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Studies on Alluvial Sediments in Hiroshima Prefecture, No. 2

By

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With 4 *Tables and* 16 *Text-figures*

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ABSTRACT: Studies on the relation of some fundamental constants taking part in soil mechanics to the quantities and qualities of several species of the clay minerals involved in the sediments concerned have been commenced. A part of the results obtained from the present work, to a certain extent, manifest the ascription of the mechanical constants determined on an average for the mixed specimens to their mineralic contents beside the other factors adopted ordinarily after the rule.

CONTENTS

I. INTRODUCTION

The estuarine deposts composing the coastal plains have been subjected commonly to soil mechanics based merely on their mechanical diagnoses almost regardless of the constituents but relatively seldom to the research combined with the geologic environments including the mineralic or mineralogenic factors. That the measures obtained in the former case, even though straightened statistically, are apt to scatter in value is to be ascribed either to random aggregation of various materials with the characters distinguished substantially from one another in spite of their values for several constants defined after the rule, e. g. JIS or to impossibility of sampling in the ideally similar condition undisturbed from the original state.

Nevertheless, the prior work carried out by the present writer under the same heading has also offered nothing other than a few data outlined on stratigraphy of the alluvial sediments in connection with qualitative relation of the clay minerals comprised in the cohesive deposits and with their plasticity concerning the specimens collected from the sea-bottom of several areas along the Seto Inland-sea in Hiroshima Prefecture and in Iwakuni Bay.

Referred to the recent works made public by some authors, the ratios determined semi-quantitatvely for respective clay minerals in the related sediments, the rôle of their particle size and their absorptivity for certain ions or salts, some of the important factors having influence on the mechanical properties, will hereunder be discoursed with use of the specimens quite similar to those disposed in the former report.

Acknowledgement: The writer is sincerely greateful to Dr. Yoshiharu UMEGAKI, Professor of the Institute of Geology and Mineralogy, Hiroshima University, under whose invaluable guidance these works have been brought about and are now in progress. Much thanks are similarly to be expressed for helpful suggestions given by Professor S. IMAMURA, Assistant Professors A. HASE and T. HIDE, Assistants M. NAKANO and A. SOEDA and Messrs. T. ONO and T. OGAWA, the graduate students, of the same institute, for various facilities presented by Mr. T. SUGA, Assistant of the Institute of Chemistry of the same university, for accommodation afforded by Messrs. Y. MATSUMURA, Head of the Reconstruction Office of Chūgoku and Shikoku Branch and Y. SEGAWA, Chief of the same office, and for fruitful assistances yielded by Messrs. S. ASHIWA, A. MATSUURA, K. MIYAHARA and some other members, Section of Geological Survey of the same office.

II. RELATION OF RELATIVE QUANTITIES OF THE CLAY MINERALS INCLUDED IN THE COHESIVE SEDIMENTS TO THEIR MECHANICAL PROPERTIES

X-ray diffraction methods developed by some authors (cf. JOHNS et al., 1954; OINUMA et al., 1959; GRIFFIN, 1962) for quantitative analysis of the clay minerals are considered not freed from some difficulty in practical use owing to interposition of the impurities and ill crystallinity of the specimens on hand. Hence, 30 mg of the specimens confined to less than 5μ in grain-size through precipitation procedure have, after mixed with 5 mg of fluorite standard, been dispersed in drops of water within the definite area (2.5 × 1.5 cm^2) on the slide-glass in order to obtain the intensity of reflection as strong as possible and to hold the similar condition in each test, dried up in the air, and then ordinarily provided for x-ray diffraction.

The spacings at 15～14 Å, 10 Å and 7 Å represented respectively by montmorillonite, chlorite, illite and kaolinite have, though different in the intensity ratio, been recognized in the resulted patterns for all the specimens. The quantitative ratios of the clay minerals in question have been estimated mainly from each totalized area of intensity for reflection of (001). In the case of illite coexisting with montmorillonite and chlorite, the specimen has been treated with ethylene glycol or heated at 300°C to discriminate its spacing at 10 Å from the latter two. Intensity for kaolinite including certain amounts of chlorite has, because of the

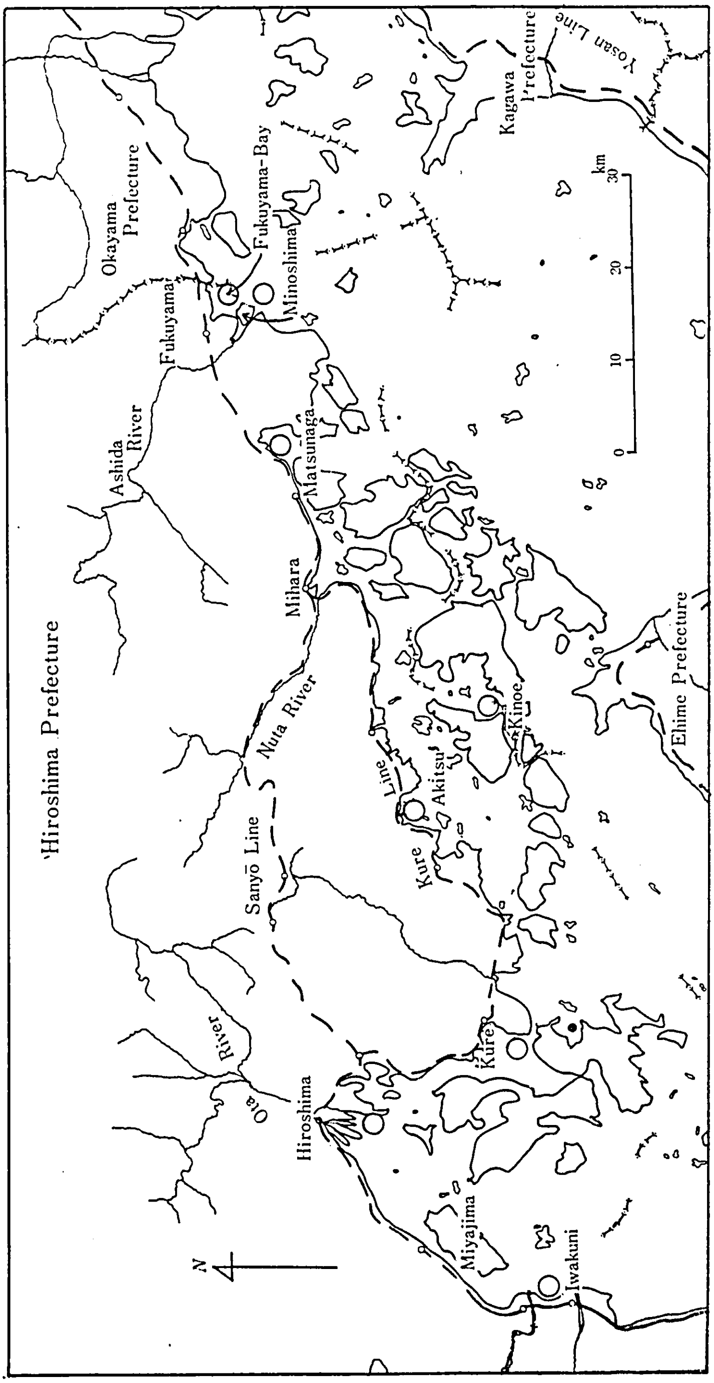


FIG. 1. Locality map

overlapping at 7 Å with that for latter, been calculated on the basis of 3.0, the average ratio of intensity for (001) to that for (002), given by OINUMA et al. (1962) for the specimens obtained from Tokyo Bay. On the other hand, montmorillonite, chlorite, illite, and kaolinite in the same quantity are reasonably considered to bear the ratio 2.6 : 0.5 : 1.0 : 1.2 in diffraction intensity, and their amounts are therefore to be derived reversely from the intensity values divided by these numbers respectively. Taking into account of this and of difficulty in sampling of the pure specimens, there has been no alternative but to follow the way mentioned above in estimating the quantitative ratio of the clay minerals, each value of which has been expressed in percentage for the total.

As the mechanical properties of the specimens collected from the boreholes of some localities, as are mapped in Fig. 1, the grain-size distribution, hydration ratio at the natural state, liquid limit, plasticity limit, void ratio and ignition loss resulted from the content of water and organic matters will be referred to hereunder.

(1) Specimen No. 3 from IWAKUNI

The specimens classified formally into "sandy silt" from their compositions of 15.2~16.8% sand, 62.3~71.6% silt and 12.0~22.5% clay have been collected from the depth of -7.5~-26.00 m under the reclaimed land.

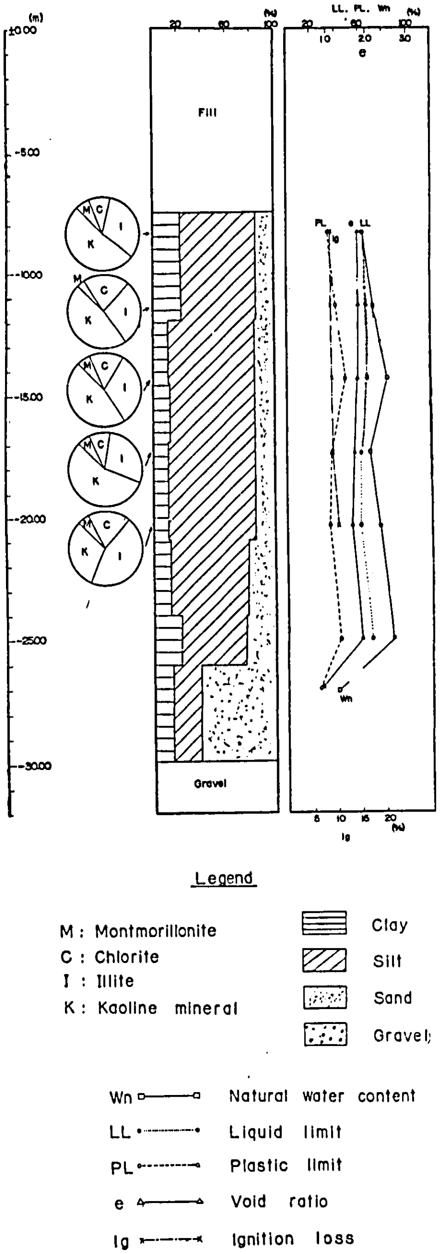
Contents of the clay minerals: montmorillonite 4~7%, chlorite 9~20%, illite 29~45%, and kaolinite 46~56%. It seems however that with depth either increase of illite or decrease of kaolinite become more conspicuous; for instance, the former amounts to 44.6% and the latter to 31.5% in the depth of -20.40 m.

Hydration ratio: 61~70%, liquid limit: 62.7~63.1%, plasticity limit: 34.3~48.0% and void ratio 1.60~1.84, being in proportion to the clay content but in obscure relation to the clay minerals, and ignition loss: 9.0~10.1% revealing an increasing tendency with depth. The related data are exhibited in Fig. 2.

(2) Specimens No. 1 and No. 4 from Hiroshima

The specimens No. 1 taken roughly as "clay silt" from its content of 0~4% gravel, 4~17% sand, 60~67% silt, and 21~30% clay indicating the increase with depth have been sampled from the depth of -7.00~-23.50 m at the estuary of the Motoyasu River, a branch of the Ota River.

Contents of the clay minerals: montmorillonite 8~22%, chlorite 10~15% excepting the mere case of 4.1% in the depth of −14.40 m, illite 29~39%, and kaolinite 34~53%. To be remarked is that 4.8% montmorillonite, 37.3% chlorite, 46.5% illite and 11.4% kaolinite, and correspondingly 3.5%, 18.8%, 35.8% and 41.9% are recognized in the silt-mingled sandy hirozon intervening between -23.50~-28.50 m and in the



Abbreviations and legend will be designated similarly in all of the following figures.

FIG. 2. Data for specimen No. 3 from Iwakuni

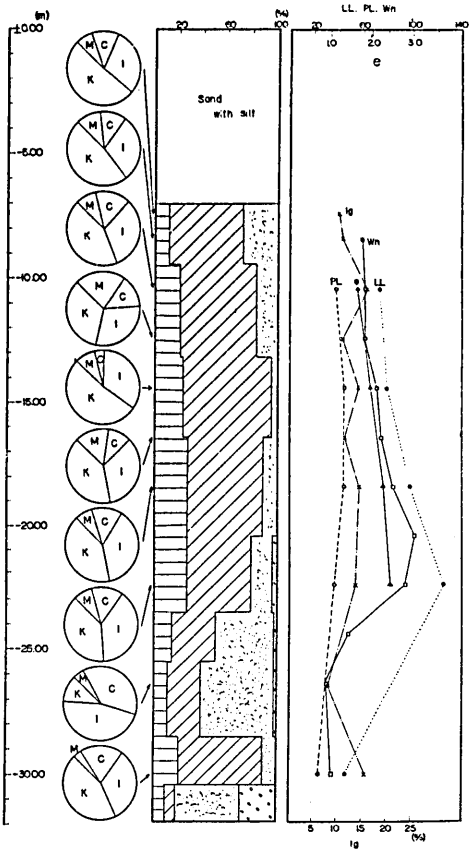


FIG. 3. Data for specimen No. 1 from Hiroshima

clayey-silty horizon situating in the depth of $-28.50 \sim -30.40$ m respectively, suggesting a general tendency of decrease of the first and increase of the second in more or less amount.

Hydration ratio: 60~100%, liquid limit: 73~126%, plasticity limit: 24.4~44.2% reaching the maximum in the central part of the horizon, and void ratio: 1.64~2.49 displaying an increase with depth and an indifference with the contents of clay and sand. The results are shown in Fig. 3.

The specimens No. 4 grouped into "clayey silt", accompanying "silty clay" in the central part and "clay" only in the lower part, with average content of 2~15% sand, 48~82% silt and 15~42% clay have been picked up from the depth of -6.50 ~ -23.00 m at the sea-bottom about 150 m off the spot for No. 1.

Contents of the clay minerals: montmorillonite 6~7% ranging from 2.5% in the upper part to 15.5% in the lower part, chlorite about 20% ranging from 8.5% in the uppermost part to 42.6% in the upper part with maximum content of sand, illite 25~32% and kaolinite 32~52%.

Hydration ratio: 59~96% and liquid limit: 74~127%, increasing with depth and decrease of sand but not always with increase of clay; plasticity limit: 36.2~50.0% decreasing with increse of sand, void ratio: 1.58~2.58 bearing a tendency similar to in the former case, and ignition loss: 13.3~16.4% decreasing a little with depth. The data for these factors are illustrated in Fig. 4.

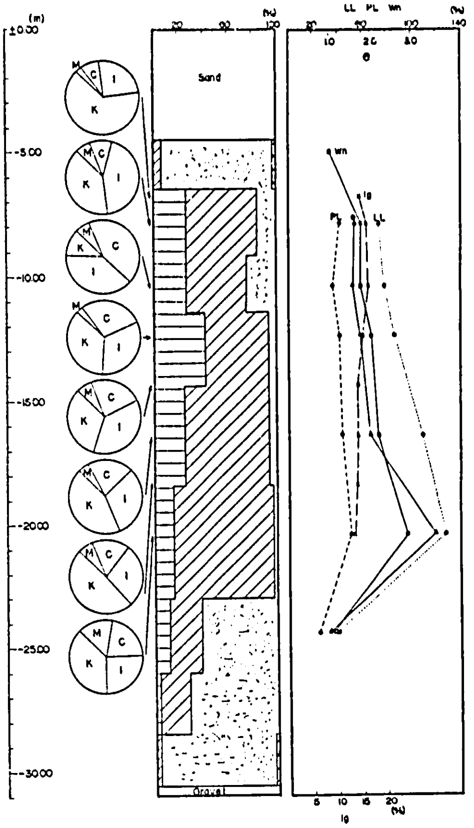


FIG. 4. Data for specimen No. 4 from Hirotshima

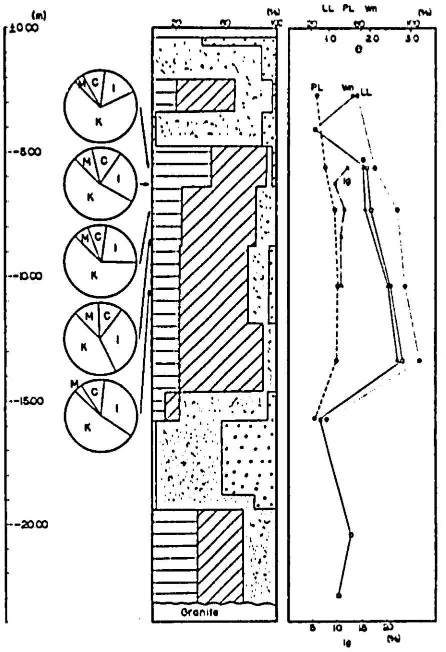


FIG. 5. Data for specimen No. n from Kure

As for contents of the clay minerals, increase of chlorite and illite as well as decrease of kaolinite with increase of the sandy component are confirmable commonly in both specimens of Nos. 1 and 2.

(3) Specimen No. n from Kure

The specimens belonging to "clayey silt", excepting the silty clay in the upper part, because of its composition of 7~22% gravel and sand, 45~68% silt and 22~48% clay, are those sampled in the depth of -4.80~-14.65m from the sea-bottom 20m off the coast of Nabe area in Kure City.

Contents of the clay minerals: montmorillonite 4~12% but a little smaller in the upper part and in the intermediate part abundant in gravel and sand, chlorite 10~13% and illite 24~33%, increasing a little with depth; and kaolinite 44~70% indicating the increase specifically in the upper part.

Hydration ratio: 64~92%, liquid limit: 71~102%, plasticity limit: 30~40%, and void ratio 1.85~2.68, being characterized with increase in the lower parts; and ignition loss 9.6~12.1%. The data are revealed in Fig. 5.

(4) Specimen No. 2 from Akitsu

The specimens, classified into clay, "clayey silt" and "silty clay", composed mainly of 5~43% sand, 39~83% silt and 7~39% clay have been taken out from the sediment ranging in thickness up to 22.00m at the off-shore.

Contents of the clay minerals: montmorillonite 5~8%, chlorite 9~20% revealing a little increase in the clay-rich horizon, illite 30~40%, and kaolinite more or less than 50% but down to 38% in the part predominant in chlorite and illite.

Hydration ratio: 87~108%, liquid limit: 81~118% and plasticity limit: 41~78% in proportion to the clay content, void ratio: 2.38~2.92 proportional to hydration ratio, and ignition loss: 8.3~11.4% increasing a little in the upper and lower parts. The results are given in Fig. 6.

(5) Specimen No. 1 from Kinoe

The specimens are those collected from "silty clay" with compositions of 2~10% sand, 40~76% silt, and 14~50% clay with a maximum thickness of about 18m at the sea-bottom in Kinoe Bay.

Contents of the clay minerals: montmorillonite 9~13%, chlorite 15~23%, illite 26~36% and kaolinite 33~47%.

Hydration ratio: 76~85%, liquid limit: 70%, plasticity limit: 30%, and void ratio: about 2~3. The data are presented in Fig. 7.

(6) Specimen No. 3 from Matsunaga

The specimens grouped into "clay" or "silty clay" containing 2~25% sand, 29~72% silt, and 17~66% clay have been obtained from the silty bed inter-

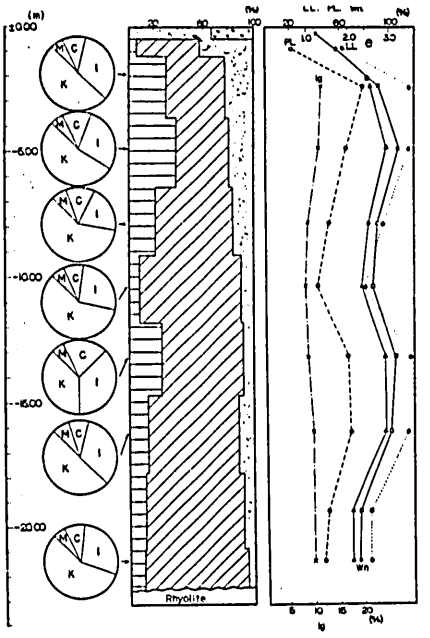


Fig. 6. Data for specimen No. 2 from Akitsu

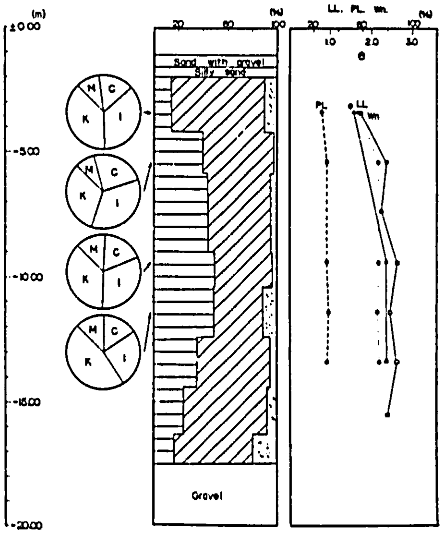


Fig. 7. Data for specimen No. 1 from Kinoe

calated between −1.50～−13.50 m at the sea-bottom in the western area of Matsunaga Bay.

Contents of the clay minerals: montmorillonite 3～13%, chlorite 9～15%, illite 27～33% with exception of 21% in the lower horizon and kaolinite 46～54% excepting the case of 66% in the lower parts.

Hydration ratio: 83～98% increasing with depth, liquid limit: 84～105% decreasing with depth, plasticity limit: 33～40%, void ratio: 2.23～2.67 increasing with depth, and ignition loss: 9.5～15% increasing a litter in the lower parts. The results are displayed in Fig. 8.

(7) Specimens No. 4, No. 11 and No. B from Fukuyama

The specimens No. 4 are those sampled at the sea-bottom near Minoshima, an islet surrounding Fukuyama Bay, and composed stratigraphically of the shell-bearing silty bed from the seabottom down to −8.60 m, the clay-mingled sandy bed in the depth of −8.60～−9.30 m, the stiff clayey bed from −9.30 m to −10.80 m, the gravelly and sandy bed from −10.80 m to −12.10 m, the sandy bed mixed mainly with the stiff clay from −12.10 m to −17.70 m, the sandy bed from −17.70 m to −19.30 m, and the gravelly and sandy bed from −19.30 m to −22.00 m.

The first bed composed of 7～19% sand, 52～69% silt and 19～39% clay is divided into "sandy silt", "clayey silt" and "silty clay".

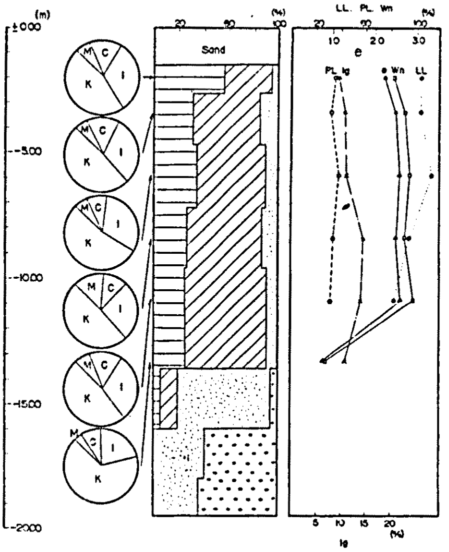


FIG. 8. Data for specimen No. 3 from Matsunaga

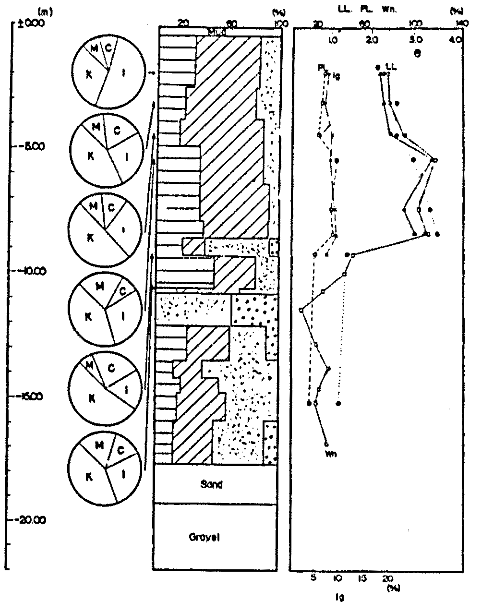


FIG. 9. Data for specimen No. 4 from Fukuyama

Contents of the clay minerals: montmorillonite 8~21%, chlorite 8~18%, illite 26~30% regardless of 51.2% in the upper part, and kaolinite 32~50%

Hydration ratio: 79~119%, liquid limit: 75~111%, plasticity limit: 48~85% and void ratio: 2.17~3.45 increasing with depth.

The second bed comprises 6.7% montmorillonite, 22.1% chlorite, 18% illite, and 53% kaolinite.

The third bed composed of 18~42% sand, 34~40% silt and 18~48% clay is divided into "silty clay", "clayey silt" and "sandy silt". In the part of silty clay, 17.5% montmorillonite, 12.8% chlorite, 26.6% illite and 43.1% kaolinite are found involved. In this bed, hydration ratio amounts to 22.1~44.9%, liquid limit to 40~47% and plasticity limit to 24.4~26.8%.

The data for these specimens are summarized in Fig. 9.

The specimens No. 11 are those taken at the sea-bottom about 2 km southeast of Minoshima and composed of the silty bed down to -8.50 m in depth, the stiff clayey bed from -8.50 m to -14.90 m, the gravelly and sandy bed from -14.90 m to -28.30 m and the stiff clayey bed from -28.30 m to -30.00 m.

The first bed composed of 3~20% sand, 35~68% silt, and 15~61% clay is classified into "clay", "silty clay" and "clayey silt".

Contents of the clay minerals: montmorillonite 9~12%, chlorite 6~10%, illite 22~26% and kaolinite 55~59%.

Hydration ratio: 70～130% decreasing with depth, liquid limit: 80～130%, void ratio: 1.9～3.0 and ignition loss: 9～10%.

The second bed composed of 5～40% sand, 25～45% silt, and 25～55% clay is divided into "clay", "sandy clay" and "clayey silt".

Contents of the clay minerals: montmorillonite 3～8%, chlorite none, illite 11 ～40% and kaolinite 57～85%.

Hydration ratio: 30% but 60% in the upper parts.

The results are illustrated in Fig. 10.

The specimens No. B are concerned with those obtained from the sea-bottom in Fukuyama Bay and composed of the shell-bearing silty bed down to -10.10 m and the gravelly and sandy bed mixed with the stiff clay from -10.10 m to -102.00 m.

The upper horizon includes 17.2% montmorillonite, 8.4% chlorite, 26.7% illite and 47.7% kaolinite while the lower horizon contains these minerals in such ratio as 2～13 : 0 : 5～44 : 52～87.

The related data are mentioned in Fig. 11.

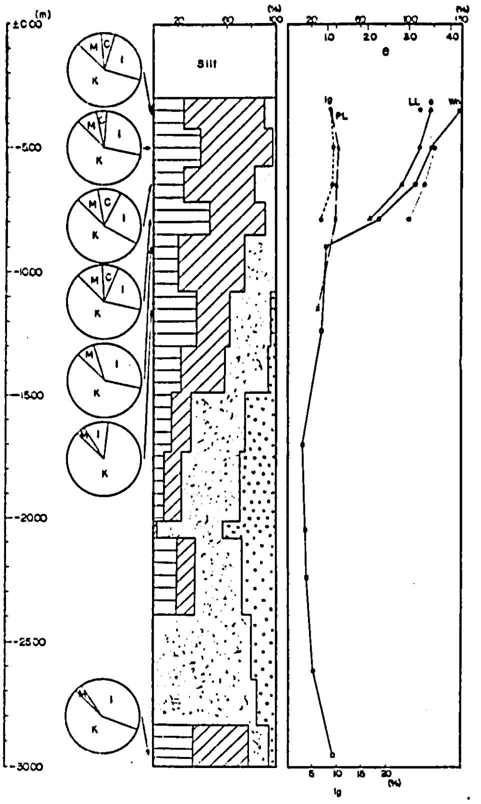


FIG. 10. Data for specimen No. 11 from Fukuyama

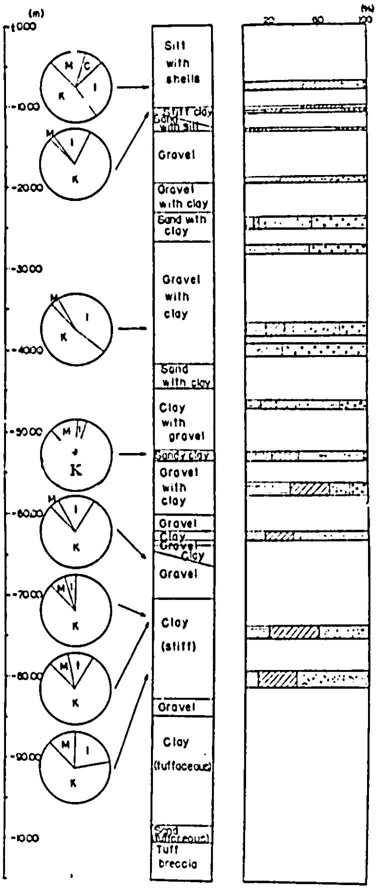


FIG. 11. Data for specimen No. B from Fukuyama

As for the specimens obtained from Fukuyama, the absence of chlorite in the stiff clayey bed lying under the silty bed is worthy mentioning in addition to the mutual difference in consistency expressed in the terms of liquid limit, plasticity limit and so on, as to a part of which the former work of the writer also referred to already. Moreover, as are plotted in Fig. 12, the grain-size integration curve revealing the normal frequency defined by TERZAGHI et al. (1948) for the former bed is clearly discernible in tendency from that for the latter, the difference being probably resulted from each condition of sedimentation.

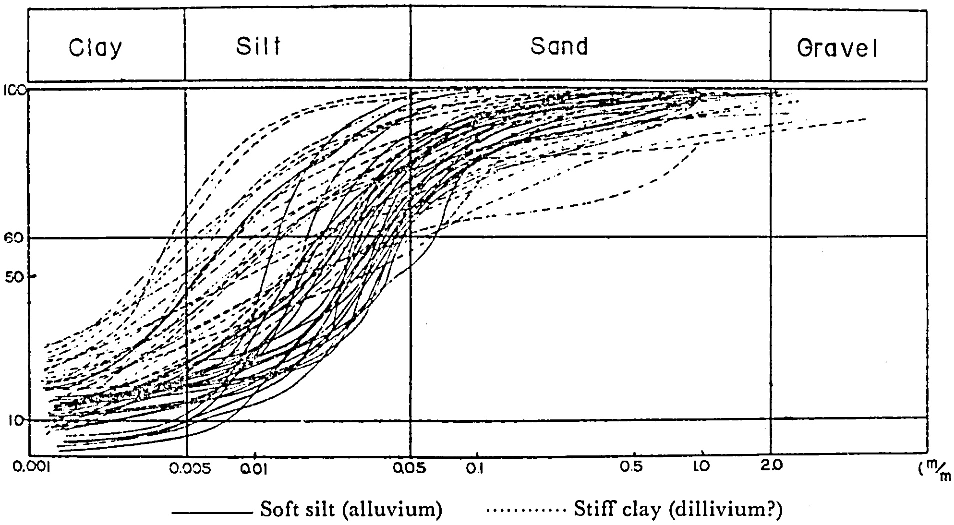


FIG. 12. Grain-size analyses

III. BEHAVIORS OF THE STANDARD CLAY MINERALS AFTER IMMERSED IN CERTAIN ELECTROLYTES

Now that most parts of the mechanical properties revealed by the clay minerals are also considered to depend primarily and secondarily on the surface potentials or negatively (rarely positively) charged states caused from their characteristic structures capable of absorbing (exchanging) various substances, the inner variations of montmorillonite, chlorite, illite and kaolinite have, after immersed in natural sea-water, solutions of NaCl and $CaCl_2$ with concentration almost similar to that of the former and pure water, been examined by means of x-ray diffraction and infrared absorption.

Prior to inspection of the behaviors of the clay minerals obtained from the sediments, the pulverized specimens, less than 200 mesh in grain-size, of the Hōjun bentonite composed of montmorillonite and cristobalite in the room of montmorillonite, the Wanibuchi penninite for chlorite, the Murakami sericite composed of sericite and quartz for illite, and the Shōkōzan dickite mixed with diaspore and pyrophyllite have been preliminarily provided for treatments.

The pH (not RpH) values shown by 5 g of these specimens held for some minutes at 25°C in 100c.c of pure water (pH=6.9) are as follows:

Bentonite 8.6, Chlorite 6.0, Sericite 5.5, and Dickite 5.8.

The fact is that excepting montmorillonite represented by bentonite the others evidently indicate the apparent inclination for acidic property. There however remains a room for inference of their essential characters merely on the ground of pHs, as these values might have been regulated by the present quantities, different from the original ones, of the absorbed substances or, in other words, sampling conditions and geologic processes in the past.

The specimens in question have been suspended in the respective reagents, stirred automatically for 10 minutes per day, repeatedly subjected to the similar treatment for 10 days, and then dried up at the spontaneous state.

(1) The data for x-ray diffraction

The specimens prepared through the procedure alluded to above and those dried up furthermore for 2 hours at 110°C have been provided for the experiments. The equipments used and the conditions regulated have been as follows:

X-ray diffractometer: GX-2B type manufactured by Shimazu Co.

X-ray: CuKα, 30 kV 15 mA with Ni filter.

Time constant: 5.0 sec for 500 cps, Scanning speed: 1 (2θ)/min, Rotating speed: 1 cm/min, Divergent slit: 1.5 mm, Receiving slit: 0.2 mm.

(a) Bentonite

Variation in the spacings for the basal planes is generally conspicuous.

As far as 14.4 Å revealed by the spacing $d_{(001)}$ at the originl state is concerned, treatment with sea-water causes a little expansion to 14.8 Å and marked decrease in intensity, that with NaCl results in its splitting into three peaks at 15.1 Å, 14.0 Å and 13.2 Å as well as in weakening similar to in the former case, that with $CaCl_2$ gives rise to a little swelling to 15.2 Å and that with pure water to a little shrinkage and weakening, while the similar treatments for the specimens dried up at 110°C attributes to conversion into the broad and weak peak at 9.9~11.2 Å. The results are illustrated in Table 1.

By the by, GRIM's opinion (1953) pointing out the presence of about 80% of the ions absorbed on montmorillonite between the interlayers in its structure are of proper significance for further considerations.

(b) Chlorite

Because of well crystallinity exhibiting the distinct reflections for (001) to (005) and for (200), the untreated specimens are structually analysed as are composed of the mixed layers of monoclinic type with a part of orthohexagonal one.

Table 1. Comparison of X-ray diffraction data for Hōjun bentonite

Untreated		Immersed in																Minerals identified (hkl)
		H_2O		H_2O (110°C, 2h, heated)		NaCl		NaCl (110°C, 2h, heated)		$CaCl_2$		$CaCl_2$ (110°C, 2h, heated)		Sea water		Sea water (110°C, 2h, heated)		
I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	
35 b	14.4	21 b	14.0			17 16 14	15.1 14.0 13.2			22 b	15.2			18 b	14.8			M(001) (Montmorillonite)
				6 vb	11.2 10.4			7 9 b	10.5 9.9			3	11.8					
												4	11.3					
												8 b	9.8 9.6			8 b	9.9	
17	4.46	18	4.46	20	4.46	16	4.46	18	4.46	16	4.46	20	4.47	15 13	4.47 4.25	19	4.47	M(110) (020)
44	4.06	38	4.06	45	4.07	36	4.05	43	4.07	37	4.05	42	4.06	35	4.07	40	4.06	Cr(101) (Cristobalite)
3	3.34	7	3.34	6	3.36	3	3.33	3	3.35	3	3.36	5	3.34	3	3.34	3	3.34	Q (Quartz)
8 b	3.11	6 b	3.12	6 vb	3.20	5	3.12	6 vb	3.26 3.19	3 vb	3.11	6 b	3.22 3.20 3.17	3 b	3.13	5	3.26	M(005)
																6 b	3.21	
6	3.03	4	3.03	4	3.03	3	3.02	3	3.03	3	3.03	4	3.02	3	3.03	4	3.02	
14	2.91	7	2.91	10	2.91	8	2.91	10	2.91	7	2.91	9	2.91	5	2.91	7	2.91	
						16	2.82	27	2.82					18	2.82	24	2.82	NaCl
														6	2.56	6 vb	2.54	
6 b	2.56	8 b	2.56	7 b	2.55	6 b	2.55	7 vb	2.56 2.53	7 b	2.54	8	2.53	6	2.53	7	2.52	M(130) (200)
9 b	2.50	10 b	2.48	10 b	2.50	8	2.49	10 b	2.51	8 vb	2.49	10 vb	2.51 2.49	8	2.49 2.48	9	2.49	Cr(200)

vb : very broad   b : broad

Table 2. X-ray diffraction data for Murakami Sericite

Untreated		Immersed in																Minerals identified (hkl)
		H_2O		H_2O (110°C, 2h, heated)		NaCl		NaCl (110°C, 2h, heated)		$CaCl_2$		$CaCl_2$ (110°C, 2h, heated)		Sea water		Sea water (110°C, 2h, heated)		
I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	
19	10.06	24	9.98	22	9.99	25	10.11	27	10.08	24	9.99	22 23	10.12 9.94	25	10.11	23	10.05	S(002) (Sericite)
2	7.22 7.16	3	7.08	3 vb	7.15	2 vb	7.20	2	7.13	2 b	7.08	1.5 vb	7.20			2 2 b	7.22 7.08	
10	4.99	13	5.00	14	5.01	7	4.99	8	5.01 4.98	11	4.99	14	4.98	9	5.01	7	4.99	S(004)
9	4.47	9	4.47	9	4.47	9	4.48	10	4.47	9	4.47	12	4.45	10	4.47	15	4.47	S(110)
50	4.26	64	4.26	70	4.26	57	4.26	56	4.26	57	4.26	63	4.26	57	4.26	50	4.26	Q(100) (Quartz)
2 b	3.71	3	3.69	4	3.71	3	3.71	4	3.71	2 3	3.70 3.63	5 4 vb	3.70 3.63	4 3b	3.71 3.65	4 4	3.70 3.65	S(023, 113)
90(+)	3.34	90(+)	3.34	3 90(+)	3.64 3.34	93(+)	3.34	92(+)	3.34	90(+)	3.34	90(+)	3.34	90(+)	3.34	90(+)	3.34	S(006) Q(101)
3 b	3.09	3 4	3.10 3.08	3 vb	3.09 3.08	3 25	3.08 3.06	4 b	3.08	3 b	3.07	6	3.08	4	3.10	2 vb	3.09	S(11$\bar{5}$, 025, 114)
						21	2.82	23	2.82					10	2.82	12	2.82	NaCl
9	2.56	8	2.56	9	2.56	9	2.56	11	2.56	9	2.56	11	2.56	10 b	2.56	12	2.56	S(20$\bar{2}$), (008)
17	2.46	18	2.46	20	2.46	16	2.46	16	2.46	17	2.46	19	2.46	17	2.46	18	2.46	S(13$\bar{3}$) Q(110)
3 b	2.38	3 vb	2.38	4 b 4 b	2.40 2.38	3 b	2.39	4 b	2.38	3 b	2.38	4	2.38	4	2.39	4 vb	2.39	S(133)
9	2.28	8	2.28	8	2.28	7	2.28	7	2.28	6	2.28	7	2.28	7	2.28	10	2.28	Q(102)
6 5	2.24 2.23	7	2.24	8	2.24	7	2.24	7	2.24	7	2.24	7	2.24	7	2.24	7	2.24	Q(111)

13	2.13	16	2.13	17	2.13	13	2.13	13	2.13	14	2.13	14	2.13	4	2.13	12	2.13	S(043)	Q(200)
		5 b	1.994	6 b	1.998	18	1.996	17	1.993	4	1.999	4 5	2.000 1.993	8	1.994	10	2.01	S	NaCl
9	1.980	9	1.978	10	1.982	10	1.981	9	1.981	7	1.980	10	1.981	9	1.981	8	1.979		Q(201)
17	1.818	16	1.817	16	1.818	15	1.818	15	1.818	14	1.818	16	1.819	15	1.818	18	1.818		Q(112)
6	1.671	6	1.670	7	1.672	5	1.672	5	1.673 1.670	5	1.670 1.667	6	1.671	5	1.672	6	1.672	S(312)	Q(202)
4 b	1.662 1.650			5	1.645	4	1.660 1.657	3 b	1.658	4	1.646	4	1.658	4	1.661	4 6	1.661 1.656	S	Q(103)
						4	1.628	5	1.629					3 b	1.629	2.5 vb	1.629	NaCl	
17	1.541	16 13	1.541 1.540	17	1.541	12	1.541	11 11	1.541 1.539	14 11	1.542 1.539	15 12	1.541 1.539	14	1.541	13 12	1.542 1.540		Q(121)
4	1.496	3	1.495	3 b	1.496	4	1.498 1.496	4 b	1.497	4	1.497	6 b	1.497	4 b	1.497 1.493	6	1.498	S(060)	
2	1.454 1.451	2	1.452 1.449	1.5 b	1.453 1.450	2 b	1.452	2 b	1.454	2 b	1.452	2 b	1.454	2 b	1.451	2.5	1.453		Q(113)
7	1.385 1.382	8	1.382	8	1.382	7 6	1.383 1.380	6	1.383	7	1.382	8	1.382	7	1.383	7	1.384		Q(122)
9	1.374					9	1.376							10	1.376				
11	1.372	12	1.372	13	1.373	11	1.373	12	1.373	11	1.372	12	1.372	11	1.373 1.372	11 b	1.375 1.372	S	Q(203)
2.5 b	1.288	3 b	1.287	2 b	1.289 1.286	3	1.287	1.5 vb	1.292 1.289	2	1.288	3 b	1.287	3	1.288 1.286	3 b	1.288		Q(104)
						3	1.261	3	1.262									NaCl	

Table 3. X-ray diffraction data for chlorite obtained from Wanibuchi Mine

Untreated		Immersed in																Minerals identified (hkl)
		H_2O		H_2O (110°C, 2h, heated)		NaCl		NaCl (110°C, 2h, heated)		$CaCl_2$		$CaCl_2$ (110°C, 2h, heated)		Sea water		Sea water (110°C, 2h, heated)		
I	d (Å)	I	d (Å)	I	d (A)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (A)	
57	14.3	65	14.3	53	14.3	46	14.3	43	14.3	75	14.3	69	14.2	52	14.3	45	14.2	Ch(001) (Chlorite)
60	7.15	76	7.14	69	7.14	50	7.13	45	7.11	80	7.13	73	7.14	57	7.14	52	7.11	Ch(002)
39	4.75	49	4.76	49	4.74	34	4.74	33	4.74	51	4.75	50	4.75	39	4.75	36	4.73	Ch(003)
16	4.58	14	4.61	19	4.58	13	4.58	18	4.59	13	4.59	18	4.59	14	4.60	21	4.59	Ch(020)
37	3.56	47	3.56	44	3.56	33	3.55	34	3.56	50	3.56	46	3.56	37	3.56	34 33	3.56 3.55	Ch(004)
9 11	2.86 2.85	13	2.85	12	2.85	16	2.83	10 19	2.86 2.82	11 b	2.84	12 11	2.85 2.84	9 19	2.84 2.82	10 23	2.85 2.82	Ch(005) NaCl
3 b	2.65	3	2.65			3	2.65	4	2.65 2.63	2.5	2.64	3	2.64	3	2.65	3	2.65	Ch(200)
14	2.58	11	2.58	13	2.58	13	2.58	15	2.58	12	2.57	13	2.57	12	2.58	15	2.57	Ch(131) (20$\bar{2}$)
24	2.54	21	2.54	26	2.54	23	2.53	26	2.54	21	2.53	23	2.53	23	2.53	31	2.54	Ch(13$\bar{2}$) (201) ; (202)
17	2.44	17	2.44	19	2.44	17	2.43	20	2.44	17	2.44	21	2.43	18	2.43	21	2.44	Ch(132) (20$\bar{3}$)
9	2.38	8	2.37	10	2.38 2.37	8	2.38	11	2.38	8	2.38	10	2.38	9	2.38 2.37	11	2.38	Ch(13$\bar{3}$) (202)
8	2.26	6	2.26	8	2.25	7	2.26	7 6	2.26 2.25	7	2.26 2.25	6 b	2.25	6	2.25	8	2.26	Ch(133) (20$\bar{1}$)
14	1.999	16	2.00	17	1.998	17	1.994	21	1.997	14	1.998	15	2.001	20	1.994	23	1.996	Ch(13$\bar{5}$) (204) NaCl
5	1.879	5 b	1.882	5	1.876	4	1.876	5 b	1.878	5 b	1.876	6	1.879	5	1.880	6	1.881	Ch(135) (20$\bar{3}$)
4	1.822	5	1.826	6	1.824 1.819	5	1.822	5	1.824	5	1.821	5	1.821	4 b	1.821	5 b	1.823	Ch(13$\bar{6}$) (205)
2	1.736 1.729	3	1.801			2	1.741	2 b	1.736	2	1.758	3 b	1.730			3	1.731	Ch(136) (20$\bar{7}$)
		4vb	1.717	2vb	1.719	2 b 2	1.710 1.701	3	1.701	2vb	1.719	3 b	1.718			3 b	1.671	Ch(13$\bar{7}$) (206)
2	1.664 1.659	5 b	1.661	3 b	1.661	2vb	1.661	2vb	1.661	3	1.662	3	1.664	3	1.663			
						3	1.627	3	1.630					2	1.628	3	1.629	NaCl
8	1.565	11	1.564	11	1.566	9	1.565	8	1.566 1.562	10	1.563	8	1.567 1.562	8 b	1.566	9	1.565	Ch(137) (20$\bar{8}$)
16	1.522	13	1.536 1.533	18	1.532	14	1.534	18	1.535	14	1.532	18	1.534	15 13	1.534 1.532	19	1.533	Ch(060) (33$\bar{1}$)
4 b	1.500	4	1.500	5	1.499	4	1.499	6	1.499	4 5	1.502 1.499	4	1.502 1.499	3 b	1.500	5	1.500	Ch(062) (331) (33$\bar{3}$)
7 b	1.393	9	1.394	8	1.395	7 b	1.395	6 b	1.398 1.392	8	1.392	8	1.397 1.392	6 5	1.397 1.393	7	1.394 1.390	Ch(0010) ; (13$\bar{9}$) (208)
4 b	1.317 1.314	4vb	1.319	5	1.316	3	1.318	4 b	1.316	3	1.313	4	1.319	2 3	1.320 1.318	4	1.319	Ch(139) (20$\bar{1}\bar{1}$)
4 b	1.288	3vb	1.290	5	1.287	2 3	1.295 1.287	5 b	1.290	3	1.287	4 b	1.287	3	1.289	5	1.290 1.288	Ch(066) (335) (33$\bar{7}$)
						3	1.260	3	1.261									
2.5vb	1.215	2 b	1.224	3 b	1.220	2 b	1.221	3	1.221	2 2 3	1.223 1.218 1.215	3 b	1.221 1.216	2 b	1.224 1.217	3	1.220	Ch(0012)

Table 4. Comparison of X-ray diffraction data for dickite obtained from Wanibuchi Mine

Untreated		Immersed in																Minerals identified (hkl)
		H_2O		H_2O (110°C, 2h, heated)		NaCl		NaCl (110°C, 2h, heated)		$CaCl_2$		$CaCl_2$ (110°C, 2h, heated)		Sea water		Sea water (110°C, 2h, heated)		
I	d (Å)	I	d (Å)	I	d (A)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I	d (A)	
3	9.18	6	9.18	4	9.18	3	9.22	4	9.19	6	9.18	5	9.19	4	9.22	5	9.14	P (Pyrophilite)
12	7.96	11	7.94	10	7.89	10	7.94	13	7.93	14	7.94	11	7.94	11	7.94	13	7.91	
90(+)	7.22	90(+)	7.17	90(+)	7.18	90(+)	7.17	90(+)	7.17	90(+)	7.19	90(+)	7.18	90(+)	7.20	90(+)	7.18	D(002) (Dickite)
43	4.71	27	4.70	12	4.71	8	4.72	23	4.67	26	4.71	8	4.71	7	4.71	7	4.70	P Di (Diaspore)
15	4.45	14	4.44	16	4.44	17	4.44	17	4.43	12	4.44	16	4.43	22	4.44	14	4.44	D(020) (110)
21	4.37	18	4.37	18	4.37	25	4.37	18	4.36	17	4.37	22	4.36	23	4.37	20	4.36	D(11$\bar{1}$)
14	4.26	9	4.27	10	4.27	10	4.28	10	4.26	7	4.26	9	4.27	13	4.27	8	4.26	D(021)
23	4.13	21	4.12	21	4.12	25	4.13	24	4.12	21	4.12	23	4.12	29	4.13	20	4.12	D(111) P
68	3.99	83	3.99	18	3.98	60	3.99	90(+)	3.99	72	3.99	90(+)	3.98	48	3.99	72	3.98	D(11$\bar{2}$) Di
18	3.80	15	3.79	17	3.79	18	3.80	16	3.79	12	3.79	15	3.79	20	3.80	15	3.79	D(022) P
90(+)	3.58	90(+)	3.58	90(+)	3.58	90(+)	3.58	90(+)	3.57	90(+)	3.58	90(+)	3.58	90(+)	3.58	90(+)	3.57	D(004) (112)
14	3.43	13	3.43	13	3.43	13	3.43	12	3.43	13	3.43	12	3.43	14	3.44	12	3.42	D(11$\bar{3}$)
8	3.35	3	3.21	6	3.21	4	3.26	3	3.26					4	3.26	2	3.26	D(023) Di
						2	3.22	11	3.21									
4	3.10	4	3.09	4	3.10	5	3.10	3	3.09	4	3.10	4	3.10	4	3.10	3	3.09	D(113)
3	3.07	6	3.07	5	3.06	4	3.07	5	3.06	6	3.07	6	3.07	6	3.07	5	3.06	P
6	2.94	4	2.94	4	2.94	6	2.94	4	2.94	5	2.94	3	2.94	5	2.94	4	2.94	D(11$\bar{4}$) P
6	2.80	5	2.79	4	2.79	5	2.82	3	2.82	4	2.79	5	2.80	4	2.82	4	2.82	D(024) NaCl
						6	2.79	5	2.79									
13	2.56	11	2.56	15	2.55	26	2.56	16	2.56	20	2.56	43	2.56	15	2.56	12	2.56	D(13$\bar{1}$) (200) P Di
		8	2.53	9	2.52	10	2.53	8	2.52	9	2.53	9	2.52	9	2.53	8	2.52	D(11$\bar{5}$)
17	2.50	13	2.51	16	2.50	15	2.51	16	2.51	13	2.50	14	2.51	18	2.51	13	2.50	D(131) (20$\bar{2}$) P
45	2.39	44	2.39	41	2.38	36	2.39	46	2.39	51	2.39	41	2.39	41	2.39	42	2.38	D(006) (132) Di
10	2.36	12	2.35	4	2.35	9	2.35	11	2.35	17	2.35	4	2.35	7	2.35	8	2.35	Di
36	2.33	29	2.32	35	2.32	39	2.32	31	2.32	33	2.32	40	2.32	44	2.32	30	2.32	D(13$\bar{3}$) (202) P Di
5	2.21	4	2.21	5	2.21	5	2.21	5	2.21	4	2.21	5	2.21	6	2.21	5	2.20	D(133)
4	2.13	3	2.13	10	2.13	8	2.13	5	2.13	6	2.13	5	2.13	13	2.13	2	2.15	P Di
3	2.11	2	2.11	3	2.10	2.5	2.11			3	2.11	2	2.10	3	2.11	2.5	2.10	D(026) Di
4	2.08	14	2.08	4	2.08	13	2.08	7	2.08	11	2.08	4	2.08	11	2.08	6	2.08	D(043) P Di
						4	1.991	4	1.992					4	1.991	4	1.989	NaCl
5	1.973	13	1.972	13	1.973	14	1.972	13	1.971	14	1.973	14	1.971	16	1.973	14	1.973	D(13$\bar{5}$) (204)
3	1.893	3	1.893	3	1.895	3	1.895	3	1.894	3	1.893	3	1.893	4	1.894	2	1.894	D(044) P
6	1.856	4	1.855	5	1.857	5	1.858	5	1.856	5	1.857	4	1.854	4	1.855	4	1.857	D(135) (20$\bar{6}$) P
20	1.790	20	1.790	15	1.787	18	1.789	20	1.789	25	1.789	15	1.789	17	1.790	20	1.789	D(117)
20	1.651	19	1.650	19	1.650	18	1.651	18	1.650	17	1.649	18	1.649	19	1.651	17	1.649	D(137) (206)
3	1.633	11	1.632	5	1.632	4	1.631	7	1.632	4	1.632	8	1.632	4	1.632	7	1.633	Di NaCl

It is generally believed that opportunity for coming-in of the other substances in the chlorite structure is to be scarce owing to self-compensation of surplus or deficit in charge by substitution of the elements involved in its own structure. Although merely for this reason the effects of Na^+ and Ca^{++} on the mineral concerned are to be not so much expectable, the reality is that for its basal planes the treatment with sea water gives no variation, that with NaCl weakens their intensities, and those with $CaCl_2$ and pure water cause their increase. The results are listed in Table 2.

(c) Sericite

Absorption of the other materials on this structure is inferable to be ascribed to the broken bonds present in the interlayers normal to the basal planes and to deficit of the positive charges caused through the substitution of Al^{+++} in the octahedron layer with Mg^{++} and Fe^{++} etc. Nevertheless, the treatments similar to those in the other cases result in not so marked variation other than a little increase in intensity. Only remarkable is the difference in that the resulted intensity at 2.81 Å with NaCl treatment amounts to two times that with sea-water. The data are shown in Table 3.

(d) Dickite

Amounts of the exchangable and dissociable ions in this structure are reasonably considered in a linear proportion to the related surface areas on account of the increasing broken bonds within the interlayers. However, it is sure that for the spacings of (002) and (004) the treatments with sea-water and pure water yield the intensities nearly similar to that in the case of the untreated specimen, that with NaCl brings about their decrease and that with $CaCl_2$ gives rise to their maximum of all. The results are mentioned in Table 4.

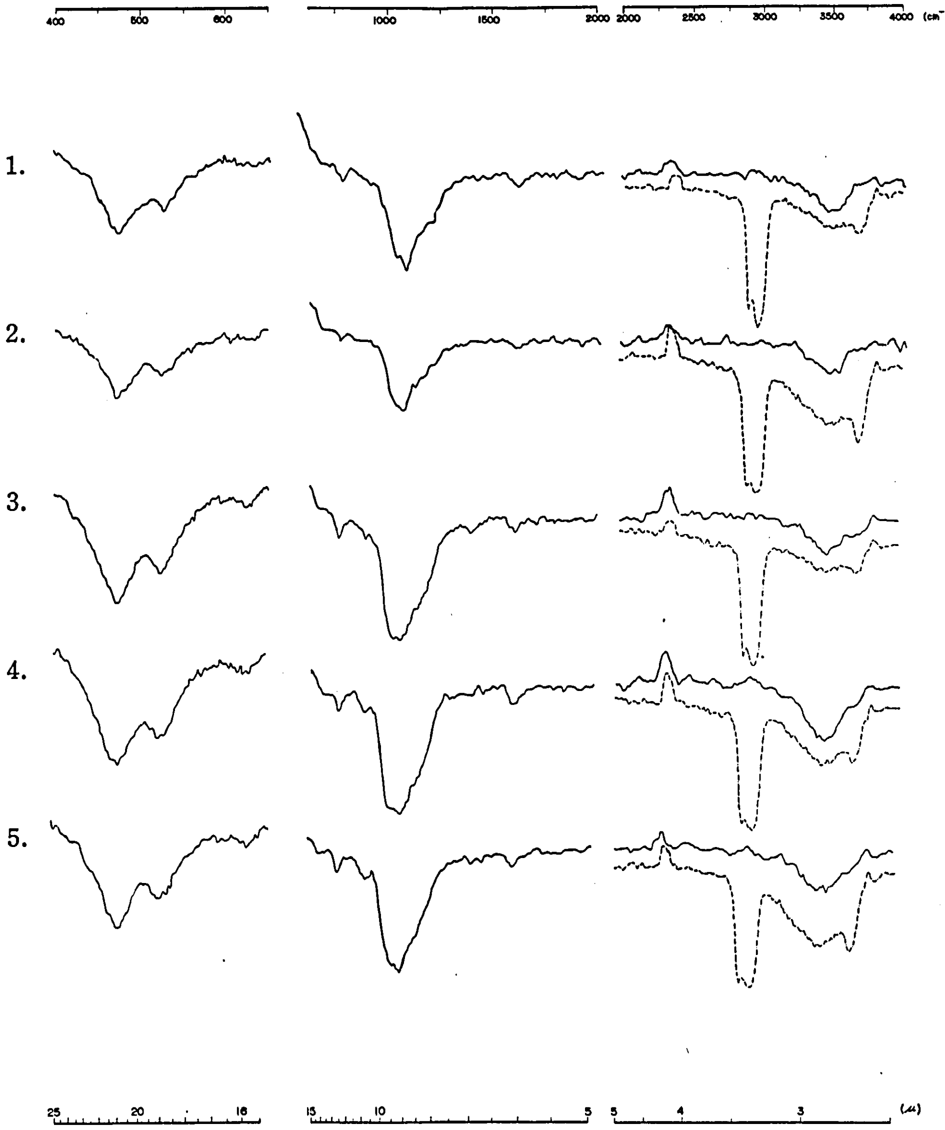
As have been expected, the precendences evidently suggest the noticeable dependence of absorptivity of the clay minerals on their varieties, inner structures and surface conditions inherent to whichever primarily or secondarily and that of absorbability of the coming-in substances on their kinds and concentration. Above all, the most important fruit obtained may be that in the cases of NaCl and sea-water treatments the reflections for pure NaCl of its own have been found remained beside those for the clay minerals while with $CaCl_2$ treatment none of those for pure $CaCl_2$ has been recognized. This probably implies the absorbability of Ca^{++} higher than that of Na^+. On the other hand, the intensities at 2.81 Å of the remained NaCl in the cases of the treatments with NaCl and sea-water of the similar concentration for the clay minerals in question are compared with one another as follows:

Mineral	Immersed in	
	NaCl	Sea-water
Bentonite	16	18
Chlorite	5	4
Sericite	21	10
Dickite	16	19

The similar treatments for the specimens of chlorite, sericite and dickite held for 2 hours at 115°C have attributed to nothing other than a little increase in intensiy.

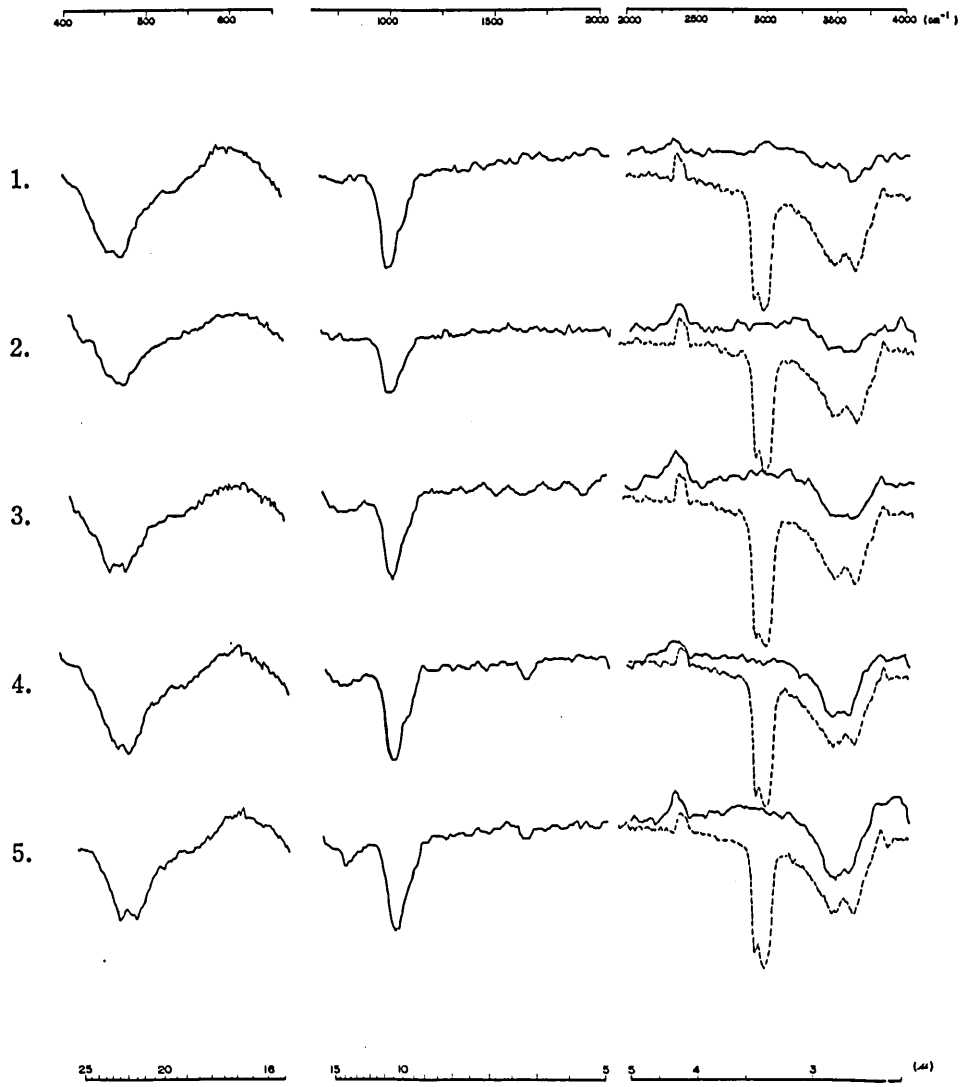
(2) The data for infrared absorption

As have long been known, the infrared absorption bands are useful for rapid



Full line: KBr method dotted line: Nujol method
1. untreated 2. H_2O 3. NaCl soln 4. $CaCl_2$ soln 5. sea water
Fig. 13. Infrared absorption spectra for the bentonite

analysis of certain silicates, isomorphic substitution and absorption or adsorption of H_2O or OH on/in their structures and so on. In view of this, the related spectra for the tablets prepared through mixing of 0.5 mg (1 mg only for dickite) specimens treated in the same manners as for x-ray diffraction with 300 mg KBr (nujol for a test of OH) have been inspected by means of the Hilger H-800 spectrometer within the range of $4000 \sim 400\ \mathrm{cm}^{-1}$ in wave-length at 25°C and 40% in relative humidity.



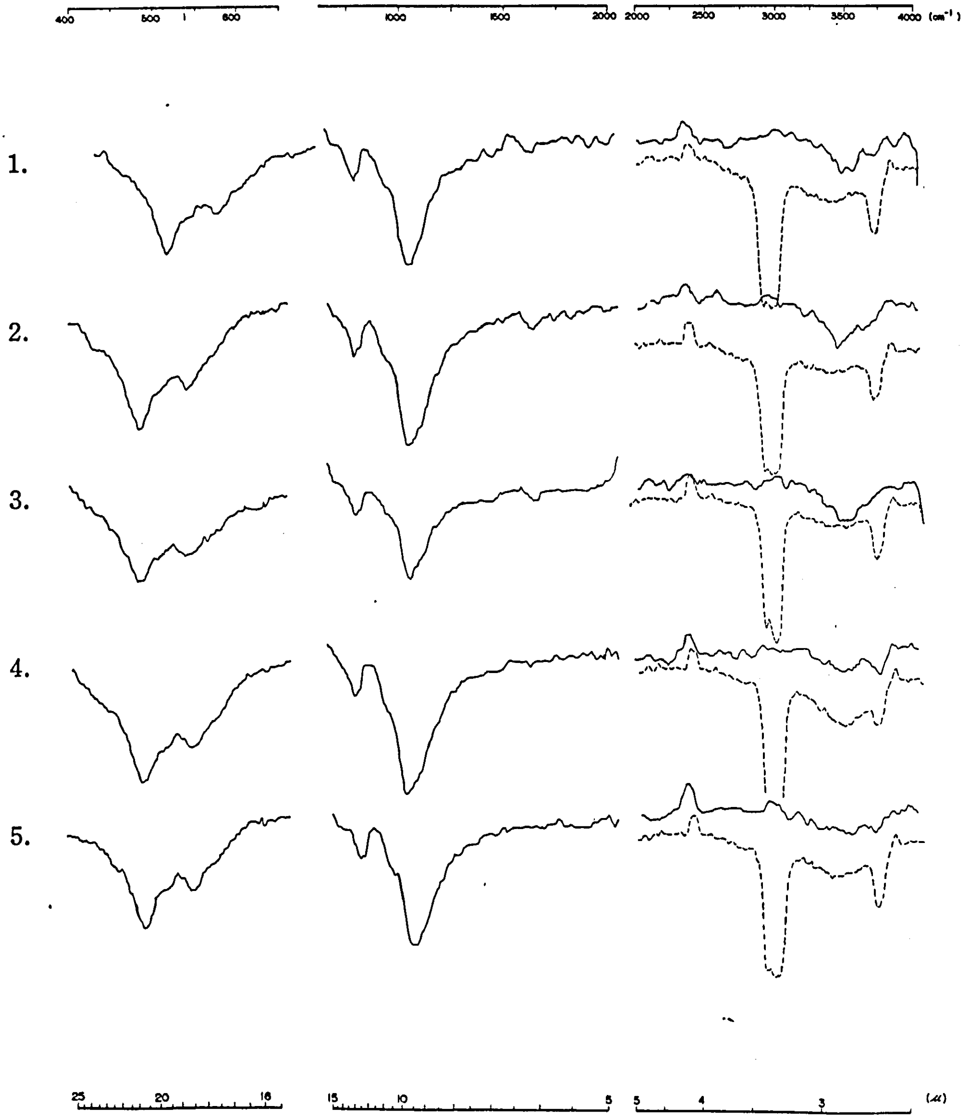
1. untreated 2. H_2O 3. NaCl soln 4. $CaCl_2$ soln 5. sea water

FIG. 14. Infrared alsorption spectra for the chlorite

(a) Bentonite (see Fig. 13)

The untreated specimen give the absorption bands at 2.72μ (the units will hereunder be omitted) connected with O-H bonds, 2.8∼2.9 and 6.2 relatetd to H_2O in the interlayers, 9.3, 9.6, 12.8, 21.2∼21.3 and 21.6∼21.3 and 21.6∼21.7 concerned with Si-O for cristobalite and montmorillonite, 19.6 bearing a complicity with (Si, Al^{IV})-O and 10.5∼11.0 regarded to Al-OH.

As for the treated specimens, each band for Si-O and Al-OH is rather weak



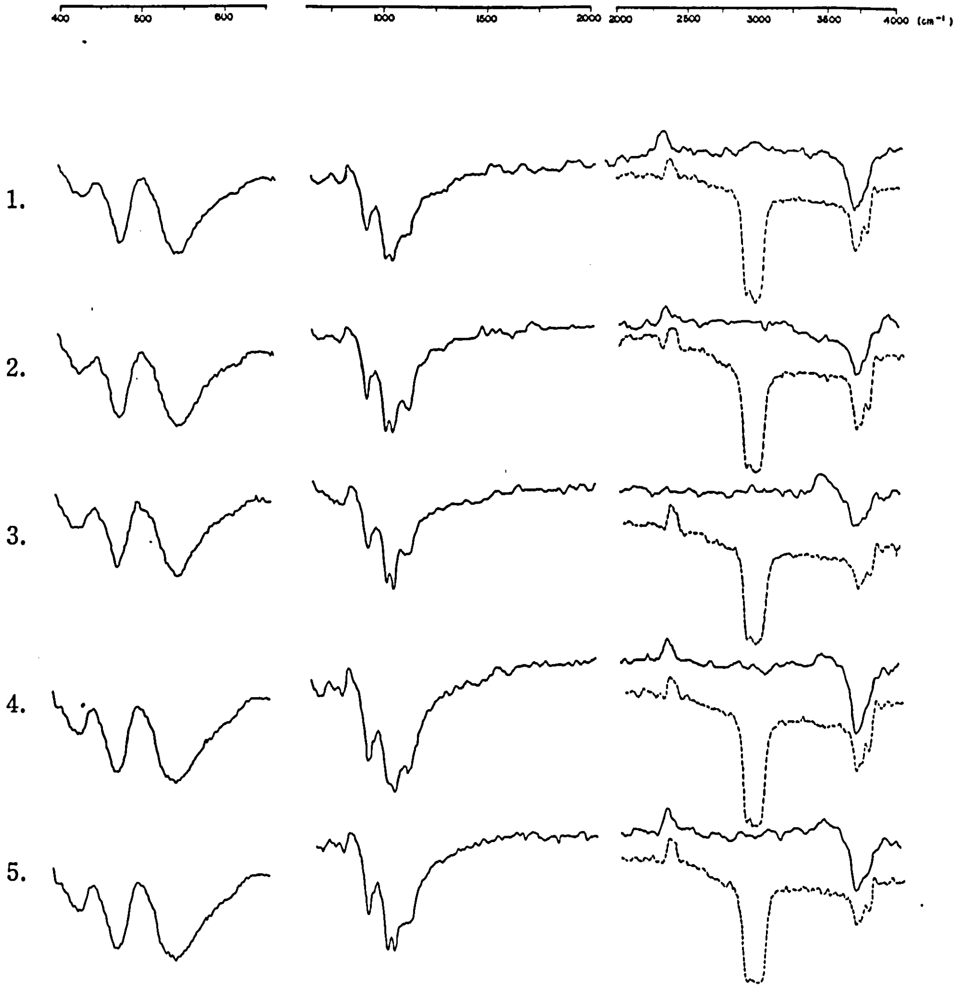
1. untreated 2. H_2O 3. NaCl soln 4. $CaCl_2$ soln 5. sea water

Fig. 15. Infrared absorption spectra for the sericite

only in the case of H_2O treatment and that for (Si, Al^{IV})-O is strong in the other three cases, while the treatments other than that with NaCl give remarkably strong bands for OH and extremely broaded bands for H_2O, differing from one another in absorption figure.

(b) Chlorite (see Fig. 14)

The absorption bands for this mineral indicate not so notable variation at the state either prior or subsequent to any treatments. Those at 2.7, 2.8, 2.9 and



1. untreated 2. H_2O 3. NaCl soln 4. $CaCl_2$ soln 5. sea water
FIG. 16. Infrared absorption spectra for the dickite

6.0~6.2 for OH and H_2O, 10.3 and 21.7 for Si–O, 11.3 for Al-OH, 19.6~19.7 for (Si, Al^{IV})-O, and 22.6 for (Si, Mg^{IV})-O are commonly observable but those near 2.9 in the cases of the treated specimens are characterized by splitting into the complicated figures.

(c) Sericite (see Fig. 15)

The untreated specimens give the absorption bands at 2.71~2.73, 2.8~3.1 and 6.2 for OH and H_2O, 9.8~9.9, 13.0~13.1 and 21.1 for Si–O, 10.8~11.0 for Al-OH, and 19.1~19.2 for (Si, Al^{IV})-O, while the specimens treated with $CaCl_2$ merely show a little stronger absorption at 2.8~3.1 compared with those in the cases of any other treatments.

(d) Dickite (see Fig. 16)

The absorption bands for 1 : 1 structure of these specimens, though not so conspicuously different from one another in both cases with or without any treatments, are discriminated as a whole and in lack of those at 2.8~3.1 from those for 2 : 1 structure of the other minerals mentiond above, appearing at 2.66, 2.72 and 6.0~6.3 for OH and H_2O, 9.1, 9.8, 10.1, 21.3 and 24.0 for Si–O, 11.1 for Al-OH, and 13.0 and 18.7 for (Si, Al^{IV})-O.

These are of course nothing but the preliminary data and hence it is still now problematical whether the results of the infrared absorption tests for the pure specimens may, just as they are, be effectively applicable to in the actual cases of the mixtures of the clay minerals obtained from the alluvial sediments or not.

IV. Conclusion

The clay minerals, though confined to the definite species for the sake of convenience, sampled from the sediments lying under the sea-bottom in several localities are those composed of 40~60% kaolinite, 20~35% illite, and more or less than 10% montmorillonite and chlorite. The relation of their relative quantities to some of the mechanial properties measured after the ordinary rule remains yet to be more precisely researched specifically in combination with their qualities.

The fact that in Fukuyama the underlying clayey bed of considerably stiff property is easily distinguishable from the overlying silty bed on the ground of the grain-size integration curve, the mechanical characters within the range of the measured constants and the relative amounts of the clay minerals (lack of chlorite in the former) together with their qualities seems of significance in such regard as imparts a clue to the interpretation for the conditions or the stage of deposition and for the process toward a step of diagenesis or, in a narrow sense, suggests the formation of the former at the diluvial or any other earlier stages.

Absorption of various ions or others on the clay minerals is to be ascribed either to presence of somewhat free broken bonds with direction perpendicular to the sheet planes in the interlayer spaces or to deficit of the positive charges derived from isomorphic substitution within the structures. In relation to this, the immersion treatments executed in the present study are believed to have caused absorption of water molecules, Na^+ and Ca^{++} on the related sheets and to have given rise to its maximum especially in the case of montmorillonite represented by bentonite with very few impurities, as have been confirmed through x-ray diffraction for some basal planes and from the strongest infrared absorption for the interlayer water.

Differences in absorptivity due to each mineral species with pure quality and in absorbability inherent to each kind of the ions dissociated in the related electrolytes have become clear to more or less extent. However, those for the mixtures sampled really from the sediments are, because of their complexity in the grain-size distribution, constituent minerals and natural conditions or geologic histories, still now of obscurity and accordingly necessiate the further scrutinies in more details, without which the principal theme as to the mechanical properties of the sediments under consideration cannot be solved.

Several constants adopted here ordinarily after the JIS rule are regarded as nothing other than those applicable merely to practical use and not so much implicative from more substantial point of view, inasmuch as, for example, MEADE (1962) has already statistically derived the formula for void ratio related intimately to all of the mechanical properties in connection of the definite numerical value with the median for grain-size, the logarithm of the dissolved salts and the percentage of the absorbed sodium. This is surely a progressive view against the previous ones but why the last factor was to be restricted only to sodium is, even if emphasis was placed on its predominance in sea-water, somewhat questionable based on such a higher absorbability of calcium, as has been recognized through the present experiments, and a lot of any other ions in spite of their lower absorbability.

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