Studies on Sandstones in the Maizuru Zone, Southwest Japan II

Graded Bedding and Mineral Composition of Sandstones of the Maizuru Group

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Graded Bedding and Mineral Composition of Sandstones of the Maizuru Group

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Abstract

Sandstones of the Permian Maizuru Group in the Maizuru Zone were studied. The turbidity current is the only probable theory to explain the structures of the graded bedded sediments of the Group. Changes of some textural properties and compositional properties from the base to the top of the unit graded strata were examined, and the cause of the changes were discussed.

Introduction

In the previous paper were presented some compositional and textural properties of the Permian and the Triassic sandstones in the Maizuru Zone. Special reference was made to the mutual relations between these two properties. It was emphasized that selective breaking and selective transportation of various components are the two factors of the greatest importance in the study on sandstone maturity. However, considerations on the relation between major sedimentary structure and minor sandstone properties were not given in the paper.

Some of the sandstones of the Permian Maizuru Group are of peculiar interest because of their remarkable graded structure and their extreme graywacke tendency, in connection with the fact that the Maizuru Group was a product when the development of the Paleozoic geosyncline in Japan entered into its final stage.

In this paper the writer will describe some compositional and textural properties of the sandstones in relation to the grading of the stones.

Here the writer expresses his sincere thanks to Prof. S. MATSUSHITA and Assist. Prof. K. NAKAZAWA of the Kyoto University for their valuable suggestion and encouragement and for reading this manuscript. The witer is greatly indebted to Assist. Prof. H. KIMURA of Kyoto Gakugei University and Dr. S. MIZUTANI of Nagoya University who gave him much constructive suggestion and criticism. Financial support for this study is in part covered by the grant from the Ministry of Education.

Sedimentary structures

The stratigraphy of the Maizuru Group cannot be fully treated here. Consequently, only those features having a definite bearing on the subject at hand will be described.

The lower formation is characterized by the products of strong volcanism, such as, meta-basalt, schalstein and diabase, and by black shale.

The middle formation is composed of shale, sandstone including conglomerate, and lenticular impure limestone. Bedding of the shale is not usually seen, but when it alternates with sandstone they form clear bedded strata, although in this case grading in beds is not distinct. The sandstones have in some cases very lithic properties and are poorly sorted.

The upper formation* is composed of shale, sandstone and conglomerate, and is more than 1000 meters thick. Black shale is the most dominant constituent and the rate of conglomelate is rather small. In this formation, the graded bedding is well developed. Occurrence, structures and lithofacies of these beds in the formation will be stated in a little more detail.

Grading usually develops in beds of two structural types. In the first type, a number of graded strata are accumulated successively and make continuous sequence. (Fig. 1a) Grading within a stratum, a sedimentation unit, is clear in some cases, with decreasing sizes of grains from the base of the unit to the top. But in some other cases, the sediments are not graded well within the stratum. Sometimes they are laminated. Sometimes the vertical distribution of sizes is more complex, and a single stratum appears to be divided into two or more parts of units of grading.

Grain sizes which constitute the graded strata vary in each stratum, that is, from granule at the base to very fine sandstone at the top, from fine sandstone to black clay, from siltstone to black clay, and so on. Inasmuch as the gradation zones between the sandy and muddy parts are very narrow at several places, the beds often appear as if they are mere alternations.

A few instances of these size distributions in the unit strata were studied under microscope and are shown in Figs. 2a–g.

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* Gujo formation in Kawanishi District is peculiar sediments characterized by thick conglomerate and presence of shallow water benthos. Graded bedding is absent in the formation. This formation is omitted from the "upper formation" stated here.

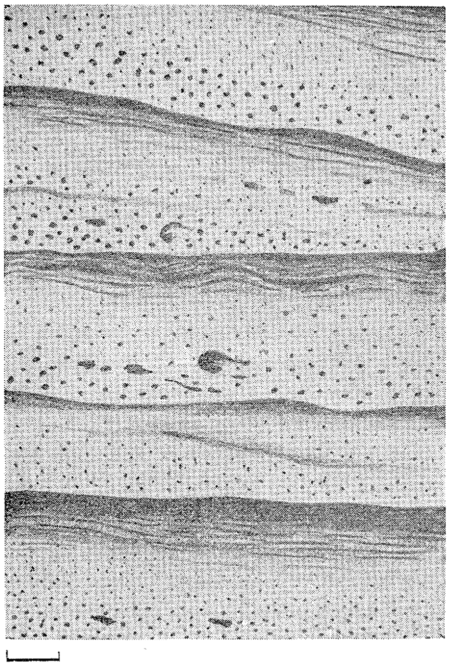

Fig. 1a. Schematic drawing of graded strata with laminated siltstones in upper parts of them, and irregular clay pebbles in sandy parts.

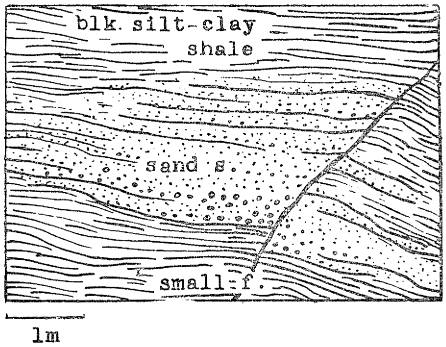

Fig. 1b. A little calcareous sandstone ~ granule conglomerate, containing fusulinid faunule. Loc. Okawa, Shidaka area, Kyoto Pref.

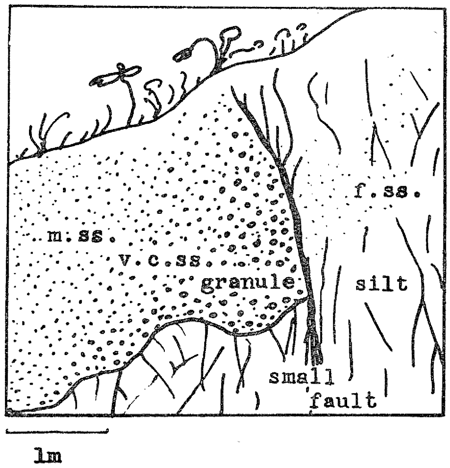

Fig. 1c. A little calcareous sandstone ~ granule conglomerate, containing fusulidid faunule. Loc. Yokoyama, Mikata area, Hyogo Pref.

The mean sizes were examined in thin sections* and were reconstructed by KRUMBEIN's formula. (KRUMBEIN, 1938) General tendency of grading is obvious in many of these examples, but the complexity of grading is also clear.

Less commonly, the strata start with fine-, or even medium-sized pebbles, and grade upward to the sand and silt fractions. Sometimes the pebbles appear several centimeters above the coarse sand forming the lower limit of the stratum, or the pebbles are concentrated in the middle portion of the stratum. Even then, the coarse grains come in more abruptly than they die out upward, as described by NATLAND and

* Grains with a diameter smaller than 0.016 mm were not treated as constituents of matrix because it is difficult to measure accurately the diameter of such small grains.

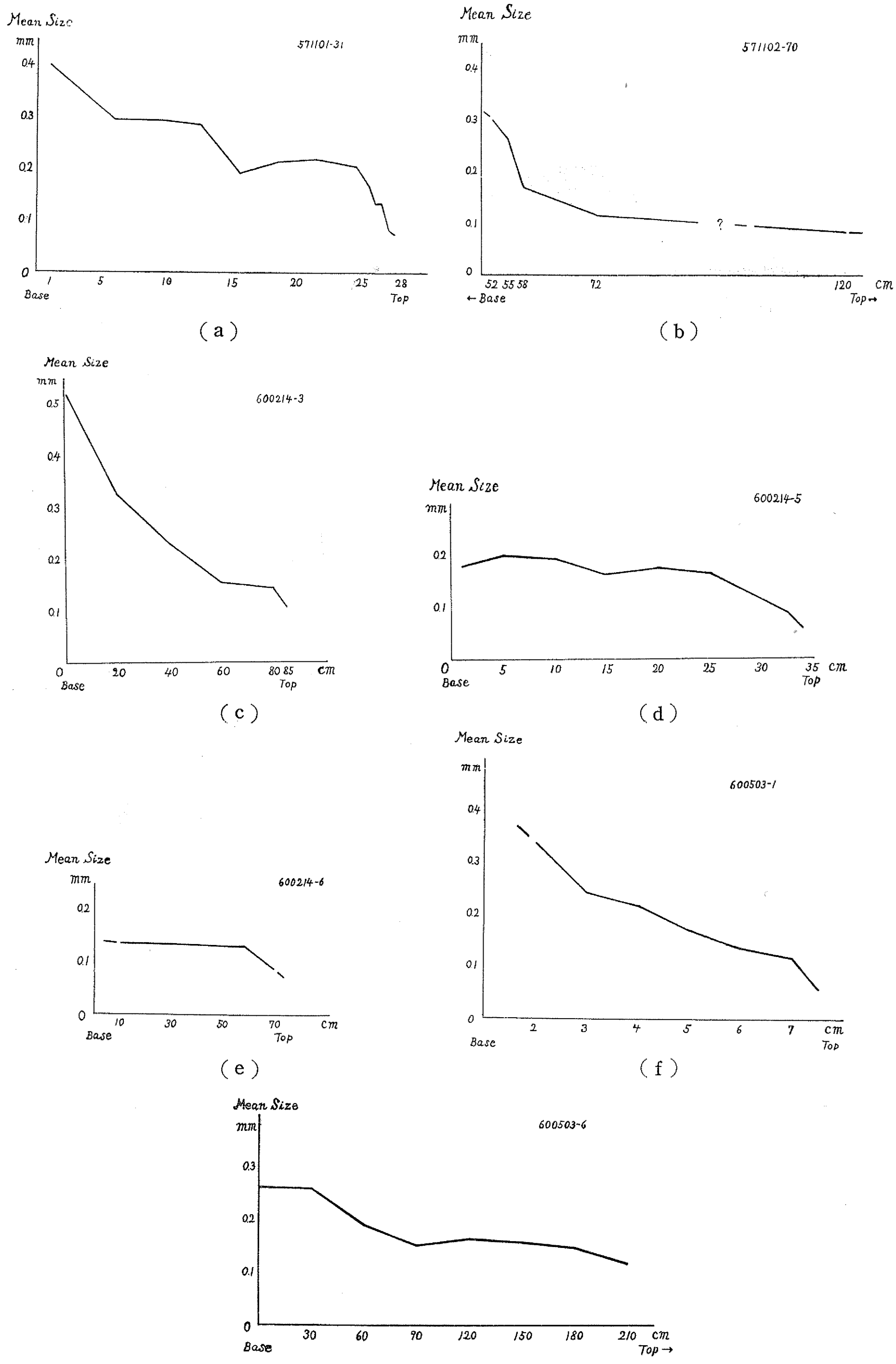

Fig. 2 a–g. Changes of mean sizes of grains (of sand∼coarse silt) in the unit strata.

KUENEN on the graded sandstones in Ventura Basin.*

Commonly many irregular patches of shale or silty shale are contained in lower or at higher levels of the sand parts.

Even the strata made of silt and clay, also have a tendency of grading, though these fine-grained graded strata are often laminated.

Broadly speaking, the coarseness of the grain size and the thickness of the stratum increase together. In some cases, grain size and thickness of strata vary rather rapidly along both dip side and strike side. If the parts consisting of large-sized grains in those several strata are accumulated successively, a cloud-like structure, like the Fossil Enclosure by IJIRI and FUJITA (1940) is constructed.** (Fig. 1b)

Some of the strata, having a thickness of more than 15 cm, show intricated folding and crumpling within the strata, especially in the laminated silty portions. The folding is entirely without breaking of the lamination lines in the stratum and does not noticeably affect the thickness of the stratum or not the smoothness of its bottom and top, as described by RICH on siltstones in the Aberystwyth area, Wales. (RICH, 1950)

Ripple marks seems to be absent. Cross-bedding is also seldom seen in the Maizuru Group.

Sole markings or flow markings may present in the graded strata. But the joints which develope nearly accompanying bedding planes obstruct the observations. The bottoms of the strata, in the cases that the strata show grading from silt to clay, are usually rather even, but the bottoms of sandy or granulic graded strata have somewhat uneven features in many places.

NATLAND and KUENEN (1951) noticed "pull apart" structure in their study on the Pliocene rocks of the Ventura Basin. No similar structure has been found in the strata of the Maizuru Group. However, many features of the beds stated above coincide well with those of sediments in the Ventura Basin, of clinothem beds of Kakegawa Nepton by MAKIYAMA (1954), of similar beds in Aberystwyth by RICH, and of other sediments which have been explained as the deposits of turbidity current.

Badness of sorting in these strata is remarkable, and indicates the peculiar mechanism of deposition of these sediments. Figs. 3a–b show size distribution of sand and silt grains from the base to the top of a few graded strata.***

* According to NATLAND and KUENEN, these structures show that we are dealing with a deposit of turbidity current advancing in two successive impulses, the second one carrying coarser material than the first.

** Indeed, fusulinid faunule or brachiopod faunule are contained commonly in the coarse sandstone and granule, mainly in the upper formation of the Maizuru Group. Besides, these, fossils are usually absent from finer beds.

*** KRUMBEIN's phi-scale was adopted for graphic representation after results of measurements under microscope was reconstructed by GREENMAN's formula. Grains with a diameter smaller than 5.5 were not treated because of difficulty of measurement of the diameter of such small grains.

The second type of the graded strata occurs in the tongue-like or semi-tuber like form rather than lense or plate, grading from the base to the top within the strata. The base is usually granule or fine pebble conglomerate unconformable to underlying and surrounding black shale. The arrangement of grains seems to converge laterally toward the boundary. Presumably, turbidity currents glided and eroded the bottom of loose sediment, making minor channels of a dentritic pattern, and then filled the channels with deposits leaving behind graded bedded structure and score diastems. (Fig. 1c)

As for the sediments of the second type, neither mechanical nor compositional analysis is treated in this paper. But the properties of the sediments cannot be considered to vary much with those of the first type. Fusulinid faunule are also often contained commonly in the calcareous sediments of this type.

The presence of a great amount of granule and very coarse sand, in both the first and the second type beds of the upper formation, is of the greatest interest in considering the mechanism of deposition of these beds.

According to the theoretical and experimental study by KIMURA (1954 a), the size of the most stable particle under changing current velocities, is about 1.5–5 mm in diameter,* unless the depth of current water is too shallow for the particle size.** On the other hand, the grains 0.2–0.3 mm in size are most liable to be transported by traction. (KIMURA, 1954 b) It may be said that, when the current velocity

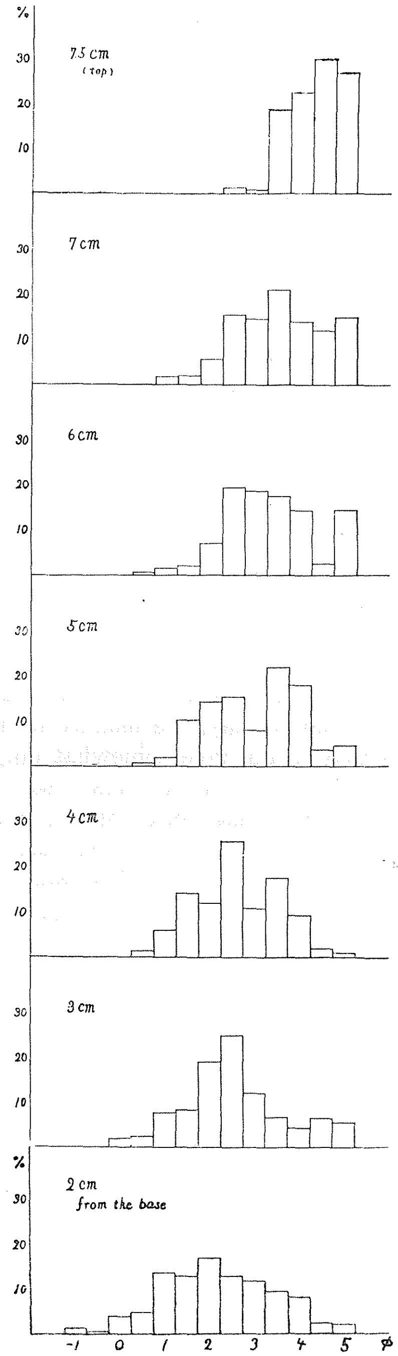

Fig. 3a. Size distribution of grains in various levels of a graded stratum.

* He named this size the first stable granularity, dc–1.

** In this case the second stable granularity, dc–2, appears.

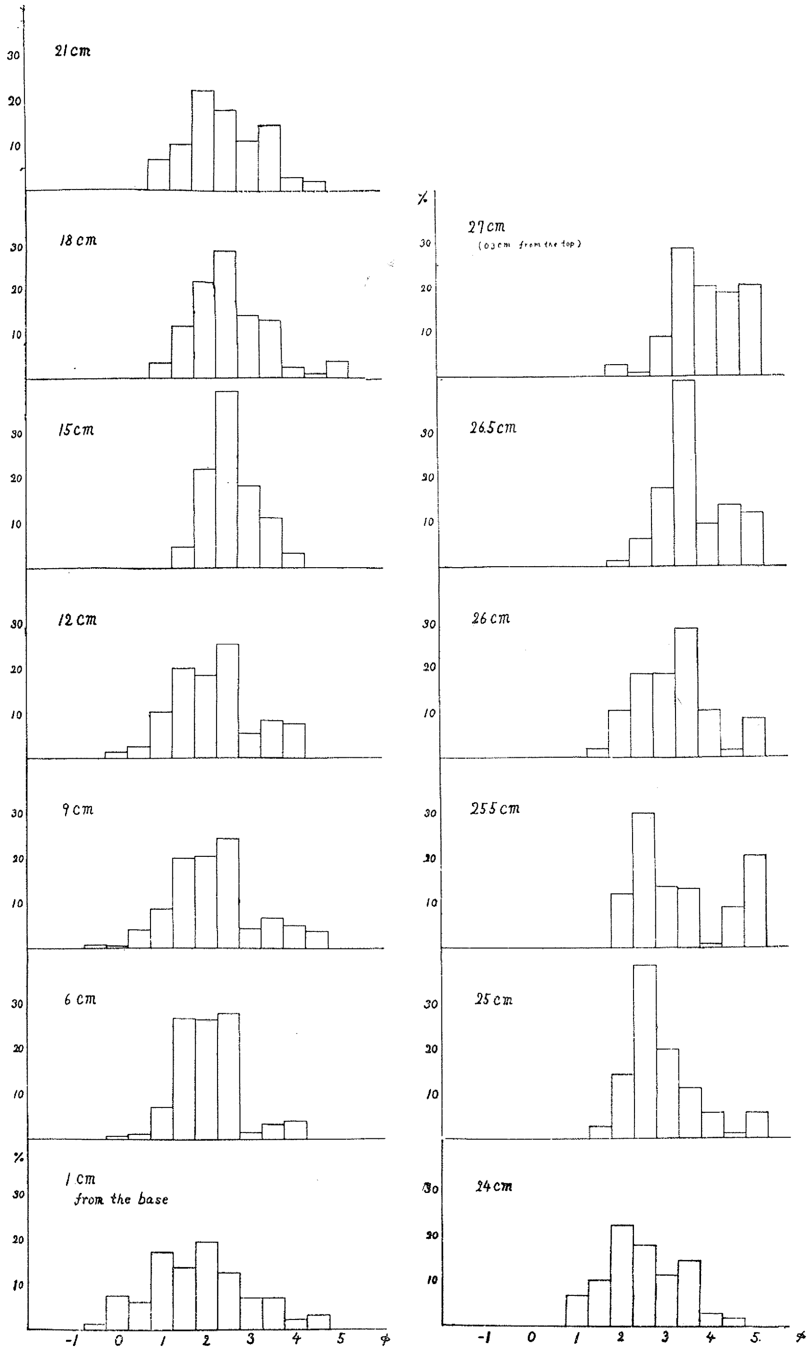

Fig. 3b. Size distribution of grains in various levels of a graded stratum.

increases, both the particles 0.2–0.3 mm in size and the largest ones in comparison with dc–1, move first.

After that, with increasing current velocity, the range of sizes of grains which move becomes larger. The smaller particles compared with "the largest", start to move, and the difference between the sizes of these two parts decreases. The particle of dc–1 is the last to move. If the current velocity decreases, the order of deposition of these particles is reversed.

For this reason, it occurs that, a large amount of grains of granule and very coarse sand remains and deposits in upper stream of rivers, and in talus or fanglomeratic beds. (Naturally, the deposits of these beds are very ill-sorted and contain also grains of many other sizes.) Marine sediments of granule size or very coarse sand size indicate whether the provenance was sharply elevated high-land from which the deposits were shed and accumulated on its foot (in sea water but a part may be on land), or the sediments were transported by some special mechanism different from usual traction current. For the explanation of this mechanism, the turbidity current is the only probable theory.

It should be added that, the rate of sandstone in the upper formation is rather small in comparison with that of black shale. Quite massive appearance of some parts of the shale, and flat paper-thin laminae in many parts show that, these sediments must have been formed in quiet water. So the presence of granule and very coarse sand, the most stable grain-size under changing current velocities, itself has great significance. Discontinuity of the beds of these coarse grains to those black shale beds in both dip side and strike side, and the unconformable phenomenon between granulic bed and black shale as mentioned above, should be noticed. Such occurence of coarse grained sediments (which contain smaller grains of various sizes), is explained only by episodic rapid transportion of these sediments into quiet water, where fine grained silt and clay deposits in normal state. The mechanism of these transportation can be none other than turbidity current.

The very interesting deposits to be mentioned besides these are the muddy conglomerate or the conglomeratic mudstone, which are quite similar to tillite in appearance.

These are dark gray to black rocks, without bedding or assortment of their constituents. Boulders and smaller fragments are scattered rather sparsely and quite at random through the unstratified matrix. The smaller rock fragments are generally somewhat more angular than the larger cobbles and boulders. The largest boulders attain 20 cm or more in diameter.

The matrix of the rocks is characterized by its great dominance over the pebble components and its extreme bad sorting. Even in thin section coarse angular grains of quartz and other minerals and rock fragments are observed in the finest siltstone or slate laminae.

The orgin of these rocks seems to be explainable by submarine slumping as stated by CROWELL (1957) concerning pebbly mudstones in California and other places. It is interesting to the writer that, CROWELL indicated that these pebbly mudstones are found in association with conglomerate, graywacke, and mudstone which were in part laid down by turbidity current as shown by graded bedding, load casts, current bedding and other structures. Supposedly, beds of conglomerate, laid down on soft water-saturated mud, became unstable, slumped down slope, and mixed pebbles with mud.

Further detailed study on these rocks will be stated in another paper.

Mineral composition

Figs. 4a–g show changes of combination of main components from the base to the top of a few graded strata chosen as typical examples.* Strata of different thickness and different types of grading are selected, but they show, when compared, rather similar tendency of changes of composition in the strata. And so, though the number of examples is small, they may be regarded to illustrate well general inclinations of distribution of the components in the graded strata in the Maizuru Group.

In all the cases, rock fragments are abundant but decrease rapidly in upper portions of the strata. Felspar and matrix are also important components but they are different from rock fragment in their inclination of distribution. They increase rapidly in upper portion of graded strata.**

It is obvious that these changes of mineral composition should be examined in relation to the changes of sizes of the sediments. As stated in the previous paper, even the samples taken from various places with no regard to major sedimentary structure show a clear relation between mineral composition and grain sizes.

It is clear that, when the Figs. 4a–g are examined jointly with Figs. 2a–g, changes of mineral composition from the base to the top of strata are related with changes of sizes in the strata.

To confirm the relation between the changes of composition and the sizes, data of the two properties of the materials taken from various places are mixed and plotted in the same diagram. (Figs. 5a–d) Thus, the relation became distinct. In short, materials of coarser grained mean size contain the smaller amount of felspar and matrix. On the contrary, the rock fragments decrease in accordance with the decrease of mean size of sand grains and especially fall off when the mean size becomes smaller than 0.2 mm.. These results resemble well those described in the previous paper, although in the present data the

* Sometimes a small amount of calcareous matter is contained in the coarser grained parts of the strata, but are not treated in the Figures.

** Amount of quartz in the sandstones of the Maizuru Group is extraordinarily small as stated in the previous paper, and the distinct relation between the quartz content and grading is not recognized.

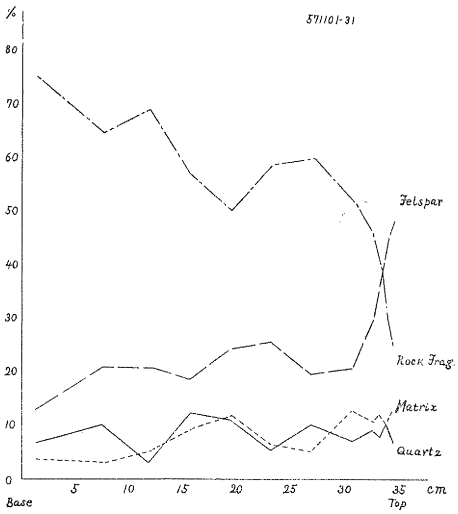

Fig. 4a.

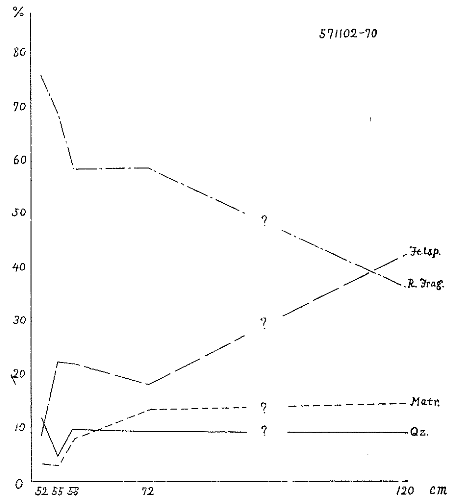

Fig. 4b.

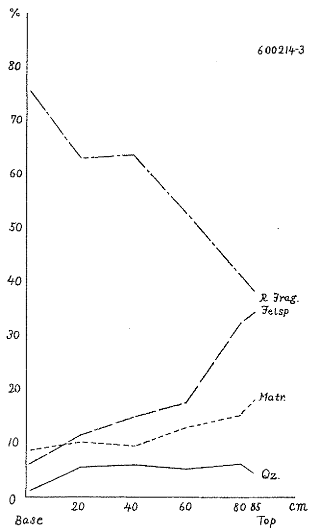

Fig. 4c.

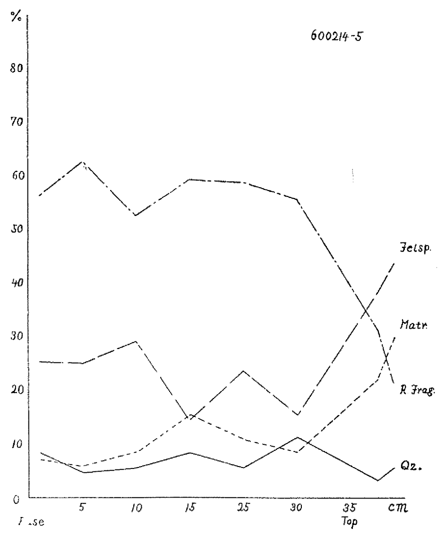

Fig. 4d.

Figs. 4 a–g. Changes of combination of main components in unit graded strata.

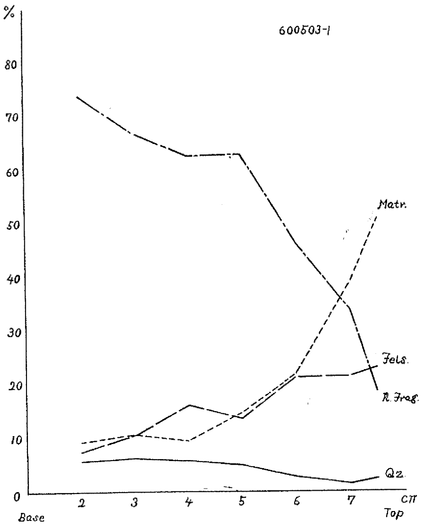

Fig. 4e.

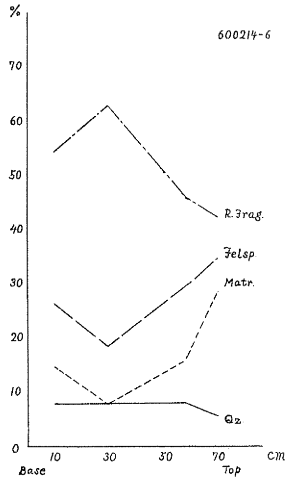

Fig. 4f.

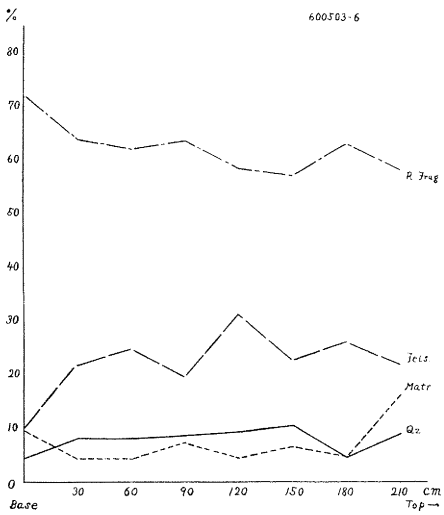

Fig. 4g.

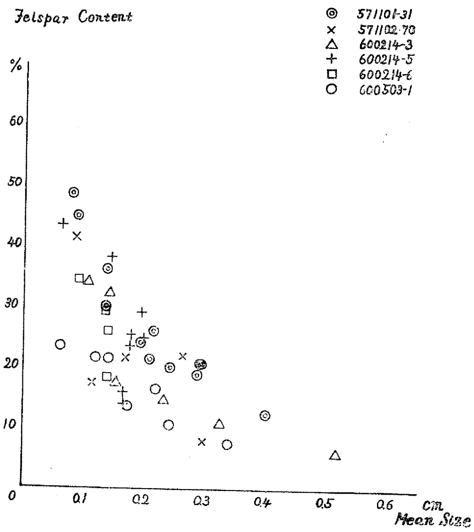

Fig. 5a. Relation between amounts of felspar and mean size of sand ∼ coarse silt size grains.

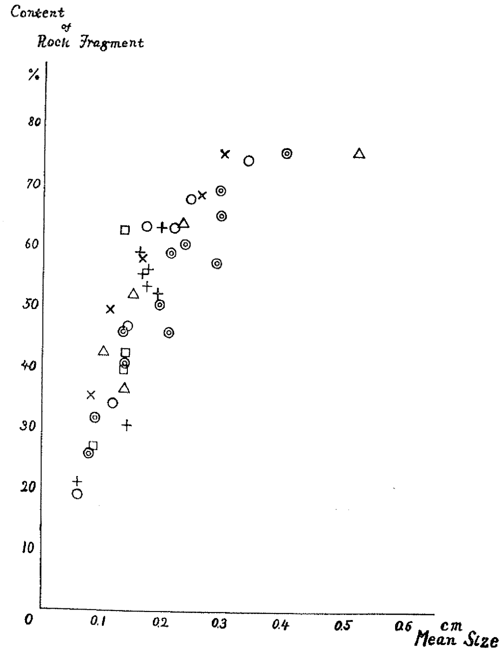

Fig. 5b. Relation between amounts of rock fragments and mean size of sand ∼ coarse silt size grains.

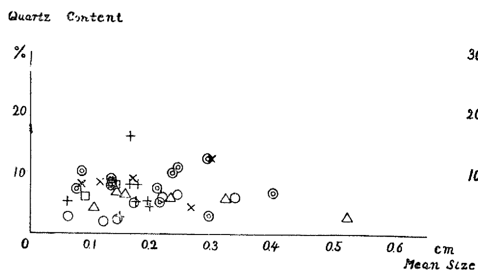

Fig. 5c. Relation between quartz content and mean size of sand ∼ coarse silt size grains.

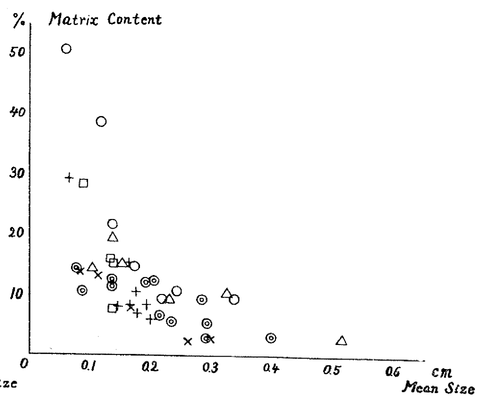

Fig. 5d. Relation between matrix content and mean size of sand ∼ coarse silt size grains.

amount of rock fragments is a little larger and the amount of quarts is a little smaller, in general, than in the former data.*

Cause of Distribution of Components

In the former chapter, the close relation between the distribution of the important components and the changes of grain sizes in the graded strata of the Permian Maizuru Group was clarified. Similar relation are also found in the case of Triassic Yakuno Group and many other sandy sediments in Japan. (T. SHIKI, 1959 a & b, and in press) But, in the case of the graded beds of the Maizuru Group, the relation should be noticed with more interest, because of its connection with the major sedimentary structure, namely grading.

In the previous papers the writer considered that, these relations are connected with selective breaking of various components and selective transportation of grains of various sizes. Each kind of components tends to take its respective grain size** during the course of weathering and transportation. And after these components attain their respective sizes corresponding to their mineralogical properties, the water current sorts out the grains according to their sizes.

Control of density of sand grains over their distribution has been noted by many authors. It may be assumed that, in the case of the graded strata in the Maizuru Group, too, the separation of various components and changes of composition from the base to the top of the strata, depends on difference of density of each components. But these differences of density is not so large if consideration is limited to the important components treated above, and relative density with the dense current in which these components are transported cannot differ so much as to separate the components.

The following assumption is probable. Indurable components of rocks and detritus were decomposed or broken partly during the course of weathering and partly during transportation. Each component had a tendency to attain its respective size. Then, these various components were sorted according to their sizes by their difference of velocity of movement (mainly settling velocity ?). Difference of density between each particle or grain of main components may not play a leading role in sorting. Dropping of grains of coarser sizes to the lower levels of turbid flow, caused decrease of density of the higher leveled parts of the flow, and thus the dropping of the coarser grains were

* These difference are caused by the fact that, many of quartzose igneous rocks, quartzite, felsite and groundmass of liparite, etc., are included in rock fragments in this paper, while some of these were included in quartz pluse chert in the former paper.

** For instance, plagioclase must have a tendency to be fractured at the composition plane or clavage. S. MIZUTANI (1959) accertained, in his study on Permian graywacke from Mugi area in central Japan, that, most of the plagioclase grains of the stones have fractured planes parallel to a cleavage plane. And the finer grains generally have only a few lamellae or show simple twining while the coarser grains are polysynthetically twined.

accelerated. Consequently the separation of components of various kinds was carried on. Rock fragments which were not yet decomposed, were deposited in the lower portion of the strata. Felspar gathered in relatively higher portion, and clay minerals were concentrated at the uppermost level of the strata.

As stated in the former chapter, transportation and deposition of these deposits were made by turbidity currents. Stirring and mixing of these components took place during the course of transportation and deposition. The separation of the components therefore was not carried on so well, that is, the deposits are immature as a whole.

Felspar rich fine～very fine sandstone and, especially, black clay shale in the upper portion of the strata, may be regarded to be a little more mature than the very lithic and very ill-sorted sandstone or granule conglomerate in the lower portion of the graded strata. However, when the manner of transportation and deposition is remembered in connection with the fact that these sediments are the constituents of a unit stratum, the difference of the maturity of these various deposits cannot be considered to be so large. In fact, the separation of clayey matrix from felspar in the portion of the mean grain sizes of fine sand, is not complete. So, the sandstones of various mean sizes in the various portion of these units of strata in the Maizuru Group, should not be named differently, notwithstanding the difference of the mineral composition.

For the examination of the classification or maturity of sandstones, we should consider both the compositional properties and the textural properties, and especially their mutual relation, as stressed in the previous paper and exemplified in this paper again. Moreover, the above consideration shows that, major sedimentary structures, which indicate physinal environment and agent of deposition, are also the important factors to be considered as the basis of classification and nomenclature as stressed by PACKHAM (1954).

Effect of selective breaking and selective transportation is obvious in the case of the sandstones of the Maizuru Group (very immature sandstones), and in the cases of those of the Yakuno Group and some other sandstones in Japan (somewhat more mature sandstones). The effect, however, may be variable in accordance with the maturity of sediments. How the effect appears in cases of much more mature sandstone, and acts on difference of composition and texture, is an important problem to be studied further.

Summary and Conclusions

Sedimentary structures of graded bedded sediments in the Maizuru Group were studied in the field and under microscope. The characters of the structures are explained only by the mechanism of transportation of turbidity current.

In the graded strata, rock fragments are abundant but decrease rapidly in upper portion of the strata. Felspar and matrix are also important components and they increase in quantity in upper portion of graded strata where the sandy part treated here is concerned. These changes of distribution of the components are closely related with changes of mean sizes of sand grains, namely grading.

As for the reasons for these changes, the following assumption may be made. Indurable components of rocks and detritus were respectively decomposed or broken during the course of weathering and transportation. Each component tended to attain its respective grain size corresponding to its mineralogical properties. These grains were then sorted out according to their sizes by their difference of velocity of settling and transportation. As a result, the separation of components of various kinds was carried on.

It is emphasized again that, for the examination of the classification and maturity of sandstones, in the case of these graded bedded sandstones also, we should consider the mutual relation between the compositional properties and the textural properties. Major sedimentary structures which indicate physical environment and agent of deposition are also the important factors to be considered as the basis of classification and nomenclature of sandstones as stressed by PACKHAM.

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Erratum of Part 1, (Importance of some Relations between Mineral Composition and Grain Size)

Page	Line	For	Read
242	1	the larger amount of felspar	the larger amount of quartz and the smaller amount of felspar