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Small-Scale Penecontemporaneous Deformation Structures of Bedded Chert from Chichibu, Japan

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Introduction

From the scanning electron microscope studies it has been confirmed that bedded chert was resulted from biogenic accumulation of siliceous organic debris, essentially of radiolarian tests, sponge spicules and their fragments (THURSTON, 1972; IMOTO and SAITO, 1973). The various sedimentary structures similar to those of ordinary clastic rocks are also reported for chert (IMOTO *et al.*, 1974). The mechanism of sedimentation of bedded chert has been debated, since IMOTO (1973) and IMOTO and FUKUTOMI (1975) presumed that cross laminations, sole markings, and depositional patterns of sponge spicules in the chert indicate the paleocurrent direction during deposition. In this paper small-scale structures of some bedded cherts from the Kwanto Mountains are described mainly on the basis of optical microscope study. Materials were also studied by X-ray diffraction and chemical analyses.

Description and Discussion

Samples examined: Bedded cherts (Permian or Triassic in age) associated with alternation of sandstone and mudstone were collected in Hosokubodani, an upper branch of the Urayama-gawa River, Chichibu, Saitama Prefecture. The sample consists of two chert layers interbedded a thin mudstone layer (Fig. 1). All parts of the chert layers having dense and vitreous appearance are medium to dark grey in colour and commonly broken by closely-spaced fractures. The thickness of chert layers varies from 5 mm to about 35 mm. The interbedded mudstone is dark chocolate brown in colour and 2 mm to 10 mm thick, invariably thinner than the chert layers. In the interbedded mudstones occur rarely chert lenses of about 1 mm thick, which can be traced along strike from 20 to 30 cm (Plate 1, fig. 1).

Macroscopically fine laminations are not observed within the chert and inter-

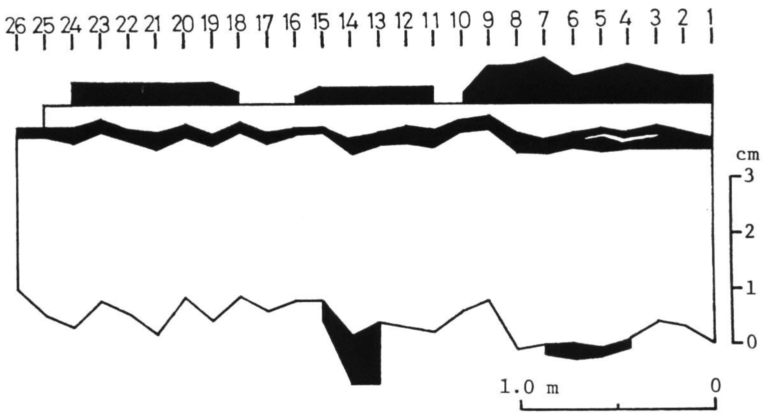

Fig. 1. Variation of layer thickness. The horizontal straight line indicates the upper boundary of the upper thin chert layer. White: chert; black: mud. Numbers at the top of the figure show the positions of examined columns.

bedded mudstone layers. Near the boundaries between the chert and interbedded mudstone in almost all parts, minute transparent spherules interpreted as radiolarian remains are visible to the naked eyes but the finer material is wholly indistinguishable. Twenty six parts taken at about 10 cm interval were etched by hydrofluoric acid as done by HAYASHI (1969) or by IMOTO and SAITO (1973) and then examined with binocular microscope and scanning electron microscope. It was indicated that the chert layers consisted mainly of spines or spicules accompanied with radiolarian remains showing various sedimentary structures (Fig. 2 and Plate 1).

Mineral composition: In thin sections the chert consists mostly of cryptocrystalline to microcrystalline quartz, within which minor clayey materials such as chlorite and sericite occur. Although minute spherules consisting of microcrystalline quartz can be seen near the contact with the interbedded mudstone, the spherules in the chert part are difficult to be distinguished from the surrounding cryptocrystalline or microcrystalline quartz. In the interbedded mudstone silt-sized particles of quartz are scattered. X-ray powder diffraction analysis shows that the chert part includes illite, chlorite, and alkali feldspar, and that the interbedded mudstone contains certainly quartz, chlorite and alkali feldspar.

The higher concentration of quartz in the chert layers is regarded as the results of accumulation of opaline spicules, radiolarians and their fragments and of their subsequent diagenetic alteration (MIZUTANI, 1970). The quartz particles in the interbedded mudstone are probably of terrigenous origin. The clay minerals such as illite and chlorite may have similarly come from the land.

Chemical composition: The chert and the interbedded mudstone were analysed by the ordinary wet chemical method (Table 1). As can be seen in Table, the chert contains more amount of silica and ferric oxide and less amount of all other detected

Table 1. Chemical analyses of chert and interbedded mudstone

	chert	mudstone
SiO_2	90.01 wt%	55.75 wt%
TiO_2	0.18	0.63
Al_2O_3	3.72	20.44
Fe_2O_3	1.20	1.04
FeO	1.36	6.02
MgO	0.05	0.20
MnO	0.31	3.16
CaO	0.23	0.38
Na_2O	0.23	1.34
K_2O	0.88	4.83
H_2O+	1.09	4.88
H_2O-	0.23	0.62
P_2O_5	0.09	0.22
Total	99.58	99.51

Analyst: T. Tiba

Table 2. Calculated mineral compositions of chert and interbedded mudstone

	chert	mudstone
quartz	84.48 wt%	23.73 wt%
albite	1.94	11.32
anorthite	0.58	0.42
sericite	7.41	40.86
chlorite	2.11	19.89
manganese oxide as MnO	0.05	0.20
ilmenite	0.35	1.20
magnetite	1.76	—
apatite	0.20	0.54
Total	98.88	98.16
excess H_2O	0.75	1.43

elements compared to the interbedded mudstone. In chemical compositions of the two portions of rock, ferrous oxide indicates higher percentage than ferric oxides, and also K_2O than Na_2O.

Mineral compositions of these rocks calculated from the chemical compositions are shown in Table 2. The calculation was made after the method of IMBRIE and POLDERVAART (1959) with slight modification for molecular formulae of clay minerals after TIBA (1974). The chert is characterized by its high concentration of normative quartz, and a small amount of normative sericite, chlorite, and feldspars. In addition to them, magnetite, ilmenite and apatite are also calculated. Montmorillonite is not computed because of lack of Al_2O_3. In the interbedded mudstone clay minerals, especially sericite, are abundant and occupy approximately 60 per cent in weight of the normative composition. There are also quartz, feldspars, ilmenite, and apatite similarly as in the chert. No montmorillonite can be calculated in this case, too.

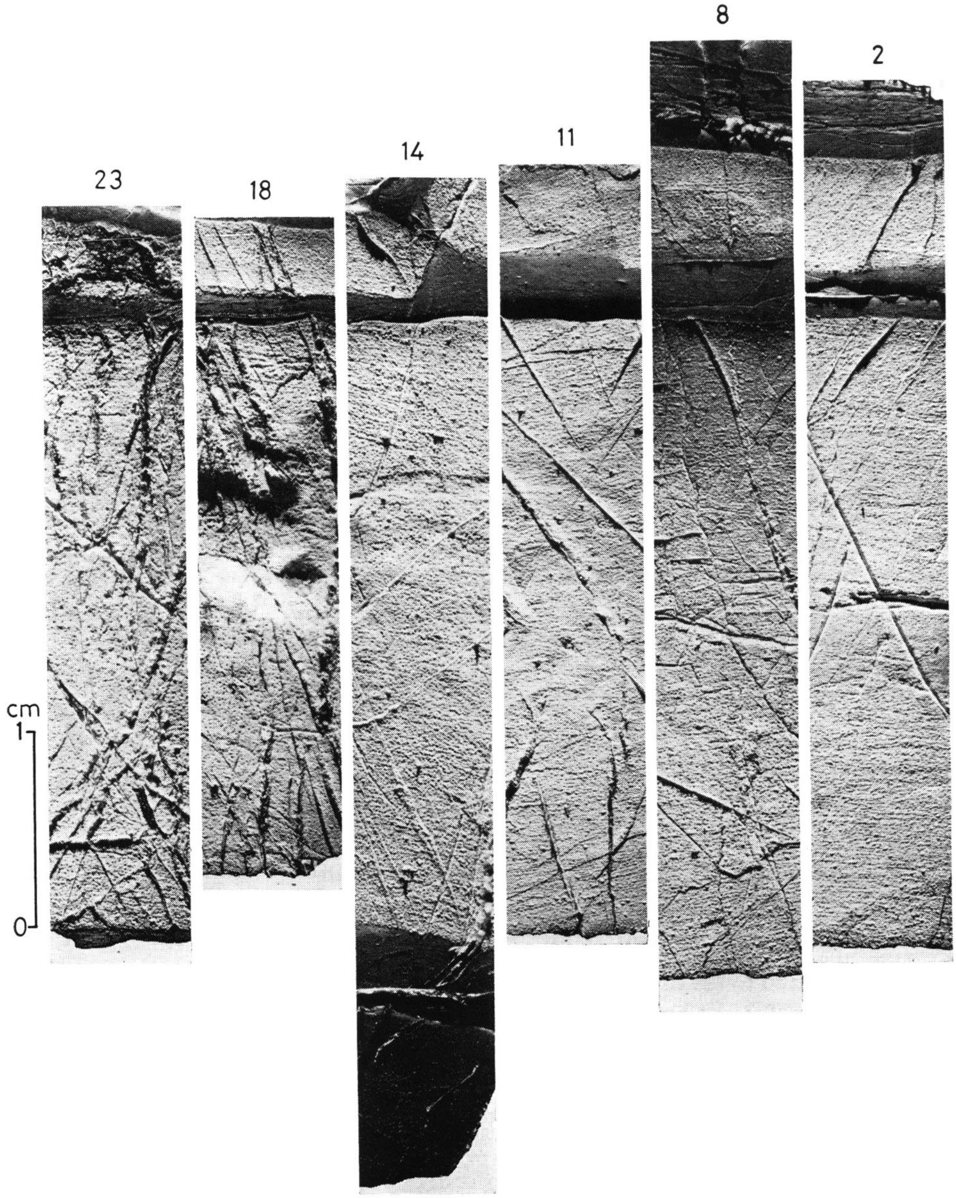

Fig. 2. Photographs of selected columns. Numbers are the same as those in Fig. 1. Light-coloured parts: chert; dark-coloured parts: mudstone.

The normative mineral compositions are not contradictory with the results of the X-ray diffraction analyses. Montmorillonite was not found also in the powder X-ray diffraction pattern on the bulk rock samples. It is suggested that montmorillonite, probably derived from detritus of volcanic materials (for instance, see AOKI *et al.*, 1974), was not supplied since the bedded chert examined was not associated with volcanic or pyroclastic rocks in the field. However, it must be considered that, as in the case discussed by THURSTON (1972), a relatively higher content of silica in sea water resulted from submarine volcanic activities may have contributed to defend siliceous organic remains from their dissolution, although volcanic or pyroclastic materials failed to have deposited together with siliceous remains and clayey material.

Primary sedimentary textures: The photographs of six selected columns are shown in Fig. 2. They show the etched surface normal to the bedding plane. Under the microscope the chert layers have horizontal and parallel laminations which are resulted from the slight variation in amounts of sponge spicules and radiolarians. When the chert layer is relatively thick, these laminations can be observed rather clearly in the upper and lower parts of the layer than the middle part. Occasionally cross lamination-like textures are developed (*e.g.*, Figs. 2-11 and -14). In the chert layers grading cannot be observed because of scarcity of coaser-sized radiolarian tests.

The lower chert layer of about 3 cm thick shown in Figs. 1 and 2 generally has sharp contact with the underlying and overlying mudstones (Figs. 2-2, -11, -14, -18 and -23; Plate 1, figs. 2 and 3). The grain-size gradation is rarely seen from the top of the lower chert layer to the bottom of the overlying mudstone of 2–5 mm thick (Fig. 2-8; Plate 1, fig. 4). This interbedded layer of mudstone has fine internal laminations. Another chert layer of about 5 mm thick which overlies the interbedded mudstone layer has also distinct boundaries to the under- and overlying mudstones. The overlying mudstone, uppermost horizon of specimen examined, shows horizontal but slightly contorted laminations in its middle part (Fig. 2-2; Plate 1, fig. 1).

The sharp boundary between the chert and mudstone layers and absence of siliceous organic remains in the interbedded mudstones suggest such a sudden supply of a large quantity of siliceous remains as inferred by FAGAN (1962). The fine lamination in the interbedded mudstone probably represents very slow settling for a relatively long period, whereas the contorted lamination may reflect the presence of turbulent current.

Small-scale penecontemporaneous deformation structure: There are many intrastratal small-scale faults in the upper chert layer which is relatively thin. These small-scale faults are developed in a restricted part ranging from Columns 4 to 14 of Fig. 1. Such faults are not observed in the other parts such as Columns 1-3 and 15-26 (*e.g.*, Plate 1, fig. 1). It is noted that almost all the faults developed exclusively in the upper chert horizon are of normal type and are not observed in the subjacent and superjacent layers (Plate 1, figs. 2 and 3). Most striking displacements by faults are observed near Column 7 in Fig. 1, where the underlying mudstone and thick chert layers are cut by the faults (Plate 1, fig. 4). In the overlying mudstone a flow fold-like structure bending downward produced by hydroplastic flow is observed (Plate 1, fig. 4). The displacement by the faults invariably disappears toward the bedding surface of the overlying mudstone. The overlying mudstone

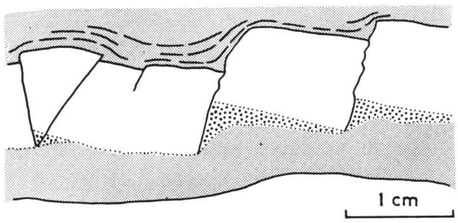

Fig. 3. Schematic sketch of Fig. 2 of Plate 1. White: chert, grey: mud, dot: intermixing of chert material and mud, dotted line: gradual boundary, solid line: sharp boundary, broken line: lamination.

thickens in the triangular parts between the down- and upthrown blocks and thins out above the upthrown blocks of the chert layer. Increasing thickness of mudstone with thrown indicates that the faults are a kind of "growth fault" (OCAMB, 1961) and the hydroplastic flow of mud must have taken place prior to lithification. This presumption is supported by the fact that siliceous organic remains in the lower part of the thinner chert layer, cut by the small-scale faults, were mixed with clayey material derived from the underlying mudstone (Fig. 3; Plate 1, fig. 2). The contained sponge spicules and radiolarians are not fractured but maintain relatively well their original shapes. In other words, the chert was not completely lithified, in particular near the contact with the underlying mudstone, when faulting happened. The difference in deformation behaviours between the chert and the interbedded mudstone may depend on the different physical natures of their material.

It is concluded that the small-scale penecontemporaneous deformation structures described here may have been formed in the following process:

1. After deposition of the relatively thick lower chert, mud was deposited probably in similar conditions, since clay minerals composing the mud are common with those contained in the chert.
2. Subsequently the thin chert layer was formed.
3. During deposition of the overlying mudstone, perhaps at the same time as the lamination was contorted, a subsidence due to fracturing occurred near Column 7.
4. As a result, in the upper thin chert layer small-scale normal faults were performed by sliding toward subsided side (near Column 7) under the influence of gravity. Still fluid mud layer flowed into and burried up the subsided channel, forming a flow fold-like structure.
5. Mud continued to have been supplied afterwards so that stratification in the mud layer became horizontal toward the top.

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Explanation of Plate

(Bar: 5 mm)

Fig. 1. Undeformed part of the upper chert layer. Near Column 3 of Fig. 1. See the slightly contorted lamination in the overlying mudstone. A thin lenticular cherty seam in the interbedded mudstone shown in Fig. 1 is seen in the left central part of this photograph.

Fig. 2. Fractured and displaced chert blocks and distorted mud layers. Near Column 14. See the text and Fig. 3.

Fig. 3. Larger displacement of fractured chert blocks. Near Column 12.

Fig. 4. Highly displaced chert blocks accompanied with distortion of its adjacent mud layers. Near Column 7.