Title	Rôle of Mineralic Constituents in Mechanical Properties of the Estuarine Sediments Along the Hiroshima Bay
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Citation	Journal of science of the Hiroshima University. Series C, Geology and mineralogy , 4 (4) : 429 - 454
Issue Date	1965-05-15
DOI	
Self DOI	10.15027/53015
URL	https://ir.lib.hiroshima-u.ac.jp/00053015
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Rôle of Mineralic Constituents in Mechanical Properties of the Estuarine Sediments Along the Hiroshima Bay

By

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With 7 Tables and 24 Text-figures

(Received April, 20, 1965)

ABSTRACT: The present research has been commenced in order to find out the relation of mineralogy to soil mechanics, since in spite of numerous works concerning the prevailing manipulations provided mostly for practical use there have hitherto been only a few dealt with and worthy mentioning from the standpoint of pure science.

The main objectives in the present case have been restricted to scrutiny of variation in Atterberg limit of some representative clay minerals comprised commonly in the estuarine sediments in relation to their absorbability ascribed not only to the simply superficial characteristics but also far more to the diagnoses derived essentially from their own inner structures, whereas of course some other factors were at the same time inspected to more or less extent.

It has thus become clear that mineral species, even if the grain-size distribution or others were taken into account, played the important rôles in mechanical properties of the soily matters in conjunction with the surrounding media.

CONTENTS

I. INTRODUCTION

Majority of the data given previously as to soils or sediments have hitherto been concerned leadingly with the manipulations for making a scrutiny into their mechanical properties from the standpoint of soil mechanics nearly regardless of their relation to the mineralic constituents contained.

In the recent studies concerning the alluvial sediments in Hiroshima Prefecture, the present writer (1963, 1965) has dealt with their stratigraphies and some mechanical characters such as plasticity and others of the fine-grained components with special respect to variation in quantity of the clay minerals comprised. As for this regard, I. Th. ROSENQVIST (1955) already skillfully referred to the conjunction of ion-exchange capacity of some minerals and other clayey substances with their plasticity though the mineralogically structural characteristics of the specimens have then been made light of to more or less extent, D. CARROLL (1959) placed emphasis of study on ion exchangeability of clay minerals, zeolites and some other allied minerals with not so much regards to their mechanical properties, R. H. MEADE (1963) statistically derived the void ratio, an essential of mechanical characters, from its relation to grain-size, absorbed amount of Na^+ and dissolved amount of the salt, and furthermore there have so far been plenty of authors elucidating the subject in question from various points of view (cf. D. W. TAYLOR, 1948; E. W. RUSSEL, 1950; G. P. TSCHEBOTARIOFF, 1952; J. F. ROMINGER *et al.*, 1952; J. M. HUNT *et al.*, 1953; G. BROWN, 1953; K. TERZAGHI, 1955; S. KAKITANI, 1953; D. M. ROY *et al.*, 1957; T. SUDO, 1958; F. DACHILLE *et al.*, 1959; M. KOIZUMI *et al.*, 1959; T. MITSUDA, 1960; G. V. CHILLINGAR *et al.*, 1960; M. YOSHIDA, 1961; T. FLUHR *et al.*, 1962; H. BOUTIN *et al.*, 1963; W. ENGELHARDT *et al.*, 1963; M. R. GALLEGO *et al.*, 1963; R. E. GEST, 1963; Y. KONDO, 1963; R. C. MACKENZIE, 1963; J. M. SERATORA *et al.*, 1963; M. C. DEKIMPE *et al.*, 1964 etc.).

It however seems regrettable that in most cases of the precedents substantial characteristics of the specimens, even if primarily and secondarily derived through miscellaneous processes or a sort of aging in certain media in relation to their inner structures, have not ever been standardized at the initial state but usually subjected to the tests just as in the sampling condition almost unconscious of such factors, and hence this may accrue in confusion or inaccuracy of the results obtained. Special care has accordingly been taken to the sampling and standardization of the specimens in the present report.

ACKNOWLEDGEMENT: The writer here wishes to express his sincere thanks for beneficial guidances and advices bestowed by Professor Yoshiharu UMEGAKI of Mineralogical Institute of Hiroshima University, for profitable criticisms imparted by Professor S. IMAMURA, Assistant Professors A. HASE and K. HIDE, Assistants M. NAKANO and A. SOEDA, of Institute of Geology and Mineralogy, Assistant Professor Y. TAI of Faculty of General Education, and for kindly helps given by T. ONO and T. OGAWA, Postgraduates of the same university. He is also indebted to Assistant T. SUGA of Chemical Institute for use of the infrared absorption spectrometer, to the members of Physical Institute for use of the electron microscope and to President K. MATSUMURA and Chief Y. SEGAWA, of Chugoku and Shikoku Reconstruction Office K. K., affording him various facilities in the course of this study and Messrs. S. ASHIBA, A. MATSUURA, K. MIYAHARA and other members of the same office for their profitable assistances.

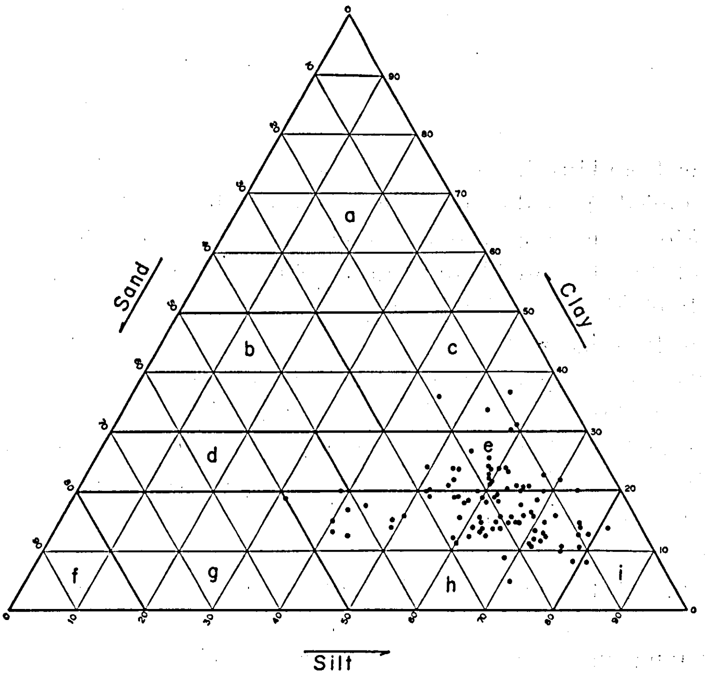
II. CHARACTERISTICS OF THE ESTUARINE DEPOSITS

A. ACTIVITY

It is generally deemed that plasticity, one of the mechanical properties, of the sediment potently depends on quantities of the clay fractions and organic matters included as well as on quality of the colloidal substances contained, of which the latter is, as has been elucidated by A. W. SKEMPTON (1953), phenomenally or mechanically defined as activity (indicated hereunder by Ac) given for the ratio of plasticity index (represented hereunder by PI) to the amount of clay, less than 2μ in size. The specimens provided for measuring activity are quite similar to those subjected to the previous researches, though selected out of the statistically predominant ones in the related area.

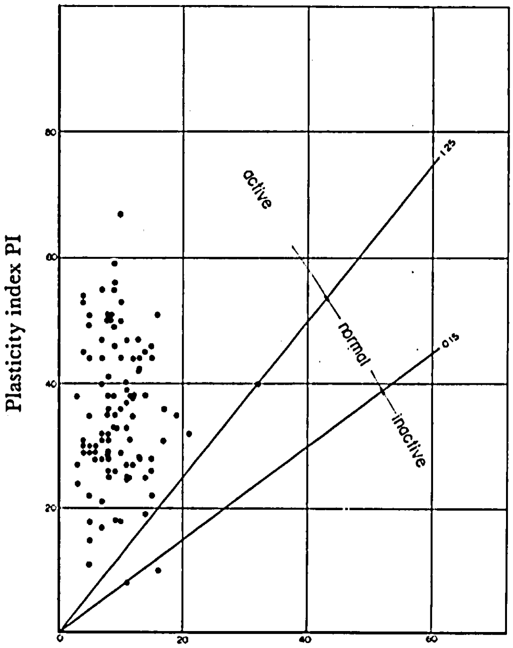
(1) Specimens from Iwakuni

Those collected from the silty bed in the depth of $-7.5\sim-26.00$m beneath the reclaimed land, grouped into sandy silt after the rule (see Fig. 1), are in the range of 20～60% in PI and more than 1.25 in Ac (see Fig. 2), and thus classifiable into active clay.



a Clay
b Sandy clay
c Silty clay
d Clayey sand
e Clayey silt
f Sand
g Silty sand
h Sandy silt
i Silt

FIG. 1 Classification of the specimens obtained from Iwakuni



Quantities of clay fractions ($<2\mu$) (%)

FIG. 2 Activity shown by the related specimen

(2) Specimens from Hiroshima

Those sampled from the silty bed in the depth of −7.00～−23.00m at the estuary of Motoyasu River, grouped foremostly into clayey silt (see Fig. 3), are in the range of 40～80% in PI and considerably more than 1.25 in Ac (see Fig. 4) and properly classified into active clay.

(3) Specimens from Kure

Those taken out from the silty bed in the depth of −4.80～−14.65m beneath the sea-bottom 20m off of the Nabe coast, grouped into clayey silt (see Fig. 5), are in the range of 5～85% in PI and abundantly more than 1.25 in Ac (see Fig. 6), and roughly classified into active clay, though dispersed in number.

(4) Specimens from Fukuyama

Those obained from the upper silty bed in the depth of 0～−10m at the sea-bottom, grouped into sandy silt, clayey silt and silty clay, are in the range of 20～90% in PI and classified into active clay, while those sampled from the lower clayey bed lying under the former, grouped into clay, clayey silt, silty clay and clayey sand (Fig. 7), are in the range of 10～40% in PI and indicate such divergencies in Ac as are dividable into active, normal, and inactive clay (see Fig. 8).

The fact is that the specimens provided for this sort of test are, as was already shown by the writer, ordinarily composed of 40～60% kaolinits, 20～35% illite and 10% montmorillonite associated with chlorite, of which the last only is almost

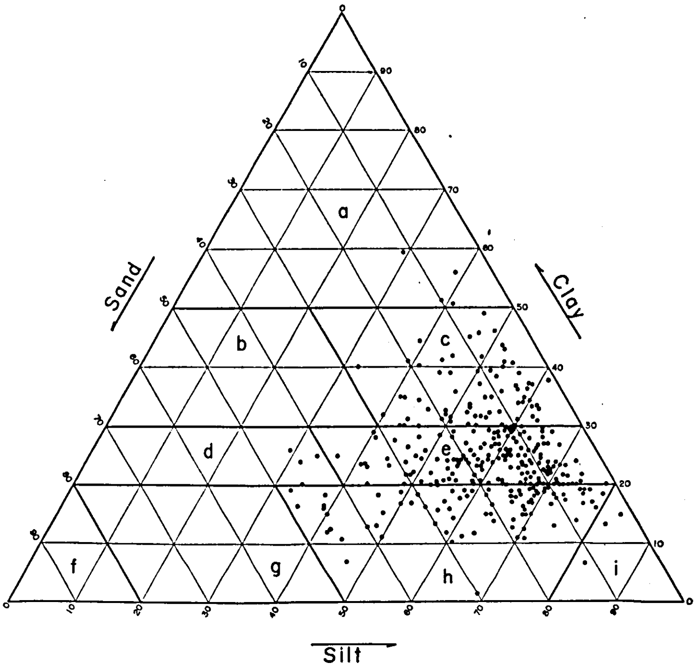


FIG. 3 Classification of the specimens obtained from Hiroshima

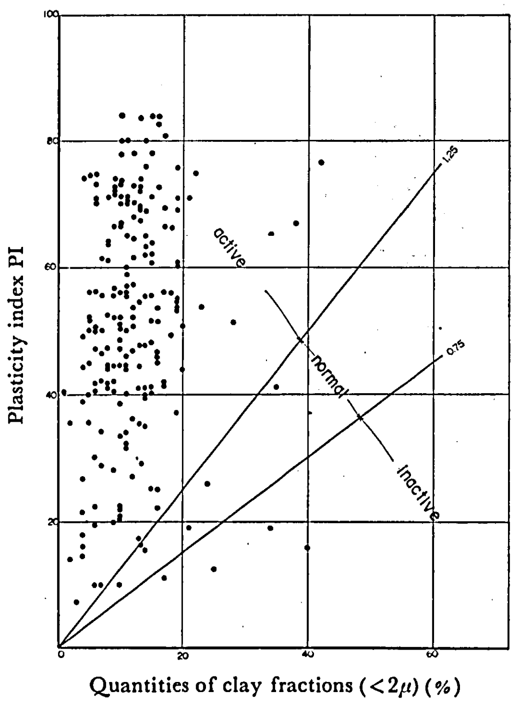


FIG. 4 Activity shown by the related specimen

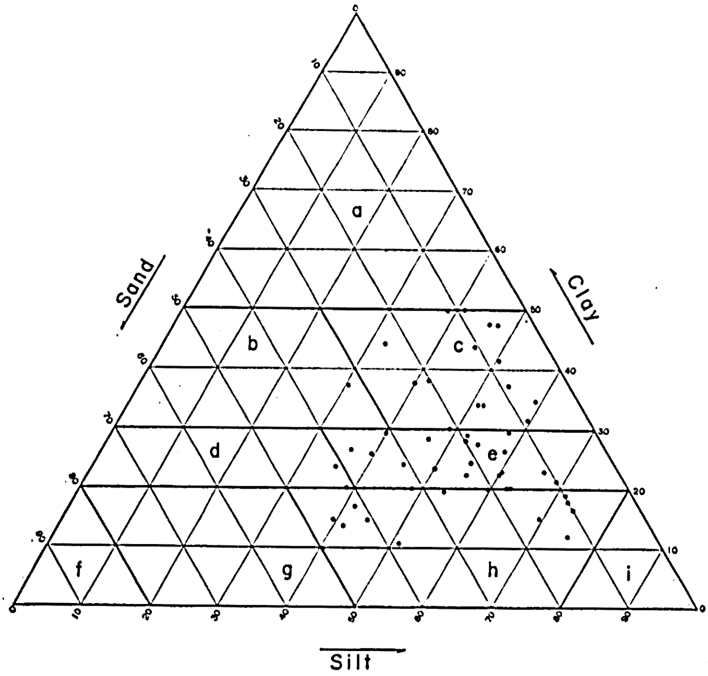


FIG. 5 Classification of the specimens obtained from Kure

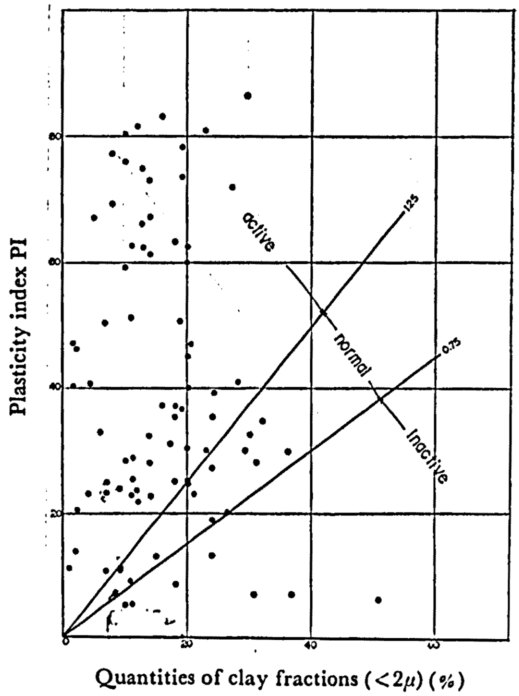
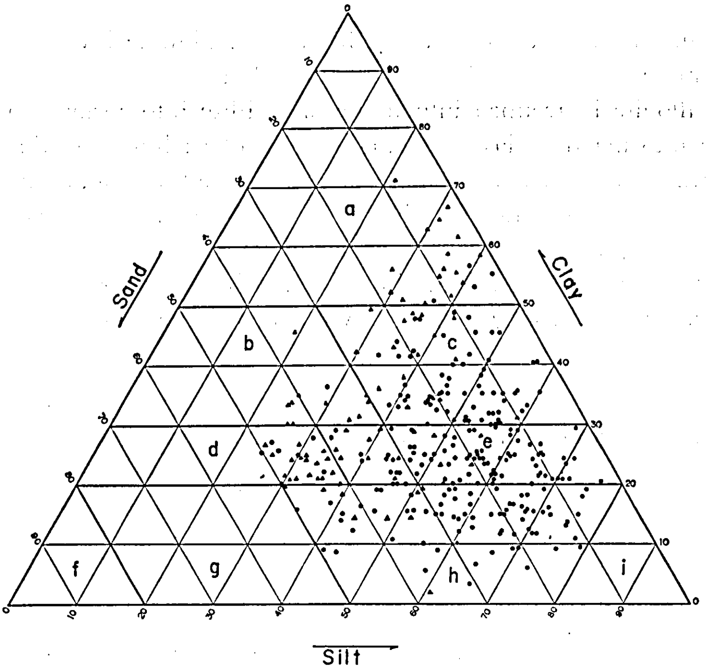


FIG. 6 Activity shown by the related specimen



● relating to those of the upper bed
▲ relating to those of the lower bed

Fig. 7 Classification of the specimens obtained from Fukuyama

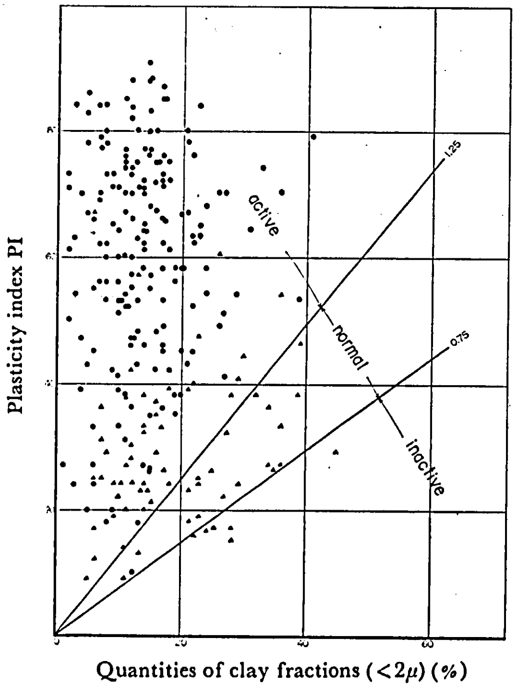
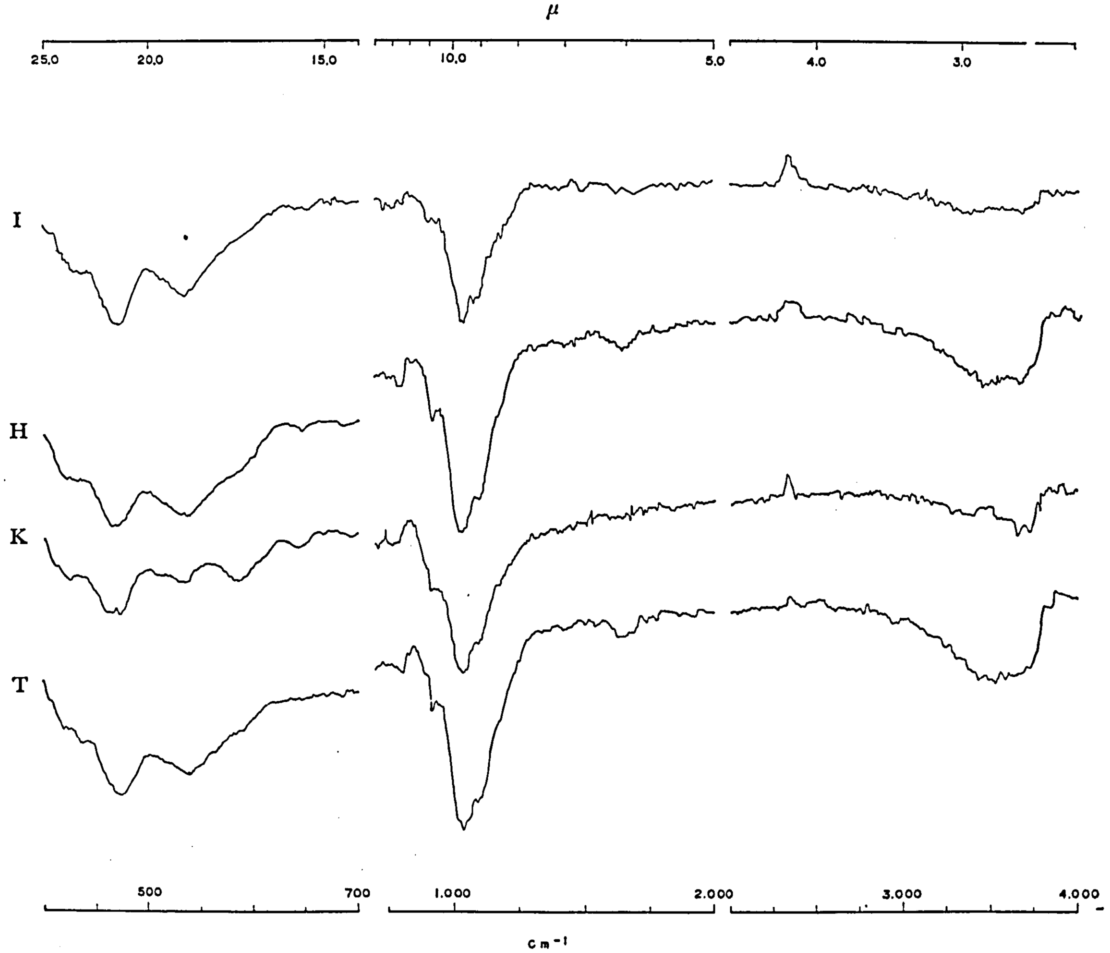


Fig. 8 Activity shown by the related specimen

completely deficient in those brought together from the lower clayey bed. In relation to these clay-mineral fractions obtained in the sediments, SKEMPTON was of opinion that montmorillonite is grouped into active clay, illite into normal clay, and micas and kaolinite into inactive clay. Taking account of such a result that a lot of the specimens with content of a little more or less than 50% kaolinite however surely pertain to active clay, some factors other than their own mineral species, for instance, the diagnostics acquired or derived primarily and secondarily in broader sense, presence, and amount of the coming-in substances such as various sorts of ions and organic matters and so on should be strictly pursued at the same time.

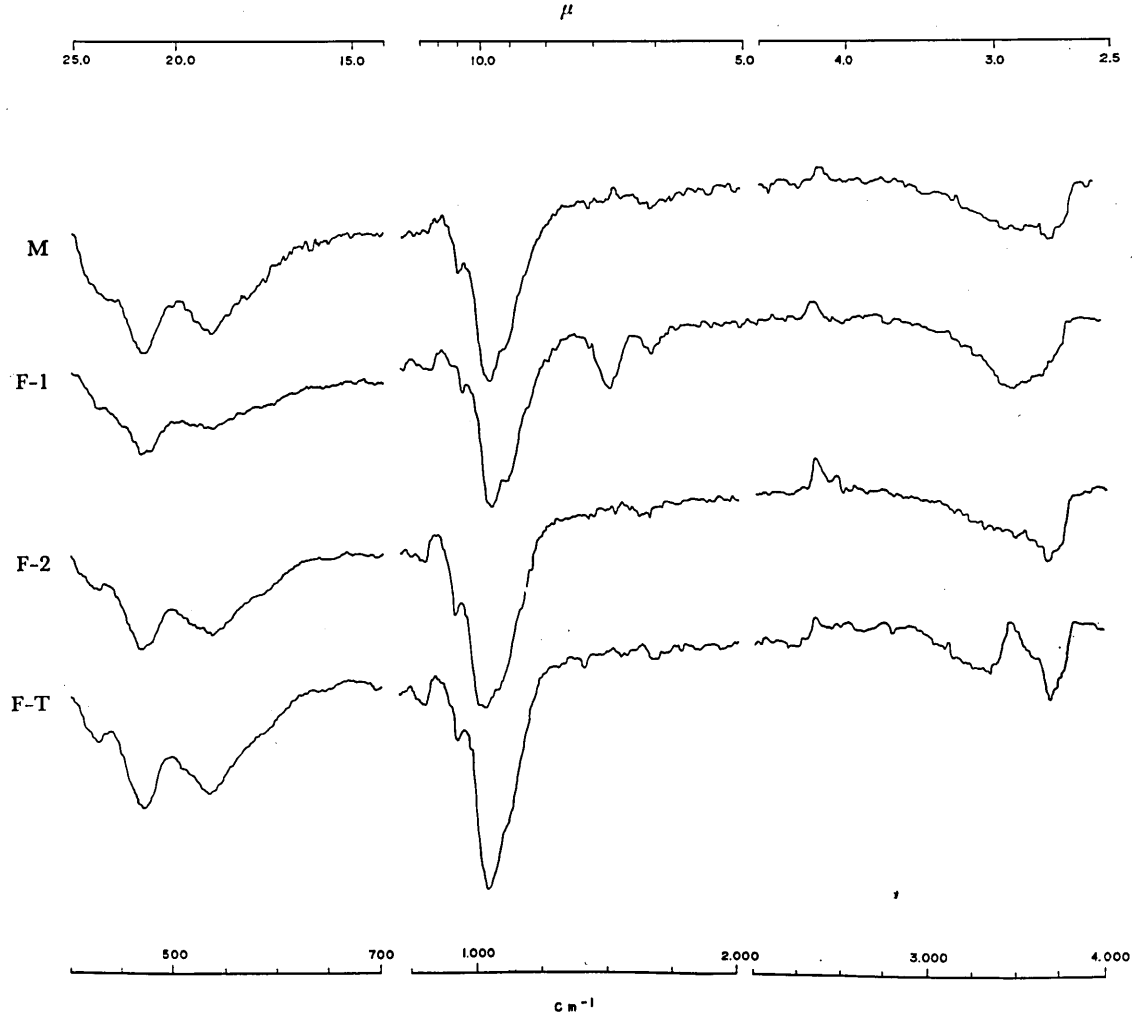
B. INFRARED ABSORPTION

As means for discriminating the synthesized characteristics of the specimens in



I: Iwakuni H: Hiroshima K: Kure T: Takehara (See T. Habara, 1963)

FIG. 9-1 Infrared absorption spectra of some clayey materials obtained from several regions



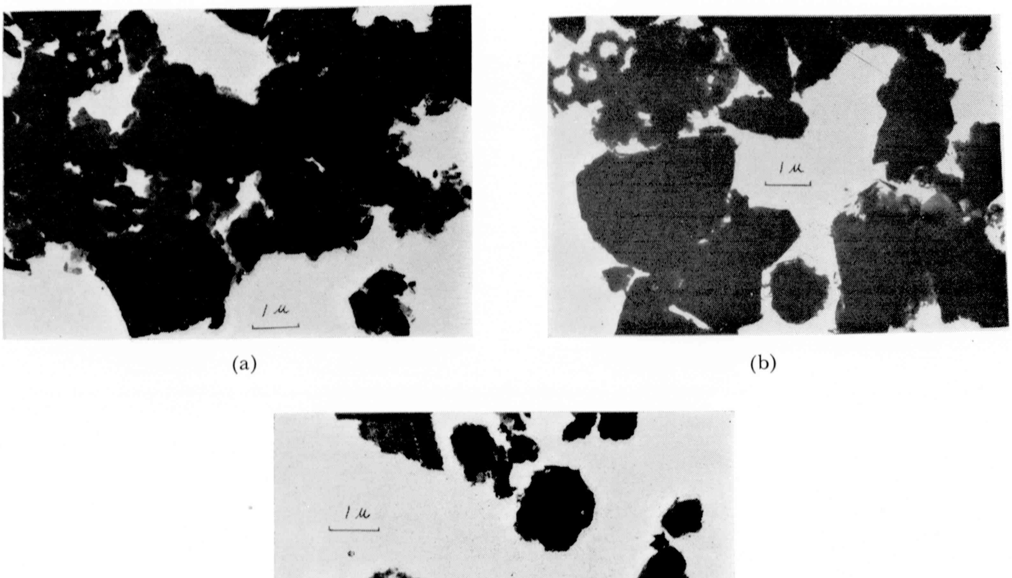
M: Mihara, F-1, F-2, F-T: Fukuyama (See T. HABARA, 1963)

FIG. 9-2 Infrared absorption spectra of some clayey materials obtained from several regions

question, patterns of the infraed absorption spectra within the range of 400∼4000cm^{-1} or 2.5∼25μ in wave length have been preliminarily inspected concerning those including really the mixtures of some clay minerals without any treatments by means of the Hilgar H-800 spectrometer in reference to the data given already for the relatively purified samples of bentonite (actually montmorillonite), dickite (representing kaolinite), sericite (instead of micaceous minerals) and chlorite. The results obtained are illustrated in Fig. 9, wherein the absorption bands appearing in the respective parts are above suspicion deemed to reflect the states of absorption and/or adsorption and of the resulted variation in the inner structures of the specimens just as was adverted to in the previous report. Remarkable are the marked absorptions in the range of 2.70～2.75μ for the specimens from Hiroshima, Fukuyama, Takehara and Mihara, of which the latter two are taken for comparison, and at 6.80μ indicating the presence of carbonate in the case of the shell-bearing one from Fukuyama.

C. ELECTRON-MICROSCOPICAL FEATURE

The enlarged micro-figures of the pulverized specimens have been examined in detail under the electron microscope. The results, though not expected so much, are given in Fig. 10, wherein the related photomicrographs only display the presence of somewhat irregular shaped but hexagonal plates reflecting the content of kaolinite, the ill-defined aggregates of montmorillonite, the fragmental diatoms and no vestige of halloysite believed a derivative of certain different origins.

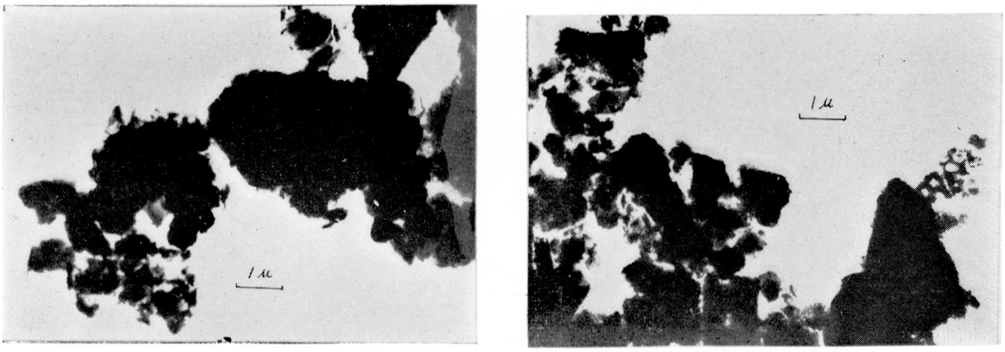


(a) (b)

(c)

FIG. 10-1 Electron-microscopical photomicrographs of some clayey materials ontained from several regions

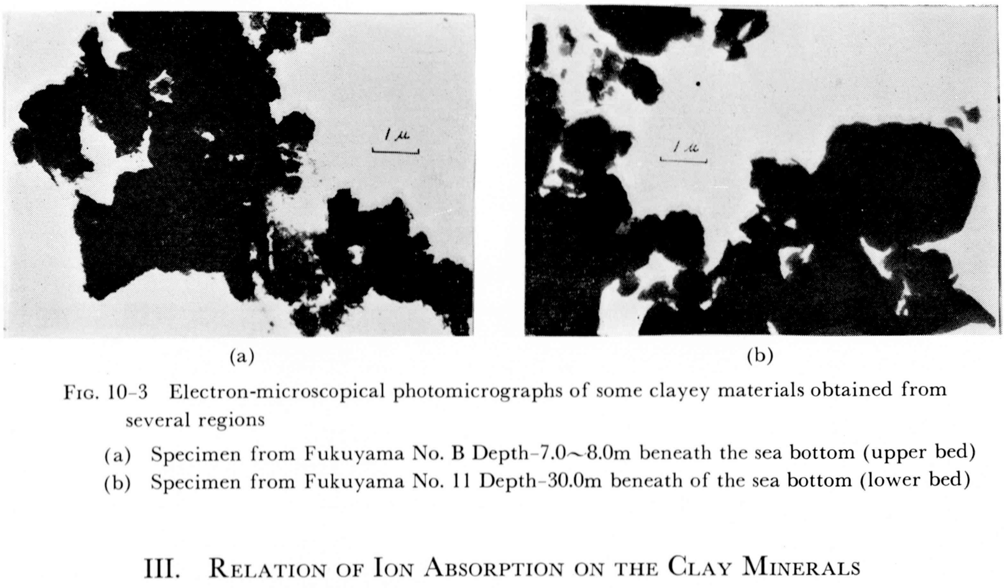
(a) Specimen from Iwakuni No. 3 Depth-8.0～8.7m beneath the reclaimed land
(b) Specimen from Hiroshima No. 4 Depth-6.6～7.0m beneath the sea bottom
(c) Specimen from Hiroshima No. 4 Depth-22.0～22.7m beneath the sea bottom



(a) (b)

Fig. 10–2 Electron-microscopical photomicrographs of some clayey materials obtained from several regions

(a) Specimen from Kure No. n Depth–7.0∼7.6m beneath the sea bottom
(b) Specimen from Kinoe No. 2 Depth–11.0∼11.8m beneath the sea bottom



(a) (b)

Fig. 10–3 Electron-microscopical photomicrographs of some clayey materials obtained from several regions

(a) Specimen from Fukuyama No. B Depth–7.0∼8.0m beneath the sea bottom (upper bed)
(b) Specimen from Fukuyama No. 11 Depth–30.0m beneath of the sea bottom (lower bed)

III. RELATION OF ION ABSORPTION ON THE CLAY MINERALS TO THEIR PLASTICITY

Since the important rôle of absorption of, or exchange with, certain ions or others occurring in inferably natural conditions on some clay minerals in their mechanical properties may, as was alluded to already in the former report, be easily deduced from inspection of their characteristics different from those pertaining to not originally but rather secondarily in every sense, some of the clay minerals such as bentonite, sericite, chlorite and dickite have been taken as standard in the experiments prior to those for the natural specimens mixted with impurities in considerable amount.

After immersed in distilled water, sea water and solutions of pure NaCl and $CaCl_2$ with concentration similar to that of sea water respectively, these standard specimens have been provided for grain-size analyses, measurements of plasticity after the JIS rule, re-examination of x-ray diffraction patterns for (001) and (002) spacings, infrared absorption in the range of $2.0\sim4.0\mu$, electron-microscopical observation and measurements of abrasion pH ascribed to primarily and/or secondarily absorbed substances.

A. TESTS FOR STANDARD MINERALS

1. *Bentonite*

The untreated specimens sent from Hôjun Yôkô K. K. are röntgenometrically composed of montmorillonite and a small amount of low cristobalite. The data for their chemical analyses are given in Table 1.

TABLE 1. CHEMICAL ANALYSES OF BENTONITE
(Analyst: Hôjun Yôkô)

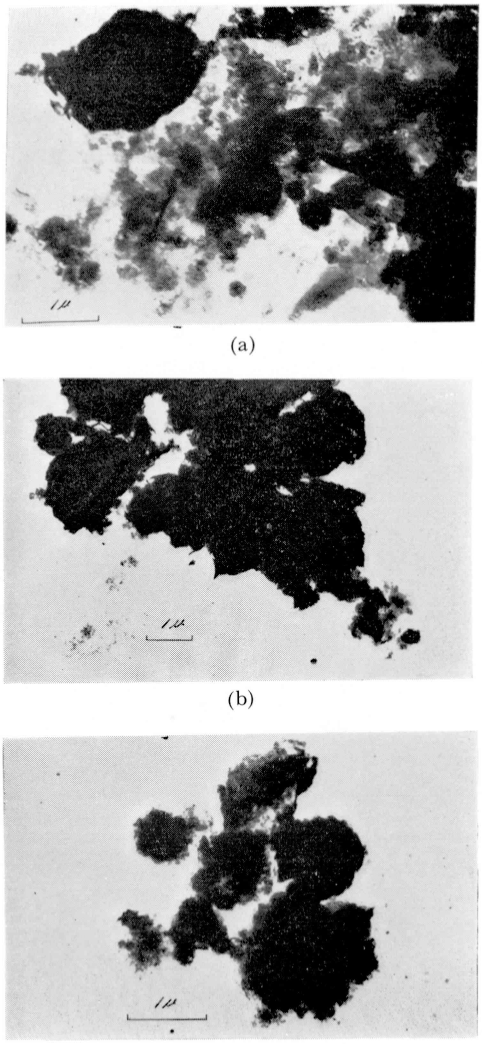
SiO_2	77.30
Al_2O_3	13.50
Fe_2O_3	1.50
CaO	1.00
MgO	2.00
K_2O	0.30
Na_2O	2.90
Ig. loss	3.80
Total	101.30 ?

In severer sense, however, it is uncertain wherefrom a part of such components as alkali earths and alkalies as well as of ignition loss might have been derived.

Those treated in the manner mentioned above reveal no remarkable variations in their electron-microscopical figures (see Fig. 11) but splitting of (001) spacing of the untreated specimens at 14.4Å into 15.1Å, 14.40Å, and 13.2Å in the case of treatment with NaCl, its contraction and decrease in intensity with pure water, and its expansion with $CaCl_2$ and with sea water are röntgenometrically recognizable (see Fig. 12).

Save for such a fact that intrusion of most of the ions absorbed into the interlayer structures, as was pointed out by R. E. GRIM (1953), hold good similarly in this case, swelling of (001) spacing is construed as a result of absorbability of Ca^{++}, higher than that of Na^{+}, due to its valence electrons and the complicate splitting of the same spacing as a result of superficial capturing of Na^{+}.

The emergence of illite from montmorillonite through ion exchange in the case of treatment with sea water is, in spite of the view proposed by S. KANEMATSU and H. ISOZAKI (1961), not discernible at all, since it may also be ascribed to presence of the resembling spacings revealed by the absorbed or remained salt owing to incomplete washing, as to the results and manipulations of which miscellaneous questions still remain to be solved.

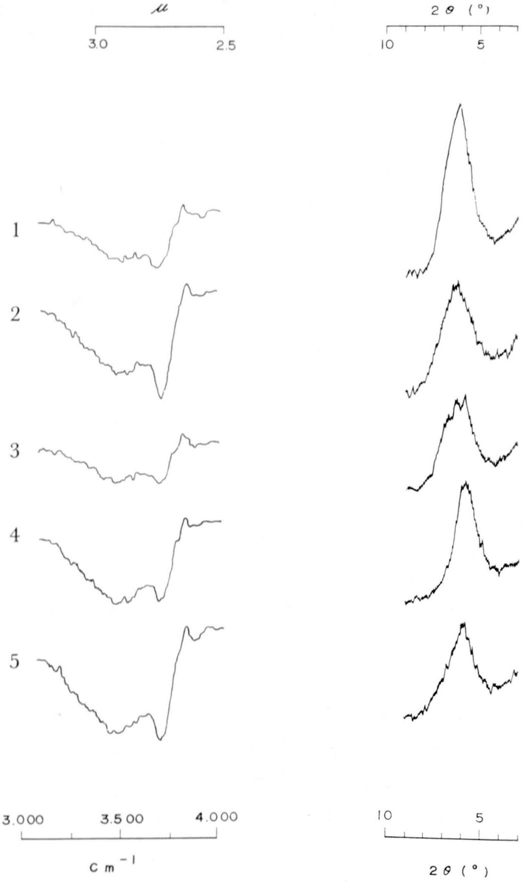


(a)

(b)

(c)

FIG. 11 Electron-microscopical photomicrographs of bentonite
(a) untreated
(b) NaCl treatment
(c) $CaCl_2$ treatment



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

FIG. 12 Effects of OH on (001) spacing of bentonite

Infrared absorptions caused by structural OH at 2.72μ are particularly conspicuous in the cases with distilled water, sea water and $CaCl_2$ while those relating to the interlayer water at 2.8~3.0μ are also remarkable in the cases with sea water and $CaCl_2$.

2. Sericite

The untreated specimens of Murakami Clay Industry K. K. have hitherto been believed to be composed merely of sericite and quartz on the basis of their chemical analyses, as are presented in Table 2, whereas the slender microcrystals, more than 1.5μ in length, observed electron-microscopically and the x-ray diffraction at 7.1~7.2Å surely point to the mixing of halloysite in certain amount and there also seems inaccuracy in the contents of alkali earths and alkalies together with ignition loss.

TABLE 2. CHEMICAL ANALYSES OF SERICITE
(Analyst: Murakami Clay Industry K. K.)

SiO_2	63.48
Al_2O_3	25.78
TiO_2	0.21
Fe_2O_3	0.34
MnO	tr.
CaO	tr.
MgO	1.01
K_2O	2.26
Na_2O	0.76
Ig. loss	5.57
Total	99.41

Those subjected to several treatments indicate almost no morphological variations under the electron-microscope (see Fig. 13), while increase in the diffraction intensity of (002) spacing however appears commonly in each treatment, and especially in the case with $CaCl_2$ the broader peak representing the same spacing becomes clear and is invariable even after heating at 110°C for 2 hrs.

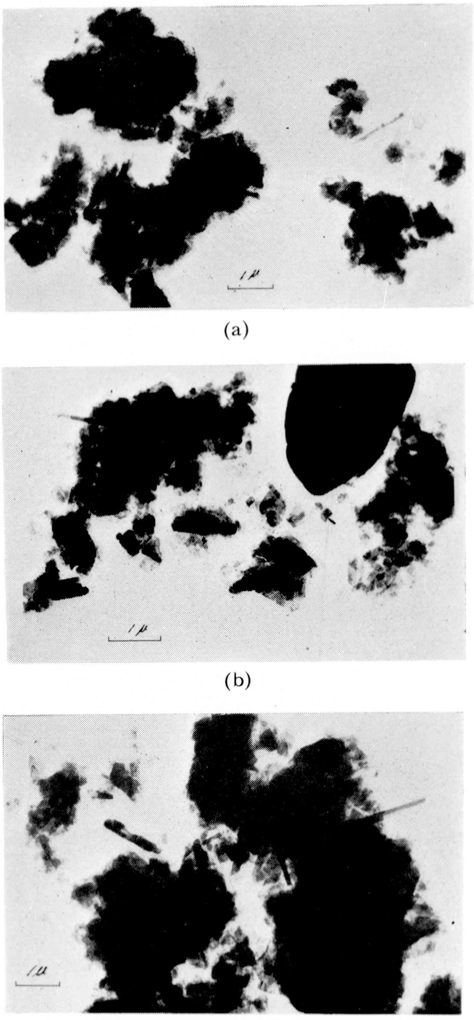
Infrared absorption bands are commonly observed at 2.72μ for OH and 2.8~3.1μ for the interlayer water, whereas $CaCl_2$ treatment yields their broadening either at 2.72μ or especially at 2.9μ, suggesting a substitution of Na^+ or K^+ in the interlayers with Ca^{++} (see Fig. 14).

3. *Chlorite*

The specimens obtained from the Wanibuchi mine, Shimane Pref. are of mixed-layer structure and mostly of well-defined linear form accompanied with irregularly platy one, indicating no difference in the effects of several treatments at least under the electron-microscope (see Fig. 15).

Compared to the x-ray diffraction peaks of the untreated specimens, those pertaining to the basal spacings (001)~(004) are found developed with immersion in distilled water, most conspicuously with $CaCl_2$, weakened with NaCl, and invariable with sea water.

Infrared absorption bands ascribable to OH contained in the structure are surely observed at 2.77μ and 2.90μ but their differences caused by any treatments are not so much remarkable (see Fig. 16).



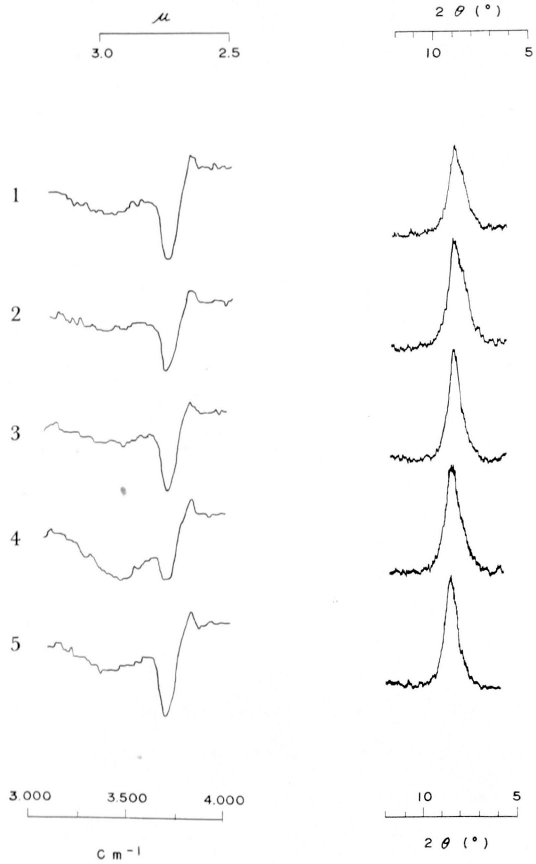
(a)

(b)

(c)

Fig. 13 Electron-microscopical photomicrographs of sericite

(a) unteated
(b) NaCl treatment
(c) $CaCl_2$ treatment



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

Fig. 14 Effects of OH on (001) spacing of sericite

4. Dickite

The specimens obtained from the Shōkōzan mine, Hiroshima Pref. are mixed with certain amount of diaspore and pyrophyllite, and electron-microscopically composed of the aggregates of thin platy microcrystals, about 4μ in diameter, though the ideally hexagonal plates have not been discriminated in the related specimens probably owing to ill dispersion (see Fig. 17).

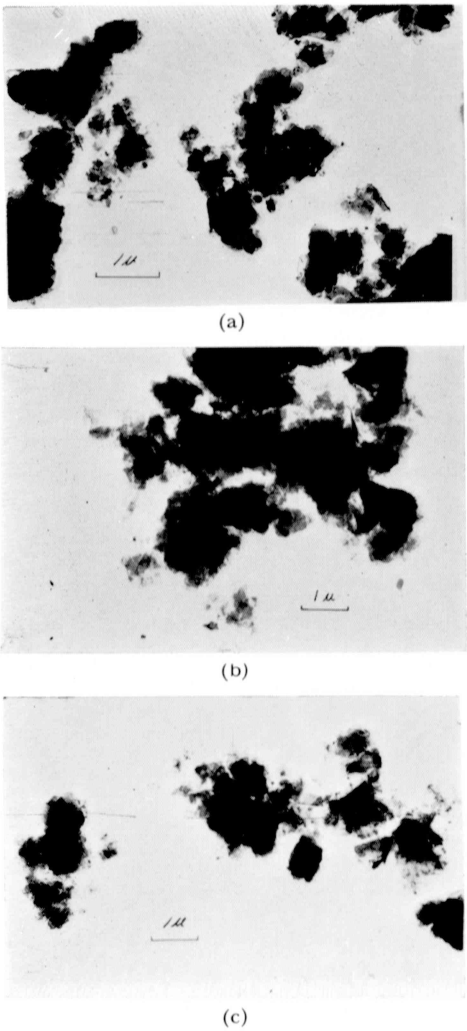
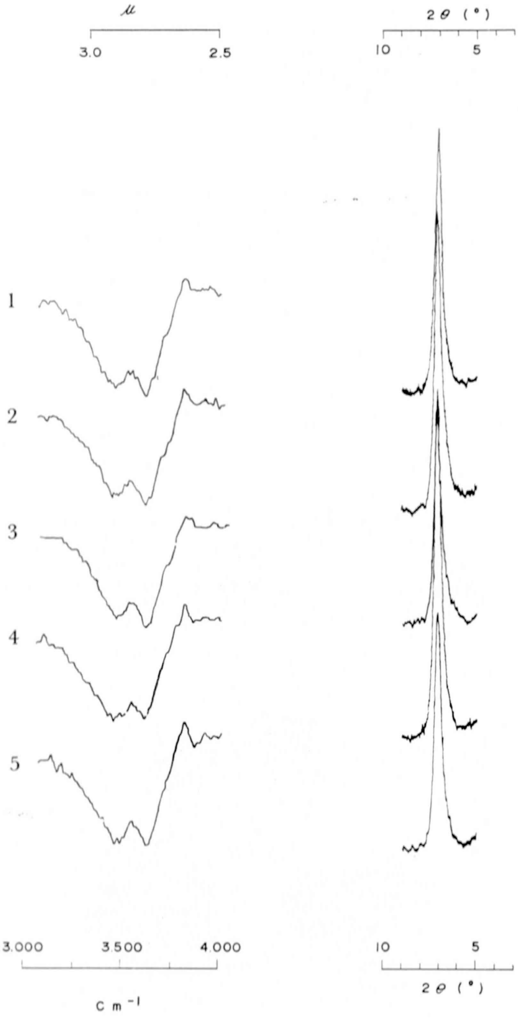


FIG. 15 Electron-microscopical photomicrographs of chlorite

(a) untreated
(b) NaCl treatment
(c) $CaCl_2$ treatment

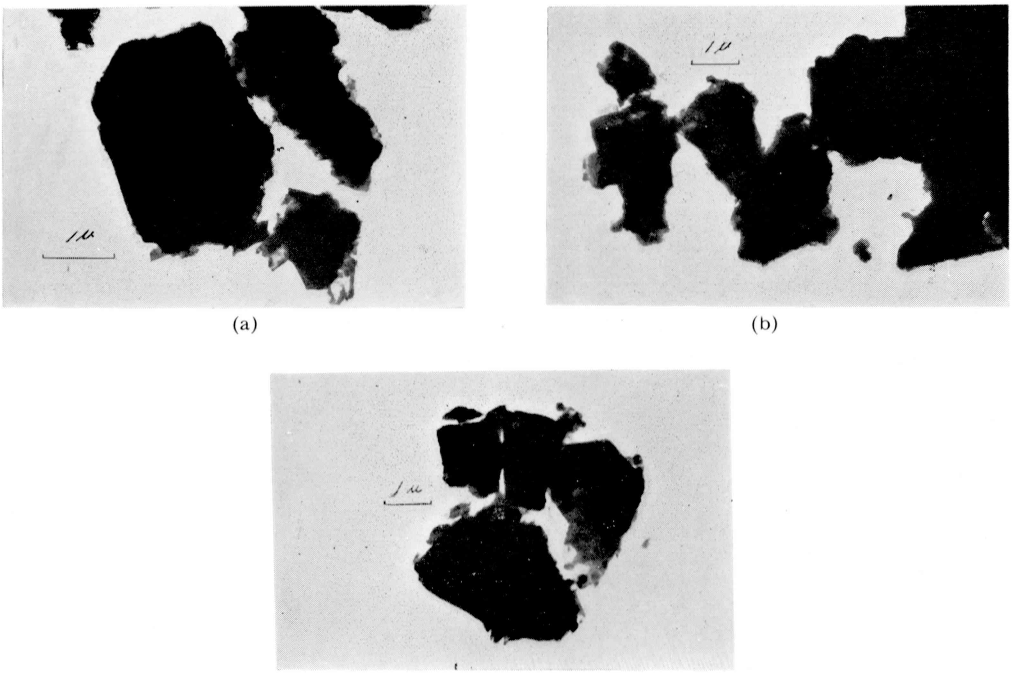


1. untreated 2. H_2O treatment 3. NaCl treatment 4. $CaCl_2$ treatment 5. sea water treatment

FIG. 16 Effects of OH on (001) spacing of chlorite

X-ray diffractions for the spacings (002) and (004) are generally strong, specifically obvious with $CaCl_2$ treatment, weakened with NaCl and invariable with distilled water and sea water.

Infrared absorption bands for the untreated specimens are confirmable at 2.66μ and 2.72μ accompanied with 2.70μ and those after the treatments with distilled water and $CaCl_2$ are found strengthen to a slight extent (see Fig. 18).



(a) (b)

(c)

FIG. 17 Electron-microscopical photomicrographs of dickite

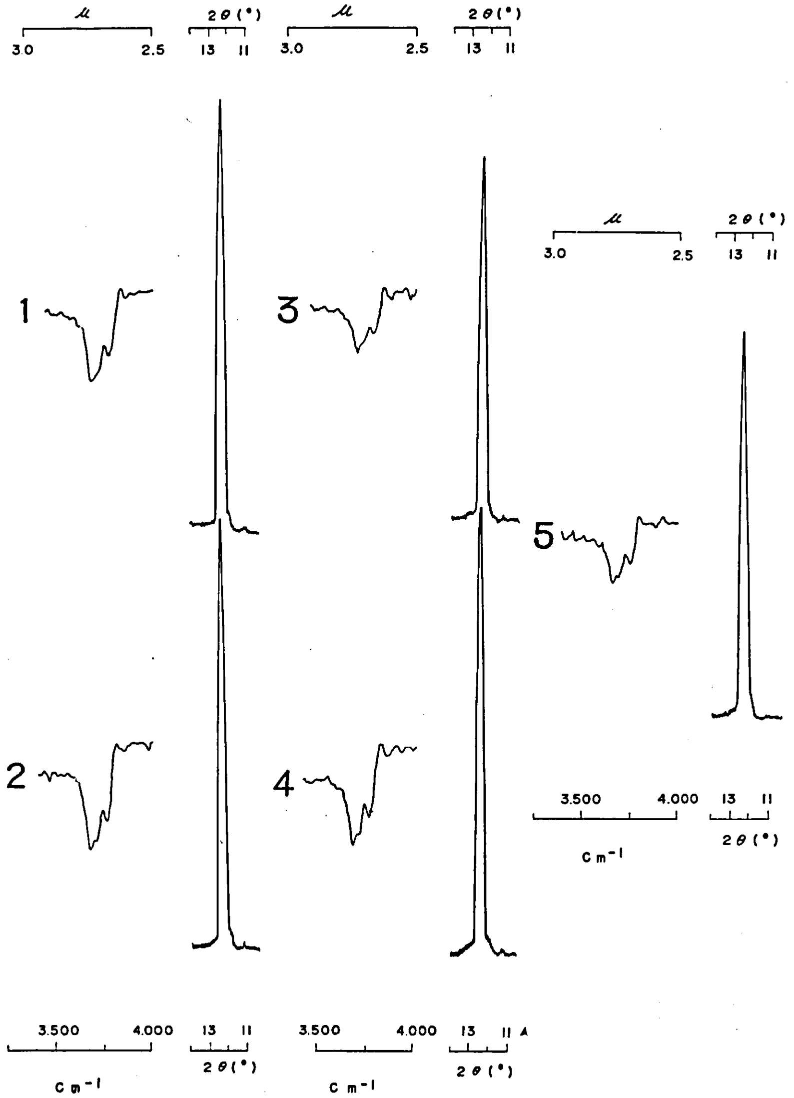
(a) untreated
(b) NaCl treatment
(c) $CaCl_2$ treatment

B. GRAIN-SIZE DISTRIBUTION

Prior to pondering on the mineralogical effects on plasticity, grain-size and crystallinity of the minerals included are to be checked. Accordingly, the grain-size analyses through the ordinary method concerning the standard clay minerals mentioned above have been put into operation, the results of which are shown in Table 3.

TABLE 3. DATA FOR GRAIN-SIZE ANALYSES OF THE STANDARD MINERALS.

Contents / Mineral	Grain-size in mm			Classification after Mississipian rule
	>0.05	0.05~0.005	<0.005	
	Sand %	Silt %	Clay %	
Bentonite	27	4	69	clay
Sericite	1	18	81	clay
Chlorite	7	19	74	clay
Dickite	10	66	24	clayey silt



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

FIG. 18 Effects of OH on (002) spacing of dickite

C. ATTERBERG LIMIT

Instead of the previous works without any regards to the histories or careers of the specimens of their own, re-examination of the results obtained for those have been added to in the present research in reference to a sort of standardized state, as will later be enlightened.

It is however necessary to place emphasis on that the Atterberg limit measured at the first step according to the ordinary rule concerns the mechanical characteristics of the specimens without any preliminary treatments indispensable for standardization of their initial states but with several treatments in the present states just as they are. The data are plotted in Fig. 19 and exhibited in Table 4.

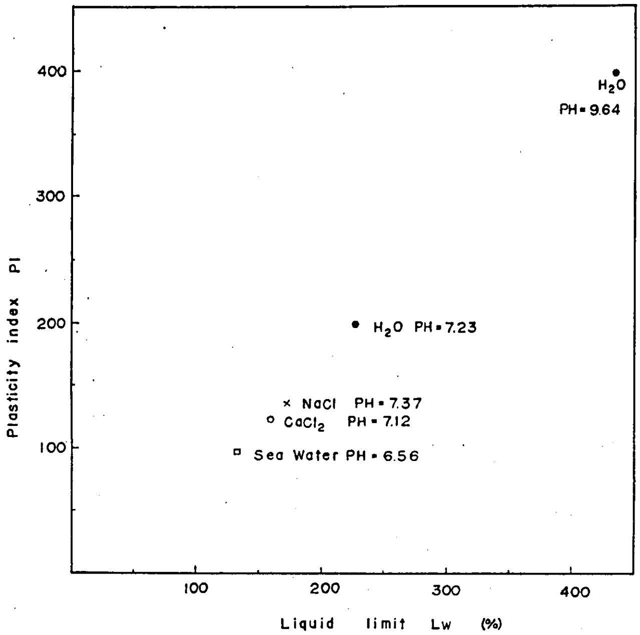
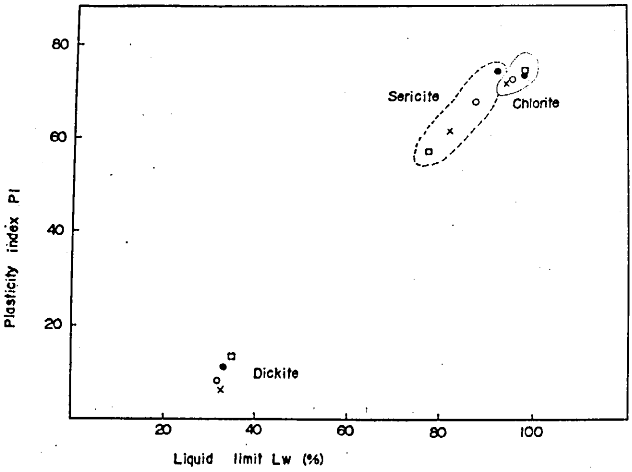


Fig. 19-1 Relation of Atterberg limit for standard mineral (bentonite) without any preliminary standardization



●: H_2O treatment ○: $CaCl_2$ treatment

×: NaCl treatment □: sea water treament

Fig. 19-2 Relation of Atterberg limit for standard minerals (sericite, chlorite, dickite) without any preliminary standardization

TABLE 4. VARIATION OF ATTERBERG LIMIT GIVEN FOR THE STANDARD MINERALS, REGARDLESS OF THEIR PREVIOUS STATES, AFTER IMMERSED IN SEVERAL MEDIA.

Mineral	treated with	Liquid limit %	Plastic limit %	Plasticity index
Bentonite	distilled water	436.3	37.8	398.5
	NaCl	174.1	37.6	136.5
	$CaCl_2$	160.0	36.6	123.4
	sea water	134.9	39.7	95.2
Sericite	distilled water	92.5	18.1	74.4
	NaCl	81.4	19.5	61.9
	$CaCl_2$	87.2	19.4	67.8
	sea water	76.9	19.7	57.2
Chlorite	distilled water	97.6	24.3	73.3
	NaCl	93.7	21.7	72.0
	$CaCl_2$	94.9	22.0	72.9
	sea water	97.7	22.9	74.8
Dickite	distilled water	33.3	22.8	10.5
	NaCl	32.4	26.6	5.8
	$CaCl_2$	32.0	24.3	7.7
	sea water	34.4	21.3	13.1

As far as the data obtained are concerned, it seems general that (1) Atterberg limit of bentonite is the highest of all for others especially in the case of pure H_2O treatment and somewhat higher for that with NaCl than for that with $CaCl_2$, (2) that of sericite is also the highest with H_2O treatment but bears an opposite tendency for NaCl and $CaCl_2$ treatments, reflecting the similar results obtained from x-ray diffraction and infrared absorption, (3) that of chlorite is found concentrated in the area for that of sericite immersed in pure water with each treatment and (4) that of dickite, though rather coaser in grain-size, is the lowest and a little higher for that with $CaCl_2$ treatment than for that with NaCl. Effect of grain-size on Atterberg limit has been affirmable in that, for example, that of the specimen No. 4 from Fukuyama, even though grouped into sandy silt, is, when passed through 200 mesh sieve, higher than that in the case of 70∼200 mesh.

On the other hand, Atterberg limit obtained for the same specimen containing clayey matter, less than 5μ in grain-size, composed of 49.7% kaolinite, 27.6% illite, 12.2% chlorite, 10.9% montmorillonite and 8.37% ignition-loss depends strikingly on further addition of 15.3% bentonite but not so much on that of sericite and chlorite in the same amount (see Table 5 and Fig. 20).

TABLE 5. VARIATION OF PLASTICITY WITH GRAIN-SIZE AND ADDITION OF OTHER CLAY MINERALS.

Variation in condition of the specimen	Liquid limit %	Plastic limtit %	Plasticity index	Marks in Fig. 20
70～200 mesh in size	73.3	24.4	48.9	○
less than 200 mesh	80.1	22.9	57.2	●
with addition of 15 % bentonite	94.2	23.1	71.1	△
with addition of 30 % bentonite	135.4	24.1	111.3	▲
with addition of 15 % sericite	72.0	21.0	51.0	□
with addition of 30 % sericite	79.8	21.0	58.8	■
with addition of 15 % chlorite	76.5	24.4	52.1	◇
with addition of 30 % chlorite	76.7	23.3	53.4	◆

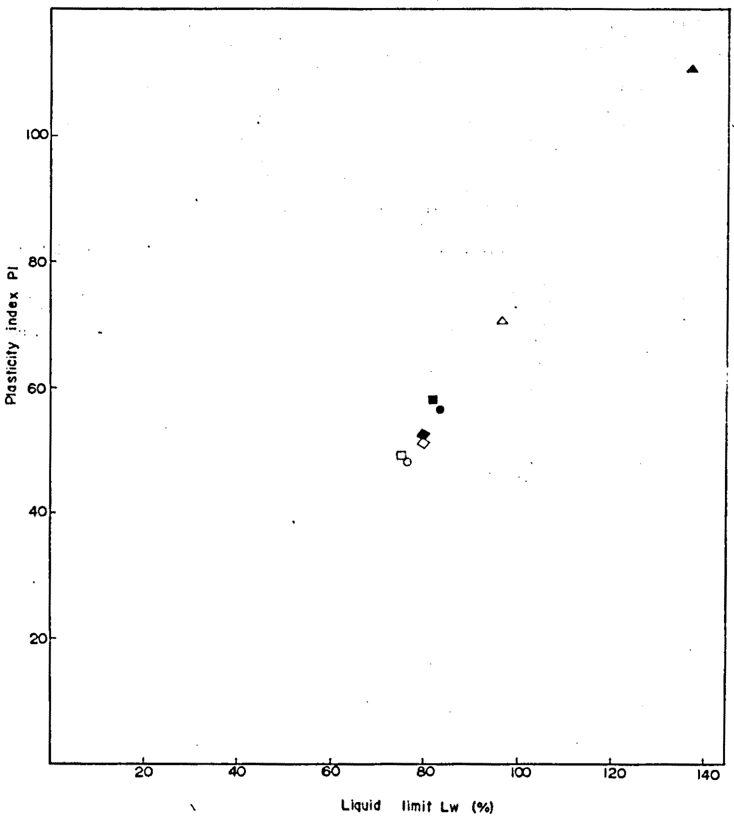


FIG. 20 Variation of plasticity with grain-size and addition of other clay minerals (see Tab. 5)

D. ABSORPTION OR EXCHANGE OF IONS

Effects of absorption in broader sense or exchange of ions or some others on the mechanical properties, specifically on plasticity, of the standard clay minerals have in the precedings been inspected for the specimens without any regards to their inner structures or to sundry characteristics derived primarily but necessarily from their inner structures in relation to the originally possessing but somewhat unstable ions in the interlayers and to the polarized water molecules, deficiency of positive charges and so on exposing on all surfaces of their particles.

As a subsequent means for estimating, though still indirectly, the amount of ions freed from the minerals, abrasion pHs shown in such media that 0.5g of the specimens were dispersed in 70cc of carefully distilled water (pH=6.9) and of other solutions respectively have, of course after expelling the dissolved carbon dioxide completely and settling the condition, been potentiometrically measured for comparison of their variation in reference to the saturated calomel electrode bridged with the hydrogen electrode immersed in the related media.

The specimens of bentonite, just as it is, revealing such a high pH as 9.64 have been washed with diluted HCI (pH=4.0) until 6.99 in pH and then immersed in diluted and saturated solutions of NaCl and $CaCl_2$ similarly in the case of sericite without any preliminary treatments. The assumed amount of Na^+ and Ca^{++} absorbed seemingly on the specimens are roughly calculated from variation in pH, as are mentioned in Table 6.

TABLE 6. APPARENT AMOUNT OF IONS ON THE MINERALS.

Mineral	Immersed in	Amount in me/100g
Bentonite	dil. NaCl Soln. dil. $CaCl_2$ 〃	Unstable and not determined
	sat. NaCl 〃	11.40
	sat. $CaCl_2$ 〃	0.23
Sericite	dil. NaCl 〃	21.54
	dil. $CaCl_2$ 〃	23.71
	sat. NaCl 〃	16.57
	sat. $CaCl_2$ 〃	0.85

It is most probable in the case of bentonite that a part of the weakly absorbed or adsorbed ions in its interlayers are easily removed away with washing but their remainders are successively dissolved in diluted solution, causing the later increase of pH value and instability of the state. Furthermore, the pH values shown by bentonite at the time of sampling are not constant because of its higher exchangeability and of complicated careers, so that such a long duration as some months to an year seems indispensable for the complete washing until its stable state. It may also be the case with allophane; though E. W. RUSSEL (1950) substantiated such a similar tendency that its cation-exchange capacity bears a random relation to pH values.

In view of this, pH values of bentonite measured in the same manner as mentioned above and Atterberg limit for the specimens obtained through immersion in water and some salt solutions and drying up in the air are shown in Table 7 and Fig. 19.

TABLE 7. pH VALUES AND ATTERBERG LIMIT OF BENTONITE.

Immersed in	pH	Liquid limit %	Plasticity index
water without washing	9.64	436.3	398.5
water after washing	7.23	228.0	192.2
dil. NaCl soln.	7.37	174.1	136.5
dil. $CaCl_2$ soln.	7.12	160.0	123.4
sea water	6.56	134.9	95.2

Most remarkable is that in spite of the same specimens of bentonite marked differences in Atterberg limit are found either in those without preliminary washing or in those washed almost to seemingly neutral state and the factors related to plasticity are roughly in proportion to abrasion pH, while it is also possible that with further washing for a long while the remainders of the absorbed matters are destined to be diminished to far more extent and to reach a far more stable state. Although it is still questionable how to obtain the most stable state admissible for the specimens on hand, the values of the second line in Table 7 at least are accountably to become diminutive and inaccuracy of the data given previously might have been attributed to this regard. In the cases with other salt solutions, the relations become somewhat complicated since deficiency, appearing through preliminary incomplete treatments restrictively on the surface, but not within the inner structure, of the ions or their excess caused contrarily by gradual increase of supply from the structure into the relatively diluted media during the later treatments may bring on confusion in the results obtained.

IV. CONSIDERATION

In order to enlighten at least a part of the factors yielding certain influences on shear strength or some other mechanical properties of the cohesive sediments, the specimens obtained from the estuarine deposits at some localities along the Seto Inland-Sea in Hiroshima Prefecture have been subjected to the related tests, on the basis of which the relation of, for example, Atterberg limit to the mineralic constituents, in severer expression, their absorbability for the coming-in substances and their separability for all of the absorbed, whatever originally or secondarily, have been clarified to more or less extent as the synthesized results derived mostly through x-ray diffraction, infrared absorption, variation of abrasion pH and so forth. At this step, however, allusions have, in view of confusion derived from coexistence of various minerals in miscellaneous ratios, been not so much to the native specimens sampled actually from the sediments but almost confined to the standard species.

Inspection of the data obtained in the present experiments clearly points not only to the highest absorbability in the case of bentonite compared with in the case of others but also rather to its separability for all captured essentially or secondarily in correspondence to each process passing precedingly. As far as absorption in broader sense is concerned, it is a matter of course that presence of the organic matters and content of colloidal substances are never to be neglected but even save for these factors differences of mineralogical compositions accompanied with their secondary characters ascribed to the inner structure are believed to reflect conspicuously on their mechanical properties.

At the same time it appears also experimentally that the x-ray diffraction patterns and infrared absorption bands are influenced, if occasionally to more or less extent, by certain treatments described above, suggesting the substitution of Si^{IV} with $Al^{(IV)}$ partly in the tetrahedron layers, less absorbability owing to so much sufficient matters as be without rooms for newly entering ones on the interlayer surfaces especially in the cases of all other than montmorillonite, and easier invasion of Ca^{++} than that of Na^{+} though differences in mobility of each ion and in numberes of valence electrons freed in the related media are here to be disputed in more details.

In addition, isomorphic substitution occurring in the octahedron layers of montmorillonite seems to play a role in adhesion of the alkalies and alkali earths but, on the contrary, to weaken the adhesive force on the surfaces of interlayers, onto which invasion of Na^{+} and holding of water molecules are surely easier than that of Ca^{++} with higher energy combining the interlayers with one another, resulting in higher plasticity. Kaolinite and others without isomorphic substitution are likely to reveal the lower values for Atterberg limit merely in relation to the randomly disposed broken bonds. As for this regard, MEADE's opinion given for the void ratio, referring only to Na^{+}, is somewhat problematical for the reason of ignoring any other substances such as organic matters, Ca^{++} and so on.

A sort of parallelism confirmed between liquid limit and abrasion pH for montmorillonite seems of due significance as an index of Atterberg limit. To be remarked here is how to interpret an abrasion pH because of its being derived from various factors alluded to already in some detail.

In the practical cases expansion of montmorillonitic clay through its own hydration has so far often been connected mechanically with, for example, some kind of landslide, while leaching and dissolving-out of the absorbed or adsorbed substances such as ions, organic matters or others through washing with, or immersion in, natural water with slightly acidic property is considered to have taken the main part in decrease of plasticity or variation of shear strength on the related spots.

But for further scrutiny into quantitative ratio of the standard minerals and into the practically collected specimens composed of some mineralic constituents, it seems impossible to reach an essentital solution for soil mechanics.

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