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Studies on Sandstones in the Maizuru Zone, Southwest Japan III

Graywacke and Arkose Sandstones in and out of the Maizuru Zone

By

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Abstract

In this paper, the provenance of sandstones in the Maizuru Zone and the importance of the so-called Yakuno intrusive rocks among the source rocks will be first disclosed. The results of investigation, of pebbles of the conglomerate which associate with the sandstones, of heavy minerals of the sandstones, and of quartz irradiation effect are examined. Arkosic and non-arkosic sandstones in the Carnian N-2 Formation and N-3 Formation of the Nabae Group are studied somewhat in detail, and the environment of deposition of these stones are suggested, in comparison with that of the sandstones of the Lower and Middle Triassic Yakuno Group. The causes for the difference in character between the "graded graywacke" and the "non-graded graywacke" are considered. Other graded graywacke out of the Maizuru Zone are mentioned in comparison with the graywacke in the Zone. The causes of formation of various graywacke and arkose are suggested, and the development of these sandy deposits is presented in order as shown in Figure 13 and 14.

I. Introduction

In the former studies (SHIKI, 1959 a and b; 1961 a) the author examined some sandstones in the Permian and the Triassic strata in the Maizuru Zone. He intended also to find a general course or manner of study on sandstone petrology. Especially, the need for the consideration of the mutual relation between compositional properties and textural properties was emphasized.

Researches on the sandstones in the Maizuru Zone are of peculiar interest, not only because of the variabilitiy of the stones, but also because of the importance of the geologic history of the Zone in studying the orogenic movement which occurred during the Permian and the Triassic Epochs in Japan. Stratigraphic sequences, facies, geologic ages, and structures, have been clarified rather in detail (NAKAZAWA, 1958; NAKAZAWA and others, 1958; SHIMIZU 1962, SHIMIZU and others, 1962 a and b; etc.). Further petrological study of the sediments will be useful in arriving at a better understanding of the sedimentary environment and the geotectonic history of the sedimentary basins in the Zone.

In this paper, the application of the course of study sought out in the former papers to some sandstones in and out of the Maizuru Zone, will be attempted. Special attention will be given to the graywacke and arkose ten-

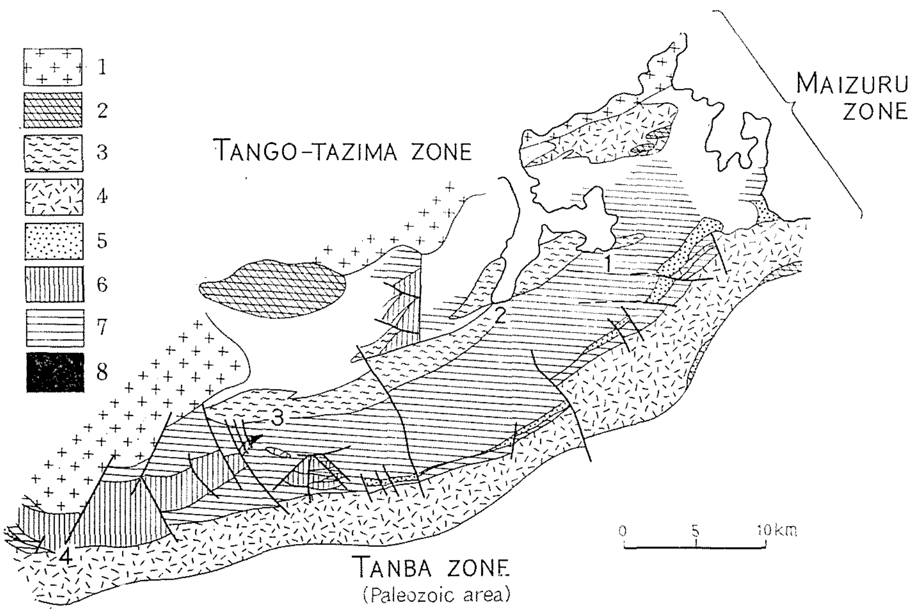

Fig. 1. General map of the northeast part of the Maizuru Zone.

Legend: 1. Younger granite 2. Serpentine
3. Acidic members of the Yakuno intrusive rocks associated with some basic members of the rocks and the Komori metamorphic rocks
4. Basic members of the Yakuno intrusive rocks and the Paleozoic strata, associated with some granitic rocks and metamorphic rocks
5. Upper Triassic Nabae Group (Carnian)
6. Lower to Middle Triassic Yakuno and Shidaka Group
7. Main part of the Permian Maizuru Group treated in this paper
8. Upper Permian Gujo Formation

District: 1. Higashimaizuru 2. Nishimaizuru 3. Komori.

dency of the stones. The comparison of various characters of these sandstones may be one way to gain a clear understanding of the cause and the environment of the formation of graywacke and arkose.

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II. Provenances of the Sandstones in the Maizuru Zone

General Statement

As is well known, provenance is one of the most important factors affecting the properties of sandstones and other sedimentary rocks. Arkose tendency and graywacke tendency of the sandstones in the Maizuru Zone, are also considered to be caused mostly or largely by the provenance factors.

It has long been suggested that, the so-called Yakuno intrusive rocks, which is one of the most remarkable components which characterize the Maizuru Geotectonic Zone, may (or may not) be the important part of the source rocks of the sediments in the Maizuru Zone. The presence of granitic, liparitic, and quartzose-mylonitic rocks, etc., among the grains of sandstones, reveals these possibilities. In connection with these matters, investigations have been made on some other components of the sediments in the Zone, in order to obtain some data.

Studies on the Conglomerates

Studies have been made on the conglomerates of the Permian Maizuru Group and Lower-Middle Triassic Yakuno and other groups, for years (KANO, NAKAZAWA, and SHIKI, 1961). These studies are very useful in reconstructing the provenance of the groups. As a matter of course, source rocks traced by the study of conglomerates may be the same as rocks which actually supplied the grains on the sandstones.

Three groups of pebbles have been recognised.

1). Pebbles of sandstone, shale, chert, limestone, and andesite or basalt.

2). Those of liparitic- porphyritic- granitic-rocks.

3). Those of porphyroid- or mylonite-like gneiss, amphibolite and amphibolite schist.

The pebbles of the 1st group are considered to have been derived from the region including the limestone plateaus, which had lain adjacent to the northwest part of the Maizuru Zone (NAKAZAWA and others, 1958; NOGAMI, 1959). The region is now occuppied by latter granites or other igneous rocks and Tertiary deposits.

The pebbles of the 2nd groups, trondjhemite granodiorite, granite-porphyry, granophyre, quartz-porphyry and liparite etc., are found among the so-called "older granite" of the Yakuno intrusive rocks which occur in the northern subzone of the Maizuru Zone. The pebbles of gneiss, amphibolite and amphibolite-schist reported by H. KANO (1961), show precisely the same appearance and lithologic properties as those of the Komori metamorphic rocks. The latter develope, in initimate relation to the Yakuno intrusives, nearest the conglomerates containing the pebbles mentioned above.

In the case of the upper Triassic Nabae Group, the conglomerates are few, and the sizes of the pebbles of stones are too small. Therefore, investigation of the pebbles of stones will not be treated here.

Heavy Mineral Analysis

Analysis of heavy mineral composition is the common way of studying the provenance of sandstones. It is regarded as the most effective method, if pebbles are scanty in the formations.

From each formation, several sandstone samples were selected, on which thin section analysis was carried out in parallel. Since the number of samples was too small, results not so satisfactory as expected were obtained. Heavy mineral content of sandstones of the N-2 Formation is remarkably small. In general, the variation in the amount of mineral contents of various formations can be easily recognized. However, the qualitative variation is the kind of heavy minerals contained in each sample of various formations, is rather small. That is to say, heavy minerals found in the sandstones of various formations or groups in the Maizuru Zone are mainly leucoxene, hematite, magnetite and/or ilmenite, titanite, zircon, garnet, epidote, tourmaline, biotite, muscovite, chlorite, and hornblende. Among these, iron opaques, titanite, epidote, biotite, are very abundant in some cases. In a few sandstones, allanite, apatite, and rutile appear.

The mineral suite of biotite, zircon, blue-green tourmaline, and allanite, indicates the provenance of rather acidic igneous or metamorphic rocks. On the other hand, the suite of leucoxene, titanite, hornblende, and brown tourmaline shows rather basic source rocks.

This combination of acidic suite and basic suite is very interesting, because the so-called "Yakuno intrusive rocks" and "Komori metamorphic rocks" include acidic and basic igneous rocks and corresponding metamorphic rocks.

Accessory minerals contained in the "Yakuno intrusives rocks" and the "Komori metamorphic racks" in the Maizuru District, studied by IGI (1959), are shown in Table 1.

Almost all the minerals of rocks listed here are also found in the sandstone

Table 1. Accessory minerals contained in the "Yakuno istrusive rocks" and the "Komori metamorphic rocks" in the Maizuru District. From IGI (1959) with minor modification.

Rocks	Granophyre -Felsite (Dike formed rock)	Granitic rock	Biotite Gneiss -Schist	Gabbro	Amphibolite
Heavy Minerals	Biotite	Biotite	Biotite	? Biotite	(Biotite)
		Hornblende	(Hornblende)	Green } Brown } Hornblende	Green } Brown } Hornblende
			(Monoclinic pyroxene)	Monoclinic pyroxene	Monoclinic } Rhombic } pyroxene
		Apatite	Apatite		
		Zircon	Zircon		Zircon
			Garnet		Garnet
		Sphen	Sphen	Sphen	Sphen
	Chlorite	Chlorite	Chlorite	Chlorite	Chlorite
		Epidote		Epidote	Epidote
		Zoisite			Zoisite
	Ilmenite				
	Iron ore	Iron ore	Iron ore	Iron ore	Iron ore

samples. Especially, some minerals of the sandstones, for example, green hornblende, epidote (including clinozoisite), some titanite, garnet and zircon, etc., show characters resembling those of the Yakuno intrusive rocks. The presence of apatite, soluble mineral in acid, in a few sandstones of the Triassic Yakuno Group, is also interesting.

A complete identification of minerals of source rocks and sandstones is, of course, very difficult. Secondary alteration, authigenesis, etc., offer a complex problem. A further detailed study on heavy mineral composition will be presented in a following paper.

Gamma Irradiation Effect on Quartz

It has been well known that X-ray and gamma-ray irradiation account for smoky quartz. Fine crystals of smoky quartz, which are very common in pegmatite druse, have been fully studied physically. Recently, HAYASE applied the Gamma irradiation to the quartz of various rocks and made the different geological occurrence clearly detectable by the wide range of the quartz smokiness grades (HAYASE, 1961). When irradiated by gamma-rays, the smokiness grade (i.e. quartz susceptibility to cobalt 60 gamma-ray irradiation) is the highest in volcanic rock quartz, intermediate in granite, and the lowest either in schist quartz or low-temperature quartz of hydrothermal origin. After the heating test of quartz at about 1000°C for 30 minutes, a marked increase of its smokiness grade is seen. Thus smokiness grade seems to indicate the crystallization temperature of that quartz.

HAYASE suggests that, the gamma irradiation method must be applied to the study of granite petrogenesis, and also in telling the original rock of a quartz grain contained in a sedimentary rock. Application of this method to the source rock problem of sediments in the Maizuru Zone may serve in obtaining some additional data.

From granitic rocks (potash-rich, potash-poor) granite-porphyry, quartz-porphyry, and gneiss, which belong to the so-called Yakuno intrusive rocks or Komori metamorphic rocks, quartz grains were selected by hand-picking and crushed to the size of 16–32 mesh. Their stains colored either by ferric or by manganic oxide were leached by immersing them in concentric HCL for 24 hours.

In general cases other than these quartz of the Maizuru Zone, quartz grains thus leached mostly remain smoky as the results of natural radioactivity. These naturally smoky quartz can be decolored by heating it at 600°C for 5 minutes. The samples thus decolored are irradiated by cobalt gamma-rays (as a rule 10 roentgen). The repetition of such decoloring and coloring cannot change the degree of quartz smokiness, so long as the conditions of these treatments remain the same. The decoloring must be done as throughly as possible for the sake of color comparison.

In the cases of the Yukuno intrusive rocks and Komori metamorphic rocks, quartz grains leached by immersion in HCl were colorless, and the heating and also the gamma irradiation did not actually change their color. It is remarkable that, even quartz from quartz-porphyry was not colored or smoked. This results coincides well with the views of other authors on petrogenesis of these rocks. That is, the so-called Yakuno intrusive rocks are protoclastic rocks which intruded, under the condition of low temperature, and by some pressure, into (and through) deep tectonic fissure zone, accompanied by the so-called Komori metamorphic rocks.

By comparing the smokiness of these quartz, examination was made on the irradiation effect of quartz grains of sediments in the Maizuru Zone. Several samples of sandstones were selected from Maizuru, Yakuno, and Nabae Group, and quartz grains were picked and crushed. Procedure similar to that taken on the quartz of igneous and metamorphic rocks stated above followed. As a result, the quartz grains of these rocks were also not smoked by gamma irradiation at all. It can be safely said that, quarts grains of the sedimentary rocks investigated have their origin undoubtedly in rocks which intruded under low-temperature condition or in schist. Around the Maizuru Zone almost no out crop of acidic rock is known except the Yakuno intrusives and Komori metamorphics containing low-temperature quartz. It may be said with reason that the quartz grains which were not smoked have their origin, not certainly but possibly, in the Yakuno intrusive rocks and/or Komori metamorphic rocks, at least in most. Some phyllitic rocks (Sangun metamorphics) and some sedimentary rocks may have supplied the quartz grains to a minor degree, but there is no clear evidence based on data of gamma irradiation effect. Of course, the presence of basic rocks in provenance, cannot be accertained by this method.

Provenances suggested

In conclusion, acidic igneous rocks such as liparite, quartz-porphyry, granophyre, granite-porphyry, granite, and granodiorite, etc., many of which have some protoclastic and/or cataclastic texture, and some gneissose metamorphic rocks, can be regarded the most important source rocks of the sediments, including sandstones, in the Maizuru Zone. Moreover, these rocks are identified as the acidic members of the so-called Yakuno intrusive rocks and as the Komori metamorphic rocks.

Some basic rocks like basalt, and amphibolite, amphibolite-schist, etc., may also be a part of source rocks of importance. Some of them have the same appearance as that of the Komori metamorphic rocks.

Pebbles of conglomerates show that, sedimentary rocks like sandstone, shale, chert, and limestone, etc., also developed in the provenant region, but this was not ascertained by the study on heavy minerals and quarts.

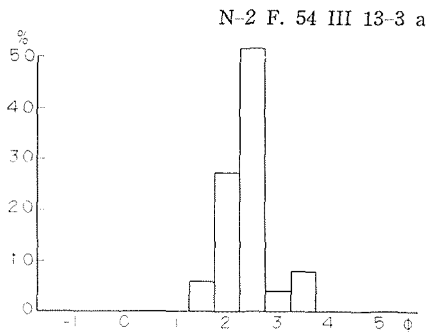
III. Properties of Sandstones of the N-2 Formation and the Comparison with Those of other Sandstones

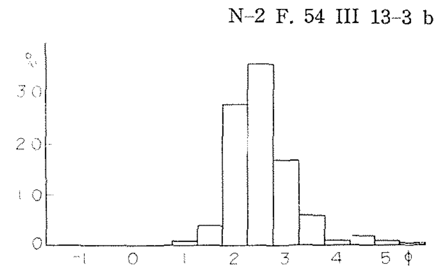
General Description

Properties of sandstones of the N-2 Formation of the Nabae Group were described briefly in a previous paper (Shiki, 1959 a). At that time, the properties were regarded to be similar throughout the areas where the formation is exposed, except in a few districts. That is, the sandstones are white to pale gray in color. They are fine to medium grained. Sorting of the grains is good. But the grains are not so well-rounded. Content of quartz and felspar is high presenting a striking contrast with that of the Maizuru Group sandstone. Rock fragment and matrix occupy only a small amount of the stones.

Recent studies on the sandstones have attempted to show more divergent textural and compositional properties of the stones. For example, a few sandstone samples have only 35% or lesser amount of quartz, and a few sandstones contain more than 25% rock fragments.

Studies were made also on several sandstone samples in the N-3 Formation of the Nabae Group. Obviously these sandstones are remarkably richer in rock fragment and, in some cases, also in matrix than in the usual sandstones of the N-2 Formation. Sorting of the grains is better in the latter than in the former. In short, the latter sandstones are more immature than the former ones.





Figs. 2 a & b. Mechanical composition of sandstones of the N-2 Formation.

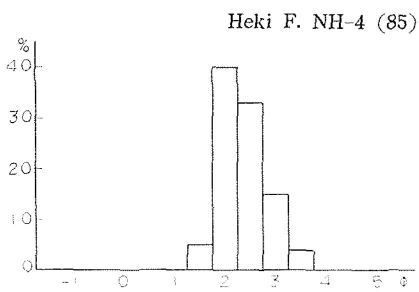


Fig. 3. Mechanical composition of a sandstone of the Heki Formation.

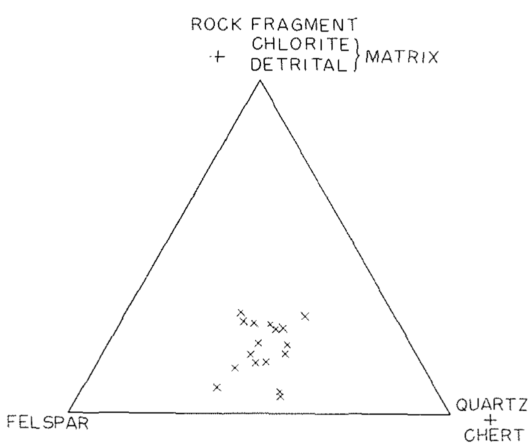


Fig. 4. Diagram showing mineral composition of sandstones in the N-2 Formation.

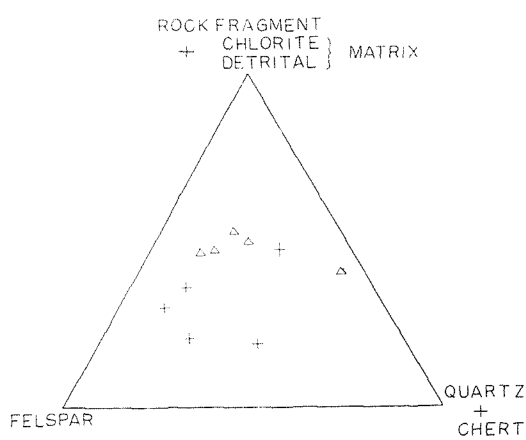


Fig. 5. Diagram showing mineral composition of sandstones in the N-3 and the Heki Formation.

△ N-3 Formation

+ Heki Formation

Problems concernig felspar content and maturity of the N-2 sandstone

As has been stated in the previous papers (SHIKI, 1959 a and b), in the case of sandstones of the Maizuru Group and Yakuno Group, a clear relationship can be observed between the composition and the grain sizes. In short, materials of coarser-grain mean size contain a smaller amount of felspar and matrix. On the contrary, the rock fragment decreases in accordance with the decrease of the mean size of sand grains, and falls off when the mean size becomes

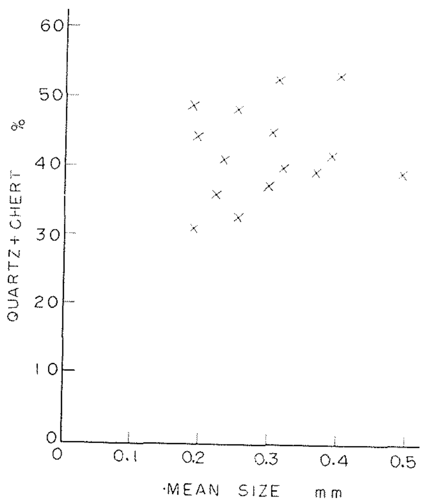


Fig. 6a.

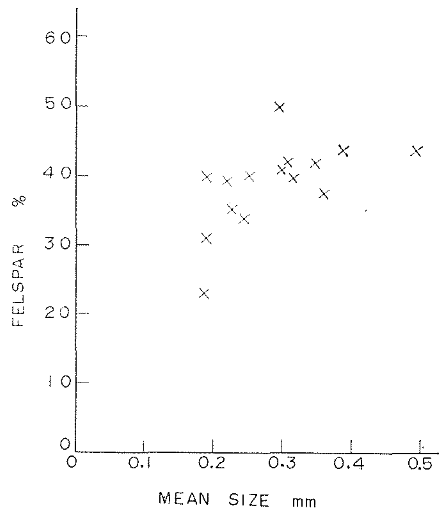


Fig. 6b.

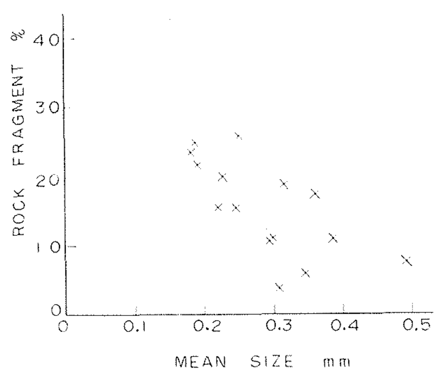


Fig. 6c.

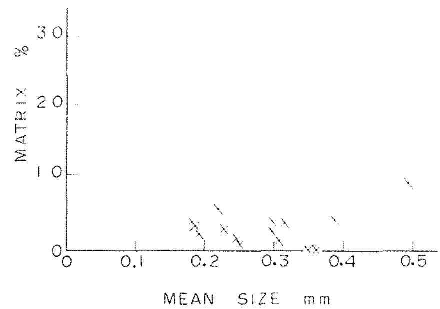


Fig. 6d.

Figs. 6a-d. Relation between amount of various components and mean size of sand grains of the N-2 Formation.

smaller than 0.2–0.25 mm.. In the case of the Yakuno Group quartz content is small in the part where the size in below 0.25 mm. or so. Similar relation between mineral content and grain size is recognized in many sandy deposits in Japan. (SHIKI 1961b) Summarizing the results of these studies, the writer

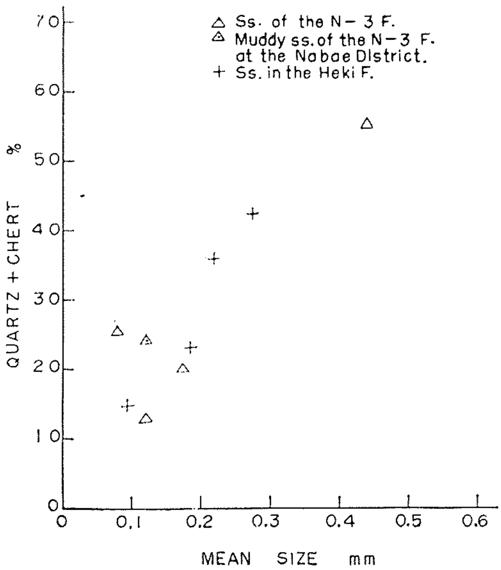


Fig. 7a.

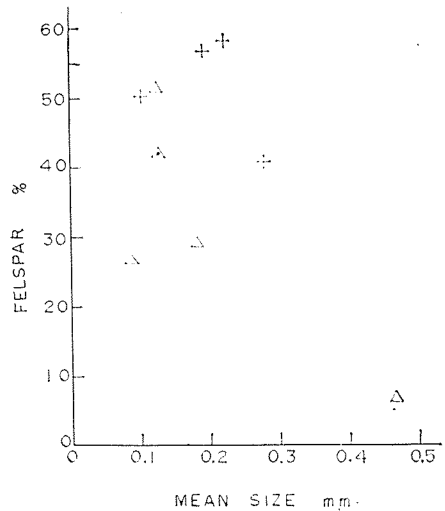


Fig. 7b.

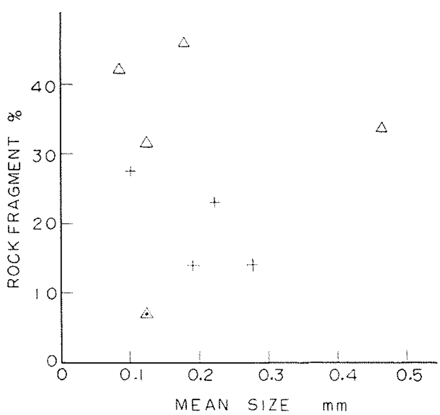


Fig. 7c.

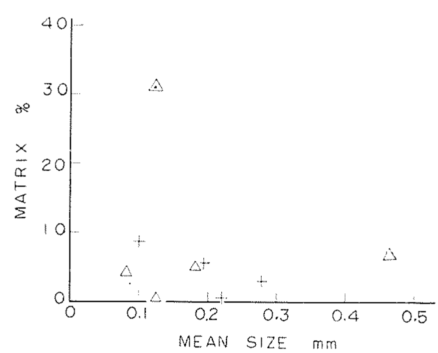


Fig. 7d.

Figs. 7a–d. Relation between amount of various components and mean size of sand grains of the N–3 and the Heki Formation.

ventured to state as follows. (SHIKI, 1961 a and b) The mineral composition of sandstones is closely related with the sizes of the grains. It is related at first with the properties of each kind of components, namely, whether it tends to be broken and decompose or not, and the sizes which the broken pieces tend to take. After these components attain their respective grain size corresponding to their mineralogical properties, the water current sorts out the grains according to their sizes. Thus, from an immature sandy deposit of some mineralogical composition, maturer deposits rich in specular components are made. For example, the decrease of felspar followed by the increase of quartz in some places, and the accumulation of felspar separated from quartz in other places, are the two aspects of a result of a series of process.

In the case of the sandstones of the Nabae Group also, samples having a smaller amount of quartz gather in the part where the mean size is below 0.2 mm.. (Figure 7a) However, rock fragment and felspar show very divergent distribution on diagrams. (Figure 6 b & c, and Figure 7 b & c) This fact indicates that the sandstones of this Group contain sediments of various environments. In cases where the examination is limited to the N-2 Formation, a somewhat reverse tendency of component distribution may be recognized. That is, the rock fragments increase in accordance with the decrease of the mean size of sand grains. As has been mentioned, the characteristic property of sandstones of the N-2 Formation is abundance of felspar in the part where the mean size is coarser. In a previous paper, it was presumed that, the felspar content may increase further in accordance with the decrease of mean size, as in the case of the Yakuno Group and many other sediments. However, sandstone samples of finer-grain mean size of the N-2 Formation, seem to contain a rather small amount of felspar, though the number of samples is still too small to arrive at any conclusion.

This question will be solved by examining the properties of each sandstone sample in more detail. In reality, the sandstone samples which contain smaller amount of felspar* have rather larger amount quartz. Moreover, grain sizes of these samples are not so small. These sandstone samples may be regarded to represent the sediments a little maturer than the other sandstones in the N-2 Formation. That is, these felspar-poor sandstones may represent the deposits which sustained long agitation, are broken or fractured partly, have lost undurable components such as felspar, and are possibly a little abraded. Fractured pieces of felspar were washed away, transported and were accumulated in some other places. These felspar-rich and much finer-grained sediments cannot be found in the N-2 Formation. The N-2 Formation is essentially a sandstone formation intercalated exceptionally with thin clay-shale beds. Very fine sandstone or coarse siltstone is very scanty in the N-2 Formation. Felspar rich

* Amount of felspar of these sandstone samples is less than 35% but more than 20%, and is never so small when compared with sandstones of same grain size in the Yakuno or Maizuru Group.

sediments, smaller than 0.15 mm. in grain size, may be represented, for instance, by very fine muddy sandstone or coarse siltstone in the N-3 Formation at Nabae seaside district (Fig. 7 b & d). This sediment indicates an environment where clay and very fine sand get mixed.

As has been repeatedly stated, in the case of sandstones of the Yakuno Group, the smaller the mean size of sand grains, the larger the amount of felspar contained, making a clear contrast with the case of the N-2 sandstone. But when examined again in detail, it is noticeable that no sample coarser than 0.45 mm. in mean size has been treated, and the samples which are coarser than 0.3 mm. have been very few. (Fig. 3 in SHIKI 1959 b, and Fig. 8) That is to say, the samples of the Yakuno Group mainly represent the part of sediments which lost fractured felspar to some degree and also the part in which these fractured felspar are concentrated. The sandstones of the N-2 Formation are regarded to belong to the part in which the fracturing and washing away of felspar occured seldom, or felspar were selectively separated away, to some degree. But, the stones do not contain the part in which fractured felspar are concentrated, forming a contrast with the Yakuno Group sandstones. In the previous paper the writer stated that the sandstones of the N-2 Formation are maturer than the sandstones of the Yakuno Group. However, when considered as above, many sandstones of the N-2 Formation of rather coarser grain sizes and containing large amount of felspar must be regarded more immature than many of the sandstones of the Yakuno Group. Felspar-poor "fine grained" sandstones (0.15–0.2 mm. in mean size) of the Nabae Group, and felspar-poor relatively coarser grained, or at least, not so fine sandstones (0.2 mm. or so in mean size) of the Yakuno Group, actually have nearly the same mean grain size, and moreover, they can be judged to stand at nearly the same maturity, though much more data are needed to arrive at a definite conclusion.

It is probable that the difference of source rock has some (or a little) effect on this difference in compositional properties of sandstones between these two groups; i.e. the Nabae Group and the Yakuno Group. Indeed, this difference of composition was attributed to provenance factor in a previous paper, but this had no logical basis. Common properties of the provenances of these two groups were discussed in the previous chapters. The amount of basic and neutral igneous (and metamorphic) rocks and the rate of various facies of acidic rocks may vary a little, but the difference may not be so large as to affect the above consideration.

Problems concerning Amount of Rock Fragment

In the case of the N-2 Formation, rock fragments increase in accordance with the decrease of mean size of sand grains. Some samples smaller than 0.25 mm. in mean size, contain rock fragments which amount to more than 20% of the stones.

The distribution of rock fragments like these in the N-2 Formation may seems to form a contrast with the distribution of those of other sandstones in the Maizuru Zone. Rock fragments of sandstones of the Maizuru Group, decrease in accordance with the decrease of mean size of sand grains, especially when the mean size becomes smaller than 0.2–0.25 mm.. In this case, the rock fragments are unlike felspar in the manner of breaking. They do not seem to have a tendency to attain the size of very fine sand or coarse silt. But they decomposed directly into finer muddy or clayey matters.

As for the sandstones of the Yakuno Group, such a distinct relation between the amount of rock fragments and mean size could not be found. The following explanation was attempted on the amount distribution of rock fragments of the stones. In the case of the Yakuno Group, sediments coarser than granule size have a large amount of rock fragments. So the very fact that sand size sediments do not contain many rock fragments, seems to reflect the selective breaking and immediate decomposition of rock fragments without passing through the particles of sand or silt size.

The consideration and explanation stated previously and repeated above, themselves contain no mistake but seem rather crude when reconsidered in detail. It is found that, in the case of the sandstones of the Yakuno Group also, many samples 0.15–0.25 mm. in mean size contain rather large amount of (20–40%) rock fragments. In sandstones coarser than 0.25 mm., the amount of rock fragment seems to decrease, although, of course, sediments coarser than granule size have a large amount of rock fragments as mentioned before. In short, a common tendency is recognized between the sandstones of the N-2

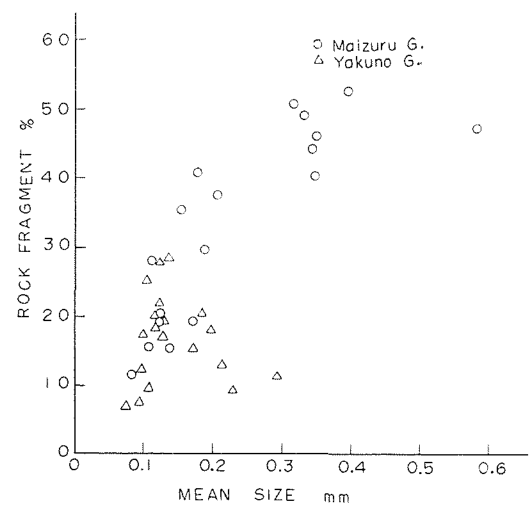


Fig. 8. Relation between amount of rock fragments and mean size of sand grains of sandstones of the Maizuru Group and the Yakuno Group.

Formation and the stones of the Yakuno Group. That is, many samples 0.15–0.25 mm. in mean size contain a rather large amount (more than 20%) of rock fragments and sandstones coarser than 0.25 mm. have a smaller amount of rock fragments. (Figure 6 c, and Figure 8)

These tendency can probably be attributed to lithological character of the rock fragments. Many rock fragments contained in the sandstones of the N–2 Formation and the Yakuno Group are those of acidic igneous rocks such as the ground mass of liparite, quartz-porphyry, granite-porphyry, etc.. In some of them, protoclastic and/or cataclastic character are recognized.

In the previous chapter, the probable provenance of the sediments were examined. Acidic igneous rocks such as liparite, quartz-porphyry, granite-porphyry, trondjhemite-granite, and granodiorite, etc., having some protoclastic and/or cataclastic texture, and so on, were regarded the most important source rocks of the sediments. Moreover, these acidic rocks were identified as the acidic members of the so-called Yakuno intrusive rocks. Therefore the acidic rock fragments contained in the sandstones of the N–2 Formation and the Yakuno Group most likely have their origin in those Yakuno intrusives also.

Thus, it is supposed that, such rocks as these contained most commonly in the sandstones of the N–2 Formation and the Yakuno Group, originally had a tendency to be broken to the sizes of very fine or fine sand (probably about 0.15–0.25 mm.). Textural properties (minuteness of space of ground mass, and its rate to phenocryst) of liparite, quartz-porphyry, and other rocks, especially more or less protoclastic and/or cataclastic character of granitic rocks, may be the cause of the tendency. As a matter of course, however, the concentration of broken pieces to some specific places is owing to the sorting action by water current according to their sizes.

Some sandstones of the N–2 Formation rich in rock fragments and relatively finer-grained, and some sandstones of the Yakuno Group rich in rock fragments and rather fine-grained, (both the stones are 0.15–0.25 mm. in mean grain size.) may be regarded to have nearly the same textural and mineralogical maturity. A similar suggestion was advanced as to the data of felspar content in a previous section.

To sum up, the problems concerning on both felspar content and rock fragment content can be settled as follows. The difference in properties of sandstones between the N–2 Formation and the Yakuno Group, may be attibuted to a certain degree to the difference in provenance factor. However, it must be caused, for the most part, by the difference in the sorting action by water current which each sandy deposit had sustained at the time of transportation and deposition.

The sandstones of the N–2 Formation coarser than 0.3 mm. in size of sand grains, have a large amount felspar grains, but they seem to have lost many rock fragments by breaking and sorting. In the case of the Yakuno Group, sandstone of these grain size are few in number, but, if present, they contain smaller amount felspar (Fig. 3 b in SHIKI, 1959 b) and are regarded a little maturer than the N-2 sandstones. In the sandstones, 0.15–0.25 mm. in mean size, of the N-2 Formation and of the Yakuno Group, the concentration of pieces of rock fragments is recognized. In some finer sandstones of the N-2 Formation, in which the mean size of sand grains of the stones is 0.2 mm. or so, the decrease of felspar is seen. In the case of the formation, places where this lost felspar is accumulated cannot be found. Fracturing or breaking, and washing away of felspar, like that of rock fragments, occured in the case of the sediments of the Yakuno Group also. As a result, the felspar content becomes small in the sandstones coarser than 0.2 or 0.25 mm. in mean size. In this case, fractured or broken felspar seems to be concentrated in the part finer than 0.15 mm. in size. The maturity of some sandstones of the N-2 Formation, in which felspar is reduced and rock fragment has increased, and that of similarly characterized sandstones of the Yakuno Group, may not differ so much.

Reexamination of Amount Distribution of Rock Fragments in Sandstones of the Maizuru Group

The contrast, which has been suggested in a proevious paper, between the properties of sandstones of the N-2 Formation and those of the Yakuno Group, is now understood to be slight in some sense as examined above. However, the contrast became marked between the properties of sandstones of the Maizuru Group and those of the stones of the N-2 Formation and the Yakuno Group. When examination is limited to the amount of rock fragments, the contrast is as follows (Fig. 8 and Fig. 6 c).

1). Sandstones of the Maizuru Group as a whole have a remarkably larger amount of rock fragments than those of the N-2 Formation and the Yakuno Group.

2). In the case of the Maizuru Group, the amount of rock fragment obviously tend to decrease in accordance with the decrease of mean size of grains and in particular falls off when the mean size becomes smaller than 0.25–0.2 mm.. On the contrary, the content of rock fragments, in the case of the N-2 Formation and the Yakuno Group, tend to increase in the part where the sizes are near 0.2 mm. (0.15–0.25 mm.).

As stated in detail in a previous paper, the difference in amount of rock fragments is caused a). by source rock control and b). by difference in the manner of transportation.

1-a). *Amount of rock fragments and source rock control.*

In the former chapter, the common development of both acidic and basic rocks as source rocks of each sandstone of the Maizuru and the Yakuno Groups, and the N-2 Formation, was inferred. But, it is probable that there is some variation in the rate of amount of these source rocks. The high content of quartz and felspar in the sandstones of the N-2 Formation, cannot be explained except by supply from granitic provenance. In the case of the Maizuru Group also, supply from acidic source rocks must be great. In this case however, the greater part of the acidic rocks is actually hypabyssal and volocanic rocks. Granulitic rocks like granite, granodiorite, etc. have a tendency to decompose easily and directly into mono-mineral grains of quartz, felspar, or micas (or chloritic minerals). On the contrary, the ground-mass of quartz-porphyry, liparite, etc., does not decompose so directly nor rapidly. The abundance of hypabyssal and volcanic rocks in source rocks, is the first and the essential cause of the large content of rock fragments in sandstones of the Maizuru Group.

1-b). *Amount of rock fragments and manner of transportation.*

The transportation and deposition of these deposits of the Maizuru Group were effected by turbidity current, as stated in the former paper. In this case also, undurable components of rocks and detritus may have been naturally decomposed or broken during the course of weathering and transportation and sustained selective sorting according to their sizes. But, on the other hand, very rapid transportation and deposition do not allow complete breakage. Furthermore, the stirring and mixing of these components took place during the course. Clayey matter, produced by earlier decomposition of undurable components and erosion of sea bottom, and mixed with grains by stirring, may have prevented the further break of the more durable remaining rock fragments. As a result, not only in the sandstones of very coarse or coarse sand size, but also in stones of medium and fine sizes, a large amount of rock fragments can be contained.

It may be needless to say again, that, on the contrary, mixing does not take place at the time of deposition of the N-2 Formation and the Yakuno Group. The breaking of undurable components were carried longer and in higher degree, and broken pieces of rock fragments were washed away to accumulate in other places.

2). *Tendency of amount distribution and its causes.*

The difference in tendency between the increase and decrease of amount of rock fragments is probably caused by source rock control. Sandstones of the Maizuru Group have, in many cases, large amount of very undurable rock fragments such as andesite, basalt, diabase, and limestone, etc.. These rock fragments are unlike felspar or acidic rocks in the manner of breaking as stated in the previous chapters. They have a tendency to decompose directly into finer muddy or clayey matters without attaining the size of 0.25–0.15 mm.. Therefore, the higher the rate of these undurable rocks in provenance, the smaller the amount of rock fragments 0.15–0.25 mm. in size, and the more rapid the decrease of amount of rock frakment in accordance with the decrease of mean size.

In fact, even in the sandstones of the Maizuru Group, variable rapidness of decrease in amount of rock fragment is found. As was previously mentioned, data given in Fig. 5b., p. 304, in Part II (Graded Bedding and Mineral Composition of Sandstones of the Maizuru Group. SHIKI, 1961a), shows a little larger amount of rock fragments than data of Fig. 4, p. 243, in Part I (Importance of some Relations between Mineral Composition and Grain Size. SHIKI, 1959b). Fig. 5b. in Part II shows that many samples 0.15–0.25 mm. in mean size contain rock fragments at the percentage of more than 60. On the contrary, samples of Fig. 4 in Part I show a decrease in the amount of rock fragment even in coarser sizes. These differences were once thought to be due to some mistake in treatment or in identification of some kinds of rocks. Indeed, some of the quartzose igneous rocks were included in quartz plus chert in the Figure of Part I. However, when reconsidered, the mis-identification cannot be considered so great in number as to affect the tendency of the decrease. The difference in the tendency of decrease of rock framents is caused essentially by the difference in the rate of durable rocks and undurable rocks contained. Actually, the samples used in Fig. 4 in Part I, possess a large number of undurable rock fragments which remained, especially in the coarser grained sandstones. On the contrary, many of the rock fragments in samples treated in Fig. 5b. in Part II, are acidic rocks like those contained in the sandstones of the N–2 Formation. So, it is natural that the stones in Fig. 5b, 0.15–0.25 mm. in mean grain size, that is, the size in which the amount of rock fragments increases in the case of the N–2 Formation and the Yakuno Group, contains a large amount of rock fragments.

Some Sandstones in other Formation of the Nabae Group

Some sandstones in the Heki and the H–3 Formation have been studied. The Heki Formation develops in the Yakuno district. It is nearly correlative to the N–2 Formation.

Properties of the sandstones seem rather similar between the Heki Formation and the N–2 Formation, as shown in Fig. 6a–d & 7a–d. In felspar content, however, some of the sandstones of the Heki Formation indicate a very different character from that of the sandstones of the N–2 Formation. That is, the amount of felspar is larger in the former than in the latter.

Sandstones of the N–3 Formation seem to be more or less different in character from those of the N–2 Formation. The N–3 Formation is composed mainly of shales and sandy shales associated with several coal-seam in some locations. These sandstones intervene only rarely as thin layers or lenses. As shown in Fig. 7a–d, properties of sandstones are very variable. One of the samples is characterized by a poor amount of felspar, and richness of rock fragments, when compared with the sandstones of similar mean size in the N–2 Formation. A few other sandstones are not so poor in felspar, but rich in rock fragments also. One sample of the sandy shales is rather rich in felspar grains and is very poor in rock fragment.

The number of samples being too small, no definite conclusion can be arrived at. The following may be said at present. When consideration involves the N-2, N-3, and the Heki Formation, no relation between these many sandstones is apparent. Probably, these various sandstones may represent the sediments supplied from different kinds of source rocks and in different states of enviroment. For instance, medium-grained sandstones in the N-3 Formation, represented by a felspar-poor and rock-fragment-rich sample, may have much less granitic provenance than sandstones of the N-2 Formation.

Depositional Enviromment of the N-2 Formation

Many sediments in the N-2 and N-3 Formations are generally regarded littoral deposits including beach sand, lagoon deposit, delta deposit, and off-shore bar deposit, etc.. Especially, the characters of sandstones of the N-2 Formation, seem to indicate off-shore bar and/or beach environment.

The bedding of the N-2 sandstone is in many places clear. It is obscure, however, in many other places, and is even quite massive in some other localities. The N-2 Formation contains many pelecypod fossils of shallow sea forms. However, the typically white and massive sandstones in the formation have no fossils. Sorting of the sandstones, especially of those masive sandstones, is remarkably well. Washing out of detrital matrix is almost thoroughly performed, and the majority of sand grains in these sandstones have sizes between 0.2 to 0.5 mm. restrictedly. All these characters seem to resemble those of beach or off-shore bar deposits.

The decrease of felspar in sandstones of relatively small grain size, shows fracturing and washing out of felspar by some mechanism of sorting and transportation. As stated in this paper, some sandstones of the Yakuno Group have grain size smaller than that of any of the sandstones of the N-2 Formation, and contain a larger amount of felspar. These sandstones probably indicate offshore (neritic) environment, in which the fractured felspar of fine grain size are transported and accumulated.

In the case of the N-2 Formation, the sediments which represent the long transportation cannot be seen. On the contrary, the sandstones of N-2 Formation indicate the places where the fracturing of felspar grains occurs, and where the very well-sorted sand grains are deposited. The environment may be beach or bar or spit.

The distinction of beach deposits and bar or spit deposits connot be stated fully here. A few of the relatively coarser grained samples may show beach condition, and some relatively smaller grained samples may be deposits of bar or such places.

Notable scantiness of heavy minerals in some of those well-sorted sandstones in the N-2 Formation as mentioned before, is another ground for regarding the depositional environment of the stones as beach or off-shore bar. Probably, the sorting action separated heavy minelals from other materials. The effect of oscillation and fluctuation, and the agent of rolling, swash, underflow, rip current, and coastal drift current, may have caused the sorting and separation of various components.

Supposed environments of the N-3 Formation correspond well with those of the N-2 Formation stated here. If any of the sandstones are deposits of beach or bar, some other kind of sediments which indicate a relationship in the littoral environment should occur accompanied by the sandstones. The N-3 Formation, overlying the N-2 Formation conformably, consists mainly of black shale, as is seen in enclosed bay or inland sea. Sandy shale as represented by one of the samples of the N-3 Formation develops in the Nabae district, and indicates the condition where fine - very fine sand and mud mixes, as is often seen in bays or inlets.

Pelecypods and brachopods of shallow water form are abundant in many districts, especially in the lower horizon of the formation. But, in many other places, life is entirely absent. Fragmental impressions of plants is the only fossils contained in some places. In some localities, coal-seams are associated with black shale. Coastal lagoons, back water swamps, etc., may be the depositional environment, at least part of these black shales or coaly deposits.

Some sandstones, rich in rock fragments and poor in felspar represented by a few samples as mentioned in the former section, may indicate supply by some river from somewhat different source rocks (different from those of the N-2 sandstone).

Properties of the sandstones of the Heki Formation are still difficult to understand. Probably, some graded sandstones may be the sediments of delta environment. Others may be the deposits of littoral or off-shore environment.

The differences in properties of sandstones of N-2, N-3, and Heki Formation, represent difference and variation of depositional conditions of these sediments. This variation of the conditions itself, is a characteristic feature of the littoral environment.

Sandstones of the N-2 Formation as "Arkose"

Some of the sandstones in the N-2 Formation, being relatively small in grain size, cannot be included in "arkose". They contain more than 25% felspar, but, on the other hand, they are also rich in rock fragments (even more than 20%). Many other rather coarser grained sandstones of the formation are remarkably rich in felspar and quartz, and contains only a small amount of rock fragments. In these stones, the amount of felspar is nearly the same as that of quartz, and in some case it even exceeds that of quartz. The amount of detrital matrix is negligible or less than 5% of the stones. Thus, mineralogical properties of these relatively coarser grained sandstones can be reasonably be called "arkosic".

According to PETTIJOHN (1957), arkose occurs either as a thin blanket-like residum at the base of a sedimentary series that overlies a granitic terrane, or as a very thick wedge-shaped deposit interbeded with many coarse granite -bearing conglomerates and deposited with a lesser quantity of red shale and siltstone. The sandstones of the N-2 Formation are a little different from the arkose described by PETTIJOHN, in manner of occurrence. They do not make the base of a series that overlies a granitic terrane, and the stones are interbedded with only few conglomerates.

Indeed, beaches and/or off-shore bars are the places where more quartzose sand accumulate usually. But, in Japan, where the subsidence of coast and uplift of provenance are rapid, and the rate of depositional supply is large, much arkosic deposits develop as seen in Recent beachs and bars, also. Circumstances may be similar in the case of the N-2 Formation. The arkosic properties of the formation may denote high relief, and vigorous erosion of the granitc and felsparthic rocks, that is, granitic rocks in the Yakuno intrusive rocks, in this case.

In short, the sediments of the N-2 Formation and the N-3 Formation including the Heki Formation, are an association of sediments formed in various local environments, involving those of the beach and fore-shore, the tidal lagoon, and both river channels with their point bars and the backwater swamps. This association is similar with that of some molasse deposits of deltaic coastal plain and its inland extension.

IV. Various Graywacke and Arkose in and out of the Maizuru Zone

Graywacke Sandstones in the Maizuru Zone

As has been described, there develope two types of "graywacke" in the Maizuru Zone; the graded graywacke sandstones and the non-graded "graywacke" sandstones.

As for the graded sandstones, their mineralogical and some of their textural properties were described and their genetics discussed in the previous papers (SHIKI, 1959a & b, and 1961a). These sandstones of graded type develope in the common Permian Maizuru Group and show very characteristic properties of "graywacke". That is, the stones are rich in detrital matrix, in rock fragments, and also in felspar when the sand grains are rather small. These grains of the stones are angular and very ill-sorted. The association of granule-size grains with sand in the strata, the relationship between the sandstone strata and shale strata, and especially the graded bedded structure, indicate episodic rapid transportation of these sediments into quiet water. The turbidity current is the only probable theory by which these properties can be explained.

The sandstones of the non-graded type develope in the Gujo Formation or Gujo facies in the Maizuru Group (NAKAZAWA and NOGAMI, 1958: SHIMIZU, 1962; SHIMIZU and others, 1962a). The properties of each kind of minerals, and rock fragments of the Gujo sandstones are nearly the same as those of the sandstones of the general Maizuru Group. But, there is a small difference in the amount of each component between the two types of sandstones (Fig. 1–5 in SHIKI, 1959b; Fig. 5, Fig. 9, and Fig. 10a–d in SHIKI, 1961a). That is, quartz is richer in the former sandstones than in the latter. The more important difference in the properties of the two sandstones is structure.

Graded bedded structure is absent in the Gujo sandstones. Rather large scale cross bedding is sometimes observed. Bedding tend to be wedge-shaped and change its facies to dip and strike side. The sandstone beds associate with many conglomerate beds which are very ill-sorted and rich in undurable rock fragments as limestone, shale, andesite or basalt, and granitic rocks. And the stones contain large amount of detrital matrix. Shallow water benthos occurs in fine-grained beds*. Some of them may be of brackish water. Clay minerals in one of the fine-grained bed, i.e. greenish black mudstone, are illite, montmorillonite, and vermiculite. This combination of clay minerals probably shows brackish sedimentary condition.

All these facts concerning the facies of the sandstones and other rocks, indicate a quite different condition of sedimentation of the Gujo Formation from the common sediments of the Maizuru Group. The extreme graywacke tendency of the sandstones of the Gujo Formation, and their very immature texture (Fig. 11a, b) have certainly been caused by short transportation and

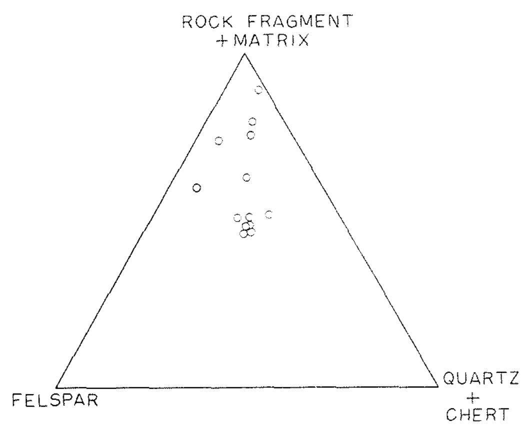


Fig. 9. Diagram showing mineral composition of sandstones in the Gujo Formation.

* In the case of the common facies of the Maizuru Group, fossils are usually absent from finer beds, in the coarse sandstones and granules, fusulinid faunule or brachopod faunule are contained. Probably, these fossils are deposits transported by turbidity current accompanied by detrital grains from shallow water to rather deep environment.

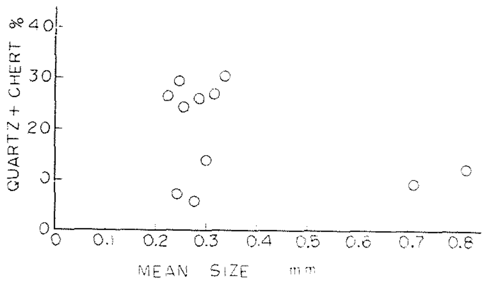


Fig. 10a.

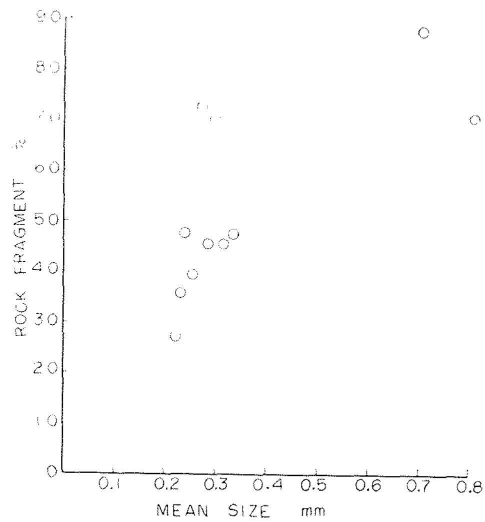


Fig. 10b.

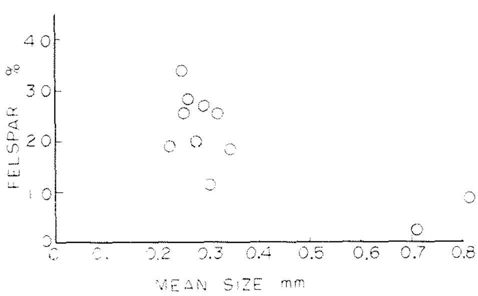


Fig. 10c.

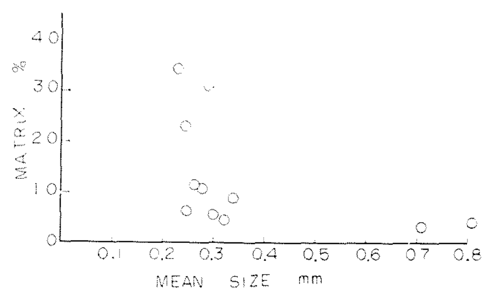
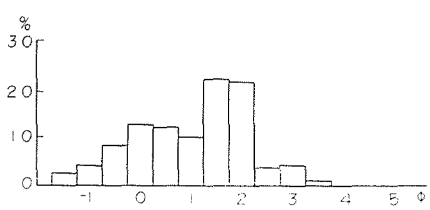


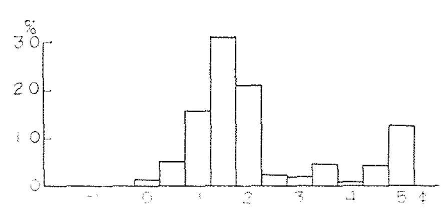
Fig. 10d.

Figs. 10a–d. Relation between amount of various components and mean size of sand grains in sandstons of the Gujo Formation.

Gujo F. GG21(d)-1



Gujo F. GG21(d)-2



Figs. 11a & b. Mechanical composition of sandstones of the Gujo Formation.

rapid deposition, but the mechanism cannot have been the turbidity current which transported the sediments into deep water. The sediments are of shallow water deposits probably accumulated exclusively at the foot of mountains then rising.

It may be suggested that, the Gujo Formation represents some of the marginal facies of the basin of the common Maizuru Group. The paleogeographical position, however, of the Gujo Formation denys this consideration. For, the Gujo Formation developes surrounded by the common Maizuru Group. Moreover, according to SHIMIZU (1961b), the faunal assemblage of the Gujo Formation probably indicates a different age from that of the common Maizuru Group. That is, brachiopod fossils from the Gujo Formation signifies a slightly upper horizon than the latter. Some of the pelecypod fossils are of Triassic type (NAKAZAWA and NOGAMI, 1958).

The following assumption is more probable. The depositional basin of the Maizuru Group, where the graywacke has deposited, became smaller and shallower in the last stage of its development. The uplift of provenance became rapid and carried large amounts of pebbles, sands, and other detrial matters to the basin. Thus, thick sedimentary bodies of very ill-sorted fanglomeratic and deltaic deposits, including non-graded type "graywacke", were accumlated at the foot of mountains then rising.

Paleozoic Sandstones in the Mugi and Tajimi Area

Sandstones in the Mugi and Tajimi area, studied by S. MIZUTANI (1957 and 1959), are some of the most minutely and fully examined Paleozoic sandstones in Japan. According to him, many of the sandstones in the area are remarkably graded, and the stones contain a large amount of detrital matrix. Therefore, these sandstones may be called "graywacke". On the other hand, some of the sandstones in the Mugi area are very poor in matrix, and rich in quartz and felspar (Fig. 12). Structurally, the strata of the stones are not graded. Therefore, the sandstones may be regarded as "arkose". When the two rock types having the same median value are compared, a graywacke is always found to be more poorly sorted than an arkose. Many distributions of the grains of graywackes obtained by the size analysis of measurable clastic grains of the stones are skewed negatively. On the other hand, the arkose has a more positive distribution. In addition, he stated that only angular grains with less variation of roundness are included in the graywacke, whereas the arkose has many rounded grains with some angular grains.

MIZUTANI assumed that, the fine particles in matrix of the graywackes were deposited as coarser particles. The original size distribution of the stones might have been nearly normal or more positively skewed, and the particles have been deposited in flocculation of sticking on to the surface of the grains from a muddy current in which many grains of a wide size range are suspended. This muddy current can be none other than "turbidity current". MIZUTANI

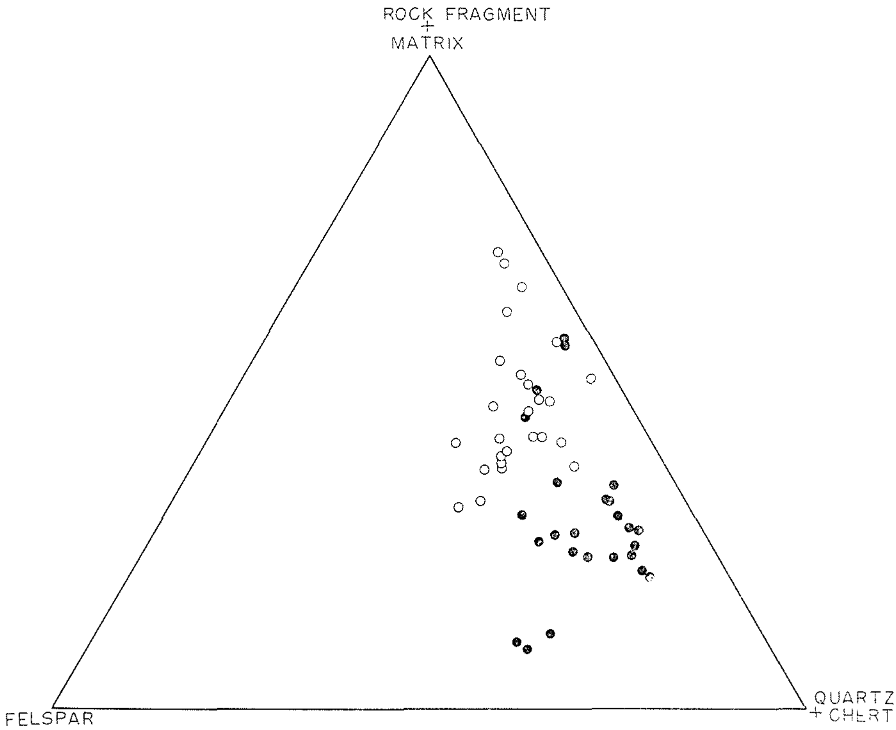


Fig. 12. Diagram showing mineral composition of sandstones in the Mugi and Tajimi area studied by Mizutani (1957).

stressed, accordingly, that it is important to give consideration to the fluidity factor as well as to the turbidity current. We may say that the graded structure of the beds in the Mugi area was formed by this process of sedimentation.

As has been stated, the characters of the arkose form a contrast to those of the graywacke. Judging from the higher maturity as shown by the poor amount of matrix, high sorting coefficient, and better roundess, the arkose must be the deposits transported by usual traction under moving water.

For the formation of the arkose, the granitic materials are indispensable, but conceivably, the graywacke in this area might have derived from the same original source as the arkose. Basaltic or andesitic rock fragments are common in the graywacke sandstones of the Mugi area, but they occupy only a small percentage of the stones in volume. The remaining rock fragments are mainly sedimentary rocks: silt and chert. Sometimes a small amount of fragments derived from a metamorphic terrain can be also observed. The amount of rock fragments is small as a whole in these graywacke. Therefore, provenance of the sandstones cannot be considered on the bases of content of these few rock fragments. In reality, the arkose sandstones are found intercalated in the graywacke. The rate of felspar to quartz does not seems to differ between the graywacke and arkose, when Fig. 8 by MIZUTANI (1957) is closely examined. This fact shows that the graywacke in this area have their origin mainly in acidic rocks, as in the case of the arkose. Scantiness of felspar (and quartz) of the graywacke must have been caused only by the abundance of clayey matrix.

MIZUTANI noticed the clastic plagioclase in the sandstones of the Mugi and the Tajimi area, and examined it in detail (MIZUTANI, 1959). He ascertained that the majority of the plagioclase are andesine and oligoclase (An 25–39). He also studied the shape and twining of the plagioclase, and considered that, in provenance, broad metamorphic terrain (composition of granodiorite) developed, which supplied these plagioclase and other detrital matters to make up the constitutent not only of arkose but also of graywacke.

Thus, it is clear that the distribution of compositional and textural properties between the graywacke and the arkose is owing little to the difference in provenance factor but practically to the difference in mechanism of transportation.

The sedimentary basin, where these sandstones of the Mugi and Tajimi area were deposited, is a large geosynclinal one, as is well known by Japanese Paleozoic stratigraphers. It is probable that, besides the clino-environment and fondo-environment, where transportation and deposition by the mechanism of turbudity current occurred, broad unda-environment may have developed in the basin. Separation of clayey matters must have been effected once, in this unda-environment. The sorting of grains may have been done also, in this condition. The high content of clayey matrix of graywacke sandstones in the area, is not caused by transportation in this environment, but by some process during the transportation in clino-environment. This process may be the erosion of bottom clay and the mixing of them into deposits brought about by the action of turbidity current.

The smallness of the amount of rock fragments in the graywacke, may have some relation with the development of unda-environment. As was stated, the main part of provenance must be some metamorphic rocks of granodioritic composition. But, a small part of the source rocks may be other rocks. However, transportation through the broad unda-environment by usual traction, might have broken or decomposed the fragments of these rocks.

As for the transportation and deposition of arkose, on the other hand, breaking of rock fragments and separation of clayes matters, were effected. Sorting of grains must have been done also. However, the mixing of clayey matter in the environment of clinothem was not affected. MIZUTANI stated that the stratification of arkose sandstone is clear, and that the current action seems to have been uniform and weak so that fine material (he means clayey matter) were separated from coarser materials. This shows, in the writter's opinion, the increase of maturity, breaking or decompositition of rock fragments and separation of clayey matters, continued from the under-environment to even deeper environment.

"Three environmental depositions" reported by RICH (1951), do not always produce turbidity current deposits. If usual traction had transported the detritus, which has its origin in grainitic terrain, some arkose deposits naturally appear even in deep environment. This arkose never indicates fanglomeratic or shallow water environment.

Three Types of "Graywacke"

As for the characteristic and definition of "graywacke" numerous studies have been made. Apparently, the sandstones which have been called "graywacke" are rich in detrital matrix, usually in rock fragments, and sometimes in felspar. Sorting is very bad, and the roundness of sand grains is very low.

When compared in detail, however, rather large differences in character are found among the sandstones which have been called "graywacke". Some of the stones are poor in rock fragments, some poor in felspar.

Remarkable properties of many "graywackes" is graded bedding. PACKHAM (1954) stressed the importance of the difference between "graded bedded strata" and "non-gradded bedded strata" in sandstone classification. According to him, sandstones of the non-graded strata, like the stones of the Gujo Formation, cannot be called "graywacke".

Among the sandstones treated in many papers, various types of graywackes have been recognized. But the following three sandstones in this paper seem to offer good examples of three characteristic types of graywacke.

1). The sandstones of the common Maizuru Group.

2). The sandstones of the Gujo Formation.

3). The sandstones of the Mugi and Tajimi area.

The sandstones of the common Maizuru Group are in every sense the almost typical graywacke. They are graded, ill-sorted, lithic, and muddy. Gujo sandstones resemble the 1st type sandstones. They are ill-sorted, rich in rock fragments, and muddy, but the stones are not graded. The 3rd type sandstones are similar in graded structure and muddy character. The stones, however, are poor in the amount of rock fragments.

These different characters of the three types of sandstones have their own causes of formation, as has been stated. For the formation of the most typical graywacke, supplies from non-granitic source rocks (surpracrustal rocks such as sandstone, shale, conglomerate, andesite, basalt, liparite, etc., and basic plutonic and metamorphic rocks) are favorable. In the case of the Maizuru Group, the presence of hypabyssal acidic rocks and some protoclastic and/or cata clastic granitic rocks caused the high content of rock fragments in fine sandstones, as stated in the previous chapter. Supply from only basic rocks and shale does not result in composition of lithic graywacke, because these rocks tend to decompose directly into clay during the course of weathering and transportation.

Too large basin having broad unda-environment is not favorable for the construction of lithic and felspathic graywacke. Long transportation under moving water destroys rock fragments and felspar, and separates these components selectively. In this case, however, if clino-environment is well -developed, this clayey matter is mixed again during the course of transportation by turbidity current, and becomes the component of graded graywacke sandstone, like the stones of the Mugi and Tajimi area.

When the development of a geosyncline enters its last stage, the basin becomes smaller and shallower, the uplift of provenance becomes rapid, and thick sedimentary body of very ill-sorted fanglomeratic and deltaic deposits are accumlated at the foot of the rising mountains. These deposits may be arkosic in some cases. Erosion of provenant mountains, however, may be insufficient usually, to make the plutonic crystalline rocks expose. As in the case of the Maizuru Tectonic Zone, granitic rocks of some particular character may crop out accompanied by basic eruptive plutonic and metamorphic rocks. In this case, the deposits inevitably have large graywacke tendency like the stones of the Gujo Formation.

Many sandstones in Japan and in foreign countries can be regarded to fall under these three types of graywacke.

The original graywacke in the Harz Mountains of Germany, consists of angular to subrounded grains of quartz and small fragments of siliceous slate, phyllite, and other rocks, and in many cases felspar, all bound together by a fine-grained matrix which imparts a great toughness and hardness to the rock, (NAUMANN, 1858, p. 663). Soring is very poor. And graded bedding is common in the formation, (HELMBOLD, 1952 in PACKHAM, 1954). The writer could not learn in detail the amount of rock fragments of the stones*, but probably, the original graywacke may resemble the "3rd type graywacke" rather than the 1st type. Early Paleozoic sandstones in Scotland and Wales (BAILEY, 1930) may be similar to the typical graywacke in their properties. Franciscan sandstones studied by TALIAFERRO (1943), were, considered a deep-water equivalent of arkose, derived mainly from plutionic rocks. These stones must have a clearer tendency of the character of the 3rd type graywacke.

Alpine flysch contains large amount of unstable minerals (KUENEN and CAROZZI, 1953). Aure Through graywacke in New Guinear is a good example of sediments which have basic volcanic materials as their main detritus source. In some cases, the quartz content of the stones is less than 0.1% of the grains (EDWARDS, 1947). These rocks may be regarded to belong to the 1st type graywacke. The latter example, Aure Trough graywacke, seems even more characteristic than the Maizuru Group sandstone.

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* According to PETTIJOHN (1957, p. 304), average of three Tanner graywackes (part of Harz graywackes) studied by Helmbold (1952), have 23 per cent of rock fragments.

The Molasse of Alpine has also a large amount of unstable minerals (KUENEN and CAROZZI, 1953), and is looked upon as epiorogenic sediments (GLAESSNER and TEICHERT, 1947) like the Gujo sediments. Siwalik sandstone, described by KRYNINE (1937) as graywacke, is a sequence of the terrestrial sediments in the southern margin of Himarayas. This sandstone is a graywacke in its textural and compositional character, but its sedimentary structure indicates that it is the deposit of shallow water traction current. In this sense, Siwalik sandstones can be judged to be correlated to the 2nd type graywacke.

The three sandstone type presented above, indicate only the most distinct and extreme cases. Of course, many grawackes which cannot be identified as any of these three type develop in various places.

Two Varieties of Arkose

Two of the sandstones treated in this paper have characteristic arkose tendency in texture and in composition. In the writer's opinion, however, these two sandstones cannot be regarded as most typical arkoses. PETTIJOHN (1957) stated, as was refered in a previous chapter, that, arkose occurs either as a thin blanket-like residuum at the base of a sedimentary series that overlies a granitic terrane, or as a very thick wedge-shaped deposit interbedded with much coarse granite-bearing conglomerate and deposited with a lesser quantity of red shale and silt-stone. This statement seems to be right. Many typical arkoses develop overlying the granitic terrain and/or as fanglomeratic deposits, as seen in many Japanese Tertiary and Quaternary sediments. Arkose sandstone in the Nabae Group is supposed to be beach sand, off-shore bar sand, etc.. Arkose in the Mugi area occurs intercalated with graywacke of deep-water environment. These two sandstones must be regarded as variant types of arkose. Although, these "arkoses" also denotes high relief and vigorous erosion of granitic and other felspathic rocks.

V. Sandy Deposits Development

In this paper, various types of sandstone, including various graywacke and arkose, are treated. Theoretically, however, other sandstones must be considered, and these sandstons should be arranged more plainly as shown below.

"Non-granitic provenance" here includes, various sedimentary rocks like shale, sandstone, and conglomerate; eruptive rocks like andesite, basalt, and liparite; hypabyssal rocks like diabase, porphyrite, and quartz-porphyry; in some cases basic plutonic rocks like surpentine, and micro-gabbro; and some metamorphic rocks like phyllite, schist, and amphibolite, etc..

When subsidence of the basin is not rapid an environment of deposition is not differentiated into three parts, sandy deposits transported from these source rocks develop from sediments of graywacke type composition and of non-graded structure into subgraywacke of similar structure, and finally, into

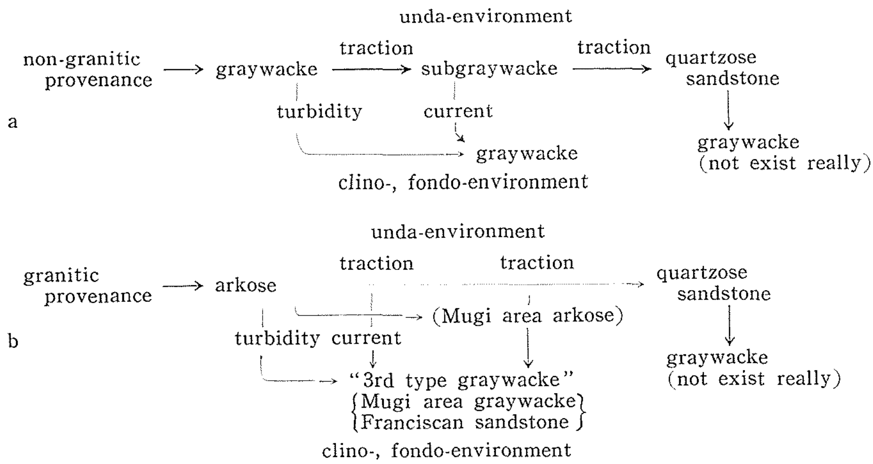

Figure 13 a & b. Development of some sandy deposits when the basin is large.

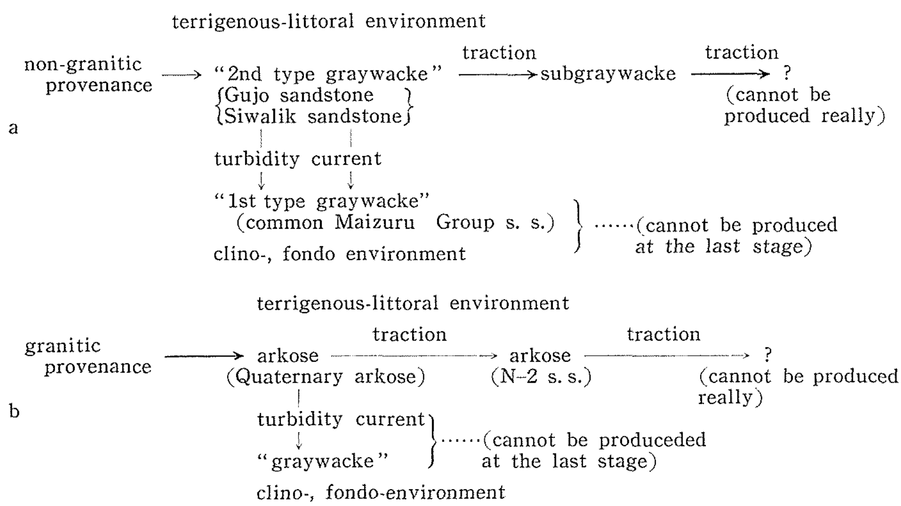

Figure 14 a & b. Development of some sandy deposits when the basin is small.

quartose sand which contains almost no unstable minerals or clayey matters. Of course, fine particles separated from the sandy part in this course, are accumlated in other places in the basin, as stressed in the former paper and this one. But, it seems needless to dwell of this subject here.

According to FOLK (1954), Upper Mississippian and Pennsylvanian sandstones in America, change their textural and conpositional properties gradually from graywacke, through subgraywacke, to quartzose sandstone which possesses very few amount of clay. These sandstones may be good example of the development of sandy deposits as stated above. (Figure 13a)

When geosynclinal subsidence is strong, and consequently development of clinothem and fondthem is distinct, typical muddy graywache is produced by the action of turbidity current. The amount of rock fragment and felspar changes in accordance with the extent of unda-environment and degree of sustaining prolonged transportation. The original graywacke in the Harz region referred to before, might represent this most general form graywacke rather than the "1st type graywacke". (Figure 13a)

In the case where unda-environment is very narrow or almost absent, more lithic and immature deposits than the general graywacke discribed above, develope. (Figure 14a) These sandy deposits were called "1st type graywacke" in the former chapter. Therefore, the "1st type graywacke" possesses, in a greater extent than general form graywacke, all the characters which have been mentioned as special features of graywacke, that is, the stones being muddy, lithic, not so poor in felspar, very ill-sorted and graded. This case can occurs at relatively later, but not last, stage of development of a geosynclinal basin. On the contrary, the "2nd type graywacke can often be produced at the last stage of the development, when the basin become much smaller and shallower, and the uplift of the provenance become much more rapid.

As for the arkose suite, lengthy explanation may be needless here. "Granitic source" here means acidic plutonic rocks like granite, granodiorite, adamerite, etc., and some metamorphic rocks like gneisses. Arkose in the Mugi area and the N-2 sandstone are not the most typical arkoses, but they are variant types of arkose as shown in Figure 13b and Figure 14b. Graywacke derived from quartzose deposits that mixed with clayey matter, may be supposed to be present in both the cases of granitic source and non-granitic source. The writer, however, cannot remember any examples of this graywacks, or the geo-tectonic condition in which this extensive environment producing quartzose sandstone, and clino-environment for the transportation by turbidity current, are possibly connected.

As a matter of fact, it is not reasonable to think that, non-granitic provenance and granitic provenance can be distinguished clearly. In reality, as is seen in the case of the Yakuno Group, and even in the common Maizuru Group and the Mugi sandstones (Siwalik sandstones, also), many deposits have complex sources composed of non-granitic and granitic rocks, supracrustal and plutonic rocks, basic and acidic rocks, etc..* The figures shown above, indicate only the most extremely characteristic type process.

* PETTIJOHN (1957) wrote that, most commonly the graywacke have a mixed composition and therefore a mixed origin. According to him, the average graywacke is mainly quartz and felspar (two-thirds), and therefore, like arkose, is derived mainly from acid plutonic rocks.

VI. Short Note on the Importance of the Yakuno Intrusive Rocks in the Sandstone Sedimentation in the Maizuru Zone

Yakuno intrusive rocks (and the associated Komori metamorphic rocks) are important not only as provenent rocks of the sandstones in the Maizuru Zone, but also as the stones having most intimate relation with the construction of the sedimentary basins of the stones.

That is to say, the intrusion and up-rising of these rocks followed the creation of the deep tectonic fissure zone, and the subsidence of the depositional basin of the Maizuru Group also resulted from the creation of the tectonic fissure zone (SHIMIZU 1962, SHIMIZU and others, 1962b). Moreover, the up-rising of these igneous and metamorphic rocks, may have affected the separation of the depositional basin from other parts of the entire geosynclinal basin in Japan. Finally, the igneous and metamorphic rocks offered many detrital matters to fill up the basins as mentioned above.

A more detailed study will be made on these subjects in one of the following papers.

VII. Summary and Conclusions

The results of study on conglomerate, heavy minerals, and quartz irradiation effect, show that, sandstones in the Maizuru Zone have acidic igneous rocks and gneisses as the most important source rocks of the stones. These acidic rocks in the provenance affect largely the formation of arkose and even graywacke in the Maizuru Zone. Some basic rocks and sedimentary rocks may have influenced the graywacke tendency of some sandstones, especially that of Paleozoic sandstones.

Depositional environments of the sandstones in various formations in the Maizuru Zone are very different from each other.

The sediments of the Carnian N-2 and N-3 Formation including the Heki Formation are an association of sediments formed in various local environments, including those of the beach and fore-shore, off-shore bars, tidal lagoons, river channels with their point bars, and backwater swamps. This association is similar to that of some molasse deposits of the deltaic coastal plain and its inland extension. Absence of very fine grained sandstone (less than 0.15 mm.) of the N-2 Formation, and various tendencies of the distribution of various components of the sandstones can be explained by the depositional conditions stated above.

On the others hand, off-shore environment was considered to be the depositional situation of many sandstones of the Lower-Middle Triassic Yakuno Group.

Graded bedded graywacke in the common Maizuru Group of the Permian Age, is thought to be the deposit of turbidity current. On the contrary, the non-graded "graywacke" of the Uppermost Permian Gujo Formation is franglomeratic and deltaic deposit accumulated at the foot of rising mountains.

The excellent study by S. MIZUTANI on graywacke and arkose in the Mugi and Tajimi area, was cited.

The followings were recognized as three characteristic types of "graywacke".

1) The sandstones of the common Maizuru Group, which are graded, lithic, and muddy.

2) The sandstones of the Gujo Formation, which are non-graded, lithic, and Muddy.

3) The graywackes in the Mugi and Tajimi area, which are graded, non-lithic, and muddy.

The cause of deposition of these three types of "graywacke" was also considered.

The development of various sandy deposits including graywacke and arkose was examined using mainly the data treated here, and summarized in Figure 13, and Figure 14. The cause of structural, textural, and compositional characters of various graywacke and arkose sandstones in and out of Japan were considered, and explained in accordance with the consideration indicated in the Figures.

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Errata of Part 2, (Graded Bedding and Mineral Composition of Sandstones of the Maizuru Group)

Page	Line (Place)	For	Read
295	2-3 (Fig. 1c, explanation)	fusulidid	fusulinid
295	1 (Foot Note)	were not treated as constituents of matrix	were treated as constituents of matrix and not taken into account
297	10	(1940)	(1949)
298	12	dentritic	dendritic
304	(Fig. 5a-5d)	cm	mm
305	3 (Foot Note)	pluse	plus
307	19	GROWELL	CROWELL