

Holocene Raised Reef Drilling at Kikai-jima, Central Ryukyus

No. 1

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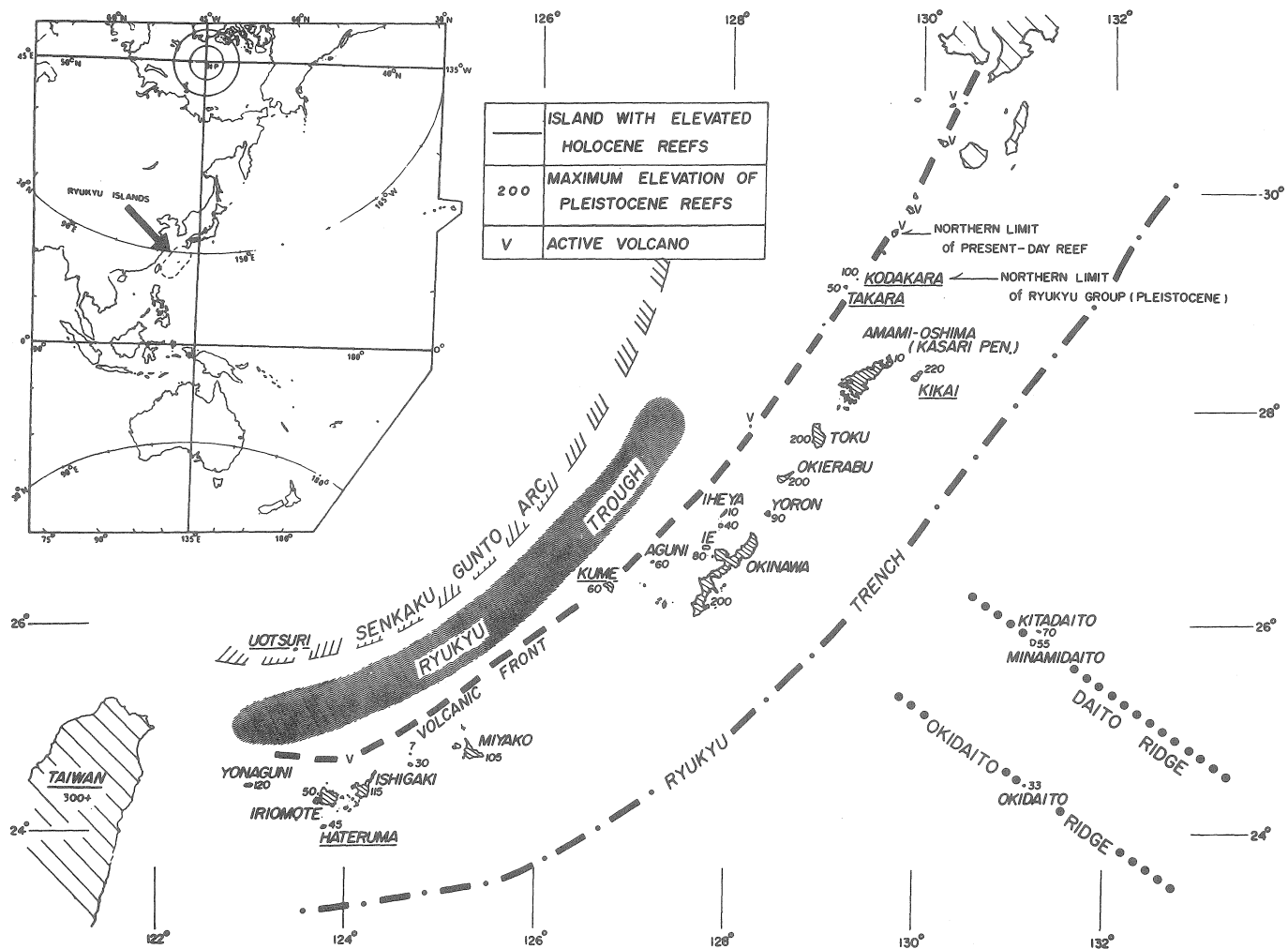
Abstract For the prime purpose to study three-dimensionally the anatomy and diagenetic history of a Holocene raised coral reef with respect to Holocene sea level change, 10 boreholes have been drilled along a traverse on a windward spur of the neotectonically uplifted fringing reef of Kikai-jima, Central Ryukyus in the fall of 1977 and summer of 1978. The location and other operational records of the drilling are documented in this interim report. A preliminary radiometric dating of hermatypic corals indicate that the Holocene reef forms a prism which ranges from 9.25 m to at least 20.20 m in thickness and has grown forward as fast as almost ten times of the vertical growth rate during Late Holocene. Chlorinity of the borehole water appears to correlate in gross with the present-day mineralogy of the matrix in the reefoid sediments. Submarine cements with stalactitic laminated crust in form are observed at a certain depth range in almost all the boreholes.

Introduction

A new approach has been undertaken in the Holocene reef stratigraphy to integrate surface observation with subsurface informations, both geological and geophysical: it provides better understanding of its three-dimensional context (Goreau and Land, 1974; Purdy, 1974; Adey and Burke, 1976; Easton and Olson, 1976; Macintyre and Glynn, 1976; Glynn and Macintyre, 1977; Macintyre, 1977; Davies *et al.*, 1977 and others). Careful studies of drilled cores from more than a single borehole are especially provoking discoveries in reef paleontology and carbonate sedimentology, hence remodeling some fundamental concepts of the reef stratigraphy.

Among the Holocene reefs fringing around the islands of the Ryukyus (Nansei shoto), the one at Kikai-jima (Lat. 28°19'N; Long. 129°56'E) makes an exception, as it has been subaerially exposed through tectonic uplift due to frequent "great earthquakes", which tend to be concentrated at the arc-trench gap of the Ryukyu Island-Arc

Text-fig. 1 Index map showing the geographic and geotectonic location of Kikai-jima, Central Ryukyus (Nansei shoto).

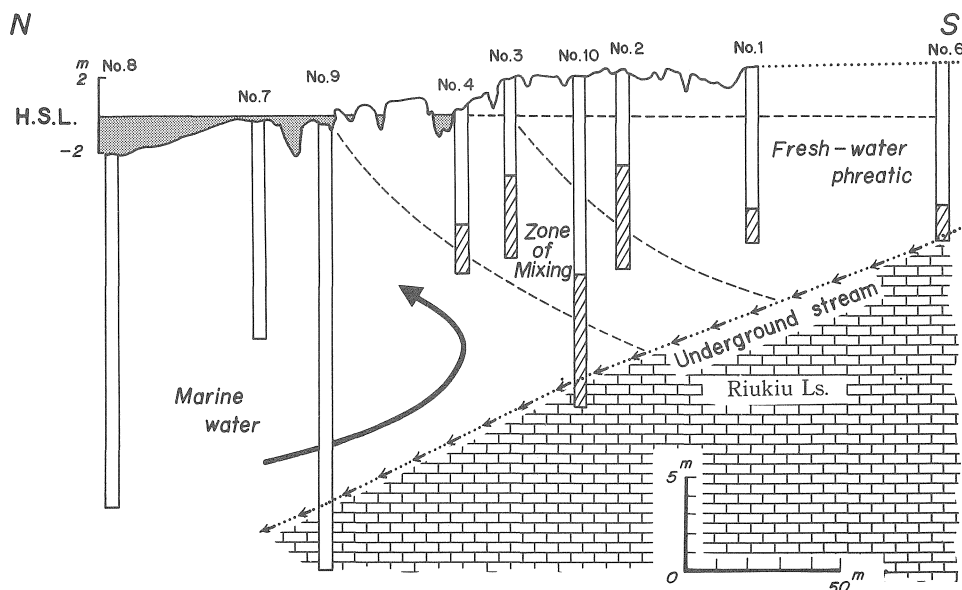


system (Text-fig. 1). Because of this geotectonically unique setting of the Holocene raised reef, the island has been studied by Konishi (Konishi, 1967; Konishi *et al.*, 1970; Konishi *et al.*, 1974) and others (Mii and Kigoshi, 1966; Nakagawa, 1969; Machida *et al.*, 1976) for more than a decade. The result of a geomorphological investigation from 1974 to 1976 was lately outlined by Ota *et al.* (1978) who documented the existence of four elevated Holocene terraces ranging from 6800 y. B. P. to 1500 y. B. P., citing 43 radiocarbon dates from them. Submarine geology off the island was surveyed under the proposal of Konishi by R/V TANSEI of the Ocean Research Institute, University of Tokyo in 1966 (Konishi *et al.*, 1970) and 1977.

Operation

Under these circumstances, 10 boreholes were drilled to recover core samples of the Holocene sequence as complete as possible along a traverse on a windward spur of the, partly emerged, fringing reef at northwestern coast of Kikai-jima. Drilling was operated by two crew members of Koken Drilling Industry Co., Ltd., with non-professional assistance by the students and Konishi of Kanazawa University. The operation took between October 15 and November 5 in 1977 and between August 4 and September 2 in 1978. The project was funded by the Grant-in-Aid for Scientific Research, Ministry of Education, Science and Culture, Japan (Grant No.249011).

Location of the 10 drilling sites at Nakakuma coast (Lat. 28°20'08"N; Long. 129°58'09"E) is shown on two aerial photos (Plates 1 and 2). As shown in Table 1 and



Text-fig. 2. Topographic cross section along the traverse at Nakakuma coast, showing the location and drilled depths of 9 boreholes (Nos. 1-4, 6-10). Interpreted subsurface geology and underground hydrographic condition are also schematically illustrated from the informations available at present.

Table 1. Drilling Statistics for Holocene Raised Reef Drilling at Nakakuma Coast, Kikai-jima.

Site No.	Date	Ground Elevation relative to H. S. L.* (m)	Penetration (m)	Recovery (m)	Depth of Thurber Discontinuity** (m)
1	Oct. 16—17, 1977	2.59	9.40	7.87	
2	Oct. 18, 1977	2.48	10.80	8.83	
3	Oct. 19—20, 1977	1.91	8.50	7.90	
4	Oct. 22, 1977	0.29	8.70	7.75	
5	Oct. 25—26, 1977	-0.95	5.50	3.25	
6	Oct. 28—29, 1977	2.76	9.50	6.00	9.25
7	Nov. 2—3, 1977	-0.32	11.50	8.05	
8	Aug. 10—14, 1978	-1.75	18.75	(14.25)	
9	Aug. 18—25, Sept. 1	-0.33	23.60	(17.35)	20.50
10	Aug. 26—29, 1978	2.11	17.65	(16.15)	16.00
		Subtotal in 1977	63.90	49.65	
		Subtotal in 1978	60.00	(47.75)	
		Total	123.90	(97.40)	

* 2.82 m above the mean sea level at Kagoshima Port on May 4, 1977.

** Holocene-Pleistocene boundary.

Table 2. Chlorinity and Temperature of Borehole Water at Nakakuma Coast, Kikai-jima (collected Nov. 10, 1977)

Well No.	Altitude of Water Level (m)	Time of Sampling	Depth of Water Sample (m)	Temperature (°C)	Chlorinity* (‰)
1	1.03	13 : 58—14 : 50	3.62	22.8	0.66
			5.50	22.2	0.85
			7.52	22.0	1.03
2	1.24	15 : 02—15 : 35	3.72	22.4	3.26
			4.70	22.4	3.35
			5.74	22.5	3.27
3	1.02	16 : 02—16 : 40	2.93	24.0	14.70
			4.30	24.0	15.26
			5.60	24.0	15.61
4	0.53	17 : 10—17 : 25	0.82	23.0	13.17
			3.50	23.0	13.38
			6.20	23.0	13.46
6	0.63	10 : 53—11 : 30	3.39	22.2	0.36
			5.00	22.2	0.37
			7.00	22.2	0.37
			7.00	22.2	0.42

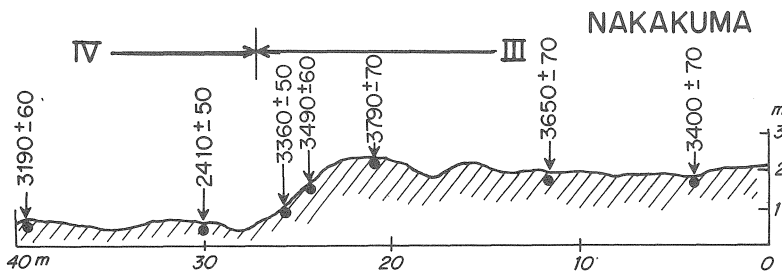
* Analyzed by Ms. S. Togashi (Kanazawa University).

Text-fig. 2, only three out of the ten holes have penetrated through the base of the Holocene sediments. Following to the drilling in 1977, 400ml of water were sampled by a specially designed sampler from three different depths of five boreholes (Table 2). Chlorinity of the water samples was measured with the conventional Mohr method by Ms. Sumie Togashi at Department of Earth Sciences, Fac. Sci., Kanazawa University. "Hatched bottom" of some boreholes indicated in Text-fig. 1 is "cave-in" fill observed during the water sampling.

Results

278 samples forming matrix of the cored reef sediments have been examined mineralogically by both Feigl solution-staining and X-ray diffraction methods. Low-Mg calcite content in the analyzed samples tends to increase towards fresh-water regime in negative correlation with chlorinity of the borehole water. This transformation of magnesian calcite from marine water to fresh-water via mixing zone and other diagenetic changes of the carbonate sediments, are being investigated extensively both petrographically and geochemically as supplemented by stable isotope analysis and SEM studies. A prominent development of laminated crustose cement composed of microcrystalline and submicrocrystalline magnesian calcite with very small amount of acicular aragonite, which is similar to that documented from Galeta Point fringing reef (Macintyre, 1977), has been observed in almost all the boreholes.

During the detailed field mapping at Nakakuma coast prior to the drilling, seven coral heads of autochthonous origin were collected from surface exposure along the proposed traverse. Their radiocarbon ages were dated with low-level liquid scintillation counter after benzene was synthesized from the coralline aragonite by Ms. M. Sato with the assistance of Mr. K. Igarashi. (Sato, 1978MS). These radiocarbon dates are listed below, together with that of a subsurface sample collected from the wall of a shallow water well near the drilling site No. 6. Notation of terrace classification in the list is after Ota *et al.* (Ibid.).



Text-fig. 3 Topographic cross section at Nakakuma coast, indicating the sample localities of radiocarbon-dated coral and the dates. Roman figures correspond to the terrace classification by Ota *et al.* (1978). Calculated with the half-life of 5730 years.

Sample No.	Taxa	Terrace	Elevation	^{14}C date
Shallow well	<i>Leptoria</i> sp.	II	1.80	4020 \pm 70
77051202	<i>Montipora</i> sp.	III	2.65	3400 \pm 70
77051204	<i>Favia</i> sp.	III	2.45	3650 \pm 70
77051206	<i>Favites</i> sp.	III	3.25	3790 \pm 70
77051207	<i>Goniastrea</i> sp.	slope	2.60	3490 \pm 60
77051209	<i>Favites</i> sp.	slope	2.10	3360 \pm 50
77051211	<i>Favites</i> sp.	IV	1.45	2410 \pm 50
77051212	<i>Goniastrea</i> sp.	IV	1.55	3190 \pm 60

Because of its great advantages as a non-destructive and timesaving measurement, the newly proposed ^{226}Ra - ^{238}U dating method (Komura *et al.*, 1978) has been applied to all the cored corals retaining original mineralogy of aragonite. The result of the coralline radiometry by this method shows a good agreement with the stratigraphic order in all the boreholes, except an apparently reverse stratigraphy at the middle portion of the hole No. 7 (Konishi *et al.*, 1978). While 3.5 mm/y is a bold estimate for the vertical growth rate, based on the scattered nine $^{226}\text{Ra}/^{238}\text{U}$ dates on hand, the radiocarbon dates suggest that the reef have accreted forwards as fast as almost 10 times of it (35 mm/y) during Late Holocene. As further radiocarbon dating is under way for all the cored corals, the result of the ^{226}Ra - ^{238}U dating will be reported else-

Table 3. Instruments used during the drilling.

Instrument	Model	Specification	Power Unit	Weight
Drilling machine	OP-1	Oil-feeding Spindle: inside-diameter 48mm Spindle-stroke 400mm Torque 23kg/min. Thrust 1300-1600kg Size: H1280 x W 682 x L1155mm	Motor 7.5ps	448kg
Water pump	MG-5h	Single reciprocating piston pump Delivery head 25-60kg/m ² Delivery capacity 25-60l/min Suction hose 38mm Delivery hose 32mm Size: H 675 x W 465 x L1630mm	Motor 5.5ps	209kg
Tripod (Tower)	6.5m high	Steel pipe 3"		(300kg)
Boring rod		Outer-diameter 40.5mm		13.3kg/3m
Core tube	Single	Outer-diameter 84.0mm Inside-diameter 77.0mm		20.8kg/3m
	Double	Inside-diameter of set bit 72.0mm* Outer-diameter 85.0mm*		
Bit	Metal-crown (W-carbide alloy)	Outer-diameter 86.0mm		
	Diamond	Outer-diameter 86.0mm Inside-diameter 72.0mm		

(as reported by Koken Drilling Industry Co., Ltd.)

* 59.2mm and 40.0mm, respectively, for the bottom 5.7m of Borehole No.9.

where together with the ^{14}C ages for the same specimens.

Acknowledgments

This is the interim progress report of the Holocene Raised Reef Drilling Project at Kikai, 1977-78. Results of our works on specific subject will appear in other journals as well as the future issues of this publication. Grateful thanks are extended to the Ministry of Education, Science and Culture for the support of the project, and also to the Koken Drilling Industry Co., Ltd. for the challenging effort to bridge between academic and commercial interests. A. Akagi, Y. Mizoguchi and Y. Setoue were technicians in the field.

Radiocarbon dates cited in this report were determined by Ms. Michiko Sato at Low Level Radioactivity Laboratory, Faculty of Science, Kanazawa University under the supervision of Professor M. Sakanoue and Konishi, as a partial fulfillment of senior thesis. Dr. K. Komura of the same laboratory kindly ran the $^{226}\text{Ra}/^{238}\text{U}$ dating of the cored corals. Thin sections and slabs of the core samples were prepared by Mr. S. Kasashima ; graphic illustrations were done by Mr. K. Nakamura.

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PLATES

Plate 1 A vertical aerial photo showing location of 10 drilling sites at Nakakuma coast, northwestern Kikai-jima ; tide was low. Photoed by the Pacific Aero Survey Co., Ltd. at 10 : 26 on June 6, 1968.

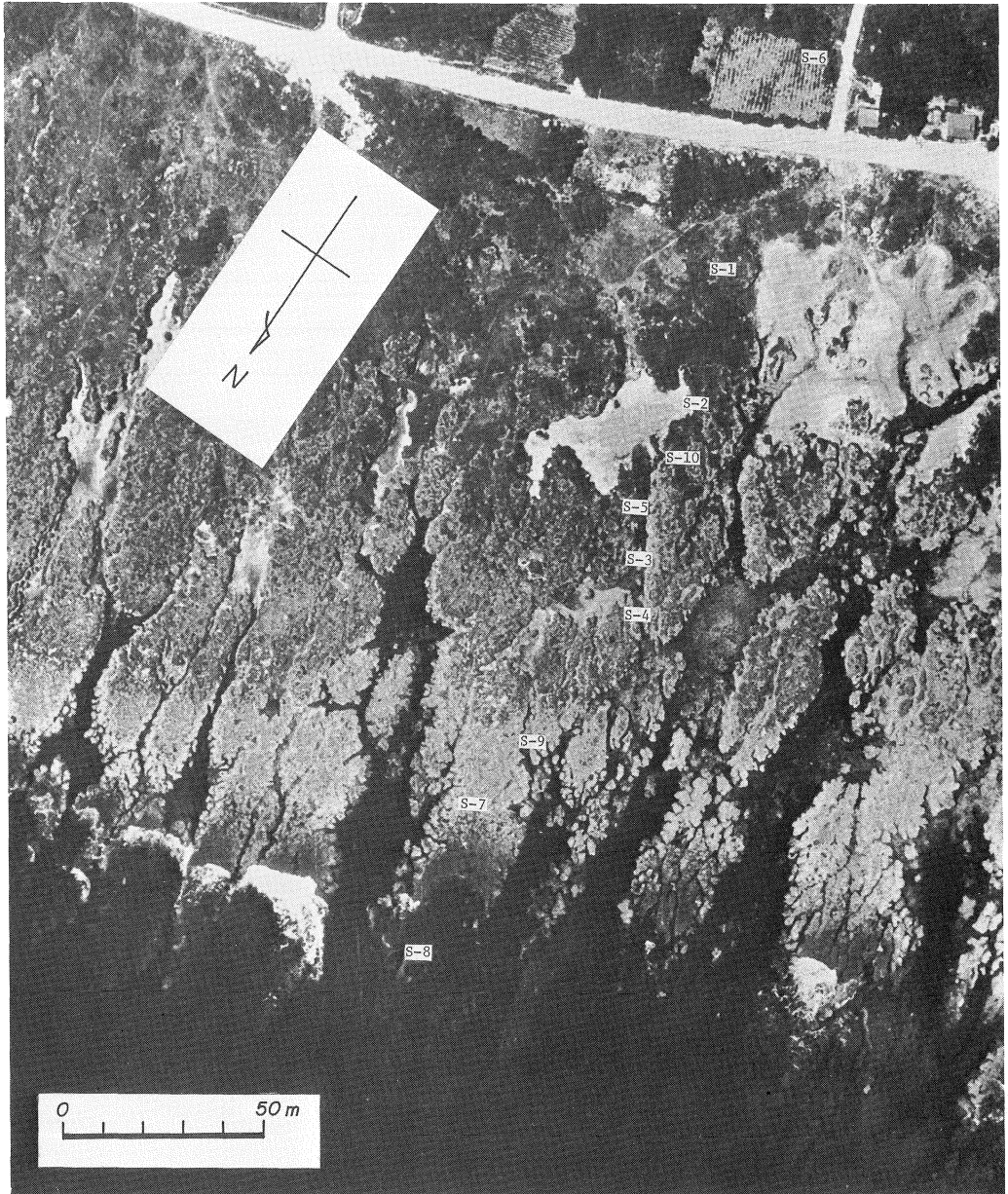
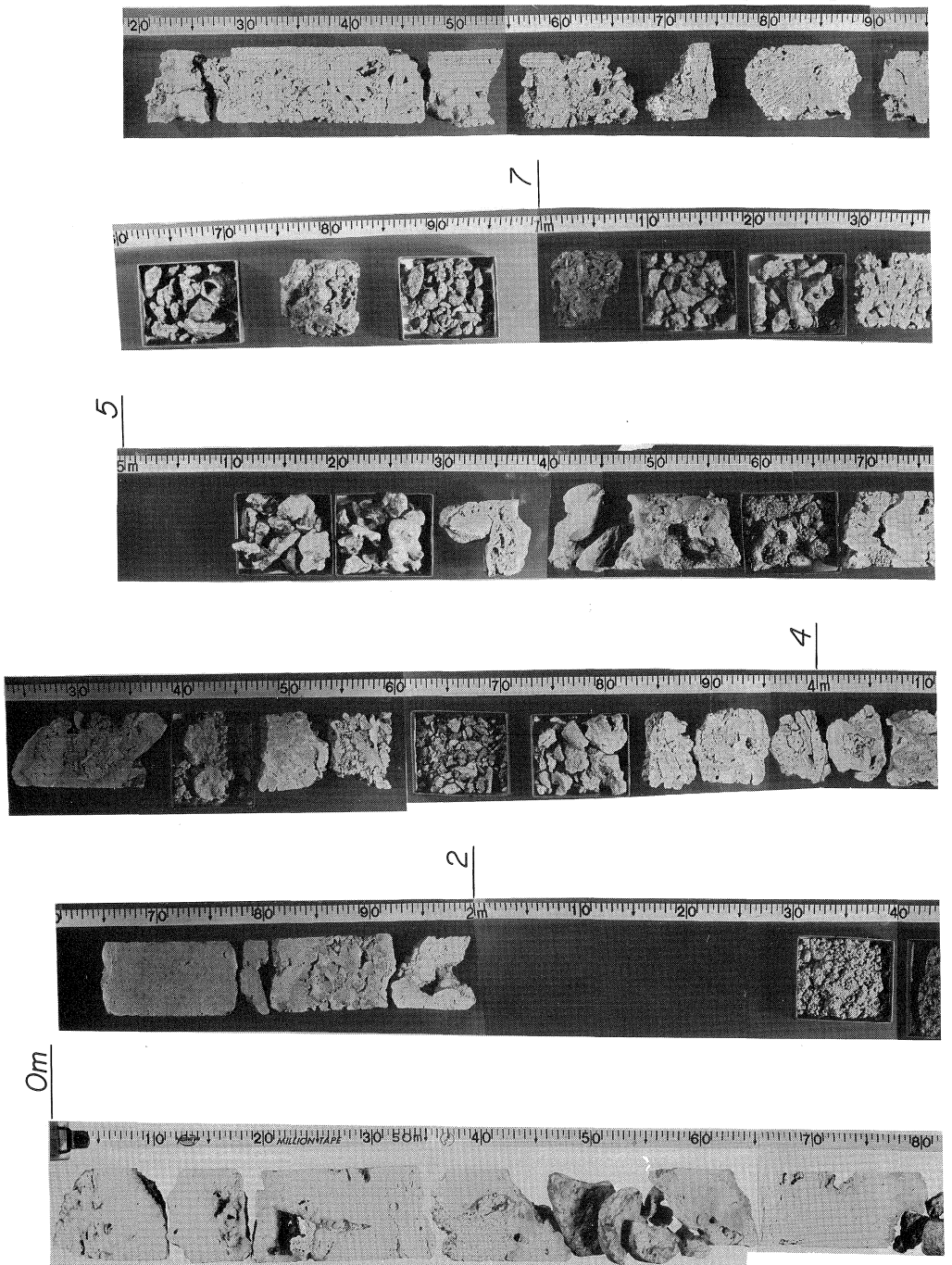


Plate 2 An oblique aerial photo showing location of 10 drilling sites at Nakakuma coast ; tide was high. Compare with the vertical aerial photo of Plate 1. Photoed by Y. Tsuji from a helicopter at 15 : 40 on November 7, 1977.



Plate 3 Photographs of Borehole No. 1 Cores



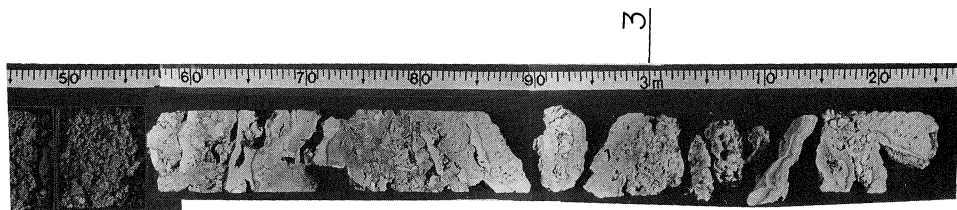
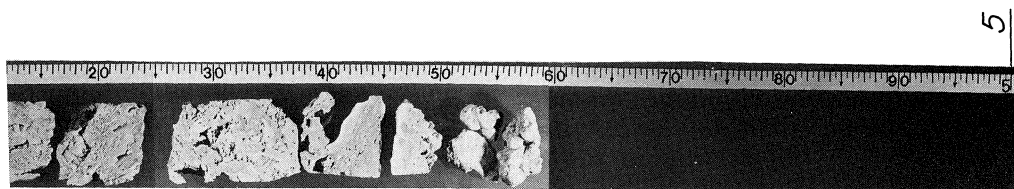
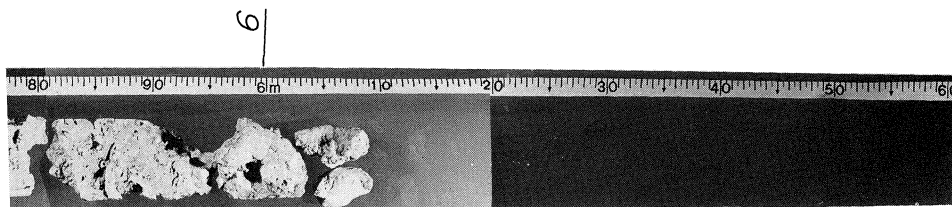
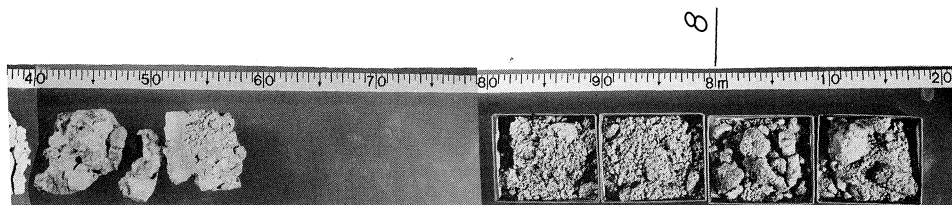
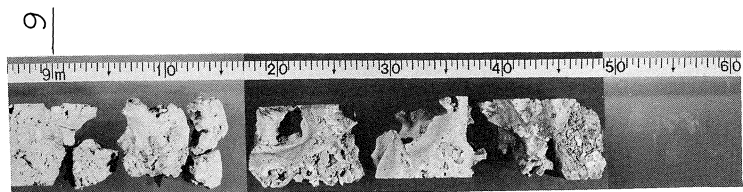
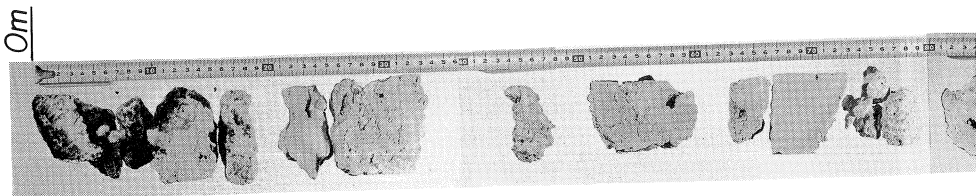
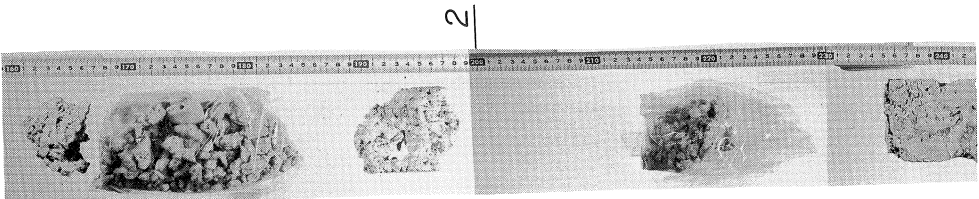
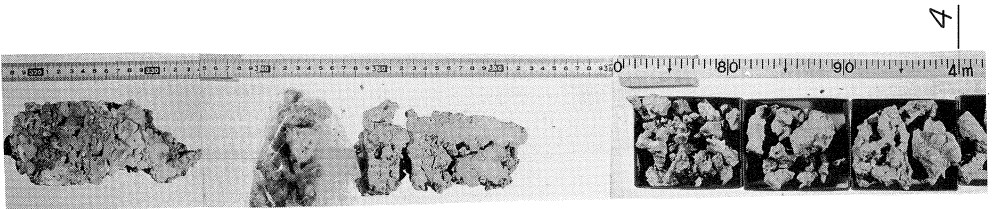
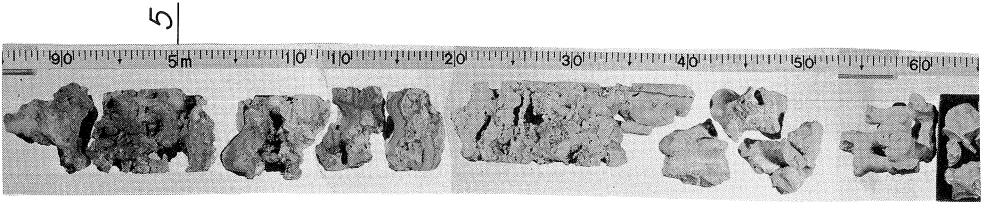
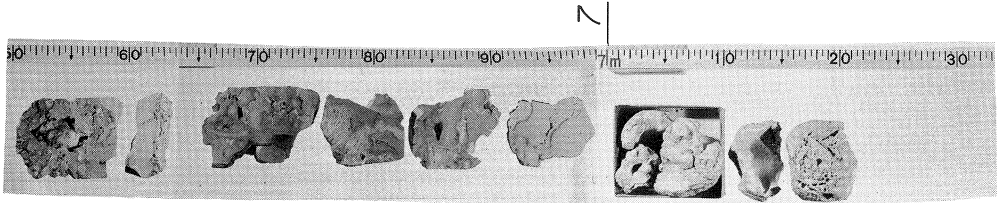
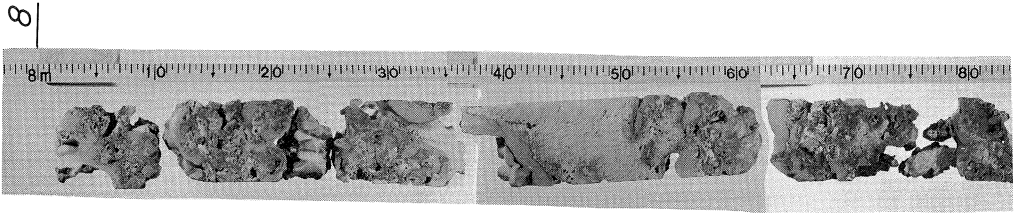
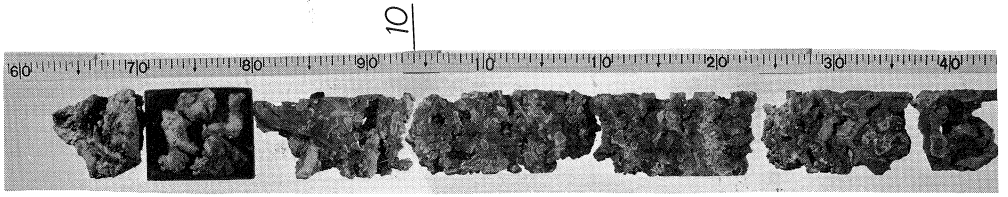
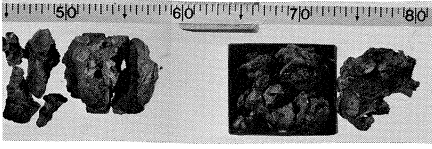
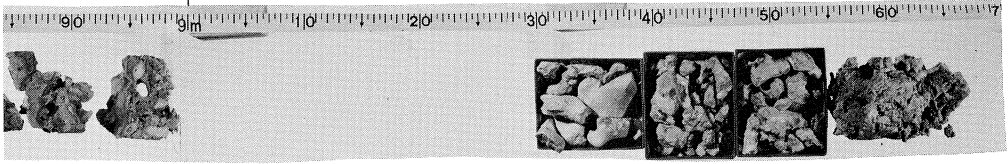


Plate 4 Photographs of Borehole No.2 Cores

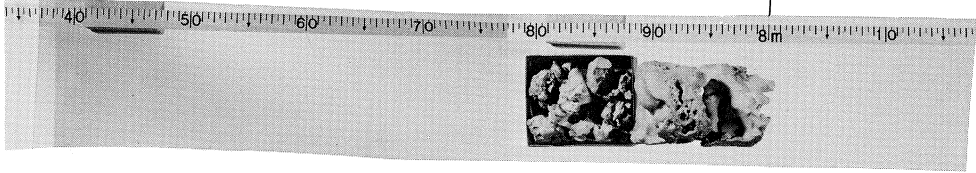




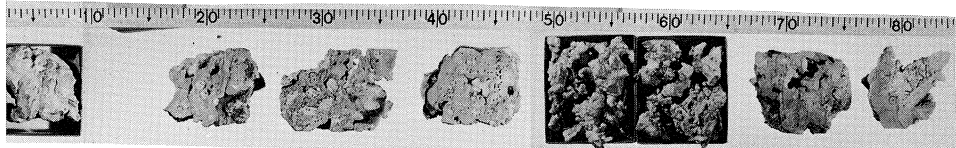
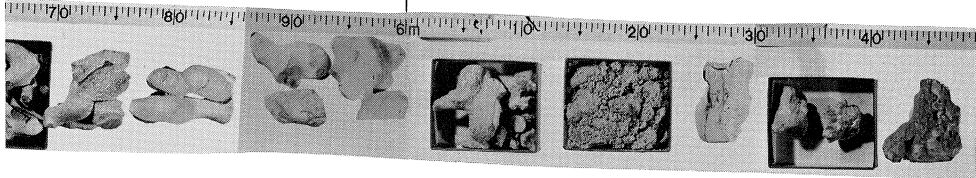
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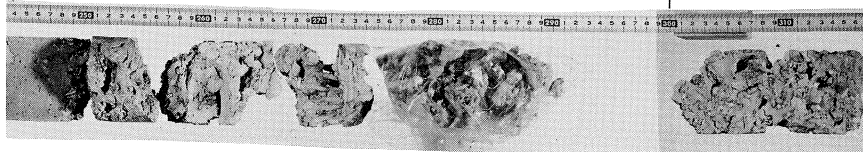
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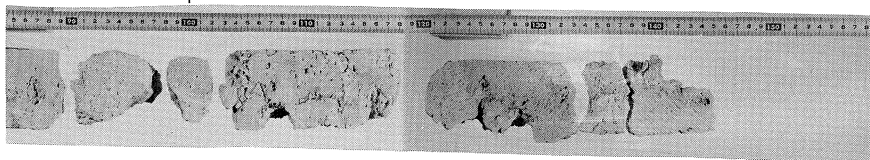
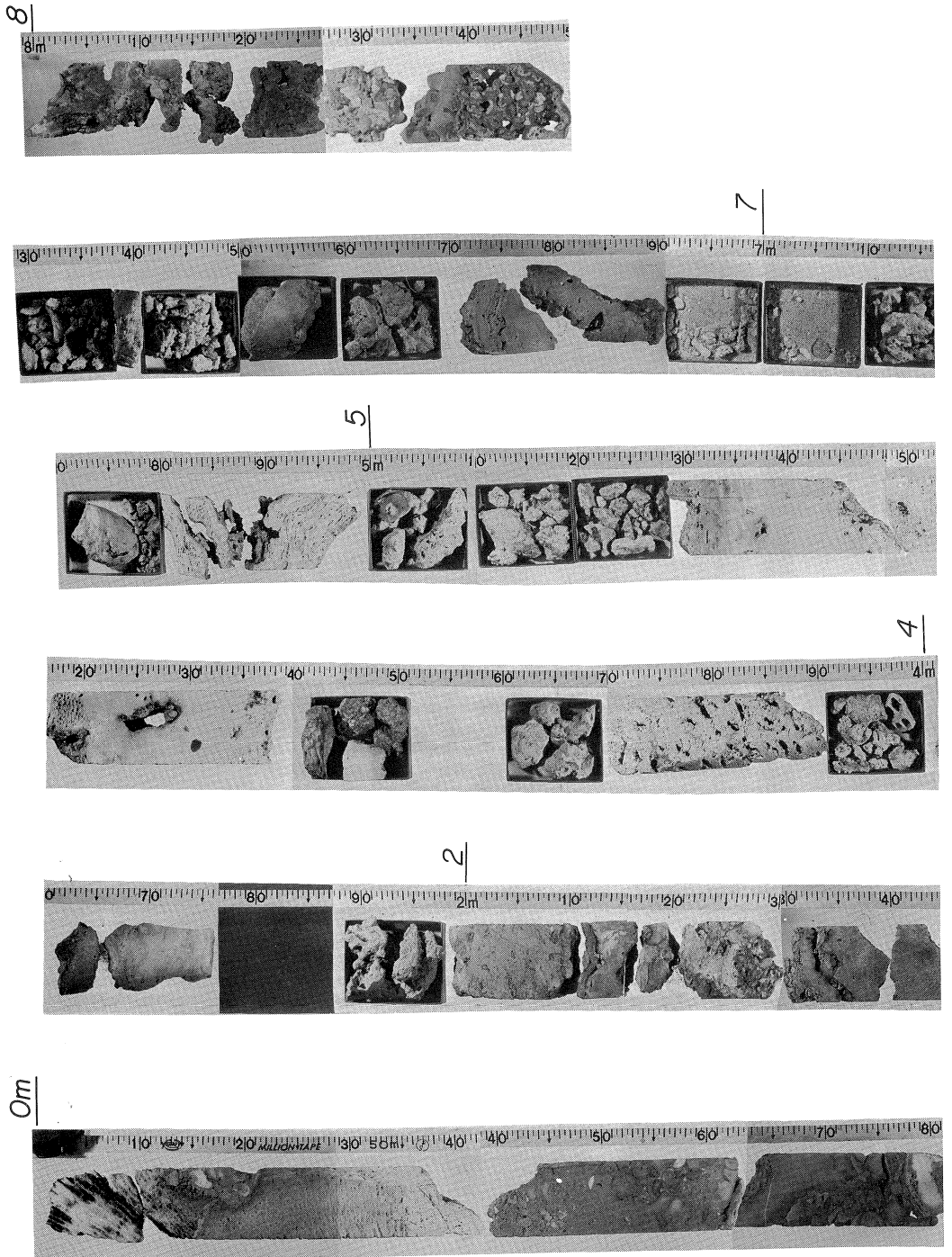


Plate 5 Photographs of Borehole No.3 Cores



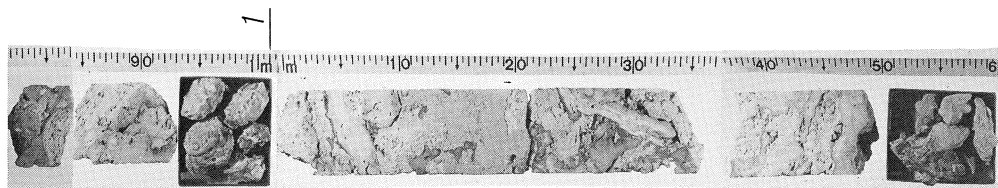
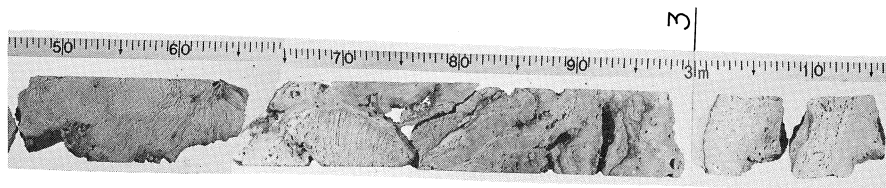
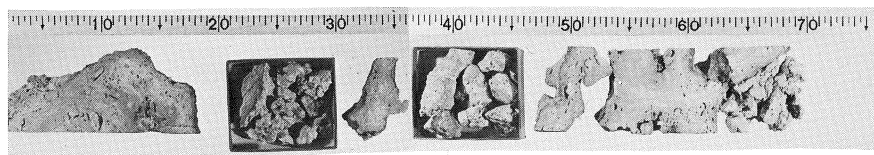
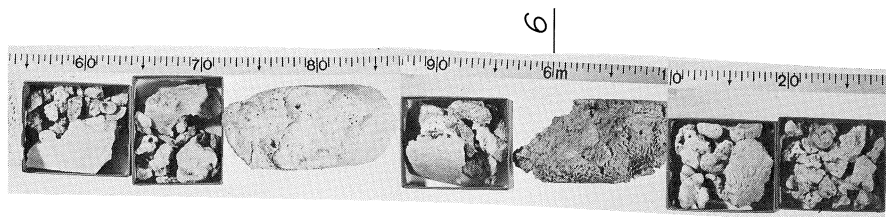
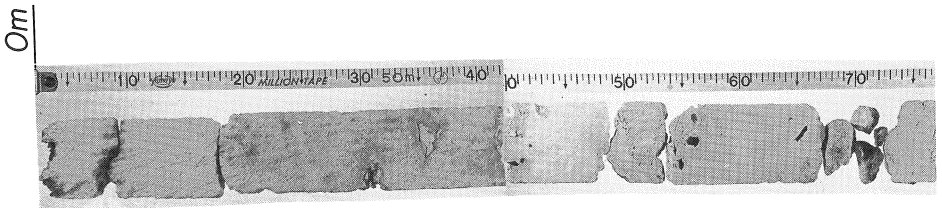
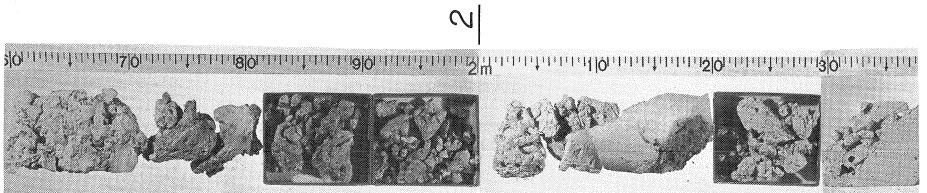
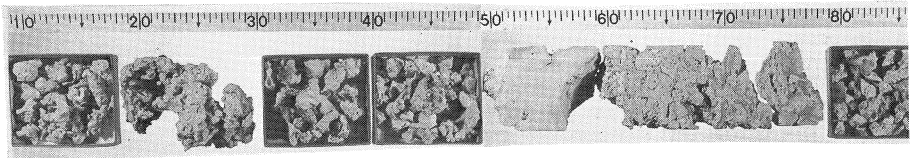
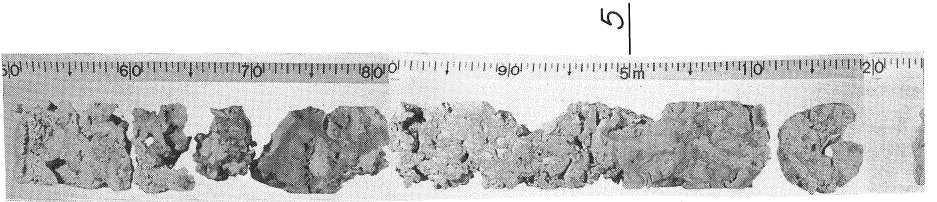
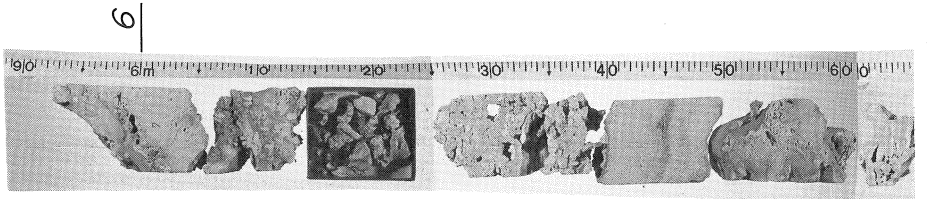
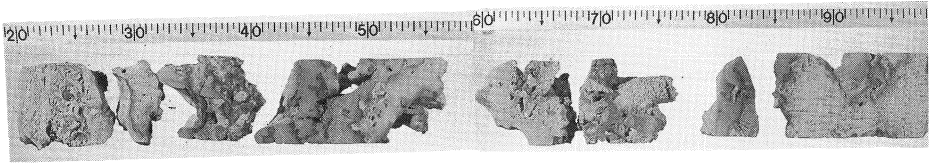


Plate 6 Photographs of Borehole No.4 Cores



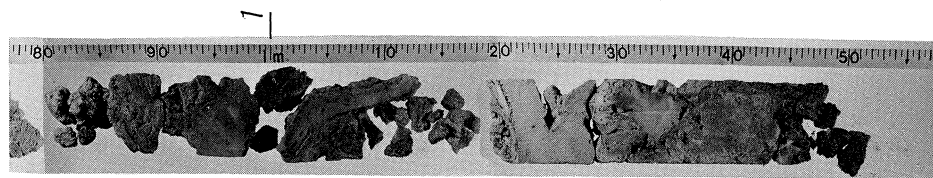
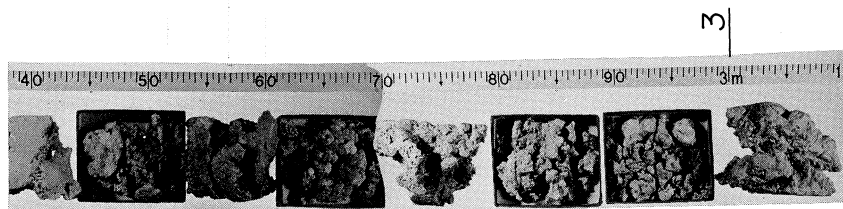
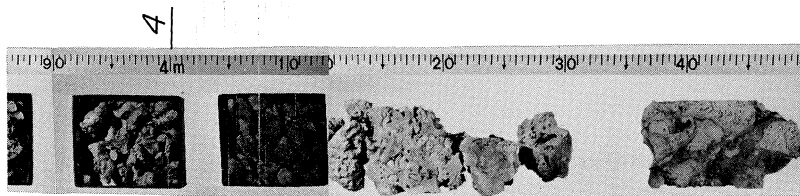
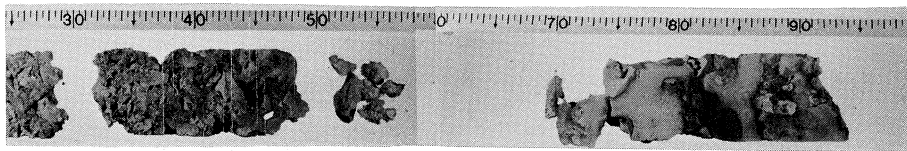
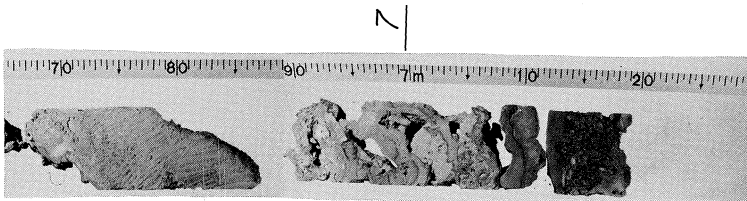
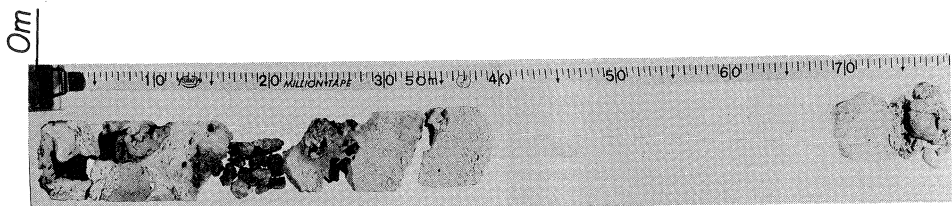
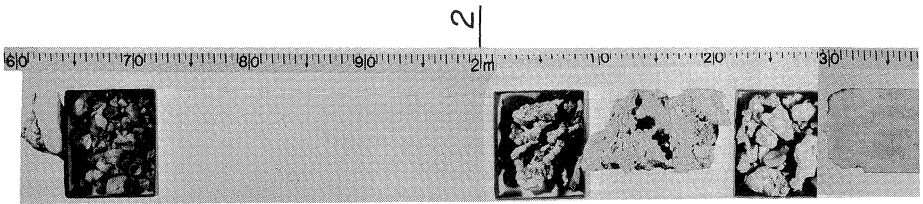
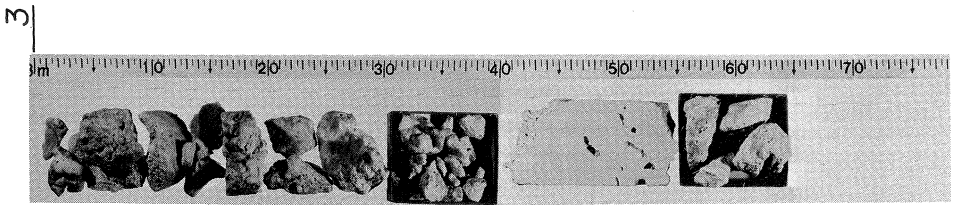
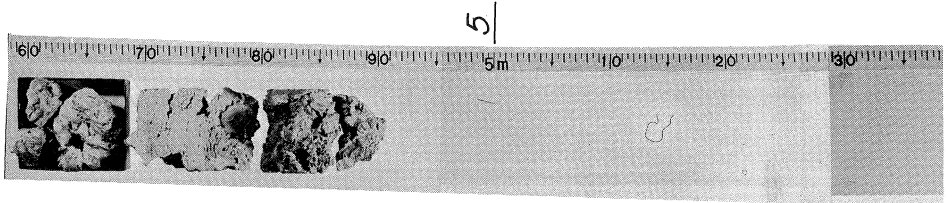


Plate 7 Photographs of Borehole No.5 Cores



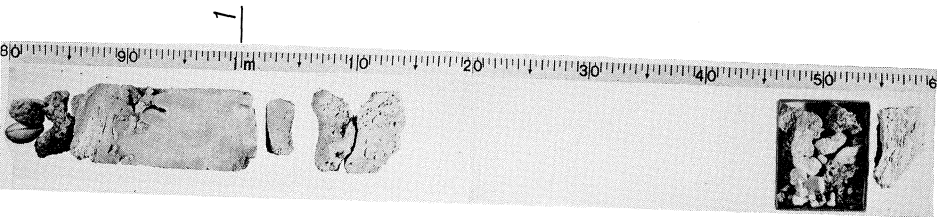
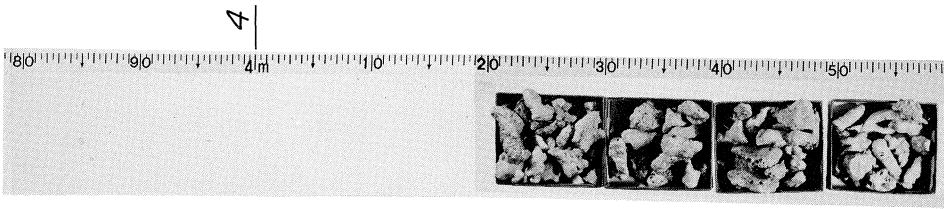
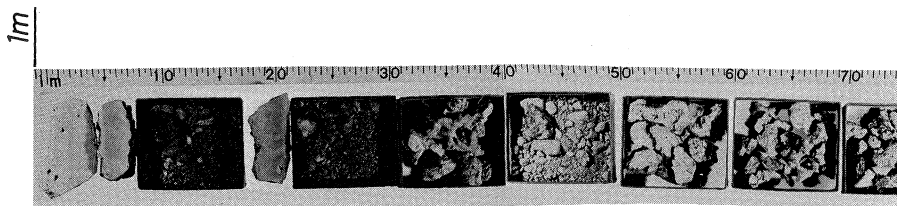
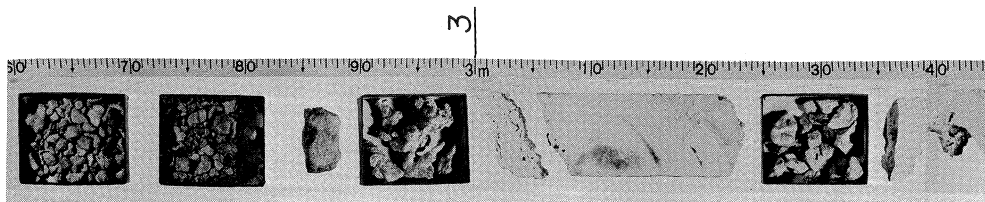
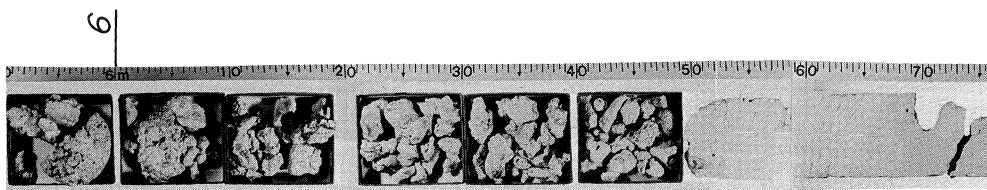
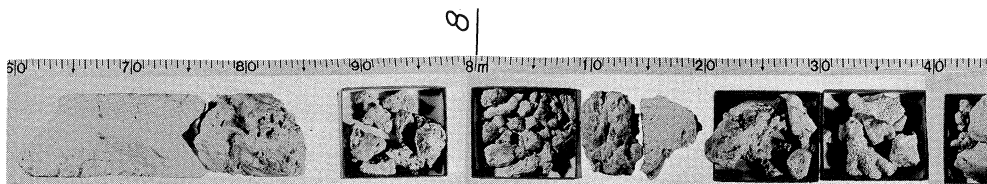
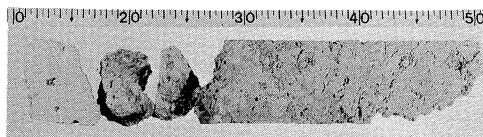


Plate 8 Photographs of Borehole No.6 Cores



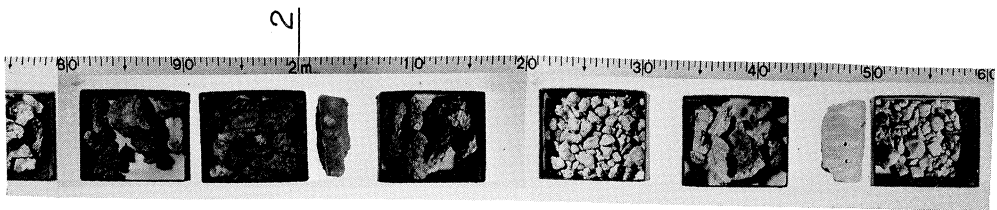
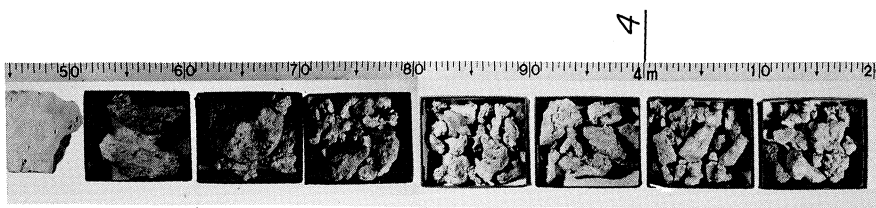
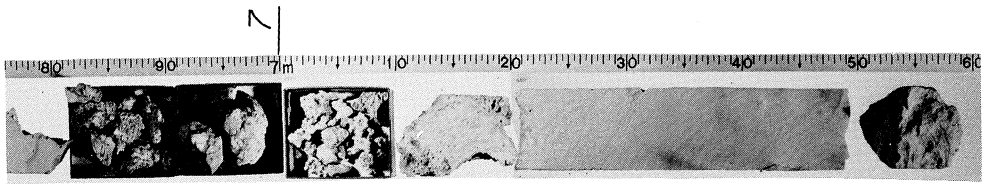
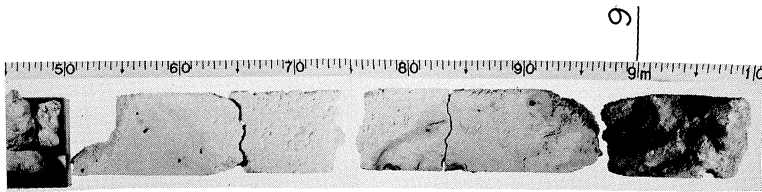


Plate 9 Photographs of Borehole No.7 Cores

