Effects of gypsum addition on sedimentation characteristics of Tondano Lake clay, Indonesia

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Abstract: A laboratory experiment was carried out to investigate the sedimentation characteristics of Tondano lake clay and effect of gypsum addition, included the settling patterns as the previous experiments. Firstly, the flocculation and dispersion characteristics, which are evaluated by turbidity, are substantially influenced by pH and salinity. Then, it was found that the addition of 5 % gypsum to this clay influenced the settling pattern and settling/consolidation rate. In the region in which consolidation settling does not occur (above 3000 % water content), the effects of gypsum addition on the settling patterns are significant; whereas in cases that the consolidation settling occurs (under 2000 % water content), the effects of gypsum addition are not so much significant. The greater water content of the clay suspension could induce a higher degree of flocculation, thus explaining sedimentation characteristics induced by gypsum treatment.
Key Words : Tondano Lake, sediment, gypsum, flocculation and dispersion, sedimentation

1.Introduction

Tondano Lake is one of the important and strategic natural resources for the people of North Sulawesi's life. This lake has multifunction, like source of fresh drinking water, washing and bathing, hydroelectric power, fish aquaculture, wet-rice field/agriculture and tourism. It is situated 693 m above sea level with an area of 4,638 ha, and Tondano River (41,100 m length) is its outlet, flowing into Manado Bay (Sinolungan et al., 2008). The Tondano attracts a lot of attention from a variety of societies, government and scientists because the condition of this lake tends to be deteriorated. Some problems of Tondano Lake are: 1) Shallowing the lake basin due to high erosion and sedimentation; 2) Decreasing the water flow at the outlet (Tondano River); 3) Blooming the aquatic plants; 4) Decreasing the habitats or species of fishes. The shallowing phenomenon may be seen from decreasing the water volume in dry monsoon, whereas in rainy monsoon the flood comes over the lake and its environs (Kemur, 1998). The Tondano is being a receiver of waste passing through the catchment's basin. For example, the Toliang Oki River carries an estimated annual sediment load of 63.01 t ha^{-1}, comprised from a variety form of land uses (Natural Resources Management Program, 2001).

Sedimentation phenomena have been the subjects of many decades of research, and while much insight has been gained concerning the hydrodynamics of sedimentation processes, comparatively little is known about the role of particle attractive forces in settling and sediment consolidation (Nasser and James, 2006). The ability of fine particles to settle rapidly is made possible by the process of particle flocculation (Kranck, 1973, 1980). Dispersion is also influenced by clay type, and cation concentration and composition as reported by Agassi et al. (1980). Ahmad and Karube (2005) found that kaolinite coagulated below pH 6 and dispersed well above that for both Na- and Ca-type of clays after it was dialyzed. At pH 8, the critical coagulation concentration for kaolinite, which was higher than for montmorillonite, was substantially influenced by the small size of particles. Kondo and Torrance (2005) demonstrated that, the presence of high-swelling smectite to low activity-mineral-dominated Leda clay increased the salinity and water content ranges above levels which consolidation settling and zone settling could occur. These settling rate patterns change with time in a manner that is dependent on the settling mode, water content and salinity.

The settling behavior of clay suspension is determined by interactions among particles as they are influenced by various aspects of the depositional environment. Understanding the depositional characteristics of soil suspension has practical applications related to the settling behavior during flocculating treatment of waste water, land reclamation by using dredged mud (Kondo and Torrance, 2003), and lake sediment formation. In this study, gypsum was used as a representative additive material in analyzing the effect of sedimentation characteristics of Tondano Lake clay, due to the fact that it dissolves over time in water.

Gypsum is found most commonly in nature as a sparingly soluble salt ($CaSO_4$-$2H_2O$) (Nettlejohn et al., 1982;

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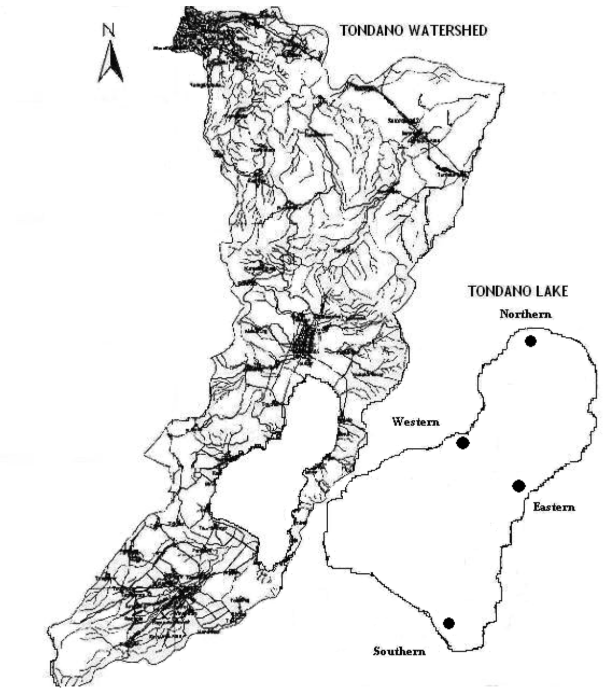
Table 1 Analytical characteristics of Tondano Lake clay.

KIND OF PROPERTIES	WEST	EAST	NORTH	SOUTH
Physical properties:				
Atterberg limits				
Liquid limit, w_L (%)	197.0	253.0	304.5	141.2
Plastic limit, w_P (%)	131.0	135.2	180.8	79.5
Plasticity index, I_P	66.0	117.8	123.8	61.7
Particle density (g/cm^3)	2.32	2.18	2.16	2.44
Grain size distribution				
Sand (> 0.075 mm) (%)	3.0	3.0	10.5	23.0
Silt (5μ m-0.075 mm) (%)	36.5	28.5	37.5	34.5
Clay (< 5μ m) (%)	60.5	68.5	52.0	42.5
Chemical properties:				
pH (1:5, soil: water extract)	6.3	6.4	6.6	6.5
CEC (cmolc kg^{-1})	29.8	27.1	30.8	25.0
Organic matter (%)	12.8	14.3	14.7	8.0
C/N ratio (%)	8.8	8.5	9.1	8.2
Total heavy metal concentration (mg/kg):				
Cd (United State-SQG = 1.2 ; Canada-SQG= 0.24)	2.25	0.51	0.63	0.52
Cr (United State-SQG = 81.0 ; Canada-SQG= 106.0)	11.32	10.68	11.85	15.36
Cu (United State-SQG = 34.0 ; Canada-SQG= 39.3)	54.92	81.64	26.23	30.07
Ni (United State-SQG = 20.9 ; Canada-SQG= 49.3)	24.75	13.30	28.67	22.06
Pb (United State-SQG = 46.7 ; Canada-SQG= 21.9)	6.72	5.46	7.44	0.74
Zn (United State-SQG = 150.0 ; Canada-SQG= 172.0)	89.74	134.45	22.04	38.43
Principal clay minerals	Kaolinite	Kaolinite	Illite	Illite, smectite



Sampling areas : **Kind of activities :**
Northern → sewage disposals, clearing forest, paddy farming,
Western → floating net, tourism, mixture crops/paddy
Eastern → clove plantation, paddy field, floating net
Southern → fishing/duck husbandry, sand mine material, paddy

Fig. 1 Sampling sites of Tondano Lake clay, Indonesia (• = Sampling area).

Verhaye and Boyadgiev, 1997). The concentration of a saturated gypsum solution is about 15 mM (Stumm and Morgan, 1970). Akae (1994) has examined that, gypsum application rate of 30 kg / 10a in the puddled water of paddy fields was sufficient to decrease the suspended solid (SS) concentration under 0.1 % in 12 hours, and basalt fertilizer was also found to promote flocculation to some extent and did not hinder the flocculation by gypsum.

The use of a number of amending materials including traditional agricultural products such as natural gypsum has been suggested for this purpose. The practical application of such a material would provide a better understanding of sedimentation characteristics in Tondano clay as prelude research. In the present work, the sedimentation characteristics of Tondano clay are experimentally examined in relation to the influence of gypsum addition.

2. Materials and methods

2.1 Stock material and sampling sites

Tondano clay material was collected from the bottom of Tondano Lake in September 2006. The sample was taken up by an Eckman grab sampler and its messenger in four different areas of the lake, as follows: 1) the northern outlet area in Tondano sub-district, 2) the eastern area in Eris sub-district, 3) the southern inlet area in Kakas sub-district, and 4) the western area in Remboken sub-district, which are shown in Fig.1. Each sampling area was determined by a distance of 50 meters, as counted from the margin line of the lake. This figure also illustrates the various activities in each area.

2.2 Physical and chemical properties of Tondano clay

Analytical characteristics of Tondano clay, which consist of some physical properties and chemical properties, are listed in Table 1. The physical properties consist of: plastic limit, liquid limit, plasticity index, particle density, and grain size distribution. Plasticity index was measured by plastic limit and liquid limit values, where the highest value (123.8) was at North clay. The highest particle density (2.4 g cm^{-3}) was at South clay. Grain size distribution was analyzed by a Hydrometer procedure and classified with a particle size of ASTM. Tondano Lake sediment was dominated by clay in all areas, and the eastern area had the highest clay content (68.5 %).

The chemical properties consisted of: pH, CEC, organic matter, C/N ratio, total heavy metal concentration, and clay mineralogy. Compared with the Japanese Agriculture Water Standard (2008), the pH value of Tondano clay, which has ranged from 6.3 to 6.6, was still suitable for all areas. The highest contents of CEC, organic matter, and C/N ratio were observed in the North clay. The content of heavy metals from Tondano clay has been compared with the Sediment Quality Guidelines (SQG) of the United States of America (National Oceanic and Atmospheric Administration, 2000) and Canada (National Research Council Canada, 1993). Some selected heavy metals, which contained in this clay, were: Cd, Cr, Cu, Ni, Pb, and Zn. Compared with the Japanese standard (Cu: 125 mg kg^{-1}, Zn: 140 mg kg^{-1}), the contents of Cu and Zn in Tondano clay were less (Ministry of the Environment of Japan, 1993). Clay mineralogy was determined by X-ray analysis procedure (Wada, 1966). Some clay minerals of Tondano clay were found. The mineralogy was dominated by illite (2:1-type) at North and South, kaolinite (1:1-type) at West and East, as well as a small amount of smectite (2:1-type) at South (Fig. 2). A clear peak can not be detected in those minerals due to the high organic matter content of the soils.

2.3 Experimental methods

2.3.1 Flocculation and dispersion measurement

The stock material (in diameter 425 μm-sieved) has been modified by the addition or removal of components, as described below, in order to test the nature of influences from various material factors on the sedimentation process. In order to clarify the effects of pH and salinity on the characteristics of flocculation and dispersion, all samples were Na saturated. Na-saturation was achieved for each experimental sequence by first washing the appropriate material both with 1M (58.5 g L^{-1}) sodium chloride (NaCl) solution and then twice with 30 g L^{-1} of the same sodium solution. The sodium saturated Tondano clay served as control material. The control material was treated into a vacuumed-condition, and the test-tube experiment (internal diameter of test tube = 15 mm; water content = 6000 %; volume of test tube = 20 mL) was done as shown below: (1) natural condition (with salinities from 30 to 2 g L^{-1} and deionized water) and 0.1 M NaOH / 0.1 M HCl solution (2, 4, 6, 8, 10 mL, respectively with salinity 30 g L^{-1}). The salinity of this experiment was controlled by using the NaCl solution; (2) alkaline and acid conditions in experimental sequences by 0.1M NaOH / 0.1 M HCl; 0.01 M NaOH / 0.01 M HCl; and 0.001 M HCl (2, 4, 6, 8, 10 mL, respectively with deionized water). Values of pH, salinity (converted from conductivity), and turbidity were measured with a pH meter, electrical conductivity meter, and turbidity meter.

According to the Japanese Industrial Water Standard (2008), the turbidity (suspended solid, SS) value is 15 g L^{-1}, whereas the Japanese Agriculture Water Standard (2008) is less than/equal 100 g L^{-1}. This figure has, therefore, shown that the flocculation and dispersion patterns of our results are divided into dispersion pattern (turbidity $>$ 100 g L^{-1}); intermediate pattern (turbidity between 16–99 g L^{-1}); and flocculation pattern (turbidity $<$ 15 g L^{-1}).

2.3.2 Sedimentation experiment

The preparation of a sedimentation experiment was conducted using a 1 L plastic bottle for each test series with the appropriate initial water contents (w_0) which ranged from 1000 to 8000 %. After these suspensions were left for one day, the soil was removed into a 6 cm diameter and 26 cm high acrylic cylinder which was then filled to 20 cm with the appropriate suspensions. For each test condition, the sedimentation processes were monitored for 14 days. The experiments for each initial water contents began from each kind of Tondano clays (West, South, East, and North). This sedimentation experiment was done with two kind of treatments, which were: 1) no added gypsum (as the control), and 2) with 5 % added gypsum. Throughout the experiments, sedimentation data were monitored by measuring electrical conductivity, turbidity, and pH of the suspensions after one day. All experiments were conducted in a laboratory at a room temperature of 27-29 °C. Sedimentation measurement (up to 48 h settlement) was carried out until an equilibrium position of the sediment-supernatant interface was attained. Subsequently the depth of interface was recorded with the settling time (Nasser and James, 2006).

Natural gypsum powder was added to the stock material to produce sub samples with the desired gypsum content with a weight of 5 % from the total dry-soil weight. The material was thoroughly homogenized using a household mixer. The gypsum content in the suspensions are 5.0, 2.5, 1.3, and 0.63 g L^{-1} for initial water contents of 1000, 2000, 4000, and 8000 %, respectively. Subsequently, insoluble gypsum powder remained in the suspensions below the water content of 2000 %, because the solubility is generally known as 2.1 g L^{-1} at 25 °C. Akae (1992) has demonstrated that the 0.25–1.0 g L^{-1} gypsum addition is very effective for flocculation of the puddled suspension. The 5

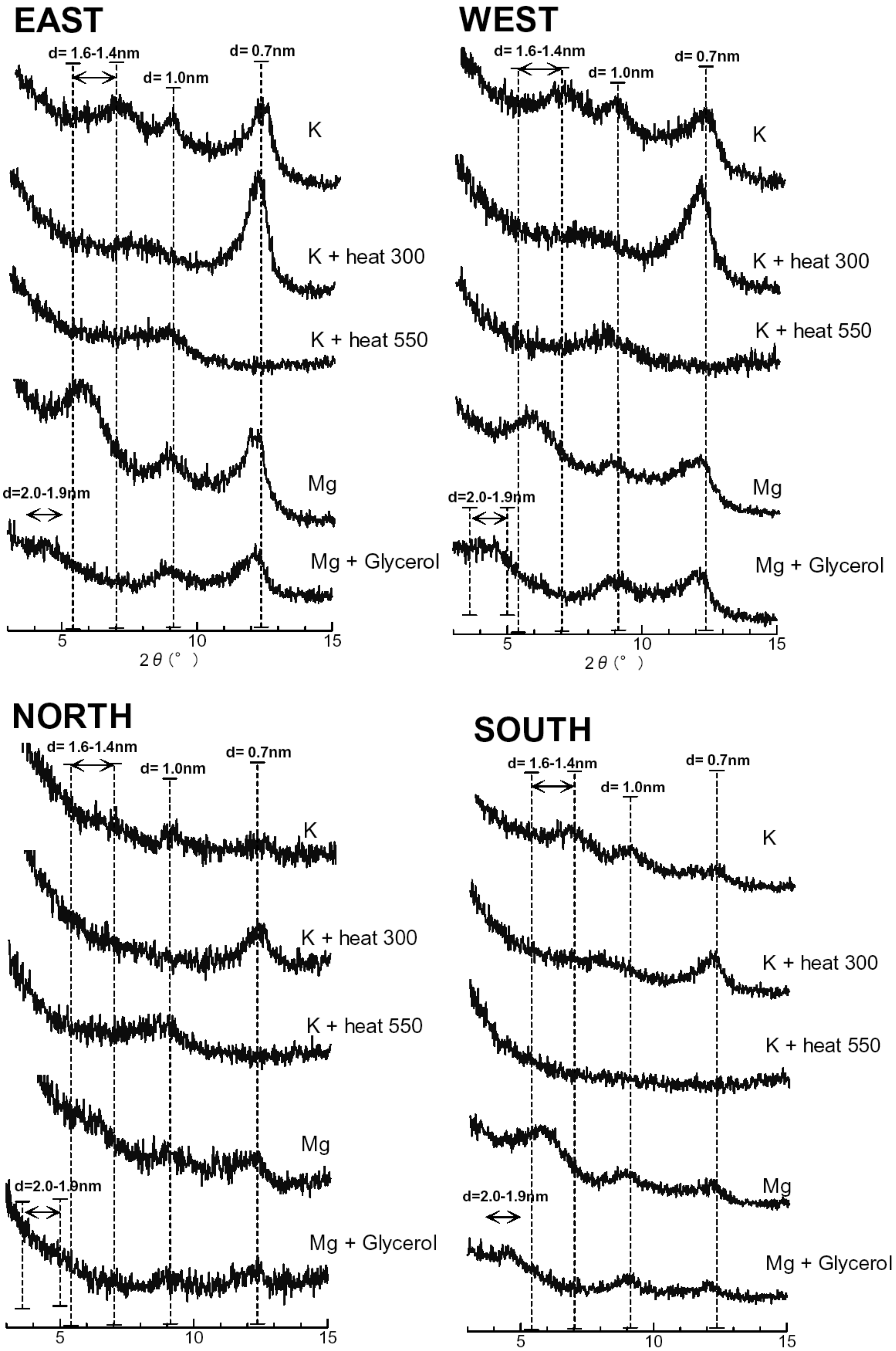


Fig. 2 X-ray diffraction patterns of Tondano clays.

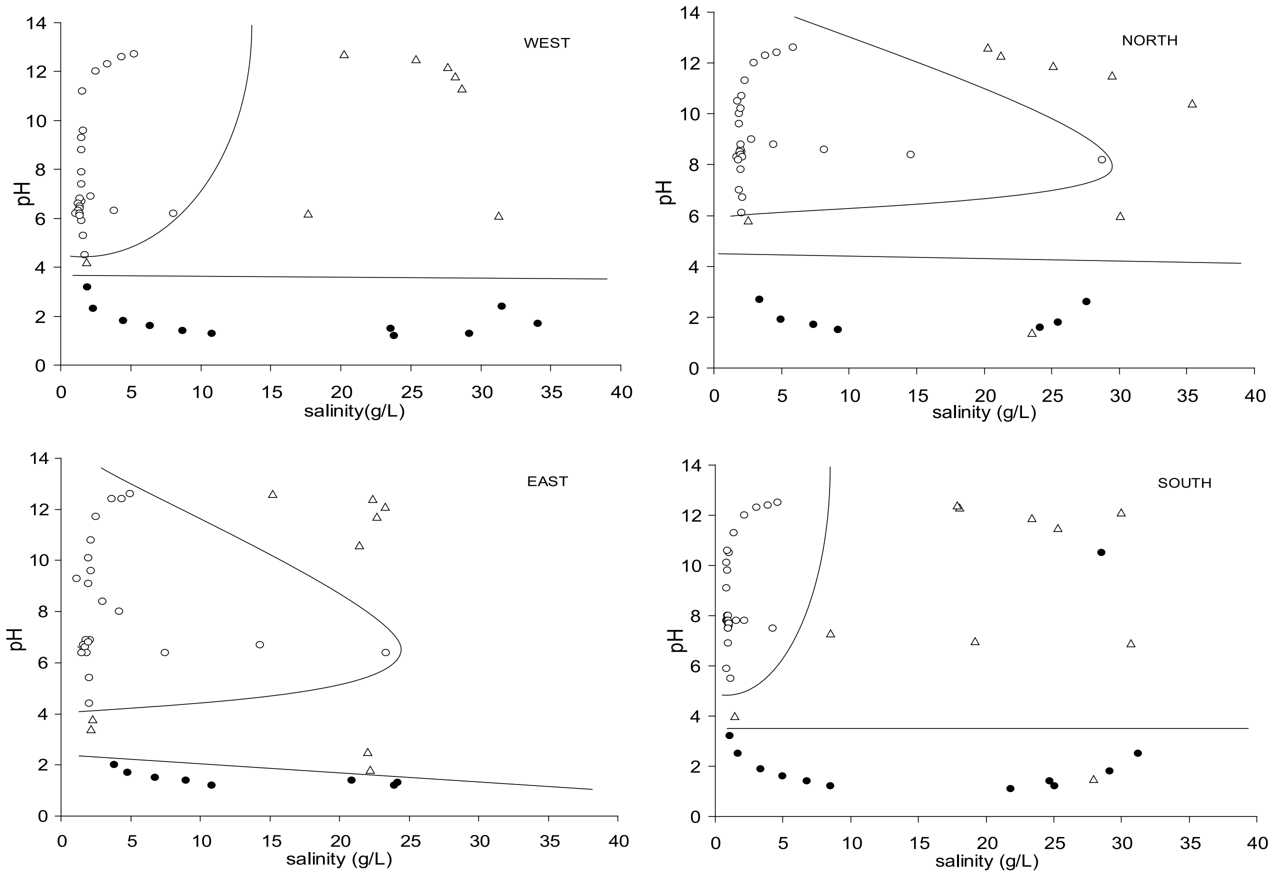


Fig. 3 Flocculation and dispersion patterns of Tondano clay. (○ = dispersion (turbidity > 100 g L^{-1}), △ = intermediate (turbidity 16–99 g L^{-1}), ● = flocculation (turbidity < 15 g L^{-1}), Solid lines distinguish the flocculation and dispersion patterns)

% gypsum addition for dry soil assumed to be enough for Ca adsorption to clay particles, and useful for flocculation of Tondano clay. But the further research is still needed to realize the most appropriate gypsum content.

2.3.3 Sedimentation pattern determination

The sedimentation pattern of our results has been determined according to the settling pattern of clay suspensions by Imai (1980), that, when the water content (or, particulate concentration) is selected as the physical condition of the suspension and the salinity is selected as the chemical descriptor of sedimentation environment, these patterns can be classified into four types: (1) dispersed free settling (DFS); (2) flocculated free settling (FFS); (3) zone settling (ZS) and (4) consolidation settling (CS). In dispersed free settling, no significant interaction between particles occurs and particles settle individually at rates according to their respective sizes; in flocculated free settling, larger flocs settle faster than smaller ones and the boundary between clear water and settling flocs is not sharp; in zone settling, flocculation occurs and the flocs settle in parallel creating a sharp interface above which the water is clear; and in consolidation settling, flocs are not formed, but rather the whole suspension gels into an interconnected flocculation that extends throughout the total volume, it then commences to consolidate (dewater) under its own weight. These settling types are widely observed, not only with clay suspensions but generally with suspensions of fine particulate materials (Fitch, 1979).

3. Results and discussion

3.1 Flocculation and dispersion characteristics of Tondano clay

Fig. 3 shows the flocculation and dispersion patterns of the Na-saturated material. Both flocculation and dispersion patterns were a part of the sedimentation characteristics. These patterns were determined by their turbidity value. Boundaries between the flocculation and dispersion patterns for Tondano clay represent the result of interactions between suspended particles under the specific conditions imposed. The extent of both dispersion and flocculation patterns is influenced by the pH and salinity of clay suspension. Below some pH levels, at flocculating salinities, the particles are sufficiently close together that flocculation occurs very quickly and extends throughout the whole volume creating a gel.

Examination of the Fig. 3 for Na-saturated Tondano clay shows that, dispersion is the dominant pattern at < 10 g L^{-1} salinity for West and South clays. However, the peak salinity which the dispersion pattern can be seen for North and East clays has been found at approximately pH 6–8. It

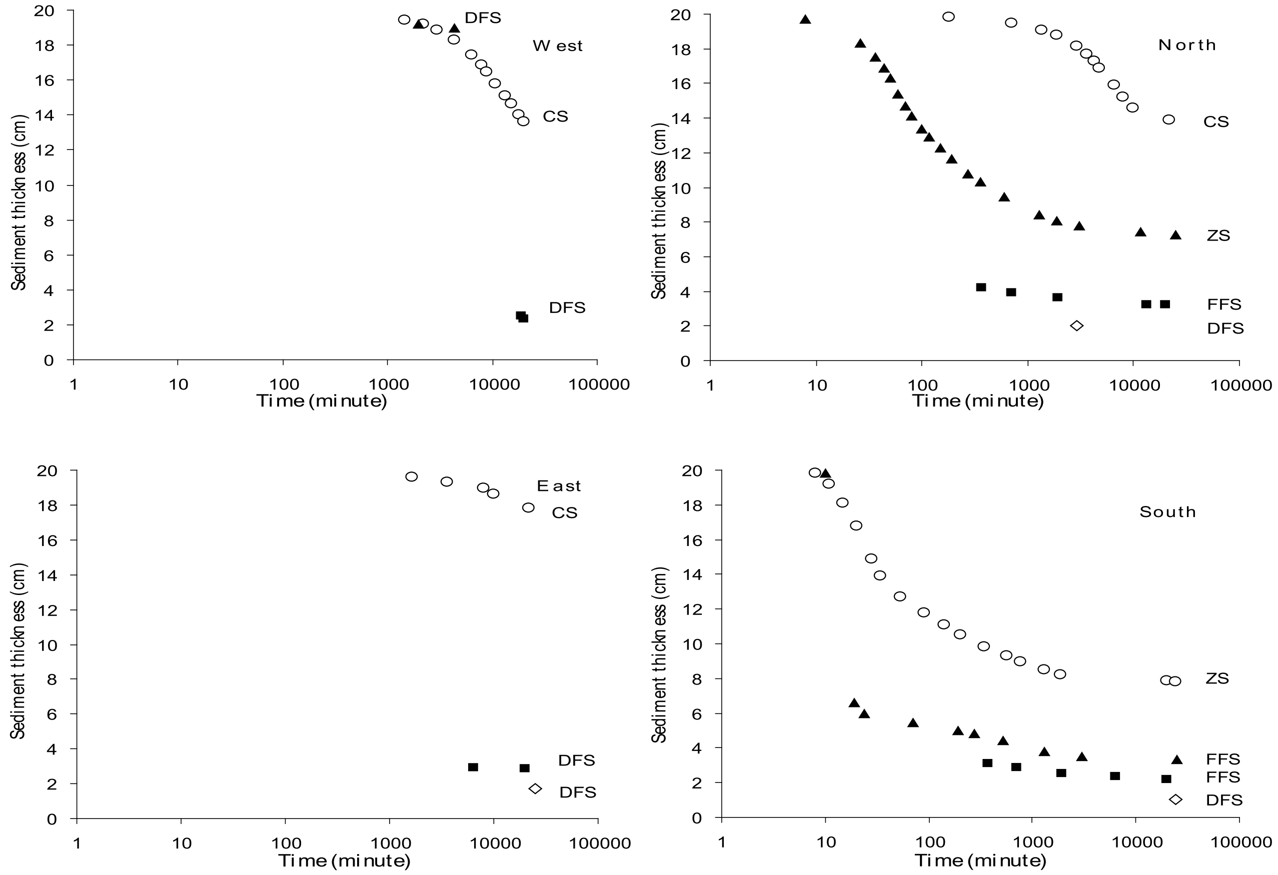


Fig. 4 Time-sediment thickness curves for control material. (Initial water content:○ = 1000 %, ▲ = 2000 %, ■ = 4000 %, :◇ = 8000 %).

has been concluded that the salinity at which a dispersion pattern occurs as the pH of the suspension approximately constant in all salinity ranges. At higher salinities, only patterns that involve flocculation and intermediate occur for all clays. Flocculation is also observed at low pH in spite of salinity range.

Because of the salinity and pH of each experimental condition can be readily identified from the graphs, the results will be identified by the alteration of experimental conditions from the standard (Na-saturated material) conditions. It is also possible to assess why the specific change occurred. As related to the clay mineralogy, kaolinite (1:1-type) is a pH-dependent mineral, whereas illite (2:1-type) is not a pH-dependent mineral. According to Brady and Weil (2002), kaolinite has mostly variable (pH-dependent) negative charges and exhibits modest positive charges at low pH values. Other factors which would affect the flocculation and dispersion patterns are organic matter and grain size distribution. Flocculation can occur easily when organic matter is low and grain-size distribution is not dominated by clay, however, dispersing activity of added organic matter inhibited the processes of flocculation and sediment accumulation (Kondo and Torrance, 2003).

3.2 Sedimentation characteristics of Tondano clay

3.2.1 Sedimentation patterns of Tondano clay with no added gypsum

Settling (time-sediment thickness) curves for selected water content of the natural material at selected areas of Tondano clay are presented in Fig. 4. This figure represents the control response to which gypsum-addition experiments are compared. The "sediment thickness" in all figures represents the thickness between the bottom of sediment and the lower zone of water which is free, or almost free, of particulate material, and the zone of high particulate concentration, where this interface can be definitively identified. The first point plotted for water content represents the earliest time that a sediment interface between clear or almost clear water and settling flocs or accumulating sediment can be identified. This does not always represent the upper boundary of the accumulated sediment because, in some cases, it is apparent that it represents the upper boundary of a large mass of settling flocs.

In the previous part of this paper it was explained by Imai (1980) that, there were various types of settling patterns such as: dispersed free settling (DFS), flocculated free settling (FFS), zone settling (ZS), and consolidation settling (CS). All settling types were observed with the ex-

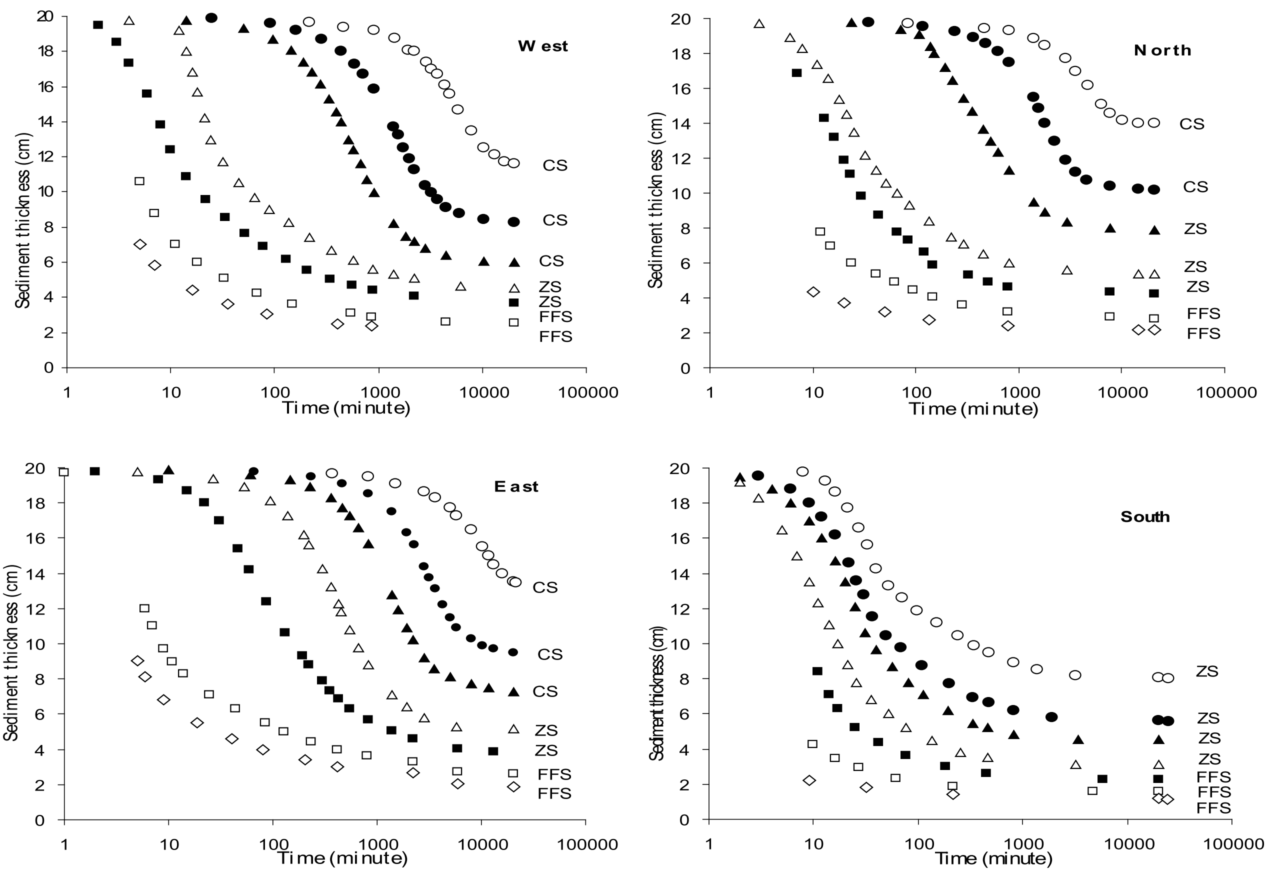


Fig. 5 Time-sediment thickness curves for 5 % gypsum added material. (Initial water content: :○ = 1000 %, :● = 1500 %, ▲ = 2000 %, △ = 3000 %, ■ = 4000 %, □ = 6000 %, ◇ = 8000 %).

perimental materials, but all types were not represented in all water contents/suspended particle concentrations. In these control experiments: in North clay, CS occurred at 1000 % water, ZS at 2000 % water, and FFS at 4000 % water, and DFS at 8000 % water; in South clay, CS did not occur and the ZS boundary occurred at 1000 % water, FFS at 2000 % and 4000 % water, and DFS at 8000 % water. Only mixed CS and DFS occurred in West and East clays for 1000-8000 % water. The differences in these patterns were due to the difference in clay content among sampling sites. For example, West and East soils have more than 60 % clay particles and their huge numbers per unit weight lead to a decrease in average inter-particle distance. This is probably a dominant factor and also explains the upward shifting of boundaries between CS and ZS (at North and South) where the environment is strongly flocculating, and depends on water content. The differences between these cases can be explained by an increased tendency towards flocculation in natural material.

The interpretation placed on these results is that a settling pattern is determined by interplay among the particles as influenced by the sedimentary characteristics of Tondano clay, such as the differences of physical and chemical properties (Table 1). Understanding depositional characteristics of soil suspension has practical applications related to flocculation treatment of lake sediments. At West and East clays with low particle concentrations, the conditions are not favorable for flocculation.

3.2.2 Sedimentation patterns of Tondano clay with gypsum addition

The settling patterns of Tondano clay supplemented with 5 % gypsum (Fig. 5) differ sharply from those of Tondano clay alone. The main differences are that DFS occurs in both West and East clays (in control group), however, when gypsum is added to all the clays, a DFS pattern does not occur. In this figure, the boundaries between the CS and ZS, and between ZS and FFS shift to a higher water content in East, West and North clays. However the CS does not occur in the South clay, but occurs directly on the ZS boundary starting at 1000-3000 % water, FFS occurs at 4000-8000 % water. These trends for CS behavior to occur at a lower water contents, and for the CS–ZS boundary and the ZS–FFS boundary to shift to higher water content increase as the gypsum has added.

Table 2 has shown that as the salinity increased according to the gypsum addition, the turbidity decreased for all clays (from 8000 to 2000 % water content). However, from 1500 to 1000 % water content, the turbidity increased. It was due to that their water content were low, so the consolidation settling were occurred, consequently

Table 2 Experimental properties on turbidity of Tondano clay with 5 % gypsum addition and the control.

WEST		Clay + 5 % Gypsum							Control			
Items	w_0 =	1000%	1500%	2000%	3000%	4000%	6000%	8000%	1000%	2000%	4000%	8000%
Gypsum concentration	(g L^{-1})	5.0	3.3	2.5	1.7	1.3	0.8	0.6	0	0	0	0
Turbidity	(1 day, g L^{-1})	73.1	22.0	12.6	19.2	36.6	65.9	90.4	631.2	92.8	155.3	332.4
pH after 1 day		4.2	3.1	5.2	5.2	5.5	4.9	4.8	6.0	5.7	5.0	5.4
Electric conductivity	(1day, mS cm^{-1})	3.8	3.2	2.5	1.80	1.43	1.06	0.83	0.48	0.175	0.112	1.14
EAST		Clay + 5 % Gypsum							Control			
Items	w_0 =	1000%	1500%	2000%	3000%	4000%	6000%	8000%	1000%	2000%	4000%	8000%
Gypsum concentration	(g L^{-1})	5.0	3.3	2.5	1.7	1.3	0.8	0.6	0	0	0	0
Turbidity	(1 day, g L^{-1})	177.5	27.7	23.4	17.3	27.2	64.4	69.6	-	58.0	94.3	443.1
pH after 1 day		3.7	3.5	3.1	3.7	4.6	4.6	4.7	5.4	5.6	4.9	4.7
Electric conductivity	(1day, mS cm^{-1})	3.3	3.1	2.5	1.78	1.43	1.05	0.83	0.67	0.35	0.23	1.37
NORTH		Clay + 5 % Gypsum							Control			
Items	w_0 =	1000%	1500%	2000%	3000%	4000%	6000%	8000%	1000%	2000%	4000%	8000%
Gypsum concentration	(g L^{-1})	5.0	3.3	2.5	1.7	1.3	0.8	0.6	0	0	0	0
Turbidity	(1 day, g L^{-1})	36.5	6.2	8.9	69.4	89.1	114.8	150.7	40.8	85.1	41.0	179.3
pH after 1 day		6.4	6.3	6.2	6.2	6.1	6.0	6.1	6.1	5.9	7.9	6.3
Electric conductivity	(1day, mS cm^{-1})	3.3	3.0	2.5	1.86	1.47	1.09	0.87	0.95	0.63	0.36	0.22
SOUTH		Clay + 5 % Gypsum							Control			
Items	w_0 =	1000%	1500%	2000%	3000%	4000%	6000%	8000%	1000%	2000%	4000%	8000%
Gypsum concentration	(g L^{-1})	5.0	3.3	2.5	1.7	1.3	0.8	0.6	0	0	0	0
Turbidity	(1 day, g L^{-1})	22.6	17.8	12.6	19.2	36.6	65.9	26.7	271.2	27.1	45.2	342.8
pH after 1 day		6.2	6.0	5.2	5.2	5.5	4.9	5.8	6.2	5.8	7.3	5.8
Electric conductivity	(1day, mS cm^{-1})	2.9	2.7	2.2	1.64	1.31	0.94	0.76	0.54	0.31	0.25	0.109

the gypsum addition was not affected effectively. In the region in which consolidation settling does not occur (above 3000 % water content), the effects of gypsum addition on the settling patterns are significant; whereas, in cases that the consolidation settling occurs (under 2000 % water content),the effects of gypsum addition are not so much significant. Gypsum is always used for calcium addition to sodic soils in aggregation and improvement of permeability without changing pH value. However, the pH values of West and East clays were decreased down to approximately 3–4 with decreasing water content. The reason for this may be attributed to the mineralogy of West and East clays, which were kaolinitic. More experiments are needed to address this result because the Tondano clays mainly contain organic matter, and also the interactions between organic matter and gypsum are not fully clarified at current stage.

Regarding the gypsum content, with clays and water content combinations where ZS and FFS settling occurred, the maximum settling rate and the earliest timing for the maximum rate occurred in the higher water content sample (Fig. 5). This is related to the process of floc formation in the different environmental clays and a degree of interference with the flocs in suspension. Once the settling process has ended and only the consolidation process is active, the rate of water loss decreases rapidly, and continues to decrease for the duration of the experiment. For the Tondano clay control group (Fig. 4), the consolidation settling has occurred at West, North, and East clays with 1000 % water content.

The greater water content of the clay suspension could induce a higher degree of flocculation, thus explaining sedimentation characteristics induced by gypsum treatment. Therefore, the effectiveness of a gypsum addition on the sedimentation characteristics of Tondano clay in improving the lake condition is well demonstrated by this paper as the preliminary results have shown.

4. Conclusion

The experimental results demonstrate that the presence of gypsum in relatively modest concentration has a substantial effect to the sedimentation characteristics of suspensions of fine-grained soil material over a wide range of water contents.

Although the Tondano clay control exhibited full-volume gelation and consolidation has occurred at North clay, the presence of 5 % gypsum greatly extended the water content range over which this behavior was exhibited. In the region in which consolidation settling does not occur (above 3000 % water content), the effects of gypsum addition on the settling patterns are significant; whereas, in cases that the consolidation settling occurs (under 2000 % water content), the effects of gypsum addition are not so much significant. The greater water content in the clay suspension could also induce a higher degree of flocculation, thus explaining the greater sedimentation characteristics induced by gypsum treatment.

The results of these controlled experiments provide guidance as to the effect of specific soil properties upon the sedimentation characteristics of high particulate suspensions such as the dredging of fine-grained lake sediments. They should prove useful in assessing what may account for differences in the sedimentation characteristics of suspensions of natural materials. The applicability of this conclusion to Tondano Lake clays awaits further experimental results for those clays.

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