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AUTHOR(S):

Nakayama, Isamu

CITATION:

Nakayama, Isamu. The Relation of the Lineation to the Geological Structure in the Sanbagawa Metamorphic Zone of the Tenryu River Basin. Memoirs of the College of Science, University of Kyoto. Series B 1954, 21(2): 273-286

ISSUE DATE:

1954-12-30

URL:

http://hdl.handle.net/2433/258013

MEMOIRS OF THE COLLEGE OF SCIENCE, UNIVERSITY OF KYOTO, SERIES B,
Vol. XXI, No. 2 Article 10, 1954.

The Relation of the Lineation to the Geological Structure in the Sanbagawa Metamorphic Zone of the Tenryu River Basin

By

Isamu NAKAYAMA

Geological and Mineralogical Institute, University of Kyoto

(Received Sept, 13, 1954)

Abstract

The lineation reflects the movement conditions at the time of its formation, and with change of movement conditions, various lineations are formed. During the process of orogenesis, as long as movement conditions change, various forms of lineation are matter-of-course. The relation which existed between the lineation and geological structure at the time of the formation of lineation, goes on changing in later movement processes and is not always invariable. However, by clarifying the character of the lineation, by analysing the relation between the lineation and the geological structure, the process of orogenic movement may be made clear.

Introduction

Several years ago the theory[1] that the formation of Sanbagawa metamorphic rocks was caused by orogenesis through the Jurassic and early Cretaceous period been generally accepted. New data on this subject have later been brought to light and have led us to another theory[2][3] which concludes that the formation of Sanbagawa metamorphic rocks was caused through late Permian and early Trias period.

The region of the Tenryu river is located where the Sanbagawa metamorphic zone turns the trend of its stratum from east-west to north-south (Refer to Plate IX). The Sanbagawa metamorphic zone to the west of Tenryu zone forms a folding structure which trends from east to west.[6] In the region of Tenryu, different movement processes can be seen in the upper and the lower formations; at first the direction of the principal differential movement of the upper formation is north-south, and that of the lower formations is east-west. After those movements, all the strata have had the differential movement of east-west direction.[9] Regarding the development of lineation it can be concluded that the upper formations trend nearly east-west and the lower formations trend nearly north-south. In the upper formations the trend of stratum and that of lineation are crossing each other.[8,9] This seems to be due to stratum deformation which is caused by the folding movement continued after the formation of lineation.

Acknowledgement

Many thanks to the members of Crystalline Schist Studying Group, Prof. George KOJIMA of Hirosima University, who criticized this study. The writer wishes to express his sincere thanks to Dr. Syoji IJIRI and Dr. Masao GORAI, who guided him throughout this study. The writer is indebted to Messers. Sadao MASUDA, Heizaburo MURAYAMA, and Yasunori OKANO for their kind help.

Stratigraphy

Table 1 shows the stratigraphy of Sanbagawa crystalline schist in Tenryu-river region. Crystalline schist and non-metamorphic palaeozoic rocks are both conformable, and as regard their metamorphic grade, they seem to be tarnsformed gradually. Besides, no fault was observed between both crystalline schist and non-metamorphic palaeozoic rocks. This was inferred by HORIKOSI,[4] and also confirmed by the collaborative study of the Crystalline Schist Studying Group.[7]

Although the rocks are considered to be in the identical horizon, non-

TABLE 1

	Formation	Composite rocks
Tenryu Group	Iinoya formation	Sandstone schist, sandstone, basic tuff and lava, limestone, black shale, chert. Thickness: not determined.
	Sibukawa formation	Chief composite rock is the black schist, the other rocks are green schist, quartz schist and sandstone schist. Thickness: about 800 M.
	Zihati formation	Alternating beds of green schist (albite-spotted and non-spotted) and black schist (albite-spotted and non-spotted) with quartz schist and limestone schist. Thickness: about 800 M.
	Kasiyama formation	Upper: alternation of sericite schist, black schist and green schist. Middle and Lower: black schist with a few thin sandstone schists. Thickness: 700 M~900 M
	Hunayo formation	Black schist. Thickness: 700M+

metamorphic rocks are seen in the western part of the region, while in the eastern part, crystalline schists are seen; accordingly, the stratigraphy and metamorphic grade seem to have more or less an oblique relation. At first the discrimination between the YOSIZAWA[9] and the Zihati formations was made by observing the features of rock facies, but in later investigation, the difficulty of making such discrimination has been made clear. Therfore, it was necessary in this study to treat them together. The same can be said of the Sinkai and Wasanma formations[9]; both formations should be treated as one and called the Kasiyama formation. The border between the Zihati and the Kasiyama formations, and that between the Sibukawa and the Zihati formations are distinguished by key-beds. Metamorphic facies of the Sanbagawa crystalline schist in this region belongs to muscovite-chlorite facies.[14]

Geological structure

Plate IX indicates the result of geological survey. The general strike of the Sibukawa formation, in the east of the region, runs to the northwest and that of the western part of the region to the northeast. The whole formation shows a manifest tendency to trend toward the southeast, when compared with the lower formations. In addition, the whole formation gently dips to the southeast or to the southwest, where as seen in the western part, this formation has a wavy folding structure with short wave-length. The Sibukawa formation in the western part, therefore, has a monoclinal structure which dips very gently when compared with the eastern part. There are the Mikabu intrusives[5] between the Sibukawa and Iinoya formations, in the part near the Iinoya formation, the Sibukawa formation shows steep dipping. As a whole, the trend of Sibukawa formation is east-west; but partially there is a trend to north-south. It is considered to be a kind of flexure structure. Basic or ultrabasic rocks accompanying small faults intrude in such a flexure zone. Many of these basic rock are massive and have saussuritic plagioclase. It may be considered that the intrusion into the flexure zone had been made in the later stage of orogenesis. As for the Zihati formation, it nearly strikes to the northwest in the southeastern region of Kuma; in the region north of Kuma and south of Zihati, it shows a plunging fold which has an east-west folding axis pitching to the west. In the north of Zihati, on the whole, it strikes to the north by east and has a monoclinal structure slanting to the west.

The above lines give an outline of the general structure of the Zihati formation. But there is a local anticlinal structure of the same formation with an axis pitching towards the west, minor folding structures of 5~10M unit with axes in east-west direction, and intraformational folding structures with east-west axes. Moreover, in the Sibukawa and Zihati formations, with the exception of the part with false cleavage structures in the intraformational folding sections, there exists only the foliation plane parallel to the bedding plane. The Kasiyama formation strikes nearly to north-south. Throughout the entire region with the exception of the upper part, the Kasiyama formation shows the intraformational folding structures in the east-west direction with axis pitching towards the west. There exists the foliation plane S_1 parallel to its bedding plane. Cleavage S_2 lies at a position corresponding with the axial plane of this intraformational folding. The strike of S_2 is nearly north-south and inclines to the west.[8)9)] This fact about the Kasiyama formation shows that the strike of S_2 corresponds with the very strike and dip of the bedding plane of both the upper Kasiyama and Zihati. The Funayo formation and the lowermost part of the Kasiyama formation striking to north-south, has a monoclinal structure slanting to the west. Partially this formation has false cleavage structure in its intrafor mational folding, but in general only the foliation plane parallel to the bedding plane can be seen. In the Funayo formation minor folding structures with north-south axis can be seen.

The Tatuyama epidote-amphibolite* is composed of synkinematic intrusives.[9)] Its strike is north-south and the formation has a monoclinal structure which slants to the west. At the uppermost part, it indicates an intraformational folding with east-west axis, and the cleavage S_2 parallel to the axial plane strikes to north-south and dips to the west. In the greater part of the Tatuyama epidote-amphibolite with the exception of the uppermost part, there can be seen only a development of the foliation which is parallal to the boundary plane between black schist and epidote-amphibolite. The following two facts are of great importance in considering how the structure was formed.

1) A distribution of S-letter appearance can be seen within the range of both the Tatuyama epidote-amphibolite and the intermidate black schist.
2) There is a remarkable tendency of S-letter distribution, especially in the area correspondings with the eastern extention of the part where the Zihati formation shows a plunging folding.

In the crystalline schist region of Tenryu river basin, the geological structure had not been affected remarkably by the faulting movement. Many faults are to be seen in the upper stratum. Most of them are strike faults, and identical rocks are often found on both sides of faults. No effect on the structure in a large extent can be recognized. Moreover, shearing zones which turns crystalline schist into paper-like schist can be seen here and there, but these zones are not items to show on the map.

The formation history of the geological structure mentioned above can be interpreted correctly only through the following consideration.

The upper stratum with the exception of the stratum below the lowermost part of Kasiyama formation formed the folding structures of the east-west trend, by the differential movement which has a trend to north-south. The middle and lower

* Classification as " meta-diabase is not right.

part of Kasiyama formation show the intraformational folding structures throughout the whole region. While the upper stratum with the exception of stratum below the lowermost part of Kasiyama was carrying out such a movement as mentioned above. The stratum lower than the lowermost of Kasiyama, formed the folding structures which trend north-south by its principal differential movement with a direction parallel to east-west. In these strata, the direction of principal differential movement in the formation of their folding structures is to east-west. However, these strata accompany gently waving with east-west axis of long wavelength, affected by the movement in the upper stratum which trends north-south. Tatuyama epidote-amphibolite has made its synkinematic intrusion between both formations, the upper and the lower formations which have been exercising on each other different movements as mentioned above. Intraformtional folding with axis of east-west direction has been carried out in the uppermost part of Tatuyama epidote-amphibolite, as in the lower part of Kasiyama formation. The greater part of Tatuyama epidote-amphibolite carried out the folding of north-south axis. During the period of those movements mentioned above, foliation parallel to bedding plane in all the range of strata has been formed. Succeeding these movements, a differential movement of east-west direction affects the whole formation. The folding structures which trend east-west in formations upper than the lowermost part of Kasiyama formation, accordingly, turn their structure into the folding structures which trend north-south. In the upper part of Kasiyama and in the formations of Zihati and of Sibukawa, through this latter movement process a differential movement was carried out along the the foliation formed through the process of former movement. In the middle and in the lower part of Kasiyama formation, and in the uppermost of Tatuyama epidote-amphibolite, a differential movement was carried out along the cleavage parallel to the axial plane of intraformational folding. In this way, the second cleavage structure[9)13)] came to be formed in the middle and lower part of Kasiyama and in the uppermost of Tatuyama epidote-amphibolite.

These movements mentioned above had been carried out in one orogenesis during the period extending from the later stage of palaeozoic era to the earlier stage of mesozoic era. Such difference of both movements between the upper and the lower formations, is to be considered with the history of geological structure formation in Ryoke metamorphic region. Recently it[10)] has been made clear that there are differences in trend among the granites of the Ryoke metamorphic zone.

The unknown mesozoic strata[12)] is in the east side of crystalline schist region and is overthrusting on the crystalline schist. In this mesozoic strata, pebbles of crystalline schist can be found. Therefore the formation of Sanbagawa metamorphic zone had been finished before the mesozoic strata deposited. The thrusting movement took place after the crystalline schist had been formed. The effect of this thrusting movement on the structure of crystalline schist, is shown by the deformation of "bedded deposit of chalcopyrite" near by the thrust. That is to say, two forms can be seen in deformation of deposit. One form shows remarkable minor folding structures with a north-south axes in the lower part of deposit. They are folding conformably with their mother rocks. The other shows in the part near the top of deposit gently wavy swells with north-south axis, accompanied by shearing of mother rocks. The deformation of deposit of the later type can be regarded as caused by thrusting. As can be seen by such an explanation, the effect of the thrusting on the geological structure of the crystalline schist is recognized partially. However, no criterion to show any large change of the geological structure of crystalline schist is observed.

Lineation

In the upper strata including the upper part of Kasiyama formation, lineation formed by mineral orientation can be seen on the foliation parallel to the bedding plane. As indicated on Fig. 1, 2, 3, the direction of lineation is within the range of N60°E~N60°W, and pitches nearly to the west, moreover it is completely corresponds with the east-west axial directon of minor folding, anticlines, and a plunging structure. What is the nature of the lineation in the middle and lower part of Kasiyama formation with the second cleavage structure? What is the nature of the lineation in the uppermost part of the Tatuyama epidote-amphibolite with the second cleavage structure? The lineation which trends east-west is on the foliation plane S_1, the lineation which trends north-south is on the cleavage S_2 parallel to the axial plane of intraformational folding. The former lineation is due to the mineral orientation, and its trend is corresponding with the axial direction of intraformational folding. The latter lineation is of the corrugation type. Plate VIII (Fig. 3) illustrates the difference between the two. In the Funayo formation and the greater part of Tatuyama epidote-ampoibolite with the exception of the upper part of Tatuyama epidote-amphibolite, lineation with trend nearly north-south (N10°E~N20°W) can be seen on the foliation plane parallel to the bedding plane. This lineation is due to mineral orientation, and its direction corresponds with that of major and minor folding axis which trend north-south. According to the analysis of the geological structure, lineation mentioned above, is formed at right angles with the differential movement.

There is a lineation of a direction of north-south like the "slickenside lineation" on the foliation plane, in some parts of the albite-spotted schist in Zihati formation. This lineation was regarded as of the same character as the corrugation type lineation which trends north-south in the middle and lower parts of Kasiyama formation. However, the true nature of this lineation has not been made clear, so it is treated separately for the time being.

The following fact is also to be noted; excepting a few instances in Zihati formation, there can be seen a perfect accordance of the range of direction deviation in the lineation which trends east-west.

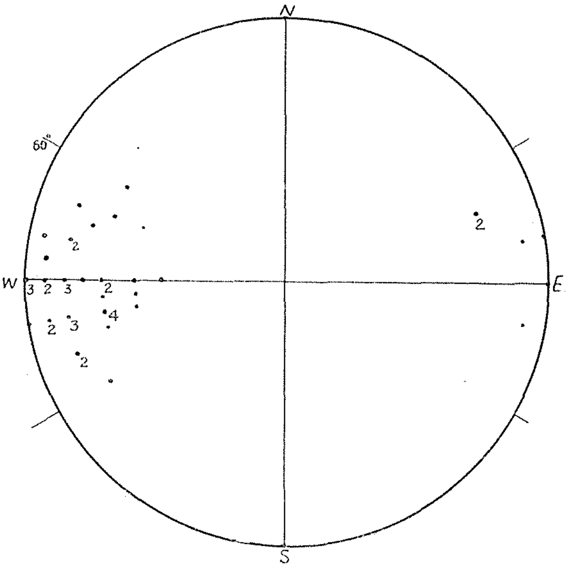

Fig. 1

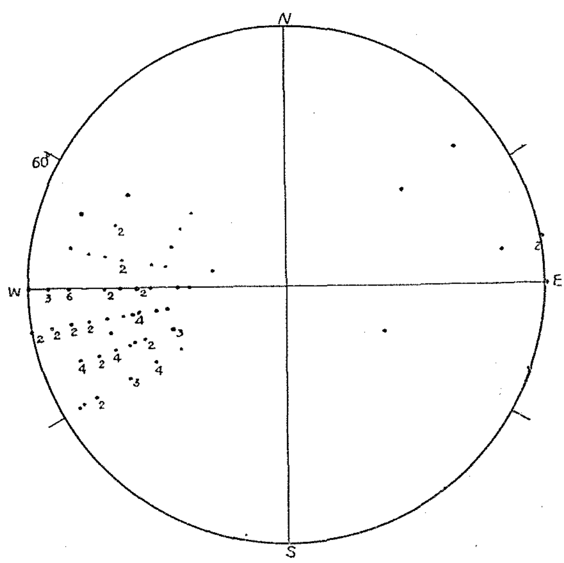

Fig. 2

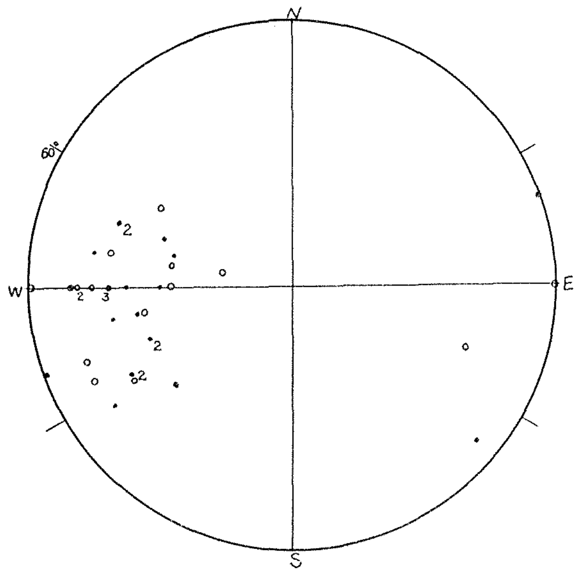

Fig. 3

Stereographic projection of lineations in the lower hemisphere. Figures in the diagram, are number of points which indicate same direction.

Fig. 1. : Linear direction of the Sibukawa.
Fig. 2. : Linear direction of the Zihati.
Fig. 3. : Linear direction of the Kasiyama.
∘ Middle and Lower part. · Upper part.

Verification about lineation by petrofabrics

Fig. 4, 5, 6, 7, 8, indicate petrofabric diagram of the formation of Sibukawa, Zihati, Funayo. Each diagram takes linear direction as B axis. The diagram of Funayo is not always typical B-girdle, but is nearly B-girdle form which takes B axis as rotational axis. Fig. 9, 10, are petrofabric diagrams indicating the second cleavage structure in Kasiyama formation. B_1 is the direction of lineation with trend east-west, by orientation of minerals. B_2 is that with trend north-south of the corrugation type. Fig. 9 is the result of measurements taken of quatz, distributed parallel to foliation plane S_1. Fig. 10 is the result of measurements taken of the recrystallized quartz, distributed in foliation parallel to cleavage S_2. It can be assumed, by observing the former, that it is affected by the movement along S_2, and by observing the latter, that it is affected by the movement along S_1. Especially in the latter instance, two movements ($B_1 \perp B_2$), are repeated in highest degree. Comparing Fig. 9 with Fig. 10, there can be found that the movement along S_1 takes B_1 as the rotational axis and Fig. 10 is characterized by the distribution curve at the part near B_1. Fig. 10 has no symmetry.

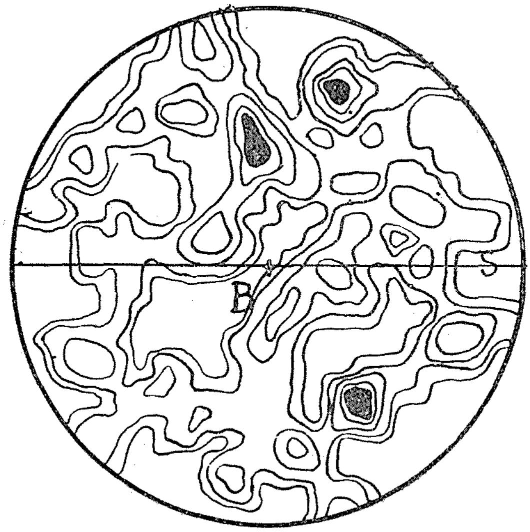

Fig. 4

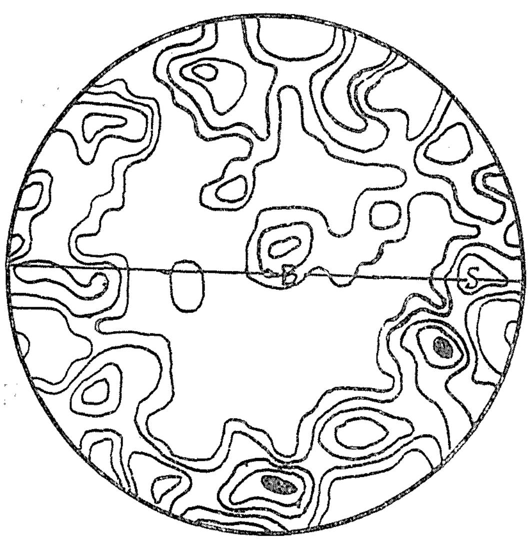

Fig. 5

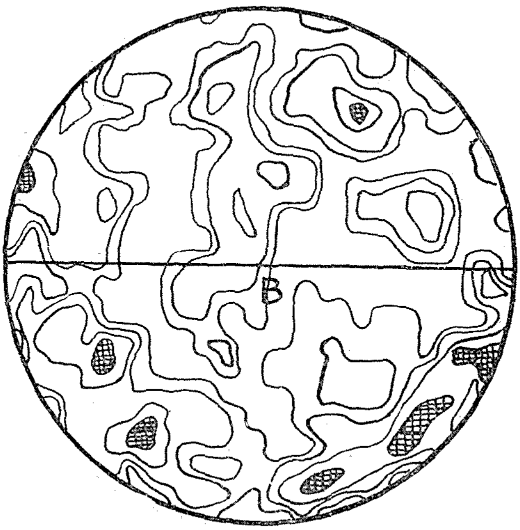

Fig. 6

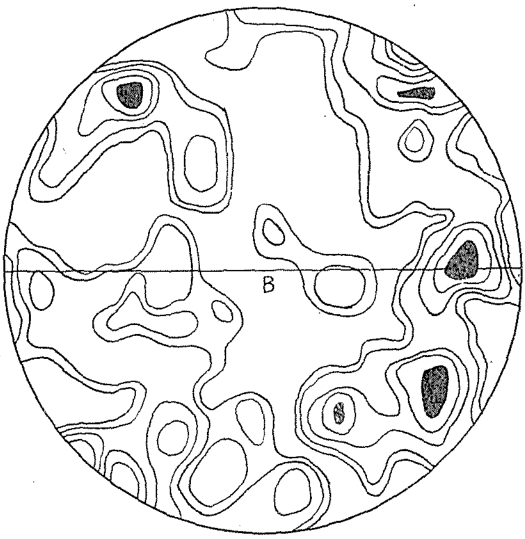

Fig. 7

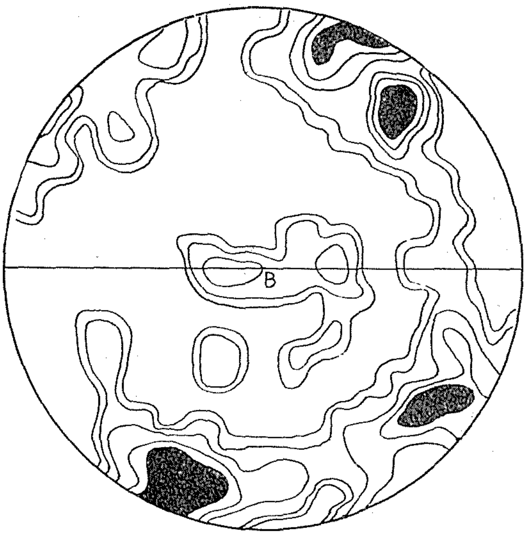

Fig. 8

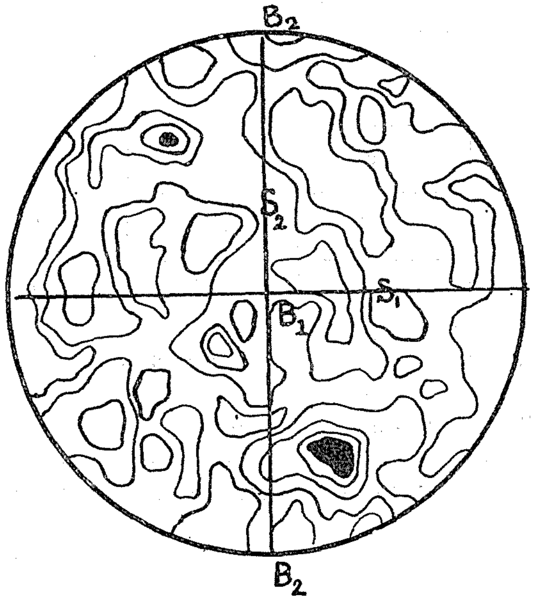

Fig. 9

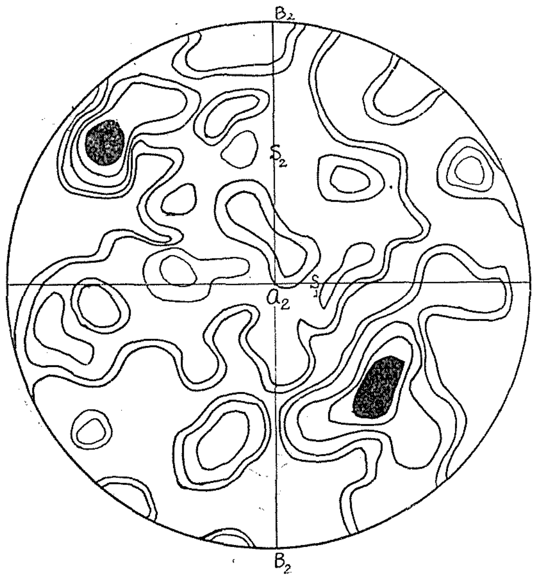

Fig. 10

Explanation of Petrofabric figures.

Figure number	Locality	Formation	Rock type	Number and type of grain measured	Countes in Percent
4	Makino valley	Funayo	Black schist	100 quartz axes	0–0.5–1–2–3–4<
5	Wasanma valley	Zihati	Black schist	〃	〃
6	Sawamaru	〃	Albite-spotted black schist	〃	0–0.5–1–2–3<
7	Adera	〃	Quartz schist	〃	0–0.5–1–2–3–4<
8	Nishikurumegi	Sibukawa	Quartz schist	〃	〃
9	Kune	Kasiyama	Black schist	200 quartz axes	〃
10	〃	〃	〃	100 quartz axes	〃

By observing distribution curve around B axis on the petrofabric diagram of the Zihati formation, it can be considered that the diagram of Zihati has the same character as that of the diagram of Kasiyama. By observing these petrofabric diagrams, it is evident that the mineral orientation type lineation is a "b-lineation". Moreover Fig. 10, having no symmetry, is in accordance with petrofabrics of a case of $B_1 \perp B_2$.[15][16] In other words, corrugation type lineation is a "b-lineation". Thus the data of petrofabrics do not contradict the interpretation about the geological structure and lineation disclosed by the analysis of the geological structure.

On the cross relation between the strike of stratum and the direction of the lineation

It is to be noted here both in the Kasiyama and the Zihati formation, a remarkable cross relation can be seen between the strike of formation and the direction of lineation. This has already been mentioned in the statement of the history of geological structure formation. The remakable difference detween the direction of lineation and the strike of strata is attributed to the deformation of the rock after the formation of lineation. This relation is attributed to the deformation[18] by such a movement as its direction differs from the movement which was carried out when the lineation formed.

A certain deviation in the direction of lineation shows that movements of each lithological unit was individually carried out.[18] The individual movement of each lithological unit was chiefly carried out when the lineation formed by mineral orientation. As for its cause there can be seen an accordance of deviation range over the formation of Sibukawa, Kasiyama and Zihati which have different rock facies and different structure. Besides, it is to be considered that the development of solidification of rock has made such movements difficult. In Zihati formation, a few instances indicate certain deviations beyond the range of common deviation. These over-deviations are corresponding to the flexure zone whose strike turns itself from east-west to north-south, and rocks in these cases are albite-spotted schist. It can be considered that the deviations have been caused by the hardened beds which had moved individually, in the stage of the movement of formation after the formation of lineation.

It will be stated how to treat lineation at the end of this treatise. The lineation reflects the movement conditions (for example: movement direction, conditions of rocks at the time of movement, etc.) at the time of its formation, and with the change of these conditions, various lineations can be formed. During the process of orogenesis, the movement condition changes naturally with the change of times and places. The varieties of lineation[17] can naturally exist. The relation which existed between the lineation and geological structure at the time of the formation of lineation, goes on changing with change in the geological structure in the later movement process and is not always invariable. However, by clarifying the character of lineation (the time of formation, the character of petrofabrics, etc.), by analysing the relation of the lineation and geological structure, the process of orogenic movement may be made clear.

Accordingly, the following ideas are unreasonable and incorrect. One idea is that the movement which formed a lineation existed with no change, before and after the formation of lineation. The other is that all of the lineation have invariably a definite relationship with the direction of movement.

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Plate VIII

Expanation of Plate VIII

Fig. 1. Second clevage structure in a_1c_1 section.

Fig. 2. Recrystallized quartz, disposed in foliation (S_1) in parallel with cleavage S_2.

Fig. 3. Corrugation type lineation in a_2B_2 section

L_1 : Mineral orientation type lineation with east-westward direction

L_2 : Corrugation type lineation with north-southward direction

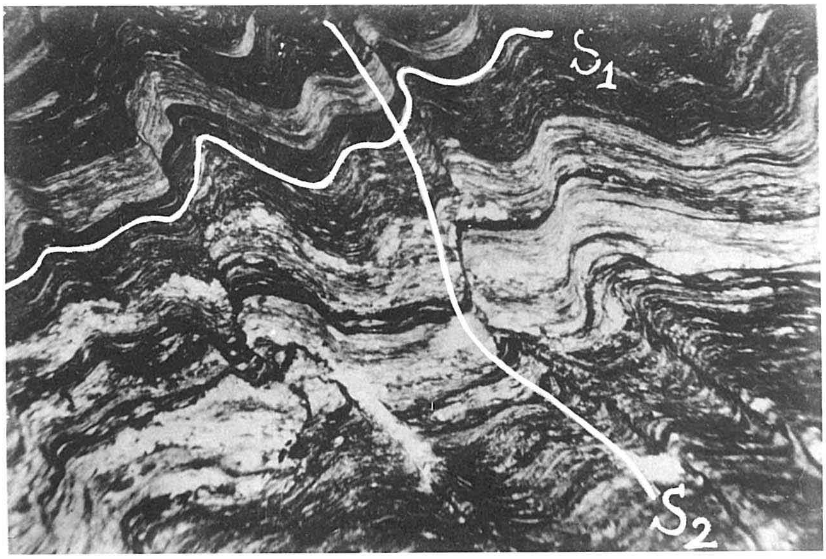


Fig. 1.

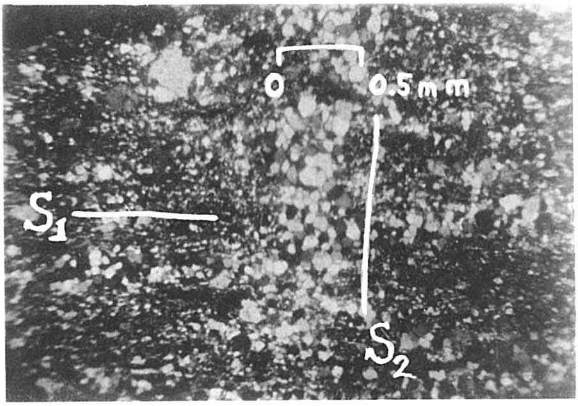


Fig. 2.

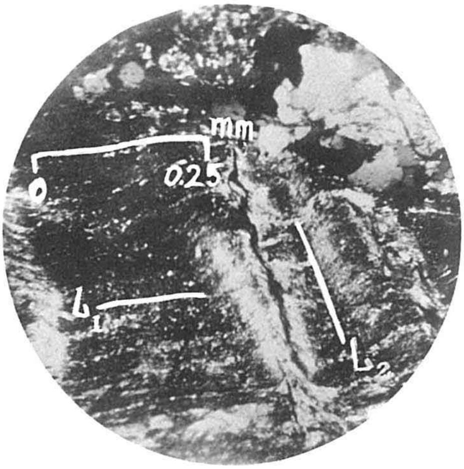
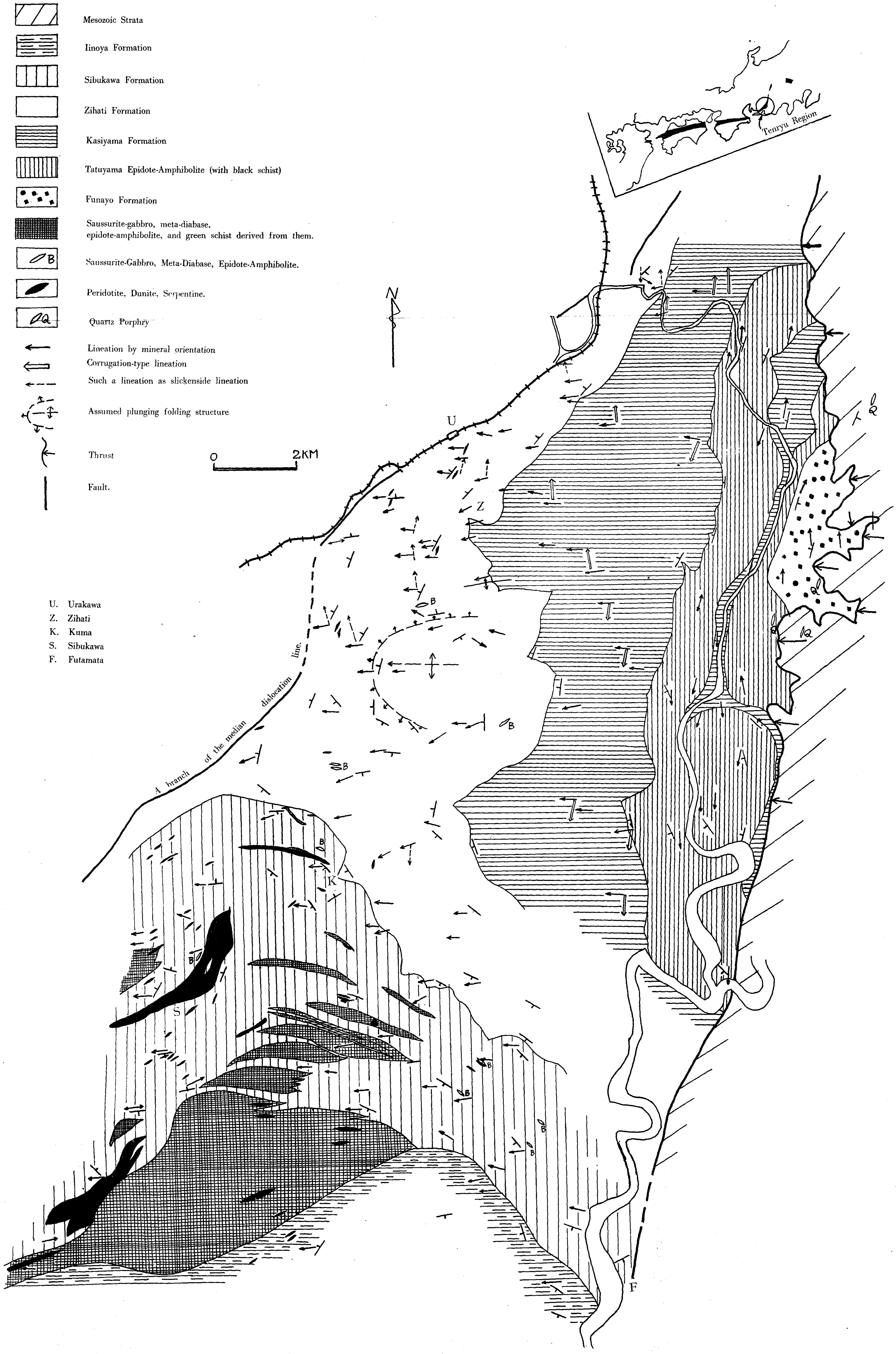


Fig. 3.


Mesozoic Strata
Iinoya Formation
Sibukawa Formation
Zihati Formation
Kasiyama Formation
Tatuyama Epidote-Amphibolite (with black schist)
Funayo Formation
Saussurite-gabbro, meta-diabase, epidote-amphibolite, and green schist derived from them.
Saussurite-Gabbro, Meta-Diabase, Epidote-Amphibolite.
Peridotite, Dunite, Serpentine.
Quartz Porphry
Lineation by mineral orientation
Corrugation-type lineation
Such a lineation as slickenside lineation
Assumed plunging folding structure
Thrust
Fault.
0
2KM
N
Tenryu Region
U. Urakawa
Z. Zihati
K. Kuma
S. Sibukawa
F. Futamata
A branch of the median dislocation line.
U
Z
K
S
F
A