Sedimentary Structures from the Shimanto Terrain, Shikoku, Southwest Japan

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Introduction and Acknowledgement

Sedimentary structures are well developed in the Shimanto terrain of Shikoku, Japan. These structures which occur in turbidites have been described in part (Katto, 1959), but are again taken into consideration based on other examples because of their importance in interpretation of the sedimentary environment of the thick deposits.

Sedimentary structures are common phenomena in turbidites, a particular facies comprising sediments transported and deposited as the result of turbidity currents. This kind of currents are common phenomenon in the Recent seas and are well developed in the geological column, ranging in age from Paleozoic or older, upwards. These kinds of sediments due to their rapid accumulation and to the strong transporting power by which they are carried for great distances, show a wide range in their composition and texture as well as in thickness. However, generally they may have considerable lateral distribution and reveal a wide variety of structures in them. Very commonly having their source in shallow water they are important for the displacement of organic and inorganic materials. Owing to the rapid deposition of turbidites due to the turbidity currents, the resulting sediments usually show peculiar sole markings, simple to intricate internal structures and exhibit surfaces features of interest.

Associated or related with turbidity currents are submarine slumping, rubble deposits and viscous flows, all of which are erosive agencies with the ability to tear up the previously deposited unconsolidated or partially or even consolidated bottom sediments to incorporate them into the turbidites. Such incorporation of erratics may be subjected to transportation by either of the three mentioned phenomena, settle rapidly and near to their source, or to be the cause for constructing a complicated sedimentary structure. Such kinds of sediments in a stratigraphic sequence may be separated by angular boundaries should the conditions be favorable. Large masses of consolidated or unconsolidated sediments may be subjected to removal and transportation by the turbidity currents.

Recognition of sedimentary structures resulting from or related with turbidity currents should be known for the interpretation of the upper or under surface of vertical or overturned strata as well as for the general features of a sedimentary deposit.

It is the purpose of the present article to describe some sedimentary structures not treated in the previous work, which have been observed during field works in the Shimanto terrain.

Here the writer thanks Professor Kotora Hatai of the Institute of Geology and Paleontology, Tohoku University, for his kind supervision with regard to the present work.

Description of the Sedimentary Structures

Pull-apart Structures. Pull-apart structures are generally developed by the stress applied to any layer by gravitational forces, whereby the layer or layers are pulled apart to produce variously shaped fragments of the original layer. These detached portions of some pre-existing layer by continued movement, generally down an existing slope and by the friction caused therefrom, are subjected to have their margins abraded and changed from angular to subangular or rounded, and the shapes of the detached portions may change from tabular and elongate to short and straight to variously curved fragments. Continued abrasion by movement down-slopewards, results in the production of well rounded pebble to cobble size soft rocks, particularly of shale, siltstone and clay or rarely even of fine grained sandstone. Such structures often resemble conglomerates, but are distinctly different in their mode of formation and significance.

In the Muroto formation (Eocene) distributed at Tateishi in Muroto City there have been found an interesting exposure showing well developed pull-aparts in the form of soft rock conglomerate (Pl. 1, Fig. 1). Although many of the cobbles are still found to show their original folded shape, they may have been the crests of an anticlinal structure formed in a slumped or convolute bedded deposit developed on the upslope of the sea-bottom. If these actually represent such structures they should be called snow-balls. Most of the other soft-rocks are detached portions of some silty or shale layers, which after being pulled-apart were subjected to downward movement by which their margins became rounded, and from their longer axis being much greater than that of the shorter one, it is also thought that these soft-rocks were originally a part of a rather thin silty or shale layer existing on the upslope. Being concentrated in the form of a lenticular conglomerate it may be interpreted that their place of rest was either in a shallow depression then existing on the clinoform or near the region where the slope and the bottom come into contact with one another.

Larger pull-aparts (Pl. 1, Fig. 2), are also found in the same formation and at the same locality but in a different horizon. These consist of large bent chunks and large snow-balls of fine grained sandstone embedded in a shale facies. Their thickness varies in the same specimen and this goes to show that considerable friction occurred during their transportation down the slope. Even parts of the same specimen where thinner show evidence of having been pulled-apart. But since their margins still retain considerable angularity, it is thought that they were not subjected to movement sufficient for producing roundness. That none of these represent pull-aparts developed from an already formed force-apart structure is evident from their general morphological features.

This exposure just described is found at Tateishi, Muroto City in the Muroto Formation of Eocene age.

Detached layers have been observed in the Shimizu formation (Eocene) at Hirano in Nakamura City (Pl. 1, Figs. 3, 4) and in the Nakamura formation (Upper Cretaceous) at Nishisuga in Sukumo City (Pl. 1, Fig. 5). These detached layers appear like simple pull-apart structures, but are here treated separately because of their shapes being more irregular and larger than the ordinary ones observed at other localities within the present field and mentioned in earlier lines.

At Hirano above mentioned, the exposure simulates a conglomerate because the enclosed detached fragment have rounded margins or in some cases of lenticular forms, and may show more or less orientation parallel with the general bedding or be at random. From this aspect a rubble deposit is called to mind because it seems as if the whole deposit, shales, sandstones and the enclosed fragments all were subjected to transportation penecontemporaneously. The shaly matrix of these sandstone detachments or bedded sandstone and shale fragments appears to be scrambled and reveals a crumpling or flowage aspect, which suggests that the detached parts were not merely incorporated into the matrix, but that the matrix and the enclosures were subjected to the same movement. This is not the same as rubble bedding described by Dorreen (1951) for the deposits in Venezuela, and should be distinguished therefrom, even though the process may have been more or less similar.

The exposure at Nishisuga in Sukumo City where the Nakamura formation is developed shows angular blocks of sandstone and variously rounded ones of the same rock enclosed in a black shale giving the impression of a pseudotectonic breccia. Aside from these enclosures there are also found granules or pebbles of cherty rocks with rounded shapes intercalated within the shaly matrix. Some of the sandstone blocks have sharply angular margins, others have more or less irregularly angular ones, and some are more or less rounded. Their sizes range from granule to boulder. As in the case described above, it is also thought that some mass movement took place before consolidation of the matrix.

Convolute Bedding. This structure which was produced while the sediments were still in an unconsolidated state are found in the Ôyamamisaki formation (Eocene) at Shimoyama, Aki City, the Muroto formation (Eocene) of Hanezaki in Muroto City and in the Misaki formation (Oligocene) of Tatsukushi in Tosashimizu City (Pl. 1, Figs. 6, 7; Pl. 2, Figs. 1−3). And although they also occur elsewhere only a few of the typical examples will be mentioned in this part of the section. The magnitude of these structures are varied extending from about five meters in length down to very small ones, and in thickness some attain as much as about three meters, while the majority are usually only about ten to 20 centimeters. Sometimes they are developed as lenticular structures having rather great lengths as much as about 20 meters.

At Tatsukushi in Tosashimizu City where the Misaki formation is well exposed there have been found (Pl. 2, Figs. 2, 3) good examples of convolute bedding. These structures consist of fine grained siltstone and fine to medium grained sandstone layers in alternation and interbedded in thicker sandstone and siltstone layers which make an alternation. Besides showing intricate folding structures without any part of them broken into slabs or fragments, they do not seem to have influence on either the under or overlying sediments. Frequently their crests seem to have been truncated, and this is thought to be due to the lateral sliding of detached portions of the superjacent layers. Within the crumpled and intricately folded portions of the convolute bedding there are sometimes seen detached portions of sandstone and of very fine grained siltstone, apparently detached while in an unconsolidated state and highly plastic because the majority of the folded layers show no disruption. Some of the sandstone layers which appear to have been detached from an original layer may have been produced after the consolidation of the sediments by underground water, which in itself produces peculiar shaped sand-pipe like structures.

The rapid deposition of the overlying sediments is readily seen by that they often are injected downwards into the convolute bedding, either by rapid loading of the sediments upon a very soft and folded substratum. In other cases it is thought that the rapid deposition of the superjacent sediments has even caused the underlying ones to be injected upwards into them and in cases even forced to flow into them, thus at such places there is often seen an admixture of the sediments especially at their contact parts. All of these features reveal the soft, plastic and highly saturated condition of the sediments at the time of formation of the structures. Since graded bedding is often associated with such structures it can be said that turbidity currents also played an important role in the rapid deposition of the sediments and also in the production of the varied structures near the contacts of the already folded and subsequently deposited ones.

Crumpled Bedding. This type of structure (Pl. 2, Figs. 4, 5) was observed in the Nonokawa formation at Nakatsuo, Monobe-mura in Kochi Prefecture, where the Cretaceous rocks are rather well developed. The undersurface of the sandstone layer exhibits numerous close-spaced crests and valleys apparently at random in close-view but when seen in broad view, there is a rather unidirectional tendency in their arrangement. The crests of the hilly portions are well rounded on top and rather broad, while the valleys themselves are either sharp to round bottomed. There has been observed no marking on the surfaces of the crests or in the valley bottom which shows that probably no drag-markings were developed at the time or after their formation. Since these structures are merely the reflection of the original muddy sea-bottom, they are good evidence for determining the lower surface of the sandstone layers in which they are preserved.

The mode of formation of such original structures in the muddy sea bottom may have been due to small ripples probably of oscillation type, but further study is needed to determine their actual cause by observations on Recent marine deposits.

Concretions and *Concretionary Structures.* Among the concretions and concretionary structures found in the different formations developed in Kochi Prefecture, it is thought best to describe the outstanding types because they are well distributed acording to places.

In the massive medium grained sandstone developed at Tatsukushi in Tosashimizu City, there are found abundant concretions (Pl. 2, Figs. 6, 7) ranging in size from a ping-pong ball to about a man's head although some larger ones also occur. These may be rounded to nearly a perfect sphere, more or less subrounded with the longer diameter nearly parallel to the general dip of the sediments embedding them. In shape they are varied, being singular spheres, three spheres connected with one another, more or less flattened, subrounded, discoid, rarely subpyriform and their density is also interesting in that they may be rather crowded together, sporadically arranged and generally not distributed throught the distribution of the sandstone. These types are all of sandstone, and generally more indurated than the sediments in which they are embodied as is the general case.

Viewed closely these concretions frequently have on their external surfaces small, irregularly distributed, variously developed, wart-like to miniature parasitic concretionary structures. These are generally roughened on surface, either with narrowed to nearly equally thickened basal parts and their heights, thickness, spacing, and shapes may vary considerably even on the same concretion.

These sandstone concretions embedded in massive sandstone are interesting from the reason that they have peculiar parasitic structures on their external surface. and also from that parastic concretions often adhere to the larger ones and seem to be an outgrowth of them. These facts suggest that growth of the concretions continued even after that of the main part had been completed.

With regard to the development of sandstone concretions, especially of spheroidal to discoidal ones, a number of papers have been published, and in general, their classification is concerned with syngenetic and epigenetic development. In the former case the concretions are formed at the same time the surrounding sediments were being deposited, and in the latter case, they are formed after deposition of the entombing rocks. However, there is said to be no sharp demarcation between the two classes, because some may have their central portions syngenetic and the outer parts epigenetic owing to the addition after burial beneath the sediments. Syngenetic growth stops after burial, but epigenetic growth may then begin. It is generally accepted that the formation of concretions is through chemical action, either by precipitation while the enclosing rock was being deposited or as aggregates deposited within the enclosing rocks after its deposition.

Although three origins for concretions have been published in literature, as of physical, organic and chemical, those due to the last mentioned is generally accepted as of true concretions. No fossils have so far been discovered in any of the concretions in the massive sandstone at Tatsukushi, the sediments forming the concretions and making the matrix are similar, the distribution of the concretions is seemingly restricted to the area of Tatsukushi, the concretions are not large although rather abundant, and the matrix being homogeneous there could be found no curvature of the beds or laminae around the concretions, and further, there could be observed no lines of stratification passing through the concretions. From this evidence it is thought that the sandstone concretions are mostly syngenetic in origin. However, the parastic wart-like or adhering miniature concretionary particles, and the development of small concretions adhering to the larger ones suggests that their growth was also epigenetic.

Aside from the sandstone concretions there was found a small calcareous one embedded in shale (Pl. 3, Figs. 1, 2). This concretions is more or less with very flat base and obliquely convex upper part. The upper part of the concretions is provided with rude concentric wrinkles without uniform spacing, and the basal part although quite flat is provided in its middle part with a slight convexly rounded portion, while at it top part with another slightly depressed area.

It is common that calcareous concretions occur in shale beds and often in the form of septaria. Owing to the homogeneous nature of the shale and also of that of the calcareous concretion, there could be observed no stratifications lines passing through it.

However, from the fact that the concretion is provided with abundant concentric wrinkles which are rudely developed, more abundant on one side than on the other, and the concretion itself developed obliquely as if pushed to one side suggests the following conclusion. After the syngenetic development of the concretion it is thought that lateral movement of the sediments enclosing it was responsible for the obliquely developed shape and for the irregular distribution of the rude concentric wrinkles on its surface. This calcareous concretion was found in the Naharigawa formation (Eocene) of a road side cliff at Jadani, Kitagawa-mura, Aki-gun, Kochi Prefecture. It may be added that this concretion was found in the same horizon and in association with abundant remains of *Nereites tosaensis* Katto.

Into this section on the concretionary structures also may be included the various shaped red-shale or marly sediments embedded in the black shales of the Muroto formation in the Muroto Peninsula. These occur in lenticular, tabular or rounded forms having various lengths and thickness. The rounded or spherical ones may measures about 20 centimeters in maximum diameter, the tabular ones about up to ten centimeters in thickness and more than several meters in length, while those of lenticular form may be with flat bottoms but with convex upper parts and attain about up to ten centimeters in maximum thickness and nearly one meter in length. These structures are all embedded in black crumpled shales, which alternate with sandstone layers.

Whether these concretionary like structures were epigenetic or syngenetic in origin, or in other words sediments subsequently transported or formed in situ may have intimate bearing on the genesis of formation of the black shales. It is thought, from their mode of occurrence, that they may in some cases be merely detached parts of an unconsolidated layer, which by transpotation and subsequent deposition were compelled to take different shapes according to the nature of the surface of the shale deposits. In other cases it seems as if they were formed in situ because of being of spherical shape with the surrounding sediment in layers arching above, bending below and abruptly terminating laterally with the concretionary structure (Pl. 3, Fig. 3).

The localities of these structures and the formation from where they were found are as follows:

1— Sea coast of Tatsukushi, Tosashimizu City, Kochi Prefecture. Misaki formation, Oligocene.

2— Cliff at Jadani, Kitagawa-mura, Aki-gun, Kochi Prefecture. Naharigawa formation, Eocene.

3— Sea coast of Nada, Ôkata-chô, Hata-gun, Kochi Prefecture. Shimizu formation, Eocene.

Desiccation Breccia. In the sandstone of the Nonokawa, Susaki and Naharigawa formations, there are found abundant shale patches showing various shapes according to their orientation, but none are very large and rounded in general. These irregular patches of shale are thought to represent desiccation breccia and to have been penecontemporaneous with the deposition of the sands in which they occur (Pl. 3, Figs. 4—8). The general interpretations of these are given in the following lines.

During deposition of the medium to coarse-grained sandstone making the formations mentioned above or forming a part of them, in the shallow near-shore regions there was deposited layers of muddy sediments, which during low tide were cracked by evaporation. After being cracked these were either torn up by waves or other aqueous agencies to become incorporated into the depositing sands. Although generally consisting of the same sizes and irregular shapes, very rarely there is incorporated into the sands rather large slabs of shale which have irregular but elongated shapes and sometimes even without orientation. This random orientation shows that they were rapidly incorporated into the sands and that their source must have been near because their shapes are irregular and still preserve angular margins. Some of these are thought to have been due to sliding into the sea bottom, transported in part probably also by aqueous agencies. Their sliding may have been due to the crumpling of near by sea-cliffs, land sliding near the coast, submarine sliding or crumpling of submerged sea-cliffs, or to other phenomena.

The occurrences of the desiccation breccia as well as of the large slabs and blocks of black shale is generally in the lower parts of the sandstone formations already mentioned. From them, it is inferred that deposition was rapid and also probably that the sea coast was an unstable one. However, when occurring as lentils it is thought that transportation may have been not individually but as a massive body. Also since the desiccation breccia is sometimes associated with graded bedding, it can also be inferred that turbidity currents may have also assisted in their formation time of their deposition.

Tongallen. Among the many interesting phenomena observed in the massive sandstone of Tatsukushi in Tosashimizu City, there was found several small shale particles of peculiar form and containing in them sand, thus presenting a sort of sandfilled cylindrical fragment.

The shale fragments just mentioned (Pl. 4, Figs. 1, 2) measure about seven centimeters in longer diameter and sometimes up to about five centimeters in width. Their shapes are lenticular in longitudinal section and their central parts are occupied with sand also of similar or tubular shape. In cross-section the lenticular bodies are more or less circular to oval and sometimes more compressed, and always have sandy material in their central parts. These are thought to represent tongallens or clay galls.

Tongallens are reported to developed from the curling up of mud-cracked layers, the incorporations of sandy materials in their central and outer parts, and because of being well dried they are subjected to transportation by the tide. Observations of recent tongallens have been made by Trusheim (1929), discussed by Richter (1926, 1929) and Twenhofel (1932), and the structures thus interpreted have been reported from the Paleozoic rocks of Scotland (Hackness, 1856), and also reported by Twenhofel (1932) from the Dresbach sandstone of western Wiconsin. Twenhofel (1932) stated that tongallens in strata may occur as lenticles.

The present structures are thought to represent tongallens because of their lenticular shape, rather small size, incorporations of sandy sediments in their central parts, sporadic to clustering mode of occurrence in massive sandstone considered to be of rather shallow water origin from other evidence. Thus if they can be interpreted as representing such structures, it becomes possible to reconstruct the conditions under which they were deposited, to infer that the strand may not have been remote from the locality of burial, and to give the first record of occurrence in the geological formations of the Japanese Islands.

Clastic Dikes. Such kind of dikes (Pl. 4, Figs. 3−7) can also be included into the sedimentary structures because of their origin. In some cases clastic dikes may be formed at the time of the development of rubble deposits, from the rising of water enclosed in silty bodies owing to the pressure of the overlying sediments before consolidation, after consolidation by thixotropy, and may occur as injected upwards from below or as fillings from above into previously formed cracks, or contemporaneous with submarine earthquakes.

Clastic dikes of fine grained sandstone injected into shale are common features in the Muroto formation along the coast of Gyôtôzaki in Muroto City. Their widths are variable, some being merely several millimeters while some are thick as 50 centimeters. Traced along their outcrop some are found to branch upwards, others are single and the majority have been more or less displaced by movements subsequent to their development. All of these dikes have sharp contact with their surrounding sediments and are thought to have been injected from below upwards into the shale facies after partial consolidation of those sediments.

From the occurrence of numerous dikes concentrated in a rather small area it may be thought that considerable instability existed during the process of sedimentation of the Muroto formation, Although such structures as graded bedding and slumping are not distinctly observed in this area, there is evidence of the shale facies being rather strongly crumpled, but this is probably a phenomena subsequent to the consolidation of the sediments.

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(Received August 19, 1961)

PLATE 1

Explanation to Plate 1

Figs. 1, 2. Pull-aparts. Sea coast of Tateishi, Muroto City, Kochi Prefecture. Muroto formation, Eocene.

Figs. 3, 4, 5. Detached layers. Figs. 3, 4. Sea coast of Hirano, Nakamura City, Kochi Prefecture. Shimizu formation, Eocene. Fig. 5. Road-side cliff at Nishisuga, Sukumo City, Kochi Prefecture. Nakamura formation, Cretaceous.

Figs. 6, 7. Deformed convolute bedding with graded deposits associated. Sea coast of Shimoyama, Aki City, Kochi Prefecture. Ôyamamisaki formation, Eocene.

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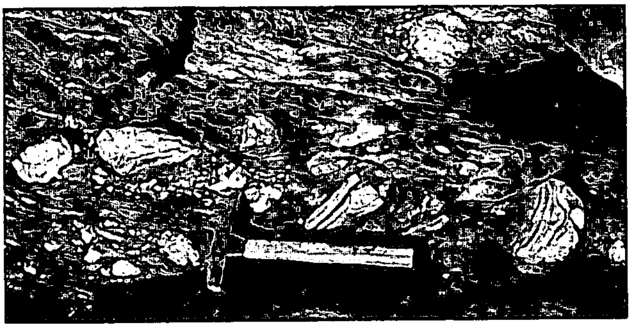

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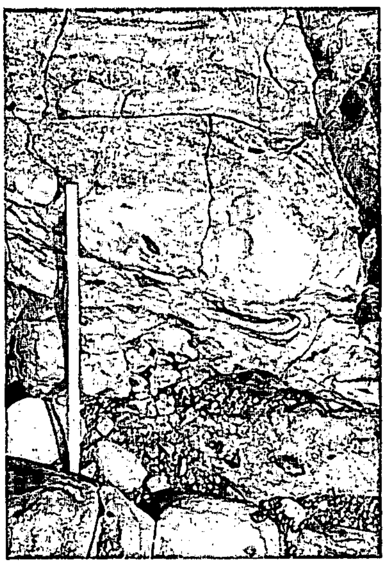

PLATE 2

Explanation to Plate 2

Figs. 1, 2, 3. Convolute bedding. Fig. 1. Sea coast of Shimoyama, Aki City, Kochi Prefecture. Ôyamamisaki formation, Eocene. Figs. 2, 3. Sea coast of Tatsukushi, Tosashimizu City, Kochi Prefecture. Misaki formation, Oligocene.

Figs. 4, 5. Crumpled bedding. Road-side cliff at Nakatsuo, Monobe-mura, Kami-gun, Kochi Prefecture. Nonokawa formation, Cretaceous.

Figs. 6, 7. Concretions. Sea coast of Tatsukushi, Tosashimizu City, Kochi Prefecture. Misaki formation, Oligocene.

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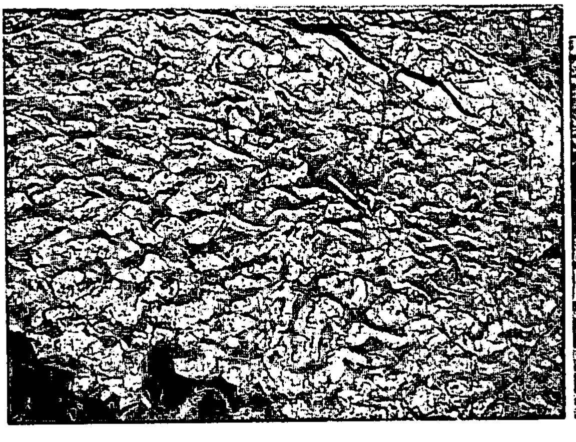

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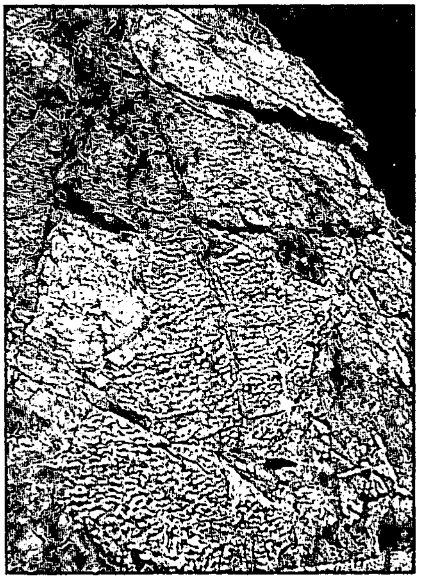

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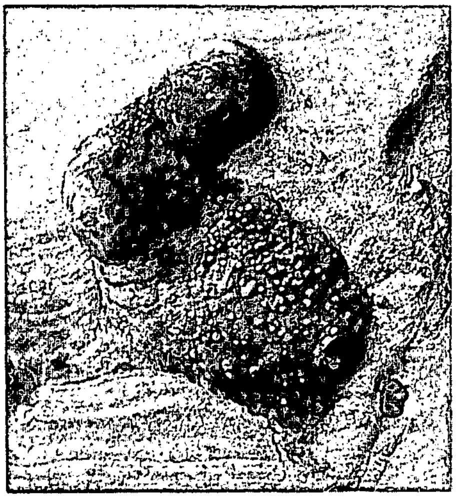

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PLATE 3

Explanation to Plate 3

Figs. 1, 2, 3. Concretions. Figs. 1, 2. Road-side cliff at Jadani, Kitagawa-mura, Aki-gun, Kochi Prefecture. Naharigawa formation, Eocene. Fig. 3. Sea coast of Nada, Ôkata-chô, Hata-gun, Kochi Prefecture. Shimizu formation, Eocene.

Figs. 4 — 8. Desiccation breccia. Figs. 4, 5. (About 1/2 Natural size) Road-side cliff at Hiso, Kito-mura, Kaifu-gun, Tokushima Prefecture. Cretaceous. Fig. 6. (About 1/7 Natural size) Road-side cliff at Kami-kito-mura, Kaifu-gun, Tokushima Prefecture. Cretaceous. Fig. 7. (About 1/2 Natural size) Ikumi, Tôyô-chô, Aki-gun, Kochi Prefecture. Naharigawa formation, Eocene. Fig. 8. (About 1/9 Natural size) Road-side cliff at Onogo, Kitagawa-mura, Aki-gun, Kochi Prefecture. Naharigawa formation, Eocene.

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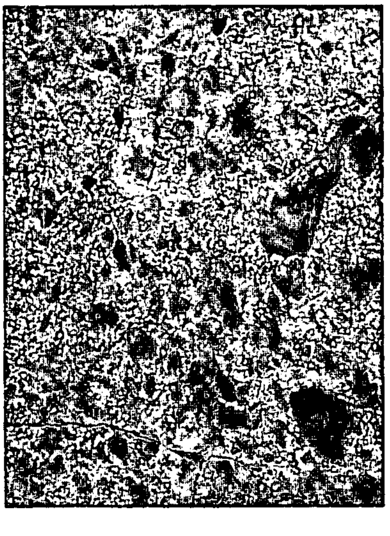

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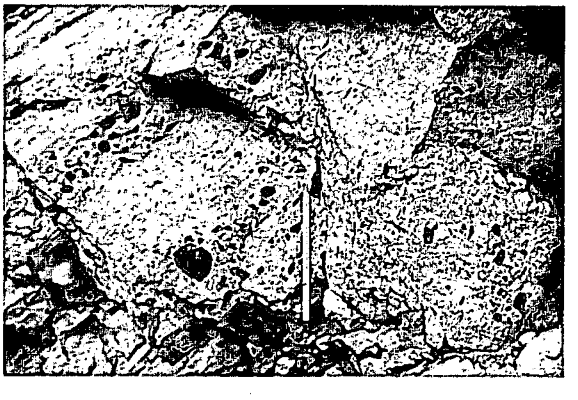

PLATE 4

Explanation to Plate 4

Figs, 1, 2. Tongallen. Sea coast of Tatsukushi, Tosashimizu City, Kochi Prefecture. Misaki formation, Oligocene.

Figs. 3—7. Clastic dikes (medium grained sandstone). Fig. 3. Sea coast of Hanezaki, Muroto City, Kochi Prefecture. Figs. 4, 5, 6. Sea coast of Gyôtôzaki, Muroto City, Kochi Prefecture. Fig. 7. Sea coast of Kuromimi, Muroto City, Kochi Prefecture. Muroto formation, Eocene.

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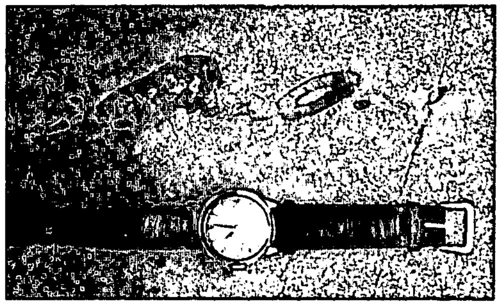

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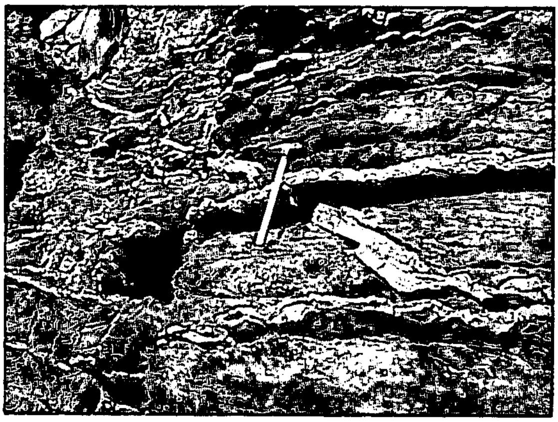

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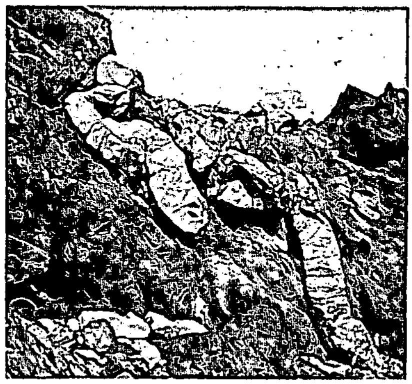

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