(17)	38	38	0
(19)	50	50	0
(20)	30	99	-69

note : (-) value denotes sand movement away from the original boundary/ (+)
value denotes sand movement over and above original boundary

* all distances measured in centimeters