Experimental Introduction of Quantitative Indexes in Drill Core Observation

-- Classifying the Strata and the Degree of Weathering by Measuring Core Sample Magnetic Susceptibility and Color --

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Abstract

The results of drill core observation are among the most important basic data for geological survey; however, these results tend to include subjective aspects, because the core sample is qualitatively evaluated through macroscopic observation by engineers with different skill levels. Similarly, the classifications of strata, rock hardness and degree of weathering, which are derived from the results of drill core observation, tend to be subjective and tend to depend on the abilities of the engineers involved in determining them. These subjective aspects sometimes result in differences in evaluations that make it difficult for others to understand the basis for evaluation.

This study aimed at adding quantitative indexes to core observation. Measurements of magnetic susceptibility and color were done for drill cores of igneous rocks and sedimentary rocks. To examine the validity of the quantitative indexes, the results of classification of strata, rock hardness and weathering from the quantitative method were compared with those from conventional core observation.

Magnetic susceptibility and color were measured using portable meters, which enabled onsite measurement.

Examinations revealed that the differences in measured magnetic susceptibility and color correspond to the differences in strata, lithofacies, rock hardness and degree of weathering. In measurements using a magnetic susceptibility meter and a color meter, it was possible to qualitatively determine the borders between different types of rock, even when it was difficult to determine the border by macroscopic observation because the changes in the borders were gradual. Using measurements of magnetic susceptibility and color in combination made it possible to examine the results by comparing and supplementing the results from the two measurement methods.

Measurements of magnetic susceptibility and color of drill cores showed that it was possible to use these measurement results as useful quantitative indexes for classifying strata, lithofacies, rock hardness and degree of weathering, for comparing multiple cores, which is conventionally done by visual inspection, and for determining the landslide slip surface.

Keywords: Rock properties, Test and survey methods, Color, Magnetic susceptibility, Drill core

1. Introduction

Results of drill core observation are one of the basic data that is the most important in geological survey. However, since most of the observation items depend on qualitative assessment, difference in technical capability and subjectivity of the observer easily occur. Therefore, data described in such reports lack in repeatability, making it difficult to compare and correlate them. Capacity difference and subjectivity of the engineer easily occur in the classification of strata and rock mass classification derived by drill core observation as a result. The authors guess most engineers have experience in hesitating in judgment for determining boundary depth such as stratum and rock mass classification by core observation. In this study, we measured magnetic susceptibility and color of drill core in depth direction continually for the purpose of adding more quantitative indexes to the drill core observation with qualitative assessment as a main method. For the measurement results, we discussed the correspondence with weathering degrees, classification of strata, rock mass classification, slip surface judgment of the landslide area by visual observation of drill core and examined their validity as quantitative indexes. Magnetic susceptibility measurement of rock and mineral is often used as one of the indices to evaluate properties of the object. Measurement of color has been attempted in recent year by Nakashima et al.(1989), Nagano and Nakashima(1989), Nakashima et al.(1992) and Mitsushita et al.(1998) though the main target of these studies is granite and therefore we studied mudstone in contrast to magnetic susceptibility in this study.

2. Measurement of magnetic susceptibility of drill core

2.1 Meaning of magnetic susceptibility of rock and sediment

All substances basically have magnetism. When external magnetic field is given to rock and sediment, magnetization is induced. Strength of the induced magnetization of rock and sediment set in an external magnetic field of intensity F is kF. Here, k is called susceptibility or magnetic susceptibility. In other words, easiness of magnetization when the external magnetic field is given is called "magnetic susceptibility". Magnetic susceptibility of rocks and sediment is determined basically by quantitative ratio of the mineral composing them and intensity of magnetic susceptibility that each mineral has (Table 1). However, even for the same mineral, magnetic susceptibility present stronger values with smaller particle size. Generally, among the mineral contained in rocks and sediment, magnetite (Fe_3O_4), which is ferrimagnetic material, has particularly high magnetic susceptibility and therefore generally the quantitative ratio of the magnetite greatly influences magnetic susceptibility of the entire rocks and sediment. When hematite (Fe_2O_3) is formed from magnetite by hydrothermal alteration, the magnetic susceptibility greatly decreases. When mineral formed secondarily is pyrite (FeS_2), the magnetic susceptibility further decreases. Further, when amorphia iron hydroxide and goethite (FeOOH) are formed by weathering, the magnetic susceptibility greatly decreases. In this way the magnetic susceptibility generally is lower with higher weathering and deterioration degrees. From these, it is presumed that magnetic susceptibility differs in accordance with constituent mineral and quantitative ratio, and weathering and deterioration degrees for both rocks and sediment. Therefore, characteristics of the magnetic susceptibility that rocks and sediment have can be used as one of the basic data for the drill core evaluation such as objective classification of strata and weathering by measuring a relative change in magnetic susceptibility of the drill core in the depth direction.

Table 1 Magnetic susceptibility of each mineral(Nakai, 2004)

Minerals	Magnetic susceptobility ($\times 10^{-6}$ SI)
ferromagnetic minerals (in normal temperature)	
magnetite (α phase Fe_3O_4)	～1000000
msghemite (γ phase Fe_2O_3)	～860000
hematite (α phase Fe_2O_3)	2000～50000
goethite (γ phase Fe00H)	1300～5000
pyrrhptite (FeS)	50000～300000
palamagnetic minerals (in normal temperature)	
biotite	900～1400
amphibole	500～8920
pyroxene	500～5000
garnet	3000
cordierite	600
siderite	3800～4200
actinolite	3560～8920
diamagnetic minerals (in normal temperature)	
quartz (SiO_2)	-13～-16
calsite ($CaCO_3$)	-13～-14
dolomite ($MgCO_3$)	-38

2.2 Magnetic susceptibility measurement method

In this study, SM20 type portable magnetic susceptibility indicator made by ZH Instruments (Photo 1) was used. In on-site simple measurement, a measuring device was put on the drill core surface in a core box to measure magnetic susceptibility. The measurement interval was selected as 10cm in principle, and for the position where a measuring device could not be sufficiently put on the core surface due to the core state, the measurement position was slightly shifted or measurement was not performed. In the case of the measurement at the column core side in particular, specimen does not adhere to the measuring device and therefore it was supposed that true magnetic susceptibility could not be measured precisely and relative change could be grasped.

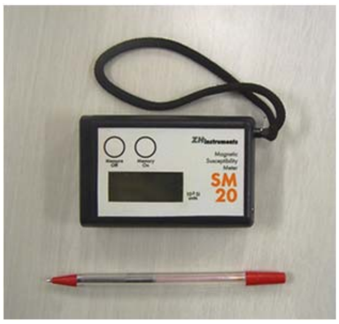

Photo 1 SM20 type portable susceptibility indicator made by ZH Instruments.

2.3 Magnetic susceptibility measurement result 1 (Volcanic rock, volcaniclastic rock)
2.3 (1) Magnetic susceptibility of each interval

Fig.1 shows magnetic susceptibility measurement examples of the drill core (φ 66mm)for andesite autobrecciated lava (ab) and tuff breccia (Tb, Tb(m)) of the Pliocene epoch. Some part of the tuff breccia stratum (tb(m)) contained mudstone gravel with several millimeters - more than 1 meter of diameters and it was sorted from the stratum (Tb) which did not contain mudstone gravel. In Fig.1, magnetic susceptibility of the base rock layer at the depth over GL-36.0m is presented with semilogarithm, and classification of strata and rock mass classification by the visual observation were shown on the right side. The drill core as a measurement subject was tuff breccia (tb(m)) stratum containing mudstone gravel till GL-62.60m, and alternation of beds of tuff breccia (tb) stratum and andesite autobrecciated lava (ab) stratum for the place deeper than the above. Boundary of each stratum is unclear visually. The magnetic susceptibility of the strata was 0 - 15 x 10^{-3} (is SI units)) for the tb(m) stratum while on the other hand it was almost 8 - 20 x 10^{-3} (with SI units)) for tb stratum and ab stratum, which were relatively great. Features of each depth interval are shown below.

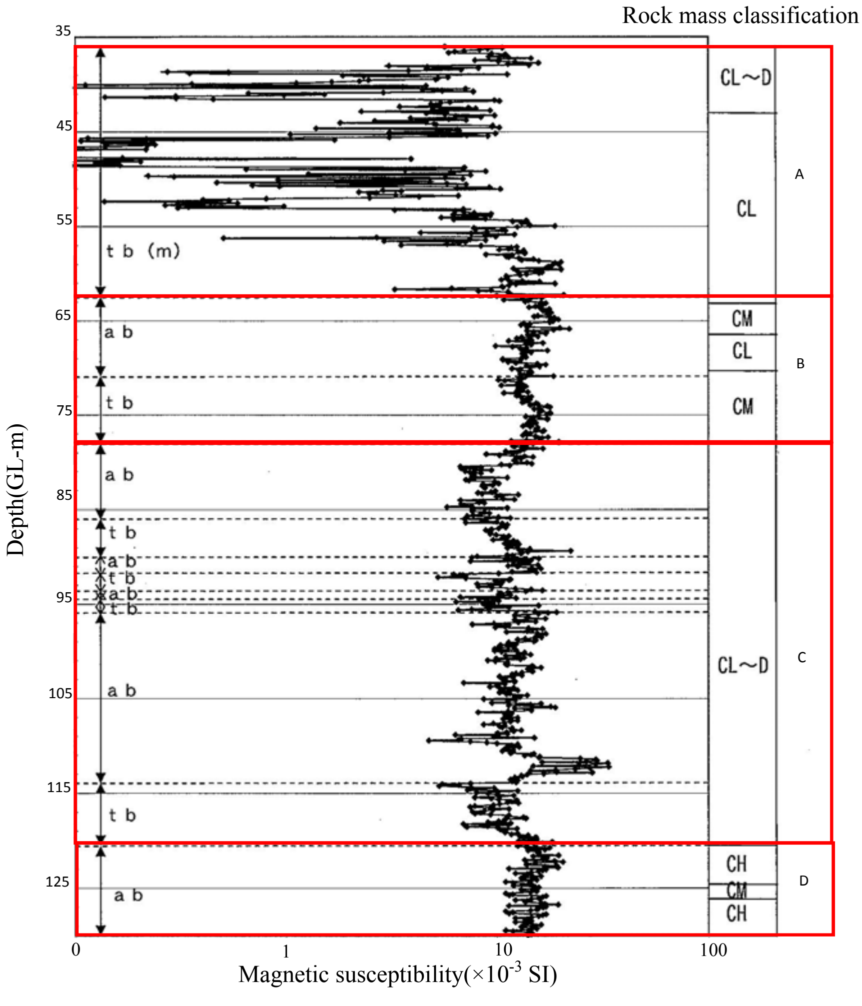

Fig.1 Magnetic susceptibility measurement result
(Volcanic rock, volcaniclastic rock)

A. GL-36.0 - 62.60m: Tuff breccia stratum (tb(m)) containing mudstone gravel (D - CL class rock mass)

Dispersion of the values is comparatively great in the Tb(m) stratum. Weathering was progressing in whole in this stratum, and magnetic susceptibility was lower than that of the underlying stratum. For the same tb(m) stratum, dispersion of the values becomes small in the place deeper than GL-53.0m where the content of mudstone gravel decreases. The magnetic susceptibility was gradually decreasing from around this GL-53.0m to around GL-62.6m of the tb(m) stratum base, which is the tendency that corresponds to the weathering degrees, we presume.

B. GL-62.60 - 77.90m: Tuff breccia, andesite autobrecciated lava bed (tb, ab) (CL - CM class rock mass)

The magnetic susceptibility of this interval presents the values that are higher than those of the interval before and after the above. In visual observation, the tb, ab stratum distributed over this interval has comparatively less crack and it was judged that fresh CM class bedrock was the main constituent. Therefore, we suppose that tendency of the magnetic susceptibility of this interval corresponds to this rock mass properties.

C. GL-77.90 - 120.80m interval tuff breccia, andesite autobrecciated lava bed (tb, ab) (D - CL class rock mass)

The magnetic susceptibility of interval C is lower than interval B and interval D, having greater dispersion. In this interval, crack was prominent in whole, and crush was developing around the crack. Weathering developed in whole accompanied with it, and magnetic susceptibility lowered. On the other hand, the reason why there exists some parts with high magnetic susceptibility is that the rock fragment except the vicinity of crack is fresh, we presume.

D. GL-120.80 - 130.00m interval andesite autobrecciated lava bed (ab) (CM - CH class rock mass)

Magnetic susceptibility of this interval is consistently high. The authors presume that the tendency of this magnetic susceptibility corresponds to the fact that this interval is hard and unweathered andesite autobrecciated lava with less crack and with CM - CH classrock mass as a main body in visual observation.

2.3 (2) The relation between classification of strata, rock mass classification and magnetic susceptibility

Fig.2 shows measurement values organized for each rock mass classification based on the visual observation for tuff breccia and andesite autobrecciated lava bed (tb, ab) among the magnetic susceptibility measurement results of a drill core shown in Fig.1. Dispersion of the values in each rock classification is around 10 - 15 x 10^{-3} (SI units) . For both tb and ab strata, variation of around 4 x 10^{-3} (SI units) average is recognized in the rock mass classification between CL and CM classes. Variation of the magnetic susceptibility corresponding to the rock mass classification was not recognized between CL - D and CL classes, and CM and CH classes of ab stratum. This is because there was difference in crack degrees though there was less difference in chemical weathering degrees comparing with the class between CL and CM classes. Difference of around 1 x 10^{-3} (SI units) average was recognized between the strata tb and ab.

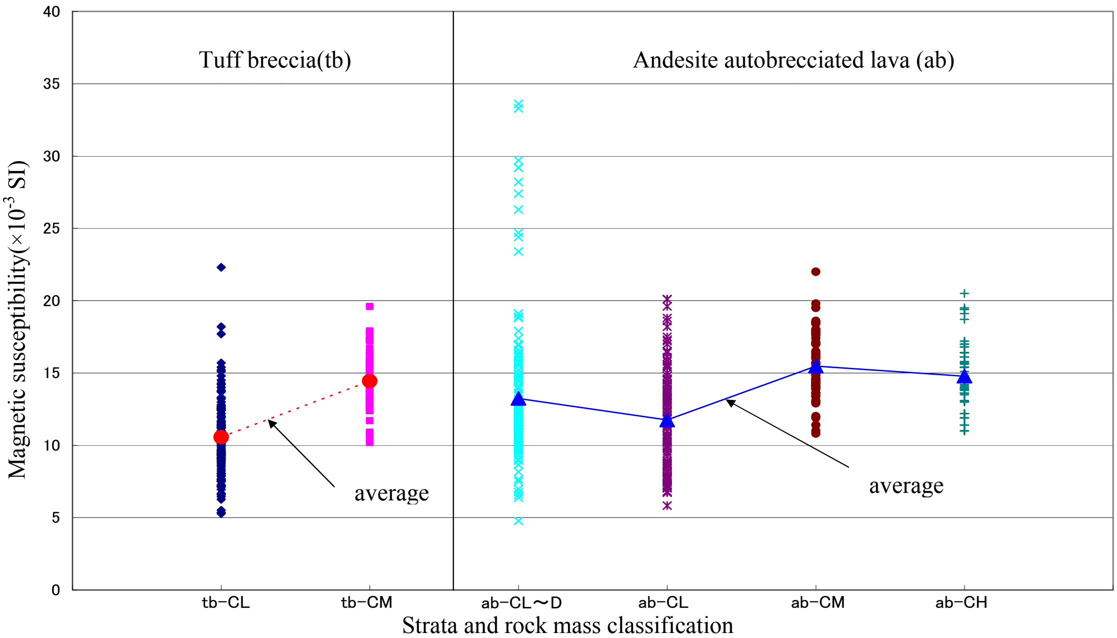

Fig.2 Measurement result of magnetic susceptibility organized for each classification of strata and rock mass classification

2.4 Magnetic susceptibility measurement result 2 (Miocene black mudstone formation of the landslide area)

Fig.3 shows magnetic susceptibility measurement example of a drill core (φ 66mm) (Photo 2) of the black shale stratum (Onnagawa formation) that belongs to Miocene. The area concerned is located in a landslide area, and it has been often confirmed that crush parts and argillaceous zones are sandwiched in mudstone in the measured drill core. In the observation of the pipe strain meter, accumulation of deformation was confirmed albeit only slightly around GL-24.00 - 25.00m. Crush parts and sandwiched clay were not recognized in the place deeper than GL-28.50m, and fresh rocks with comparatively fewer crack were confirmed. Fig.3 presents relationship between magnetic susceptibility in logarithmic scale and depth, and stratum classifications and N-values confirmed by the visual observation are shown on the right side. The drill core for the measurement, from the bottom, consists of mudstone stratum, terrace sediment (argillaceous gravel, gravel with cobble stones) stratum, loam and topsoil. Magnetic susceptibility was 0.05-0.5 (x 10^{-3} SI unit) for mudstone part, which was smaller than that of volcanic rocks and volcaniclastic rocks shown above. On the other hand, it was 0.1-2 (x 10^{-3} SI unit) for loam and was 1-13 (x 10^{-3} SI unit) for terrace sediment, and therefore the magnetic susceptibility greatly differ according to strata. Variation of the magnetic susceptibility in the mudstone stratum is slightly higher in the yellowish-brown weathering part than in the lower gunmetal fresh part. Although magnetic susceptibility tends to lower in the weathering part in most cases, opposite tendency is shown in the weathering part of this core. For GL-12.95m - 17.50m of the upper gunmetal part, magnetic susceptibility is smaller in lower part. Top of the gunmetal part is relatively fresh core with less crack though a number of crush parts are recognized in the place deeper than GL-17.15m and discoloration and weathering along the crack are recognized, and therefore the above is the tendency that indicates weathering degrees. At the depth GL-17.15m - 28.50m, a number of crush parts that are possibly slip surface presenting rubble- clay are sandwiched. At GL-17.35m and GL-22.50m, slickenside is recognized though it is unclear, and it is possibly slip surface. At the depth GL-26.50m - 26.60m, argillaceous tuff is sandwiched. As shown in Fig.3, magnetic susceptibility of the gunmetal mudstone tends to be lower than those in the sections before and after it around these crush parts. In the place deeper than GL-28.50m, crush parts was not

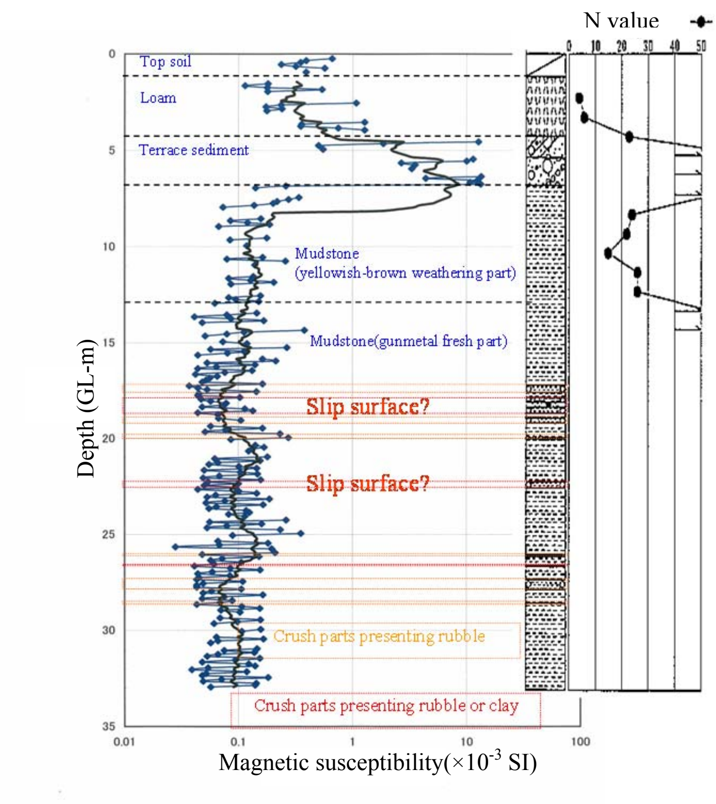

Fig.3 Measurement result of magnetic susceptibility (black mudstone formation).
(The black curved line is the moving average deviations.)

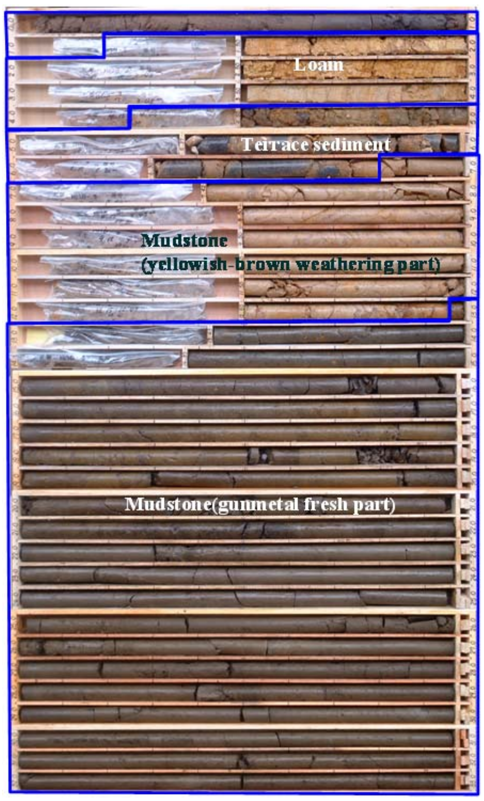

Photo 2 The measured drill core of the black mudstone formation.

recognized and relatively fresh cores with fewer crack were spread to GL-33.0m. The magnetic susceptibility of this section was more constant than that on the top, and the moving average deviations was about the same. Fig.4 shows magnetic susceptibility measurement result of the drill core collected from outside of the landslide area in the vicinity of core collecting point shown in Fig.3. The stratum is same as that of the core collecting point shown in Fig.3. The core at this point has relatively fewer crack and CL class rock mass is spread. Magnetic susceptibility of the same stratum in the landslide area where a number of crush part was recognized as shown in Fig.3 was 0.05-0.5 (x 10^{-3} SI unit) while on the other hand that of the core shown in Fig.4 out of the landslide area was around 0.1-0.3 (x 10^{-3} SI unit) , variation of the values was small in whole, and it was higher by 0.1-0.2 (x 10^{-3} SI unit) average. Great variation of the values in the depth direction was not recognized. In this way, from the comparison of magnetic susceptibility of the same stratum inside and outside the landslide area, it has been confirmed that in the mudstone stratum inside the landslide area, weathering developed in whole more than outside the landslide area. Further, around the crush parts where there may be slip surface, tendency that magnetic susceptibility decreased locally was recognized.

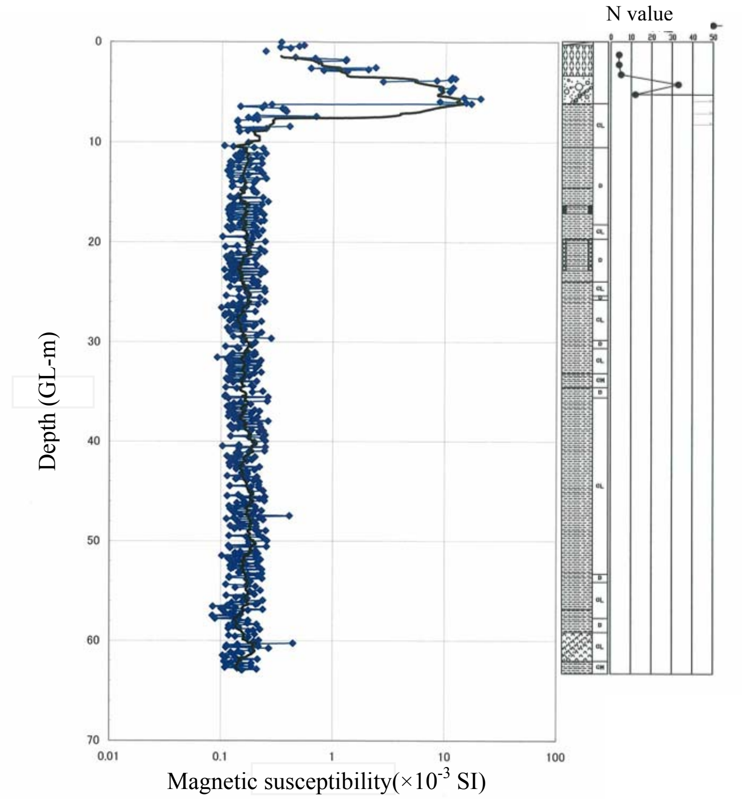

Fig.4 Measurement result of magnetic susceptibility
(black mudstone formation out of landslide area).
(The black solid line is the moving average deviations.)

3. Measurement of drill core color

3.1 Color measurement method

Generally, it is thought that colors of rocks and sediment are determined by constituent mineral and its form, component ratio, weathering degree, moisture content, surface state and so on. In particular, red and yellow are greatly governed by existence of oxide (iron hydroxide) of the iron mineral contained and its form. This implies that color measurement possibly enables to evaluate weathering degrees and rock mass classification more objectively and quantitatively. Further, measurement of the drill core color has meaning in the fact that color, which is one of the items for the drill core observation, can be quantified. Most of the observation items of drill cores are qualitative and dispersion of evaluation caused by individual cannot be avoided. Above all, color is one of items that have great dispersion and if color of the core can be quantified, it would be very effective in terms of securing repeatability and common view. CD100 type spectral colorimeter made by Yokogawa MC was used for measurement of rock color. The measurement interval was 10cm in the depth direction and the measuring device was set on the drill core side for measurement. The sensor diameter was 8mm. Light source is D65 (light source for measurement of object lighted up with daylight containing ultraviolet region, base light of CIE (the International Commission on Illumination) and ISO (International Organization for Standardization). The view angle was 10 degrees and the measurement was performed with the setting that specular reflection was excluded (SCE method: Specular Component Excluded method). Although the measurement was performed in curved surface of the side of the column core and accurate measurement values might not be obtained, we supposed that tendency of variation in relative values could be grasped.

3.2 Color measurement result of drill core (Neogene Onnagawa formation black mudstone in the landslide area)

Color of the drill core of φ 66mm in the Miocene Onnagawa formation black mudstone in the landslide area shown in Chapter 2.4 was measured. Measurement result is shown in Fig.5 and 6 in CIELAB color system. Fig.5 also shows magnetic susceptibility measurement result. The CIELAB color system is the color system with which colors are quantified with three axes which are L* value (black - white), a* value (green - red) and b* value (blue - yellow). The measurement result was evaluated by a* and b* values, which are less influenced by wet condition or the surface smoothness of the specimen. In the measurement, the following results were obtained.

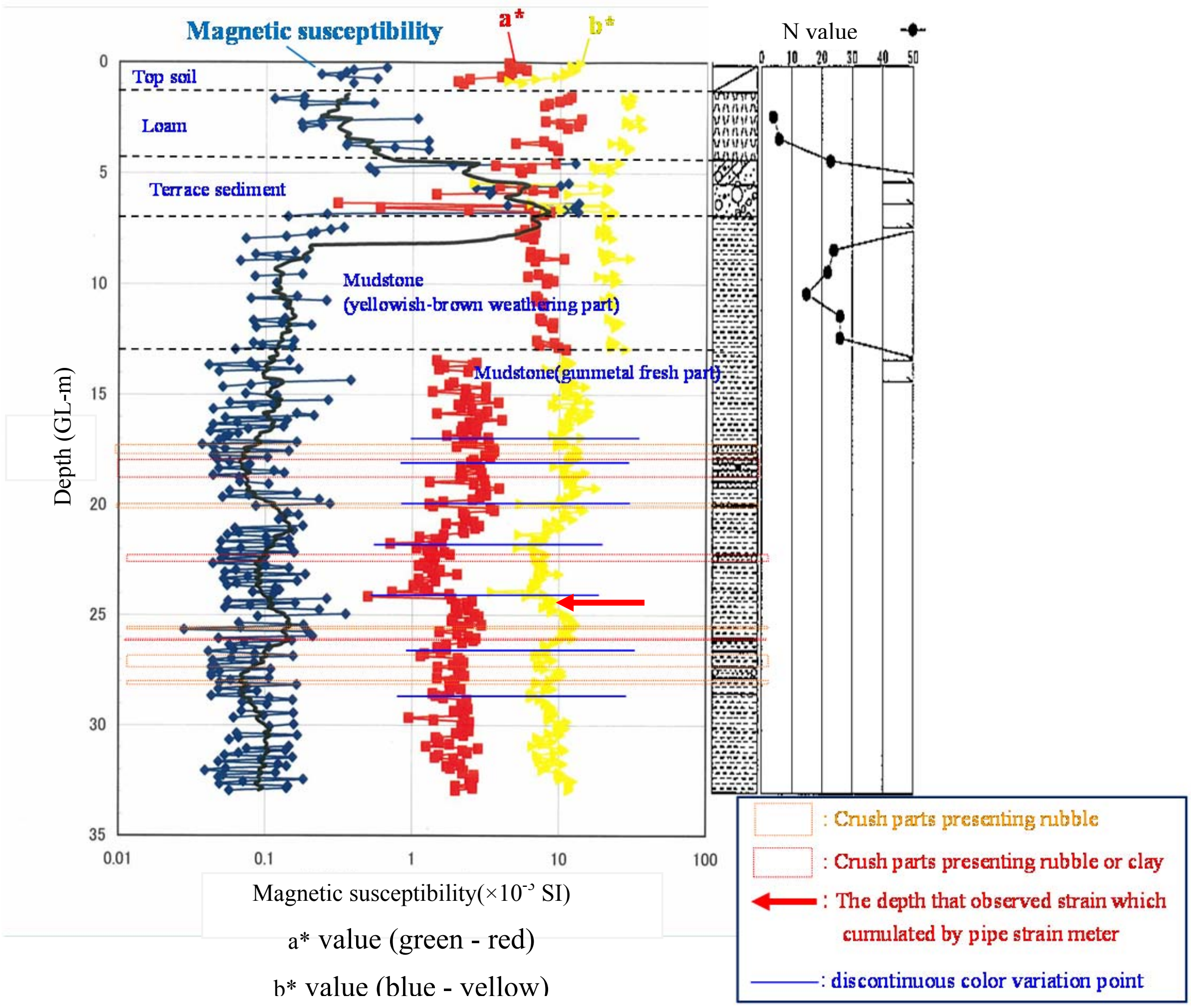

Fig.5 Color measurement result of drill core
(Black mudstone formation in the landslide area).

* There was no physical obstacle in the core surface measurement under the condition that it is put in the core case and the measurement was performed smoothly. No great difference was recognized between the measured values and the colors visually observed, and abnormal values were not recognized.

* Discontinuous variation was recognized in both a* value (green - red) and b* value (blue - yellow) around the stratum boundary, weathered rocks and fresh rock boundary.

This boundary almost agrees with the boundary confirmed by visual observation.

* At GL-17.1-28.59m where crush part in gunmetal mudstone stratum was distributed intermittently, the tendency that both a* and b* values were high locally around the crush part was recognized. The color variation around this crush part was small and clear classification was difficult by visual observation.

* Cumulative strain was observed by pipe strain meter observation, and at the depth around 24-25m, which was assumed slip surface, both a* and b* values vary slightly discontinuously . It is difficult to distinguish the discontinuity of this color by visual observation. Although it is thought that this discontinuous variation of color was caused by progress of discontinuous weathering due to landslide, it is required to accumulate data to judge if it is the tendency commonly seen around slip surface of landslide.

* On a*-b* correlation diagram shown in Fig.6, correlation is recognized between measurement values, and it agrees with tendency of the color variation with weathering reported by Nakashima et al.(1992). Further, distribution areas were clearly divided for sediment, weathering mudstone and black mudstone (fresh rock).

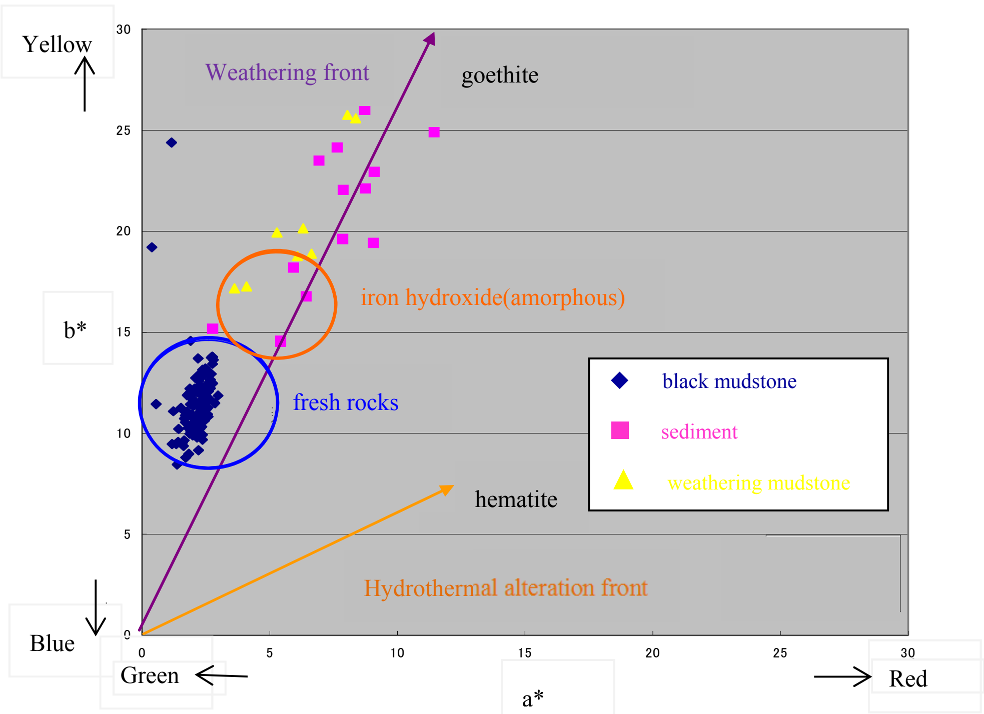

Fig.6 a*-b* correlation diagram about the color measurement result shown in Fig.5
(This figure edited and added Nakashima et al.(1992))

4. Conclusion

In the measurement result of magnetic susceptibility and color of the drill core, variation that reflected stratum, rock facies, rock mass classification and weathering degrees was recognized, and in the crush part and slip surface, tendency to present singular values was recognized for magnetic susceptibility and color. The measurement result of magnetic susceptibility and color of the drill core implies that application to (1) Classification of strata * (2) Rock facies classification * (3) Rock mass classification * (4) Weathering classification * (5) Slip surface judgment by landslide investigation * (6) and quantitative correlation between plural cores in the same area for (1)-(4) is possible. These are mainly performed by visual core observation though measurement of magnetic susceptibility and color enables to add quantitative indexes as information for judgment.

In particular, in the case that rock facies or weathering degrees transition, it maybe difficult to determine boundary depth of rock facies classification and weathering classification by visual observation, and the above results are effective for judgment.

Measuring devices superior in outdoor portability can be used for measurement of magnetic susceptibility and color, and the drill core in a core case can be measured easily on the site. The authors conclued that it is a measurement method that can be relatively easily applied to general geological survey.

The measurement result of magnetic susceptibility and color revealed that both of them come under a great influence of iron mineral contained in rocks and sediment as a common characteristic. Therefore, the properties of a drill core are grasped mainly through iron mineral and they supplement mutually.

The authors are going to accumulate various data of rocks and sediment so as to verify the validity of measurement of color and magnetic susceptibility of a drill core in future.

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