DEFORMATION FACIES, SERIES AND GRADES

TAKESHI UEMURA*

Abstract Deformation facies are controlled by two groups of factors representing the mechanical properties of the materials being deformed and the deformational environment. The former allows the discrimination of the deformation series in a definite environment, and the latter is expressed by the deformation grade for a definite material. Ductility contrast and mean ductility are available as indices to qualify such series and grades respectively. On the basis of this concept, various types of facies structures can be systematically arranged on the newly proposed deformation facies diagram taking the ductility contrast and the mean ductility as reference axes. It enables us to put into practice the identification, correlation and zoning of deformation facies in nature, and discuss and interpret their mutual relationship in terms of deformational processes and mechanisms.

Introduction

The concept of "facies" in geology has been developed in order to grasp the general aspects of any geological objects in relation to their formative environment. The facies concept has proved useful when the generation and preservation of objects themselves depend on a definite environment. In the case where pre-existing objects are transformed into others because of changes in their environment, however, aspects of renewed objects must reflect not only the environment of innovation but also the properties of pre-existing objects. Metamorphic facies are a good example. Likewise, deformation facies can be defined here as comprehensive aspects relating to deformation and rupturing of geological bodies. They reflect both the deformational environment and the physical properties of the materials being deformed and/or ruptured.

There are some proposals to be reviewed, which have been made about the concept allied or related to deformation facies. DONATH(1963) emphasized the role of ductility

and anisotropy in determining the mode and geometry of deformation. Based on tri-axial test of limestone, HOSHINO (1966) proposed the "deformation diagram" putting total strain and ductility on two coordinate axes, on which he discriminated three regions: elastic, plastic and fracturing. He used the term "henkei-sō" in Japanese without any more explanation, which seemed to imply "deformation phase" rather than "deformation facies". In Japanese, "facies" and "phase" are both expressed as "sō". HOSHINO's proposed diagram, therefore, can be regarded as a kind of deformation phase diagram. DONATH *et al.* (1971) showed by experimental deformation of limestone that the mode of deformation is a function of confining pressure and total strain. Taking two factors as coordinates, they proposed D. M. F. diagram (deformation mode field diagram) on which the respective areas of extension fracture, brittle faulting, ductile faulting and uniform flow are figured. These experimental studies were made on homogeneous and mono-mineralic rocks.

In the folded zones in Japan, KIMURA (1968) recognized four kinds of folding styles forming three types of series. He emphasized the rôle of confining pressure for similar lithological strata in a folded zone at a par-

Received October 1, 1980

* Department of Geology and Mineralogy, Faculty of Science, Niigata University, Niigata, 950-21 Japan.

ticular stage, and pointed out that the various folding styles can be classified into the “deeper”, “intermediate” and “shallower” ones. KIMURA (1979) proposed a general idea about the relationship between the structural layers and genetical environment (temperature and pressure) of folding styles. It can be regarded as showing the environmental side of deformation facies in folds.

It was HANSEN (1971) who introduced the concept of “strain facies”. He regarded the specific strain features of rocks as products under a definite strain environment. Based on such an essential recognition, he presented the strain facies map of the Trollheimen area, Norway, using three types of mesoscopic folds, sahfold, norfold and discfold, as indices of strain facies in this area. In Japan, UEMURA (1974) and UDA (1978) applied the concept of strain facies to the study of the metamorphic rocks of Abukuma plateau and that of deformed gravels in the Tertiary conglomerate at the Cape Erimo area, Hokkaido, respectively.

The term “fabric facies” was proposed by HARA (1974) and HARA *et al.* (1976). It was defined as the type of deformation lamella in quartz grains, which are determined by temperature, pressure and strain rate during deformation. This could be regarded as a kind of deformation facies although it is restricted to the special type of structure.

It seems that previous studies mostly stressed the deformation environment; little attention has been paid to the effects of the nature of original materials, which is arguably just as important. In this respect, a concept of deformation facies by UEMURA (1978a, 1978b, 1979) and UEMURA & YOKOTA (1977, 1981), which is based on the structural analysis of the Jurassic Kuruma Group, implies the both factors of environment and material represented in terms of ductility. OGAWA (1978) discriminated two types of accretionary fold belts in central Japan and showed the fold styles in different series referring the basic concept of UEMURA (1978a).

In this article, the concept of deformation facies, series and grades are systematically

presented together with the facies structures and the deformation facies diagram as their graphical expression. Some considerations are also given to the identification, the correlation, and zoning in the light of deformation facies.

Factors controlling deformation

A number of factors controlling the deformation and rupturing of rocks can be classified into two basically different groups. One is “environmental factors” consisting of temperature, pressure, time and their derivatives, such as hydrostatic confining pressure, interstitial pore fluid pressure, deviatoric tectonic stress, and their time rates. The other is called here “material factors” and consists of lithological composition and fabric, such as grain size and its distribution, degree of compaction, mineralogical and chemical compositions, preferred orientation of linear and planar fabric elements, mechanical anisotropy, etc.

These two groups of factors nearly correspond to the environmental factors and rock factors of DONATH & FRUTH (1971) except for the evaluation of the strain rate, which these authors included in the environmental factors. The environmental factors should be those relating purely to the environment alone, and be completely independent of the kinds and properties of the materials existing there. Namely, they constitute the external conditions of the phenomena: in other words, they are attributes of field. In this respect, the strain rate is not purely an environmental factor, because it is a physical quantity determined by the response of materials to a given environment. This is clearly shown by the fact that the strain rate is dependent on the mechanical properties of materials. In the strain-controlled tri-axial test of rocks, however, the strain rate is an artificially controlled test condition. In this connection, loading rate or stress rate (time rate of stress) is purely environmental.

On the other hand, the material factors are purely of material, that is, they are at-

tributes of matter irrespective of properties of the field governing there. Namely, they compose the internal cause of the phenomena.

It is needless to say that the both groups of the controlling factors mentioned here should be reflected on the deformation facies. It is noted here that the most essential factors for producing deformational structures of geological bodies are the deviatoric stress as an environmental factor, and the mechanical anisotropy as a material factor. No structures can be formed without these two factors.

Indices of deformation facies

Mineral facies are specified at a definite pressure and temperature when the chemical compositions are fixed. In the case of the deformation facies, it is very difficult to find what factors could specify them. Since there are so many factors relating to the deformation, it is impossible to define the deformation facies by two or three single factors. Consequently, another category of indices is required, and it is of the present writer's opinion that two indices derived from "ductility" are the most adequate for this purpose; namely, "mean ductility" and "ductility contrast" which were introduced by DONATH (1963) and DONATH & PARKER (1964) to classify folding on the basis of mechanism.

Ductility was originally defined as strain percent at breaking point (HANDIN & HAGER, 1957), and thereafter, somewhat modified proposals were made to mean the permanent strain alone at breaking point (GRIGGS & HANDIN, 1960; MOGI, 1971), or strain percent at the point of ultimate strength or yield point for the rocks without breaking point (HOSHINO, 1966). It is of prime importance that the concept of ductility implies some factors of both the environment and the material, that is, the ductility is of compound concept. This is well understood as the ductility is dependent not only on rock species (material factors) but also on environmental factors, such as temperature, confining pressure, differential stress and their time rate. In rock deformation, the

most important meaning of ductility is that when two kinds of rocks have the same ductility, their deformational behaviour should be similar even if their individual factors differ from each other, and naturally, the resultant structures show similar facies.

Taking into account that most rocks are not homogeneous in lithology but have some internal structures or they consist of multilayered strata, the ductility as a whole should be expressed by the average of constituent portions and layers. This is "mean ductility". On the other hand, internal movement of rocks, which results in the deformation fabric, is expected to be largely dependent on the relative difference of ductility between adjacent constituents, namely it is the second index "ductility contrast". DONATH & PARKER (1964) only referred to the qualities of these two indices, and so their numerical representation will be mentioned later.

Without regard to the descriptive forms of mean ductility and ductility contrast, the environmental and material factors can be represented by these two indices respectively. For instance, it is possible and convenient to make relative discrimination of the materials by means of difference of ductility contrast, namely, ductility contrast (Dc) is mostly a function of material factors, such as lithological composition (l) and fabric (s) in a definite environment. On the other hand, the change of environment can be indicated by the change of mean ductility for a definite material, where mean ductility (Dm) can be regarded mostly as a function of environmental factors such as temperature (T), stress (σ), time (t), etc. Such relations are briefly described as follows:

$$Dc \approx f(l, s) \text{ in a definite environment,}$$

and

$$Dm \approx f(T, \sigma, t) \text{ for a definite material.}$$

Strictly speaking, mean ductility and ductility contrast are not completely independent, since ductility contrast for a definite material will probably decrease with increase of mean ductility. Generally speaking, high temperature,

low strain rate, and high stress level are expected to increase the ductility of every portion of any material. As a result, ductility contrast of a definite material weakens as mean ductility rises. This will have an effect on the configuration of the deformation facies diagram introduced later.

Deformation series and deformation grades

As stated previously, ductility contrast can be used as an index to express the relative difference of materials in a definite environment. This suggests that "deformation series" must be discriminated depending on the ductility contrast. The difference of ductility contrast is due not only to difference of constituent materials alone but also to their mode of composition. This is quite obvious from the fact that the alternation of well-sorted sandstone and mudstone has a higher ductility contrast than that of ill-sorted muddy sandstone and sandy mudstone even if both sand and mud are equal in quantity and quality. For discrimination of deformation facies series, it is necessary to classify the deformation structures into several groups, for example, low-, moderate-, and high-ductility contrast series. Among them, layered rocks exemplified by alternations of sandstone and mudstone are representative of the moderate ductility contrast series, and result in various types of deformed structures. Whereas, rocks of homogeneous lithology, which belong to zero ductility contrast series, are barren of such structures apart from some fractures. Although both homogeneous sandstone and homogeneous mudstone belong to the same series of zero ductility contrast, they can be distinguished by the difference of their mean ductility in the same environment.

On the other hand, there are different types of deformed structures made from the same material with the same composition. They may have been deformed under a different environment, which can be represented by the change of mean ductility as formerly mentioned. Accordingly, it is reasonable to

grade the deformed structures of the same materials depending on the mean ductility, under which each structure is made up. This is defined as "deformation grade". It is noteworthy here that the problem of the cause of change in mean ductility is of prime importance. Therefore, a careful examination is necessary for each case to find out which is the most effective environmental factor; temperature, pressure, or time rates of them.

Facies structures

A concept of "facies structures" is herewith introduced. Although it follows the concept of "facies fossils" in palaeontology, the meaning is enlarged to include the material factors in addition to the environmental factors. That is, they are defined as key structures contributing to the interpretation of their deformational environment as well as the properties of materials.

Geological structures are formed by some fundamental types of rock deformation in general, which are divided into elastic deformation, fracturing and flow with increase of mean ductility. Among the structures, fault, joint and some types of cleavages, etc., can occur even in lithologically homogeneous rocks; however, folds and some other structures cannot be formed unless the rocks were originally layered or anisotropic, namely, the rocks had ductility contrast. Taking notice of these points, main facies structures are tentatively summarized in Table 1 although some of their mechanisms are still open to discussion.

Deformation facies diagram

The above-mentioned and proposed scheme can be illustrated on a diagram in terms of the mean ductility and ductility contrast as ordinate and abscissa of a rectilineal coordinate respectively. The same type of diagram was used by DONATH & PARKER (1964) to show the mechanisms of folding. The deformation facies are represented by means of their series and grades on the coordinate axes (Fig. 1). This "deformation

facies diagram" is based on the following concept:

On the diagram, each deformation series is not parallel to the ordinate axis but somewhat inclined to it. This results from the probability that an increase of mean ductility may cause a decrease of ductility contrast. At the extremely high level of mean ductility, ductility contrast of any series will be reduced to zero, where all the series converge into the ordinate axis. The left-side series, near the ordinate, is of the homogeneous lithology, namely it is zero ductility contrast series, where the fundamental types

of deformations (extension fracture, fault and uniform flow) were proposed by GRIGGS & HANDIN (1960). Except for this, three series of low-, moderate-, and high-ductility contrast are figured schematically.

With respect to the deformation grade, it may satisfactorily be divided into three fields. The lower part of the diagram is the low grade field, where various types of faults and joints play important rôles. As types of failure in the series of homogeneous lithology, wedge fractures, single shear fracture, and network shear fractures are experimentally confirmed to be developed successively with increase of ductility (HOSHINO *et al.*, 1972). Characteristics to be noted for rocks with ductility contrast (including anisotropy) are "reflection" or curving of fracture surface, which are commonly elucidated by the difference of angle of "internal friction". The upper boundary of this field is gently sloping

Table 1. Main facies structures in deformation and rupturing. The letter Z, L, M and H mean "zero", "low", "moderate" and "high" respectively.

TYPES OF STRUCTURES		PRINCIPAL MECHANISM	MEAN DUCTILITY			DUCTILITY CONTRAST			
			L	M	H	Z	L	M	H
FRACTURES	FISSURE, VEIN, CRACK	EXTENSILE FRACTURING	—			—			
	JOINT	SYSTEMATIC FRACTURING	—			—			
	BRITTLE FAULT	SHEARING WITH SLIP	—			—			
	DUCTILE FAULT	"ZONE FLOW"	—	—		—			
	BEDDING FAULT	BEDDING-SURFACE SLIP	—	—				—	—
	FAULT, REFRACTED OR DEFLECTED	SHEARING	—					—	—
FOLIATIONS	FRACTURE CLEAVAGE	SHEARING		—		—	—		
	SLATY CLEAVAGE	FLATTENING OR SHEARING		—	—	—	—		
	CRENULATION CLEAVAGE	MICROFOLDING WITH OR WITHOUT SHEARING			—			—	—
	BEDDING CLEAVAGE	FLATTENING OR SHEARING		—	—			—	—
FOLDS	PARALLEL FOLD	FLEXURAL-SLIP	—	—				—	—
	DISJUNCTIVE FOLD	FLOW AND FRACTURING	—	—				—	—
	SIMILAR FOLD	SHEARING OR FLEXURAL-FLOW		—	—		—	—	—
	DISHARMONIC FOLD	FLEXURAL- AND PASSIVE-FLOW			—		—	—	—
	KINK BAND	"ZONE FLOW" WITH OR WITHOUT SLIP	—					—	—
OTHER STRUCTURES	BOUDINAGE	PARTING BY PARALLEL FLOW		—				—	—
	ELONGATED PEBBLE	SHEARING AND/OR FLOW		—				—	—
	PINCH-AND-SWELL STRUCTURE	ELONGATION BY PARALLEL FLOW		—				—	—
	CUSP STRUCTURE	PARALLEL FLOW		—				—	—
	IRREGULAR TECTONIC LENS	SHEARING AND/OR PARTIAL FLOW		—				—	—
	INCOMPETENT STRUCTURES	TOTAL FLOW			—		—	—	—

Fig. 1. Deformation facies diagram with schematic illustrations of some facies structures.

down to the right, because high ductility contrast means that more ductile materials should be included, and the partial flow of the system may be promoted by them. The upper part of the diagram is the field of high grade, where the total flow of materials takes place. Various kinds of "flow structures", sometimes with disharmonic and inhomogeneous strains, are taken as characteristic of this field. The series of zero ductility contrast is represented by uniform flow types of failure (GRIGGS & HANDIN, 1960) at high grade. The lower boundary of this field is gently sloping upwards to the right, because less ductile materials included in the high ductility contrast series at the right hand area are less prone to flow. The field of moderate deformation grade is located above two fields, where two kinds of movements, slip along fracture and flow, occur depending on the ductilities of constituent materials. As a result, various types of structures are formed. The representative facies structures of moderate to high ductility contrast series are folds, and the principal mechanism of

folding varies with change of deformation as shown in Table 1.

On the basis of deformation series and deformation grade, the deformation facies can be classified into some groups on the diagram. These are appropriately expressed in terms of mean ductility (D_m) and ductility contrast (D_c), such as "moderate D_c —high D_m facies", "low D_c —moderate D_m facies", or shorter as "moderate contrast—high grade facies", etc. Another expression by the names of characteristic structures in a structural assemblage is also available, namely, "boudinage—disjunctive fold facies", "slaty cleavage facies", and so on. In the case of "deformation zoning" to be mentioned later, zone I, II, ..., are available to assemblages of deformed structures.

Considerations

The identification of the similar deformation facies is the problem to be considered at first. Isofacies or anisofacies structures do not always mean that all of factors concerned are individually equal or unequal. Similar

structures can be formed in different materials in different conditions. Generally speaking, the solution of this problem lies in the principle of scale model experiment; any model can be similar to the prototype in quality as well as in quantity provided that the conditions of physical similarity are held. Since the various combinations of model ratios can satisfy such conditions, plural numbers of similar models can result from them. This is clearly shown by a well known example, namely, the similarity condition for the modelling of slow plastic deformation is described as,

$$C_\eta = C_l \cdot C_\rho \cdot C_t,$$

where, C_η , C_l , C_ρ , and C_t are model ratio of viscosity, geometrical dimension, density, and time respectively. Whenever the equation is satisfied, the resultant models are always similar to the prototype regardless of the individual values of model ratios. Likewise, in the case of deformation facies, situation is expressed in terms of ductility in such a way that as far as ductilities (mean ductility and ductility contrast) of rocks are equal, the resultant structures always can be isofacies regardless of the individual values of factors concerned. Accordingly, it can be said that all of the isofacies structures are related as prototype and models, in other words, the similarity conditions are implicitly held between them.

The second problem, the correlation of deformation facies, has dual meanings, one is environmental and the other is material. The former is expressed by deformation grade as mean ductility, and the latter by deformation series as ductility contrast. Consequently, taking two facies denoted by mean ductility and ductility contrast as Dm_1 , Dm_2 , and Dc_1 , Dc_2 respectively, the following combinations are qualified to be correlative (UEMURA, 1980):

$$\begin{aligned} Dm_1 &= Dm_2, \quad Dc_1 = Dc_2 \quad \text{---} \\ &\quad \text{isofacies (iso-series and iso-grade),} \\ Dm_1 &\neq Dm_2, \quad Dc_1 = Dc_2 \quad \text{---} \\ &\quad \text{iso-series and aniso-grade,} \\ Dm_1 &= Dm_2, \quad Dc_1 \neq Dc_2 \quad \text{---} \\ &\quad \text{aniso-series and iso-grade,} \end{aligned}$$

$$Dm_1 \neq Dm_2, \quad Dc_1 \neq Dc_2 \quad \text{---}$$

anisofacies (aniso-series and aniso-grade).

In the last case, two facies are incorrelative. Insofar as two facies belong to the same geological unit (the same deformation belt or deformed body), there are no more problems in particular about the correlation on the basis of the above-described principle. Because, these two facies are ascertained to be derived from a geologically common origin. On the contrary, the circumstances are quite different when two facies have been subject to the deformation different in time and/or space. The viewpoint of comparative tectonics is applicable to this situation, where the correlation of deformation facies will contribute to analyse and recompose the deformation units together with the "deformation zoning".

The idea of "deformation zoning" is based on the recognition of assemblages of structures. In a certain unit of deformation, whether in deformation belt or in a single fold, some different types of deformation structures are commonly found in some assemblages. Deformation diagram is available to determine their status (grades and series) as deformation facies and to clarify the mutual relation. This leads to an idea of the zoning of a deformation terrain or a deformed body depending on the deformation grades. When exotic or disharmonic structures mixed in a definite structural assemblage occur, their origin may be attributed to the local condition, or probably they are the relict structures surviving from the preceding stage of deformation. Deformation zoning was put into practice by UEMURA (1979) and UEMURA & YOKOTA (1977 ; 1981), who described the facies structures of the Jurassic Kuruma group, Japan, and discussed the tectonic environment and mechanisms of deformation.

Another interesting problem is related to the progress of deformation. Deformed structures are developed and are sometimes transformed into other types with increase of deformation grade. For example, mechanism of folding is mostly bedding slip at the initial stage where mean ductility is low, then, as

it gradually increases, the principal mechanism changes as shown in Table 1, and as a result, fold shapes are transfigured from parallel type to similar types. If the mean ductility increases abruptly, intermediate type of fold shape cannot appear. This is indicated on the facies diagram as a jump from low grade facies to high grade facies. This phenomenon in nature suggests the abrupt change of environmental factors. Discussions on the series of fold shape should be carefully made from the viewpoint of grade and series of deformation facies, and especially of their time dependence, namely their mode of progress.

The problem of quantifying the deformation facies diagram remains. Inasmuch as the diagram presented here is qualitative, the numerical discussions are not possible without marking the absolute values on the coordinate. The following quantification was proposed for the materials consisting of n layers of strata (UEMURA, 1977):

$$Dm = \frac{\sum_{i=1}^n (t_i \cdot d_i)}{\sum_{i=1}^n t_i},$$

$$Dc = d_i \sim d_{i+1}, \text{ and on the mean,}$$

$$\overline{Dc} = \frac{\sum_{i=1}^n (d_i \sim d_{i+1})}{n},$$

where, Dm and Dc are mean ductility and ductility contrast, t_i and d_i are thickness and ductility of individual layer, $i=1, 2, 3, \dots, n$. In addition, he proposed to take $f_i \sim d_i$ instead of d_i for the strata with pre-existing fractures, where f_i is the factor of fracture effect, probably related to the density of fractures, reduction of strength, and so on. It is of the present writer's opinion that the ductility contrast is better quantified in terms of ductility ratio of the adjacent layers.

In this connection, the problem of obtaining the absolute values of mean ductility and ductility contrast should be mentioned. This problem eventually leads to determination of ductilities of various rocks in various environments. It is not until these data are obtained that the sufficient information can be selected and applied to the subject on hand. Since the strain rate in natural de-

formation is lower by some powers of ten than that obtainable by tri-axial test apparatus, experiment is practically next to impossible in this condition. The situation can be improved by the use of more ductile materials. This may be likened to a kind of scale model experiment. Providing that the ranges of mean ductilities and ductility contrasts required to cause main mechanisms of deformation can be determined by these experiments, the quantification of deformation facies diagram will be accomplished, which will make numerical discussion of all the deformation facies possible. Nevertheless, even at the qualitative stage of the present, the deformation facies diagram is sufficiently useful as previously stated.

Acknowledgement The writer expresses his sincere thanks to Dr. C. J. TALBOT of the Department of Geology, The University of Dundee for helpful advice and critical reading of the manuscript.

References

- DONATH, F. A., 1963 : Fundamental problems in dynamic structural geology. In W. DONNELLY ed.: *The earth science—problems and progress in current research*. 83–103. Univ. Chicago Press, Chicago.
- , FAIL, R. T. and TOBIN, D. G., 1971 : Deformational mode field in experimentally deformed rocks. *Bull. Geol. Soc. Amer.*, **82**, 1441–1462.
- , and FRUTH, L. S. JR., 1971 : Dependence of strain-rate effects on deformation mechanism and rock type. *Jour. Geol.*, **79**, 347–371.
- , and PARKER, R. B., 1964 : Fold and folding. *Bull. Geol. Soc. Amer.*, **75**, 45–62.
- GRIGGS, D. and HANDIN, J., 1960 : Observation on fracture and a hypothesis of earthquakes. *Mem. Geol. Soc. Amer.*, **79**, 347–377.
- HANDIN, J. and HAGER, R. V. JR., 1957 : Experimental deformation of sedimentary rocks under confining pressure: Tests at room temperature on dry samples. *Bull. Amer. Assoc. Petrol. Geol.*, **41**, 1–50.
- HANSEN, E., 1971 : *Strain facies*. 207p, Springer-Verlag, Berlin.
- HARA, I., 1974 : Study on deformation condition

- in the Sambagawa metamorphic belt—Velocity of the Hizikawa folding—. *GDP News, Structural Geol.*, **2**, 1—12 (in Japanese).
- , PAULITSCH, P. and HIDE, K., 1976 : An estimation method of velocity of orogenic movement. *Abh. N. Jb. Geol. Paläont.*, **151**, 58—72.
- HOSHINO, K., 1966 : Rock deformation and geologic structure. *Jour. Geol. Soc. Japan*, **72**, 105—116 (in Japanese).
- , KOIDE, H., INAMI, K., IWAMURA, S. and MITSUI, S., 1972 : mechanical properties of Japanese Tertiary sedimentary rocks under high confining pressures. *Rept. Geol. Surv. Japan*, **244**, 200p.
- KIMURA, T., 1968 : Some folded structures and their distribution in Japan. *Japanese Jour. Geol. Geogr.*, **39**, 1—26.
- , 1979 : *Japanese Islands—Till its completion* —. **IIa**, 245—578p (in Japanese), Kokinshion, Tokyo.
- MOGI, K., 1971 : Fracture and flow of rocks under high triaxial compression. *Jour. Geoph. Res.*, **76**, 1255—1269.
- OGAWA, Y., 1978 : Two types of accretionary folded belts in central Japan. *J. Phys. Earth.*, **26**, 321—336.
- UDA, T., 1978 : *Deformation of Utau conglomerate*. Thesis, Ph. D., 85p., Hokkaido Univ. (unpubl.).
- UEMURA, T., 1977 : Classification of landslides and ductility. *Rept. A Symposium, Japan Soc. Landslide*, 3—6 (in Japanese).
- , 1978a : Deformation facies and deformation series. *Abst. Annual meeting Geol. Soc. Japan*, 391 (in Japanese).
- , 1978b : On deformation facies. *Bull. Tectonic Research Group in Japan*, **22**, 12—13 (in Japanese).
- , 1979 : Folding and deformation facies of the Jurassic Kuruma group. *Studies on Late Mesozoic Tectonism in Japan*, **1**, 75—79 (in Japanese).
- , 1980 : Iso-facies and aniso-facies in deformed structure. *Abst. 26th IGC*, **1**, 404.
- and YOKOTA, Y., 1977 : On the deformation of the Jurassic Kuruma group. *Abst. Annual meeting Geol. Soc. Japan*, 110 (in Japanese).
- and ———, 1981 : Deformation facies of the folded Kuruma Group, central Japan. *Earth Sci.*, **35**, 43—50.
- UEMURA, H., 1974 : On the strain facies of Gosaisho-Takanuki metamorphic rocks—A preliminary Report—. *Abst. Annual meeting Geol. Soc. Japan*, 400 (in Japanese).

変形相, 変形系列および変形グレード

植 村 武

(要 旨)

変形相は, 変形物質の力学的性質および変形環境を表わす二つの因子群によって支配される。前者によって一定環境下における変形系列が識別され, 後者は一定物質の変形グレードによって表わされる。このような概念に基いて, さまざまな示相構造を, 延性度較差と平均延性

度とを両軸にとった新提案の変形相ダイアグラムの上に系統的に配列することができる。このダイアグラムによって天然の変形相の同定・対比・分帯などが可能となり, それらの相互関係を変形過程や変形機構に基いて議論したり解釈したりすることができる。