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On the Paleogene Sandstone Dikes in the Muroto District, Shikoku Island, Southwest Japan

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Abstract

In the Paleogene rocks of the Muroto district sandstone dikes are found in many localities. They occur invariably within shaly flysch-type rocks and not essentially associated with slumping. The material of the dikes was filled into fissures from above and/or below. In addition the paper deals with the origin of the dikes and their deformation. Fissuring in the desposits was probably caused by an underwater earthquake. The sandstone dikes show not only ptygmatic folding by the compaction of the surrounding rocks, but also are folded, faulted, and fractured through later orogenic movements, depending on their initial attitude.

I Introduction and Acknowledgements

The Paleogene flysch-type sediments in the Shimanto terrain have many interesting sedimentary structures, which were in recent years reported by many writers, such as KATTO (1961), MIZUNO & IMAI (1964), HARATA (1965) and others. However, they have not paid much attention to clastic dikes. The clastic dikes reported from the Shimanto terrain are sandstone dikes and this writer also observed many sandstone dikes in the Muroto district, which offer some information about the tectonic development of the Shimanto geosyncline. Hitherto, classifications, origins, and geological significances of the clastic dikes have been published by a number of writers (NEWSOM, 1903; STRAUCH, 1966; HAYASHI, 1966; etc.), but few papers deal in detail with the relation of deformation of the clastic dikes to other tectonic structures. Therefore, this paper deals with not only the description and geological significance, but also with the tectonic deformation of the sandstone dikes.

The observation on which this paper is based is a part of stratigraphic and tectonic investigations of the Muroto district. The writer wishes to express his thanks to Prof. K. NAKAZAWA for his kind help and guidance in the field work. Thanks are also due to Ass. Prof. S. ISHIDA and Dr. Y. NOGAMI of Kyoto University,

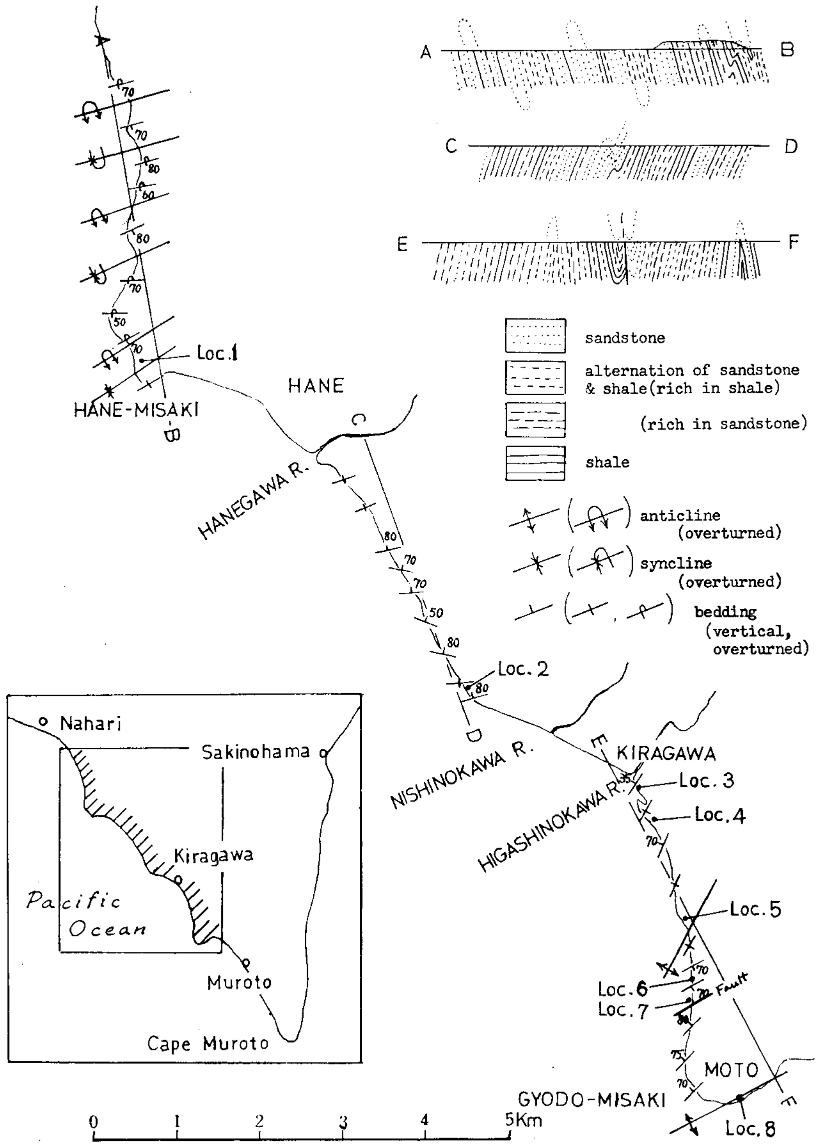


Fig. 1. Geologic profiles and distribution of the dikes along part of the western coast of the Muroto district.

and Dr. E. MATSUMOTO of the National Science Museum in Tokyo, for their kind suggestions.

II General Geology of the Muroto District

The Muroto district belongs to the southern part of the Shimanto belt, the outermost major belt of southwest Japan, and consists of a complex of Mesozoic and early Cenozoic geosynclinal deposits. The eugeosynclinal condition lasted mainly during the late Mesozoic and was followed by the flysch-type sedimentation of miogeosynclinal character in the Paleogene. During the late Paleogene to the early Miocene, intense deformations took place in the geosyncline, which are called the Takachiho disturbances (KURODA & MATSUMOTO, 1942).

On the basis of the writer's survey and other works (SUZUKI, 1930; KATTO *et al*, 1961) the geology of the Paleogene of the Muroto district is summarized as follows:

The Paleogene strata include the Shijujisan formation and the Muroto formation, of which the former is exposed in a limited area of Mt. Shijuji and blocked in among the Muroto formation by faults. Therefore, the Paleogene mentioned below is limited to the Muroto formation which is developed in most parts of the district. The geological characters of the formation are as follows: (1) The Paleogene strata consist of sandstones and shales sometimes intercalated with conglomerates, limestones, basic igneous rocks, pyroclastics, and tuffaceous rocks. These rocks are geosynclinal sediments, attaining to a thickness of several thousand meters. (2) Alternations of sandstones and shales are generally of flysch type, and many sedimentary structures are found in them. (3) Various types of trails of worms (*Nereites*, etc.) and a problematic *Paleodictyon* are found on the base of sandstone beds. (4) Although the sequence is not accurately dated owing to the scarcity of reliable fossils for age determination, it can be assigned to Oligocene to Eocene on the basis of comparison with similar formations of other regions and the molluscan fossils (*Solemya murotoensis* KOBAYASHI, *Venericardia mandaica* (YOKOYAMA)) reported by KATTO, *et al* (1961) from the Muroto formation. (5) The basic igneous rocks such as gabbro, dolerite, and their pyroclastics, are products of igneous activities during the sedimentation of the rocks mentioned above. (6) The rocks were intensely folded and faulted through the Takachiho movements during the late Paleogene to the early Miocene. Major folds are close to isoclinal. Their axial planes stand generally vertical or dip steeply to the south, and there are considerable changes in plunges of the fold axes. Cleavage is usually developed weakly in shales, but in the axial parts of the major folds considerably well-developed cleavage subparallel to axial plane is observed.

III Description of the Dikes

Various sandstone dikes are observed in the strata which crop out in considerably good exposure along the western coast of the Muroto district. But since in the area of the southern coast, sandstone layers of alternations are severely fractured into tectonic lenses, the writer could not find any sandstone dike there. Hence the writer's observation is limited to the coast from Gyodo-misaki to Hane-misaki, as shown in Fig. 1, in which are given localities of coccurrence of sandstone dikes and geologic profiles. The dikes at each locality are described briefly below and the trends of the dikes stated here indicate initial trends determined by returning of the bedding to its original horizontal position, using the strike of bedding as a rotation axis.

Loc. 1. A little north of the fishing port of Hane-misaki a number of sandstone dikes occur. They range mostly from 1 to 5 cm in thickness, but the thickest one reaches 20 cm thick and can be followed more than several meters in the outcrop. They are generally extremely curved, but are sometimes almost straight or fractured in pieces. The rocks containing these dikes are overwhelmingly shale-rich formations. The dikes strike roughly north-south, though variously folded.

Loc. 2. On the shore some 1.5 km northwest of the mouth of the Nishinokawa River many dikes are observed in shales. Most of the dikes are less than 8 cm thick and several meters long, and show branching and remarkable folding. The dikes tend to run northeast-southwest.

Loc. 3. Several dikes are found about 100 m south of the mouth of the Higashinokawa River. One of them is 30 cm in thickness and several meters in length, and has a strike of north-south. The dike has a branch shooting perpendicular, being more than 1 m long and about 5 cm thick. Another is about 1 cm thick and runs northeast-southwest more than 4 m in horizontal length. As shown in Fig. 2, when these dikes meet with sandstone layers, their continuations begin from other points so that they have a step-like appearance. The surrounding rocks are shaly alternations.

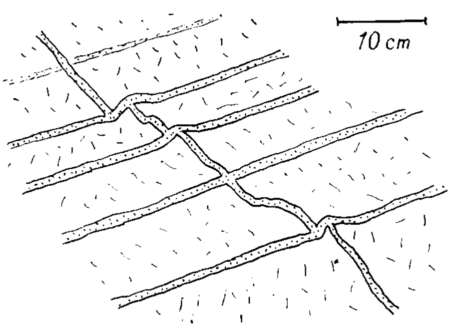


Fig. 2. Deformation of sandstone beds at the points of connection with a dike. Boundary between the dike and the sandstone beds is invisible. Loc. 2.

Loc. 4. Some 500 m south of Hoji many long dikes can be found, the longest of which is less than 15 cm thick and more than 10 m high vertically. The dikes occurring here are folded, perpendicular or oblique to the bedding and shoot branches. These branches (Pl. 2, fig. 5) diminish in thickness downwards. Sometimes the inclusions of the country rocks are found in the dikes (Fig. 3). At this locality step-like dikes are found not only related with sandstone beds as in the case at Loc. 3 but even in shale beds (Pl. 2, fig. 3). The dikes have a strike of northwest-southeast in general and the penetrated rocks are shaly alternations.

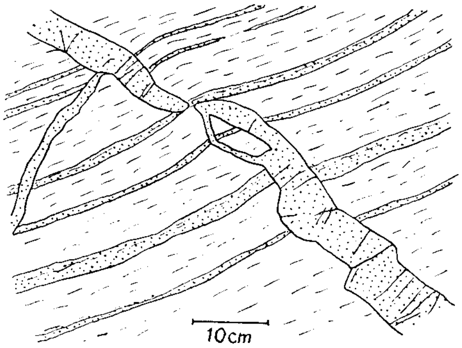


Fig. 3. Dike having a branch and a captured country rock. Loc. 4.

Loc. 5. In the vicinity of Kuromi was observed a dike penetrating massive coarse-grained sandstones in slump beds (Pl. 2, fig. 4). It is medium to fine-grained and lighter in color than the enclosing sandstones. It is more than 15 m long and has a 1 cm thick branch at a right angle with itself. The writer discovered a dike in slump only at this locality.

Loc. 6. In the vicinity of Shimura, dikes about 3 cm thick occur abundantly. Some of them are parallel to, or at small angles to, bedding plane, and the dikes shown in Pl. 2, fig. 1 thins out upwards. Some are ptygmatically folded.

Loc. 7. On the coast of Hirao, parallel-running dikes cocur and, though they are folded, they make a definite angle with bedding plane (Fig. 4). They are 1 or 2 cm thick and strike N25°W. The country rocks are shaly units.

Loc. 8. On the coast south of Gyodo dikes of various thickness amounting to 30 cm are found in the axial part of an anticline. The dikes have different shapes or are deformed. The penetrated rocks are shales or shaly units.

Most of the sandstone dikes observed penetrate shaly flysch-like alternations of thin sandstones (2 or 3 cm thick) and much thicker shales as stated above. In sandy and normal flysch-type alternations the writer did not find any dikes, while few slump deposits contain them.

The dikes are massive and composed of medium- to fine-grained, poorly sorted sandstone, and are light brown in color, resembling sandstones of the surrounding rocks. The thickness of the dikes ranges from a few millimeters to tens of centimeters, and is usually between 1 and 5 cm. Generally individual dikes do not show a sudden change in thickness. The length of the dikes attains to more than 25 m horizontally and more than 15 m vertically.

Angles that the dikes make with bedding plane are various, between 0° and 90°, and in most cases show a value of 70° to 90°. Not all dikes penetrate the enclosing layers maintaining the same angle with them, and a few dikes turn even at an almost right angle.

The dikes tend to be arranged parallel with each other (Fig. 4 is a typical example) within individual horizons in which they occur. For instance, the dikes at Loc. 4 possess a northwest-southeast trend and at Loc. 7 a northnorthwest-southsoutheast trend. On the other hand, the dikes occurring at Loc. 2 trend approximately northeast-southwest.

The dikes observed are variously spaced away from each other and no solitary dike could be found except in slump beds. The dikes change not only their thickness and direction, but also branch out. Branches and the parent dike make generally an angle of about 60°, and sometimes joint together again so that blocks of the country rock are captured in the dikes (Fig. 3). In Loc. 4 it was observed that every time the branching-out is repeated, the branches diminish in thickness and finally thin out downwards.

IV Origin of the Dikes

In spite of the abundance of the dikes, the writer could not determine with certainty source beds of the material of the dikes in the field, not only because of insufficient outcrops or no chance of exposure, but also because of the obscure relationship between the dikes and their source beds made by later phenomena. The dikes are massive and have no structures that indicate the direction of material movement. However, it is supposed that the filling of materials into fissures may be from above in the case of most dikes showing the downward thinning and the downward shooting of their branches (typical in Loc. 4).

But F. STRAUCH (1966) theorized that a dike crossing the bedding plane with a small angle was evidence of the filling from below. Occurrence of the dike at Loc. 6 (Pl. 2, fig. 1) seems to be such a case, and moreover the thickness of the dike decreases upwards. However, the connection with the thicker sandstone lying immediately below which may be its source bed, is not preserved. Furthermore, it is of interest that where the dike meets with a sandstone bed, its continuation shoots sometimes from another point of the bed, as shown in Fig. 2. The field evidence indicates that in this case no bedding-slip has taken place between such a sandstone bed and the adjoining shale bed. Therefore, this step-like fissure is probably the original one. It is considered that the unconsolidated sand between the mud deposits must have been forced both down and up into the fissure by the weight of overlying beds.

From the evidence mentioned above in the case of the dikes of this area it appears not to be important whether the dike were filled from above or below. Even if, as in the case of the occurrence at Loc. 4, the direction of material filling is probably from the top, the writer failed to determine whether the source sandstone layer was the uppermost sediment on the sea floor when the fissures were formed.

The sandstone dikes observed in this area are considerably long, both horizontally and vertically, and some of them attain to more than 10 m in vertical height. The dikes do not occur in all horizons but in definite units of the flysch-like sequence. Moreover they have generally clear orientations (especially in Loc. 2, Loc. 4 and Loc. 7). Judging from these facts it is obvious that the dike fissures are not of any sort of mud cracks.

Hitherto, papers on the formation of the sandstone dikes attributed them to submarine slumping (FAIRBRIDGE, 1946; SMITH & RAST, 1958; etc.). The Paleogene deposits of the Muroto district also contain many slumps, but nevertheless these slumps rarely have the sandstone dikes. In the area investigated it is only Loc. 5 where the writer found the dike in slump unit, and hence, the sandstone dike formation is regarded as not essential in slump phenomena.

As mentioned in the description of the dikes, their trends do not show the general parallelism with regional structure, and from this fact it cannot be deduced that the dike formation was caused by a tectonic movement such as incipient folding (refer to JANKOWSKY, 1955).

A majority of writers regard sedimentary dikes occurring in normal undisturbed sequences as an indication of ancient seismicity (e.g. WATERSTON, 1950; ZEIL, 1958), and this writer likewise attributes the fissuring in the Paleogene deposits of this area to underwater earthquakes during sedimentation.

Evidence that surrounding rocks in which the dikes occur are restricted to shaly flysch-type strata, excepting the case of slumping, will be of importance from a paleogeographic and tectonic point of view. However, slumping, the cause of which is supposed to be likewise submarine earthquakes, is not especially related to muddy or sandy deposits. This difference in effect of earthquakes on sediments is presumably concerned with sedimentary environments, for instance such as the inclination of the sea floor, and with the intensity of seismicity, but it remains unknown why the overwhelming majority of the dikes are discovered in the shaly alternations in this district.

V Deformation of the Dikes

The sandstone dikes are not single tabular bodies, but show remarkably variable shapes and relations to other structures. Judging from the relationships of the dikes to other structural elements, these shapes cannot be regarded as being made at the same time.

On the angle between the dikes and the bedding plane. The dikes occur at different angles to the bedding plane, but it is difficult to find the definite angular relation of the dikes to bedding, since the dikes are generally highly folded or not parallel to each other. However, in Loc. 7 many dikes, though finely folded, run parallel and make a fairly constant angle with bedding (Fig. 4). The bedding strikes

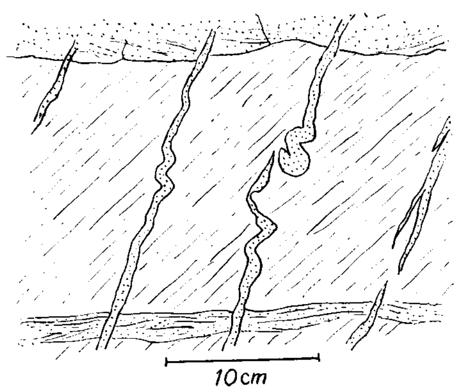


Fig. 4. Parallel-running dikes which make a definite angle with bedding plane. Loc. 7.

N85°W and dips 50°S, and the dikes strike N15°E and dip 50°E, and hence the angle made by them is 65° to the west side toward the top. Slightly south of this locality lies a syncline axis which plunges N25°E, 35°S, as known from a cleavage-bedding intersection. The one-sided inclination of the dikes to the bedding plane can be considered as mainly resulting from flexural-flow in the process of folding. That is to say, since in flexural folding the upper material of a layer of a syncline must move away from the hinge, the dikes, which were presumably perpendicular to bedding before folding, followed the material movement of the surrounding shale in folding. However, the amount of flow which took place could not be measured because the dikes do not lie parallel to the syncline axis.

Folding of the dikes. Three kinds of "folding" of the dikes can be given. (1) The rocks were fissured with rugged surfaces from the first, and sands were introduced into the wrinkled fissures. (2) After the sand-filling into the fissures, most of the water escaped from the muds of a very high water content and compaction caused the decreasing in initial thickness of beds. Since in sand, however, compaction is negligible, the thin sandstone dikes running nearly vertical to bedding plane were folded in shrinking shale. (3) During the orogenic movement the deformation of the dikes was brought about by tectonic forces in the main folding. Of these three possibilities, though the effect of the initial wrinkling (1) cannot be easily known in the field, the second was probably the most significant cause for the folding of the dikes observed. SAITO, *et al.*, (1954) reported on the compactional wrinkles of the sandstone dikes in coal beds of Hombetsu, Hokkaido, and calculated the rate of compaction. The degree of folding of the dikes found in the present district is highly various and the present writer could not know to what extent compaction of sediments has taken place. It appears that the sand filling took place in variously compacted sediments judging from the evidence that the fissuring reached different depths.

It is of interest that Fig. 2, which shows the bending of the sandstone bed about the point of the connection with the dikes, indicates the resistance of the dikes to the compaction of the enclosing mud layers. The compaction of the mud deposits causes the ptygmatic folding of the dikes, but also probably makes them step-like in muds, as shown in Pl. 2, fig. 3.

It is generally difficult to determine in the field the influence of later tectonic processes on the dike folding, but Fig. 5 offers an intersting example of the relation

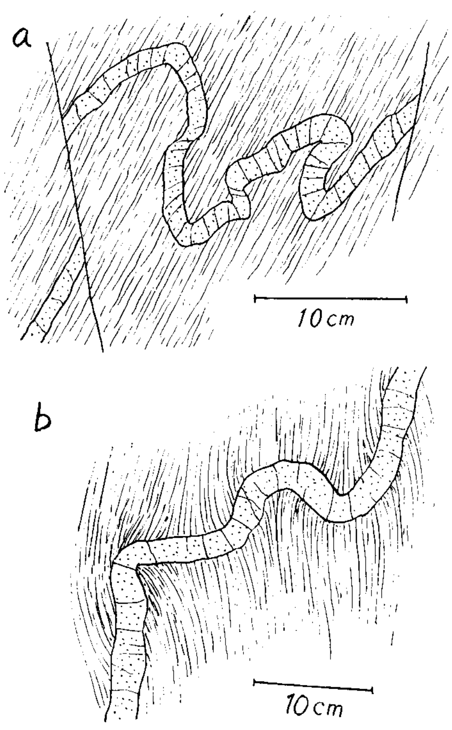


Fig. 5. a. Folded dike not related to cleavage development in shale.
b. Dike showing an influence of its folding on the development of cleavage. Loc. 8.

between the folding of the dikes and the cleavage development. In Fig. 5a the cleavage is developed, not being affected by the dike, and in this case the dike was already folded before the movement causing cleavage; on the other hand, Fig. 5b demonstrates that the folding of the dike was going on still during the cleavage formation.

In the axial part of the close anticline of Gyodo occur many dikes that are folded isoclinally and the axes of the folds of dike lie in the axial plane of the anticline. These dikes, with a thickness up to 15 cm, were probably folded through the compression within the anticline core.

Fracturing of the dikes. The dikes are traversed by joints that are approximately vertical to the dike surface. In the fine-grained dikes in cleavage-developed shale the joints occur like a coarse cleavage refracting at the boundary between the shale and the dike sandstone. Frequently the dikes are offset by faults traversing the rock mass (Fig. 5a) and in some cases by bedding-slips taking place in the flexural folding. The displacement by the bedding-slip amounts to approximately one meter. Good examples of the displacement of the dikes by bedding-slip are reported by HAYASHI (1957) from the Miocene beds of Chita Peninsula, Central Japan.

It is often observed that the dikes are fractured into lens-like masses in cross section. Two varieties of lenses are recognized, namely, the one pulled off into lozenge-shaped segments (Fig. 6), and the other formed by compression more or less in the direction of the strike of the dikes (Fig. 7). The difference in these phenomena is due to the fact that the former dike was by chance approximately in the cleavage surface and subjected to the compressive force vertical to the dike surface, whereas the latter crossed the cleavage and fold axis, and was sheared into lenticular segments with edges parallel to cleavage plane.

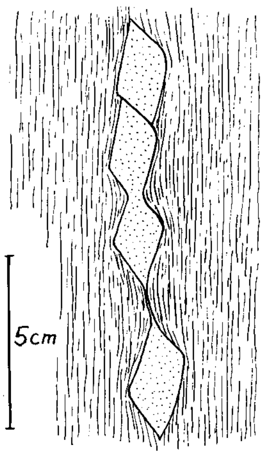


Fig. 6. Thin dike deformed into lozenge-shaped segments. The figure represents the cross-joint surface perpendicular to the axis of main fold. Loc. 8.

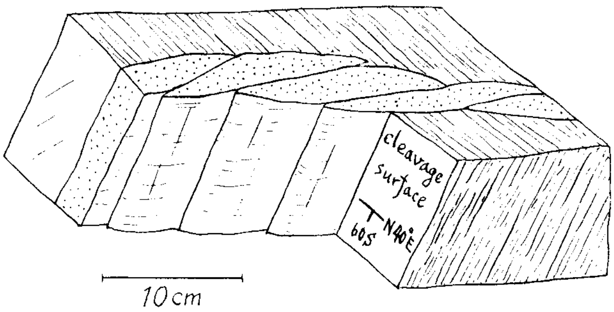


Fig. 7. Diagrammatic figure showing a dike cut into lenses of which edges are nearly parallel to the dip direction of the cleavage surface.

As mentioned above the deformation of sandstone dikes is, especially in fracturing, related to the main movement, but the manner of deformation may depend greatly upon the relationship between the initial trend of the dikes and the direction of the structural elements of the fold. Furthermore, it is natural that there is a difference in the time of deformation.

References

DZULYNSKI, S. and E.K. WALTON (1965): Sedimentary Features of Flysch and Greywackes, 274p. *Elsevier Publishing Company.*

FAIRBRIDGE, R.W. (1946): Submarine slumping and location of oil bodies. *Bull. Amer. Assoc. Petr. Geol.*, **30**, p. 84–92.

HARATA, T. (1965): Some directional structures in the flysch-like beds of the Shimanto terrain in the Kii Peninsula, Southwest Japan. *Mem. Coll. Sci. Univ. Kyoto, Ser. B*, **32**, p. 103–176.

HAYASHI, T. (1957): Sandstone dikes in the Miocene of Chita Peninsula (in Japanese). *Bull. Aichi Gakugei Univ.*, **6**, p. 69–76.

HAYASHI, T. (1966): Clastic dikes in Japan (1). *Jap. J. Geol. Geogr.*, **37**, p. 1–20.

JANKOWSKY, W. (1955): Schichtenfolge, Sedimentation und Tektonik im Unterdevon des Rheintales in der Gegend von Unkel-Remagen. *Geol. Rdsch.*, **44**, p. 59–86.

KATTO, J. (1961): Sedimentary structures from the Shimanto terrain, Shikoku, Southwest Japan. *Res. Rep. Kochi Univ.*, **10**, *Nat. Sci.*, p. 135–142.

KATTO, J. *et al.* (1961): Geological and mineralogical resource map of Kochi Prefecture with explanatory text, scale 1:200,000. *Naigai-Chizu Co., Tokyo.*

KURODA, H. and T. MATSUMOTO (1942): Geology of the southern part of Hyuga province, a preliminary report (in Japanese). *Jour. Geol. Soc. Jap.*, **49**.

MIZUNO, A. and I. IMAI (1964): Explanatory text of the geological sheet map of "Tanami" (1:50,000). *Geol. Sur. Jap.*

NEWSOM, J.F. (1903): Clastic dikes. *Bull. Geol. Soc. Amer.*, **14**, p. 227–268.

SAITO, R. *et al.* (1954): On stone intrusions in the 2nd coal seam at the Hombetsu coal-mine, Hokkaido (in Japanese). *Bull. Geol. Comm. Hokkaido*, **26**, p. 25–32.

SMITH, A.J. and N. RAST (1958): Sedimentary dikes in the Dalradian of Scotland. *Geol. Mag.*, **95**, p. 234–240.

STRAUCH, F. (1966): Sedimentgänge von Tjörnes (Nord-Island) und ihre geologische Bedeutung. *N. Jb. Geol. Paläont. Abh.*, **124**, p. 259–288.

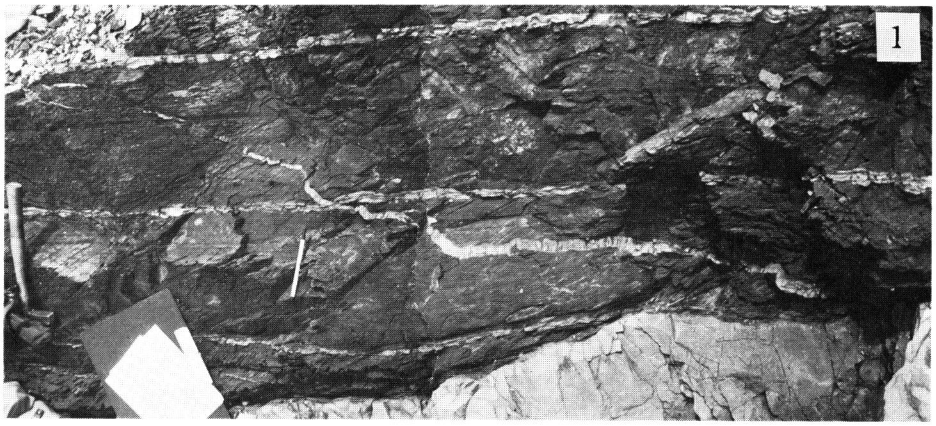
SUZUKI, T. (1930): Geological sheet map of "Muroto-misaki" with explanatory text, scale 1:75,000. *Geol. Sur. Jap.*

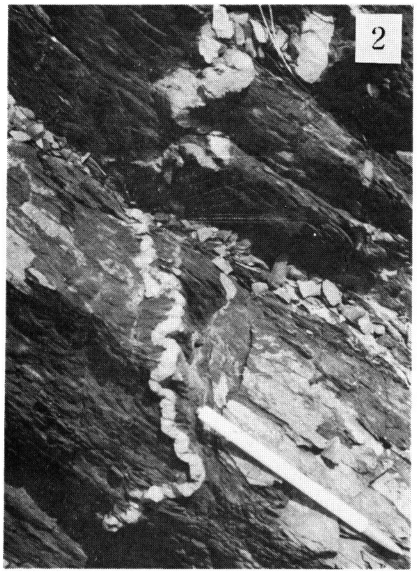
WATERSTON, C.D. (1950): Note on the sandstone injections of Eathie Haven, Cromarty. *Geol. Mag.*, **87**, p. 133–139.

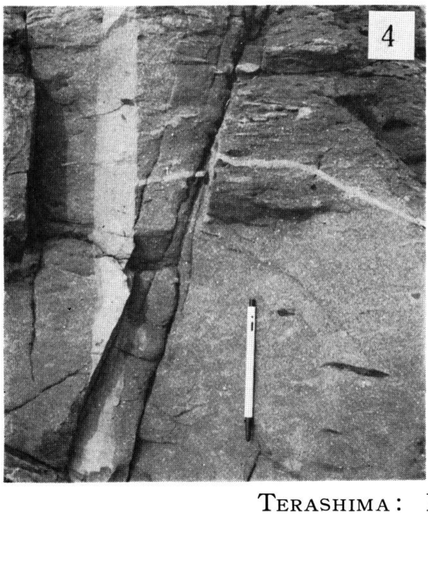
ZEIL, W. (1958): Sedimentation in der Magallanes-Geosynklinale mit besonderer Berücksichtigung des Flysch. *Geol. Rdsch.* **47**, p. 425–443.

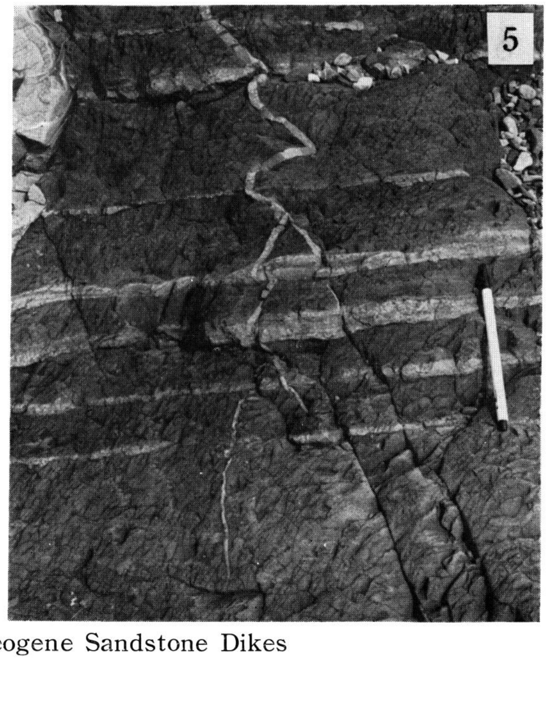
Explanation of Plate 2

Fig. 1. Dike intersecting at bedding plane at a low angle. Loc. 6.
Fig. 2. Ptygmatically folded dike. Loc. 1.
Fig. 3. Branch showing a step-like appearance. Loc. 4.
Fig. 4. Dike penetrating coarse sandstone in slump. Loc. 5.
Fig. 5. Dike showing downward branching. Loc. 4.









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